USAID
FROM THE AMERICAN PEOPLE

National Smart Grid Mission
Ministry of Power
Government of India

July 2016

Course material for

Basic Smart Grid Training Program for Utility Professionals

Partnership to Advance Clean Energy-Deployment (PACE-D)
Technical Assistance Program

USAID FROM THE AMERICAN PEOPLE

National Smart Grid Mission
Ministry of Power
Government of India

Partnership to Advance Clean Energy-Deployment (PACE-D) Technical Assistance Program

Course material for

Basic Smart Grid Training Program for Utility Professionals

July 2016

This report is made possible by the support of the American People through the United States Agency for International Development (USAID). The contents of this report are the sole responsibility of Nexant Inc., and do not necessarily reflect the views of USAID or the United States Government. This report was prepared under Contract Number AID-386-C-12-00001.

पीयूष गोयल
PIYUSH GOYAL

विद्युत, कोयला, नवीन और नवीकरणीय ऊर्जा एवं खान
राज्य मंत्री (स्वतंत्र प्रभार)
भारत सरकार
Minister of State (Independent Charge)
for Power, Coal, New & Renewable Energy and Mines
Government of India

Message

Countries across the globe are modernising their electricity grids to monitor, measure and control power flows in real-time; and optimise the operational performance of their grids. Smart grid technologies are no longer a futuristic thing – they are a prerequisite in the new world order with growing energy demand and concerns about climate change and emissions. Thus, India too is now transitioning to better power infrastructure to achieve the Hon'ble Prime Minister Shri Narendra Modi ji's vision of 24x7 Affordable and Environment Friendly "Power for All".

For this, the Government of India has approved establishment of National Smart Grid Mission (NSGM) in March 2015. The Mission serves as an institutional mechanism for planning, monitoring and implementation of Smart Grid policies and programmes. Corresponding to the National Smart Grid Mission, each of the Indian States is expected to have a State Level Mission to effectively implement their respective Smart Grid projects.

The Government has also proposed to set up a National Smart Grid Knowledge Centre under NSGM that will be a central repository of smart grid technologies, best practices, standards, case studies, international policies and experiences. The Knowledge Centre will build the capacity of utility professionals to enable them to deliver quality power at an affordable cost.

Shram Shakti Bhawan, New Delhi-110 001 Phone : +91-11-23717474, 23710411, Fax : +91-11-23710065
E-mail : piyush.goyal@nic.in, Website : www.piyushgoyal.in

Building the capacity of utility professionals is high on the agenda of the Government and we are actively engaging with different stakeholders to identify the gaps in existing knowledge and developing focused training for the same. I am delighted to note that the first such training material is now available. Developed jointly by the NSGM in partnership with USAID PACE-D TA programme, the training material will provide well-rounded exposure to the utility participants on varied aspects of Smart Grid planning and deployment.

Smart Grids will strengthen our distribution system by making it more resilient, effective and self-sustaining. Making the grid 'smart' is the single most critical piece if we have to transform India's energy sector.

I encourage all training institutes in the power sector to use the training course to skill their utility professionals. My best wishes are with them in their efforts to build an army of skilled "smart" workforce in India.

Piyush Goyal

प्रदीप कुमार पुजारी
सचिव
भारत सरकार
P. K. PUJARI
Secretary
Government of India

सत्यमेव जयते
Ministry of Power
Shram Shakti Bhawan
New Delhi - 110001

विद्युत मंत्रालय
श्रम शक्ति भवन
नई दिल्ली–110001
Tele : 23710271/23711316
Fax : 23721487
E-mail : secy-power@nic.in

15 July 2016

Foreword

Power utilities in India are now set to transition towards Smart Grid infrastructure upgrade to find solutions to some of the fundamental issues plaguing the Indian power sector. To embark on this Smart Grid journey, it is important that utilities have adequate resource pool of Smart Grid trained professionals who would be the flag bearers for developing and implementing Smart Grid technologies.

Training and capacity building has been identified as one of the key objectives and focus areas of the National Smart Grid Mission (NSGM). The National Smart Grid Knowledge Centre under NSGM is proposed to act as a resource centre for Smart Grid capacity building activities. NSGM in partnership with USAID PACE-D TA program, has developed a basic Smart Grid Training Program for utility professionals.

I take this opportunity to commend the entire team for bringing out a foundation course that ensures relevance to the Indian context and also delivers a balanced mix of lectures and practical insights and case studies.

I hope the course proves useful to the utility professionals and enables them to expand their knowledge on Smart Grid technologies and related operational issues and effectively plan and deliver a smarter grid for its consumers.

(P.K. PUJARI)

RIGHT TO INFORMATION

स्वच्छ भारत
एक कदम स्वच्छता की ओर

संयुक्त सचिव
JOINT SECRETARY

भारत सरकार
GOVERNMENT OF INDIA
विद्युत मंत्रालय
MINISTRY OF POWER
श्रम शक्ति भवन, रफी मार्ग
SHRAM SHAKTI BHAWAN, RAFI MARG

नई दिल्ली - 110001
NEW DELHI - 110001

सत्यमेव जयते

FOREWORD

Smart Grid enables real time exchange of electricity and information. Use of Smart Grid technologies can bring efficiency and sustainability in meeting the growing electricity demand of the country with reliability and high level of quality.

Smart Grids provide numerous benefits to both utilities and consumers. While utilities can leverage Smart Grid technologies to address challenges of loss reduction, demand and outage management, consumers can choose when and how to use energy, and thereby save on their electricity bills.

The National Smart Grid Mission (NSGM) acts as an institutional mechanism to plan and monitor the implementation of Smart Grid policies and programmes in India. One of the key activities envisaged under the NSGM is the capacity building of utility professionals and train them on Smart Grid-related areas.

The NSGM, in collaboration with the PACE-D TA Program has developed a Basic Smart Grid Training Course for utility professionals. The course, developed under the guidance of the Working Group set up by the Ministry of Power, will be delivered as part of a three-day training programme for utility personnel, focuses on the basic concepts and building blocks of Smart Grid, its applications and various considerations for deployment.

I would like to take this opportunity to congratulate all the Working Group members who provided their expert guidance and contributed to the development of the training course in partnership with USAID PACE TA program.

I hope the training course will facilitate knowledge sharing between stakeholders and also accelerate Smart Grid deployment in India.

(Dr. Arun Kumar Verma)
Joint Secretary

Foreword

Bilateral cooperation between the United States and India on addressing key energy concerns plays an important role in the strategic partnership between the two countries. This cooperation has expanded and evolved over the years to address the twin challenges of energy security and climate change.

One U.S.-India initiative – the *Distribution Reform, Upgrades, and Management* (DRUM) program, launched by the U.S. Agency for International Development (USAID) in 2004 – offered specialized training programs focused on electricity distribution. A second activity -- the *USAID Partnership to Advance Clean Energy -- Deployment Technical Assistance Program*, a five-year bilateral initiative to accelerate clean energy deployment -- builds on the DRUM legacy, further strengthening and expanding joint cooperation in this important area.

A key activity within that program is knowledge transfer focused on industry best practices and project implementation, with a view toward supporting "Smart Grids" in India. Against that backdrop, USAID is pleased to share this basic Smart Grid Training Course, designed to equip utility personnel with the technical, commercial and regulatory knowledge needed to effectively design and implement Smart Grid projects.

The training course, developed in partnership with the National Smart Grid Mission within the Government of India's Ministry of Power, seeks to improve the skills of utility professionals and while also helping to establish an integrated and efficient approach to generate and deliver electricity. A smart, reliable grid will in turn serve as a key enabler for flagship projects such as "100 Smart Cities" and "Power for All," helping to ensure that they meet their targets and objectives.

USAID very much appreciates this opportunity to partner with the Government of India in building a strong institutional structure, providing an essential foundation for a dynamic Smart Grid network that strengthens innovation in India while also helping to further transform it.

Ambassador Jonathan Addleton
Mission Director to India

ACKNOWLEDGEMENTS

This training course module is prepared under the Partnership to Advance Clean Energy-Deployment (PACE-D) Technical Assistance (TA) Program, which is funded by the United States Agency for International Development (USAID).

The PACE-D TA Program acknowledges the support and guidance provided by the numerous experts in India who were interviewed by the Program and who provided useful information on their experience and insights on the subject. The Program would particularly like to thank Mr. B N Sharma, Additional Secretary, Ministry of Power, under whom this initiative was taken up while at the Ministry of Power, Dr. A K Verma, Joint Secretary, Ministry of Power, Mr. P N Singh, Director, National Smart Grid Mission, Ms. Kumud Wadhwa, DGM and Mr. Atul Bali, DGM and Mr. Sachin Shukla, Senior Manager for their valuable inputs and support.

The report substantially benefited from the overall guidance of the Working Group constituted by the Ministry of Power to review the contents of the report.

USAID Program Managers
Anurag Mishra
Apurva Chaturvedi

PACE-D Technical Team
Nithyanandam Yuvaraj Dinesh Babu
Bhaskar Natarajan
Sujatha Ramasamy
Vikas Gaba
Saurabh Gupta
Varun Anand

Editorial Team
Kavita Kaur
B. Anil Kumar
Rahul Kumar

Working Group Members

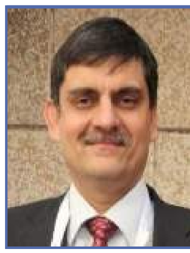
S. Padmanaban
Former Program Director &
Senior Energy Advisor,
USAID/India

Arup Ghosh
Senior Advisor, Tata Power
Delhi Distribution Ltd.

Vijay L. Sonawane
Former Member,
Maharashtra Electricity
Regulatory Commission

Vivek Goyal
Director, Central Electricity
Authority

N S Saxena
Professor, Operations
Management, Management
Development Institute



Vikram Gandotra
Head of Strategy and
Marketing, Digital Grid Unit,
Siemens Ltd.

Atul Bali: Convenor
DGM-NSGM Project
Management Unit

Table of Contents

List of Tables

List of Figures

List of Boxes

Acronyms

Acronyms	Definition
3GPP	3rd Generation Partnership Project
AC	Alternate Current
ADMS	Advanced Distribution Management System
ADR	Automatic Demand Response
AEEG	Italian Regulatory Authority for Electricity and Gas
AHR	Asset Health Rules
AMI	Advanced Metering Infrastructure
AMM	Advance Metering Management
ARR	Annual Revenue Requirement
ASKMA	Advanced SCADA Key Management Architecture
AT&C	Aggregate Technical and Commercial
AutoDR	Automated Demand Response
BEE	Bureau of Energy Efficiency
BEMS	Building Energy Management Systems
BGE	Baltimore Gas and Electric
BIS	Bureau of Indian Standards
BMS	Building Management Systems
BPL	Broadband Over Power Line
BRPL	BSES Rajdhani Power Limited
BSES	Bombay Suburban Electric Supply
CAIDI	Customer Average Interruption Duration Index
CAIFI	Customer Average Interruption Frequency Index
CBM	Condition-based Maintenance
CCTV	Closed Circuit Television
CDN	Canadian Dollar
CEA	Central Electricity Authority
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CEO	Chief Executive Officer
CERC	Central Electricity Regulatory Commission
CEUD	Consumer-Specific Energy Usage Data
CFL	Compact Fluorescent Light
CGRF	Consumer Grievance Redressal Forum
CI	Customer Interruptions
CIM	Common Information Model
CIS	Customer Information System
CMI	Customer Minutes of Interruption

Acronyms	Definition
CMP	Central Maine Power
CP	Critical Pricing
CPP	Critical Peak Pricing
CPR	Critical Peak Rebate
CPRI	Central Power Research Institute
CPU	Central Processing Unit
CPUC	California Public Utilities Commission
CRM	Customer Relationship Management
CSR	Customer Service Representative
CVPP	Commercial Virtual Power Plant
CVR	Conservation Voltage Reduction
CVT	Capacitance Voltage Transformer
DA	Distribution Automation
DAN	Distribution Area Network
DC	Direct Current
DC	District of Columbia
DCU	Data Concentrator Unit
DDUGJY	Deen Dayal Upadhyaya Gram Jyoti Yojana
DeitY	Department of Electronics and Information Technology
DER	Distributed Energy Resources
DHS	Department of Homeland Security
DISCOM	Distribution Company
DLC	Direct Load Control
DMS	Distribution Management System
DNP	Distributed Network Protocol
DOE	Department of Energy
DOS	Denial-of-Service
DOT	Department of Telecommunications
DPR	Detailed Project Report
DR	Demand Response
DRA	Demand Response Aggregator
DRAS	Demand Response Automation Server
DRM	Demand Response Management
DSCADA	Distribution Supervisory Control and Data Acquisition
DSL	Digital Subscriber Line
DSM	Demand-Side Management
DT	Distribution Transformer

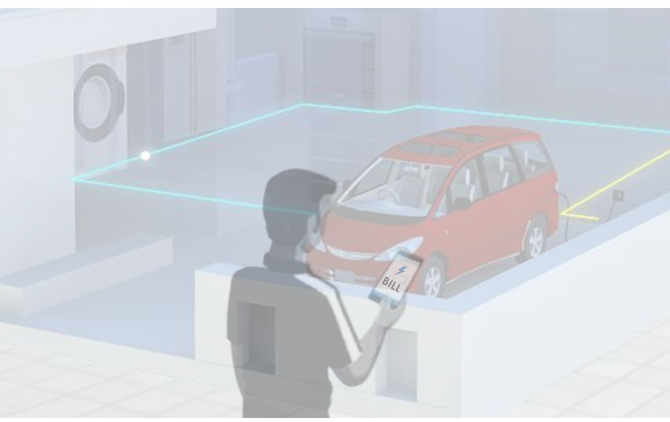
Acronyms	Definition
DVVC	Distribution Volt-VAR Control
EA	Electricity Act
EAM	Enterprise Asset Management
EESL	Energy Efficiency Services Limited
EM&V	Evaluation, Measurement and Verification
EM/RF	Electromagnetic/Radio Frequency
EMS	Energy Management System
EPRI	Electric Power Research Institute
ERP	Enterprise Resource Planning
ESCO	Energy Service Company
ESI	Energy Services Interface
ESS	Energy Storage System
ETSI	European Telecommunications Standards Institute
EV	Electric Vehicle
FAN	Field Area Network
FFA	Field Force Automation
FLISR	Fault Detection, Isolation and Service Restoration
FOR	Forum of Regulators
FPL	Florida Power & Light
FTC	Federal Trade Commission
G2V	Grid-to-Vehicle
GIFT	Gujarat International Finance Tec-City
GIS	Geographic Information System
GOI	Government of India
GPRS	General Packet Radio Service
GPS	Global Positioning System
GW	Gigawatt
HAN	Home Area Network
HEMS	Home Energy Management Systems
HERC	Haryana Electricity Regulatory Commission
HES	Head End System
Hz	Frequency
ICT	Information and Communication Technologies
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Device
IEEE	Institute of Electrical and Electronics Engineers
IEEMA	Indian Electrical and Electronics Manufacturers Association
IEGC	Indian Electricity Grid Code
IHD	In-Home Displays

Acronyms	Definition
INR	Indian Rupee
IOT	Internet of Things
IP	Internet Protocol
IPDS	Integrated Power Development Scheme
ISGF	India Smart Grid Forum
ISGTF	India Smart Grid Task Force
IT	Information Technology
IVRS	Interactive Voice Response System
IWA	Indian Welfare Association
Kbps	Kilobits Per Second
KDC	Key Distribution Centre
Km	Kilometre
KPI	Key Performance Indicators
KUB	Knoville Utility Board
kW	Kilowatt
LAN	Local Area Network
LED	Light Emitting Diode
LKH	Logical Key Hierarchy
LTE	Long Term Evolution
LV	Low Voltage
M2M	Machine to Machine
MAC	Media Access Control
MDAS	Meter Data Acquisition System
MDS	Managed Data Services
MGP	Mera Gao Power
MIS	Management Information System
MOP	Ministry of Power
MOUD	Ministry of Urban Development
MPLS	Multi-Protocol Label Switching
MPLS-TE	Multi-Protocol Label Switching - Traffic Engineering
MSEDCL	Maharashtra State Electricity Distribution Company Ltd.
MV	Medium Volt
MVAR	Mega Unit of Reactive Power
MWh	Megawatt Hour
NAN	Neighbourhood Area Network
NCEM	National Council for Electric Mobility
NERC	North American Electric Reliability Corporation
NISC	National Information Security Center
NIST	National Institute of Standards and Technology

Acronyms	Definition
NMEMP	National Electric Mobility Mission Plan
NPMU	NSGM Project Management Unit
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
NSGM	National Smart Grid Mission
NTU	Nanyang Technological University
NWP	Numerical Weather Prediction
NYISO	New York Independent System Operators
NYSERDA	New York State Energy Research and Development Authority
OAM	Operations, Administration and Maintenance
OFGEM	Office for Gas and Electricity Markets in Great Britain
OG&E	Oklahoma Gas and Electric
OLPF	Online Power Flow
OMS	Outage Management System
ONR	Optimal Network Reconfiguration
OpenADR	Open Automated Demand Response
OT	Operational Technologies
OTA	Online Trust Alliance
OTN	Optical Transport Network
PA	Public Address
PCT	Programmable Communicating Thermostat
PEV	Plug-in Electric Vehicle
PG&E	Pacific Gas and Electric
PGCIL	Power Grid Corporation of India Ltd.
PHEV	Plug-in Hybrid Electric Vehicle
PIER	Public Interest Energy Research
PII	Personally Identifiable Information
PLC	Power Line Carrier
PLM	Peak Load Management
PMU	Phasor Measurement Units
POS	Packet Over SONET
PPA	Power Purchase Agreement
PQ	Power Quality
PSU	Public Sector Undertakings
PUC	Maine Public Utilities Commission
PV	Photovoltaic
QOS	Quality of Service
R&D	Research and Development
R-APDRP	Restructured Accelerated Power Development and Reforms Program

Acronyms	Definition
RE	Renewable Energy
REMC	Renewable Energy Management Center
RES	Renewable Energy Sources
RESCO	Renewable Energy Secure Communities
RF	Radio Frequency
RFB	Request for Bid
RFID	Radio Frequency Identification
RFP	Request for Proposal
RSSI	Received Signal Strength Information
RTP	Real-Time Pricing
RTU	Remote Terminal Units
RWA	Resident Welfare Association
SAC	Standardization Administration of China
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCA	Short-Circuit Analysis
SCADA	Supervisory Control And Data Acquisition
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
SDH	Synchronous Digital Hierarchy
SER	Smart Energy Reward
SERC	State Electricity Regulatory Commissions
SG	Smart Grid
SGCC	State Grid Corporation of China
SGF	Smart Grid Fund
SGIG	Smart Grid Investment Grant
SGIP	Smart Grid Interoperability Panel
SGMM	Smart Grid Maturity Model
SKE	SCADA Key Establishment
SKMA	SCADA Key Management Architecture
SLA	Service Level Agreement
SMOCK	Scalable Method of Cryptographic Key Management
SMS	Sensor Management System
SMUD	Sacramento Municipal Utility District
SOE	Sequence of Events
SONET	Synchronous Optical Networking
SOP	Standards of Performance
SPI	Smart Power India
SPRD	Smart Power for Rural Development Initiative

Acronyms	Definition
SRTP	Secure Real-Time Transport Protocol
SSO	Single Sign On
STAR	University of Delaware's Science, Technology and Advance Research
STLF	Short Term Load Forecast
STM-1	Synchronous Transport Module Level-1
SVE	Sioux Valley Energy
T&D	Transmission and Distribution
TDM	Time-Division Multiplexing
TLM	Transformer Load Management
TLS	Transport Layer Security
TOD	Time of Day
TOU	Time of Use
TPDC	Transmission Performance and Diagnostic Centre
TPDDL	Tata Power Delhi Distribution Limited
TSO	Transmission System Operators
TVPP	Technical Virtual Power Plant
UCSD	UC San Diego
UDAY	Ujwal DISCOM Assurance Yojana
UGVCL	Uttar Gujarat Vij Company Ltd.
URL	Uniform Resource Locator
U.S. D.O.E	US Department of Energy
USAID	United States Agency for International Development
USD	United States Dollar (USD 1 = INR 67)
V	Voltage
V2G	Vehicle-to-Grid
VAR	Volt-Ampere Reactive
VEC	Vermont Electric Cooperative
VEE	Validation, Editing and Estimation
VPN	Virtual Private Network
VPP	Variable Peak Pricing
VVO	Volt-VAR Optimization
W	Watt
WAMS	Wide Area Management System
WAN	Wide Area Network
WG	Working Group
WMS	Work Management Systems



Module -1

Introduction to Smart Grid

1.1. Course Background

Course Objective

The Government of India has established the National Smart Grid Mission (NSGM) – an institutional framework with dedicated manpower and resource to implement Smart Grid activities on a large scale in the country to make Indian power infrastructure cost effective, responsive, reliable and self- healing.

Under the NSGM, training and capacity building has been identified as one of the key objectives and focus areas. The training programs will be housed in the National Smart Grid Knowledge Centre. Additionally, the National Smart Grid Vision and Roadmap specifies the following goal for capacity building: "10 percent of the utility technical personnel to be trained in Smart Grid technologies".

The NSGM, with support from the Partnership to Advance Clean Energy – Deployment Technical Assistance Program led by the United States (U.S.) Agency for International Development, has designed this basic Smart Grid course for utility personnel. The course has been developed under the guidance of the Working Group constituted by the Ministry of Power (MOP) on August 25, 2015. The working group comprised of industry experts, academicians, key utility personnel and representatives from planning and regulatory bodies.

The course is intended to be delivered as part of a three-day training workshop. Some of the key objectives of the course are:

- Introduce the participants to basic concepts and building blocks of Smart Grid.
- Share applications of Smart Grid along with case studies and practical deployment from India and abroad.
- Understand aspects related to cyber security and communications.
- Understand the regulatory considerations in planning for Smart Grid projects.

The overall course objective is to provide a well-rounded exposure to utility participants on various aspects of Smart Grid planning and deployment.

Course Structure

This basic level course is intended to be delivered in classroom style training. It focuses on case studies highlighting deployment experience of Smart Grid technologies nationally and internationally. The overall structure of the course includes:

Day 1	Day 2	Day 3
Introduction to Smart Grids	Grid Integration of Renewables: Role of Smart Grid	Customer Engagement and Participation
Building Blocks of Smart Grid	Smart Grids and Quality of Supply and Service	Regulatory Considerations in Smart Grid Projects
Peak Load Management & Demand Response	Communications Technology	Smart Grid Analytics
Loss Reduction, Asset Monitoring & Optimization, and Outage Management System	Cyber Security	Smart Grid Smart City

1.2. Overview

1.2.1 Relevance of Smart Grid to the Indian Power Sector

The Indian power sector has come a long way since the introduction of the Electricity Act (EA) 2003. The Act gave a major boost to the power sector which resulted in increase in generation capacity, investments in transmission and distribution, introduction of a power market and power trading activities and enhanced private sector participation.

In order to meet the growing challenges of the sector the Electricity (Amendment) Bill, 2014 is under consideration[1]. The Electricity (Amendment) Bill, 2014 seeks to bring in further competition and efficiency in the distribution sector by giving choice to the consumers, promotion of renewable energy (RE), maintenance of grid security, rationalisation of tariff determination and strengthening of the regulatory commissions.

Generation

The power generation sector has benefitted significantly due to the entry of private players. The magnitude of capacity being added each year has increased manifold when compared to previous planning periods. India's generation capacity stands at 303,083.21 MW[2] as on May 31, 2016. Also, with the use of new and more advanced technologies, the efficiency of thermal power plants is improving and the emission levels are reducing substantially. Operational requirements related to scheduling and dispatches are driving the implementation of automation across the power system and for the generators. All new plants now have sophisticated operational information technology (IT) systems and the existing generation fleet is also slowly getting upgraded to match the same. RE-based electricity generation has gained prominence

[1] Bill introduced in Lok Sabha in Dec 2014: http://pib.nic.in/newsite/PrintRelease.aspx?relid=113779 [Accessed: 03-12-2015]
[2] CEA Report May 31, 2016 : http://cea.nic.in/reports/monthly/installedcapacity/2016/installed_capacity-05.pdf [Accessed: 22-06-2016-]

over the years. Several fiscal and policy measures have been introduced to promote RE and GOI has set a target of generating 175,000 MW of RE by 2022[3].

Smart RE control centres which can forecast and monitor RE availability and potentially use energy storage to manage dispatch of power to match grid conditions are expected to become critical to the future integration of RE in order to comply with the requirements laid down by the Indian Electricity Grid Code.

Transmission

The total transmission capacity of 220 kV India stands at 343,033 circuit kilometres as on May 31, 2016[4]. The transmission sector in India is moving towards higher voltage levels of 1200 kV (which has higher power transfer capacity of 6,000-8,000 MW) and is introducing a higher level of automation and grid intelligence. Power Grid Corporation of India Ltd. (PGCIL) is now implementing the world's largest Wide Area Management System (WAMS) as a part of the unified Real-Time Dynamic State scheme[5]. WAMS can be used as a means to address not just immediate reliability concerns but also operational issues like enhancing transfer capability in real time, advanced automatic corrective actions like adaptive islanding, blocking/de-blocking distance relay zones under power swings, better visualization through state measurements, decision support tools, etc. Significant technological advancements such as increasing the capacity of transmission corridors through the use of static Volt-Ampere Reactive (VAR) compensation and re-conductoring of lines using High Temperature Low Sag wires are also being taken up. Managing these systems requires real-time monitoring and control, which is only possible with a robust state-of-the-art communication system.

PGCIL has also evolved a comprehensive plan for integration of renewable capacity addition envisaged in the 12th Five Year Plan as part of "Green Energy Corridors" report[6]. The plan includes intra-state as well as inter-state transmission strengthening(s) and other related infrastructure like dynamic reactive compensation, energy storage, Smart Grid applications, forecasting of renewable generation, real time monitoring, establishment of RE management centre, electric vehicles (EV), investment, etc. The implementation of a Green Energy Corridors is currently under progress.

Distribution

India has one of the largest distribution networks in the world, yet it faces a number of challenges including inadequate electricity access, poor quality and reliability of supply, rampant power theft, poor efficiency through the electricity value chain, etc. There is therefore an urgent need to bring in new technologies and systems to arrest these leaks.

[3] Includes 100,000 MW grid connected Solar Power in the country, out of which 40,000 MW has to come from Solar Rooftop system
[4] http://powermin.nic.in/content/growth-transmission-sector (Accessed on 22-06-2016)
[5] Powergrid Annual Report FY15
[6] Powergrid Annual Report FY15

The Restructured Accelerated Power Development Program (R-APDRP) introduced by the GOI aimed at reducing the Aggregate Technical & Commercial (AT&C) losses to 15 percent. Part-A of the program aimed at establishment of baseline data and its application for energy accounting/auditing and IT-based consumer service centers, which until its introduction was largely missing in most of the distribution utilities in the country and part B aimed at strengthening the physical network.

In December 2014, the MOP launched the Integrated Power Development Scheme (IPDS) with the sanction of the President of India. The R-APDRP scheme has been subsumed in this scheme as a separate component relating to IT enablement of the distribution sector and strengthening of the distribution network. IPDS aims at strengthening of sub-transmission and distribution networks in urban areas, metering of distribution transformers/feeders/consumers in urban areas and IT enablement of the distribution sector.

Other government initiatives in the distribution sector include the 24x7 - Power for All[7] (24x7 PFA) program and the Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) which aims to provide uninterrupted power supply to rural households and agricultural customers. Additionally, the Ujwal Distribution Company (DISCOM) Assurance Yojana (UDAY) scheme aims to enable financial turnaround and revival of DISCOMs and envisages compulsory smart metering of all consumers consuming above 200 units per month[8].

All these schemes envisage an improvement in the distribution sector through deployment of advanced technologies and automation thus providing a strong foundation for evolution to Smart Grid in the power distribution segment.

The implementation of Smart Grid would act as an enabler to transform the existing distribution grids to become more efficient, self-healing, reliable, safer and less constrained, thus benefiting all stakeholders.

1.3. Concept of Smart Grid

1.3.1 Definition of Smart Grid

Smart Grid can be defined as *"An electricity network that uses information and communication technology to gather information and act intelligently in automated manner to improve the efficiency, reliability, economics, and sustainability of generation, transmission and distribution of electricity"* [9].

The idea of a Smart Grid is to make the existing grid infrastructure as efficient as possible

---

[7] (24x7 PFA) is a Joint Initiative of Government of India (GoI) and State Governments with the objective to provide 24x7 power available to all households, industry, commercial businesses, public needs, any other electricity consuming entity and adequate power to agriculture farm holdings by FY 19

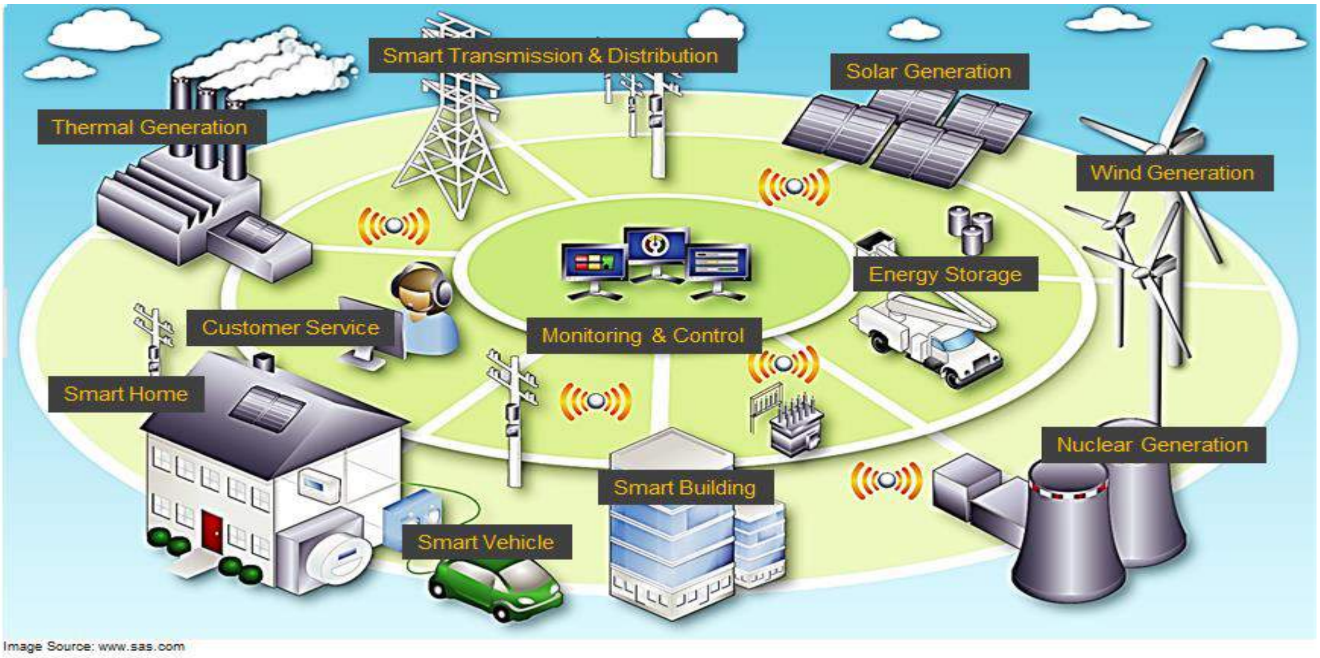
[8] MOP, http://powermin.nic.in/upload/pdf/Power_Sector_Reforms.pdf [Accessed on: 03-12-2015]

[9] As per the Electricity (Amendment) Bill, 2014

through the use of intelligent, automated supply-side and demand-side devices and legislate business practices that provide incentives for the efficient production, transmission, and consumption of electricity across the entire supply/value chain. In simple terms, it can be defined as application of a wide array of technologies to make the electricity grid as smart/efficient as possible.

The technological innovations of the last decade and the increased penetration of communications networks present a unique opportunity to coalesce advancements in power engineering, IT and communications to our energy infrastructure to create a "Smart Grid" – an energy grid with embedded sensing, control and automation, supported by two-way communications.

Figure 1.1: Smart Grid concept[10]



1.3.2 Smart Grid Key Characteristics and Benefits

Table 1.1 describes the key characteristics of Smart Grid in comparison to the traditional grid.

[10] Image Source: www.sas.com

Table 1.1: Smart Grid key characteristics

Characteristic	Traditional Grid	Smart Grid
Self- heals	Needs human intervention to respond to outages and prevent further damage.	Automatically detects and responds to actual and emerging transmission and distribution problems.
Optimization of assets	Minimal integration of limited operational data with Asset Management processes and technologies. Time-based maintenance.	Greatly expanded sensing and measurement of grid conditions. Grid technologies deeply integrated with asset management processes to most effectively manage assets and costs. Condition-based maintenance.
Resist attack	Current grid is vulnerable to malicious acts and natural disasters.	Resilient to cyber-attack and natural disasters; rapid restoration capabilities.
Provides quality power	Main focus is on outage problems rather than power quality. Slow response in resolving power quality issues.	The main focus is on providing quality power to the customers. Rapid resolution of issues.
Accommodation of all generation and storage options	Almost no penetration of storage and decentralized generation options, which create obstacles for interconnecting RE.	Large numbers of storage options are deployed and focus is given to integrate RE in the grid.
Motivates and includes the consumer	Consumers are uninformed and do not participate in demand side management.	Consumers are well informed, and involved in the activities of the power system.

1.3.3 Smart Grid Key Components

Some of the key information technologies (ITs) and operational technologies (OTs) that form the building block of Smart Grid are briefly discussed in the following sections.

Supervisory Control and Data Acquisition (SCADA)

The SCADA is the core component of a Smart Grid decision making process. It is a centralized system for real-time data acquisition (and its analysis), monitoring and control of remote equipment. This equipment in a power network means sensors and other devices installed along the length of the network for assessing its state of health. Major components of SCADA include Remote Terminal Units (RTUs) or Intelligent Electronic Devices (IEDs), a communication interface, a master interface/control station and a human machine interface.

Geographic Information System (GIS)

A GIS integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically-referenced information. GIS allows the utility to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts. A GIS helps you answer questions and solve problems by looking at your data in a way that is quickly understood and easily shared. GIS technology can be integrated into any enterprise information system framework.

Enterprise Resource Planning (ERP)

The ERP is a computer software system which is used for managing all of processes and information in a DISCOM. Typically, ERP consists of many modules which share their information with each other. Work management, project management, document management, billing system, and customer information system are some instances of ERP modules.

Customer Information System (CIS)

A CIS handles all customer data and information of a DISCOM. The main applications of CIS usually include billing and accounting functions. Therefore, CIS functions can be classified as customer and billing payment functions, and customer relationship management (CRM).

CRM includes methodology, software and network techniques, which aims at improving the relationship between enterprises and customers. CRM is the business function which integrates sales, marketing, and customer service. As a consequence of this integration, customer interaction is simplified. Data resources of CIS/CRM include all customer-related data from inner enterprises or outside, which are integrated on the same system.

Outage Management Systems (OMS)

The OMS is a system which combines the trouble call centre and Distribution Management System tools to identify, diagnose and locate faults, then isolate the faults and restore supply. It provides feedback to customers that are affected. It also analyses the event and maintains historical records of the outage as well as calculating statistical indices of interruptions. Outage management is important in distribution networks with goals (and sometimes penalties) to restore the supply to a fault section of the network within a period of time. The main functions of OMS include fault identification, fault diagnosis and fault location, supply restoration and event analysis and recording.

Apart from the above conventional ITs and OTs, there are new technologies which form the platform for Smart Grid. These are briefly mentioned in the following sections.

Communication Technologies

Communication technologies facilitate a two-way communication between utility and customers which is the first step to optimizing electricity production, and the crucial link to all the solutions provided by Smart Grids. Different technologies are applied to the core network, the Distribution Area Network (DAN), the Neighbourhood Area Network (NAN) and the Home Area Network (HAN). New technologies are being developed and existing technologies are being improved in ways that allow the implementation of communications for the Smart Grid.

Advanced Metering Infrastructure (AMI)

The AMI is a collective term to describe the whole infrastructure from smart meter to two way-communications network to control centre equipment and all the applications that enable the gathering and transfer of energy usage information in near real-time. AMI makes two-way communications with customers possible and is the backbone of Smart Grid. The objectives of AMI can be remote meter reading for error free data, network problem identification, load profiling, energy audit and partial load curtailment in place of load shedding.

AMI comprises of various hardware and software components which include smart meters, communication network, Meter Data Acquisition System (MDAS), Meter Data Management System (MDMS) and HAN.

Advanced Distribution Management System (ADMS)

An ADMS is a set of technologies that enables a utility to remotely monitor, coordinate, and operate distribution components in a real-time mode from remote locations. The ADMS function performs:

- Integrity checking of the distribution power system model,
- Periodic and event-driven system modeling and analysis,
- Current and predictive alarming,
- Contingency analysis,
- Coordinated volt/VAR optimization,
- Fault location, isolation, and service restoration,
- Multi-level feeder reconfiguration,
- Pre-arming of restoration schemes and coordination of restorative actions in distribution, and
- Logging and reporting.

These processes are performed through direct interfaces with different databases and systems, (Energy Management System (EMS), OMS, CIS, Market Operations System, SCADA, AM/FM/GIS, AMS and WMS)), comprehensive near real-time simulations of operating conditions, near real-time predictive optimization, and actual real-time control of distribution operations.

Data Analytics and Visualization

Analytics provide the services needed to make sense out of the data being created by Smart Grid sensors. Visualization helps in graphical representation and reporting of this data.

Data Centre

A data warehouse is a subject-oriented, integrated, time-variant, and non-volatile collection of data in support of a manager's decision-making process. Because data is of vital importance in all kinds of applications in the Smart Grid environment, it is appropriate to have a data centre available for exchange, management, and utilization of data. Data warehouses in general are useful as they help in finding the patterns, trends, facts, relations, models, and sequences hidden in the raw data of the operational environment, to enable better decision making for the optimum operation of the system.

These building blocks, and how some of these conventional IT and OT integrate in a Smart Grid world, are described in detail in following modules.

1.4. Smart Grid Applications

Some of the key applications enabled by Smart Grid include:

- Peak Load Management and Demand Response (DR)
- Loss Reduction
- Outage Management
- Asset Management
- Renewable Energy Integration
- Micro-Grids
- Power Quality and Consumer Management

Each of these applications is briefly discussed in Table 1.2.

Table 1.2: Smart Grid applications

Application	Description
Peak Load Management and Demand Response	Involves optimal utilization of energy resources by uniform distribution of load across the day, to save additional investment in capacity expansion, improved access of power to rural areas, reduction in technical losses, enhanced consumer satisfaction by load curtailment instead of load shedding. Key features include: • Load curtailment instead of load shedding • Consumer sign-up processes • DR program commencement

Application	Description
	• Load pattern forecast • Real time price computation • Real time pricing • Remote curtailment process • Curtailment due to contract violation • Special provision for defaulters • Demand side management • Load monitoring at demand side • Provision of re-checking for automatically generated disconnection or load limiting commands; on demand disconnection/reconnection • Initiation of direct load control event, etc. Further, when such applications are installed, real time demand data is likely to be generated. Such demand data, when combined with portfolio optimization tools, can provide opportunities for power purchase optimization that is likely to provide a platform for better power purchase and sale planning.
Loss Reduction	Loss reduction has been dealt under several programs earlier, especially the R-APDRP, IPDS and UDAY program. Smart Grid projects envisage deployment of AMI. AMI systems provide advanced energy monitoring and recording, sophisticated tariff/rate program, data collection, and load management command and control capabilities. Additionally, these mechanisms will enable consumers to better manage their energy usage, and allowing the grid to be run more efficiently from both a cost and energy delivery perspective. These advanced capabilities allow utilities to provision and configure the advanced meters in the field, offering new rate programs, and energy monitoring and control. AMI enablement coupled with analytics can provide enough information and alerts to the utilities to detect technical and commercial losses and initiate corrective actions for loss reduction.
Outage Management	Outage management is extremely important for the utilities and the consumers they serve. The utilities can leverage existing OMS (if it exists) and utilize the capabilities of AMI and grid automation (SCADA, GIS, etc.) to improve grid reliability by self-healing and more quickly and accurately identifying the location and magnitude of an outage, resulting in faster restoration.

Application	Description
Asset Management	Asset Monitoring and Management involves optimizing and prioritizing investments in assets to maintain or improve performance and life expectancy throughout the asset's life cycle. The use of Smart Grid technologies (Smart sensors, RTU, SCADA, GIS, etc.) enables condition-based maintenance by allowing online monitoring of the vital parameters of the field asset. The technologies also provide for system alarms for abnormal asset health. Smart Grid data combined with analytics can allow for predictive maintenance as well. Thus Smart Grid provides utility with a company-wide view of asset information so as to make fact-based decisions that decrease operating costs, improve regulatory compliance, enhance safety, and maximize return on investment.
Renewable Energy Integration	Due to its variable and uncertain nature, incorporation and integration of RE, particularly wind and solar, into the grid is likely to present severe challenges for generators, distribution utilities, system operators and planners. Appropriate controls through Smart Grid can facilitate integration of large-scale RE into the grid. Smart Grid offer significantly high level of control and responsiveness to varying grid conditions, and hence aid in rectifying grid disturbances, active power control and frequency regulation, reactive power control and voltage regulation.
Micro-Grids	Micro-grids are modern, localized small-scale versions of the centralized electricity system. They achieve specific local goals, such as reliability, carbon emission reduction, diversification of energy sources, and cost reduction, established by the community being served. Like the bulk power grid, smart micro-grids generate, distribute, and regulate the flow of electricity to consumers, but do so locally. Smart micro-grids are an ideal way to integrate renewable resources on the community level and allow for consumer participation in the electricity enterprise. Micro-grids can be grid-connected or off-grid depending on its application like powering operations of military bases, mines, remote villages, islands, campus environments, hospitals, emergency services, communication towers, commercial buildings and electric vehicles.
Power Quality and Consumer Management	Managing voltage, frequency, etc. within certain thresholds allows electrical systems to function in their intended manner without significant loss of performance or life. Power Quality management applications cover aspects such as: (i) power quality categories and metrics to be monitored; (ii) installation of voltage/VAR control; (iii) site selection and installation; (iv) power quality event capture and transmittal; (v) data storage, characterization and reporting; and (vi) real-time alerts. The Electricity Act, 2003 requires power quality and consumer service

Application	Description
	standards to be notified and deviations to be penalized[11], and even for licenses to be suspended[12]. However in the absence of measurement and control systems, these provisions become difficult to implement. Smart Grid can help implement these standards, to the benefit of consumers at large.

These Smart Grid applications provide a number of benefits to the key stakeholders. Some of these benefits are described in Table 1.3.

Table 1.3: Smart Grid key stakeholder benefits

Stakeholder	Key Benefits
Utilities	• Optimizing system asset utilization • Reduction of T&D losses • Peak load management • Better asset management • Increased grid visibility • Self-healing of grid • Renewable integration
Consumers	• Higher accessibility to electricity • Improved power reliability • Backup power requirement minimized/eliminated • Improved quality of supply • Improved customer service • User friendly and transparent interface with utilities • Increased options such as TOU tariff, DR programs, net metering
Government	• Satisfied customers • Financially sound public utilities to avoid burden for revival packages • Reduction in emission intensity to meet the nation's environmental goals

The benefits and application of a Smart Grid as detailed above are many, but the implementation of Smart Grid is still in its initial stages in India. It is thus imperative that strong institutional, regulatory and policy structures are in place to promote large-scale deployment of Smart Grid systems. In this context, a number of measures have taken place across all three fronts in India and these are briefly discussed in Section 1.5.

1.5. Smart Grid Scenario in India

1.5.1 Institutional Framework

Several developments have taken place in the Smart Grid space in India in the last few

[11] Section 57 of Electricity Act, 2003

[12] Section 24 of Electricity Act, 2003

years. The initial institutional setup for Smart Grid comprised the India Smart Grid Task Force (ISGTF) and the India Smart Grid Forum (ISGF) established in 2010 under the MOP.

Indian Smart Grid Task Force

The ISGTF is an inter-ministerial group which was formed to serve as the government focal point for activities related to the Smart Grid. Members of ISGTF were selected from the concerned ministries (power, home, defence, communications and IT, new and renewable energy, environment and forests, and finance) and organizations (Planning Commission, Department of Science and Technology, Central Electricity Authority (CEA), Central Power Research Institute (CPRI), Bureau of Energy Efficiency (BEE), NTPC, PGCIL, Bureau of Indian Standards (BIS), Power Finance Corporation (PFC), and Rural Electrification Corporation (REC). The ISGTF has undertaken feasibility studies to understand the market environment for Smart Grid in India. Various white papers have also been published.

The main functions of the ISGTF is to ensure awareness, coordination and integration of the diverse activities related to Smart Grid technologies, practices and services for Smart Grid research and development; co-ordinate and integrate other relevant inter-governmental activities; collaborate on interoperability frame work; and review and validate the recommendations from ISGF, etc.[13]

India Smart Grid Forum[14]

The ISGF is a public-private partnership initiative of the MOP for accelerated development of Smart Grid technologies in the Indian power sector. ISGF's mandate is to advise government on policies and programs for promotion of Smart Grid in India, work with national and international agencies in standards development and help utilities, regulators and the Industry in technology selection, training and capacity building.

The main objectives of ISGF are to:

- Help the Indian power sector deploy Smart Grid technologies in an efficient, cost effective, innovative and scalable manner by bringing together all key stakeholders and enabling technologies.
- Create a platform for public and private stakeholder members, research institutions and power utilities to exchange ideas and information on Smart Grid and develop use case scenarios for India.
- Bring together experts from regulation, policy, and the corporate sector to build support for Smart Grid policies.
- Conduct research on the capabilities of Smart Grid in the Indian context through case studies, cost-benefit analysis, study of technical advancements in RE sources and other ancillary activities.

---

[13] Pib.nic.in, 'India Smart Grid Forum Website Launched', 2015. [Online]. Available: http://pib.nic.in/newsite/PrintRelease.aspx?relid=71397 . [Accessed: 01- Dec- 2015].

[14] Indiasmartgrid.org, 'ISGF', 2015. [Online]. Available: http://indiasmartgrid.org/about-us.php . [Accessed: 01- Dec- 2015].

- Make recommendations to the government, regulators, utilities and consumers through reports, white papers, technical seminars, etc.

National Smart Grid Mission (NSGM)

In 2015, the Government approved the NSGM, an institutional mechanism for planning, monitoring and implementation of policies and programs related to Smart Grid activities. The NSGM provides support to Smart Grid projects through assistance in project formulation (pre-feasibility studies, cost-benefit analysis, financial modeling and so on); partial funding of projects; training and capacity building; consumer engagement; and project appraisal post implementation.

A three-tiered departmental structure has been formed[15] to ensure smooth functioning of project activities under the NSGM.

- At the apex level, the NSGM has a Governing Council headed by the MOP. Members of the Governing Council are Secretary level officers of concerned Ministries and departments. The Governing Council will have necessary functional and financial autonomy within the overall budgetary allocation for meeting its objective of rolling out Smart Grid operations in different parts of the country.
- At the second level, the NSGM has an Empowered Committee headed by Secretary (Power). Members of the Empowered Committee are Joint Secretary level officers of concerned Ministries and departments. The role of the Empowered Committee is to provide policy input to Governing Council, approve specific Smart Grid projects and subsequent revisions/modifications guidelines/procedures, approve procedures/guidelines for Smart Grid projects, etc.
- In a supportive role, the NSGM has a Technical Committee headed by Chairperson (CEA). Members of the Technical Committee are Director level officers of concerned Ministries and departments, and representatives from industries and academia. The role of the Technical Committee is to support the Empowered Committee on technical aspect, standards development, technology selection guidelines, etc. (Figure 1.2)

For day-to-day operations, the NSGM has a NSGM Project Management Unit (NPMU) headed by the Director, NPMU who is a member of the Governing Council and Empowered Committee, and Member Secretary of Technical Committee. NPMU is the implementing agency for operationalizing the Smart Grid activities in the country under the guidance of the Governing Council and Empowered Committee. NPMU will be housed at PGCIL. The present ISGTF secretariat will be merged with the NPMU.

The indicative components of Smart Grid in the 12th plan under NSGM would include:

- Deployment of Smart Meter and AMI

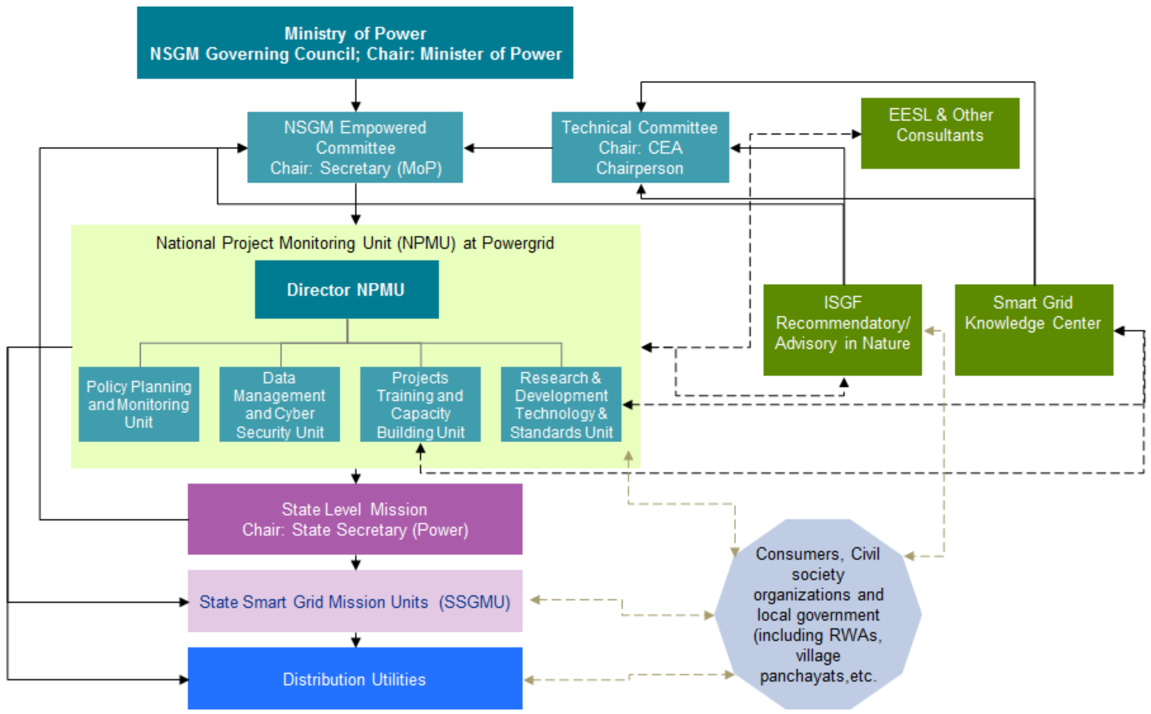
[15] MOP, 'National Smart Grid Mission, Office Memorandum', 2015. [Online]. Available: http://powermin.nic.in/upload/pdf/National_Smart_Grid_Mission_OM.pdf. [Accessed: 01- Dec- 2015].

- Substation renovation and modernization with deployment of GIS wherever economically feasible
- Development of medium-sized micro grids
- Development of distributed generation - Rooftop Photovoltaic (PV)
- Consumer engagements and training
- Real time monitoring and control of distribution transformers
- Provision of harmonic filters and other power quality improvement measures
- Creation of EV charging infrastructure for supporting proliferation of EVs

As a part of the NSGM, PGCIL is also developing a Smart Grid Knowledge Centre which will act as a resource centre for providing technical support to the mission, including development of technical manpower, capacity building, outreach, etc.

The total outlay for NSGM activities for 12th Plan is estimated to be INR 980 crores (USD 146.26 million) with a budgetary support of INR 338 crores (USD 50.44 million). In the 12th Plan, the NSGM will focus on coordinating development of Smart Grid activities in 30 medium-sized cities.

Figure 1.2: NSGM institutional structure[16,17]



[16] MOP, 'National Smart Grid Mission, Office Memorandum', 2015. [Online]. Available: http://powermin.nic.in/upload/pdf/National_Smart_Grid_Mission_OM.pdf. [Accessed: 01- Dec- 2015].

[17] MOP has issued guidelines for implementation of National Smart Grid Mission which provides guidelines on project formulation and implementation, role of stakeholders, fund disbursement and program monitoring among others [Source: http://nsgm.gov.in//upload/files/NSGM%20Guidelines.pdf [Accessed: 06- Dec- 2015].

A number of organizations in India are engaged in contributing towards development of different aspects of Smart Grid technologies and standards. These include:

Bureau of Indian Standards

The BIS, the national standards body, is one of the core members of the ISGTF, and also a part of the Working Group on "Physical Cyber Security, Standards and Spectrum". Considering that IT architecture is an important constituent of power system control and automation to facilitate Smart Grid deployment, a Panel on Digital Architecture has been constituted by BIS under Power System Control and Associated Communications Sectional Committee LITD 10 to formulate standards on IT architecture with a view to harmonize the interface and integration of various IT solutions.

The draft reports after incorporating the comments from various members of other Panels of LITD 10 have been circulated[18]. The BIS in 2015 has also released standard for smart meter (IS 16444: Static Direct Connected Watt-hour Smart Meter Class 1 and 2 – Specification).

Central Power Research Institute

The CPRI serves as an independent authority for testing and certification of power equipment. It has set up laboratories under its purview which carry out the following activities:

- **Metering Protocol Laboratory**: This laboratory is involved in setting meter standards and management of intelligent meters. CPRI advocated the use of open standards in meters. It has also set up "Conformance Test Laboratory" for verifying if the provisions of Device Language Message Specification protocol are implemented correctly in the metering device.

- **Substation Automation System Laboratory**: The laboratory develops tests, and certifies protocol-related substation communication as per the national and international standards like IEC 61850, IEC 62056, and BIS Indian companion specification. This national laboratory has played a critical role in certifying the protocols for the communication between different substations in Smart Grid pilot projects.

CPRI also conducts various workshops/training programs to sensitize the personnel on Smart Grid technologies. These workshops cover the following aspects:

- Application of Information Technology to Power Systems
- International Electricity Metering Protocols (IEC 62056)
- Distribution Automation
- Cyber and System Security of Power sector

[18] Available online at http://www.bis.org.in/sf/ltd/LITD10_3299.pdf (Last accessed at 01-12-2015)

A Smart Grid test bed at CPRI Bengaluru is proposed to be setup under a grant from the USTDA. The test bed, which will consist of an integrated Interoperability Laboratory and Smart Grid Technology Demonstration Centre, will allow CPRI to research and perform controlled evaluations of integrated Smart Grid technologies[19].

Central Electricity Authority

The CEA provides technical support for Smart Grid development in India. A Committee was constituted by the MOP during April 2011 under the Chairmanship of Chief Engineer (DP&D), CEA, comprising 17 members, from utilities, meters, and chip manufacturers, to finalize the functional requirement specifications for cost-effective single-phase smart meters.

The key mandate provided to the Committee was as follows:

- Finalization of functional requirement/specifications for cost-effective single-phase electricity meters,
- Suggest changes in applicable Indian Standards (IS), and
- Review of the CEA regulations on installation and operation of meters.

The Committee finalized the functional requirement specifications for cost-effective single-phase meters during March 2012.

Department of Electronics and Information Technology (DeitY)

The DeitY was constituted under the Ministry of Communications and IT with a mission to promote e-Governance for empowering citizens, promoting the inclusive and sustainable growth of the Electronics, IT and ITeS industries, enhancing India's role in Internet Governance, adopting a multipronged approach that includes development of human resources, promoting R&D and innovation, enhancing efficiency through digital services and ensuring a secure cyber space.

The DeitY looks into matters relating to cyber laws, administration of the Information Technology Act, 2000 (21 of 2000) and other IT-related laws. A National Cyber Security Policy - 2013 has been released by the Department[20].

Department of Telecommunications (DOT)

In May 2015[21], the network of technologies cell of DOT released the National Telecom Machine to Machine (M2M) Roadmap realizing the growing importance of M2M as the basis for

[19] Smart Grid Bulletin, Volume 1, 7th ed. India Smart Grid Forum, 2014.
[20] Department of Electronics and information technology (DeitY, http://deity.gov.in/)
[21] Department of Telecommunications, 'Networks & Technologies (NT) Cell', 2015. [Online]. Available: http://www.dot.gov.in/ntcell. Accessed on 03/12/2015.

automated information interchange between machines and a control centre for various industry verticals like Smart City, Smart Grid, Smart Water, Smart Transportation, Smart Health, etc.

The DOT has also released the 'National IPv6 Deployment Roadmap' to promote the adoption of IPv6-based innovative applications in areas like rural emergency healthcare, tele-education, smart metering, Smart Grid, smart building, Smart City, etc. To complement the roadmap, the DOT also released 'Compendium on IPv60-based Solutions/Architecture/Case Studies for Different Industry Verticals' which, among other use cases, enumerates the advantages of implementation of Smart Grid on IPv6-based infrastructure in the power sector.

Indian Electrical and Electronics Manufacturers' Association (IEEMA)[22]

The IEEMA, a national representative organization of manufacturers of electrical, industrial electronics and allied equipment in India, established a Smart Grid cell in association with the MOP in 2012. Seventeen member companies have opted for Smart Grid Division membership. Some of the key motivations for setting up the cell include:

- To work with national and state government organizations with regulatory and policy setting powers
- To work closely with the IT companies and industry associations involved with the development of the Smart Grid
- Occupy a thought leadership position in Smart Grid
- Create megawatts as a fifth fuel and monetize the potential of energy efficiency and DR
- To create jobs and marketplace innovation

1.5.2 Legal, Policy & Regulatory Framework

The Electricity (Amendment) Bill, 2014

The Electricity (Amendment) Bill, 2014 was introduced in the Lok Sabha in December 2014. The Bill aims to promote competition, efficiency in operations and improvement in quality of supply of electricity in the country resulting in capacity addition and ultimate benefit to the consumers.

With respect to Smart Grid, the Bill defines a Smart Grid and seeks to promote provision of electricity through Smart Grid, net metering, ancillary services and decentralized distributed generation. The Bill also provides for installation of smart meters for proper accounting and measurement of consumption of electricity.

The proposed amendment regarding smart meter is reproduced below:

"Provided that smart meters, as specified by the Authority, shall be installed at each stage for proper accounting and measurement for the purpose of metering and consumption from the

[22] [Online] Available: http://ieema.org/division/smart-grid/ [Last Accessed: 10-02-2016]

point of generation up to such consumers who consume more than the quantity of electricity in a month as prescribed by the Central Government".

The Bill also provides for a number of other provisions that facilitate higher technology adoption and automation in the distribution sector.

National Smart Grid Roadmap

The GOI has brought out the Smart Grid Vision and Roadmap for India in August 2013. The vision formulated is as follows: *"Transform the Indian power sector into a secure, adaptive, sustainable and digitally enabled ecosystem by 2027 that provides reliable and quality energy for all with active participation of stakeholders".*

The roadmap aims at 24x7 power for all, reduction of T&D losses, greater RE integration, reduction in power cuts, improved power quality, development of EV infrastructure, nationwide Smart Grid roll-out and capacity building in Smart Grid technologies among others [23].

National Tariff Policy

The Union Cabinet, on January 20, 2016, approved the proposal of the MOP for amendments in the tariff policy to ensure 24X7 affordable Power for All. The objective of the amendments is to ensure the 4 E's - Electricity for all, Efficiency to ensure affordable tariffs, Environment for a sustainable future, and Ease of doing business to attract investments and ensure financial viability.

The policy aims at providing power in remote unconnected villages through micro grids and provides continuity of power supply with regulator to mandate compulsory purchase of power into grid from such micro grids at regulated tariff.

The policy also requires faster installation of smart meters to enable "Time of Day" metering, reduce theft and allow net-metering[24]. It mandates the State Electricity Regulatory Commissions (SERCs) to install smart meters for all consumers with:[25]

- Monthly consumption greater than 500 units by December 2017
- Monthly consumption greater than 200 units by December 2019

[23] Smart Grid Vision and Roadmap for India http://www.powermin.nic.in/whats_new/pdf/Smart_Grid_Vision_Roadmap_for_IndiaMOP_Sept2013.pdf [Accessed: 03-12-2015]

[24] http://pib.nic.in/newsite/PrintRelease.aspx?relid=134630 [Accessed: 03-04-2016]

[25] http://powermin.nic.in/upload/pdf/Tariff_Policy-Resolution_Dated_28012016.pdf [Accessed: 03-04-2015]

EV Program by the Ministry Of Heavy Industries[26]

The GOI has set up a National Council for Electric Mobility (NCEM) to promote electric mobility and manufacturing of electric vehicles in India. It will be aided by the National Board for Electric Mobility (NBEM) formed by the Ministry of Heavy Industries.

The GOI has recognized the fact that at present there are immense barriers to greater adoption of EV. Given the importance of the initiative, the government launched the National Mission for Electric Mobility (NMEM).

The NCEM formulated the National Electric Mobility Mission Plan 2020 (NEMMP 2020), which is the mission document for the NMEM. The NEMMP 2020 has set a target of six-seven million units of new electric/hybrid vehicle sales year on year, along with resultant savings of liquid fuel of 2.2 – 2.5 million tonnes that can be achieved by 2020.

The cumulative electric/hybrid vehicle is expected to reach 15-16 million by 2020. It is expected to save 9,500 million litres of crude oil equivalent to INR 62000 crores (USD 9,254 million) savings. The government has also launched the scheme namely Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME India) under NEMMP 2020 in the Union Budget for 2015-16 with an initial outlay of INR 75 Crores (USD 11.2 million). The scheme is expected to provide a major push for early adoption and market creation of both hybrid and electric technologies vehicles in the country[27].

Evolving Smart Grid Regulatory Framework (Electricity)

In order to provide regulatory impetus to Smart Grid investments, model Smart Grid regulations have been approved by the Forum of Regulators (FOR) in 2015. These model regulations provide a framework for SERCs to adopt these regulations in their respective states according to their needs and priorities.

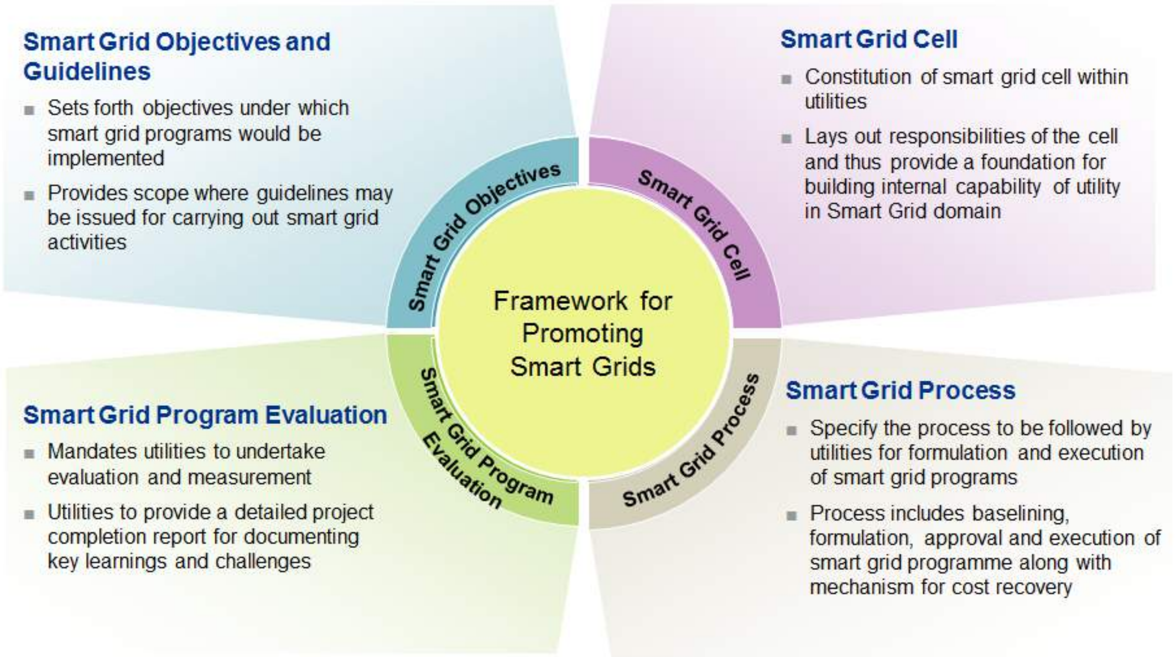
The overall framework consists of broadly four sections: Smart Grid Objectives; Smart Grid Cell; Smart Grid Process; Smart Grid Program Evaluation. These are discussed in Figure 1.3.

---

[26] *National Electricity Mobility Mission Plan 2020*, 1st ed. Department of Heavy Industries, Ministry of Heavy Industries & Public Enterprises, GoI, 2015.

[27] http://pib.nic.in/newsite/PrintRelease.aspx?relid=116719 [Accessed: 04-12-2015]

Figure 1.3: Model Smart Grid regulatory framework



The draft Smart Grid Regulations have already been issued by SERCs of Assam, Madhya Pradesh and Karnataka, Tripura and Haryana[28].

Haryana Electricity Regulatory Commission Order on rRmote Disconnect and Brownout[29]

The Haryana Electricity Regulatory Commission (HERC) has passed an order based on the petition received by it for seeking approval for Peak Load Management (PLM) through remote disconnection and through brown out concept through advanced Smart Grid technology on pilot basis in Panipat sub-division.

The final regulatory order allowed remote disconnection and connection for load violation only for feeders where quality of supply disruptions (voltage drop by 6 percent) is expected. The details of the regulatory provisions include:

- If maximum demand > the sanctioned load, then an alarm will be sent on consumer mobile/in home display system.
- If the maximum demand is > 10 percent of sanctioned load, supply to be automatically disconnected for 5 minutes interval and thereafter reconnected automatically.
- This will work for three instances of violation. For further violations, meter lock out period shall be 15 minutes for 4th and 5th instance and 30 minutes after the 5th instance.

[28] Status as on 1st March, 2016

[29] Final Order, HERC/PRO-58 of 2014, 16-Dec-2015

- The functionality shall be evoked only on those feeders on which a consumer faces voltage drop of 6 percent or more in order to maintain the reliability and quality of supply as per the voltage regulation (± 6 percent) defined in the standard of performance.

The order allows for implementation of brown out in cases of overloading/partial availability of supply for preventing blackouts. The order also calls for adequate awareness of consumers is required as part of implementing the functionality. The details regarding the brown out case include:

- Whenever 11 KV feeder/feeders become overloaded to the extent that will result in the tripping of the feeder, brown out shall be implemented on those feeders till the overloading continues.
- Whenever power is partially available due to failure in transmission network or generating station or in sub-station, brown out shall be implemented.
- Consumers shall be intimated through display communicated on the smart meter with an alarm/SMS before calling 'brown out'.
- Licensee shall ensure sensitization of consumers and wide publicity of the above, before implementation of the concept.
- The implementation of brown-out is without prejudice to duty of licensee to augment its infrastructure and supply electricity as per T&C of licensee and regulations in vogue.

1.5.3 Smart Grid Activities

A number of schemes and projects have been introduced by the GOI which would provide a solid foundation for transforming our grid into a Smart Grid. Some of these key initiatives are discussed in the following sections.

Integrated Power Development Scheme (IPDS)

During the 11th Five Year Plan (2007-2012), the GOI launched the R-APDRP scheme which focused on reduction of AT&C losses and overall strengthening of the sub-transmission and distribution level.

Under the R-APDRP program, the DISCOMs are building a set of basic IT and automation systems to enable evaluation of performance improvements before and after implementation. Automated systems would also enable sustained collection of accurate base line data and processes for energy accounting and would lead to internal accountability of the state utilities.

Project execution under the scheme is taken up in two parts. Part-A includes the projects for establishment of baseline data and IT applications for energy accounting/auditing and IT-based consumer service centres. Part-B includes regular distribution strengthening projects.

The key schemes under R-APDRP are given in Table 1.4.

Table 1.4: Key schemes under R-APDRP

PART- A	PART-B	PART-C
• Establishment of the base line data system. • Consumer indexing, GIS mapping, metering of distribution transformers and feeders. • Asset mapping of the entire distribution network. • Automatic data logging for all distribution transformers and feeders. • SCADA/Distribution Management System (DMS) in towns/cities. • IT applications for meter reading, billing and collection. • Energy accounting and auditing, Management Information System (MIS). • Redressal of consumer grievances. • Establishment of IT-enabled consumer service centers.	• Renovation, modernization and strengthening of 11 kV level substations, transformers and transformer centers. • Re-conductoring of lines at 11kv level and below. • Load bifurcation, feeder separation, and load balancing. • Replacement of electromagnetic energy meters with tamper proof electronics meters. • Installation of capacitor banks and mobile service centers, etc. • Strengthening at 33 kV or 66 kV levels only in exceptional cases, where sub-transmission system is weak.	• Validation of baseline data. • Capacity building and development of franchisees. • Project evaluation. • Consumer attitude survey. • Pilot projects in areas of innovative technology.

The R-APDRP program has now been subsumed in the IPDS scheme as a separate component relating to IT enablement of the distribution sector (and strengthening of the distribution network).

The IPDS has been launched by the GOI with a focus on improving power supply quality and availability in urban areas. The key components of this scheme are:

- Strengthening of the sub-transmission and distribution network in the urban areas
- Metering of distribution transformers/feeders/consumers in the urban areas
- IT enablement of the distribution sector and strengthening of the distribution network

The fulfilment of these objectives will help in realizing the benefits such as reduction in AT&C losses, establishment of IT-enabled energy accounting/auditing system, improvement in billed energy based on metered consumption and collection efficiency.

The scheme also envisages completion of optical fibre missing links to connect all the 33kV or 66kV grid sub-stations under National Optical Fibre Network. A National Power Data Hub at the CEA would also be established under the scheme.

All DISCOMs, including private sector DISCOMs and State Power Departments, will be eligible for financial assistance under the scheme. In case of private sector DISCOMs where the distribution of power supply in the urban areas is with them, the projects under the scheme will be implemented through a State Government agency and the assets to be created under the scheme will be owned by the State Government/State-owned companies.

Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY)

DDUGJY is a scheme launched by the GOI with the aim of providing uninterrupted power supply to rural households and agricultural customers. To achieve this goal, several infrastructural strengthening and renovation steps will be undertaken such as feeder separation; strengthening of sub-transmission and distribution network; metering at all levels (input points, feeders and distribution transformers); micro-grid and off-grid distribution network and rural electrification, and completion of sanctioned projects under the Rajiv Gandhi Grameen Vidyutikaran Yojana. The REC is the nodal agency to implement the DDUGY scheme. All DISCOMs, including private sector DISCOMs and State Power Departments, are eligible for financial assistance under this scheme.

Ujwal DISCOM Assurance Yojana (UDAY)

UDAY, launched in 2015 by the GOI, provides for the financial turnaround and revival of DOSCOMs, and also ensures a sustainable permanent solution to the problem. It empowers DISCOMs with the opportunity to break even through four initiatives: (i) improvement of operational efficiencies of DISCOMs; (ii) reduction of cost of power; (iii) reduction in interest cost of DISCOMs; and (iv) enforcement of financial discipline on DISCOMs through alignment with State finances.

As a part of the initiative, the UDAY scheme has set a target of 35 million smart meters by December 2019[30].

Smart Grid Pilot Projects

Various Smart Grid pilot projects have been initiated by the GOI. These pilots will assist in testing and selection of appropriate technologies and communication systems and provide inputs to policy and regulatory framework for further scale up of the program. A Smart City pilot has also been approved by the MOP at IIT Kanpur. It is envisaged that lessons from these Smart Grid pilots shall provide useful inputs to scale up Smart Grid deployments in the country and plan new initiatives.

The details of the Smart Grid pilot projects are presented in Table 1.5.

[30] http://powermin.nic.in/upload/pdf/Power_Sector_Reforms.pdf

Table 1.5: Key schemes under R-APDRP[31]

State Utility	Smart Grid Functionalities	Project Area
APDCL, Assam	AMI-R, AMI-I, PLM, OMS, PQ, DG	Guwahati distribution region (15,000 Consumers)
CESC, Mysore	AMI-R, AMI-I, OMS, PLM, MG/DG	Additional City Area Division (ACAD), Mysore (21,824 Consumers)
HPSEB, Himachal Pradesh	AMI-I, OMS, PLM, PQ	Kala Amb Industrial Area (1,251 Consumers)
IIT Kanpur- Smart City Pilot	Smart City	IIT Kanpur
PED, Puducherry	AMI-R, AMI-I	Division 1 of Puducherry (34,000 Consumers)
PSPCL, Punjab	AMI-R, AMI-I, PLM	Tech-II Sub-division, SAS Nagar (2,734 Consumers)
TSECL, Tripura	AMI-R, AMI-I, PLM	Electrical Division No.1, of Agartala town (42,676 Consumers)
TSSPDCL, Telangana	AMI-R, AMI-I, PLM, OMS, PQ	Jeedimetla Industrial Area (11,904 Consumers)
UHBVN, Haryana	AMI-R, AMI-I, PLM, OMS	Panipat City Sub Division (11,000 Consumers)
UGVCL, Gujarat	AMI-R, AMI-I, OMS, PLM, PQ	Naroda of Sabarmati Circle and Deesa-II of Palanpur Circle (39,422 Consumers)
WBSEDCL, West Bengal	AMI-R, AMI-I, PLM	Siliguri Town in Darjeeling District (5,275 Consumers)

Legend: AMI-R: Advanced Metering Infrastructure- Residential; AMI-I: Advanced Metering Infrastructure- Industrial; PLM: Peak Load Management; OMS: Outage Management System; PQ: Power Quality; MG/DG: Micro Grid/Distributed Generation

[31] Status of Smart Grid Pilot Projects, May,2016
http://www.nsgm.gov.in//upload/files/Status%20of%20Smart%20Grid%20Pilots%20and%20NSGM%20Smart%20Grid%20Projects%20-%20May%202016.pdf
[Accessed: 27-06-2016]

1.6. References

[1] Context of Smart Grid in India. FICCI; 2013.

[2] J. Momoh, Smart Grid: Fundamentals of Design and Analysis. Hoboken, N.J.: Wiley; 2012.

[3] MOP, Deendayal Upadhyaya Gram Jyoti Yojana, Office Memorandum, 2014. [Online]. Available: http://powermin.nic.in/upload/pdf/Deendayal_Upadhyaya_Gram_Jyoti_Yojana.pdf.[Accessed: 01- Dec- 2015].

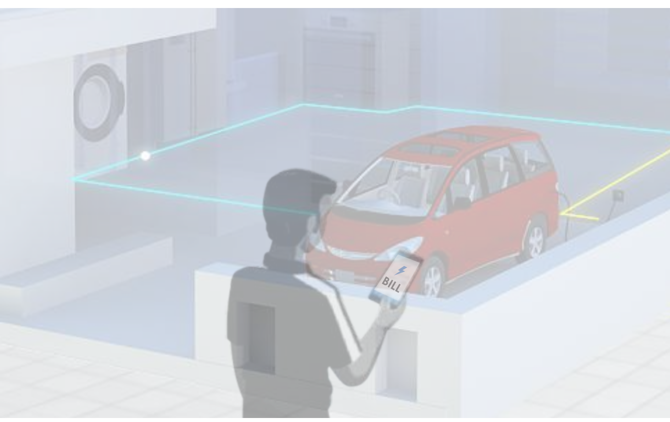
[4] Smart Grid Vision and Roadmap for India. Ministry of Power, Government of India; ISGTF; ISGF, 2013.

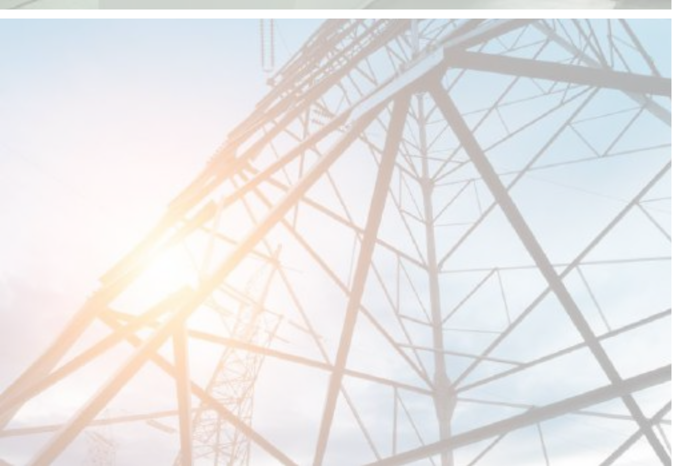
[5] Model Smart Grid Regulations. Forum of Regulators, 2015.

[6] MOP, Integrated Power Development Scheme, Office Memorandum, 2014. [Online]. Available: http://powermin.nic.in/upload/pdf/Integrated_Power_Development_Scheme.pdf.[Accessed: 01- Dec- 2015].

[7] Accelerating Successful Smart Grid Pilots. World Economic Forum; 2010.

[8] MOP, National Smart Grid Mission, *Office Memorandum*, 2015. [Online]. Available: http://powermin.nic.in/upload/pdf/National_Smart_Grid_Mission_OM.pdf. [Accessed: 01- Dec- 2015].





Module - 2

Smart Grid Building Blocks

2.1. Introduction

This chapter outlines the basic building blocks for Smart Grid. The key components of Smart Grids including AMI, GIS, SCADA, and DMS are discussed in detail in the following sections.

2.2. Geographic Information System (GIS)

GIS applications allow the user to map, model, run a query and analyze large amount of spatial information within a single database. GIS tools enable creation of maps, integration of information, visualization of scenarios, and development of effective solutions. GIS applications such as the creation of a customer database and indexing; mapping of the sub-transmission and electrical distribution network and so on, can provide a number of advantages, such as efficiency improvement, loss reduction, downtime reduction and costs. GIS mapping of the distribution network (33KV substation down to consumer level) allows proper identification, location mapping and documentation of electrical network assets. In addition to the above advantages, the existing connection and consumer details can be graphically displayed on the GIS map linked to the database.

GIS enables the proper operation of Smart Grid components, such as OMS and for real-time system management, as well as informs other applications for system planning and engineering.

Some key characteristics/aspects of GIS solutions include:

- The GIS software has a dynamic, flexible, and user friendly interface where required - functions can be quickly developed, efficiently operated and maintained.
- It provides a comprehensive inventory of the electrical distribution network components and their spatial locations.
- The application has the capability for storing all information (both attribute and spatial) in a centralized Relational Database Management System which allows real-time analysis of the network, and determines the current state and condition of the system.
- The software can support, capture and store schematic diagrams for different types of networks.
- The GIS supports easy web enabling of the application and also helps in understanding the relationship of networks with surroundings because it is an essential tool for restoration, storm tracking and security monitoring.

2.2.1 Applications of GIS

Some of the applications enabled by GIS in Smart Grid are discussed in Table 2.1.

Table 2.1: GIS applications

Application	Description
AMI Loss Reduction	▪ GIS mapping enables positioning of consumers on digitalized map and their source of supply (MV/LV substation) and hence allows for feeder and DT-wise energy auditing. ▪ GIS consumer mapping combined with other customer data can help identify billing patterns and when combined with analytics, it can help identify sudden change of load patterns to determine cases of theft.
Load Forecasting	▪ Combining GIS spatial data of network with consumer load data, current land use, urban centers, etc. can enable forecasting the future load growth for every small area. The future system can then be planned from these load forecasts.
Demand Response	▪ GIS with integration with systems like CIS and Energy Data Management Systems can be used for targeted DR programs. Spatial analysis of this data can enable utilities to quickly identify areas where load relief is required.
AMI Roll Out	▪ GIS can be used to determine optimal locations for Smart Grid components. The optimum location for placing a smart meter unit can be obtained through spatial analysis and similarly the optimum location of communication devices can also be determined.
Outage Management	▪ Real-time weather data integrated in GIS increases the operator’s situational awareness and enables operators to quickly determine facilities with increased risks of outage. GIS maps can also be combined with real time line loading information to identify lines with increased risk of flashovers and faults. ▪ With precise network layout, GIS combined with AMI data, can help identify the exact locations affected by outages.
Workforce Management	▪ GIS combined with Global Positioning System (GPS) can enable automatic vehicle location to allow the electronic map to track the crew in real-time and help in workforce scheduling.
Asset Management	▪ GIS allows utilities to visualize the entire network asset in a single platform and helps them in understanding the physical and spatial relationships among all network components. GIS thus provides the means for real time monitoring and displaying the health of asset.

A practical case study of GIS implementation and its benefits to Tata Power Delhi Distribution Ltd. (TPDDL) is presented in Box 2.1.

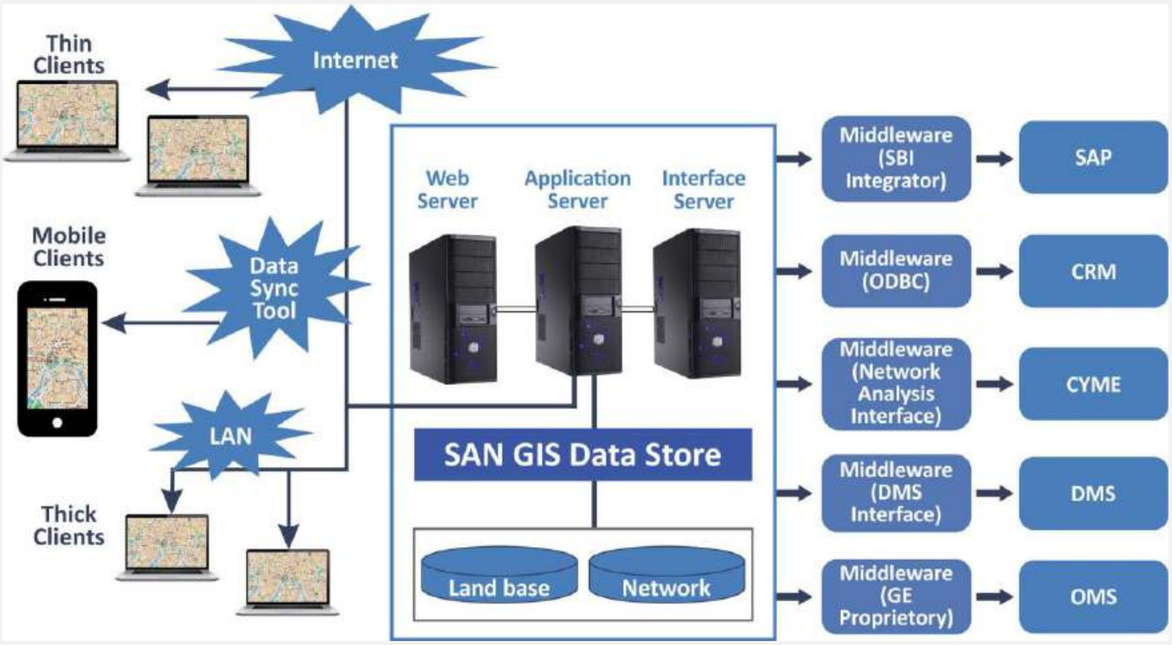
Box 2.1 Case Study: GIS experience of TPDDL[32]

Project Overview: TPDDL in 2006 implemented a GIS solution with the goal of mapping the entire asset base of TPDDL for ensuring improved asset management.

Approach: Broadly, the following approach was followed:

- For implementing GIS, a clear roadmap of which business processes will use GIS was identified. Of the total 360 business processes which existed, 40 which could use GIS were identified.
- In order to optimize the value derived from GIS, it had to be integrated with other enterprise systems like ERP, CRM, DMS, OMS, and electric network modeling (SYME).
- For the long term success of GIS, it was important to make sure that a robust schema was developed for the database in which land base, customer, and facility information is stored since it would be difficult to rework a poorly structured database.

The GIS architecture employed is shown below.



Lessons from Implementation:

- **Ensuring the land base is up to date** – new developments such as subdivisions (estates) and renovations to existing sites occur continually and the utility has to implement processes to ensure these changes are captured and regularly updated.
- **Ensuring the facilities database is up to date** – new subdivisions and renovations to existing sites means new electric power circuits and equipment. In addition, the power network requires replacement and upgrading (reinforcement). Business processes that ensure these changes are captured in a timely fashion in the facilities database are required. Many utilities have as-built backlogs that extend to months and even years.

[32] http://www.indiageospatialforum.org/2014/proceedingPDF/energy/Arup%20Ghosh.pdf .[Accessed: 01- Apr- 2016].

- **Updating consumer data** – consumers move, they get disconnected and reconnected, and increasingly they request for new services. A business process that ensures these changes are captured in a timely fashion is required.

GIS Benefits to TPDDL: TPDDL invested INR 12 crores (USD 1.8 million) in implementing a GIS. Annual maintenance and operations for the GIS cost INR 1.5 crores (USD 0.22 million). The estimated annual rate of return on the investment is INR 4 crores (USD 0.6 million) per year. It is estimated that the investment in GIS paid for itself in 3.5 to 4 years. Other benefits to TPDDL are as follows:

Application	Benefit
Asset Management	▪ Reduced redundant data by implementing a single source of truth for asset data
	▪ The asset lifecycle was streamlined by integrating GIS, CYME, SAP and financial asset management. This helped TPDDL optimize their capital expenditure and investment planning.
Operation Management	▪ Integrating GIS and DMS for their 11 kV network, and integrating GIS and OMS helped them improve outage management.
	▪ The network diagram extracted from the GIS was used for operations and streamlining the permit to work process.
	▪ The asset attributes data stored in the GIS improved maintenance planning and scheduling.
	▪ As a result of GIS the causes of their technical losses were understood and plan for mitigation was developed.
Commercial Management	▪ Being able to exactly geo-locate their customers, and link each customer to phase, transformer, feeder, and substation TPDDL provided better services and improved their collections efficiency which is now 99.7 percent.
	▪ TPDDL's pole inventory and street lights have also been implemented in their GIS. It has also helped to automate customer connection/disconnection and speed up revenue generation.
	▪ GIS has also helped with being able to respond more rapidly to power availability requests from high demand consumers.

GIS implementation has been taken up pan-India by utilities as part of the R-APDRP implementation. One such case of Maharashtra State Electricity Distribution Company Ltd. (MSEDCL) highlighting the best practices in GIS is presented in Box 2.2.

Box 2.2 Case Study: R-APDRP best practices and innovations in GIS delta update of MSEDCL[33]

As a part of its R-APDRP implementation, MSEDCL implemented the GIS application module and documented a set of best practices for various stages of implementation. These best practices include:

Pre-Survey:

- Workshop of agencies conducted before the survey to clearly set out the requirements.
- Process for consumer indexing and asset mapping was defined and made mandatory.

[33] http://www.apdrp.gov.in/Forum_File/Best_Practice_MSEDCL_innovations_in_GIS_100914.pdf [Accessed: 01- Apr- 2016].

Survey/Managed Data Services (MDS):

- Consumer indexing and asset mapping was done by ITIA/MDS agency as per the process approved by MSEDCL.
- For a faster GIS update, new connection module was designed to add new consumers from R-APDRP towns to the GIS database directly without opening the GIS web application window.

Post Survey:

- Survey done by ITIA/MDS agency was verified with the billing data and was approved by respective town in-charge.
- Third party quality assurance of digitized GIS data was undertaken and corrections undertaken by MDS agency were verified by town in-charge.

System Operations:

- Specific responsibilities were entrusted to town officers vide the GIS responsibility matrix. The town in charge was made responsible for town level GIS activities including updating of day to day changes of network and consumers in GIS.
- Network Augmentation Schemes were prepared using the GIS-based Network Analysis Module.

Delta Updates:

Initially, there was a GIS data gap between start of GIS survey and digitization process of the town by ITIA. This was primarily because of:

- Lack of dedicated resources to cater to delta update process requirements.
- Insufficient field staff and lack of skill of GIS data collection and update.

To make sure such a gap does not arise post-implementation, MSEDCL outsourced its MDS by hiring dedicated trained manpower for town activities and GIS experts for DC activities on Service Level Agreement (SLA) basis. Post go-live, MSEDCL appointed an independent third party Managed Data Services Agency for helping MSEDCL staff to carry out GIS delta update and regular update work and training/handholding.

System Developments:

- A core team of IT and Electrical Engineers both from Head Office and field operation was formed.
- Detailed verification of the documents by the core team was prepared before approval was conveyed to ITIA.
- Like other R-APDRP applications, the Web-based GIS application was designed to be accessed through Single-Sign-On (SSO) feature. The town user could view/edit GIS data related to his town, only.
- Additional dummy fields were reserved in GIS Data model for future requirements (the Data Model had fields mentioned in the RFP and MSEDCL specific requirements).
- GIS system was seamlessly integrated with other applications. For example:
    - I. New connection module where technical feasibility and DTC load profile was calculated by GIS system.
    - II. Energy audit module which considered billed consumption of only those consumers who were in GIS.
    - III. Disconnection and dismantling module was also integrated for generating shortest route map of defaulters.

2.3. Supervisory Control and Data Acquisition

At the core of Smart Grid decision making lies SCADA, a centralized system for real-time data acquisition and its analysis, monitoring and control of remote equipment. This equipment in a power network means sensors and other devices installed along the length of the network for assessing its state of health. Major components of SCADA include RTUs or IEDs, a communication interface, a master interface/control station and a human machine interface.

2.3.1 SCADA Functions

The basic SCADA functions include data acquisition, remote control, human-machine interface, historical data analysis, and report writing, which are common to generation, transmission, and distribution systems.

Data acquisition is the function by which all kinds of data—analog, digital, and pulse—are acquired from the power system. This is accomplished by the use of sensors, transducers, and status point information acquired from the field.

Remote control involves the control of all required variables by the operator from the control room. In power systems, the control is mostly of switch positions; hence, digital control output points are abundant, such as circuit breaker and isolator positions and equipment on and off positions.

Historical data analysis is an important function performed by the power system SCADA, where the post-event analysis is done using the data available after the event has happened. An example is the post-outage analysis where the data acquired by the SCADA system can provide insights into such information as the sequence of events during the outage, malfunctioning of any device in the system, and the action taken by the operator. This could be a powerful tool for future planning and is extensively used by power engineering personnel.

Some of the advanced distribution application functions enabled by SCADA in Smart Grid are detailed in Table 2.2.

Table 2.2: SCADA applications

Application Function	Description
Power Quality (PQ) monitoring	▪ PQM devices connected to the network can be monitored centrally through SCADA network to monitor harmonics, voltage sags, swells, and unbalances. ▪ Corrective measures such as switching of capacitor banks and voltage regulators can be implemented to improve the power quality via SCADA interface.

Application Function	Description
System Planning	▪ Sequence of Events (SOE) recording by SCADA systems which time-stamp crucial events in the system provides crucial data about the system loading patterns. ▪ This historical sequential data helps planners in designing new feeders, and networks for the future.
Load Balancing	▪ With a real-time view of loading on various substations, feeders, transformers and other equipment, and the ability to control from a central location, utilities can achieve proper load balancing on the system, avoiding unnecessary overloading of equipment and ensuring a longer service life for the components.
Equipment condition monitoring	▪ By automatically tracking vital equipment parameters abnormalities can be detected and with proper maintenance the life of costly equipment can be extended. ▪ SCADA interface enables transition from time-based to condition-based maintenance with continuous monitoring.
Fault identification, isolation, and service restoration	▪ Fault Detection, Isolation, and Service Restoration (FLISR) systems use SCADA-enabled switches and sensors to locate the faulted area, isolate the fault, and restore service to non-fault areas. ▪ Some switching operations can also be performed automatically using SCADA to control action to field devices.

2.4. Advanced Metering Infrastructure

AMI can be defined as "the infrastructure required to enable the distribution licensee to accurately collect, monitor and analyse real-time consumption data from consumers, communicate price signals to consumers and where permitted control load; and communications hardware and software"[34].

2.4.1 AMI Architecture

AMI is an integrated system comprising of smart meter, two way communication networks and data management systems that provide the backbone for enabling much of the Smart Grid functions like remote meter reading, connect-disconnection, theft-tamper detection, outage management and distributed generation management, among others.

Key components of AMI are:

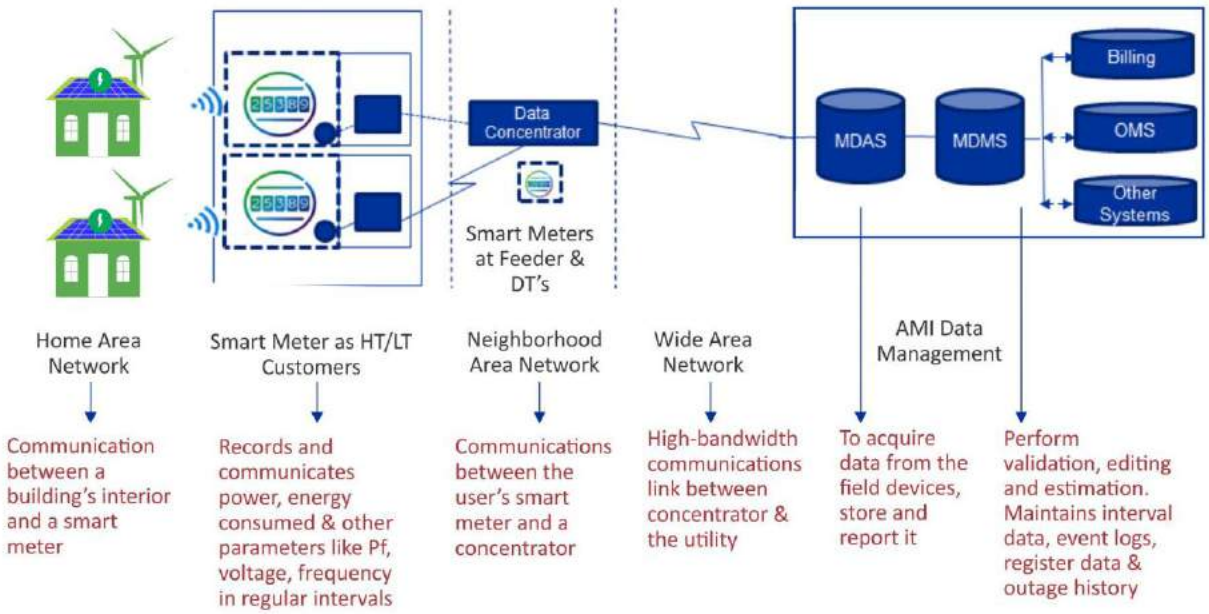
- A smart meter.
- A communication infrastructure which provides the backbone for transmitting meter data from customer premises to the utility control centers.
- A MDAS which acquires data from the field devices, analyzes and reports it.

[34] *Model Smart Grid Regulations*. Forum of Regulators, 2015

- A MDMS which is a software package specifically designed to receive and analyze reads and other information sent by the meter (alarms, etc.).

  AMI architecture is presented in Figure 2.1

Figure 2.1: AMI architecture



The key components are described in the following sections.

Smart Meters

Smart meter is an AC static watt-hour meter with time of use registers, internal connect and disconnect switches with two way communication capability. It is designed to measure flow of energy, store and communicate the same along with other parameters defined in this standard. It can be remotely accessed for data, programming and load switch, thereby enabling rollout of AMI[35]. Smart meters not only measure instantaneous power and the amount of energy consumed over time but also other parameters such as power factor, reactive power, voltage and frequency, with high accuracy. (Refer BIS standard IS16444 for smart meters)

Communication Technologies

A Smart Grid consists of several basic networks:

- HAN: Communications between a building's interior and a smart meter,

[35]BIS Standard, IS 16444:2015 A.C static direct connected watt-hour smart meter class 1 and 2 – specification http://www.bis.org.in/sf/etd/ET-13(6823)_11022015.pdf [Accessed: 01- Dec- 2015].

- NAN: Communications between the user's smart meter and a concentrator (or aggregator), and
- Wide Area Network (WAN): A high-bandwidth backhaul communications link between the concentrator and the utility.

HAN

HAN is at the customer end of the network architecture. It supports communications among household appliances from a smart meter, in-home displays (IHDs) and/or home energy management (HEM) systems. HAN applications include home automation, optimal thermostat set points, controlling and managing loads and providing total electricity costs.

A HAN is connected to other Smart Grid actors, e.g., an electric utility or a third party energy service provider, via a smart meter or an Internet gateway.

NAN

A NAN or Field Area Network (FAN) supports information data flow between WAN and a premises area network.

NAN allows electricity usage information to be transmitted from energy meters to a utility, and allows field devices to be controlled remotely, e.g., in distribution automation applications. NAN is connected to WAN via a backhaul network, where data from many NANs are aggregated and transported between NAN and WAN.

WAN

A WAN supports real-time monitoring control and protection applications, which can help prevent cascading outages with real-time information related to the state of the power grid. It also provides communication links for Smart Grid backbones; and covers long-haul distances from NAN to a control center. Media used for WAN communications typically use long-range, high-power radios or Ethernet IP-based solutions.

MDAS

A MDAS is an important interface to the field devices such as smart meters, data connector unit, distribution transformers and feeders at substations with centralized monitoring system. Its primary functions are to acquire data from the field devices, analyze it and report it. It automates the meter reading thus avoiding any human intervention. It has the ability to process huge amount of data with high performance and efficiency for ensuring system-wide monitoring and decision support.
MDAS is the core application for interface to the smart meter. The MDAS can perform following functions:

- Acquisition of meter data on demand and at user selected periodicity
- Two way communication with smart meter/data concentrator unit (DCU)
- Connect and disconnect for load control and pricing signal
- Audit trail and event and alarm logging
- Encryption of data for secure communication with smart meter, DCU and MDM
- Maintain time sync with DCU/smart meter
- Handling of control signals/event messages on priority
- Setting of smart meter configurable parameters

Meter Data Management System

A MDMS is a database with analytical tools that enable interaction with other information systems such as the following:

- CIS, billing systems, and the utility website
- OMS
- ERP power quality management and load forecasting systems
- Mobile Workforce Management
- GIS
- Transformer Load Management (TLM)

The MDMS supports storage, archiving, retrieval and analysis of meter data and various other MIS along with validation and verification algorithms. One of the primary functions of an MDMS is to perform Validation, Editing and Estimation (VEE) on the AMI data to ensure that despite disruptions in the communications network or at customer premises, the data flowing to the systems is complete and accurate.

2.4.2 AMI Applications

Key AMI applications include:

- **Time-based pricing** : A smart meter is capable of recording consumption that incorporates dynamic pricing mechanism (TOU, Critical Peak Pricing (CPP)) to provide options for the consumer to limit use of power during peak period (high price) and maximize use during off-peak (low price). Also, by establishing bi-directional communication to consumer devices over the HAN interface and WAN interface, it enables real-time DR and as a result more dynamic pricing schemes.

- **Real time display of consumption data**: AMI can transmit or communicate information of the load and energy consumed in minutes (or seconds) to both the utility and consumer. This feature enables consumers to understand their load patterns and undertake suitable demand side management measures. The data from AMI maintains integrity and accuracy by automatically resuming functionality after loss of power and retaining all information held in its storage prior to power failure.

- **Net metering**: It is capable of recording exported and imported power (bi-directional flow) of consumers for applications like rooftop solar PV.

- **Faster restoration of services**: It can detect errors, record and transmit loss and restoration of power notice to both utility and consumer. This feature enables OMS and improves system reliability through real-time outage information.

- **Remote turn on/turn off operations**: A smart meter can be remotely turned on and turned off. This feature enables, among others, DR mechanisms on voluntary load shedding during emergency plans. It can determine when power supply usage exceeds predetermined value such as contracted load, record it, send alerts and automatically disconnect supply till load goes below contracted amount.

- **Energy prepayment**: It can provide prepaid service options which allow users to better manage their energy consumption and benefit the utility in optimizing its collection efficiency since the utility gains from advance payment for future consumption and simplified billing and collection operation.

- **Power quality monitoring**: It can detect errors, record and communicate notices on abnormal power quality beyond acceptable standards.

- **Tamper and energy theft detection**: It has security features that can detect any attempt of unauthorized physical meter tampering. It can provide evidence of such an attempt through the use of tamper evident seals. It can also send an alert notice of unauthorized usage via its available interface and disable the supply.

- **Enabling Plug-in Electric Vehicle (PEVs)**: AMI combined with smart charging technologies will allow PEV owners to charge their vehicles at non-peak times when electricity rates are cheaper. This will lower the PEV cost per mile driven and encourage additional consumers to switch to PEVs.

- **Customer convenience**: With the rollout of AMI, utilities will be able to provide better customer service, especially around customer directed shut-off and reconnection dates. These improvements in service result in increased levels of customer satisfaction.

2.4.3 Cost Benefit Analysis

A guide to key costs and benefits for the utilities is provided in Table 2.3.

Table 2.3: AMI cost-benefit analysis

Costs	Benefits
▪ AMI Metering Equipment and Communications Infrastructure Implementation • AMI Meters & Installation • AMI Communications Network Hardware & Installation ▪ IT Systems and Integration: MDAS,MDM, storage system, data integration platform, analytics software ▪ Program Management ▪ AMI Operational Costs – Metering Operations (Maintenance, field servicing, inventory management) – Communications Operations ▪ Consumer Education	▪ Reduction in Meter Reading Costs ▪ Reduction in Field and Meter Services (Manual Disconnect/Reconnect of Meters, Manual Off-Cycle/Special Meter Reads) ▪ Theft/Tamper Detection and Reduction ▪ Efficiency Improvement in Billing and Customer Management ▪ Improved Capital Spend Efficiency – Distribution System Management – Asset Management Planning – Avoided Meter Purchases ▪ Improved Outage Management Efficiency

Apart from these utility benefits, many consumer/societal benefits emerging from AMI implementation also need to be considered. Examples include DR program which enables reduction in peak demand, avoided economic cost for customer due to shorter restoration times and increased level of customer service leading to higher customer satisfaction levels.

2.4.4 AMI International Deployment Experiences[36]

Globally, grid modernization programs have been initiated and national roll-outs of AMI across continents is in progress. To study the AMI deployments world over and generate insights into the best practices, the International Smart Grid Action Network has come out with a set of case studies on AMI across ten countries. An analysis of a few of these case studies on various key parameters identified is presented in Table 2.4.

[36] *AMI Case Book Version 2.0*. International Smart Grid Action Network; 2014.

Table 2.4: AMI global case study result summary

Key Parameter	Country			
	Canada Ontario Smart Meter Deployment Project (2004-2012)	Ireland Smart Meter Pilot - Customer Behavior Trial using "Opt-in" Model (2009-2012)	Netherlands National Smart Meter deployment project (Phase-1 2012-2014)	Italy Telegestore Automated Meter Management Project by Enel (Private DisCom) (1999-2006)
Project Highlights	Mandatory adoption of smart meter - 4.8 million smart meters installed and 4.5 million customers on time of use (TOU) rates.	• Initial 6000 smart meter deployment for a national pilot • To proceed for national smart meter roll-out from 2015-2019	• A 2 year small-scale AMI rollout for regular replacements, new houses and on customer request to gain deployment experience • Large scale roll-out for all consumers as phase-2 of the plan	Full deployment of AMI meter- 32 million smart meter vs 37 million total customers
Project Drivers	• Reduction in energy consumption and lower cost of electricity supply	• Shift peak electricity demand and reduce overall electricity consumption	• Easy switching for consumers between suppliers • Improve operational efficiency • Support energy savings for end use consumers	• Greater reliability and power quality • Creating more customer choice
Customer Engagement Undertaken	• Yes- To communicate changes to customers and help set their expectations for future Smart Grid initiatives • A central TOU roll-out working group formed to develop consumer engagement material	• Yes- Emphasizing the opportunity for the consumers to reduce their bill • DR participant received supporting information in form of stickers and consumer bill contained detailed usage and supplied tips on energy reduction	• No- Mandatory rollout announced without consumer interaction • Faced opposition from national association of consumers for privacy and security concerns which resulted in policy change to voluntary rollout	• Yes-To inform customers about the replacement campaign, and spread awareness of benefits • Communication plan included brochure & documents, congresses, promotional billboards, press releases and dedicated trade papers.
Other Key Project Aspects	• Single centralized MDM/R integrated with AMI of all DISCOMs to provide aggregated consumption for future policy and program planning	• Consumer behavior trials conducted to determine smart meter potential for reduction in energy consumption	The rollout (phase-2) will partly be funded from the current meter tariff. This tariff will be stable in the first years of the roll out and could remain unchanged or even drop	Remote curtailment functionality ensures minimum social supply to all for a limited period of time, instead of outright cut-offs (power limited to 10 percent of their

Key Parameter	Country			
	Canada Ontario Smart Meter Deployment Project (2004-2012)	Ireland Smart Meter Pilot - Customer Behavior Trial using “Opt-in” Model (2009-2012)	Netherlands National Smart Meter deployment project (Phase-1 2012-2014)	Italy Telegestore Automated Meter Management Project by Enel (Private DisCom) (1999-2006)
	• Created robust guidelines for managing meter data - incorporated privacy by design as a principle • Off peak time of 10 PM faced opposition because of impracticality of waiting to switch on heavy load devices and hence was shifted to 7 PM	• Participants who had an In-home display were able to reduce their consumption more than others		contract value in case of load violation)
Key Benefits	• Reduced the number of crew visits to read and service meters • Savings in avoided/deferred capacity investments in new generation and transmission	• TOU tariffs were effective in both reducing and shifting consumption	• Energy saving • Savings on call center costs • Lower cost level as a result of the market mechanism (increased switching) • Savings in meter reading costs	• Replacement of worn-out meters, which measured lower consumption • Correction of database records • Detection of tampered installations from fraud and theft • Elimination of consumption estimation with real time data
Results and Current Status (as on 2014)	• Completed in 2012 at a cost of CDN 1 billion • 3 percent shift from peak to off-peak • Benefit value: CDN 1.6 billion	• Opt-in model - achieved 30 percent response rate • Overall 2.5 percent consumption reduction and 8.8 percent peak demand reduction from TOU tariffs • Net Present Value (NPV): EUR 174 million if implemented	• Small scale pilot in final stages • Cost-benefit-analysis shows a positive NPV of approximately EUR 770 million	• Completed in 2006 at a cost of EUR 2.1 billion • EUR 500 million yearly savings • 1.5 TWh energy recovered in 2005 • 30,000 tons CO_2 emissions reduced in 2010

Key Parameter	Country			
	Canada Ontario Smart Meter Deployment Project (2004-2012)	Ireland Smart Meter Pilot - Customer Behavior Trial using “Opt-in” Model (2009-2012)	Netherlands National Smart Meter deployment project (Phase-1 2012-2014)	Italy Telegestore Automated Meter Management Project by Enel (Private DisCom) (1999-2006)
Way Forward	Aggregate MDM/R data provides a valuable resource to create innovative projects and services for customers. To enable this innovation, Ontario is conducting a Green Button pilot to determine best practices for granting customers and third parties safe access to customer data.	National smart meter rollout by early 2019 to enable real time monitoring of the LV network level and allow increase of distributed generation and virtual power plants.	Start of a large-scale role out of Smart Grid expected in 2015/2016	• Design and development of second generation smart meters to replace the current smart meters at their end of life (expected lifetime 15 years) is underway. • Proposal to exploit synergies between electricity metering and metering systems of other utilities such as gas and water.

Some of the key learnings from these deployments that can be considered while designing AMI programs in India are presented in the following sections.

Phased Approach for AMI Deployment

A phased approach to AMI deployment is preferable over a complete system upgrade. Undertaking pilot projects at initial stages enables the utilities to understand the challenges and benefits from these deployments and incorporate these learnings to undertake a smooth large-scale roll-out.

Customer Engagement and Inclusivity

Consumers are an integral part of the Smart Grid ecosystem. Experience from the case studies indicates that the utilities that involved customers from the start of the project have been able to execute the program hassle free without any major opposition from the consumer. It is therefore important to educate the consumers about Smart Grid benefits prior to roll-out to obtain their support.

A number of utilities also undertook consumer behavior studies in the pilot stages to understand the potential effect of Smart Grid technologies on consumers. These studies enabled the utilities to apply the learnings to deliver a smooth large scale roll-out.

Mandatory versus Voluntary Smart Meter Roll-Outs Policy

It is important to choose a right policy among the options based on the regulatory environment and market context of individual countries. Italy employed a gradual approach to deployment and used a mixed strategy between mandatory and voluntary policies. When applying only mandatory policy, there might be strong customer resistance as was in the case of Netherlands, which changed to a voluntary policy. A voluntary policy provides the consumers with the flexibility of either the opt-in or opt-out model and therefore a few cases of opposition would not lead to stalling of the entire project.

Experience from these case studies show that initially a balanced approach may be required wherein consumers with a certain minimum load may be eligible for smart metering plan whereas others can be put in on an opt-in or opt-out model.

Privacy and Cyber Security

Privacy and security are major concerns voiced by various NGOs and consumer groups across all regions. It is thus important to address these concerns through proper institutional, regulatory and policy measures. Privacy and security issues should be tackled by utilities at the time of Smart Grid planning and should not be an after-thought during implementation.

For example, Ontario's Privacy Commissioner worked with DISCOMs to develop the Privacy by Design principles which were incorporated into a guideline of best practices for Smart Grid companies to follow when designing their systems.

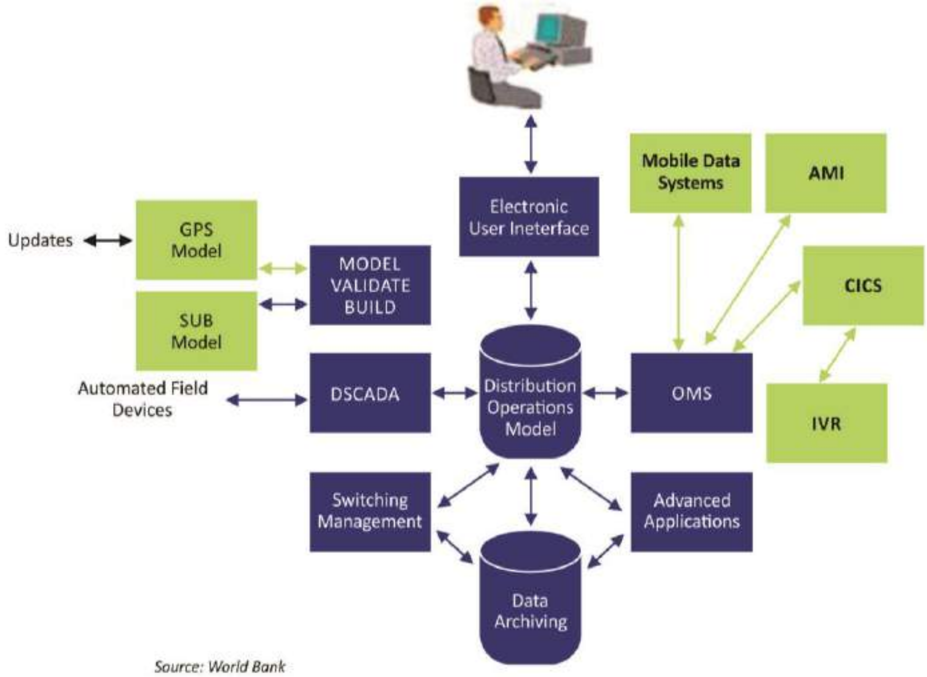
2.5. Advanced Distribution Management System (ADMS)

ADMS is a collection of applications designed to monitor and control the entire distribution side in a power network. It includes a number of applications such as SCADA, OMS, GIS, CIS, and Interactive Voice Response System (IVRS) and so on. Key outcomes of ADMS include power quality, minimizing outages and improving reliability of the system. The use of ADMS enables some of the important functions in Smart Grid such as network connectivity analysis, state estimation, volt-VAR control, fault management and system restoration.

The Smart Grid system requires management by a system that has a holistic view of power system conditions which is what the ADMS provides. The ADMS integrates monitoring ("sensorization"), grid analytics, and control applications into an effective decision support system that will enable distribution dispatchers to effectively manage a distribution system of growing complexity during normal and emergency conditions.

A representative ADMS architecture is presented in Figure 2.2.

Figure 2.2: ADMS architecture[37]



[37] Source: World Bank, Practical Guidance for Defining a Smart Grid Modernization Strategy
Note: GIS = geographic information system; DSCADA = distribution supervisory control and data acquisition; OMS = outage management system; AMI = advanced metering infrastructure; CICS = Customer Information Control System; IVR = interactive voice response.

The foundation on which the ADMS is based is the Distribution Supervisory Control and Data Acquisition (DSCADA) system. The DSCADA system provides the field-facing interface that enables the ADMS to monitor the distribution field equipment in real-time. DSCADA also enables the ADMS to initiate and execute remote control actions for controllable field devices in response to operator commands or application function control actions. Examples of control actions include opening/closing a medium voltage line switch, raising/lowering a voltage regulator tap-setting, and switching a capacitor bank on or off. To perform these actions, the ADMS also requires integration with other Smart Grid applications to get the required inputs which are discussed in Section 2.5.1.

2.5.1 Integration of ADMS with external systems

GIS: This interface enables the ADMS to obtain information from the GIS for building the static network connectivity model, displays, and electrical model used by the distribution application functions. This interface streamlines the initial static network connectivity model and display building process and simplifies the creation of the electrical model used by the ADMS applications. The GIS would provide up-to-date information about distribution assets that is needed to build and maintain the feeder model used by the advanced ADMS distribution applications.

AMI: Voltage measurements, acquired via the AMI system from selected AMI meters installed at customer premises near feeder extremities, provide feedback to the Volt-VAR Optimization (VVO) application to ensure that voltage at the customer locations are within specified limits.

OMS: The interface to OMS is used for real time data capture of partial restorations, device status changes, and temporary device additions and deletions (jumpers and line cuts).

The information acquired from DSCADA and integration with other applications is used by ADMS to enable a number of advanced distribution applications which are discussed in the following section.

Field Force Automation System (FFA): The FFA or Workforce Automation is about getting the right technician or crew to the right place at the right time at the least cost to the business. The FFA optimizes the way utilities complete planned work without overtime, respond quickly to emergency situations, make the most productive use out of mobile workers, provide easy access to required information, automate validation of field data and improve overall workforce performance.

The FFA processes data and jobs from a variety of sources, example GIS or OMS for operational tasks such as servicing, maintenance, meter readings, etc. Functions for route planning, analysis and workflow control are also a part of the FFA.

2.5.2 Advanced Distribution Applications

The addition of advanced distribution applications in ADMS provides a clear distinction between ADMS and DSCADA. Some of the advanced distribution applications that are often included in ADMS are listed in the following sections.

On-Line Power Flow (OLPF)

An OLPF program is used to determine the electrical conditions on the utility's distribution feeders in near real-time. The OLPF provides the control center personnel with calculated current and voltage values in place of actual measurements and can alert the operators to abnormal conditions out on the feeders, such as low voltage at the feeder extremities and overloaded line sections. In addition, other ADMS application functions such as Switch Order Management (SOM), VVO, and FLISR can use the OLPF results to accomplish their specified functionality.

Short Circuit Analysis (SCA)

A SCA function enables utilities to calculate the three-phase voltages and currents on the distribution system due to postulated fault conditions with due consideration of pre-fault loading conditions. The SCA function can also enable users to identify estimated fault location using measured fault magnitude, pre-fault loading, and other information available at the time of the fault. The results of SCA can be used for other applications like FLISR, relay protection and coordination.

Switch Order Management (SOM)

A SOM function assists the dispatcher in preparing and executing switching procedures for various elements of the power system, including both substation and field devices (outside the substation fence). The ADMS SOM function assists the user in generating switching orders that comply with applicable safety policies and work practices. The SOM function also supports the creation, execution, display, modification, maintenance, and printing of switching orders containing lists of actions that are needed to perform the switching, such as opening/closing various types of switches, implementing cuts and jumpers, blocking, grounding, and tagging.

Volt/VAR Control

A VVO function automatically determines optimal control actions to achieve specified operating objectives while maintaining acceptable voltage and loading at all feeder locations. It could include the following utility-selectable operating objectives:

- Reduce electric demand
- Reduce energy consumption
- Improve feeder voltage profile
- Maximize revenue

- Energy loss minimization/power factor improvement
- Weighted combination of the above

The VVO function operates either in closed loop or advisory (open-loop) mode. In advisory mode, the VVO function generates advisory control actions that may then be implemented by the dispatcher. In closed loop mode, the VVO program automatically executes the optimal control actions without operator verification. The VVO is executed periodically at a user-adjustable interval, upon occurrence of a specified event, (significant change in the distribution system such as significant load transfer, topology change and so forth), or manually by user.

Fault Location, Isolation, and Service Restoration (FLISR)

A FLISR function is used to improve the System Average Interruption Duration Index (SAIDI). It provides SAIDI improvement benefits for a wide variety of feeder configurations with various levels of protection and automation, ranging from feeders in which the substation circuit breaker is the only controllable device and source of information to feeders that are equipped with automated line switches, ties switches, fault detectors, and other facilities for monitoring and control.

The FLISR main logic automatically detects faults and approximate fault location and then restores service automatically to as many customers as possible.

The ADMS will analyze all available real-time information acquired from field devices, including fault detector outputs, fault magnitude at various locations on the feeder, feeder segment and customer meter energization status, and protective relay targets, to detect faults and other circuit conditions for which service restoration actions are required. All control actions identified by centralized FLISR is executed by issuing supervisory control commands to substation circuit breakers and reclosers and various feeder-switching devices (reclosers, load break switches, and sectionalizers that are equipped with supervisory control capabilities).

Optimal Network Reconfiguration (ONR)

An ONR function identifies ways in which the utility can reconfigure a user-selected interconnected set of distribution feeders to accomplish a user-specified objective function without violating any loading or voltage constraints on the feeder. The ADMS ONR function enables the following:

- Minimize total electrical losses on the selected group of feeders over a specified time period.
- Minimize the largest peak demand among the selected group of feeders over a specified time period.
- Balance the load between the selected groups of feeders (that is, transfer load from heavily loaded feeders to lightly loaded feeders).

Short Term Load Forecasting (STLF)

A STLF function uses historical load and weather data to forecast the system load automatically. Weather data is used to support the short-term load forecast function. The STLF results are available for viewing and outage planning and should be used by other ADMS application functions that require an estimate of expected peak loading in the near term, such as FLISR, Switch Order Management (SOM), Network Reconfiguration, and large area restoration.

A case study on utility benefits of implementing ADMS and AMI is presented in Box 2.3.

Box 2.3 Case Study: Duke Energy – Ohio Smart Grid project[38,39]

Project Highlight: A total investment of USD 100 million was allotted for Ohio grid modernization project in AMI and Distribution Automation (DA) application under which ~140,000 new Smart Grid meters have been installed since 2008 in Ohio impacting 700,000 consumers.

Project Objectives:

- Implement distribution automation to help prevent and shorten outages
- Enable AMI and reduce the need for estimated bills
- Enable remote service connections and disconnections for faster customer service
- Capture and post daily energy usage data online so that customers can make wiser energy decisions
- Incorporate more renewable, distributed generation into the grid

Project Benefits: Following the audit and assessment of the project a set of 25 operational benefits from employing AMI and DA. A few of the benefits post-Smart Grid operations are compared with the baseline grid operations pre-deployment and presented in the following infographic.

38 Duke Energy Ohio Smart Grid Audit and Assessment, 2011

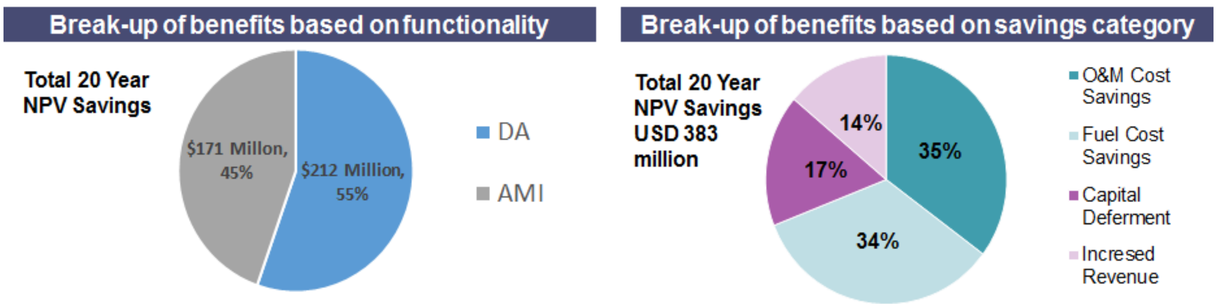
39 naruc.org/international/Documents/Duke%20Smart%20Grid%20%20-%20Don%20Schneider%20Duke%20Energy.pdf

Key Elements		Traditional Operations	Smart Grid Operations
Key Elements	**Meter Reads**	Meter Readers walk from house to house to capture electric and gas meter data with handheld equipment	Smart meters send interval data directly to the utility and hence eliminating most of annual meter reading labor costs
	Meter Diagnostics	No capability to understand if a customer issue was on the utility or customer-side of the meter	Real-time remote diagnostic helped determine if meter is operating normally. If meter was receiving voltage, no field personnel are sent to investigate.
	Power Theft	Traditional meters did not offer capabilities to detect tampering (mis-wired or bypassed meters)	Smart meters generated tampering alarms and monitored meter data to identify theft. This resulted in increased revenue by 0.5% of overall revenue
	Capital Costs	Traditional meters need to be replaced over time resulting in regular capital cost	Smart meters do not require the use of equipment related to manual meter reads such as handheld devices resulting in reduced costs
	Operational Costs	Traditional meters and associated handheld equipment decrease in accuracy over time, requiring routine testing	Due to their digital nature, smart meters do not require regular testing to ensure accuracy hence resulting in reducing testing and refurbishment costs
Key Elements	**Outage Detection**	No capability to detect the outage locations and extent of customer outage	With capability to analyze and detect customer outage using real time meter data it avoided "already restored" tickets and reduced assessor labor costs
	Accuracy Improvement	Traditional meters on average, register a slightly lower energy use reading than actual consumption.	The electric smart meters do not have moving parts and can correct temperature-related error, making them inherently more accurate and resulting in revenue gains of 0.3-0.35%
	Billing	Issuance of bills were delayed by as much as two days	Bills to be made available on the first day of the billing cycle leading to acceleration of cash collections and interest expense reduction
	Vehicle Management	Traditionally meter readers used meter reading vehicles to manually read meters on door-to-door routes	Metering data is communicated via wireless network to utility which reduces need for manual meter reads, resulting in the reduction of vehicles used for meter reading

Key Elements		
System Voltage Reduction	Load Tap Changers and capacitors in traditional grids not automated	Algorithms in the DMS continually make control decisions based on real-time voltage readings (eg. Reduce the voltage drops along the line) providing energy savings and thus reduction in fuel cost
VAR Management	Difficult to detect faulty capacitors, capacitors might be offline for a year before being detected	Equipment monitoring, faulty capacitors can be identified and repaired or replaced immediately. This improved capacitor effectiveness and enabled the avoidance/deferral of capital expenditures.
System Fine-tuning	No real time data or automation to fine tune system for conditions like peak load	DMS is engaged to activate fine tuning. Fine tuning enables more efficient distribution of power and resulted in less capital investment for handling peak load and improved overall operating expenses
Asset Management	No capability to analyze real time load data or perform automatic on-demand load switching	Improved grid data access and analysis capabilities is used for optimized load switching. Resulting in delayed capacity upgrades by one-two years thus deferring capital expenditures.

Project Results:

The estimated 20-year net present value of the individual benefit was derived and the aggregate 20 year NPV was estimated to be USD 383 million. The result breakup is presented in the chart below.



Thus, a number of operational benefits were unlocked as a result of AMI implementation which generated positive NPV for the project. The analysis also helps in allaying fears of utilities of unpractical high initial costs of Smart Grid implementation.

2.6. Smart Grid Enterprise Integration

2.6.1 IT & OT in Smart Grid[40]

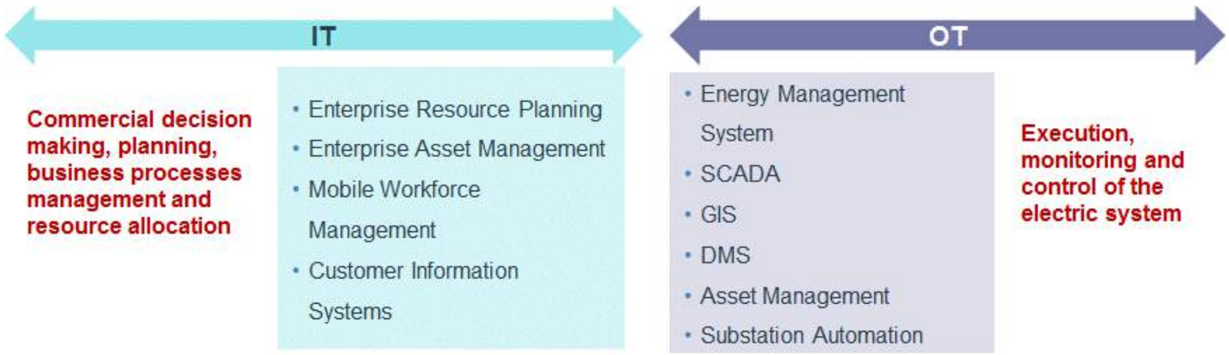
IT is associated with back-office information systems relating to accounting, billing and revenue, workforce records and time-keeping, customer records, and other transactions. IT in Smart Grid is mostly software applications that involve commercial decision making, planning, business processes management and resource allocation.

[40] ABB, "Convergence of Information and Operation Technologies (IT & OT) to Build a Successful Smart Grid".

OT, on the other hand, includes software applications that provide operational control of assets in the electric network in real time (or near real time). Most OT systems involve device-to device, or device-to computer communications, with relatively little human interaction.

Some of the applications that come under IT and OT are summarized in Figure 2.3.

Figure 2.3: IT-OT applications in Smart Grid



Historically, OT and IT for distribution operations have been used in silos. However, with emergence of Smart Grid the need for IT-OT integration becomes necessary in utilities.

Business drivers for IT-OT integration

As utilities incorporate more smart devices into their operational environment on a continuous basis, the case for integration of IT-OT grows stronger to get the maximum benefits from these system upgrades. Key business drivers for integration include:

- The manifold increase in the volume of data generated across multiple OT and IT applications and disparate IT and OT systems to manage various business processes can lead to inaccuracies in asset status data and a lack of a synchronized view of asset information across enterprise and operational systems.
- With increasing array of sensors in the infrastructure of utilities, it becomes increasingly imperative for utilities to leverage software to interpret the numerous streams of data flowing from these sensors.
- The need for IT-OT integration is all the more important considering that most vendors offer separate solutions for these two domains, resulting in duplication of systems and processes. Another consequence of such an arrangement is that split responsibilities between IT and OT for organizational security lead to higher risks.
- The need to integrate new types of assets/agents to the electric network and realize their full operational benefit is another driver for integration of IT-OT.

An integrated approach that shares platforms across IT and OT can enable utilities to reduce costs across the software management landscape, including enterprise architecture and information and process integration. Integration of IT and OT will bring together real time systems such as SCADA, EMS and DMS with corporate applications such as Enterprise Asset Management (EAM), EOM, CIS, MWFM and DRMS and this can be a significant driver in helping utilities cut operational expenses by improving their asset management capabilities.

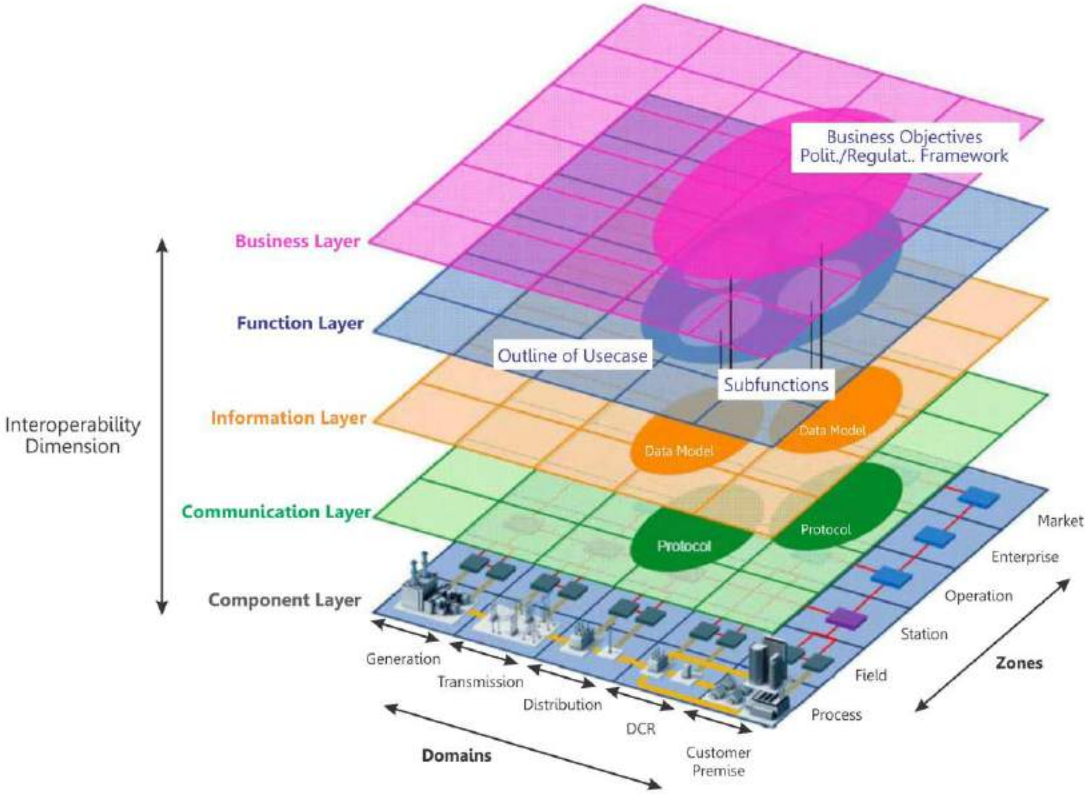
Benefits of IT and OT Integration

Some of the benefits include:

- Lowering of operational and capital costs across the value chain through faster response to real time conditions
- Accuracy and consistency in data across different application for operational and informed business decision making
- Preventive and predictive maintenance techniques leads to reduced maintenance and renewable costs

Smart Grid architecture integrating IT and OT layer is presented in Figure 2.4 below

Figure 2.4: Smart Grid architecture integrating IT and OT layer[41]



Select applications enabled by IT-OT integration are discussed in the following sections[42].

[41] *CEN-CENELEC-ETSI Smart Grid Coordination Group*

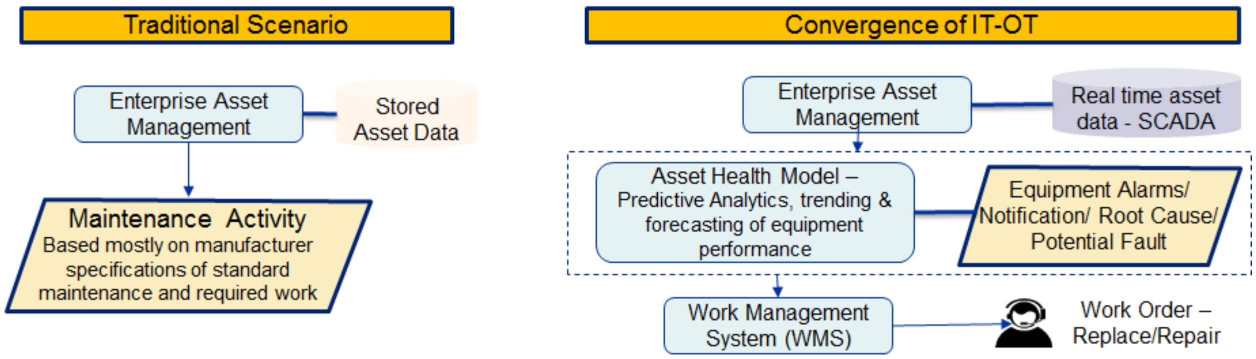
[42] ABB, "Convergence of Information and Operation Technologies (IT & OT) to Build a Successful Smart Grid".

Use-Case 1 Asset Health Monitoring

Traditionally, EAM would store and manage asset data and work-related tasks such as maintenance for a particular asset, based on standard manufacturer specifications and without taking into consideration actual working or loading conditions, operational parameters, etc.

EAM with IT-OT integration is presented in Figure 2.5 below

Figure 2.5: EAM with IT-OT integration

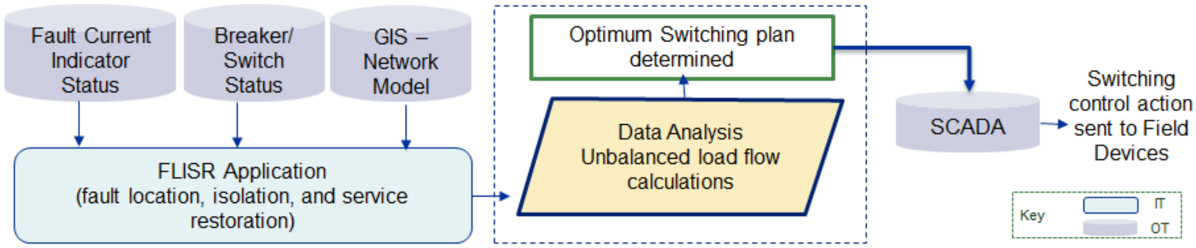


When near real time data from OT system like SCADA can be retrieved for the asset, advanced IT applications can be implemented to perform predictive maintenance, trending and forecasting of equipment performance. This analysis can determine not only the impact of asset's health on the overall system (technical and economic), but also remedial actions that need to be taken to improve the asset's performance.

Use-Case 2: Self-Healing Networks

The FLISR is an example of IT-OT convergence of GIS network models and field operational data. FLISR application is presented in Figure 2.6 given below.

Figure 2.6: FLISR application



The FLISR IT application uses inputs such as fault current, faulted circuit indicator status, and breaker/switch status (from OT device like SCADA), along with the electrical network model (from GIS), to determine the optimal switching plan to isolate a fault and restore service quickly to as many customers as possible.

Unbalanced load flow calculations using the network model can then be performed to determine if any thermal or voltage violations will be produced for the possible switching plans. Once the optimal switching plan has been chosen, the appropriate control actions can be transmitted to the field devices through SCADA (OT) communications. Benefits for the distribution organization include improved reliability performance and higher customer satisfaction.

Integration Framework for IT & OT

Technologies available for system integration have evolved over time. Real-time messaging middleware has made it possible to apply some of the principles of enterprise application integration to distribution operations.

Data modeling and integration interoperability standards, which are developed by numerous bodies including IEC and the Institute of Electrical and Electronics Engineers (IEEE), are starting to be employed. This includes IEC 61968, the Common Information Model (CIM) for distribution management. CIM will cover various aspects of distribution operations, AMI, distributed energy resources, and DR. The maturation of such standards is crucial to facilitate further IT/OT convergence[43].

At a broader level, while implementing IT-OT integration, the architecture design must be flexible and adaptive enough to meet future needs while providing the scale and security required for mission-critical aspects of the system. Some other considerations for integration architecture can be assigning of tags to assets that ensure that any asset can be correlated across the organization's operational systems for different requirements. Also, an optimal framework for IT-OT integration should provide key stakeholders with easy access to asset information. Top decision makers should not need not to log into multiple systems, rather, they should be enabled with customized dashboards containing specific functionalities, key performance indicators (KPIs) and reports.

[43] ABB, "IT/OT Convergence: How their coming together increases distribution system performance," 2012.

2.7. References

[1] Ericsson, "Making the Metering Smart - A Transformation towards Smarter Cities".

[2] National Energy Technology Laboratory ,U.S, "Advanced Metering Infrastructure," U.S DOE, 2008.

[3] ISGF, "Smart Metering Scenario in India," 2014.

[4] World Alliance for Thai Decentralized Energy Association (WADE THAI), "Smart/Intelligent Grid Systems Development and Deployment," European Union, 2013.

[5] Ameren ,Illinois , US, "AMI Cost/Benefit Analysis," 2012.

[6] International Smart Grid Action Network, "AMI Case Book 2.0," 2014.

[7] A. Datta, "Enterprise GIS and Smart Electric Grid”," TERI, 2013.

[8] J. Sinha, "GIS application in Power Distribution Utility," UPCL , Dehradun.2011

[9] N. Rezaee, M. Nayeripour, A. Roosta and T. Nikam, "Role of GIS in Distribution Power Systems," World Academy of Science, Engineering and Technology, 2009.

[10] D.-I. A. C. Adams, "Using Geographic Information Systems to provide better E-services," SmartCities.info. 2011

[11] M. S. Thomas and J. D. McDonald, "Power System SCADA and Smart Grid," CRC Press, 2015.

[12] J. Abawajy and R. J. Robles, "Secured Communication Scheme for SCADA in Smart Grid Environment," *Journal of Security Engineering.* 2010

[13] M. Madrigal and R. Uluski, Practical Guidance for Defining a Smart Grid Modernization Strategy, World Bank. 2015

[14] "Distribution Management Systems Planning Guide," EPRI, 2013.

[15] A. Dehariya and J. Mohammed, 'Role of Geographic Planning in Smart Grid Deployment', Infosys, 2015.

[16] A. Sekhar, K. Rajan and A. Jain, 'Application of Geographical Information System and Spatial Informatics to Electric Power Systems', *IIIT/TR/2009/41*, 2008.

[17] B. Meehan, 'Enterprise GIS and Smart Electric Grid', ESRI, 2008.

[18] Jeff Meyers, P.E , "How the Convergence of IT and OT Enables Smart Grid Development," Schneider Electric, 2013.

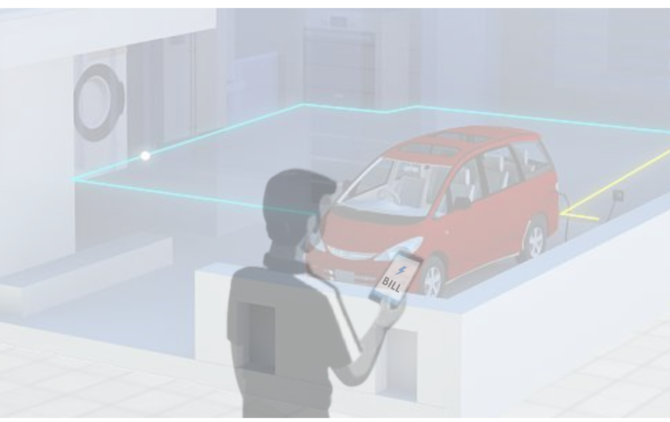
[19] ABB, "Convergence of Information and Operation Technologies (IT & OT) to Build a Successful Smart Grid". 2015

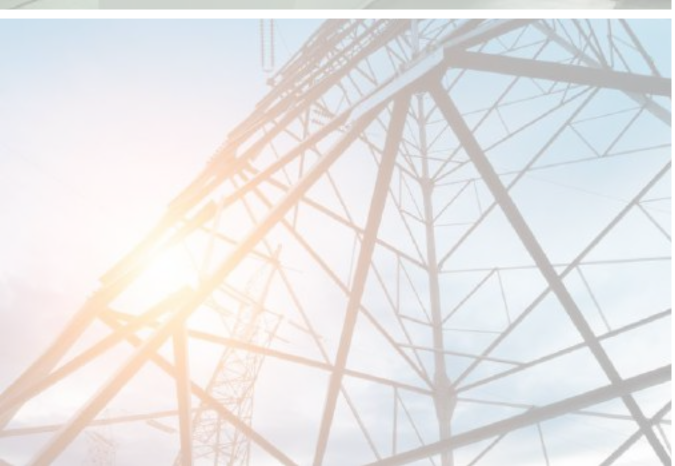
[20] TCS, "A process approach to Smart Grid deployment," 2013.

[21] R. Karnad and M. Chandrahasan, 'Building the Future Smart Utility through IT OT integration: Leveraging an Asset Information Management Framework', TCS, 2015.

[22] ABB, "IT/OT Convergence: How their coming together increases distribution system performance," 2012.

[23] "Building a Smart Grid Business Case", National Energy Technology Laboratory, 2009.

Module - 3

Peak Load Management and Demand Response

3.1 Peak Load Management

Load management is the process of balancing the supply of electricity on the network with the electrical load by adjusting or controlling the load rather than the power station output. This can be achieved by different ways: a) direct intervention of the utility in real time, b) use of remote connect/disconnect for partial load curtailment, c) demand side management, or d) using special tariffs to influence consumer behaviour.

As India focuses on increasing power generation, adding RE capacity and scaling up energy conservation and efficiency, load management needs be included as a potential option to bridge the gap between demand and supply during various time blocks. Load management enables:

- Optimal utilization of energy resources by uniform distribution of load across the day (which can, in turn, reduce costs by eliminating the need for peaking power)
- Saving in additional investment in capacity addition
- Reduction in technical losses and enhanced customer satisfaction by load curtailment in place of load shedding
- Better utilization of variable RE generation in the state as load management in specific time slots could provide valuable demand/supply balancing resources.

For example, in case of sudden reduction in RE generation, the grid operator requires immediate flexible generating resources for balancing power in the grid. Variation/reduction in demand through effective load management mechanism can thus play an important role in balancing power in the grid and promoting RE in the country.

The following sections of this chapter thus focus on the role of Smart Grid in peak load management through DR mechanism.

3.2 Concept of Demand Response

DR is a consumer's ability to alter electricity consumption at their location when prices are high or the reliability of the grid is threatened. DR is dependent upon the ability of the consumer to change consumption patterns, without economic impact or loss of revenue, such that the electricity consumption can be reduced or increased during time of need as required by the system operator or DISCOM to balance supply and demand. In all instances non-essential load can be curtailed and specific examples could be as presented in Table 3.1.

Table 3.1: DR curtailment opportunities

Customer Type	Curtailment Opportunity
Industrial Customers	Slowing down or stopping production or specific processes in the production line. Alternatively, ramping up consumption if required.
Commercial Customers	Reducing/increasing or staggering the use of lighting, chillers, lifts, escalators, etc. during specific time blocks
Domestic Customers	Raising the temperature of AC thermostats; altering lighting loads

In the present scenario, for managing the peak load, utilities either resort to building new capacity which proves to be quite expensive or go for involuntary load shedding activities which have high economic impact for the customer. Also, most utilities do not have real time data on demand usage and hence peak load management becomes more reactionary step than a proactive one due to the lack of predicative ability.

Smart Grid-enabled DR can provide the scale to make peak load management cost effective and convenient. Smart Grid technology provides the advantages of a real time information system, two-way network communication and integration of utility information system to enable an effective PLM implementation.

DR programs can provide benefit to both the utility and the consumer. From a long term perspective, DR programs can help utilities avoid or delay the need for capacity addition. In the short term, DR is a viable solution for utilities to avoid load shedding and over drawl of power to manage real time imbalances of power. Additionally, this could also enable integration of variable RE generation by providing demand/supply balancing. The consumer on the other hand would be assured of reliable power and could also gain in terms of financial incentives for participation in a load management program.

DR does not include the reduction of electricity consumption based on normal operating practice or behaviour. For example, the reduction of electricity due to closure or scaled-back operation of a company due to a holiday is not considered a DR activity.

Various requirements of the distribution sector can be realized by implementing DR. A stakeholder view of the benefits of DR program is summarized in Table 3.2.

Table 3.2: DR stakeholder benefits

Stakeholder	Benefit
Consumers	• Financial incentive for participating in schemes • Provides focus on energy efficiency • Improved supply reliability (in the long term) • Reduced cost of power (in the long term)
DISCOM	• Provides focus on load patterns and energy efficiency • Low cost/fast to deploy mechanism to balance supply and demand • Avoided cost in purchasing expensive power from wholesale market/short term contracts required to meet supply deficit • Deferral of asset investment for infrastructure required only to meet peak demand • Improved revenue due to avoidance of load shedding through better load management • Increased integration of RE resources into the grid
System Operators	• Low cost/fast to deploy mechanism to provide ancillary services
Regulators	• Provides an additional resource to help address power shortages • Demonstrates a move towards energy efficiency and greener solutions for meeting load requirements • Positive impact on cost of power to consumers as DISCOMs and system operators rely less on purchasing expensive power
Economy	• Positive impact on cost of power to consumers as DISCOMs and system operators rely less on purchasing expensive power • Low cost/fast to deploy additional resource to help address power shortages
Environment	• Less dependence on thermal power required to manage balancing and regulation issues. • Deferral of asset investment for infrastructure required only to meet peak demand. • Increased RE penetration

With these benefits, DR can act as a reliable tool for managing demand as well as efficiently utilizing the variable RE potential.

Another tool for PLM is demand-side management (DSM). Although it is sometimes used interchangeably with DR, these are two different methodologies as explained below.

DSM[44] essentially refers to the actions of a distribution licensee to facilitate change in the pattern of end-use i.e., the demand side of electricity, and includes any increase or decrease in the demand, shifting the demand between high and low peak periods, managing the intermittent load demands, etc., with the objective of reducing the power purchase and/or DISCOM's costs.

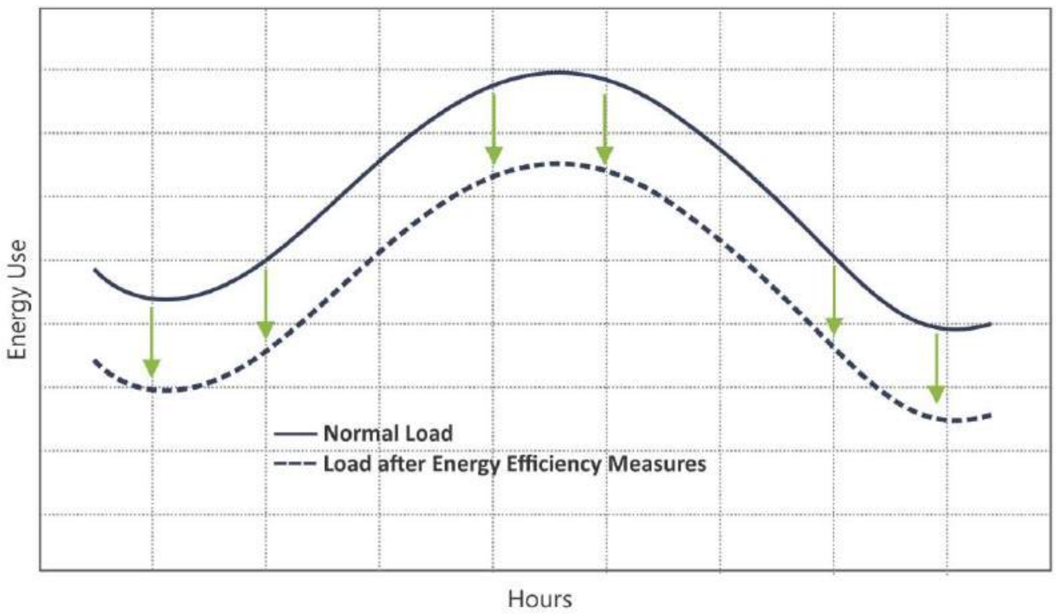
DSM broadly includes: energy efficiency – technical and operational changes that reduce the amount of energy required to provide a particular service, e.g. building retrofits, switching to compact fluorescent light (CFL) or Light Emitting Diode (LED) bulbs.

Conservation – behavioural changes that reduce overall energy consumption, e.g. turning down thermostats, turning off lights and equipment when not required.

In brief, DSM are actions (often incentive-driven) which result in sustained reductions in energy use for a given energy service, thereby reducing long-term energy and/or capacity needs, whereas DR are actions (often market-driven) that result in short-term reductions in peak energy demand.

Figures 3.1 and 3.2 illustrate the difference in the effect of DSM and DR on load curve. With DSM initiatives the entire load curve of the consumer can be brought down, whereas with DR the peak load is reduced for the duration the DR event is called for.

Figure 3.1: Effect of DSM on load curve



[44] Draft DSM Regulations issued by FOR

Figure 3.2: Effect of DR on load curve

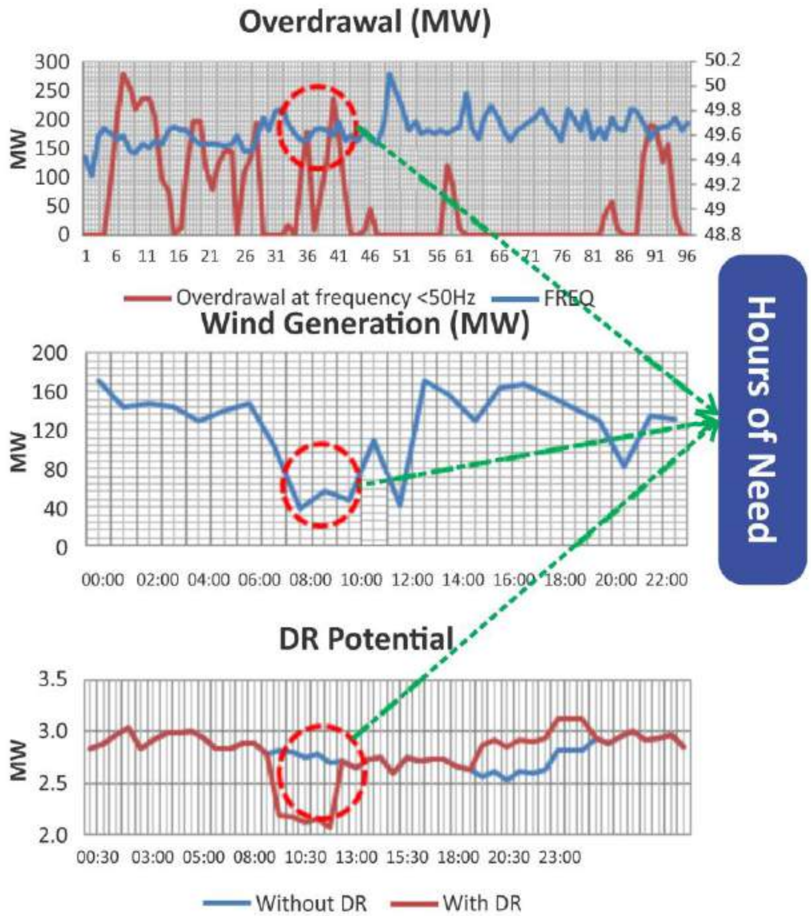


Figure 3.2 shows the effect of DR on load. During the over drawl from the grid and dip in wind energy generation, a DR event call helps to lower the energy demand till the system stabilizes.

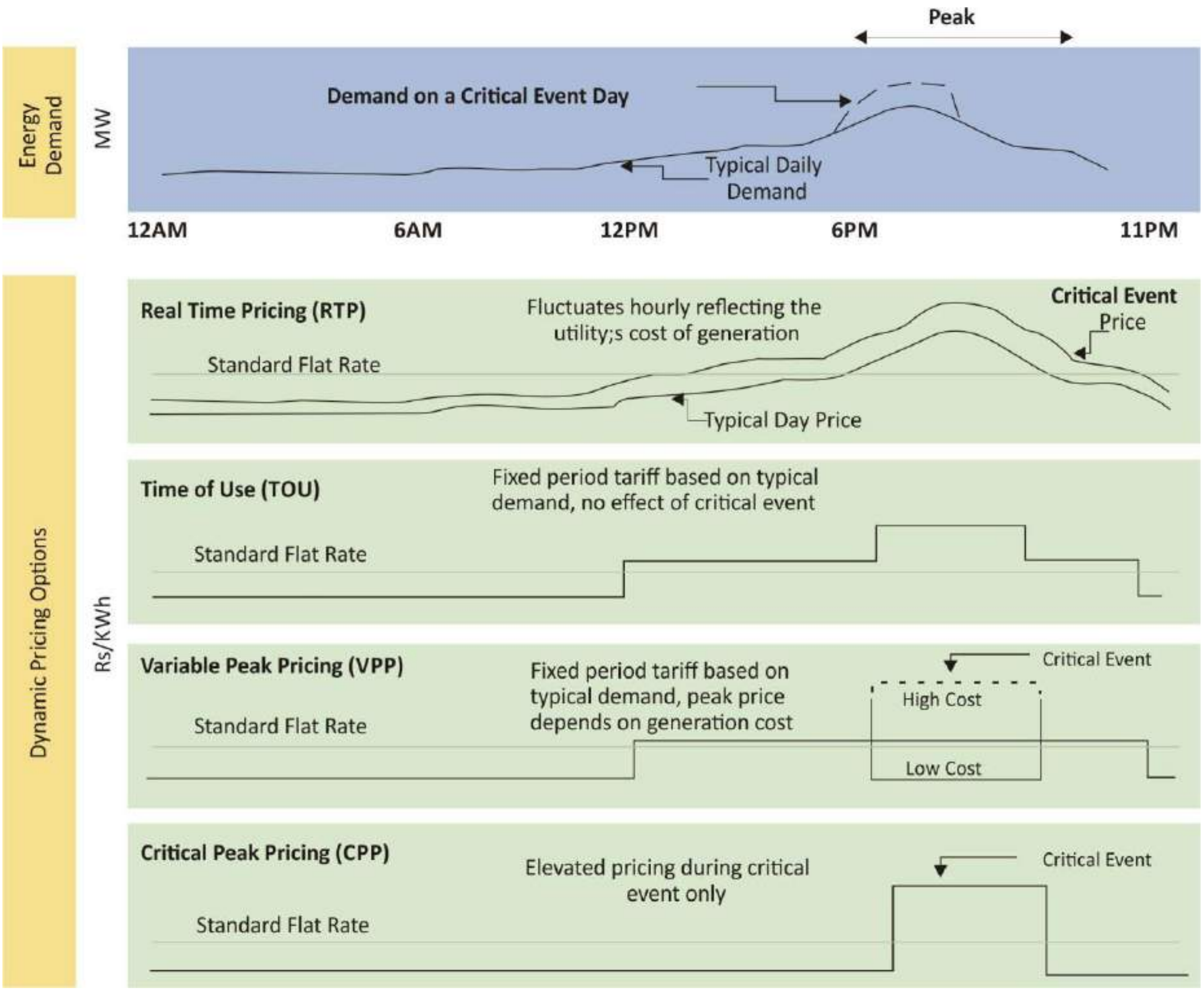
3.3 Types of DR Programs

DR programs are established to motivate changes in electricity use by end-use customers in response to changes in the price of electricity over time, or to give incentive payments designed to induce lower electricity use at times of high-market prices or when grid reliability is jeopardized. Thus, DR programs can be categorized into two types: (i) Price-based DR and (ii) Incentive-based DR. These are discussed in detail in the following sections.

3.3.1 Price-Based Demand Response

This includes programs such as Real-Time Pricing (RTP), Critical Peak Pricing (CPP), Variable Peak Pricing (VPP) and Time-Of-Use (TOU) tariffs which charge customers time-varying rates that reflect the value and cost of electricity in different time periods. Customers, who have access to the electricity rates they are paying, will tend to use less electricity when electricity prices are high. DR Price-based tariffs is presented in Figure 3.3 given below.

Figure 3.3: DR price-based tariffs



Time of Use Pricing

In TOU tariffs, different tariffs are charged based on the time at which electricity is consumed, that is, higher tariffs are charged for energy consumed during peak hours than during off-peak or normal hours.

Critical Peak Pricing

In CPP, TOU prices are in effect except for certain critical peak days, when prices may reflect the exceptionally high costs of generating and/or purchasing electricity at the wholesale level. CPP events may be triggered by system contingencies or high prices faced by the utility in procuring power in the wholesale market. Unlike TOU slabs, which are typically in place for 6–10 hours during every day of the year or season, the days for critical peaks are not designated in the tariff, but dispatched on relatively short notice as needed, for a limited number of days during the year.

Real-time Pricing (RTP)

Electricity prices may change hourly, or even sub-hourly, with price signals provided to the user shortly in advance, reflecting the utility's cost of generating and/or purchasing electricity at the wholesale level.

Variable Peak Pricing (VPP)

VPP is a hybrid of TOU and RTP where the different periods for pricing are defined in advance (e.g., on-peak = 6 hours for summer weekday afternoon; off-peak = all other hours in the summer months), but the various price levels established for the on-peak period varies according to the costs of delivering electricity. VPP rates have a dual purpose: a) to change the timing of a customer's consumption of electricity (i.e., shifting from peak hours to off-peak hours), and b) to reduce a customer's consumption of electricity over a certain number of hours on a limited number of days when certain system conditions occur (e.g., extremely high costs or system emergencies) by making it much more costly to purchase during on-peak periods on these limited days. A case example of VPP in use is provided in Box 3.1.

Box 3.1 Case Study: OG&E demand response program[45]

Project Objective: The primary goal of OG&E was to assess the DR achieved through various technologies and dynamic rate plans. The program was designed to test, and gain knowledge about customer acceptance of time-based rate designs and enabling technologies.

Project Description: Customers were randomly assigned to either a Time-of-Use – Critical Pricing (TOU-CP) option or a Variable Peak Pricing (VPP-CP) option or a control group. Customers in the control group were left on their existing standard rates. The Critical Price component in each rate plan was to raise the price level to the critical price when a Critical Price event was issued with a minimum of two hours' notice. The VPP-CP was designed by replacing the on-peak price (from 2:00 PM to 7:00 PM on weekdays) in the TOU rate with one of four variable prices shown in the chart below. Four defined price levels – Low, Standard, High, and Critical – simplify communications of price level. The day-ahead on-peak prices for VPP-CP are communicated to the customer by 5:00 PM on the previous day via email, text message, and/or voicemail.

[45] *OG&E Smart Study Together Impact Results 1299-02*, 1st ed. Global Energy Partners, 2012.

TOU		VPP
4.2c/kWh	Off-peak/Low	4.5c/kWh
23c/Wh	Standard	11.3c/kW
	High	23c/kWh
	Critical	46c/kWh
46c/kWh	Critical Price Event	46c/kWh

Project Results: Approximately 35,144 residential customers were participating in the SmartHours pricing program, and 61.5 percent of those customers also accepted a free Programmable Communicating Thermostat (PCT) and are referred to as Smart Hours Plus participants. Study results show that the overall maximum impact of the program was 51.4 MW, which occurred during a Critical Price event day on the day of the system peak (August 1, 2012). Across the three system peak Critical Price event days held, SmartHours Plus customers averaged a reduction of 1.82 kW per customer, and SmartHours VPP customers averaged a reduction of 0.73 kW per customer.

Project Learnings: The most effective rate/technology combination for residential customers is the VPP-CP with PCT. The VPP rate provided the highest load reduction on the hottest days, and also provides a full range of prices for OG&E to work with. On days when capacity is plentiful, there is no need for customers to reduce on peak energy, so the low rate can be set. When capacity is short, a High or Critical price can be set, and the Load reductions will be greater. The VPP-CP allows OG&E to tailor the price to the capacity. Combining the PCT with the rate automates the load reduction, giving the customer the ability to choose between the relative importance of cost and comfort, and to vary that choice across different prices.

A number of DR pilots have been undertaken as part of the Smart Grid Investments Grant (SGIG) program of the U.S. Department of Energy (USDOE). An analysis of results of three such SGIG demand-side project studies conducted through the summer of 2011 is presented in Table 3.3[46].

[46] *'Demand Reductions from the Application of Advanced Metering Infrastructure, Pricing Programs and Customer-Based Systems - Initial Results'*, U.S Department of Energy, 2012.

Table 3.3: Result summary of three U.S. DR pilot studies

	Oklahoma Gas and Electric (OG&E)	Marblehead Municipal Lighting Department	Sioux Valley Energy (SVE)
Program Objective	To assesses whether customers make use of enabling technologies to actively manage their consumption and costs	To evaluate customer responses to CPP and access to web portals	To analyze customer acceptance and the reasons for different peak demand impacts of the program
Consumers Sample for Study	5,000 residential and 1,200 small commercial customers and one year testing period	500 residential customers and a two-year test period during the summers	900 residential and rural residential/farm customers and a two-year test period during the summers
Tariff Structure	VPP (5-hour peak period) and TOU	CPP tariff (six-hour period for critical peak events)	CPP tariff (two groups: one "opt-out" and other "opt-in"[47]), Third group no CPP tariff but use of IHD for monitoring
Trial design strategy	Randomized control trial design	Randomized control trial design	Randomized control trial design
Enabling Technologies Trialed	Web portal, IHD and PCT employed	Web portal	Web portal, IHD
Program Results and Observations	• The largest reductions were observed for the customers with PCTs (about 30 percent) especially with VPP tariff • Customer acceptance was favorable and customer complaint and drop-out levels were relatively low • Average bill reduction over the summer periods was over USD 150	• Customers on CPP reduced peak demand by about 40 percent on average over the peak period, with a maximum reduction of about 1.1 kW per customer • 86 percent consumers had an overall positive experience but did not use the web portals often	• 0.85 kW avg. peak demand reduction per customer during events • Customers in opt-in model appear to provide greater peak demand reductions than those placed on opt-out • Customer surveys show high levels of satisfaction and interest in continuing participation

[47] An opt-in policy requires a *potential customer* to self-select the services they wish to subscribe to whereas in opt-out policy consumer are presumed to be consulting to the project unless they register their unwillingness to subscribe to the service

3.3.2. Incentive-Based Demand Response

These programs pay participating customers to reduce their loads at times requested by the program sponsor, triggered either by a grid reliability problem or high electricity rates. An overview of the most commonly deployed incentive-based DR programs is provided in the following sections.

Direct Load Control (DLC)

In DLC, a utility or system operator remotely shuts down or cycles a customer's electrical equipment on short notice to address system or local reliability contingencies in exchange for an incentive payment or bill credit. Operation of DLC typically occurs during the times of system peak demand.

The most common form of DLC is a program that cycles the operation of heavy usage appliances such as air conditioners. Typically, a remote switch or digital control receiver is connected to the air conditioning unit. Peak loads can be reduced by remotely switching off the load at the appliance. In addition, remote control of individual appliances is being supplanted by remote control of smart, communicating thermostats. A practical application of DLC in use is presented in Box 3.2.

Box 3.2 Case Study: Home depot direct load control

Home Depot, a U.S. retailer of home improvement and construction products and service company, implemented a sophisticated direct load control system. They started by installing interval meters at each location. In addition to verifying curtailments to the New York Independent System Operator's (NYISO), interval meters also provided valuable time sensitive usage data that can be used to better operate buildings. Next, an energy management system was installed. This allowed for two-way communications, sending metered data back to corporate and accepting communications from corporate. Home Depot allowed communication through their Local Area Network (LAN). This enabled Home Depot to receive data from, and send commands to each of Home Depot's store's energy management system. Next, it programmed a command to shut off every other overhead light and all display lighting.

These measures resulted in a load reduction of about 130 kW per store. A total of 36 stores of Home Depot have been enabled by this program. This has positioned Home Depot to reliably reduce New York's peak demand by approximately 4.7 MW when called on by the NYISO's DR Program. The effectiveness of direct load control is highlighted by the fact that the corporate energy manager was not working on the day of the event. He received notification of the NYISO event at home and was able to curtail load at each store from a laptop computer in his living room. New York State Energy Research and Development Authority (NYSERDA) provided incentives of approximately USD 250,000 (for this store location) to offset the capital cost of the equipment, and additional performance revenue was earned from the NYISO.

Interruptible/Curtailable (I/C) Rates

Customers on I/C tariffs receive a rate discount or bill credit in exchange for agreeing to reduce load during system contingencies. If customers do not curtail, they can be penalized. Interruptible programs are not designed for all categories of customers. In particular, customers with 24 hour-a-day, seven-days-a-week operations or continuous processes (e.g., hospitals) are not good candidates.

Tata Power Mumbai had implemented a DR program on curtailable rates in 2012. The benefits and learnings of this program are presented in Box 3.3.

Box 3.3 Case Study: The Tata Power Company Ltd. Mumbai distribution – DR program(FY 2012)[48]

Program Objective: The objective of the DR program is to manage short time peak demand. There are several occasions when the cost of power to utility becomes very high for a short time. But utility has to supply at the same predetermined tariff. The power purchase cost goes above INR 10/KWh whereas the average cost of power sale to commercial consumers (using air conditioning) was INR 6 to 6.50/KWh.

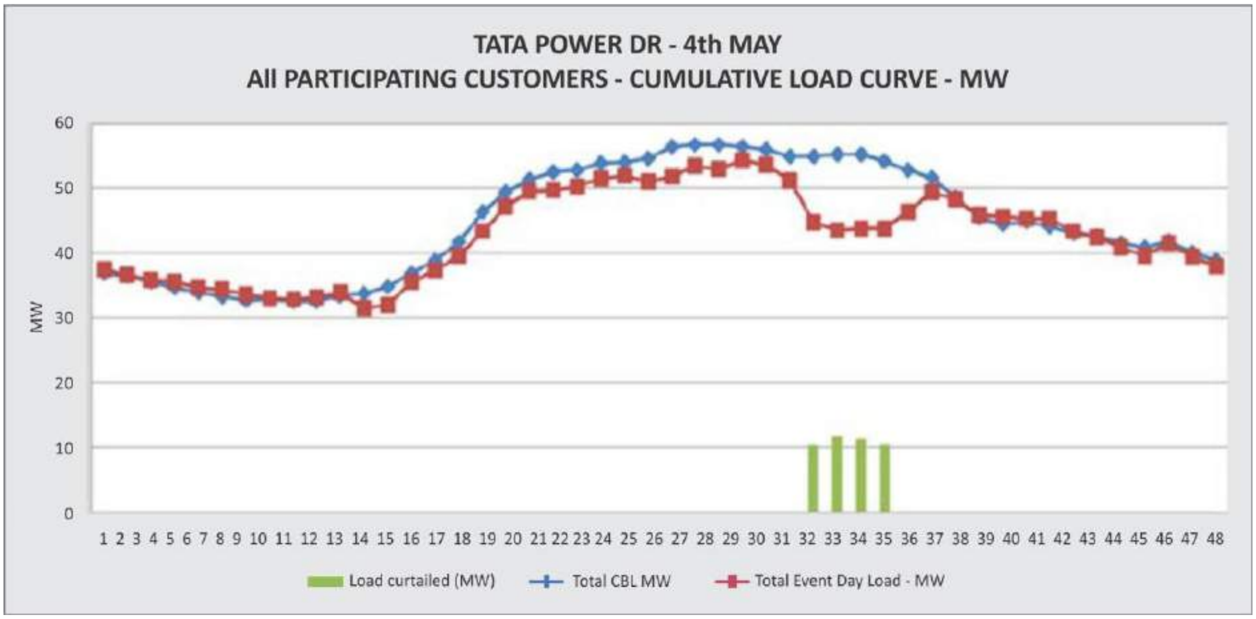
Program Structure:

- Tata Power Company enrolls customers above 500 KW; advises and educates regarding curtailment options.
- A Memorandum of Understanding is signed with the consumer.
- Load dispatch decides the event call based on ex-ante price/transmission constraints.
- Aggregator gives call to all consumers and coordinates the curtailment.
- Event is of max 2 hours each; 50 events per year.
- Meter data is down loaded from AMR/hand-held meters.
- Tata Power pays incentive to aggregator and the aggregator pays to the consumers as per their curtailment.

The figure below shows the DR in action at the facility level.

[48]BEE, 'Tata Power Demand Response Program'. [Online]. Available: https://beeindia.gov.in/sites/default/files/ctools/Shekhar%20Khadilkar%20Tata%20Power%20DR.pdf. [Accessed: 01- Dec- 2015].

Program Benefits:
12 MW DR capacity was enrolled. Ten events of two hours each called in six months. The following graph shows the load curtailed in one such event**:**



The following table lists the customer wise breakup of DR enabled.

	Customer name	Location	DR - MW	kWH
			1 Hr	2 Hrs
1	Tata Consultancy Services	Powai	1.4	1527
2	Supreme Properties	Powai	0.1	237
3	Lake View Developers	Powai	0.5	833
4	National Stock Exchange	BKC	0.0	0
5	Sahara Hospitality Limited	Andheri	0.0	0
6	Seven Hills Hospitals	Andheri	0.7	1112
7	Bharat Diamond Bourse	BKC	0.2	352
8	Godrej & Boyce	Vikhroli	1.6	3012
9	Graur & Weil	Kandivali	0.2	355
10	BMC pumping station	Bhandup	0.3	545
11	Accenture	Vikhroli	0.3	459
12	Intelenet Global	Malad	0.3	355
13	Technopolis Knowledge Park	Andheri	0.1	188
14	JP Morgan	Various sites	Data to be received	
15	Zenta	Powai	0.1	149
16	Ambassador's Sky Chef	Andheri	0.2	227
17	L&T, Powai (E)	Powai	0.2	130
18	BMC Pumping	Ghatkopar	0.5	1042
19	Infiniti Mall	Malad	0.0	0
20	Crisil Ltd	Powai	0.2	432
21	Air India- Engineering Division	Andheri	Data to be received	
22	Nirlon Ltd.	Goregaon	2.5	4101
23	Ordnance factory	Ambernath	0.4	575
24	Mumbai International Airport Ltd.	Andheri	1.3	2526
25	Taj Sat Air Caterers	Andheri	0.0	0
26	Hotel Holiday Inn	Andheri	0.0	0
27	IL & FS	BKC	0.0	0
			11.1	18157.00

The benefits included:

For Participating Consumer:

- A participating consumer gets INR 2.25/KWh saved.
- Consumer gets his hourly load curves, guidance and advice from the utility.
- No capital investment is required.

For DISCOM supplying power :

- Saves on high cost power purchase of INR 8 to10/KWh by paying INR 2.25/KWh.
- Develops curtailable demand side asset similar to power plant.
- Helps to manage system emergency.
- Facilitates more engagement with consumers and more consumer satisfaction.

Program Learnings:

- Significant DR capacity can be developed but it can be used for very short periods and only few times a year.
- DR is not a solution for daily peak power shortage. DR has to be used judiciously.
- Aggregator-based DR is very cost effective and gets wide acceptance.
- Managing air conditioning is the most effective way of achieving DR curtailment. Hence controls on room ACs must be promoted.
- The consumers remain interested for long time only if attractive incentives are offered.

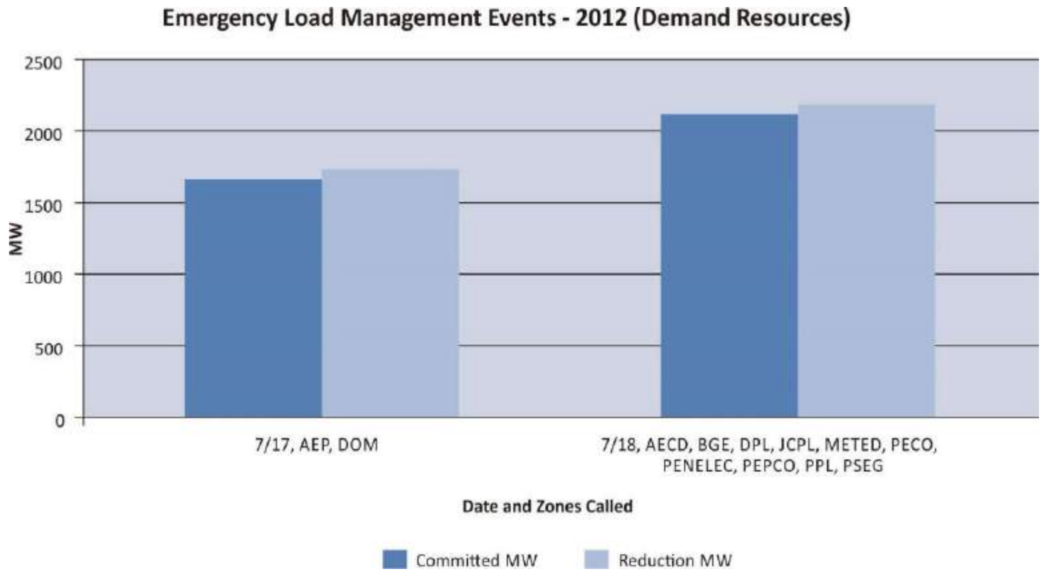
Emergency Demand Response

An emergency DR program provides incentive payments to customers for reducing their loads during reliability-triggered events, but curtailment is voluntary i.e., customers can choose to forgo the payment and not curtail when notified without penalty. If customers do not curtail consumption, they are not penalized. The level of the payment is typically specified beforehand. The disadvantage of emergency DR to utilities and system operators is that they cannot accurately forecast how much load curtailment will occur when an event occurs. A case of emergency DR executed by PJM, a U.S.-based utility is presented in Box 3.4.

Box 3.4 Case Study: PJM interconnection– emergency demand response program[49]

In this program DR consumer agrees to be interrupted up to ten times per delivery year by PJM. The interruptions may be up to six consecutive hours in duration on non-holiday weekdays from noon until 8 PM EPT in the months from May through September. The interruptions must be implemented within two hours of notification by PJM. Those resources that can be fully implemented within one hour of notification are considered Short Lead Time Resources, while those that require more than one hour but not more than two hours of notification are considered Long Lead Time Resources. This agreement by Emergency DR (Load Management) resources to allow PJM to provide notice of the interruptions enables PJM to procure less generation capacity while maintaining the same level of reliability according to the current reliability criteria and practices within the PJM market.

The Emergency DR (Load Management) commitments for three years averaged just less than 13,000 MW each year and up to 14,800 MW by 2015/2016. The overall performance of Emergency Demand Response is depicted for two events called in 2012.



A DR aggregator's performance is measured for each event by zone for all resources that were dispatched by PJM. The DR reductions made in a zone are compared to each aggregator's reduction commitment. Under performance is penalized and over performance is to be rewarded.

[49]Pjm.com, 2015. [Online]. Available: http://www.pjm.com/~/media/markets-ops/dsr/emergency-dr-load-management-performance-report-2012-2013.ashx.
[Accessed: 01- Dec- 2015].

Capacity Market Programs

In these programs, customers commit to providing pre-specified load reductions when an event occurs, and are subject to penalties if they do not curtail when directed. Eligibility of customers for the program is based on a demonstration that the reductions are sustainable and achievable. For example, the requirements to receive capacity payments in NYISO's Special Case Resources program are minimum load reductions of 100 kW, minimum four-hour reduction, two-hour notification, and to be subject to one test or audit per capability period. These requirements are designed to ensure that the reductions can be counted upon when they are called.

Many customers prefer these programs because they provide guaranteed payments, instead of the prospect of uncertain payments. For grid operators this represents a secure resource that can be implemented quickly.

Demand Bidding/Buyback Program

These programs encourage large customers to offer to provide load reductions at a price at which they are willing to be curtailed, or to identify how much load they would be willing to curtail at posted prices. These demand-bidding programs provide a means to elicit price responsiveness when prices begin to increase. If customer bids are cheaper than alternative supply options or bids, the load curtailments are dispatched and customers are obligated to curtail their consumption. These programs are attractive to many customers because they allow the customer to stay on fixed rates, but receive higher payments for their load reductions when wholesale prices are high. Customers, who are not on time-based rates, can use the demand-bidding programs to receive value for their reductions. Otherwise, these customers are on fixed retail rates.

As example, in programs such as NYISO's Day-Ahead Demand Response Program, customers typically bid a price at which they would be willing to curtail their load and the level of curtailment in MW on a day-ahead basis. If these bids are selected for operation during the security constrained dispatch process, then customers must execute the curtailment the next day. If they do not reduce their load, they are subject to a penalty. In another form of demand bidding, the customer acts as price-taker. When participants in this program reduce consumption when notified, they receive the market-clearing price, whatever it may be, as payment.

Another case of demand bidding program is of PG&E, a U.S. utility, the details of which are presented in Box 3.5.

Box 3.5 Case Study: PG&E–demand bidding program

DBP is a voluntary DR bidding program that provides enrolled customers with the opportunity to receive financial incentives for providing load reduction on event days. Credits are based on the difference between the customers' actual metered load during an event to a baseline load that is calculated from each customer's usage data prior to the event. For the most part, customers are notified of events by 12:00 noon on the previous day.

PG&E called six events, with an hour-ending 13:00 to 20:00 event window. All DBP customers were called for three of the events, while the remaining three were dispatched for a sub-set of locations. Enrolment in PG&E's DBP averaged 952 service accounts across the three event days during which all customers were called. The sum of enrolled customers' coincident maximum demands was 856 MW. The total program load impact for PG&E's three full-dispatch events averaged 36 MW, or 4.3 percent of enrolled load. Event-specific load impacts ranged from a low of 31.0 MW to a high of 43.6 MW.

In order for all DR programs detailed above to be effective, participation in DR events is crucial. One of the liabilities of DR programs is that most processes are manual or semi-manual, therefore, they run the risk of the participant taking no action for a DR event. Additionally, manual participation requires DR participant to make decisions and implement the actions to reduce the demand within the necessary timeframe. To overcome these challenges and risks, fully automated demand response (AutoDR) can be implemented.

Automated Demand Response

AutoDR involves complete automation of the entire DR process. No human intervention is required in case of AutoDR and it allows participants the choice to override or opt out of DR events.

The primary building blocks of AutoDR includes a two way communication channel between the building and the utility or the DR aggregator, a building/home automation system to receive signals and automatically control loads based on the signals and a smart meter to measure and verify the load reductions. AutoDR helps maximize participation and reliability of the program and also reduces the response time significantly for DR events from days/hours to seconds/minutes but it can be overall expensive to implement. To implement AutoDR, OpenADR standards can be applied.

OpenADR[50]

The Demand Response Research Centre at the Lawrence Berkeley National Laboratory has led the development of an open communications specification to automate DR, known as Open Automated Demand Response, or OpenADR. OpenADR is intended to facilitate reliable and cost-effective automation of both electricity price and system grid reliability signals for DR. The OpenADR specification, known as OpenADR v1.0, was published in April 2009. In May 2010, OpenADR became one of the first 16 Smart Grid Standards supported by the USDOE, the National Institute of Standards (NIST), and the Technology Smart Grid Interoperability Standards effort.

OpenADR provides a non-proprietary, open standardized DR interface that allows electricity providers to communicate DR signals directly to customers using a common language and existing communications such as the Internet. Open standards lower the cost of technology and

[50] Ghansah, Isaac, 2009. *Smart Grid Cyber Security Potential Threats, Vulnerabilities and Risks* California Energy Commission, PIER Energy-Related Environmental Research Program. CEC-500-2012-047.

allow control companies to embed the communication protocols in their controls at a low cost. Lower cost automation enables innovation and development of products that are compatible within multiple utilities or ISOs without having to develop customized products in different regions of the country or world. A more ubiquitous energy and DR event messaging standard will support a more effective means to match energy supply and demand providing benefits to consumers, utilities, system operators, and society at large. OpenADR provides the communication of DR signals that enable consumer choice and interoperability among control equipment and emerging energy markets.

OpenADR architecture consists of a Demand Response Automation Server (DRAS) and a DRAS Client. A server provides signals corresponding to DR events to notify customers and a client at the customer's site listens to the signals and automates signals to pre-programmed control systems.

Information flow in the OpenADR architecture happens in the following five steps:

1. The utility or ISO defines DR event and price signals that are sent to DRAS.
2. DR event and price services are published on a DRAS.
3. DRAS clients, that can be a client and logic with integrated relay for a legacy control system or web service software for a sophisticated control system, request event information from DRAS every minute.
4. Pre-programmed DR strategies determine action based on event and price.
5. Energy Management & Control System carries out load shed based on DR events and strategies.

An AutoDR pilot has also been initiated in India by TPPDL and by Reliance Infra. The results and program structure of both are mentioned in Box 3.6 and Box 3.7.

Box 3.6 Case Study: The Tata Power Delhi Distribution Ltd. – auto demand response project[51]

Program Background: TPDDL implemented utility-level ADR with smart meters for its high end commercial and industrial consumers in the year 2014 as part of its Smart Grid project.

The objective of the DR program was to manage peak demand and to manage grid stress situation and thus ensure better reliability of power supply to the customers. For the project, TPDDL enrolled 161 consumers, engaging them in ADR through auto controller along with smart meter based on Radio Frequency (RF) Mesh communication covering 250 sq. km geographical area with shed potential of 11 MW.

[51] BEE, 'TPDDL ADR & AMI Project'. [Online]. Available: https://beeindia.gov.in/sites/default/files/ctools/G%20Ganesh%20DasWorkshop.pdf. [Accessed: 01- Dec- 2015].

Program Description:
The C&I consumers entered in agreement with TPDDL for enrolment after detail auditing of their connected loads and business process. The enrolled consumers are intimated four hours in advance through SMS or email for participation in DR event called with option of opt out through return SMS or email reply. Only an aggregated pool of non-critical resources identified at consumer end is shaved or usage time of non-critical load is shifted through DR event created by utility operator and the balance supply of consumer is not affected

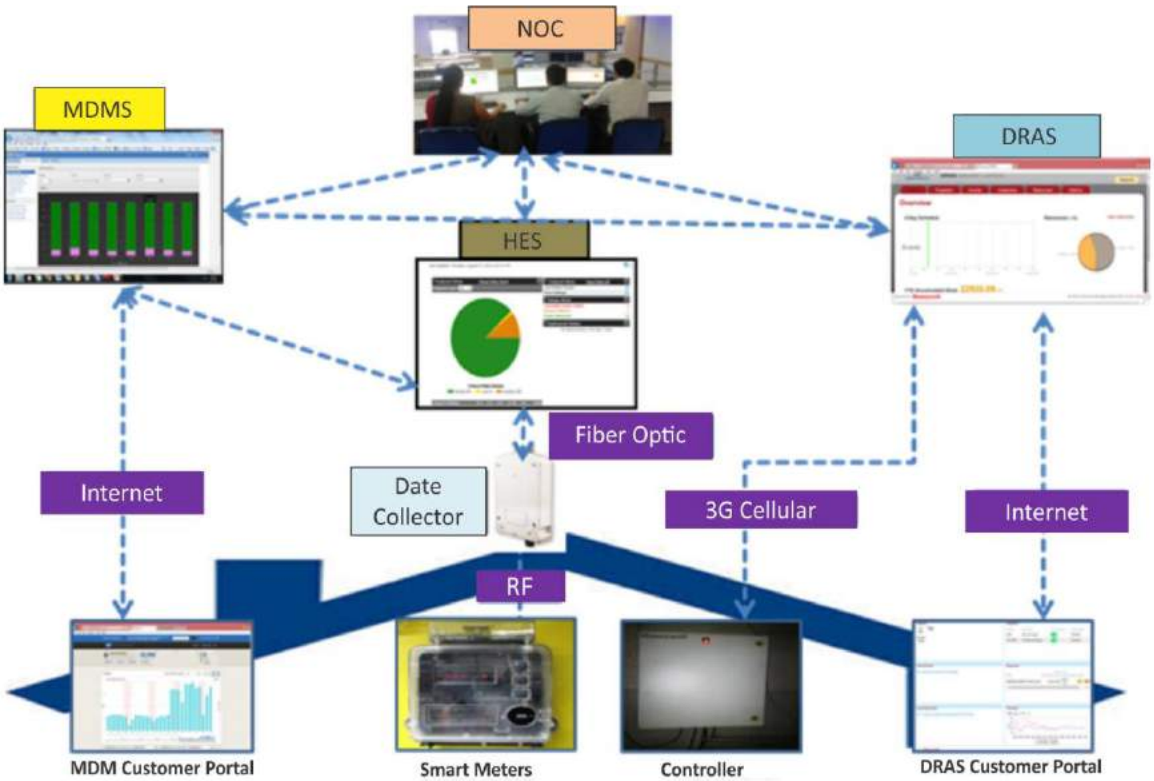
The project components included:

ADR infrastructure including DR server and site controllers: The load control at consumer end is achieved through site digital controller integrated with DR software (DRAS) as SaaS hosted in cloud server.

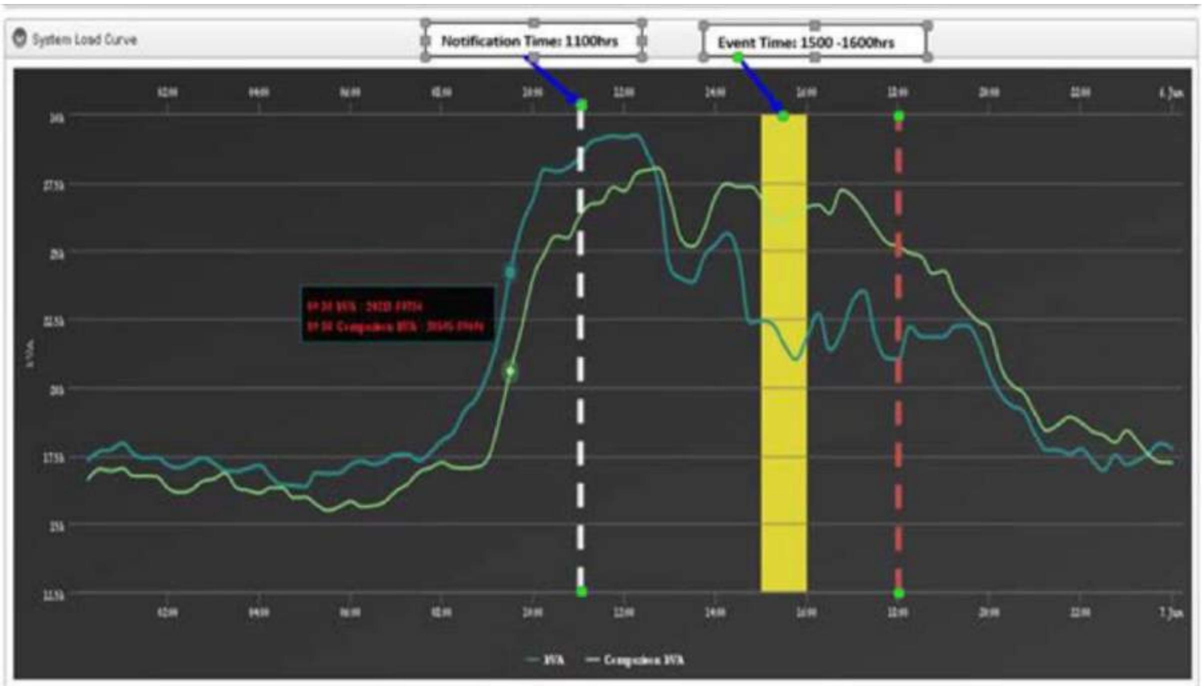
Smart Meters, RF Mesh-based Communication.

MDMS and its integration with other OT & IT systems like OMS, SAP and ADR.

The figure below shows the ADR architecture employed:



A snapshot of an event day is provided below.



System Demand as on 6-Jun-14 | Comparable System Demand as on 5-Jun-14

Program learnings:

- Increased reliability – Consumers ready to forego some consumption if it ensures increased reliability at all times.
- For industries, non-continuous processes with buffers in between can be shed for couple of hours without hampering productions.
- Consumers value information which helps them optimize energy consumption – alerts with respect to low power factor, load limit violation are seen as value added services.
- With correct advance intimation, consumers are ready to even shut down complete load.
- Early adopters of technology can be used as ambassadors for encouraging more participation in such programs.
- As the financial incentives to participate are introduced, consumer flexibility to manage load increases.

Project Results:

Maximum load shifting/shaving of 7.2 MVA and average of 5.09 MVA was achieved through 17 DR events conducted in FY 2014-2015 which demonstrated excellent DR performance at utility level. Accordingly it would save new power purchase agreement (PPA) of 5.73 MW at generator bus during shortage and grid contingency. It was observed that 17 percent of the aggregated peak load of the enrolled consumers had been reduced on an average during the 17 ADR events which TPDDL conducted. In monetary terms, TPDDL could save INR 9.93 Crores (USD 1.48 million) against sale of surplus energy by avoiding new PPA of 5.73 MW due to successful DR events.

Box 3.7 Case Study: Reliance infrastructure – ADR Project[52]

Program background:
Reliance Infrastructure Limited (RInfra) tied up with the U.S.-based Innovari Inc. for the implementation of the ADR in its licensed distribution area. The ADR pilot program was be conducted for one year for a load of around 1 MW and ended in October 2014. High end consumers like ITC Hotels, Raghuleela Mall, Mariott, and Blue Dart participated in the pilot program.

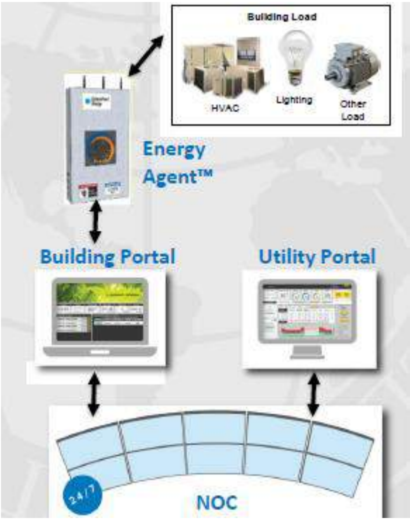
Program description:
Once consumers agreed to participate in the ADR program, the utility team visited the consumer's premises to identify and install 'energy agents or intelligent devices' which analyzed in-house consumption pattern and identified where and when power could be saved by adopting which techniques.

Electricity consumption was reduced in stages; in the first stage, lighting or other gadgets in non-strategic areas such as showcases, wash rooms, changing rooms, lobbies, corridors were controlled. In the second stage, alternate lights of the floors and some escalators in the commercial, corporate or industrial installations were shut down. The operational steps followed in the ADR pilot were as below.

1. Utility forecasted 24 hours in advance the load requirement, considering the capacity available from DR system.
2. Utility's IT based network would then flash load reduction schedule to the participating consumers.
3. Participating consumers would have option to opt out.
4. If the participating consumers did not opt out, the intelligent device would schedule the load reduction in the premises as per the requirement of the utility.
5. Utility's system demand would then reduce to the extent of load reduced under DR scheme
6. Utility's automated system then indicated the load reduced by each participant, and this was passed on as incentives to the respective participating consumer.

The figure below shows the architecture employed by the pilot program.

[52] http://indiasmartgrid.twgtrademissions.com/wp-content/uploads/2014/12/5.4-India-Smart-Grid-Workshop_Reliance-Energy_RR-Mehta.pdf [Accessed: 01- April- 2016]. http://www.rinfra.com/pdf/pressreleases/Media_Release_RInfra_Innovari_18thJul'13.pdf [Accessed: 01- April- 2016]



Program results: The pilot saw an average reduction by about 15 percent of overall monthly bills of the participants. A snapshot of these reductions is presented below.

	Total Load (kW)	Load Under DR (kW)	Percent Reduction in Jun	Percent Reduction in Jul	Percent Reduction in Aug	Percent Reduction in Sep
Raghuleela	490	145	(7)	(46)	(27)	(24)
Mariott	400	120	(6)	(13)	(13)	(12)
Blue Dart	170	50	(1)	(3)	(6)	(4)
Borivali	212	65	(4)	(9)	(15)	(9)
MIDC	100	30	(6)	(13)	(18)	(13)

Box 3.8 Case Study: Remote control of water pumps[53]

In April 2016, the Union Government launched the scheme on 'National Energy Efficient Agriculture Pumps Programme' in Vijayawada, Andhra Pradesh. Under this programme, farmers can replace their inefficient pumps free of cost with the new BEE star-rated energy efficient agricultural pump-sets. These pumps will come enabled with smart control panel that will have a SIM card and a smart meter, giving farmers the flexibility to remotely control these pumps from their mobile phones and from the comfort of their homes, while the smart meters will ensure the farmers can monitor consumption on real time basis.

The scheme was implemented by Energy Efficiency Services Limited (EESL), a joint venture of public sector undertakings (PSUs) under the MOP. EESL will distribute 200,000 BEE star-rated pump-sets to the farmers under this program, which would lead to 30 percent of energy savings by 2019. This translates into an annual savings of approximately INR 20,000 crores (USD 2,985 million) on agricultural subsidies for saving of 50 billion units of energy every year.

As discussed above, a number of DR options are available to utilities. Selecting the right option among these programs and designing a successful DR strategy would require a balancing act among several key parameters so that the objectives of the utility as well as the needs and

[53] http://pib.nic.in/newsite/PrintRelease.aspx?relid=138678 [Accessed: 01- April- 2016]

concerns of end-use customers are met. Some of the key design parameters for designing a DR program are discussed in Section 3.4.

3.4 Demand Response: Key Design Elements

A successful DR program design will maximize the number of utility customers that are receptive to the program while meeting the objectives of system operators. The following are the key program design elements to be balanced when creating a DR program.

3.4.1 DR Triggers and Availability

Utilities and system operators must decide when the DR resources will be available to respond to dispatch. Variations are by:

1. Season
2. Days of the week
3. Hours of the day
4. Length of the event

The selected periods of availability and operation can have significant implications for the overall cost and amount of DR resources available to the program.

To determine the time periods when a DR event can be implemented would involve identifying the level and periods of overdrawal by the state utility and defining the time of need during which a DR event needs to be triggered. The key factors that need to be considered are:

A) **Overdrawal at state level**: Periods of overdrawal where frequency is below 50 Hz make the grid unstable. These time periods are basically the hours of need for the utility i.e. DR needs to be triggered during these time periods in order to (i) maintain stability in the grid and (ii) reduce level of overdrawal.

B) **Renewable generation**: DR can support the grid during the time when there is a sudden loss of RE generation. Thus, RE variability should be factored in the analysis while determining the hours of need.

C) **Power exchange prices**: The short term power exchange prices are also considered in tandem with the frequency levels. These prices are used to reflect the level of monetary benefit that the utility can achieve during a DR event. Additionally, the level of incentives to be distributed to DR partners for compliance will be decided based partially on the monetary gains achieved through the DR event.

D) **Balancing resources available**: To derive net variability that needs to be balanced through DR.

In addition to the above factors, the rules and amendments related to the grid code should also be considered. The grid code governs the grid discipline required to be followed by grid-connected entities. The Central Electricity Regulatory Commission (CERC) (Deviation Settlement Mechanism and related matters) Regulations, 2014 (DSM) is the commercial mechanism that is implemented to ensure that the schedule submitted to the State Load Dispatch Centres and the Regional Load Dispatch Centres is maintained.

DSM attempts to tighten the frequency band even further than the earlier implemented UI mechanism in order to maintain system stability. Because of these changes, there are heavy penalties on deviations beyond 150 MW from the schedule irrespective of grid frequency i.e. even when the grid frequency is close to 50 Hz and the grid-connected entity deviates more than 150 MW from the schedule, the deviation charge increases exponentially. Therefore, even if exchange-based prices may have declined, the deviation penalty due to high generation of renewable energy would still be very high. DR events would therefore no longer be related to prices on the exchange (if they are low) but will be related to overdrawal or underdrawal from the ISTS network, because of the deviation prices.

3.4.2 Preliminary Analysis and Customer Group Selection

Site selection depends on the following key parameters:

a) **Target customer:** Before implementing the DR program, the utility must decide on the customer category where it wants to implement the DR program, i.e. residential, commercial or industrial category. Selection of target customers depends on the potential savings, ease of managing the program and the load profile of customers.

b) **Assessment of load profile of different utility area:** This includes assessment of load contribution by target customer category and local balancing needs of the selected area.

3.4.3 DR Infrastructure Requirements

A key requirement for most DR programs and time-based rates is the availability of enabling technology.

Examples of DR-enabling Smart Grid technologies include, but are not limited to:

- AMI (interval meters with two-way communications capability) that allow customer utility bills to reflect their actual usage pattern and record consumption on a frequent basis, preferably between 15-60 minutes.
- Multiple, user-friendly communication pathways to notify customers of load curtailment events.
- Load controllers and building energy management control systems that are optimized for DR and which facilitate automation of load curtailment strategies at the end use level.

- Servers which include functionalities like generating reports based on the load profile of each consumer, billing profile, deviation of declared v/s actual demand, trend comparing utility schedule v/s actual demand, creating schedules, pricing structures, DR potential at a given period of time, M&V, etc.
- Modification of internal circuits of consumer to segregate essential and non-essential loads.
- For AutoDR DRAS[54], which is based on a client-server, infrastructure is required. The automation server distributes and receives information among its entities, such as utilities. The purpose of the DRAS is to automate dynamic pricing and reliably communicate related messages and information received from utilities to optimize the consumption of electricity during peak hours. The DRAS is an integrator between a utility and DR participants. The major role of DRAS is to notify the participants regarding RTP, DR events and DR-related messages including dynamic pricing.

3.4.4 DR Cost Benefit Analysis

While there would be some capex and opex to the project, there would also be some financial benefits as well as tangible socio-economic benefits. An indicative financial cost/benefit to consumer and utility is presented in Table 3.4 and Table 3.5 respectively.

Table 3.4: DR consumer cost-benefit analysis

Consumer	
Cost (INR/Unit)	**Benefit (INR/Unit)**
• Joining fee • Increased tariff (Alternatively, utilities can recover cost by adjusting in the benefits payment accrued to the consumer) • Impact on productivity (there should be none if done properly) • Modification of internal circuit for segregating essential and non-essential load if required	• INR'x'/unit * 'x' hrs/yr earned due to financial incentive to for participating in scheme. • INR'x'/unit * 'x' hrs/yr saved due to non-utilization of energy during events. • Improved Supply Reliability (in the long term) INR 'x'/unit for DG backup. • Reduced cost of power (in the long term) due to reduced cost of power to utility.

Table 3.5: DR utility cost-benefit analysis

Utility	
Cost (INR/Unit)	**Benefit (INR/Unit)**
• Cost of metering infrastructure (should be covered through R-APDRP, sampling frequency may need to change)	• Provides focus on load patterns and energy efficiency. Therefore enabling better load forecasting. INR 'x' per year through optimized

[54] Ghansah, Isaac, 2009. *Smart Grid Cyber Security Potential Threats, Vulnerabilities and Risks* California Energy Commission, PIER Energy-Related Environmental Research Program. CEC-500-2012-047.

Utility	
• Cost of developing MDAS, MDM, Customer Baseline, Event Management, M&V process. • Incentive to consumer. • Administration cost to DRA if relevant. In general costs can be socialized; however threshold on impact on tariff would need to be agreed with SERC[55].	use of assets and resources. • INR 'x' per unit avoided cost in purchasing expensive power from wholesale market/short term contracts required to meet supply deficit • INR 'x'/yr * 'x' yrs in deferral of asset investment for infrastructure (lines, substations. etc.) required only to meet peak demand. • INR 'x' per additional units supplied due to avoidance of load shedding through better load management.

TPDDL implemented DR in 2014. It is estimated that during the top 5 percent peak hours for TPDDL, it would have resulted in an average savings of INR 4.5 per kWh from avoided purchases in the wholesale day-ahead market. While these avoided costs are approximately equal to TPDDL's weighted average cost of generation from the marginal generation units of INR 4.2 per kWh, additional savings are also estimated resulting from avoided transmission charges and losses[56].

3.4.5 DR Program Administration

DR programs are usually voluntary, but a customer is contractually bound once the decision to be a part of the DR program is taken.

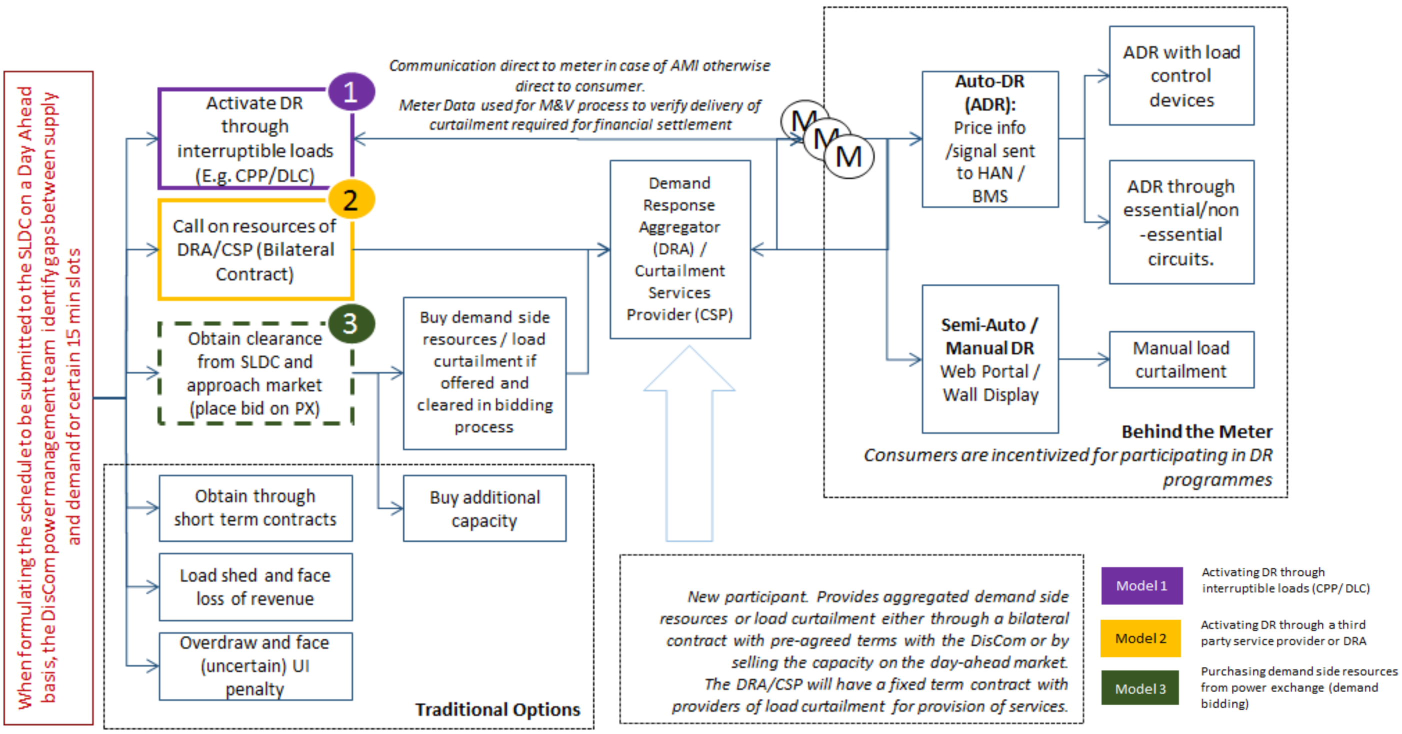
i. Voluntary DR: Participants are notified of the need for load curtailment through signal and can decide whether or not to participate without providing any advanced commitment.
ii. Contractual DR: Once participants have qualified for the DR Programme, they are obligated to curtail their demand on execution of the trigger signal. They are paid an incentive for delivery.

DR can be administered either by interacting directly with consumers to curtail load according to a program design or through a third-party service providers such as a Demand Response Aggregator (DRA) or by purchasing demand side resources from the power exchange, commonly known as demand bidding. Figure 3.4 shows the different models available to DISCOMs to implement DR programs.

[55] Cost socialization refers to methodology where the cost of new technologies is spread evenly across the end users and is not restricted to only direct beneficiaries of the benefits. Raising consumer tariff to recover utility Smart Grid upgradation cost is one such example.

[56] Deshmukh, R., Ghatikar, G., Yin, R., Das, G. G., & Saha, S. K. (2015). Estimation of potential and value of demand response for industrial and commercial consumers in Delhi. *Presented at the India Smart Grid Week (ISGW)*.

Figure 3.4: Demand response models



DR programs, while they can be managed by utilities, can make use of DRAs in several regimes. DRAs act as intermediaries between the licensee and the individual users. In such a model, the licensee seeks to minimize its operational cost and offers incentives/fixed fee to the aggregators to achieve certain goals and provide specific services. The aggregators, in order to maximize their profit, work towards promoting deployment, creating awareness and encouraging users to adopt the DR scheme.

3.4.6 Incentives and Penalties

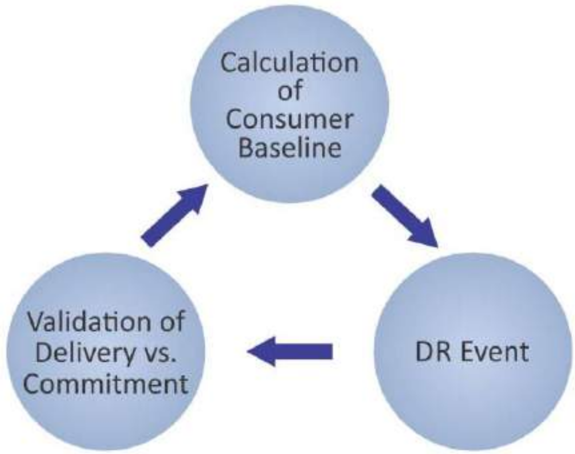
Incentives are designed based on the power purchase behaviour of the utility in wholesale markets and balancing markets (or mechanisms) and on the basis of consumption patterns of participating consumers. In general, higher payments will elicit increased and more frequent customer demand reductions. Compensation can include capacity payments (INR/kW-month), availability and/or reservations payments (INR/kW-hour), and/or energy payments (INR/kW-hour).

Penalties are decided based on the incentive structure. Substantial non-performance penalties can provide strong incentives for reliable DR program performance. Penalties that are set excessively high can result in poor DR penetration, except in the cases where third-party DR providers shield participating customers from this risk by absorbing penalties.

3.4.7 Performance Measurement and Feedback

This involves calling of the DR event and recording its performance. This performance analysis aids in determining the effectiveness of the DR event when called and ensure transparent transaction. This will essentially depend on load profiles of industries.

Establishing an accurate and fair measurement and verification of performance for DR programs is critical for the success of DR as a trusted resource. Ensuring that a customer is able to understand how their performance is being measured and receive feedback (and payment) on performance in a timely manner can contribute to the success of a DR program.



Calculation of customer baseline is an estimate of the electricity that would have been consumed by the consumer in the absence of a DR event.

3.4.8 Regulatory Approval

For approval by regulators, a comprehensive cost benefit analysis must be undertaken and the regulator must be made aware of the positive implications of the DR scheme and its long term benefits such as lowering power purchase cost, reliable and good quality power supply, better peak management, etc.

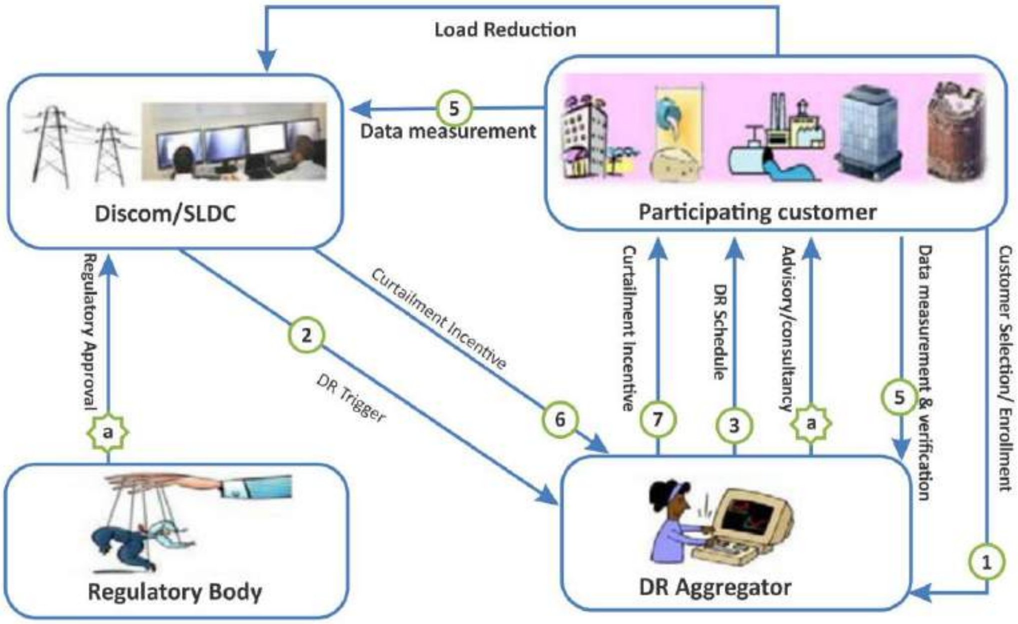
In addition, based on the cost benefit analysis, one of the key regulatory requirements would also be the design of an incentive and penalty mechanism. An attractive incentive mechanism is required to ensure higher customer participation. At the same time, penalty mechanism needs to be built in to ensure customer participation once the commitment is made.

An Indian and an international example of how the various DR design elements are incorporated into a successful program design is presented in Box 3.9 and Box 3.10.

Box 3.9 Case Study: Jaipur Vidyut Vitran Nigam Limited - DR pilot project[57]

Program Objective:
The objective of the DR program was to establish a case for DR programme through a pilot DR project in Rajasthan and showcase the benefits as a proof of concept for scaling up such projects across the country.

Program Description:
The project duration was one year from July 2013 to March 2014 with a DR Target of 20 MW. 4 DR events were triggered in three Industrial areas of Bagru, Jhotwara and VKIA in Jaipur. A total of 17 participants were enrolled in the program.



Program Implementation:

Pre-DR events

- Industry survey: Assessed the DR potential of various industries.
- Customer enrollment: Educate consumers about DR program to help them understand the concept and its benefits well.
- Baseline methodology: Adopted internationally accepted methodology for calculation of baseline. i.e. high 5 of 10 days
- DR event decision: DR response lead time of four hours, four number of DR events to be conducted of one hour duration and incentive to be given as per the bids submitted by consumers at INR 2.25/kWh.
- Infrastructure development: GPRS enabled modems at all consumers' ABT meters, DR server-cum-operations centre set up to receive the meter data in real time. DR portal for data access by consumers & utilities.

[57]BEE, 'Demand Response Pilot Project for JVVNL Discom, Jaipur, India'. [Online]. Available: http://bee.shivsoftwares.com/sites/default/files/ctools/Akhilesh%20IEX%20DR%20Ppt.pdf. [Accessed: 01- Dec- 2015].

During-DR events

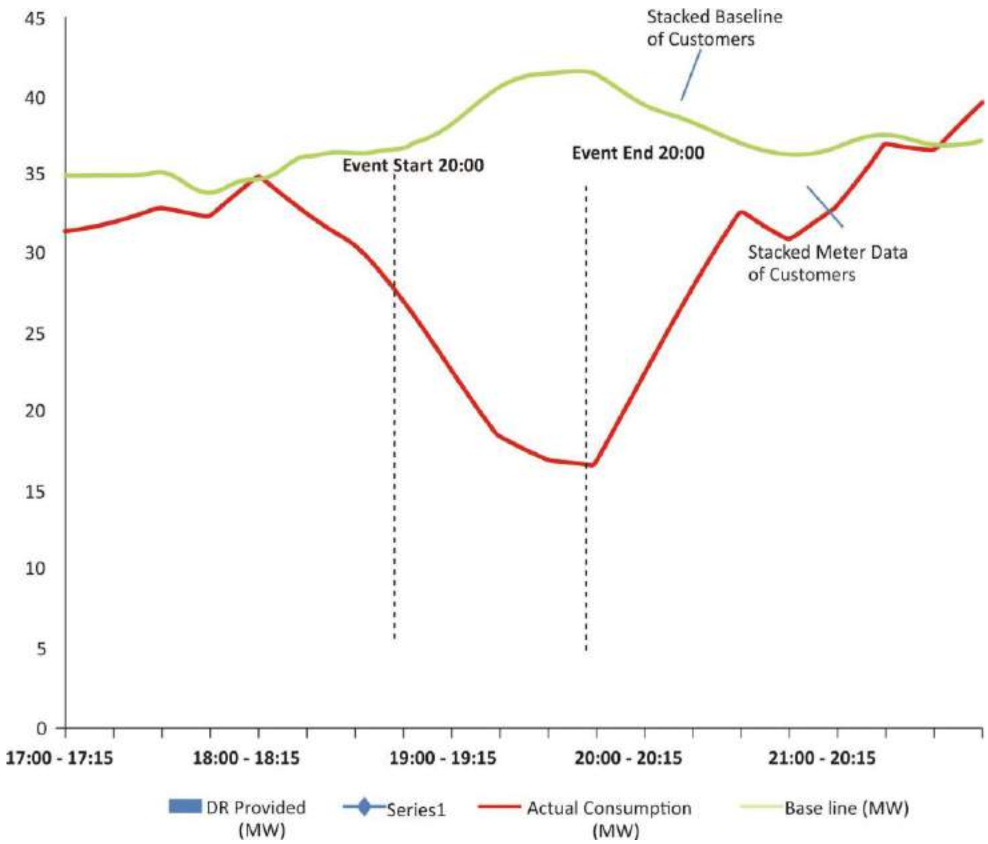
- DR Bidding: Aggregator submitted DR bids for the interested consumers to Indian Energy Exchange-based on DR participation form and after seeking verbal consent from consumers.
- DR Trigger: Rajasthan DISCOM's Power Procurement Centre gives trigger to aggregator four hours prior to the event which would in turn give trigger to the consumers by phone call followed by SMS and Email. Consumer then acknowledges the trigger and confirms the load curtailment as per the bids.

Post-DR events

- Load curtailment by all participants measured and verified by DR software
- Incentive calculated based on the pre-defined mechanism and the incentive payment delivered to the participants.

Program Result:

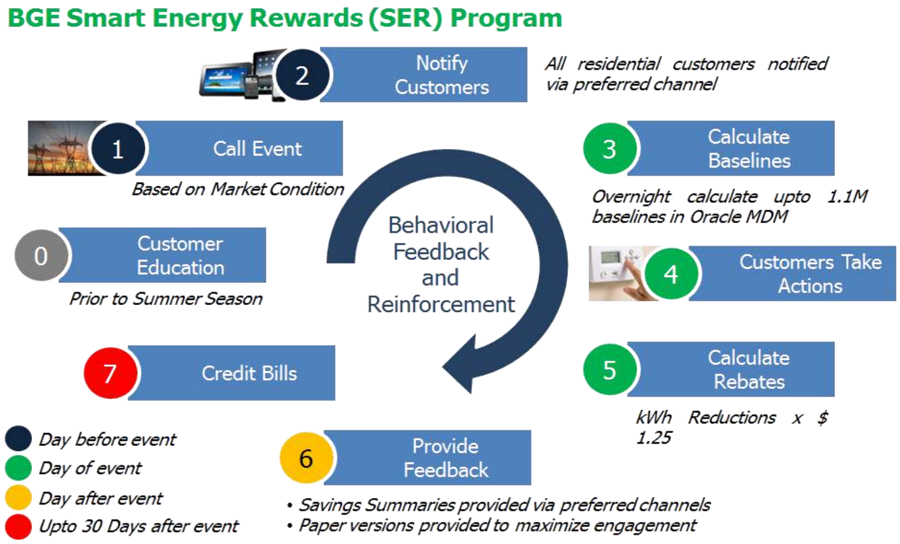
On an average, over the four events called, a DR of 21.96 MW was achieved. A snapshot of one such event day is provided below.



Box 3.10 Case Study: Baltimore Gas and Electric (BGE) Residential Smart Energy Rewards (SER) program

Project Objective: The BGE SER program was designed to encourage customers to use less electricity when energy demand is high. Managing summer peak demand would help BGE reduce the need for power generation plants and therefore keeping down the overall cost of electricity and easing the burden on electricity systems.

Program Description: Peak time rebate program was introduced for all residential customers who had smart meters installed in 2013. Default tariff is applicable to all residential customers with a smart meter but customers can earn bill credits for reducing electric consumption on approximately 5-10 peak event days each summer called Energy Savings Days. Reducing consumption during these days can enable consumers to get a bill credit of USD 1.25 for every kilowatt-hour saved compared to typical usage.



Project Results: A total of four energy savings days were initiated with around 315,000 residential customers eligible. Customer rebates ranged from USD 8.00 to USD 11.00 per event. The percentage of customers who earned a rebate ranged from 75 percent to 93 percent.

3.5 DR Implementation Challenges

Key challenges that can deter the implementation of a DR program are listed in Table 3.6.

Table 3.6: DR key implementation challenges

Stakeholder	Key Challenges
Consumer	• Resistance in participating in DR program particularly direct load control programs • Inadequate, misaligned incentive • Lack of flexibility, absence of opt-out provisions • Lack of awareness
Utility	• Financial constraints vis-à-vis cost of implementation • Inter-operability issues with legacy systems • Institutional and manpower constraints including familiarity with information and communication technologies • Challenges associated with integrating DR with resource planning • Perception of loss of revenue
Regulator	• Challenges in DR design – number of events, customer response and program payments, assumed value of lost load, structuring of incentives and penalties • Conflicting objectives - least cost vs. least risk • Challenges in estimating net benefits • M&V framework – challenges in measuring DR impact

The challenges associated with DR are not insurmountable. To a great extent, the success of the program lies in obtaining the customer buy in and the incentive framework proposed should attract the consumers. These challenges can be addressed through a positive communications strategy to make sure stakeholders are aware of the benefits and to assure them that they are not in a net loss position.

Also, most of the 14 Smart Grid pilots being implemented by the GOI have envisaged implementation of peak load management functionality. The experience of these Smart Grid pilot projects can enable utilities to suitably design their DR programs and overcome any implementation challenges.

3.6 REFERENCES

[1] D. Kulkarni, Smart Grid: An Approach to Dynamic Pricing in India. USAID India, Partnership to Advance Clean Energy - Deployment (PACE - D) Technical Assistance Program, 2015.

[2] Benefits Of Demand Response In Electricity Markets And Recommendations For Achieving Them. U.S. Department of Energy; 2006.

[3] Automated Demand Response *TODay*. Electric Power Research Institute (EPRI); 2012.

[4] EnerNOC, Inc*. Designing A Successful Demand Response Program*. ACEEE; 2008.

[5] Ghansah, Isaac. *Smart Grid* Cyber Security Potential Threats, Vulnerabilities and Risks California Energy Commission, PIER Energy-Related Environmental Research Program, 2009. CEC-500-2012-047.

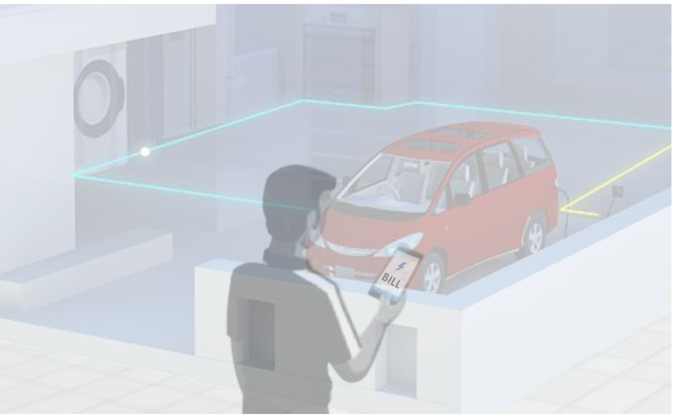
[6] Pjm.com. Retail Electricity Consumer Opportunities for Demand Response in PJM's Wholesale Markets. 2015. Available at: https://www.pjm.com/~/media/markets-ops/dsr/end-use-customer-fact-sheet.ashx. Accessed December 1, 2015.

[7] Assessment Of Demand Response And Advance Metering. Federal Electricity Regulatory Commission; 2008. Docket No: AD-06-2-00

[8] A Primer On Demand Response. Thomas Weisel Partners; 2007.

[9] Demand Response For India. USAID India, Partnership to Advance Clean Energy - Deployment (PACE - D) Technical Assistance Program; 2013.

[10] Implementation Of Demand Response Program In Tamil Nadu. Shakti Sustainable Energy Foundation; 2014.



Module - 4

Loss Reduction, Asset Monitoring & Optimization and Outage Management Systems

4.1 Smart Grid for Loss Reduction

4.1.1 Distribution Losses Overview

T&D loss is the percentage of energy lost in the power grid in the process of transporting from generating station to point of consumption. The concept of AT&C losses was introduced in India in the past decade. The advantage of the concept of AT&C losses is that it provides a realistic picture of energy and revenue loss situation at distribution level. While T&D losses are technical, the AT&C losses comprise of two elements namely:

- Technical losses
- Commercial losses

Technical losses are physical losses that include load losses (copper or Joule effect) and no load losses (corona losses, and iron losses in transformers).

Commercial losses consist of delivered and consumed energy that have not and cannot be invoiced to an end user. This category of losses can be split into fraudulent losses such as theft, or non-metered public lightning and hidden losses such as the in-house consumption of equipment in the distribution network (e.g., the power needed to cool transformers and to run control systems).

While all-India AT&C losses have declined from 26.6 percent in FY 2010 to 22.7 percent in FY 2014[58], the reduction has only been marginal. Also, a number of states and circles, zones within the state have losses above 30 percent. The recently launched UDAY'[59] scheme of the GOI envisages reduction of losses to 15 percent in a phased manner.

Implementation of AMI provides a cost effective mode of reducing AT&C losses. The focus of this module is to detail out how Smart Grid can enable utilities to:

i) Effectively track, reduce and maintain the system;
ii) Better manage their assets; and
iii) Effectively identify, isolate and rectify outages.

4.1.2 Role of Smart Grid in Loss Management

Non-Technical Loss Identification:

Locating the sources of commercial losses within the distribution network has been traditionally challenging for the utilities. AMI presents a solution for monitoring LV networks for losses by supplying data regarding the energy performance of the network. As a part of this, the first step is to install smart metering equipment at each measurement point. This includes:

---

[58] PFC Report on the Performance of the State Power Utilities FY 11 and FY 14

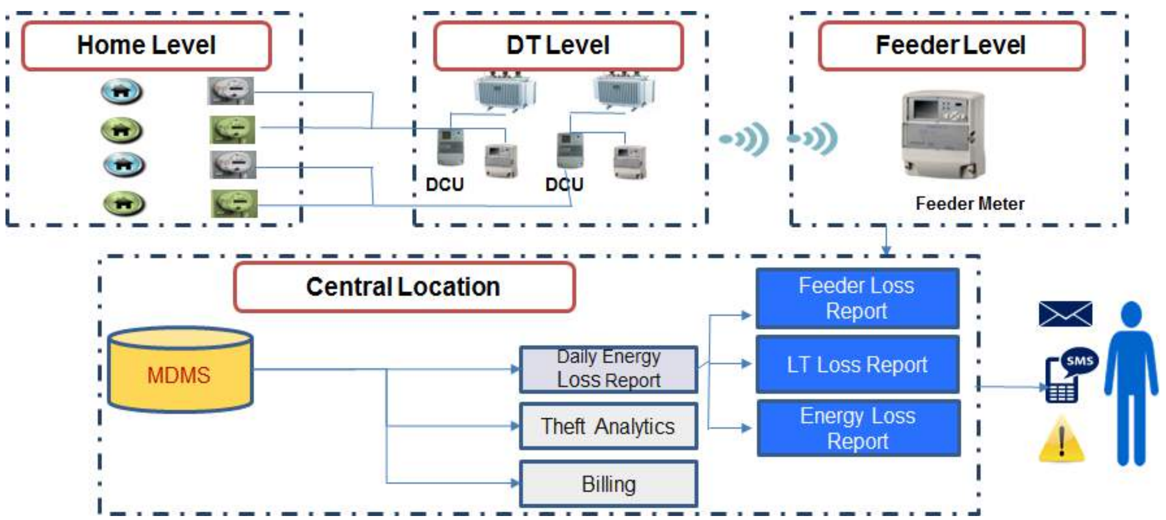
[59] Ujwal DISCOM Assurance Yojna targets smart metering of all customers above 200 units/month by 2019 to reduce theft.

- Smart Meter along with DCU at the local feeder level
- Smart Meter along with DCU at each DT connected to the feeder
- Smart Meter at all consumers connected to the DTs

MDAS[60] and MDMS[61] solutions installed at the central utility level would enable real time energy audit of the distribution system and guide utilities to identify the exact points at which losses are occurring and take corrective action based on this exercise. AMI deployment for automatic energy audit is presented in Figure 4.1.

The AMI system thus enables the following functionalities for the utility:

Figure 4.1: AMI deployment for automatic energy audit



Hourly, daily scheduled meter readings from consumer meters to central server: Utilities can read instantaneous parameters on an hourly, daily basis and on demand. The hourly, daily readings as scheduled remotely along with power quality information are automatically sent to the central server and stored.

Hourly readings of the DT meters: The hourly readings and the reports to understand peak loads at DT level during the day are made available as well as the daily consumption pattern during the week and month.

---

[60] Acquires data from the field devices, stores it, analyzes it and reports it. The MDAS can perform following functions:

- Acquisition of meter data on demand & at user selectable periodicity
- Connect & disconnect for load control and pricing signal
- Audit trail and event & alarm logging
- Maintain time sync with DCU/smart meter

[61] MDMS is a database with analytical tools that enable interaction with other information system such as the following CIS, OMS, ERP, GIS & mobile workforce

Daily automatic feeder loss report: The system time synchronises the feeder meter and all the DT meters. At zero hours the feeder meter reading would be automatically compared with the summation of all DTs (all DTs connected under this feeder) and the feeder energy loss pertaining to that day will be computed. This information would be automatically sent by e-mail, SMS to registered e-mail address, mobile number of concerned utility officials.

Daily automatic LT energy loss report: The system time synchronises the DT meter and consumer meters. At zero hours the DT meter reading would automatically be compared with summation of all consumer meter readings (all consumers connected under this DT) to ensure that daily automatic LT energy loss report is reported by SMS and Email.

Theft detection: The data generated and obtained from the AMI deployment above, combined with data analytics, can also be used for theft monitoring. AMI system using analytics can record and automatically send alerts by E-mail/SMS for various theft indicators. Some of these conditions/exceeding thresholds include:

a. Disconnection of meter
b. Unchanged meter reading for a significant period
c. Low consumption from monthly average
d. Low reading compared to the last meter read
e. Illegal prepayment, prepayment low balance
f. Open meter cover, meter terminal cover
g. Phase reverse
h. Comparison consumption with neighbouring connections (system used to detect & track theft suspects)[62]

Box 4.1 highlights an example of how analytics on AMI data has helped Caribbean utilities in identifying and reducing theft.

Box 4.1 Case Study: AMI analytics aids loss prevention for caribbean utilities

Background:
Government-owned utilities in the Caribbean Islands were grappling with system losses in the range of 33 percent, with some 25 percent of that coming from non-technical losses. With a problem quite extensive, utility managers needed a way to precisely pinpoint illegal taps on the system. Loss prevention crews did not have time or resources to patrol and inspect all the feeders as closely as the situation required.

Solution implemented: To tackle the problem, two public utilities implemented an AMI system with theft detection software. The software leveraged data from the meters at premises and transformers to identify 14 different types of meter tampering and illegal taps.

[62] Another method of managing non-technical losses would be installation of prepaid meters. A number of countries have implemented prepaid meters in their markets. Prepaid meters allow customers to purchase in advance the monetary equivalent of the amount of energy to be consumed. The meters inform consumers when most of the credit energy has been consumed, and the consumer then purchases additional energy. The international experience has shown that prepaid meters are a good alternative for reducing non-technical losses due to billing and commercial irregularities.

Results:
To date, several types of theft have been uncovered. In one case, a supermarket installed an electronic switch to turn the meter on and off remotely. When data from the transformer meter was compared to data from premises connected to the transformer, large discrepancies in load showed up. Analysis indicated that the shutoff activity was taking place consistently during the same hours and days of the week. That information allowed utility to notify police and catch the culprits in the act of stealing, a key requirement for a successful prosecution.

Engineers also have found resistors on meters, a form of tampering that alters the sensing circuitry. Comparing virtual meter readings with onsite readings showed which premises had small consumption when the transformer devices showed peaks. With this information, engineers can then find the meter tampering sites.

Theft of service losses dropped from 25 percent of generation to 5 percent within a year and a half after the solution was deployed. While putting a damper on non-technical losses was the original intent of the service offering, the utilities are also leveraging the data for other applications. For instance, at one utility, the engineers found that 20 percent of transformers were carrying only 10 percent of their load capacity. Such findings allowed the utility to trade underutilized transformers for ones more appropriately sized.

Addressing Other Revenue Leakages[63]

Apart from theft various other areas of utility's commercial activities can contribute to loss of revenue. Some of these areas include faulty metering, inadequate billing process, deficiencies in credit handling, etc. A generic list of some common revenue leakage areas is presented in Table 4.1.

Table 4.1: Revenue leakage due to commercial reasons

Process	Key Activity	Reason for Revenue Leakage
Customer switching (especially important once carriage and content segregation is introduced in India)	• Credit scoring • Customer consumption assessment (before and after switching)	Delay in entering customer records in CIS system; lack of customer information
New, replaced meter	• Customer load assessment • Meter Calibration and Database update	Delay in entering customer records in CIS system

[63] "Software thwarts theft", Elster, 2015.

Process	Key Activity	Reason for Revenue Leakage
Metering	• Energy audit • Estimation for faulty meters	• Faulty meter • Estimate for non-metered connection • Wrong meter reading • Inaccurate transfer of meter reading to CIS
Billing	• Usage calculation, revised billing • Invoice preparation and delivery • Exception reporting	• Data entry error • Application of wrong tariff rate • Delay in bill delivery • Non delivery of bill,
Collection and credit control	• Reconciliation • Deposit management • Payment extension • Disconnections • Integrating multi-modal payment options	• Reconciliation issues • Delay in processing remittances • Idle consumption • Inadequate customer rating system • Customer payment defaults

Studies have shown that revenue leakage in developing countries can account for as high as 20 percent of their revenues whereas it is around 1 to 5 percent for developed countries.

IT-based customer analytics solutions, on top of a CIS and billing system, can be utilized as a tool to acquire new customers, better serve customers and minimize revenue leakages. By analysing the customer and billing data, exception reports can be generated based on pre-defined parameters like drop in customer consumption compared to historical average consumption for the same time period, history of irregularity in customer load violation, default payment, etc.

The analytics solution can thus flag customer for suspect behaviour post which checks could be carried out at customer premises to identify if there is a possibility of revenue leakage.

Technical Loss Identification:

Load Imbalance Management

By utilizing the monitoring and control units of Smart Grid, utilities can reduce their technical loss levels. One such solution is to equip LV feeders with smart energy meters connected to the RTU in the sub-station. The system can then calculate imbalances on LV feeders in real time and locate each LV consumer on the network, feeder, and phase. Based on the imbalance data, rebalancing of loads can be performed by repartition units installed along the network that switch a targeted customer from one phase to another. This particular architecture allows the network to accommodate more distributed energy resources since it addresses the issues of load imbalance and helps to reduce technical loss by reduced joule losses in cables[64].

Volt/ VAR Optimization

VVO can also play a major role in reducing the technical electrical losses that occur in the electric power delivery system. Technical losses primarily consist of electric power that is consumed by the power delivery facilities themselves (conductors, transformers, and so on) in the form of heat. This is energy that must be produced by central and distributed generators, but does not perform any useful work for the end-user or result in any revenue for the electric utility. VVO can reduce electrical losses by switching capacitor banks on or off to compensate for reactive power drawn by the distribution feeders. Switching in a capacitor bank reduces the amount of reactive power that would otherwise be supplied by the central generators via the transmission system. This reduces the current flow on both the transmission and distribution systems and, as a result, reduces the technical losses given by the formula I^2R[65].

With implementation of VVO, care must be taken by utilities for maintenance of capacitor banks, which has been a serious issue in many utilities in India. Under normal conditions, capacitors could operate trouble-free for long periods. However, conditions such as harmonic currents, high ambient temperatures and poor ventilation can cause premature failures in capacitors banks and related circuitry. These failures can lead to substantial increases in energy expenses. Therefore, it is critical to inspect power factor correction capacitors on a regular basis to ensure they are working properly and this can be done remotely through IED and SCADA network as well. For maintenance, it would be a prudent to follow preventive maintenance strategy, as detailed in the following sections, for capacitor banks.

A practical case of VVO deployed for loss reduction is presented in Box 4.2.

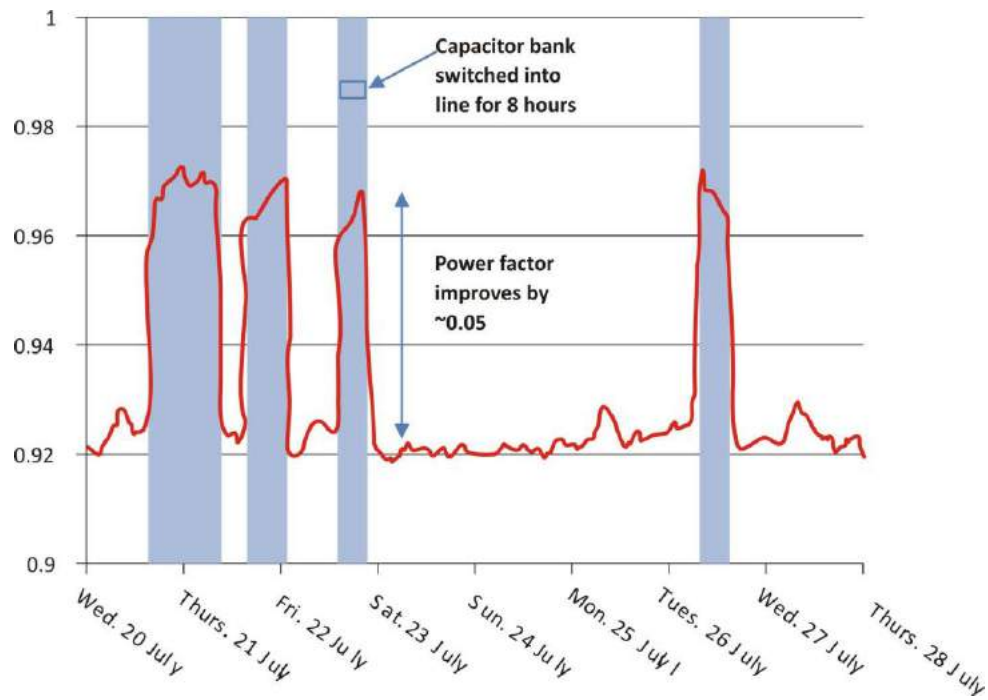
[64] M. Clemence, R. Coccioni and A. Glatigny, 'How Utility Electrical Distribution Networks can Save Energy in the Smart Grid Era', Schneider Electric, 2013

[65] M. Madrigal and R. Uluski, 'Practical Guidance for Defining a Smart Grid Modernization Strategy: The Case of Distribution', World Bank CC BY 3.0 IGO, Washington, DC, 2015.

Box 4.2 US D.O.E distribution automation projects – VVO for loss reduction

Under the US D.O.E American Recovery and Reinvestment Act Smart Grid project, 26 utilities are implementing advanced voltage and volt-ampere reactive (VAR) optimization technologies to improve electric distribution system operations. Advanced VVO is made possible through recent improvements in sensors, communications, control algorithms, and information processing technologies that monitor voltage levels throughout the distribution system. This information is sent to devices that can adjust voltage regulating equipment and capacitor banks on distribution feeders in near-real time enabling quick adjustments in response to constantly changing load and voltage conditions. Adjustments to individual devices and systems can also be coordinated so that voltage levels can be optimized along feeder lines. As of March 31, 2012, eight of the 25 SGIG VVO projects have reported initial results on 59 switched capacitor banks involving 31 feeders.

The figure below provides an example of capacitor bank control for a nine day period in July 2011. The capacitor bank in this example switched on and off four times, as shown by the shaded areas in the chart. Switching intervals of several hours were common for the equipment deployed on this feeder. The chart shows that one of the results was an improvement in the power factor of the feeder of about 0.05 due to reactive power compensation by the capacitor banks. Improvement in the power factor reduces the amount of current flowing on the feeder and results in line loss reductions of about 4 percent.



Apart from these direct measures for reducing AT&C losses, Smart Grid also enables reduction in losses through improved visibility, control and maintenance of distribution network assets. The role of Smart Grid technologies in asset management and monitoring is explained in Section 4.2.

4.2 Asset Management and Monitoring in Smart Grid

The profitability of DISCOMs is affected by frequent breakdown of lines, transformers and feeders and therefore requires proper asset and maintenance management for improving the power reliability and for prolonging the life of equipment.

Some of the major concerns for a typical power utility related to transmission and distribution assets are related to its reliability and performance optimization. To resolve these concerns, there is an immediate need to increase visibility of all asset classes across the utility network powered by real-time tracking and performance management. This visibility can be facilitated by asset management, which can be defined as optimizing and prioritizing investments in the utility's assets in order to improve their performance and life expectancy.

In Smart Grid, asset and maintenance management can be enhanced to include condition-based monitoring so that preventive action can be initiated and optimal operational levels can be maintained. This can, furthermore, include real-time work management i.e. work allocation and follow-up with O&M crew, real-time feedback of abnormal field conditions, complete documentation of all tasks, restoration of works, etc.

Additionally, with online-monitoring of field devices, predictive analytics software can be employed in Smart Grid. Predictive analytics is a process of using statistical techniques from predictive modelling, machine learning, and data mining to analyse historic and current data sets, to predict future events. Predictive analytics can identify variances in certain operational parameters for each of the equipment, which often warn of impending problems that might have gone unnoticed otherwise. Utilities can use predictive analytics to generate automated warning notifications and help diagnose the source of anomalies, in addition to prioritizing issues based on severity.

In Smart Grid, smart sensor with advanced communication systems, information collection and control devices, and analytics provide the basic element for network asset monitoring.

4.2.1 Smart Sensors

The advancement of sensor and sensor technologies has enabled distribution network automation in Smart Grid. Sensors with advanced telemetry systems have made it possible to monitor the electrical grid with increased accuracy and to process sensor data at remote locations for intelligent information gathering and decision making for a host of applications of a smarter grid. The use of sensor technologies can not only lead to better operational efficiency, but can also contribute significantly to energy efficiency, from the intelligence gathered from sensor data from key locations of electrical distribution network.

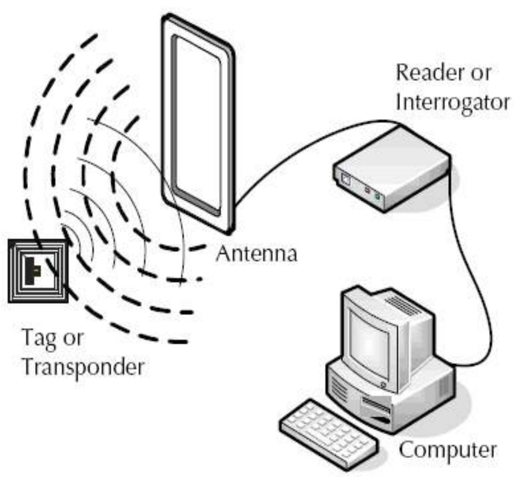
Spread over the grid, sensors and sensor networks monitor the functioning and the health of grid devices, monitor temperature, provide outage detection and detect power quality disturbances. Some of the examples of the sensors in power network include inductive and capacitive sensor, optical sensor, voltage sensor, temperature sensor (surface and winding), oil level sensors, fault passage sensor, gas sensors, acoustic sensors, etc.

Equipment health sensors monitor conditions and measure parameters, such as power transformer insulation oil temperatures, that can reveal possibilities for premature failures. These devices can be configured to measure different parameters on many types of devices. Typically, these devices are applied on substation and other equipment whose failure would result in significant consequences for utilities and customers. When coupled with data analysis tools, equipment health sensors can provide grid operators and maintenance crews with alerts and actionable information. Actions may include taking equipment offline, transferring load or repairing equipment.

Some of the key application where sensor based technologies can be applied by the utilities for improving operations, revenues and energy efficiency are discussed in the following sections[66].

Asset Management System: Distribution utilities can track their network assets throughout the life cycle using the "wireless" tracking devices. Tiny wireless radio frequency identification (RFID) tags can be placed on a network asset such as distribution transformer or smart meter. These RFID devices communicate with the asset management system to log the real-time location of the tagged assets and the complete history of an asset or its movement through the use of active asset tags. This data enables the utilities in asset planning, deployment, tracking and optimization. Figure 4.2 represents wireless RFID for asset tracking.

Figure 4.2: Wireless RFID for asset tracking



Transformer Monitoring System: Distribution transformer is the heart of the LV distribution networks. The health of the distribution transformer has to be monitored at all times to ensure continuous and reliable supply of electricity services. Introduction of sensors for on-line

[66] Source: Jayant Sinha , Enzen Global Ltd , UK, Automating LV Distribution networks using sensor technologies, ISGW, 2015

monitoring of key operating parameters reduces the risk of transformer failure and cuts maintenance costs. The parameters which can be monitored on a distribution transformer are:

1. Surface temperature
2. Winding temperature
3. Transformer oil level
4. Oil temperature
5. Gas and moisture in transformer oil

Figure 4.3 represents distribution transformer monitoring

Figure 4.3: Distribution transformer monitoring

Online monitoring of transformer parameters can be used to generate system alarm for abnormal health parameters of the asset (e.g. load crossing threshold, temperature crossing threshold, unbalance, etc.) thus reducing risk of transformer failures.

Fault Monitoring: Fault[67] passage current sensors on LV distribution systems can measure the current flow in real time and help in the early detection of overloading, short circuit or earth fault. The current signals can be graphically displayed on a remote Digital Fault Recorder and the information could be utilized to validate the location of possible fault occurrence.

Early detection of an impending fault can provide operators with a better understanding of the vulnerable sections of the network and the maintenance crew can be dispatched to reinforce those sections before a catastrophic fault may occur. The sensor data help in optimal design of the switching plans of LV networks, considering all network constraints, system interlocks, protective devices and safety issues, and facilitate early restoration of services to a large part of

[67] A fault condition occurs when one or more electrical conductors contact ground and/or each other. Types of faults include phase to ground, double-phase to ground, three-phase to ground, phase-to-phase, and three-phase. A fault current is several times larger in magnitude than the current that normally flows through a circuit

the network and customers, without overloading. The FLISR application enabled by the sensors is detailed in subsequent section.

Real Time Network Analysis: Substation SCADA receives regular data from sensors via RTUs[68] in real time, which is analysed to know the state of the networks. With real time analysis, it is possible to detect sudden sags or swells in feeder voltages and current, any abnormal load variations or physical conditions.

Sensor-based technologies have also made predictive analysis possible on the electrical networks which help in network fault prevention, optimization and enables condition-based maintenance. This is discussed in detail in Section 4.2.2.

4.2.2 Condition-based Maintenance (CBM)

Another application of remote sensor devices is to enable utilities to proactively monitor equipment in the field to make maintenance decisions based on the current conditions of the assets. This is referred to as CBM, and stands in contrast to “reactive” or traditional “preventive” maintenance strategies.

Traditional approaches to maintaining electrical grid infrastructure are based on “preventive” or in some cases, “reactive” methods. Under a preventive maintenance approach, assets are generally inspected using a calendar-based schedule. Under a reactive maintenance approach, assets are inspected and repaired only after they fail. Neither approach fully mitigates the risk that critical assets will fail while in service, in some cases resulting in disastrous consequences. CBM reduces the risk of asset failure by performing maintenance activities on an “as needed” basis, prior to asset failure. Under this approach, field assets are fitted with remote sensors that monitor, record and share data relevant to the condition of the assets[69].

The CBM strategy involves the following[70].

1. On a periodic basis, or upon the occurrence of an event, the remote devices transmit this sensor data to back office systems for monitoring and analysis**.** The asset management system thus includes a mix of operational (transmitted via existing SCADA) and non-operational data which are archived in the data historian.

2. Typically an analytics engine within the asset management system would retrieve the sensor data from the ‘historian’ and analyse it using Asset Health Rules (AHR**)** and other asset-specific configuration data. AHR consist of a set of rules, formulas and algorithms

[68] An RTU collects data from the field devices, processes the data, and sends the data to the master station through the communication system to assist the monitoring of the power system. At the same time, the RTU receives control commands from the master station and transmits these commands to the field devices

[69] 'System operator uses monitoring data for condition-based maintenance programs', Edison SmartConnect ARCH_D19_Use Case_v2_090506, 2009.

[70] 'System operator uses monitoring data for condition-based maintenance programs', Edison SmartConnect ARCH_D19_Use Case_v2_090506, 2009.

used to calculate a series metrics related to asset condition. The frequency of this analysis depends upon the asset and type of analysis.

3. After calculating a series of asset health metrics using the AHR, analytics engine would run these metrics against a set of notification rules. These notification rules would determine the appropriate personnel to notify as well as any recommended actions.

4. Recommended actions might include clearing the capacitor bank, reduce load, alert the asset management engineer to any abnormalities or any other defined action.

The benefits of using CBM data to determine asset maintenance needs include the following:

- **Improved system reliability:** Sensor devices alert utility to impending asset failures, allowing the equipment to be repaired or replaced prior to failure. These assets can be repaired or replaced prior to failure, increasing grid reliability.
- **Reduced costs**: Use of remote sensors allows utilities to increase equipment capacity utilization and extend operating life of equipment thus increasing the return on the initial capital investment in the equipment.
- **Operations improvements**: Frequent monitoring of transformers improves diagnostic capabilities and, thus, the appropriateness of maintenance activities for these assets. Utilities can use historical data to more accurately forecast equipment needs. For example, utilities could more accurately estimate the remaining useful lives of assets, and incorporate this into asset replacement planning.
- **Workforce effectiveness**: CBM data could be made available to field personnel via a handheld device**,** equipping them with more relevant and timely information, and improving their effectiveness.
- **Increased customer benefits**: A reduction in catastrophic failures reduces potential customer interruption and economic loss, loss of capital assets and loss of revenue; and as a result would lead to increased customer satisfaction.

A case of how intelligent sensors have helped a U.S. utility in predicting and preventing grid failures is presented in Box 4.3.

Box 4.3 Smart Grid solutions strengthen electric reliability and customer services in Florida

Project highlights: As of April 2012, Florida Power & Light, a utility operating in the state of Florida, U.S., had installed more than 5,000 intelligent monitors, sensors, and controls on their transmission and distribution grid, to predict and prevent outages, transformer failure and enhance service reliability to customers. This installation effort included replacing about 50 electro-mechanical protective relay systems with state-of-the-art computer-based systems, and installing feeder breaker and regulator intelligent electronic devices at nearly 100 substations and more than 200 automatic feeder switches.

Smart devices have been installed on 78 substation transformer banks.

FPL's Performance and Diagnostic Centres help to monitor the health of the grid

One of the new Smart Grid-enabled FPL capabilities involves “enhanced diagnostic systems,” which collect and interpret data from substation devices such as battery banks and transformers and transmit that information to FPL diagnostic centers (Transmission Performance and Diagnostic Center (TPDC)) for problem detection and outage prevention.

Project benefits:

A number of use cases discussed below provide an overview of the benefits realized from the project.

- **Use Case-1:** New bushing monitors – monitors, that can detect and diagnose problems before they occur, have been installed on some of the transformers to evaluate the health of both the high and low voltage bushings, including capacitance, power factor, and the extent of current imbalance.

  In January 2012, a newly installed monitor detected an out of tolerance high voltage bushing. Customers served by this transformer were temporarily switched to another transformer and the affected transformer was removed from service. Meanwhile, the faulty bushing was replaced, preventing an outage that would have affected several thousands of customers.

- **Use Case-2:** The TPDC is also monitoring the battery banks that provide power to 500 FPL substations. The battery banks are monitored for both high and low voltage levels and high impedance. In February 2011, a TPDC monitor received an alarm signal indicating a battery problem at a substation located in a remote section of FPL’s service territory. A local field engineer was dispatched to the site and found the alarm was caused by a loose interconnection strap. The repair was made and prevented a battery malfunction which might have resulted in an extended outage for the hundreds of customers served by that substation.

- **Use Case-3:** The TPDC is also monitoring capacitance voltage transformers (CVTs) and is measuring voltage levels and other power flow variables. TPDC engineers implemented an algorithm that uses these data to detect early CVT degradation so preventative maintenance measures can be taken. In September 2011, the TPDC received an alarm signal indicating potential problems with a degraded phase on a CVT. Local field engineers were dispatched, located the damaged CVT, removed the affected transmission line section from service, and replaced the defective CVT, thus preventing a failure that could have resulted in an extended outage and affected several thousand customers.

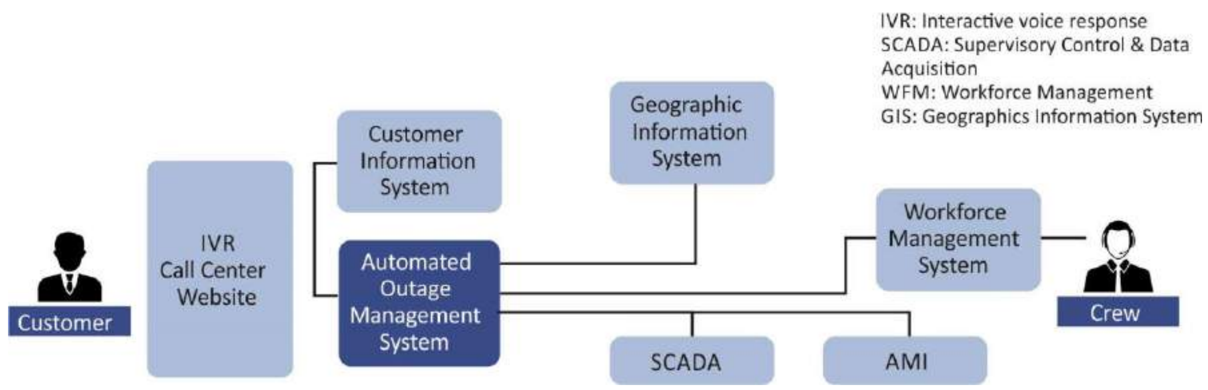
Apart from smart asset management and maintenance strategies, utilities can also leverage Smart Grid systems to significantly improve their outage management system and thus improve the overall system reliability**.** Section 4.3 outlines how Smart Grid enables an advanced outage management system (OMS).

4.3 Smart Grid for Outage Management

Advanced Outage Management System[71]

An OMS is a network management software capable of restoring the network model after an outage. They are integrated tightly with other Smart Grid systems, resulting in timely and accurate actions along with supervisory control. OMS are not only capable of performing restoration activities related to service, but are also capable of tracking, displaying and grouping outages. The OMS analyses the location and extent of an outage and has outage prediction capabilities enabled by a detailed representation of the distribution network. This helps dispatchers and crews determine trouble locations. The objective of OMS is thus to improve availability and reliability, customer satisfaction and enable proactive maintenance to avoid failure. Figure 4.4 represents advanced outage management system.

Figure 4.4: Advanced outage management system



[71] "Appendix G - Outage Management Systems (OMS)", New Hampshire Public Utilities Commission, 2008.

The modern OMS requires an accurate customer-to-electrical system model to provide accurate predictions of outage locations. It must gather, compile, and display information from a variety of sources which may include the following:

- **CIS:** Computerized system used to track customer information.
- **IVR systems**: Interactive computer system which can answer telephone calls, route information, compile data, return calls, and call back customers as programmed. It can be linked to record customers' locations and link these with locations in the distribution system.
- **SCADA status information**: System to gather data from field devices to monitor their status and control them remotely.
- **Distribution Automation (DA) systems**: System for controlling distribution devices. Includes monitoring and controlling breakers, reclosers, and distributed generators.
- **AMI systems**: Refers to integrated working of technologies viz. smart meters, communications network and data collection & processing equipment.
- **GIS**: Refers to collection, record, and display of geographically referenced or spatially-oriented information.
- **Automatic Vehicle Locator systems**: Uses global positioning system information to monitor in near real time the location of vehicles in a utility's fleet.

OMS, if integrated with all available systems, can be of great value during both large and small outages. It can provide call-based and independently-derived data, and in turn, display this data in useful forms to aide operators in making the proper decisions as to where resources can best be allocated. A properly-used OMS can also track the restoration efforts by monitoring how many crews are allocated to each outage and where those crews are located. It can also record the time it takes to complete restoration, which can then help project restoration times for all customers as the restoration process progresses.

The Advanced OMS system integrated with other Smart Grid modules as described above system may function in the following way during an outage scenario:

1 Outage identification

- Customers inform the call center to notify the utility that their power is disconnected.
- The AMI system detects the outages and transmits outage messages to AMI head end system.
- The customer call is logged into the OMS system.
- The AMI network also sends its outage data to the OMS.

2 Outage verification

- OMS orders AMI to periodically "ping" all the meters to real time verify the connection status.
- OMS integration with GIS provides a graphical display to show operators where outages exist.
- OMS also provides a graphical display of the status of breakers and switches.

- SCADA system detects which breakers and relays have operated and transmits this information to the OMS.

3 System restoration

- Operators remotely close breakers and switches and reconfigure the system to restore power where possible using the SCADA and DA systems (explained in the section below).
- Available field crews are dispatched to the location of fault detected using the workforce management system.
- WFM for outage management ensures accurate and reliable orchestration between all the different systems that are required to effectively support planning, execution, monitoring and closing of field work. This is achieved using:
  - Work orders from internal sources such as ERP, OMS and CIS;
  - Work preparation, crew mark-up and material allocation;
  - Schedule, dispatch and tracking of field personnel, subcontractors, special tools and vehicles; and
  - Manage spare parts inventory and receive real-time reports from the field.
- AMI reports restored meters to the OMS.
- OMS graphically displays meters as they are restored.
- OMS system records restoration time for each meter. This information helps operators calculate estimated restoration times for meters still not restored.
- OMS sends graphical data to the web-based customer information system that indicates the size of the outage, the number of crews working in each area, and the estimated time for restoration for each customer. This helps customer service personnel respond with accurate information to outage affected customers

4 Restoration verification

- AMI detects sustained voltage and transmits message to OMS.
- IVR call-back system calls customer to notify that power is restored and confirm the customer's power is restored.

5 Event analysis and recording

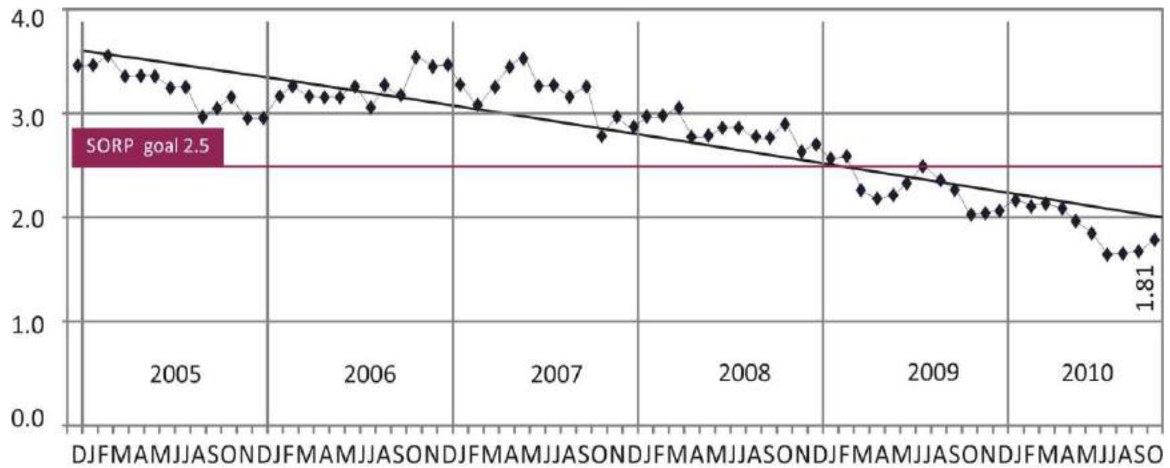
- Any outage event will be analyzed and the information kept as a historical record to record the cause, number of customers affected and duration.
- Such information is used for calculating performance statistics, for example, Customer Interruptions (CI) and Customer Minutes Lost as well as for planning and budgeting maintenance activities, for example, condition-based maintenance.

Some of the local and international experiences of implementing an advanced OMS incorporating the various elements discussed above are discussed Box 4.4.

Box 4.4 Vermont Electric Cooperative (VEC) – outage management system

Project highlights: VEC has provided about 80 percent of customers with smart meters before receiving Smart Grid Investment Grant (SGIG) funding. VEC also installed an outage management system for pinpointing locations when dispatching repair crews.

Project results and benefits: Since 2008, when VEC's outage management system was completed, two key reliability indicators have demonstrated improved performance: the System Average Interruption Frequency Index (SAIFI) decreased 50 percent, and the Customer Average Interruption Duration Index (CAIDI) decreased 40 percent. VEC's results from its Smart Grid investments, including improved reliability, are being studied and replicated by other Vermont utilities in the Vermont SGIG project.



Over the past six years, VEC"s SAIFI has steadily declined, indicating much-improved reliability.

Source: VEC

The benefits of investing in outage management were highlighted after the 2011 tropical storm Irene, which resulted in flooding throughout VEC's service territory. The storm caused USD 1.1 million in damages to VEC's grid and about 12,000 customers experienced power outages of varying lengths. One initial result of the company's Smart Grid investments in outage management at work is highlighted below:

During one afternoon of initial stages of the storm, the lights went out for 1103 customers in one district. But there was no requirement of customer calls as VEC personnel could see immediately from the OMS the outage including the exact number of customers affected.

At night, with the wind still raging, the lights came back on for most of the customers but immediately the OMS showed that 199 customers were still without power and this information was also available to the customers on the utility website.

Without smart meters, the crews would not have known about the second break for quite some time since the people who were cut off by it would have just assumed that the original problem had not been fixed yet and would not have called again until they lost patience or saw their neighbors' lights on.

Following an outage last winter as well, Chief Executive Officer (CEO) of VEC David Hall Quist said that the utility received "…more than 150 thank you notes from customers for the job we did, and we credit that to the Smart Grid."

Box 4.5 Knoxville Utility, U.S. – Integration of outage management system with WFM[72]

Knoxville Utility Board (KUB), a multi-utility providing water, wastewater, gas and electric services to more than 400,000 customers in the Knoxville, Tennessee, U.S., area, implemented an integrated outage and mobile workforce management system. KUB has integrated this solution with the geospatial infrastructure management, customer information, SCADA, interactive voice response and high-volume call systems.

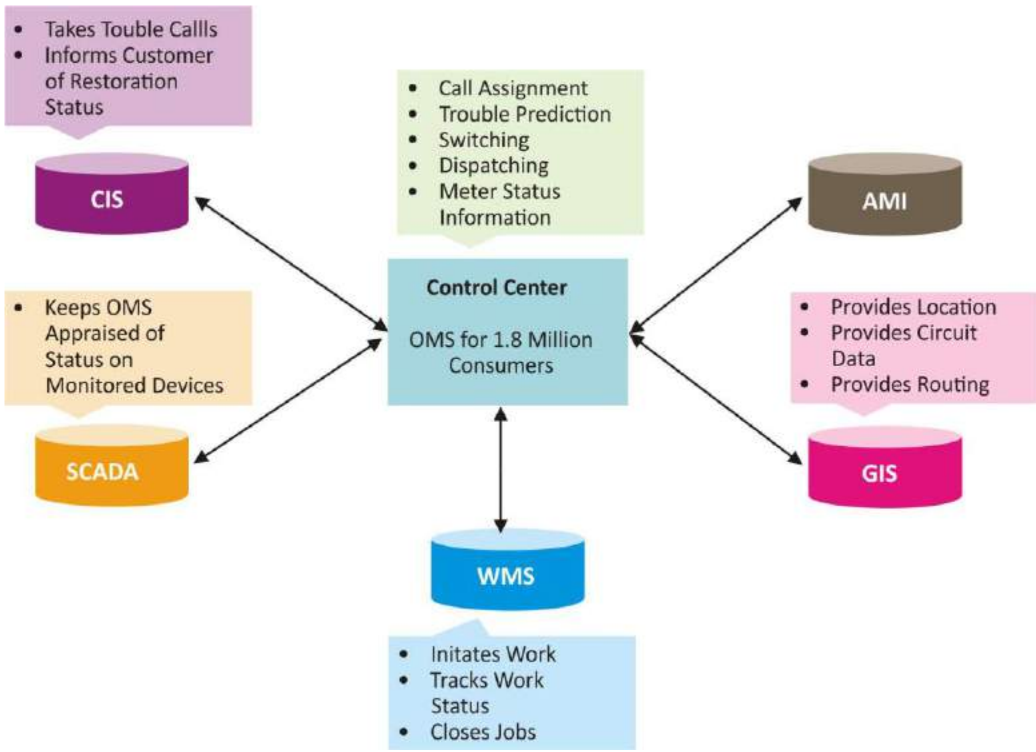
The system provides a seamless environment for dispatching, mobile workforce management, scheduling, crew management and outage management. This allows KUB to create a consolidated operations environment and make informed decisions related to both trouble and service-order work. The system tracks individual trouble calls from customers and associates these calls with an outage event for a specific device. In addition, the outage management system minimizes paper forms in the field and reduces radio voice communication.

Operations personnel can optimize assignments by viewing each vehicle's location in real time on detailed map displays. The system also tracks the events that a crew has worked on, the time spent on the event and the resolution of the problem when the outage is restored. By integrating operations, KUB has increased productivity, decreased back-office support, improved resource allocation, and increased the speed of deployment of job-related information to the field.

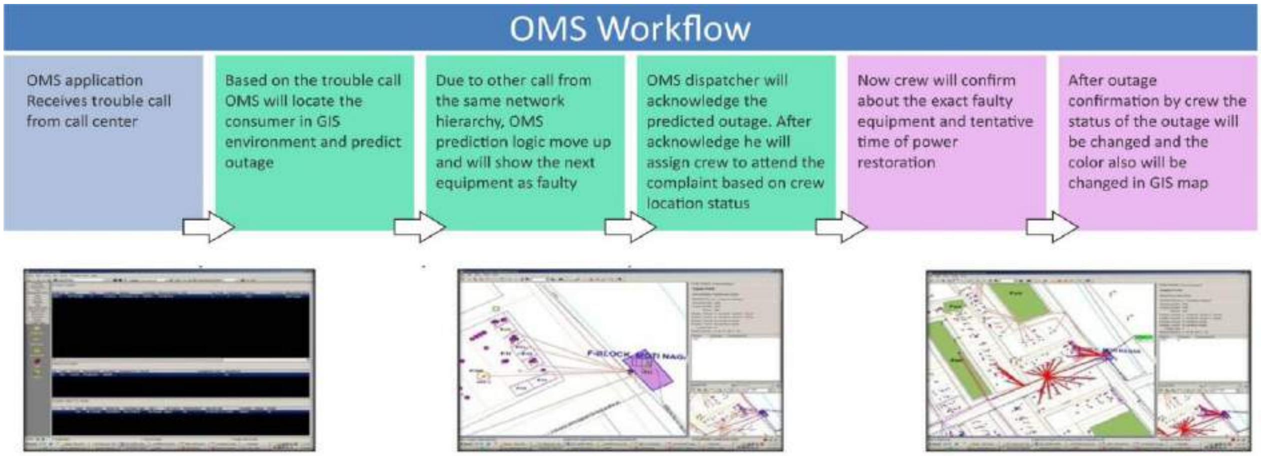
[72] http://tdworld.com/distribution-management-systems/benefits-field-force-automation [Accessed 01-04-2016]

Box 4.6 TPDDL, India – experience in implementing OMS[73]

Project Overview: In FY 2010, TPDDL implemented an integrated OMS with the system interfaces as described in the following figure.

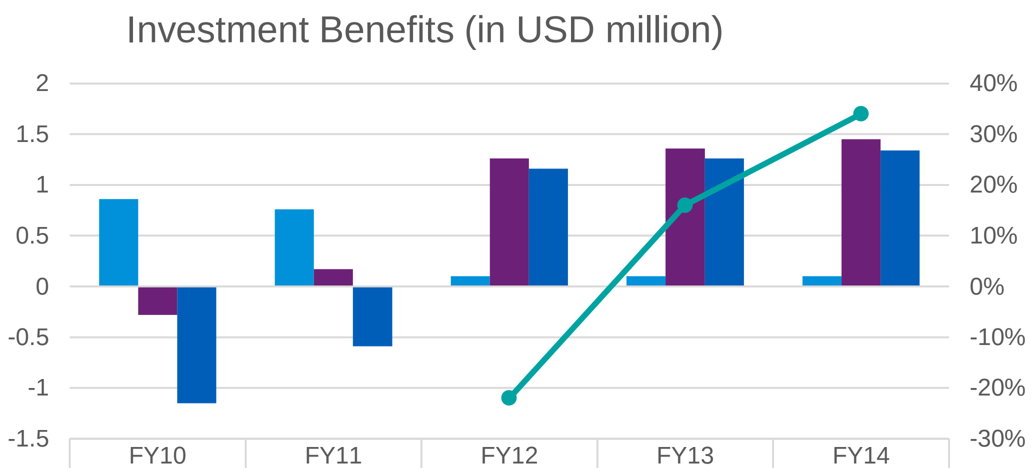


Project working description: The overall workflow of the integrated OMS followed the steps as detailed in the following figure.



[73]North Delhi Power's Experience in Outage Management, presented at Male, Maldives at Transitioning South Asian Market, July 2011http://www.sarienergy.org/PageFiles/What_We_Do/activities/Maldives_Transitioning_South_Asian_Energy_Market_July_2011/presentations/Day%203/NDPL's%20experience%20in%20Outage%20Management%20and%20Demand%20Side%20Management.pdf [Accessed 01-04-2016]

Project benefits: Integrated OMS ensures prompt restoration of the outages affecting customers, assists the utility for improving work processes related to operations and maintenance. The following benefit is expected to be realized by TPDDL.



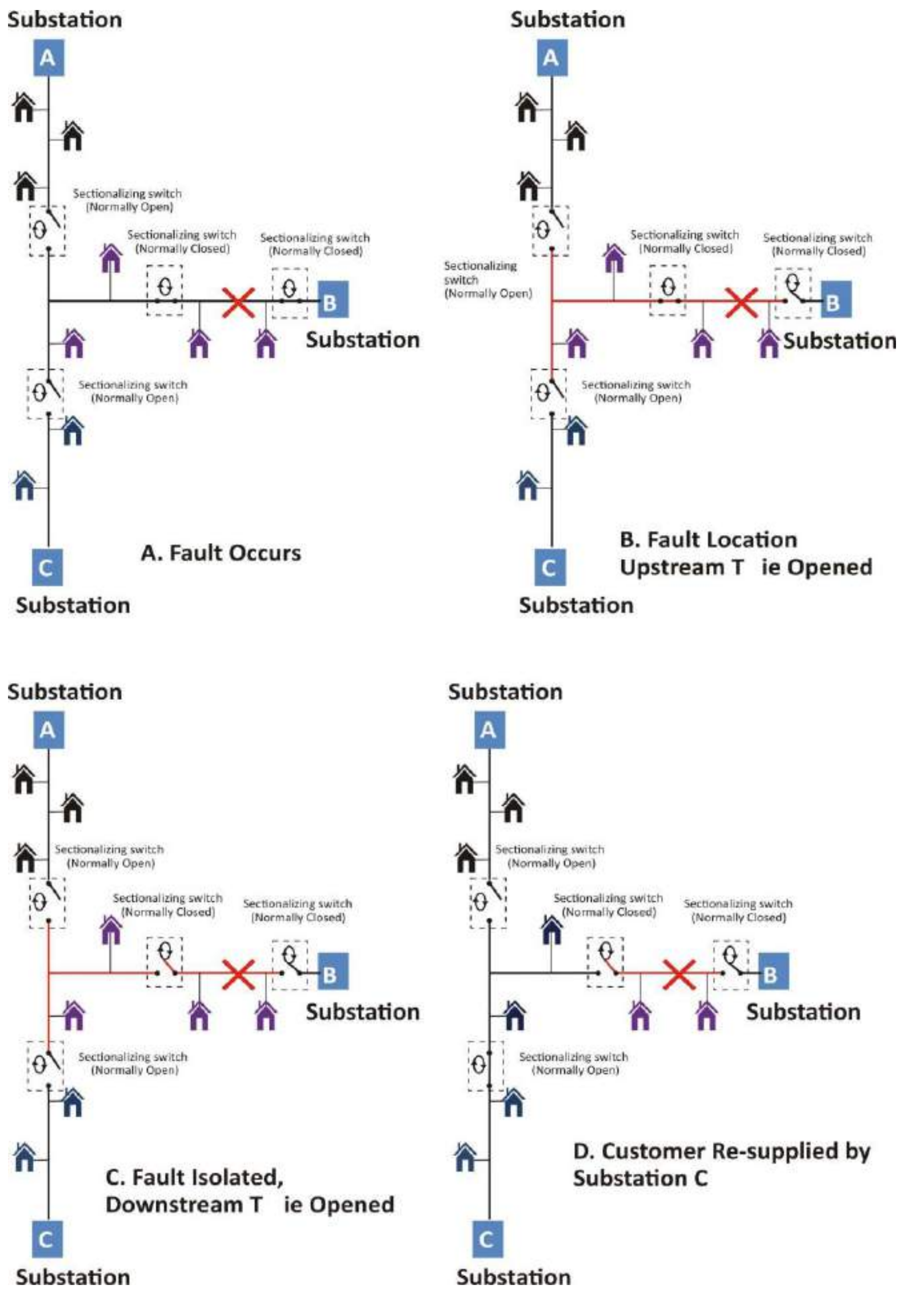
	FY10	FY11	FY12	FY13	FY14
Cash out flow	0.86	0.76	0.1	0.1	0.1
Cash in flow	-0.28	0.17	1.26	1.36	1.45
Net flow	-1.15	-0.59	1.16	1.26	1.34
IRR			-22%	16%	34%

Integration of DMS applications in OMS further improves outage performance and enables automatic supply restoration to un-faulted area by using the FLISR application of DMS. This is explained below.

Fault Location Identification and Service Restoration

FLISR includes automatic sectionalizing and restoration, and automatic circuit reconfiguration. These applications accomplish DA operations by coordinating operation of field devices, software, and dedicated communication networks to automatically determine the location of a fault, and rapidly reconfigure the flow of electricity so that some or all of the customers can avoid experiencing outages. Since FLISR operations rely on rerouting power, they typically require feeder configurations that contain multiple paths to single or multiple other substations. Figure 4.5 represents simplified examples to show how FLISR operations typically work.

Figure 4.5: Fault location and service restoration: Flow of operations[74]



In **Stage-1**, the FLISR system locates the fault passage indicators that monitor the flow of electricity and measures the magnitudes of fault currents, and communicates conditions to other devices and grid operators.

[74]Image Source: 'Fault Location, Isolation, and Service Restoration Technologies Reduce Outage Impact and Duration', U.S Department of Energy, 2014.

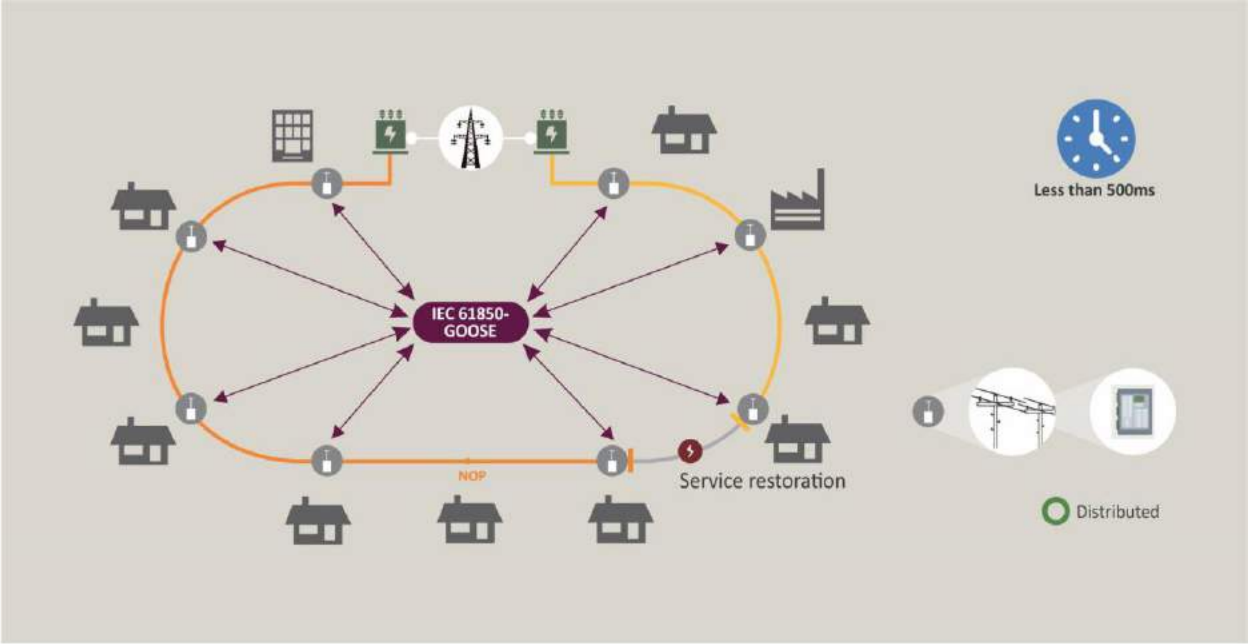
In **Stage-2 and 3**, once fault is located the FLISR systems opens switches on both sides of the fault: one immediately upstream and closer to the source of power supply (Stage-2), and one downstream and further away (Stage-3). The fault is now successfully isolated from the rest of the feeder.

In **Stage-4**, with the faulted portion of the feeder isolated, FLISR system closes the normally-open tie switches to neighbouring feeder(s). This re-energizes un-faulted portion(s) of the feeder and restores services to all customers served by these un-faulted feeder sections from another substation/feeder. The fault isolation feature of the technology can help crews locate the trouble spots more quickly, resulting in shorter outage durations for the customers impacted by the faulted section.

In a typical ring network configuration, FLISR can be implemented using a distributed automated switching solution. In this solution, the type and location of faults, such as short circuits and ground faults are unequivocally detected by the fault indicator and forwarded by automation unit. The “in the ring" installed automation units exchange fault information with each other. The decision to determine the sequence of the necessary actions to be carried out is done hence to the generic self-healing algorithm implemented in the automation units. The restoration process is performed in steps automatically. Between each step the self-healing algorithm verifies the correct execution based on the information exchanged among the distributed automation units[75]. Figure 4.6 represents distributed automated switching for isolation and services restoration for overhead lines.

[75] Source: V. Gandotra, and R. Schmidt, Siemens Ltd., "Self-Healing Distribution Networks in India context – a paradigm shift", 2016.

Figure 4.6: Distributed automated switching for isolation and service restoration for overhead lines



A distributed solution offers several benefits:

- Cost-effective and future-proof solutions for automatic and rapid fault analysis, fault location and restoration of power supply
- Flexible solution supporting central and distributed configurations
- Automated switching procedure to return to normal operation - No manual intervention required
- SCADA system connectivity to self-healing solution for monitoring and control purposes
- Improvement of distribution grid reliability indicators (e.g. SAIDI, SAIFI) by reduction of outages

To evaluate the benefits of FLISR and OMS, the avoided CAIDI and CAIFI can be used as a measure. It is important to note also that FLISR does not avoid outages but works to minimize their impacts on customers when they do occur. A case study on self healing concept is presented in Box 4.7.

Box 4.7 Case Study: The Duke Energy Smart Grid Demonstration – self healing network

Program Objective

Duke Energy has deployed self-healing networks as part of its Smart Grid efforts. Two systems are deployed; one using a decentralized control approach and the other employing centralized control. These networks are part of Duke Energy's on-going field demonstration and testing of the auto restoration schemes in approximately 100 deployed self-healing networks across Duke Energy service regions as of mid-2014.

Project Approach

The decentralized network uses the Smart Grid Restoration System to reconfigure the network when a fault occurs within the network. Each of the three automatic circuit reclosers in the decentralized scheme is programmed to know its normal role in the network, and other local settings, such as its maximum current carrying capacity and normal source. Each of the three reclosers monitors real-time voltage and currents via embedded sensors. The telemetry data is shared by direct communications between the three reclosers. When a fault occurs within the network, the Smart Grid Restoration System determines the location of the fault and opens the appropriate reclosers to isolate the fault.

The centralized approach uses the Substation Automation Platform with unique distribution automation (DA) logic software to perform the self-healing functions for each network. The software allows the DA controller to act as a master controller of the utility defined network. The DA controller polls each intelligent electronic device (IED) in the network via SCADA to determine the state of the network devices. When a fault occurs, the DA controller analyses the IED information to determine where the fault is located. Based on the utility-defined system reconfiguration parameters, the DA controller initiates trip and close commands to automatically restore service to as much of the network as possible.

Results

As of the end of 2013, the deployed self-healing networks had seen 91 successful operations. These operations prevented a sustained outage for approximately 124,000 customers. As a result, it is estimated that Duke Energy saved roughly 13 million customer interruption minutes via the automatic restoration schemes. Building on this achievement, Duke Energy plans to add 52 self-healing networks to its distribution system in 2014.

Lessons Learned & Key Recommendations

- The majority of failures associated with self-healing networks are due to communication issues. As a result, the utility must make repairing sustained communications failures a priority for field technicians.
- Due to the complexity of the schemes, the installation of and the settings for the devices must be performed correctly for the self-healing network to function properly. Source and load instrument transformers must be identified and wired correctly for accurate sensing. Thermal ratings of equipment and conductors of all circuits involved must be factored into the logic of the scheme.

4.4 REFERENCES

[1] 'India Energy Security Scenarios 2047', India Smart Grid Forum, 2013.

[2] M. Clemence, R. Coccioni and A. Glatigny, 'How Utility Electrical Distribution Networks can Save Energy in the Smart Grid Era', Schneider Electric, 2013.

[3] National Energy Technology Laboratory, 'Electric Power System Asset Optimization', U.S Department of Energy DOE/NETL-430/061110, 2015.

[4] M. Madrigal and R. Uluski, 'Practical Guidance for Defining a Smart Grid Modernization Strategy : The Case of Distribution', World Bank CC BY 3.0 IGO, Washington, DC, 2015.

[5] Enzen Global Ltd., 'Automating LV Distribution networks using sensor technologies', India Smart Grid Week, 2015.

[6] Cognizant, 'Using Predictive Analytics to Optimize Asset Maintenance in the Utilities Indust', 2014.

[7] New Hampshire Public Utilities Commission, 'Outage Management Systems (OMS) Overview', 2008.

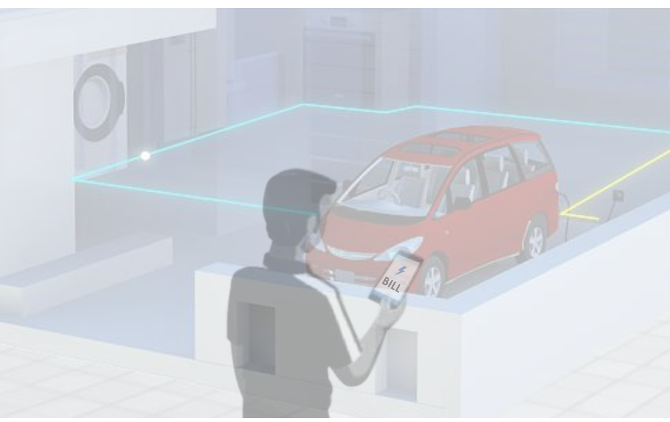
[8] 'System Operator uses monitoring data for condition-based maintenance programs', Edison SmartConnect ARCH_D19_Use Case_v2_090506, 2009.

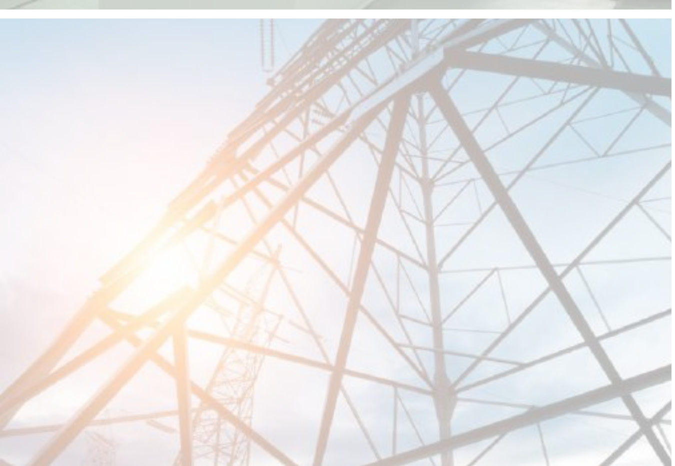
[9] M. Kezunovic, Y. Dong, W. Jewell, V. Aravinthan and P. Dongale, 'Integration of Asset and Outage Management Tasks for Distribution Application', Power Systems Engineering Research Center, 2009.

[10] 'Fault Location, Isolation, and Service Restoration Technologies Reduce Outage Impact and Duration', U.S Department of Energy, 2014.

[11] 'EPRI Smart Grid Demonstration Initiative - Final update', Electric Power Research Institute, 2014.

[12] Jayant Sinha , Enzen Global Ltd , UK, Automating LV Distribution networks using sensor technologies, ISGW, 2015

Module - 5

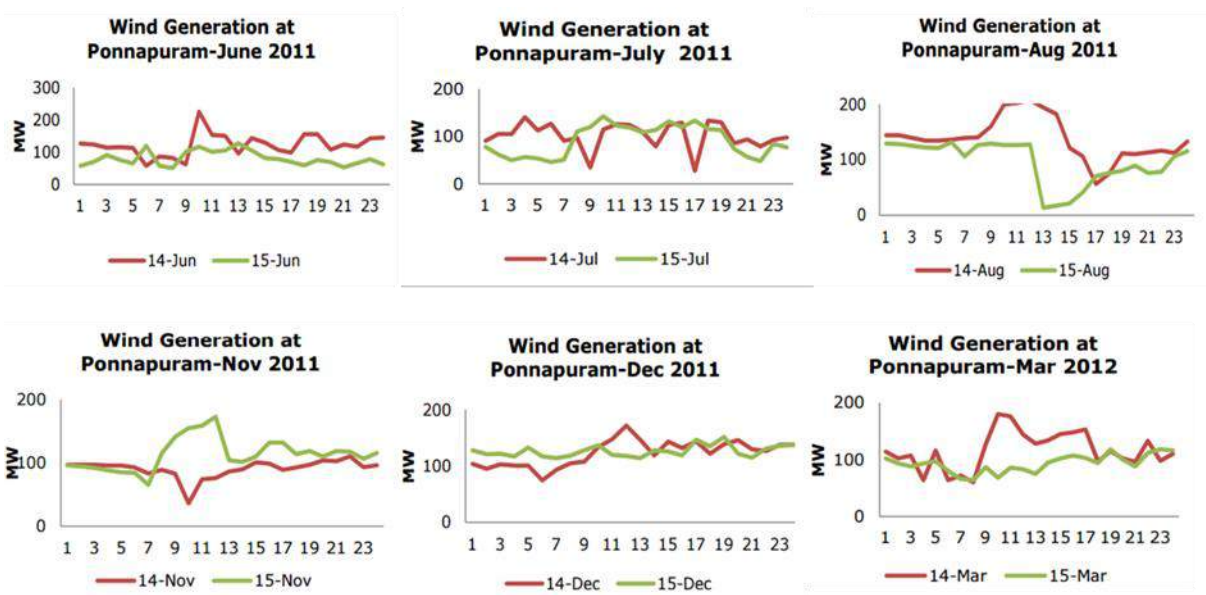
Grid Integration of Renewables: Role of Smart Grid

5.1 RE Grid Integration Issues

India is one of the fastest growing RE markets in the world. The GOI has set a target of achieving 175 Gigawatt (GW) of RE by 2022 comprising 100 GW of solar, 60 GW of wind and 15 GW of other RE sources. Alongside, India, in the recent 21st session of Conference of the Parties, has also committed to have 40 percent of its power generation coming from clean energy sources by 2032. Both the above trends indicate increasing role of RE in India's power generation mix.

Due to its variable and uncertain nature, grid integration of RE sources (particularly wind and solar) presents severe challenges for generators, distribution utilities, system operators and planners. The impact of variability can be understood from Figure 5.1 which shows wind generation data at a substation level. It can be observed that there is significant variation in the generation both across two consecutive days and also within a given day. Additional issues emerge due to lack of availability of forecasts with desired level of accuracy. Solar generation variability is presented in Figure 5.2.

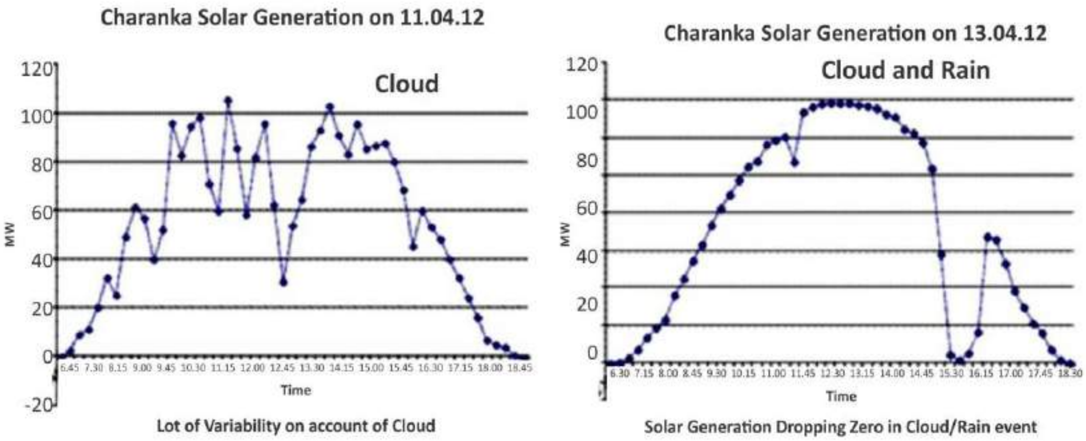
Figure 5.1: Wind generation profiles in a wind heavy state in India



Source: "Integrating Variable Renewable Energy with the Grid: Lessons from the Southern Region", Shakti Foundation, 2012

Similarly, in case of solar, while some degree of certainty exists during the day, variation can occur due to cloud cover which obstructs the sunlight reaching the generators.

Figure 5.2: Solar generation variability



Source: PGCIL

Because the generation from RE sources fluctuates in a manner that generators cannot control by themselves, there is a need for additional energy to balance supply and demand on the grid on an instantaneous basis. Several options are used to manage such as **"Real Power Imbalance"** ranging from ramp up and ramp down of generators, to bringing in ancillary services/reserves, or even load shedding.

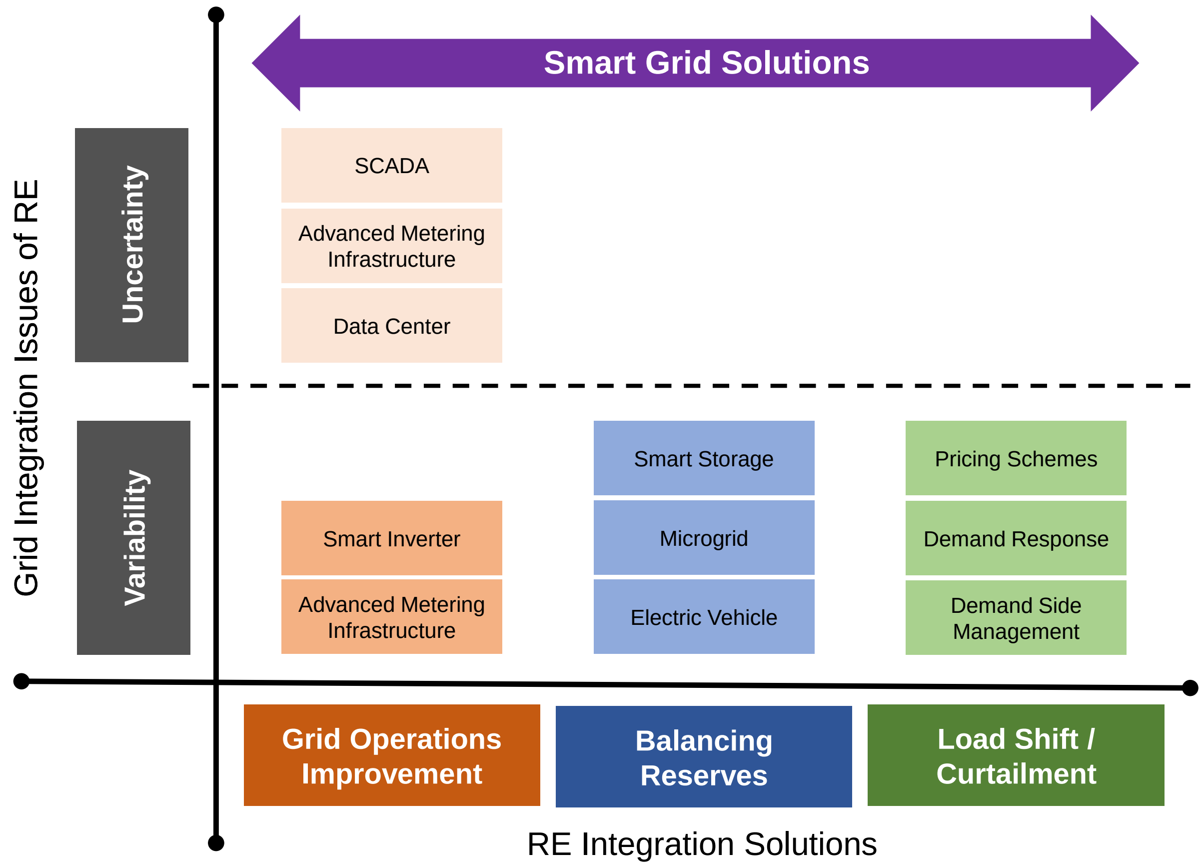
In addition to above, RE generation, particularly from wind, can lead to **"Voltage Management"** issues. Reactive power drawl by wind power generators can result in voltage management issues for grid operators. These generators contain induction motors which absorb heavy reactive power during start-up and also during normal mode of operation. The presence of reactive power in the system requires an increased amount of current to transfer the active power. The increased amount of current leads to voltage variations. These variations, if not managed promptly, can lead to grid instability. Voltage imbalance can also produce transient inrush currents. These currents can cause temporary voltage sag, thermal stress, and can also sometimes cause the protection system to trip.

Smart Grid provides better visibility, advanced controls and responsiveness of the power system, and hence can significantly assist in enabling better RE integration.

5.2 Role of Smart Grid in Supporting Grid Integration of RE

This section highlights various Smart Grid applications that can facilitate integration of RE effectively. RE integration solution framework is presented in Figure 5.3

Figure 5.3: RE integration solution framework

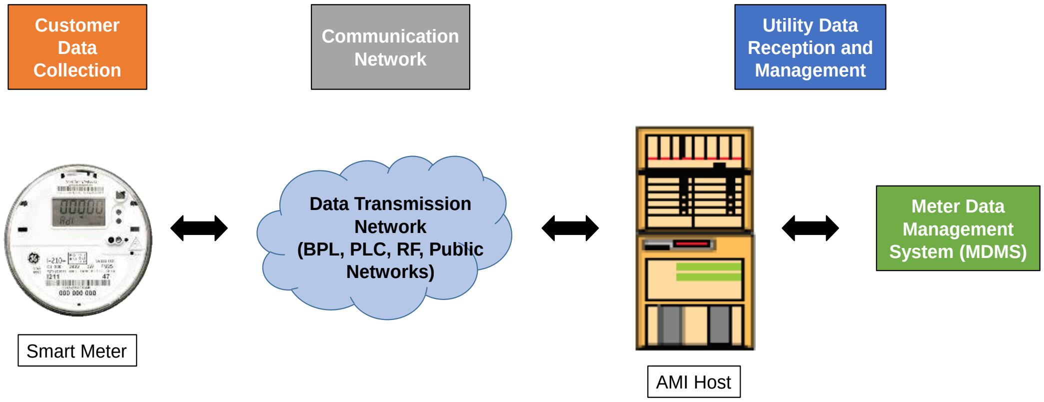


Each of the above solution is explained in the following sections.

5.2.1 Advanced Metering Infrastructure

AMI refers to integrated working of technologies viz. smart meters, communications network and data collection and processing equipment. Data collected from smart meters is communicated to utility by using the underlying communication network. The data gathering and management unit at the utility's end receives the collected data for further processing. In the reverse flow of information, communication from the utility to the smart meter may include price signal, connect and disconnect signals, and DR information. At the consumer's end, energy management systems i.e. Home Energy Management Systems (HEMS) or Building Energy Management Systems (BEMS) translate the information received from the utility to a user-friendly format and display it to the consumer. This integrated working enables efficient data collection processes, high accuracy and transparency. AMI helps in clear demonstration of incentives provided by various schemes under Smart Grid. AMI enables several features that facilitate grid integration of RE. Figure 5.4 represents the main components of AMI.

Figure 5.4: Components of AMI



Some of the specific aspects where AMI can be of use include:

- **Measurement of RE output**: Smart meters, being a part of AMI, facilitate real time monitoring of the power generated from RE sources. The data collected can be used for designing and evaluation of incentive programs for consumers. Additionally, analysis based on collected information can also be relayed to HEMS/BEMS.
- **Integration of RE into DA**: DA refers to various automated control techniques that optimise the performance of power distribution networks. AMI provides two-way communication channel for DA. This will enable RE by dynamically adjusting distribution controls to accommodate variability, power ramping and bidirectional power flows. DA, with the help of communication networks provided by AMI, can be used to control smart inverters, thereby helping in efficient management of RE sources.
- **Enabling Dynamic Pricing and Demand Response schemes**: AMI, through its two way communication capability, enables load reduction/shifting schemes like dynamic pricing and DR. These schemes can help the utility to shift the electricity consumption to the times when RE is available. In the dynamic pricing schemes, pricing schedules can be adjusted at regular intervals in order to match the fluctuations in the RE generation. DR, with its ability to ramp the demand quickly, can help in countering the grid imbalances that happen during the times of excess of RE generation. Also a DR event can be called in case of sudden loss of RE generation leading to demand supply imbalance.
- **Enabling Net Metering**: Net metering encourages distributed generation through roof top solar and other RE sources. Under net metering, a consumer can sell excess electricity (generated from distributed generation) to the local grid. In return the consumer is paid at electricity tariff rates as per regulations. This consumer-side incentive scheme helps in promoting the widespread use of RE sources. For accounting this bi-directional flow of electricity, an electricity meter is required which can record this flow of energy. Smart meter, a component of AMI, fulfils this requirement and helps in successfully implementing net metering.

The cases, discussed in Box 5.1 and Box 5.2 and Figure 5.5 and Figure 5.6, further highlight how some of these Smart Grid components have enabled better grid integration of renewables.

Box 5.1 Case Study: Smart map distribution monitoring and control system, Ontario, Canada

Ontario, through its Smart Grid Fund (SGF) program, is supporting the demonstration and commercialization of enabling technologies that allow for better distribution network planning and more reliable system operation with growing proportions of variable RE.

One key example is Essex Energy Corporation's Smart Map distribution monitoring and control system. Smart Map is an analytical software tool that leverages multiple real time data sources (meters, re-closers, line sensors) and provides powerful operational and asset management capabilities at a low cost. This tool uses geographic analysis over the collected data from smart meters and other sensors to create distribution system simulation. The geographic user interface allows utility to view important information about any individual feeder line, including real and reactive power, percentage loading, current, and losses. With this vital information, utilities are better able to plan for, and operate, a grid with increasing RE penetration.

With the support of SGF, Smart Map was integrated into Essex Powerlines' operations from 2012 through 2014. Smart Map's functionalities has enabled smooth RE integration in Essex Powerlines due to the following:

- Use of a 5-minute and 1-hour interval data to identify minimum, maximum, and median system conditions thereby addressing variability issues of RE.
- Identification of loading capacity and fault current capacity down to the individual feeder for ensuring system stability during surge in RE generation.
- Accurate simulation of proposed future system states thereby helping in accurate forecasting and mitigating uncertainty issues of RE.
- Monitoring of secondary voltage levels on all transformers in 15 minutes increments for detecting momentary dips in RE generation and ensuring system reliability.
- Automatic response to generator dispatch requests from the province-wide system operator for better load management.

Smart Map solution has helped Essex Powerlines to safely integrate numerous solar PV projects, representing 550 kW of capacity, with complete visibility into the performance of resources as small as 10 kW or less.

Figure 5.5: Smart Map's load flow analysis

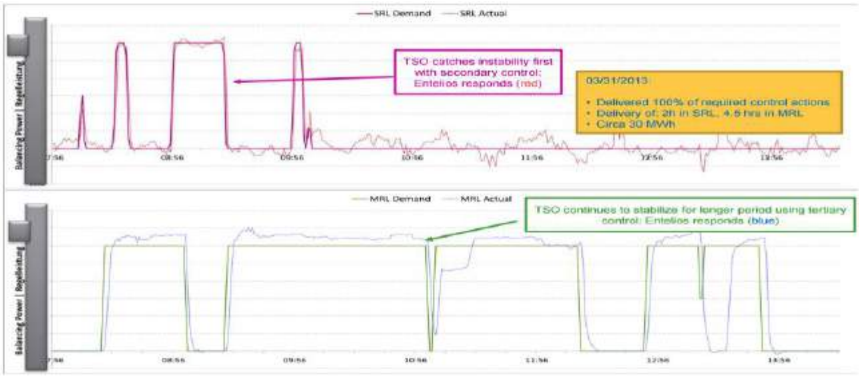
Box 5.2 Case Study: RE integration, Germany

RE Scenario: Germany has a high degree of RE penetration in its grid. More than 27 percent of Germany's generation capacity is renewable based. About 3/4 of the RE capacity is wind and solar based which makes it intermittent in nature. On account of intermittency, it comes to the grid operators to balance demand-supply and generation from conventional sources. As RE is being used on priority, residual load must be generated by conventional sources. Fluctuations in generation of up to 15 GW are possible due to high penetration of RE.

Demand-Side solutions for RE integration: High penetration of RE and priority of dispatch requirement have created a much more dynamic grid in Germany. Large amount of generation fluctuation makes supply-side-only adjustments difficult and expensive. Thus, transmission system operators (TSO) in Germany are using demand-side adjustments like DR for grid stability and management. DR was introduced in Germany through the ancillary services markets. Fully-automated technology platform of Entelios (a German DR aggregator) is capable of responding real-time to TSO demand signals, instantaneously delivering generation and load adjustments to help the TSO balance the grid.

Real time application of DR: As on March 31, 2014, weather forecasts were unanimously predicting sunshine, especially in central & south Germany. However, actual weather did not turn out as predicted. Cloud cover over the solar generators in southern areas and wind from Africa brought fine sand particles (which deposited over PV panels) from the Sahara. As a result large solar generation deficit was observed during the morning time and TSO reported 3 GW (40 percent) shortfall in generation. Moreover, 10 generation units reported failure on short notice to TSO. To manage this severe imbalance, TSO requested secondary reserve and minute or tertiary reserve throughout the day. Entelios executed both services in parallel and delivered 100 percent of required control actions. About 30 MWh load reduction was realized by executing the DR (2 hrs in secondary reserve and 4.5 hours in minute reserve).

Figure 5.6: Use of secondary and tertiary reserve for grid stability



SRL: Secondary Reserve

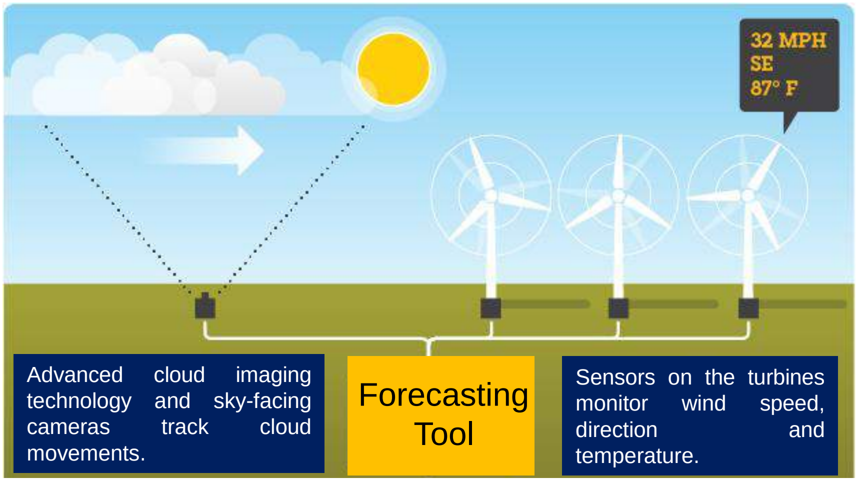
MRL: Minute or Tertiary Reserve

5.2.2 Renewable Resource Forecasting

Accurate forecasting of wind and solar resources can alleviate many challenges related to their variability. The prevalence of forecasting in a given area depends on the level of RE penetration and the regulatory structure. In areas where solar and wind penetrations are low, forecasting is not economical due to low return on investment. In areas of high RE penetration and where contravening regulatory structures do not exist, forecasting is typically considered indispensable. Figure 5.7 shows the diagram of a typical forecasting tool which may include more advanced components in particular application. Different forecasting methods used for two future time ranges are as follows:

- **One to two-day-ahead predictions** are made using numerical weather prediction (NWP) models. NWP models have time resolutions in the range of one to three hours and spatial resolutions of 1 km or more. NWP uses physics-based models to process large amount of data and extrapolate future weather from current conditions at meteorological towers.
- **One to six-hour-ahead predictions**, also called now-casting, are made using statistical models that forecast future weather based on real-time local conditions. Historical weather statistics are used to predict future weather with 15-minute time resolution. Newer techniques that bring time resolution down to five minutes are becoming more common. Current error rates of about 30 percent for short-term, high-resolution now-casts are expected to improve.

Figure 5.7 Components of a forecasting tool for RE sources



In the context of forecasting, Smart Grid acts as an enabler of accurate and efficient forecasting. The data gathering equipment viz. smart meters, programmable logic controller and sensors, etc. deployed across the network collects data about system performance, system's critical parameters, power usage, etc. Data collection units aggregate data from these sources and send it to data centres for storage and further processing. With this assimilated real-time data and historical weather data, forecasting can be done with high accuracy. The direct advantage of better forecasting is better management of power reserves that has to be kept as a stand-by for any sudden variation in wind or solar energy. Better forecasting can help in more flexible grid operations that would allow maximum RE to be accepted in the grid.

In India, the Renewable Energy Management Center (REMC) is enabling better forecasting for renewables, details of which are discussed in Box 5.3.

Box 5.3 Case Study: REMC, India

Under the Indo-German Technical Cooperation between the GOI and Government of the Federal Republic of Germany, technical assistance is being provided by Germany for "Green Energy Corridors" project in India. Activities under this project include integration of RE through: a) support in setting up of REMCs; b) methods and tools for forecasting and scheduling and balancing; c) market design; and d) regulatory framework.

India has set a target of installation of 175 GW of RE by 2022. This massive deployment of RE strongly needs to be supported by state-of-the-art forecasting schemes for the fluctuating wind and solar power generation. This forecasting functionality would be a major component of the REMCs to be established in or attached to the existing regional and state dispatch centers. There are some mandatory requirements for REMC systems which include: 1) state of the art SCADA; 2) support real-time monitoring at refresh rates of at least 2-4 seconds and capability to perform remote control operations. These monitoring and control requirements are basic elements of Smart Grids.

Recommended functionalities of REMCs are:

- Forecasting of RE generation (day ahead and intra-day, ramp prediction, etc.).
- Online geospatial monitoring of RE generation – at the transmission grid boundaries and at RE pooling stations (through direct data acquisition or through interface with RE developer monitoring systems).
- Responsible for quality and reliability of RE data.
- Propagate RE-related data to its partner XLDC, forecasting, scheduling and balancing systems.
- Coordinating with XLDC for dispatching and balancing RE power.
- Central repository for RE generation data for MIS and commercial settlement purposes.
- Coordination agency on behalf of XLDC for interacting with RE developers.
- Training and skill building for RE integration into the grid.

REMC comprise the following features:

- Data acquisition, monitoring and control.
- Geo-spatial visualization of RE generation within the area of responsibility.
- Information exchange with XLDC, forecasting, scheduling and control reserve monitoring/balancing tools.
- Data engineering.
- Data archiving and retrieval.
- Reports and MIS to support commercial settlements.
- Future readiness for advanced functions such as virtual power plants, storage, etc.

5.2.3 Smart Inverters

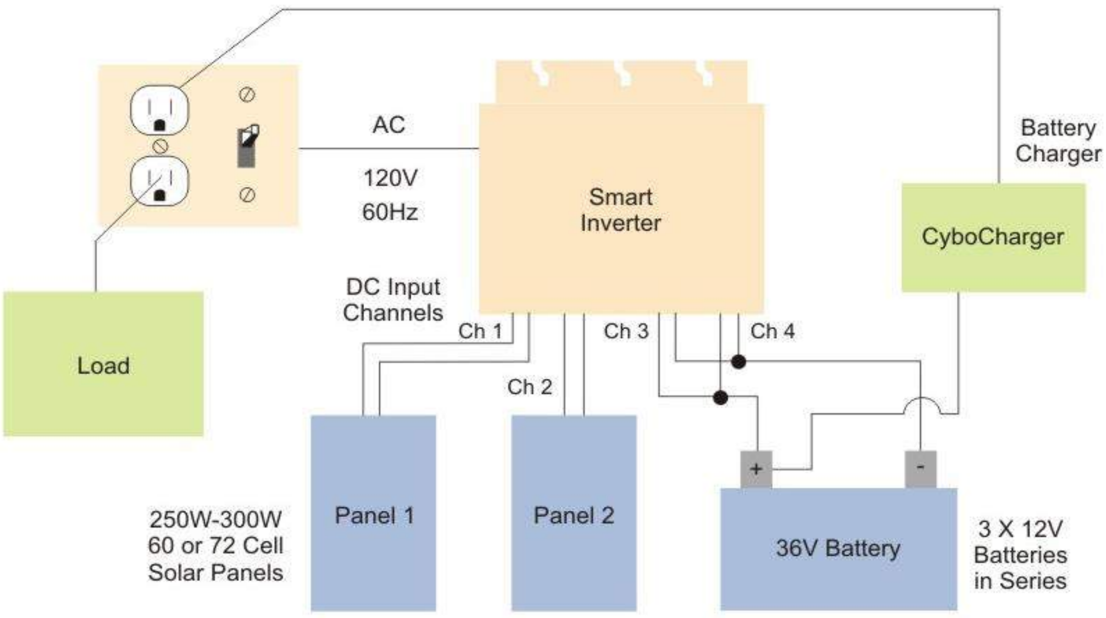
RE integration with the grid has several challenges, namely transient, grid voltage fluctuations (“flicker”), steady-state grid voltage problems, frequency deviations, etc. However, when smart inverters are used to interface RE sources with the electricity grid, these problems can be mitigated[76]. Figure 5.8 shows the line diagram of a typical smart inverter for solar plants. The smart inverter in this figure has 4 input channels, where Channel 1 and 2 can connect to 2 solar panels, and Channel 3 and 4 can connect to a 36V battery set. Its AC output can power customer load as well as battery during the day. When there is sufficient sunlight, inverter will pull power from the solar panels and leave the batteries idle, extending battery life.

[76] Casey, L.F., *et al.* (2010), “Advanced Inverters Facilitate High Penetration of Renewable Generation on Medium Voltage Feeders—Impact and Benefits for the Utility”, IEEE (Institute of Electrical and Electronics Engineers) Conference on Innovative Technologies for an Efficient and Reliable Electricity Supply (CITRES), September.

Smart inverters can provide some specific functions that can help RE systems operate more reliably and efficiently.

- **Volt/Volt-Ampere Reactive Control**: Injection of reactive power to control voltage is called volt-VAR control. At the simplest level a smart inverter can regulate voltage by injecting VARs which is a function of grid voltage. This action does not require any communication on the inverter's part. Alternatively, a smart communication link can enable inverters to output reactive power at the command of the grid operator thus helping in reducing voltage variations caused due to RE.

Figure 5.8 Line diagram of a typical smart inverter[77]



- **Voltage and Frequency Event Ride-Through**: Voltage and frequency event ride-through are control technologies that allow inverters to stay online and support the grid during brief periods of frequency or voltage deviation. These functions are typically pre-programmed into smart inverters and performed without any need for communication with the grid operator. Thus, grid voltage or frequencies variations are resolved by smart inverter without disrupting the RE supply.
- **Grid Monitoring**: Smart inverters monitor grid voltage, frequency, current and phase angle at Point of Common Coupling. If a Smart Grid communication link is available, inverters can send this information to grid operators, increasing the granularity of grid measurements without the expense of additional sensors. This information can help the utility to continuously keep a track of the grid sensitive parameters and take appropriate actions when these parameters change on injection of RE into the system.

77 http://www.solarpowerworldonline.com/2015/05/cyboenergy-offers-off-grid-and-micro-grid-solar-inverters/

- **High Frequency Power Reduction**: This functionality enabled by smart inverter facilitates power reduction from RE sources when the grid frequency reaches a specific higher threshold value. The reduction of power from RE sources can be done gradually as the frequency increases or all at once when the frequency reaches a particular value. This helps in maintaining the grid stability.

- **Ramp Rate Control**: Power from renewable resources can ramp up and down very rapidly, causing challenges for grid operators. In this regard, smart inverters can be controlled to limit the rates at which power ramps up or down. Moreover, the rate at which power ramps down can also be limited if very small amounts of super capacitor energy storage are included within smart inverters. A case study on Smart Grid RE deployment is presented in Box 5.4.

Box 5.4 Case Study: Puerto Rico, U.S.

Puerto Rico has an installed capacity system of 5.8 GW, of which RE is only 1 percent (hydro generation only). Considering its over-dependence on fossil generation, Puerto Rico has planned for RE installation of over 1 GW capacity. As Puerto Rico is an island, it cannot rely on neighboring countries for power balancing. Therefore, it requires that new RE plants are able to regulate both real power and reactive power output, in addition to performing other smart inverter functions. Solar project developers are complying with this mandate by installing smart inverters with VAR control and fault ride-through capability, and by including battery storage systems in parallel with PV plants, the first of which were completed in 2012.

These planned RE projects are part of a broad Smart Grid rollout that began in 2010. The Smart Grid roll out initiative includes DA with FLISR, installation of PMUs, DR, AMI, and EV infrastructure. Puerto Rico's RE plans include solar PV, wind, landfill gas plants and solid waste fired plants. Communications and control will be provided by an upgraded radio system and new broadband over-power-line communications systems. Pilot projects have been initiated for most of these technologies.

Puerto Rico has also explicitly adopted a variety of international standards related to Smart Grid and RE deployment, helping to ensure interoperability of its various systems.

All of the smart inverter functions mentioned can be implemented at a modest additional cost relative to the cost of a conventional (non-smart) inverter. In general, smart inverters are not necessary when variable renewables provide a small portion of grid capacity, but they become beneficial as higher penetrations (around ~15 percent). They become essential at very high penetrations (around ~30 percent)[78].

[78] Hoke, A. (2013), R. Butler, J. Hambrick, and B. Kroposki, "Steady-State Analysis of Maximum Photovoltaic Penetration Levels on Typical Distribution Feeders,"

5.2.4 Energy Storage

Advanced communications and control features of Smart Grid make it possible to integrate widely dispersed energy storage systems[79]. These systems can then be treated as a single huge resource serving multiple applications resulting in multiple benefits. A major benefit is support in RE integration.

Energy storage is an enabler of RE integration due to its tremendous range of uses and configurations. These uses include matching generation to loads through time-shifting; balancing the grid through ancillary services, load-following, and load-levelling; managing uncertainty in RE generation through reserves; and smoothing output from individual RE plants.

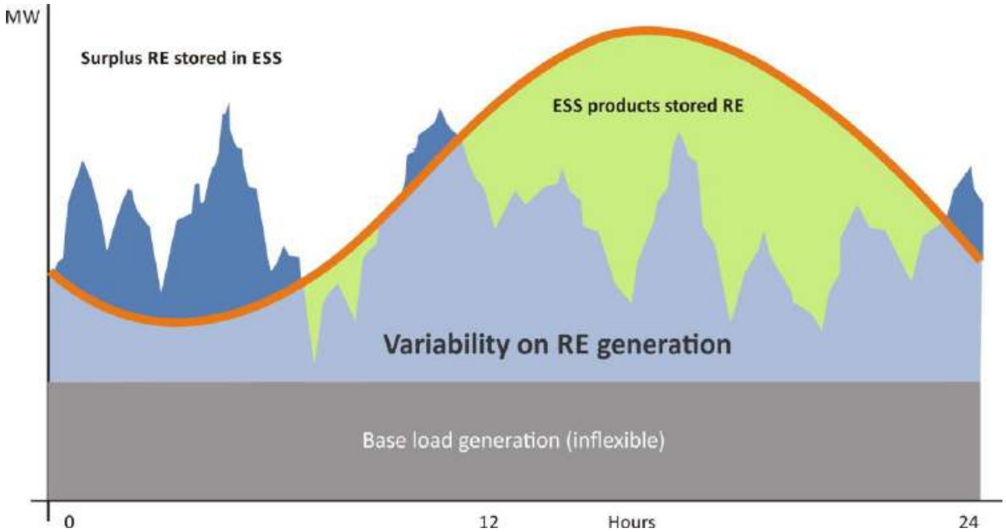
Following are some of the ways in which energy storage can act as an enabler for smooth RE integration:

- Integration of RE in the grid requires frequency control capability due to frequent changes in the power generated due to its variable nature. Energy Storage System (ESS) can be used to provide this capability to the grid by its ability to charge and discharge whenever needed thereby acting as a balancing reserve. As ESS is implemented at plant level for realizing frequency control capability, the need for power quality and ancillary services on the grid is greatly reduced.
    - Smart Grid through its two-way communication capabilities provides an effective medium to communicate when charging/discharging of the storage device is needed and also the rate of charging/discharging to counter the frequency variations. Thus, bringing in automation in the usage of storage devices which can start charging, discharging without any manual intervention as soon as it receives a signal from the communication channel.
- ESS can also absorb the excess of RE from the system. This energy can be used later during the times when the demand in the system is high. This functionality can make RE output both predictable to grid operators and aligned to demand. Storage efficiency is very important for economical operation of this functionality as an inefficient storage facility will lose significant share of stored energy.
    - Smart Grid is equipped with various sensor devices which monitor the grid parameters at regular intervals of time. During the time of high demand when the electricity supply is insufficient to meet the load, these sensors can generate a distress signal which is communicated to the storage devices via two-way communication enabled by Smart Grid. On receiving these signals the storage devices automatically start discharging and start supplying electricity to the grid to meet the demand.

Figure 5.9 represents application of energy storage in RE integration

[79] Energy Storage–A Key Enabler Of The Smart Grid, NETL, U. S. Department of Energy.

Figure 5.9 Application of energy storage in RE integration



- The increase in RE generation requires augmentation and strengthening of current transmission and distribution infrastructure. This requirement poses an additional financial burden on the distribution and transmission utilities. However, with the help of ESS this requirement can be deferred to a certain extent. ESS with support from Smart Grid helps in managing the variation and uncertainty of RE generation. The excess RE generation can be stored in ESS and used to provide ancillary services for load balancing. In case of less generation, the current infrastructure will be adequate to handle the energy flow.

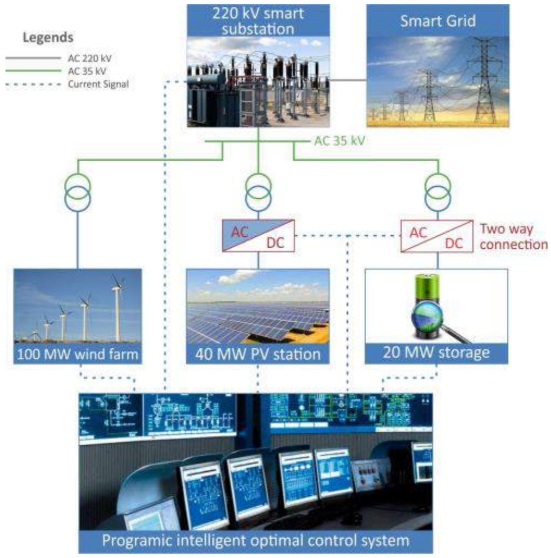
A case example of how China has employed ESS for grid integration is presented in Box 5.5.

Box 5.5 Case Study: Grid-side ESS project, China

Under the national demonstration projects in China, RE power plants consisting of 100 MW of wind power, 40 MW of solar PV, 20 MW - 36 MW battery storage and smart transmission technologies was completed in 2011[80]. The planned capacity of the project is 500 MW wind power, 100 MW PV power and 110 MW of energy storage. The project is located in North Zhangjiakou and co-sponsored by the Ministry of Finance, the Ministry of Science and Technology, the National Energy Bureau and SGCC. It is a premier example of utility-scale hybrid RE plant to integrate utility-scale wind and solar PV generation with large scale lithium-ion battery energy storage. This State Grid Corporation of China (SGCC) project serves as a demonstration of a stable solution for transferring large amounts of predictable, dependable, and dispatchable renewable electricity to the national transmission grid on an unprecedented scale.

Although the generation site had rich solar and wind resources, the local load was small and the installation was far away from the Beijing-Tianjin-Tangshan load centre. Thus the energy was transmitted to the load centre by a high-voltage and long-distance transmission network. The enabling system in the project for grid integration of RE was a panoramic intelligent optimal control system, panoramic monitoring, intelligent optimization, smooth mode-switching between wind, solar and storage. This system of intelligent technologies helped the project to meet targets of output smoothing, schedule following, load levelling and frequency regulation. Moreover, the storage system has contributed in making the wind farm and PV station more grid-friendly. Figure 5.10 shows the architecture of phase 1 of the project.

Figure 5.10 Application of energy storage in RE integration



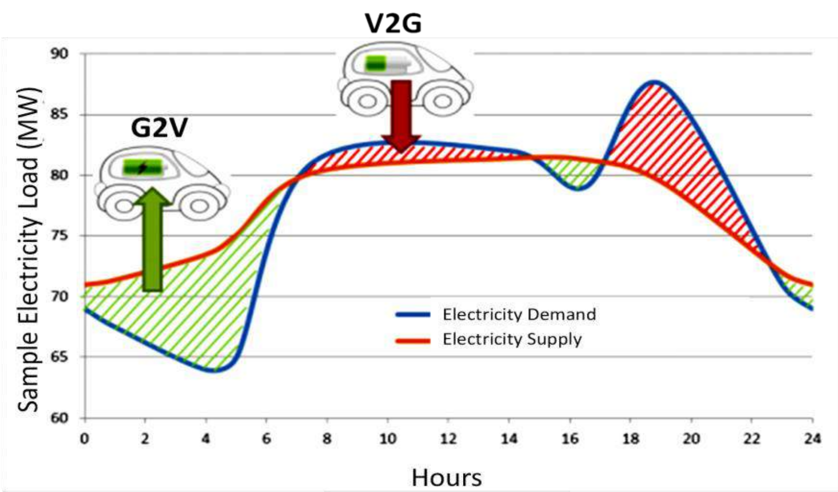
[80] http://www.cleanenergyactionproject.com/

5.2.5 Electric Vehicles

Electric vehicles use electric motors to drive their wheels and derive some or all of their power from large, rechargeable batteries. The distance an EV can drive between recharges is known as its range which is limited by the charging capacity of the battery. If EVs are deployed on a large scale, their batteries could be used as distributed storage.

Smart Grid Technologies Supporting EVs: Smart Grid capabilities support PEV deployment through real-time pricing structures, bi-directional energy flows, and bi-directional metering and vehicle-to-grid applications. Real-time pricing encourages customers to recharge vehicles during off-peak hours at reduced cost. Bi-directional metering enables customers to purchase energy at off-peak hours for charging batteries and sell stored energy in batteries back to the electricity grid during peak periods at higher rates. EVs improve customer's return on investment and minimize grid infrastructure requirements which make their widespread adoption possible. With Smart Grid technologies, PEVs could represent a grid resource for distributed storage, DR, etc. Figure 5.11 below represents v2g and g2v technologies in load management.

Figure 5.11 V2G and G2V technologies in load management[81]



Electric Vehicles Acting as Enabler of RE Integration: PEV can be used as an effective resource to balance the fluctuations and intermittency arising from RE integration. In a situation of grid imbalance, the energy stored in battery of PEV can be utilized to balance the grid (Vehicle-to-grid, V2G) and as soon as the grid returns to normalcy the batteries are charged again (Grid-to-Vehicle, G2V). Figure 5.11 shows scenarios where V2G and G2V technologies can be applied for load management. During the times when the RE generation is high, battery of the EV can be used to absorb the excess of energy that is available. Battery in an EV acts as a source of storage and can exhibit all the advantages for RE integration as discussed above in previous section. The energy stored in the EV battery can also help in managing the imbalances caused in the electricity grid due to high RE penetrations. For implementing these features

[81] Source: http://www.energie.sia-partners.com/20150330/vehicle-to-grid-la-brique-manquante-au-developpement-des-smart-grids

Smart Grid also enables smart charging infrastructure where EVs can respond to signals that are sent by the utility and automatically take appropriate actions of charging and discharging as per the grid conditions.

Smart Grids enable smart charging of PEV which can help in RE integration. This is realized through controlling the rate of charge and discharge of batteries. As RE generation decreases in the grid, smart charging increases the rate of discharge of batteries thus managing the ramp-down effect of RE generation. Similarly, the increase in RE generation will lead to increase in rate of charge of batteries which manages the ramp-up effect of RE generation.

A practical implementation of this technology is presented in Box 5.6, Box 5.7 and Box 5.8.

Box 5.6 Case Study: V2G project, Newark, U.S.[82]

Overview: In 2013, a major automobile company partnered with University of Delaware's demonstration project for experimental V2G technology. This project was aimed at providing a potentially valuable energy storage resource to grid while providing for more cost-effective ownership of a Plug-in Hybrid Electric Vehicle (PHEV). A PHEV with added V2G capabilities was supplied to the University's Science, Technology and Advanced Research (STAR) Campus to investigate the potential of V2G.

Concept: Using Smart Grid technology, the V2G system was capable of monitoring the status of the grid to determine requirement of either additional power for balancing or load for power absorption. Such a system has the potential to reduce or eliminate the frequency and voltage fluctuations in the grid introduced by wind or solar power integration. Electric vehicle owners potentially benefit from supporting a more stable power grid, which can lead to reduced utility costs for the vehicle owner.

Latest developments: University of Delaware's V2G research group has been selected for a share in up to USD 6.5 million federal funding from the Department of Energy's National Renewable Energy Laboratory (NREL). The team will test its technologies in NREL's unique megawatt-scale Energy Systems Integration Facility.

Figure 5.12: University of Delaware's V2G system

[82] http://www.udel.edu/

Box 5.7 Case Study: Nanyang Technological University (NTU), Singapore campus

The Laboratory of Clean Energy Research at the NTU conducted an analysis to assess suitability of PHEVs in a campus-scale micro-grid. Impact of PHEV integration in Smart Grid with RE besides the conventional thermal power plants and diesel generators was observed. The analysis consisted of two options:

Option 1: Without considering PHEV integration

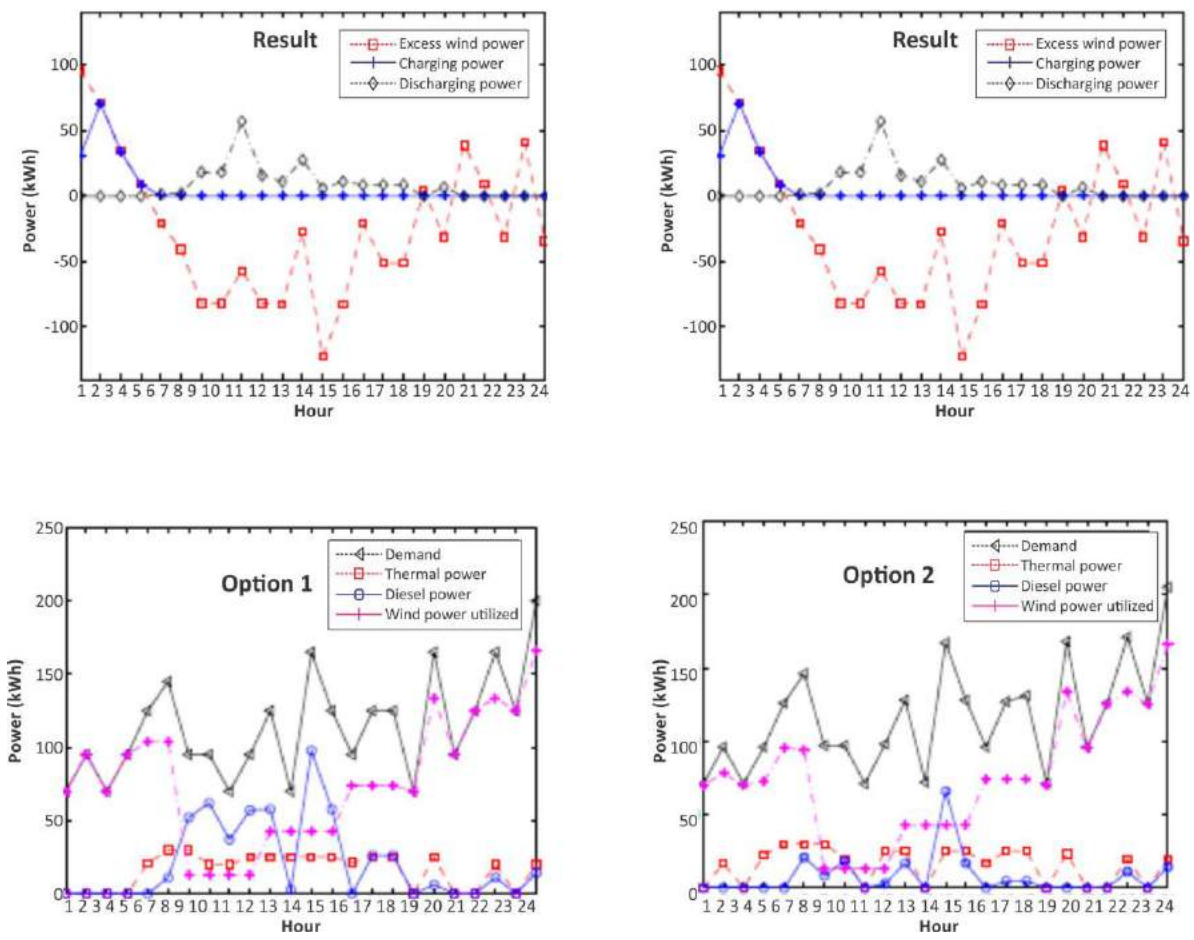
- Wind energy is used primarily as it is utilized at zero cost.
- Diesel and thermal generators are used to balance wind generators.

Option 2: With PHEV integration

- Excess wind energy generation is stored in the PHEV battery (charging, G2V) and returned back when generation is less (discharging, V2G).
- Diesel and thermal consumption is lower.

Result: As it can be observed in Figure 5.13, when there is excess wind energy, batteries of the PHEV are charged. These batteries of the fleet are discharged when wind generation is low to support the grid.

Figure 5.13: University of Delaware's V2G system power consumption in option 1 and option 2; and PHEV charging and dis-charging with respect to amount of wind generation



Box 5.8 Case Study: E-rickshaws, Delhi

Battery operated e-rickshaws were introduced in the city of New Delhi during the Commonwealth Games 2010. Prime motive of this initiative was to eventually phase out the physically taxing cycle-rickshaws in the city. Till 2014, the unofficial number of e-rickshaws plying in Delhi reached approximately 1,00,000. However in 2014, the Delhi High Court banned e-rickshaws in Delhi due to absence of rules and safety guidelines. After the ban, a set of safety, eligibility and operational guidelines were formulated to regularize e-rickshaws. In March 2015, the Motor Vehicles (Amendment) Bill, 2015 to amend the 1988 Act was passed by Rajya Sabha which paved the way for plying of e-rickshaws in Delhi.

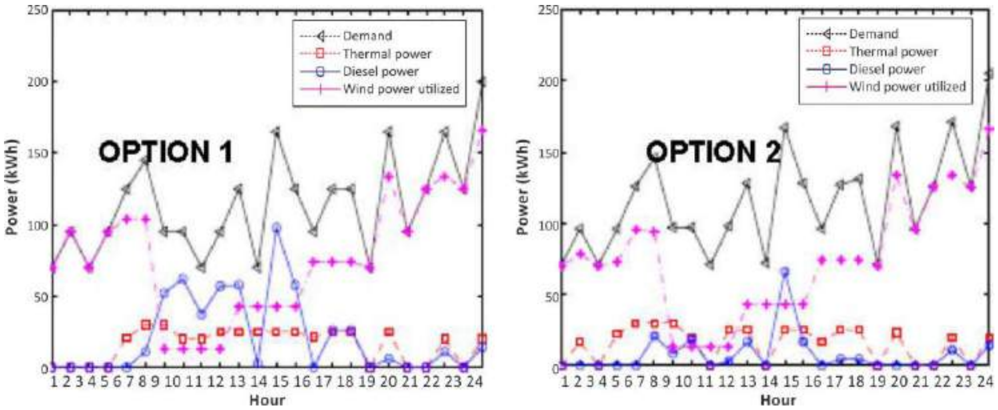
Currently there are no dedicated spots for charging e-rickshaws. As a result, majority of owners of e-rickshaws are tapping on to LV mains for charging. This illegal tapping results in commercial losses to power distribution company. To curb electricity theft, the Delhi Court has directed the State Government to prepare modalities to create legal recharging stations for e-rickshaws to stop electricity theft in the national capital.

The court's order presents an opportunity to formulate smart charging infrastructures for e-rickshaw battery charging. Employing differential pricing, V2G and G2V technologies can enable e-rickshaws as efficient energy reserve. The local DISCOM can utilize these e-rickshaws to balance peak demand by drawing stored energy and to offload excess energy generation by charging batteries. Also, the charging stations can deploy rooftop solar PV plants to generate electricity which will be used to charge e-rickshaw's batteries. The batteries will receive cheaper electricity and in-return provides support to mitigate variability and uncertainty challenges of RE integration by acting as energy reserve.

5.2.6 Micro-Grids

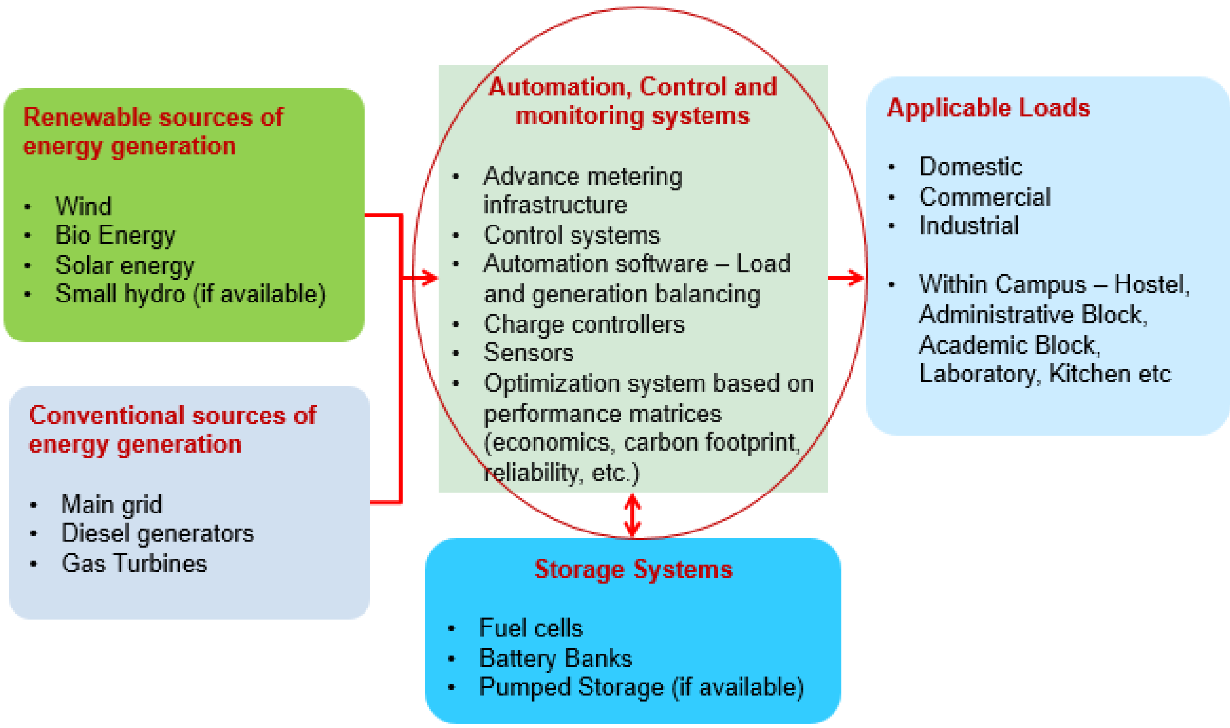
A micro-grid is a small energy system capable of balancing captive supply and demand resources to maintain stable service within a defined boundary. It can operate as a part of a larger grid or independently of the larger grid. Micro-grid can be categorized at two levels such as urban/campus scale micro-grid and rural/off-grid scale micro-grid.

An urban or campus micro-grid is fully interconnected with a local utility grid, but can also maintain some level of service in isolation from the grid, such as during a utility outage or power quality drop. Typical examples are university and corporate campuses, military bases, etc. Rural micro-grids are isolated grids which are not connected to the local utility grid. These micro-grids have their own captive generation (conventional and/or renewable source) which caters to a near-by load. Due to their isolation, these systems operate only locally and cannot avail benefits of utility programs such as DR or TOU pricing. Off-grid micro-grids generally are located on islands and remote sites, such as isolated rural communities.



A typical composition of various components of a micro-grid is shown in Figure 5.14. One of the key components of micro-grid is automation, control and monitoring system. This monitoring and control system analyzes the energy generation data and demand data to make decision for voltage and frequency regulation, energy optimization, etc. This smart decision making capability is introduced by Smart Grid.

Figure 5.14: A typical composition of a micro-grid



Micro-Grids Acting as an Enabler of RE Integration:

- When a micro-grid operates without a connection to the central grid, it is said to be "islanded." It may island itself from the central grid during a grid outage or when grid power quality is poor, and continue providing improved electricity. This ability allows renewable resources within the micro-grid to continue operating even during grid outages.

- Micro-grid has the ability to regulate voltage and frequency using controller. Therefore, variability of RE can be managed by the micro-grid controller.
- Micro-grid controller uses predictive analysis and forecasting for managing demand and supply locally. In this analysis, predicted wind and solar profile are also included. Thus, by enabling forecasting, micro-grids can help to maximize the penetration from RE sources of energy.
- Energy storage resources are an integral part of micro-grid which support RE integration. During the period of excess RE generation, energy is stored in energy storage resources and utilized whenever RE energy intermittent or not available. Moreover, the imbalances originating from brief fluctuations in RE can be easily managed by energy storage capabilities of micro-grid.

Therefore, Smart Grid, through its various applications, provides indispensable support in integrating energy from RE sources with the main grid. A case study on UC San Diego, California Micro grid is presented in box 5.9

Box 5.9 Case Study: Micro-grid, UC San Diego, California, U.S.

Overview: This campus micro-grid generates 92 percent of the electricity used on campus annually and saves more than USD 8 million (compared to importing energy.) On campus generation capacity is 35.1 MW, which is sufficient to fulfill 75 percent of the campus peak power demand. Any additional power needs are provided by San Diego Gas & Electric (SDG&E), the local utility. This project is complementary to the California Energy Commission's Renewable Energy Secure Communities (RESCO) project funded under the Public Interest Energy Research (PIER) program. RESCO's USD 2 million program with CA Energy Commission will deploy advanced SmartGrid Power Management Systems for Micro-grids at UCSD.

Generation capacity details: Following types of energy generators are used by San Diego micro-grid:

- Fuel Cell: 2.8 MW fuel cell provides about 8 percent of total energy needs.
- Solar: 2.3 MW of solar power comes from conventional flat panel photovoltaics (rooftop solar) and two sun-tracking, light-concentrating photovoltaic arrays.
- Cogeneration: 30 MW natural-gas-fired combined heat and power system provides 85 percent of the campus's annual electricity needs.

Integration of solar with storage optimization: Following storage management solutions are employed at UCSD for solar energy integration:

- Automated cloud detection alert system uses dense network of microclimate data provided by 16 advanced weather stations across campus. This system has the potential to manage energy storage in real time.
- Management of PV output using energy storage based control has resulted in decrease of PV ramp rates from 50 kW/sec to 1 kW/sec and mitigation of voltage flicker and power outages.
- Micro-grid controller improves grid utilization through integration of intermittent solar energy.

Some examples of rural micro-grids operating in the state of Uttar Pradesh, India are presented in Table 5.1.

Table 5.1: Rural micro-grids operating in Uttar Pradesh

Parameter	Mera Gao Power Micro-grid Program	Naturetech Infra AC Solar Mini-grid Program	Smart Power for Rural Development Initiative (SPRD)
Implementing agency/company	Mera Gao Power (MGP) - a private company	Naturetech Infra - a social enterprise	Smart Power India (SPI)
Area of deployment	500 hamlets serving 15000 households	10 villages in UP & 1 village in Bihar	Rural areas of UP & Bihar
Hours of supply	5-7 hours/day	24 hours/day	24 hours/day
Connection provided	Solar DC based mini-grid 2 light points (LEDs 1W each)and facility for mobile phone charging	2 LED lights & 1 power point for TV/music system/ computer, etc., electric transport, rural micro enterprises	Anchor tenant (telecom tower)/ aggregation of load & households, institutional, shops & commercial loads
Service delivery	• MGP is responsible for installation, commissioning, generation & supply of electricity • Community model - local women's group supports MGP in revenue and collection	• Naturetech Infra- responsible for installation, laying of distribution network & internal household wiring (assisted by villagers) • Naturetech Infra has identified a person within the village to collect monthly charges	• SPI provides technical advice, policy advocacy, project development support to the Energy Service Company (ESCO) • ESCOs responsible for building & operating the generating system & the distribution network • ESCOs take care of revenue collection & customer grievance redressal
Tariff determination	Connection fee – INR 50 and weekly tariff of INR 25/ week	Customers pay as per their estimated usages in advance like prepaid mobile phones	Tariffs packages are applicable depending upon the type of customer

Parameter	Mera Gao Power Micro-grid Program	Naturetech Infra AC Solar Mini-grid Program	Smart Power for Rural Development Initiative (SPRD)
Achievement	• MGP has connected 15,000 households spreading across 500 hamlets in Sitapur and Barabanki districts in Uttar Pradesh	• Solar micro grids have been operating at about 98 percent availability & 100 percent reliability • Naturetech Infra has created socio-economic benefits in the 11 villages (2 states). Also provides complementary clean energy products	• SPI has invested in 6 companies, operating 81+ mini-grids serving nearly 20,000 customers • Overall customer base increased by 48 percent (Nov. 2015 to Jan. 2016)

5.3 References

[1] “SMART GRIDS AND RENEWABLES: A guide for effective deployment,” IRENA, 2013.

[2] M. M. Bethany Speer, “The Role of Smart Grid in Integrating Renewable Energy,” NREL, 2015.

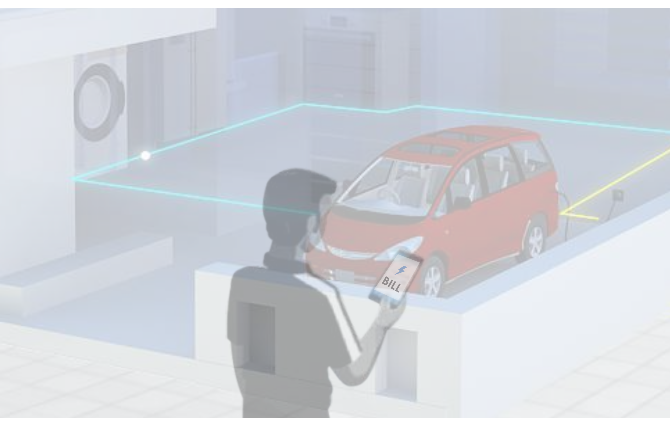
[3] T. Schulz, “Demand Response as a Market Component in Europe,” Entelios AG, September 12, 2014.

[4] C. Richts, “Report on Forecasting, Concept of Renewable Energy Management Centres and Grid Balancing,” GIZ - India Green Energy Corridors, IGEN-GEC, New Delhi, May 2015.

[5] “Grid integration of large-capacity Renewable Energy sources and use of large-capacity Electrical Energy Storage,” IEC.2012

[6] “School of Electrical & Electronic Engineering, Nanyang Technological University,” 2009.

[7] “The UCSD Microgrid –A Case Study in Success,” Virtual Microgrid Summit, March 15, 2012.



Module - 6

Smart Grid and Quality of Supply and Service (QoSS)

6.1 Role of Smart Grid In Managing Power Quality

6.1.1 AMI for Power Quality Management

Smart meter roll-out presents a unique opportunity for improvement in the low voltage network visibility. The smart meter installed at consumer end and at distribution transformers and feeders can be used for monitoring the supply voltage and generate overvoltage, under voltage, sag and swell notifications to alert the utilities when the set thresholds are exceeded. In addition to simple interruption reporting, some of the smart meters can also be used to detect important events such as harmonic and flicker measurements. Poor power quality results in high O&M costs. Power interruptions can be avoided by identifying and analysing the cause of power disturbance.

IT system integrated with MDMS stores various power quality records and calculates KPIs such as the SAIFI and SAIDI in the utility and consumer categories considering parameters like power factor, total harmonic distortion, spikes, impulses, flicker, sag (momentary under voltage), swell (momentary over voltage), power on/off, over voltage and under voltage. This information could then be utilized by OMS and Workforce Management System for predictive maintenance or installation of fast power factor correction equipment by the utility.

Without smart meters, utilities usually base their equipment settings on voltage readings at an electric substation and then use engineering estimates based on the substation data to determine voltage level at each customer's home served by that substation. This estimation could result in utilities setting line voltages unnecessarily high to ensure that the last home on a line does not receive voltage below the regulated limit. But with smart meters, utilities can get actual information on voltage, and utilities can use Smart Grid technology to optimize the voltage for every customer they serve; settings would be based on actual customer voltages rather than engineering estimates, which would enable a more efficient and accurate supply of power.

Information from smart meter voltage measurement can provide utility with simple visual representation on the voltage margins left in the grid. This can be used by utilities not only to check compliance with standards and regulations, but also as an input parameter to grid planning. If the utility wishes to verify the voltage margins for planning of future asset upgradation needs, it will be possible using smart meter data to view the voltage conditions for each transformer in real time. Only for transformers where the voltage margins have gone beyond the limit, will it be necessary to spend more resources to evaluate the conditions.

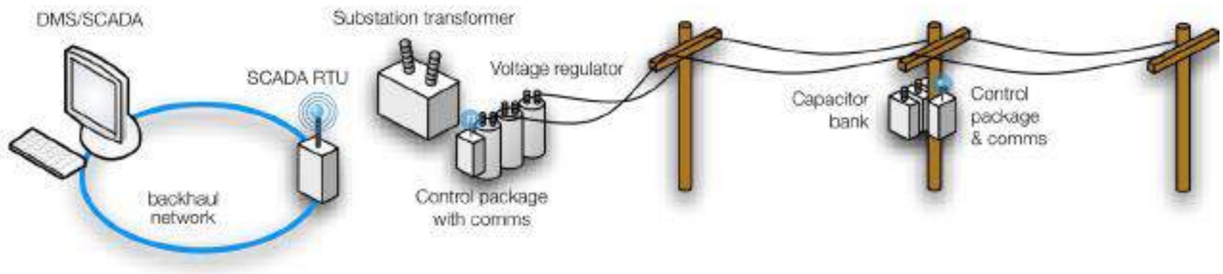
With Smart Grid deployments like AMI and Voltage-VAR Control, utilities can have real time visibility to power quality data at both substation and consumer end point. This would allow utilities to resolve power quality issues in the network in a precise and quick manner and avoid unnecessary visit to the field to verify the problem.

6.1.2 VOLT-VAR Optimization (VVO) in Smart Grid

Voltage regulating devices are usually installed at the substation and on the feeders. The substation transformers can have tap changers, which are devices that can adjust the feeder voltage at the substation, depending on the loading condition of the feeders. Special transformers with tap changers called voltage regulators are also installed at various locations on the feeders, providing fine-tuning capability for voltage at specific points on the feeders. Reactive compensation devices (i.e., capacitor banks) are used to reduce the reactive power flows throughout the distribution network. The capacitor banks may be located in the substation or on the feeders. Capacitor banks can be fixed or switched.

To utilize these regulating devices efficiently, information needs to be shared among all voltage and VAR control devices so that the consequences of possible actions of an individual device is consistent with optimized control objectives of the entire system. This was not possible in the traditional grid system, but with Smart Grid this could be done centrally using a substation automation system or a distribution management system. This approach is referred to as integrated VVO. A typical VVO configuration is presented in Figure 6.1.

Figure 6.1: Typical VVO configuration[83]



VVO is an advanced application that runs periodically or in response to operator demand, at the control centre for distribution systems or in substation automation systems. Combined with two-way communication infrastructure and remote control capability for capacitor banks and voltage regulating transformers, VVO makes it possible to optimize the energy delivery efficiency on distribution systems using real-time information. VVO attempts to minimize power loss or demand without causing voltage/current violations. The control variables available to VVO are the control settings for switchable capacitors and tap changers of voltage regulating transformers.

VVO operations provide utilities with enhanced capabilities compared to traditional approaches. Expected benefits include:

[83] Image Source: "Applications of Automated Controls for Voltage and Reactive Power Management- Initial Results", U.S Department of Energy, 2012.

Improved Voltage Control: VVO systems enable utilities to control voltage and reactive power levels more precisely in real-time and near real-time basis. VVO provides operators with alerts for conditions such as over/under voltage, voltage unbalance, etc. so that necessary corrective action can be taken. Also as customer loads change constantly, utilities can take advantage of VVO to respond quickly and adjust voltages to keep them closer to optimum levels, including flattening voltage profiles along feeders, when it is advantageous to do so.

Peak Demand Reduction: Conservation voltage reduction (CVR) is an operational strategy designed to reduce the energy used by customer appliances and equipment by reducing distribution feeder voltages. Traditionally, the inability to observe voltage levels along the length of distribution feeders has made the implementation of CVR strategy difficult.

But using VVO, utilities can apply CVR for short periods of time to reduce peak demand. This can be valuable for deferring capacity additions and distribution upgrades. As an example, one US utility attempting to reduce peak demand with a distribution energy efficiency project, estimated a potential demand reduction of 200 MW if implemented on its 560 distribution feeders[84]. Another example is of a US utility implementing capacitor controls and an integrated VVO model aimed at reducing both line losses and peak demand. Deployment of advanced VVO on 400 circuits is anticipated to reduce this utilities peak demand by about 75 MW. Pilot testing by the utility on four circuits has produced peak demand reductions between 0.8 percent and 2.4 percent[85]. Reductions on this scale represent a significant opportunity to distribution utilities.

Improved VAR Control: VVO can compensate for reactive power from inductive loads using switched capacitors to improve power factor and reduce line losses. This saves energy and the fuel required to produce electricity to serve customers.

Improved Operations and Maintenance: Adding automation to capacitor banks, load tap changers and voltage regulators can reduce operations and maintenance costs by enabling CBM as opposed to the traditional scenario where a lineman must travel to a capacitor bank to physically operate the switch or check on the health of a voltage regulator.

Some practical cases on how VVO has been employed internationally for power quality improvement are discussed in Box 6.1 and Box 6.2.

[84] "Can a Grid be Smart without Communications? A look at an Integrated Volt VAR Control Implementation," Barry Stephens, Georgia Power, Bob McFetridge, Beckwith Electric, April 25, 2012.

[85] "Ventyx Launches Network Manager DMS v5.3 With Model-Based Volt/VAR Optimization," Ventyx, December 5, 2011.

Box 6.1 Case Study: Avista Utilities, Washington, US, Smart Grid smart circuit project

Project Scope: Avista Utilities (Avista's) Smart Circuit project upgraded and automated targeted sections of its distribution system. New switches, capacitors, and sensors were installed in substations and on distribution circuits across the project area. This equipment provides automated regulation of power quality, rapid response to grid disturbances, and improvements to grid reliability. A radio and fiber optic communications system integrates real-time data from grid sensors with the grid operator's distribution management software platform.

Volt-VAR Optimization project description: The Avista Distribution Management System (DMS) that was implemented included an Integrated Voltage and VAR Control algorithm that automatically monitored and controlled individual capacitor banks to minimize feeder losses while maintaining voltages and power factor within specified limits. The DMS estimated the feeder loads to calculate voltage, branch flows, and power factor. The capacitor banks were sorted according to the reactive load they detected, and the capacitor seeing the highest reactive load became the switching candidate. The DMS checked the capacitor banks on each feeder and prioritized the "OFF" capacitors according to the reactive loads they detected. If switching could be done without violating a voltage limit, the capacitor was switched "ON". If the capacitor could not be switched, the DMS selected the next capacitor down the list. The DMS used a dead-band to prevent excessive switching. Failures of the capacitor bank switches were reported through alarms.

Project Results: Voltage controls reduced Avista's distribution system voltage by 2.1 percent, which is expected to translate into about 7.8 Gigawatt-hours of annual energy savings and USD 500,000 in reduced annual costs for its feeder distribution power lines[86].

[86] http://phys.org/news/2015-07-nation-largest-smart-grid-demo.html

Box 6.2 Case Study: VVO- Southern California Edison's Irvine Smart Grid demonstration

Program Objective: The project had two overall goals. While the primary goal was to reduce average consumer voltage in order to decrease associated energy use, the secondary goal was to utilize the system to optimize VAR flow at the substation transformer bank.

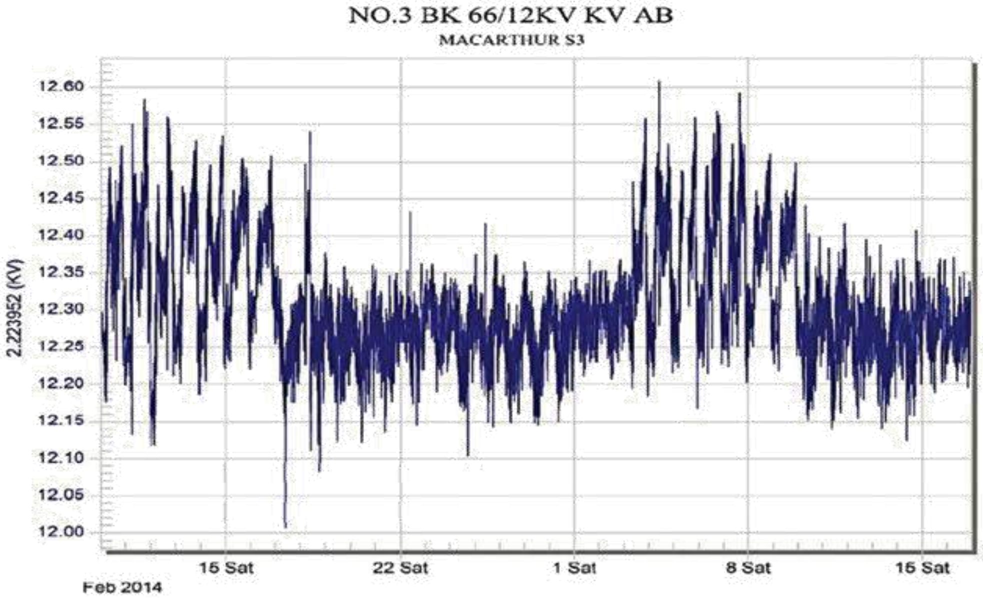
Project Approach: The following steps were undertaken to achieve project goals and objectives:

- A distribution volt-var control (DVVC) algorithm was designed to optimize the voltage and VARS on each circuit by dynamically controlling substation and field capacitors.
- Implemented the DVVC algorithm as part of their DMS.
- Utilized existing capacitor controls through use of the radio communication system.
- Tested the DVVC on 7 circuits connected to the same substation.

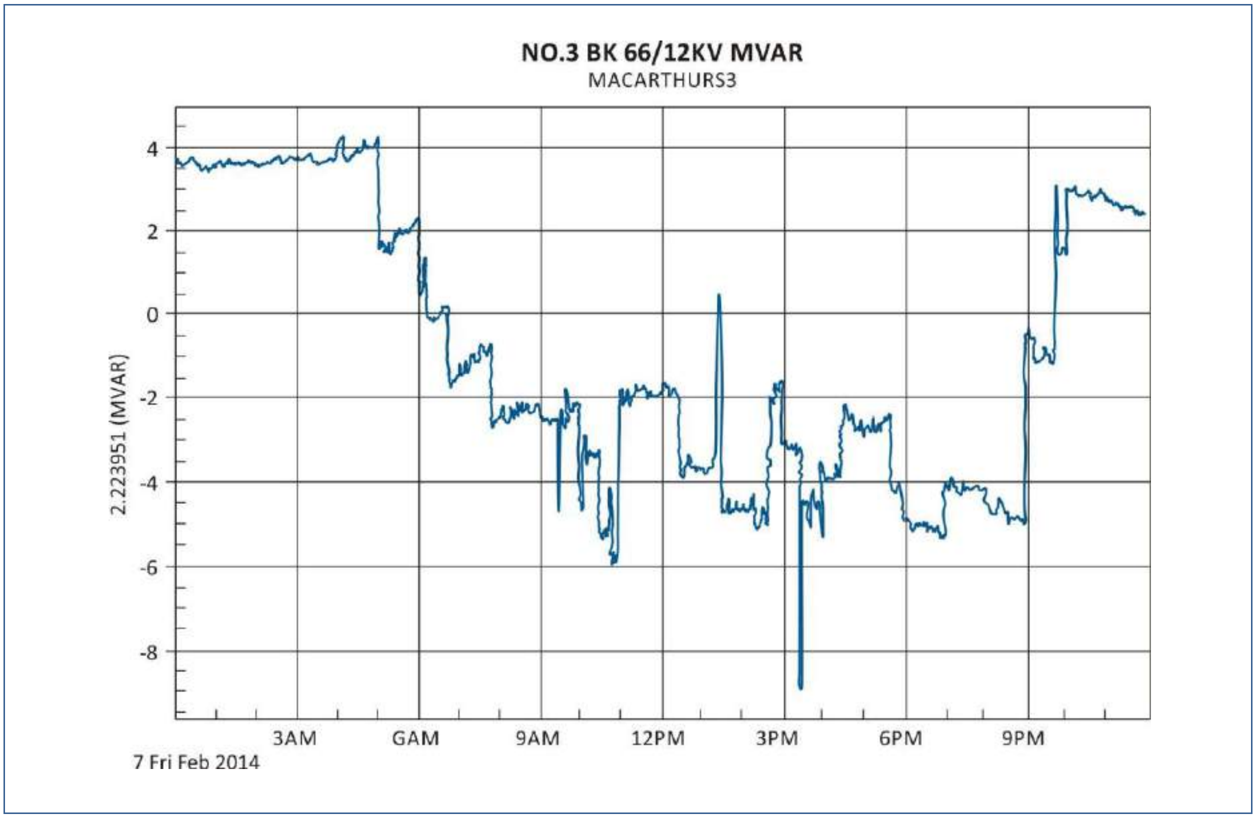
The DVVC algorithm solves for the optimal system capacitor switching combination that will satisfy user-defined constraints for minimum and maximum voltage and reactive power flow. It calculates the optimal solution based on expected capacitor voltage changes derived from detailed circuit models.

Results: Tests have been conducted resulting in a system average voltage reduction of 2 volt at the customer service entrances. Additionally, tests have been conducted that cause the distribution system to provide reactive power to the substation transformer.

The following graph demonstrates voltage reduction at the substation bus on alternating weeks in February and March 2014 when DVVC was running. This reduction translates to approximately a 2 volt system average reduction at the 120V services of customers on the 7 circuits at the substation.



The graph illustrates the ability of DVVC to regulate reactive power flow (VAR) at the sub transformer secondary. The algorithm was set to provide leading reactive power, such as from the distribution network to the substation transformer. The result is indicated on the graph below by the decreasing negative values for Mega Unit of Reactive Power (MVAR).



6.2 Quality of Service

The electricity 'quality of service' standards addresses issues such as time frames for provision of customer services requests, fault handling, electricity account queries and complaints amongst others. The standard details all measures that the licensees have to take to ensure that customers get quality service. In this regard model standard of performance regulations for distribution licensees has been released by the FOR (this has also been issued by various SERCs). Some of the parameters defined in the regulations, along with role of Smart Grid in improving the performance of these parameters, are presented in Table 6.1.

Table 6.1: Standard of performance parameters and role of Smart Grid

S. No.	SOP Parameters	Role of Smart Grid
Operation of Call center		
1.	First response against a consumer call	No direct impact of Smart Grid
2.	Registration of Consumer Call and issue of docket number	
Restoration of Supply		
3.	Normal fuse off	With application of advanced OMS, FLISR and supply restoration, utilities can significantly lower the duration of outage as well as number of customers affected by outage.
4.	Overhead Line/cable breakdowns	
5.	Underground cable break down	Field level automation combined with AMI data can pinpoint the location and cause of outage thus minimizing the troubleshooting time.
6.	Distribution transformer failure	
7(a)	Maximum duration of scheduled outage	
7(b)	Number of scheduled outages in a year	Using condition based and predictive maintenance strategies through Smart Grid, utilities can predict equipment deterioration and thus take corrective action before any outages are caused by failure of equipment.
Quality of Supply		
8.	Voltage fluctuations in case no expansion, augmentation of network required	Smart Grid technologies such as AMI and Volt-VAR optimization enables improved voltage control in the grid and enables protection against events like harmonic distortion, spikes, impulses, flicker, sag (momentary under voltage), swell (momentary over voltage), power on/off, over voltage and under voltage.
9.	Voltage fluctuations in case expansion, augmentation of network required	
10.	Voltage fluctuations in case erection of substation required	
Meter Complaints		
11.	Meter reading	Meter complaints can be significantly reduced through AMI implementation and utilities can get status of meter in real-time and integration with CIS and WFM systems can then lead to reduction in time to take necessary actions.
12.	Meter inspection and replacement	
13.	Replacement of burnt meter	
Shifting of Meters and Service Lines		
14.	Shifting of meter, service lines	No direct impact of Smart Grid

S. No.	SOP Parameters	Role of Smart Grid
New Connection, Additional Load, Temporary Connection for Consumers		
15.	New connection, additional load where supply can be provided from existing network	No direct impact of Smart Grid
16	Issue of Temporary Connection	No direct impact of Smart Grid
Disconnection of Supply		
17	Disconnection of Supply	Smart Meter can be used for automatic remote disconnection of supply avoiding any delays due to manual operations.
Reconnection of Supply Following Disconnection Due to Non-Payment of Bills		
18	Reconnection of supply after disconnection	Smart Meter can be used for automatic remote reconnection of supply avoiding any delays due to manual operations.

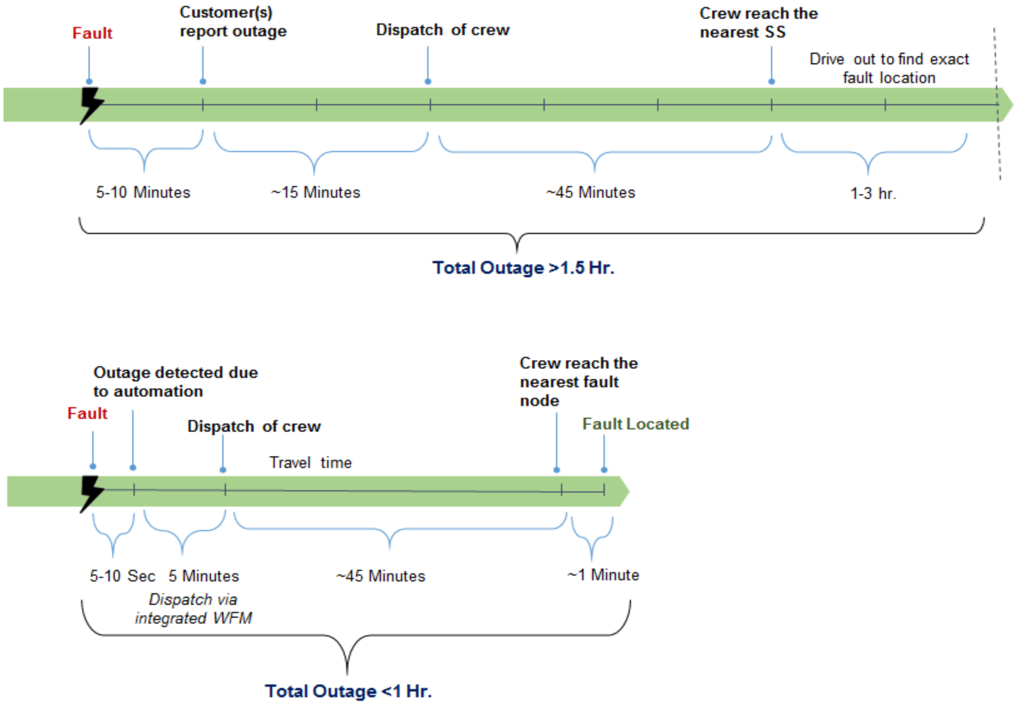
Some of these improvements through use of Smart Grid technologies are discussed in the sections below.

6.2.1 Improvements in Restoration of Supply

Customer supply interruption improvements: Utilities can significantly improve the customer interruption statistics by implementing advanced OMS and FLISR applications, and through the DR mechanism. Fault restoration time with and without OMS and fault restoration time with and without FLISR is shown in Figure 6.2 and 6.3

- With advanced OMS, integrating systems like AMI, DMS, IVRS, GIS, SCADA and Workforce Management, utilities would be able to detect outage location instantaneously and often before any consumer complaints. This means the workforce can be dispatched immediately to the problem location and therefore significantly reducing the time to respond to outages.

Figure 6.2: Fault restoration timeline with and without OMS[87]



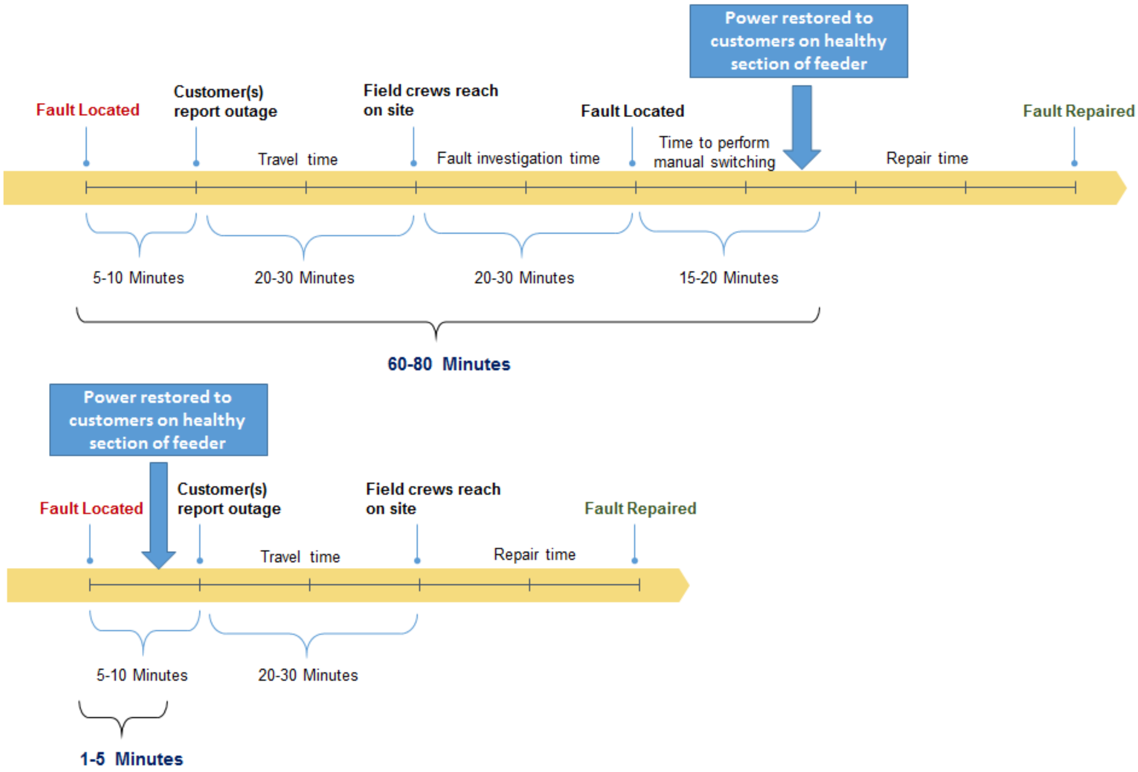
- Further with integration of FLISR, the number of consumers affected by outages can be significantly reduced as automatic switching action is performed to restore supply to healthy feeders in near real time.

- Another aspect of Smart Grid is the enablement of CBM, which allows utility to detect system abnormalities and take necessary corrective actions well before failure. This allows utility to reduce, eliminate blackouts and scheduled outages.

- DR is another application that can be utilized to control demand in periods of shortage and thus can be used to reduce or eliminate blackouts.

[87]Gegridsolutions.com, "GE Digital Energy: Industry Solutions: Distribution Automation", 2015. [Online]. Available: http://www.gegridsolutions.com/IndSolutions/ind_distAutomation.htm [Accessed: 13- Dec- 2015].

Figure 6.3: Fault restoration timeline with and without FLISR



A case study from the U.S. highlighting the service improvements through FLISR is presented in Box 6.3.

Box 6.3 Case Study: Smart Grid investment grant program –quality of service improvement through FLISR implementations

Project Description: Under the SGIG program of the U.S., five utilities undertook their Smart Grid project with implementation of FLISR system. The table below shows the main features of the FLISR activities operated by these utilities and their projects. The projects use different types of field devices, apply manually validated or fully automated modes of operation, and accomplish operations with distributed servers or a centralized DMS.

Overview of FLISR Project Activities

Features	CenterPoint	Duke	NSTAR	PHI	Southern
Name of FLISR System	Self-healing grid	Self-healing teams	Auto restoration loops	Automatic sectionalizing and restoration	Self-healing networks
Field Devices Involved	Intelligent Grid Switching Devices act as switching devices and monitoring	Electronic reclosers, circuit breaker and line sensors	Telemetry communications, line sensors, and “smart” switches	Substation breakers, field switches, reclosers, and “smart” relays	Automated switches, reclosers, and fault indicators

	equipment				
Mode of FLISR Operation	Manual validation required	Fully automated	Transitioned to full automation during the project	Fully automated	Fully automated
Location of FLISR Operation	Dedicated server; to be transitioned to DMS	Dedicated self-healing application	DMS	Dedicated server in the substation	Dedicated server on DMS

Result Analysis: Between April 2013 and March 2014, the utilities collectively implemented 266 FLISR operating events that resulted in:

- Reduced number of customers interrupted: About 270,000 fewer customers suffered interruptions (of > 5 minutes) compared to estimated outcomes without FLISR.
- Reduced outage impact: Customers experienced about 38 million fewer customer minutes of interruption compared to estimated outcomes without FLISR.

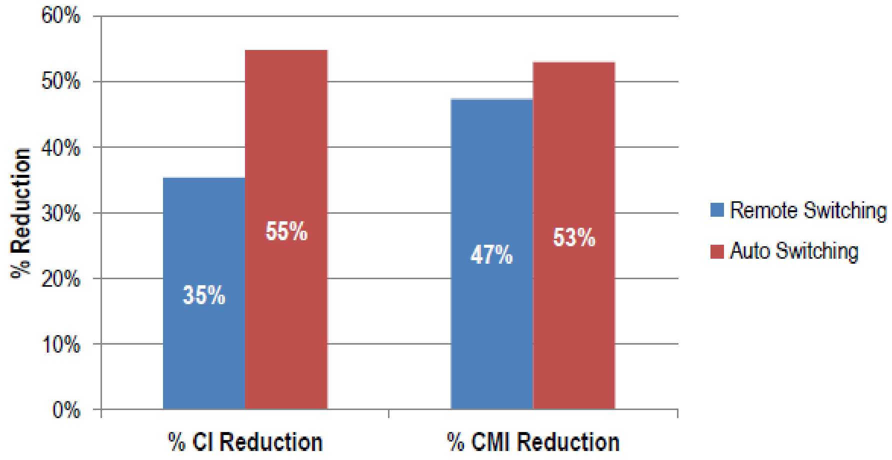
FLISR operations were applied to: (1) full-feeder outages where the fault is upstream of a sectionalizing switch (and thus interrupts service to all customers on a feeder), or (2) partial-feeder outages where the fault is downstream of a sectionalizing switch (and thus interrupts service to a portion of customers on a feeder).

The following table provides results for FLISR operations for both full-feeder and partial-feeder outages and shows substantial reductions in the number of customers interrupted (CI) and customer minutes of interruption (CMI).

Effects of FLISR Operation on Customers Interrupted by Type of Outage			
Type of Outage	**Total Estimated CMI Without SGIG Technologies**	**Total Actual CMI without SGIG Technologies**	**% Reduction as a Result of SGIG Technologies**
Full Feeder Outage	255,424	160,792	37
Partial Feeder Outage	206,763	92,726	55

Effects of FLISR Operation on Customers Minutes Interrupted by Type of Outage			
Type of Outage	**Total Estimated CI without SGIG Technologies**	**Total Actual CI without SGIG Technologies**	**% Reduction as a result of SGIG Technologies**
Full Feeder Outage	18,301,994	9,016,784	51
Partial Feeder Outage	17,470,615	8,676,751	50

The effectiveness of FLISR operations varied by the type of operating scheme employed by the utility. The following graph shows the number of customers interrupted and the customer minutes of interruption by type of FLISR operating scheme: (1) remotely controlled with manual validations, or (2) fully automated control and validation.



Remote switching operations that are manually validated by control room operators typically suffer from time lags that do not occur with fully automated switching. Also as sustained outages are defined as service interruptions that last five minutes or longer, manually-validated FLISR operations typically have less impact on CI than automated FLISR operations.

Apart from improving restoration time and number of customers affected by outages and hence improving the reliability parameters (SAIFI, SAIDI, CAIFI, and CAIDI[88]), Smart Grid systems such as AMI and VVO can enable utilities to accurately record and keep track of these parameters. Without existing infrastructure, it has been difficult for utilities to accurately keep track of these important reliability parameters particularly with lack of feeder and DT-wise consumer indexing and also due to lack of visibility on the accurate number of customers affected and duration of outage. Further, important information such as consumer category-wise, region-wise (urban, rural) distribution of interruptions is not available, which makes it difficult to do any meaningful analysis based on these numbers and therefore utilities are not able to gauge their current performance accurately and understand how overall system reliability could be improved.

6.2.2 Improvements in Complaint Resolution and Service Handling

Handling of customer complaints in a quick and efficient manner and with access to complaint information to both utilities and customers is a current pain point among utilities, but implementation of Smart Grid can help improve the entire customer resolution process. Some of these Smart Grid measures to improve complaint resolution are discussed below.

Auto Disconnection and Re-connection: With smart meter installed at the consumer end, supply can be disconnected or re-connected automatically instantaneously from remote utility location either due to load violation, theft, late bill payment or due to consumer request. This

[88] CAIDI: Customer Average Interruption Duration Index

ensures that the time to service a request for disconnection or re-connection, which takes days, can be accomplished in a matter of minutes.

Transparency of Information: The current practice of manual meter reading, performed typically once a month, leads to a number of doubts and queries raised by consumers on the accuracy of the data. With smart meter data integrated with utility billing process, consumers can now get a transparent and detailed analysis on their consumption on a daily/hourly basis. By use of smart web-based applications, utilities can provide consumers with a real time tracking of their energy usage. All these measures thus help significantly reduce any queries that consumers have on their billing and any query resolution time is also decreased due to availability of detailed information by utilities.

Faster Query Resolution: The time to resolve consumer queries is significantly resolved in a Smart Grid environment as IT-enabled customer care centres have access to detailed consumer information through effective integration of various systems (OMS, AMI, GIS, CIS, etc.).

During outages, by integration of IVS and OMS, utilities can instantaneously inform consumer about the outage and the expected restoration time. This can be sent through SMS or Email to registered consumers as well. Similar messages can be sent on successful restoration. Another example would be resolution in case of faulty meter. Real time tracking of meter data can now alert utilities of a meter fault well before it is detected by consumer and hence corrective action can be taken without any trouble to consumer.

Apart from these, development of customer portals to provide energy data, outage information, bill payment services, etc. would provide high quality experience for the customers and will make it easy for them to communicate with utility through the web instead of direct phone calls or visits. This in turn will improve customer satisfaction and reduce work load on the employee.

6.3 References

[1] "Model standard of performance regulations for distribution licensees", Forum of Regulators, 2009.

[2] E. Pratibha and A. Manjunath, "An Overview of Power Quality Issues in Smart Grid",*International Journal of Innovative Research in Advanced Engineering (IJIRAE)*, vol. 1, no. 10, pp. 294-298, 2015.

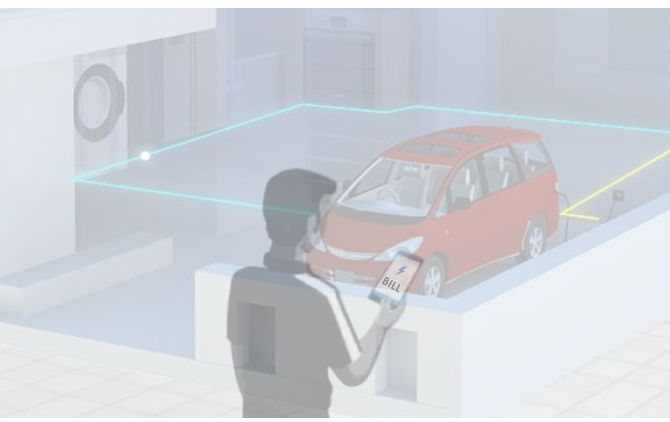
[3] H. Seljeseth, H. Kirkeby and H. Taxt, "Benefits of Voltage Measurements with Smart Meters", 23rd International Conference on Electricity Distribution, 2015.

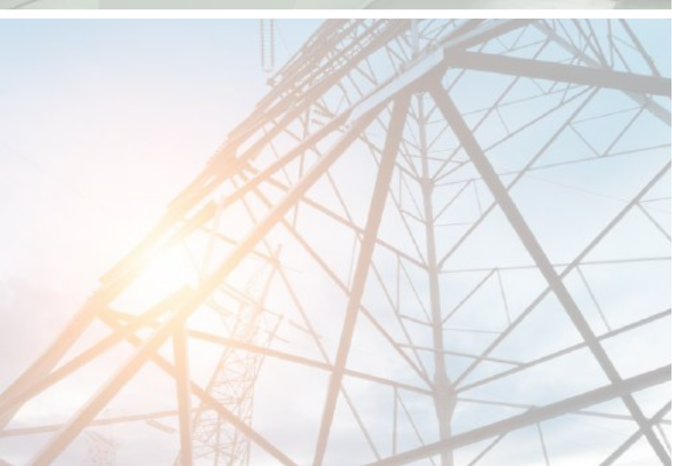
[4] "Smart Grid and Power Quality", Smart Grid Consumer Collaborative, 2014.

[5] "A Smart Grid is an optimized grid", ABB. 2013

[6] "Applications of Automated Controls for Voltage and Reactive Power Management- Initial Results", U.S Department of Energy, 2012.

[7] "Using wireless broadband for power grid network transformation", Alcatel-Lucent, 2010.





Module - 7

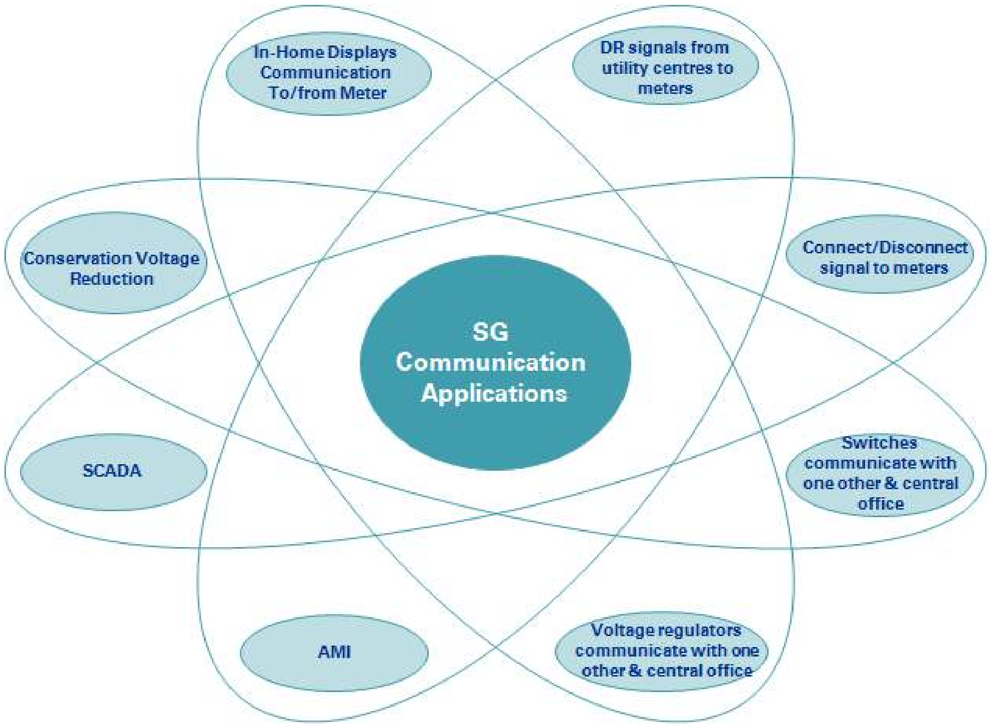
Smart Grid Communication Systems

7.1 Role of Communications in Smart Grid

One of the most important requirements of a Smart Grid is a fast, reliable and secure communication network. Communication technology can be thought of as the backbone of the Smart Grid. The efficiency and reliability of a Smart Grid immensely depends upon the choice of the underlying Information and Communication Technologies (ICTs) and OTs adopted for various applications. Irrespective of the functionality adopted, the transfer of information from one point to another is a common feature across all Smart Grid applications.

Defining communications as the backbone of Smart Grid becomes apparent when looking at a range of Smart Grid functions. Smart Grid communication applications is presented in Figure 7.1 below.

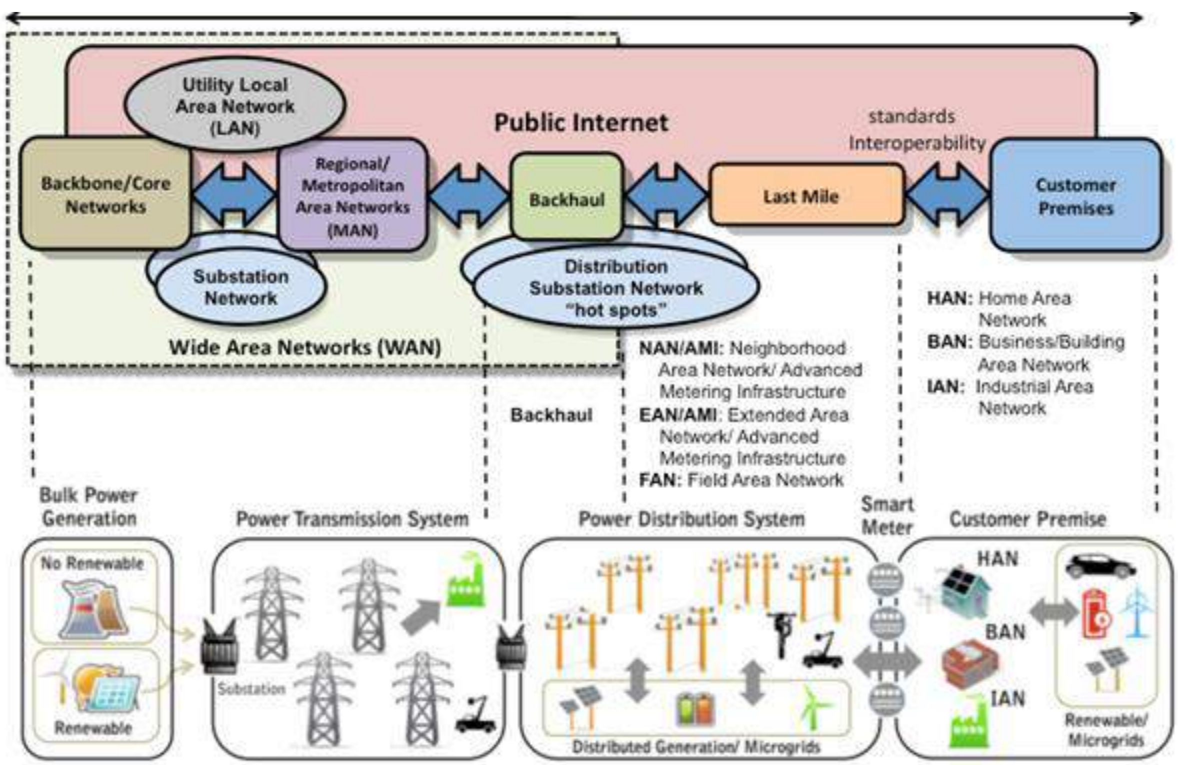
Figure 7.1: Smart Grid communication applications



7.2 Smart Grid Communication Architecture

The communication infrastructure in Smart Grid must support the expected Smart Grid functionalities and meet the performance requirements. As the infrastructure connects an enormous number of devices, it is constructed in a hierarchical architecture with interconnected individual sub-networks with each responsible for separate geographical regions. The communication networks architecture can be categorized into the following building blocks: wide area networks, last mile networks, home area networks, backhaul and utility local area network. A brief summary of these building blocks is provided in Figure 7.2.

Figure 7.2: Smart Grid communication architecture[89]



The various building blocks are explained below.

7.2.1 Wide Area Network

A WAN forms the communication backbone to connect the smaller area networks that serve the power systems at different locations. It transports real-time measurements taken at the electric devices to the far away control centres and in the reverse direction as well to transport instruction communications from control centres to the electric devices. This part includes a mix of networks including fibre optics, Power Line Carrier (PLC) systems, copper wire line, and several wireless technologies. WAN is needed to support utility applications for safe and reliable operation of the electric utility infrastructure including SCADA and EMS, protective relays, distribution feeder automation, etc.

7.2.2 Backhaul

It is the branch that connects the WAN to the last mile network. It aggregates and transports customers' Smart Grid telemetry data, substations automation critical parameter data, IED's

[89] Source: NIST PAP 01, "The Role of the Internet Protocol (IP) in AMI Networks for Smart Grid," National Institute of Standards and Technology, 2009

field information data, mobile workforce information from/to the utility head end to and from the last mile network.

7.2.3 Utility LAN

Enterprise LANs are used to manage operations, control and enterprise processes and services such as billing and automation, meter reading, outage management, DR, load control, etc. LAN interconnects to the WAN through secure wired or wireless communications. It also interconnects to the Internet to exchange customer data to third party providers.

7.2.4 Last Mile

The last mile is a two-way wireless or wired communications network overlaid on top of the power distribution system. It is usually named as NAN or FAN. The last mile could be an integrated and multipurpose network technology alternative for AMI (smart meters, DR, etc.) services, Distribution Automation (IEDs in the field) and substation automation.

The power system applications operating in the distribution domain utilize last mile networks to share and exchange information. These applications can be categorized as either field-based (related to sensors, voltage regulators, etc.) or customer-based (related to end customers, like houses, buildings, industrial users, etc.). Field-based applications include OMS, SCADA applications, Distributed Energy Resources (DER) monitoring and control, etc. and customer-based applications include AMI, DR, Load Management System, MDMS, etc.

7.2.5 Home Area Network

HANs are needed in the customer domain to implement monitoring and control of smart devices in customer premises and to implement functionalities like DR. Within the customer premises, a secure two-way communication interface called Energy Services Interface (ESI) acts as an interface between the utility and the customer. The ESI may be linked to a smart meter capable of sending metering information. This information is communicated to the utility. The ESI also receives real time pricing information from the utility over the AMI infrastructure and sends it to the customers. The customers may use a display panel (called In-home devices) linked to the ESI or a web-based customer Energy Management System (residing in the smart meter, an independent gateway, or some third party) and respond to pricing signals from the utility.
For each of these communication building blocks, different communication technologies can be deployed based on their technical requirements. Some of these communication technologies available for Smart Grid systems are discussed in the following section.

7.3 Smart Grid Communication Technologies

Communication technologies can be broadly classified into two types: wireless and wired. The difference is that wired technologies require a physical medium like cable to transmit information while wireless technologies use micro-waves or radio-waves.

Many network technologies can be used for communications in the transmission, distribution and customer domains in Smart Grid, but none of them suit all the applications and there is always a best fit of a technology or a subset of technologies that may be chosen for a group of power system applications, either operating in the same domain or having similar communication requirements. Before a communication technology is chosen for a particular power system application, a thorough analysis is required to match the application requirements with the technology properties. The available network technologies are discussed in Section 7.3.1 (see table 7.1) along with their advantages and disadvantages.

7.3.1 Wireless Communication

Table 7.1 provides the various wireless technologies available along with their applications.

Table 7.1: Wireless communication technologies[90]

Technology	Advantage	Disadvantage	Smart Grid Application Areas	Existing Practical Applications
Zigbee	• Very low cost - inexpensive consumer devices • Low power consumption - years of battery life • Self-organizing, secure, and reliable mesh network • Network can support a large number of users	• Very short range • Does not penetrate structures well • Low data rates • Small memory size	HANs for energy management and monitoring, V2G	Smoke and intruder warning, Industrial equipment control
Wi-Fi	• Low-cost chip sets - inexpensive consumer devices • Widespread use and	• Does not penetrate cement buildings or basements • Small coverage and short distances limit	Could be used for HANs, FANs and V2G	Internet access, device to device communication

[90] V. C. Gungor, D. Sahin, T. Kocak, S. Ergüt, C. Buccella, C. Cecati and G. P. Hancke, "Smart Grid technologies: communication technologies and standards," Industrial informatics, IEEE transactions , pp. 529-539, 7 April 2011. **and** S. Elyengui, R. Bouhouch and T. Ezzedine, "The Enhancement of Communication Technologies and Networks for Smart Grid Applications," International Journal of Emerging Trends & Technology in Computer Science (IJETTCS), pp. 107-115, 2013.

Technology	Advantage	Disadvantage	Smart Grid Application Areas	Existing Practical Applications
	expertise • Low-cost application development • Stable and mature standards	wide spread use • Security issues with multiple networks operating in same locations		
3G Cellular	• Expensive infrastructure already widely deployed, stable and mature • Well standardized • Cellular chipset very inexpensive • Large selection of vendors and service providers	• Utility must rent the infrastructure from a cellular carrier for a monthly access fee • Utility does not own infrastructure • Technology is in the transition phase to Long Term Evolution (LTE) deployment • Public cellular networks not sufficiently stable, and secure for mission critical utility applications • Not well-suited for large data, high bandwidth applications	AMI Backhaul, FAN, V2G	Voice telephony, Internet access, video conferencing, GPS, telemedicine
4G LTE	• Low latency, high capacity • Fully integrated with 3GGP, compatible with earlier 3GPP releases • Full mobility for enhanced multimedia services • Low power consumption	• Utility must rent the infrastructure from a cellular carrier for a monthly access fee • Utility does not own infrastructure • Not readily available in many markets • Equipment cost high	AMI Backhaul, SCADA Backhaul, DR, FAN, Video Surveillance	Voice telephony, Internet access, Video conferencing, GPS, Telemedicine, IP telephony, 3D television, cloud computing, telemetry
WiMAX	• Efficient	• Tradeoff between	AMI Backhaul,	Internet access,

Technology	Advantage	Disadvantage	Smart Grid Application Areas	Existing Practical Applications
	backhaul of data – aggregating 100's access points • Quality of Service (QOS) supports service assurance • Battery-backup improves reliability and security • Simple, scalable network rollout and customer-premises equipment attachment • Faster speeds than 3G cellular	higher bit rates over longer distances • Asymmetrical up and down link speeds • User shared bandwidth • Competing against future 4G cellular	SCADA Backhaul, DR, FAN, video surveillance , WAN	middle-mile backhaul for cellular networks
Wireless Mesh	• Cost effective solution • Dynamic self-organization, self-healing, self-configuration • Manageable and secure connectivity (IPSec is inbuilt) • Can be used in the sub-GHz range	• Network capacity issues • Network fading and interference problem	HANs for energy management, AMI	Battlefield surveillance, real-time racing-car telemetry, VoIP

7.3.2 Wireline Communication

Table 7.2 provides the list of various wireline technologies available along with their applications.

Table 7.2: Wireline communication technologies[91]

Technology	Advantage	Disadvantage	Application Areas	Existing Practical Applications
Digital Subscriber Line (DSL)	• Widespread availability, infrastructure already established • Low cost • High bandwidth data transmissions	• Reliability and potential down time of DSL technology may not be acceptable for mission critical applications • The wired DSL- require communications cables to be installed and regularly maintained, and thus, cannot be implemented in rural areas due to the high cost of installing fixed infrastructure for low-density areas.	AMI, FAN	Broadband access
PLC	• Communication infrastructure for Smart Grid is already established • Low costs • Separation from other communication networks.	• Non-interoperable • High signal attenuation • Channel distortion • Interference with electric appliances and electromagnetic sources • High bit rates difficulties • Complex routing	HAN/AMI , FAN	broadband over power lines, in-vehicle network communication of data
Fiber	• Very Long-distance • Ultra-high bandwidth • Robustness against interference	• High costs • Difficult to upgrade • Not suitable for metering applications	WAN	Telephone signals, Internet communication, cable television signals

[91] V. C. Gungor, D. Sahin, T. Kocak, S. Ergüt, C. Buccella, C. Cecati and G. P. Hancke, "Smart Grid technologies: communication technologies and standards," Industrial informatics, IEEE transactions , pp. 529-539, 7 April 2011. **and** S. Elyengui, R. Bouhouch and T. Ezzedine, "The Enhancement of Communication Technologies and Networks for Smart Grid Applications," International Journal of Emerging Trends & Technology in Computer Science (IJETTCS), pp. 107-115, 2013.

The technical specifications of the various technologies discussed above in terms of coverage range and data rate are provided in Table 7.3.

Table 7.3: Coverage range and data rate for communication technologies[92]

Technology	Standard/Protocol	Coverage Range	Data Rate
Zigbee	Zigbee	Up to 100 m	250 Kbps
Wi-Fi	802.11x	Up to 300 m	2-600 Mbps
3G Cellular	3G	Up to 50 km	2 Mbps
4G/LTE	4G	Up to 50 km	100 Mbps
WiMAX	802.16	Up to 50 km	75 Mbps
DSL	ADSL	Up to 5 km	1-8 Mbps
	VDSL	Up to 1.5 km	15-100 Mbps
PLC	Home Plug	Up to 200 m	14-200 Mbps
	Narrowband (PLC PRIME and PLC G3)	Up to 3 km	PLC G3 up to 30 Kbps PLC PRIME up to 130 Kbps
Wireless Mesh	Various (e.g., RF mesh, 802.11, 802.15, 802.16)	Depending on selected protocols	Depending on deployment
Fiber	Passive Optical Network	Up to 60 km	155 Mbps - 2.5 Gbps
	Wavelength-Division Multiplexing	Up to 100 km	40 Gbps
	SONET/SDH (Synchronous Optical Networking/ Synchronous Digital Hierarchy)	Up to 100 km	10 Gbps

7.3.3 Global Deployment of Communication Technologies

Table 7.4 provides a list of various Smart Grid projects around the globe and the communication technologies deployed.

[92] M. Kuzlu, M. Pipattanasomporn and S. Rahman, "Communication network requirements for major Smart Grid applications in HAN, NAN and WAN," Computer Networls, pp. 74-88, 2013. **And** V. C. Gungor, D. Sahin, T. Kocak, S. Ergüt, C. Buccella, C. Cecati and G. P. Hancke, "Smart Grid technologies: communication technologies and standards," Industrial informatics, IEEE transactions , pp. 529-539, 7 April 2011.

Table 7.4: Global deployment of communication technologies[93]

Organization	Region	Application	Technologies	Description
UGVCL (Proof of Concept)	Gujarat, India	• AMI • Meter Reading	PLC, RF mesh and GPRS	• PLC has excellent performance in underground and secure electrical network. • RF mesh provides healthy communication in specific range of area; metal, concrete structure will reduce the penetration of signals; Meter addition/ replacement are auto detected. • GPRS is used for point to point communication; more dependency on signal strength in the area.
TPDDL	Delhi, India	• Automatic DR • SCADA • GIS	RF mesh and Optical Fiber	• Optical fiber backbone with capacity of 2.4 Gbps in core ring and 644 Mbps in sub rings. The communication backbone is used for both operational SCADA and GIS. • Last mile connectivity to all zones is extended through radio frequency and optical fiber with minimum bandwidth of 2 Mbps.
Austin Energy (2012)	Texas, U.S.	• AMI • Metering reading • Pricing • Distribution automation • DR	Optical fiber and RF mesh network	Smart Grid project with 410,000 smart meters, 86,000 smart thermostats, 2500 sensors, 3000 computers and network elements.
Baltimore Gas and Electric Company (2010)	Maryland, U.S.	• AMI • Metering reading • Pricing • Customer information and messaging • DR	Optical fiber, RF mesh network	Smart Grid project with 1,272,911 smart meters, AMI communication systems, MDMS, customer web portal access for residential/small commercial customers, and 400,000 direct load control devices.

[93] M. Kuzlu, M. Pipattanasomporn and S. Rahman, "Communication network requirements for major Smart Grid applications in HAN, NAN and WAN", *Computer Networks*, vol. 67, pp. 74-88, 2014.

Organization	Region	Application	Technologies	Description
Eandis and Infrax (2011)	Flanders, Belgium	• Advanced Metering Management (AMM) • Meter reading	PLC, DSL, Cellular (GPRS)	Pilot project, two-way communication between central systems and electricity and gas meters
Acea Distribuzione (2004)	Rome, Italy	• AMM • Meter reading	PLC, Cellular (GPRS)	One of Europe's largest smart metering projects, gas and water meters, serving 1.5 million households
China Southern Power Grid	Southern China	• AMI • Meter reading • Pricing • DR	Cellular (2G and 3G)	Large-scale AMR project, monitor end-users' electricity usage in real-time, to both prepare accurate bills and estimate ongoing demand
Public Power Corporation (2009)	Larissa, Greece	• DR	Wi-Fi, BPL	A large-scale pilot project, remote monitoring and control of irrigation pumps during peak hours

Due to a variety of communication protocols, devices and message formats to be used in an end-to-end Smart Grid system, it is important that a set of common interoperable standards are in place to facilitate seamless interaction and data exchange between different Smart Grid systems. The next section discusses in brief the interoperability requirements and developments that have taken place in the Smart Grid space.

7.3.4 Integrated Network Monitoring System[94]

In Smart Grid, hybrid communications networks would become the norm. For example, a utility may choose to build out a new RF mesh network for AMI but then take advantage of existing fibre for backhaul purposes. Customers located in areas that cause issues for RF network may require additional connection via cellular or another network.

In such a hybrid network setup, a highly reliable, scalable, secure, robust and cost-effective integrated communications monitoring infrastructure is needed to avoid possible disruptions of the grid system.

An integrated network monitoring system would allow the utility to centrally monitor various networks it may use while providing a complete end-to-end view of the system health and fault and performance data from different network elements. The platform would also incorporate rules-based management functions to be followed for a specific network issue across the system so as to decrease the likelihood of service disruption.

[94] http://www.electricenergyonline.com/show_article.php?mag=78&article=644 [Accessed 01-04-2016]

In general, utility network operators will see the following benefits from using a centralized network monitoring platform:

- Meet QOS expectations through end-to-end service visibility
- Optimize network resources to improve performance and quality
- Cut network operating costs
- Support network planning process to roll out more Smart Grid network services
- Expedite Smart Grid network diagnostics

7.4 Interoperability

7.4.1 Need for Interoperability

The Indian power sector consists of diverse participants including generation, transmission, and distribution utilities, and system and market operators. For efficient functioning of the sector, effective communication between these entities is of vital importance. The power sector can be seen as a logical information network where nodes, representing information sources and sinks, are interconnected with information links. Information travels from source nodes to destination nodes over information links across devices belonging to different systems, organizations, people, information representation formats, and communication protocols[95]. To facilitate seamless communication between these nodes, a set of Interoperability Standards[96] are required.

The general meaning of interoperability is to ensure that new products and services can operate in a multi-vendor and multi-operator environment, defining a strong possibility to interact. The different steps from no interoperability at all to the highest grade of interchangeability are often described according to the International Electrotechnical Commission (IEC) TC65:

Incompatibility ➔ Coexistence ➔ Interconnectability ➔ Interworkability ➔ Interoperability ➔ Interchangeability[97].

- **Incompatibility –** the inability of two or more devices to work together.
- **Coexistence –** the ability of two or more devices, regardless of manufacturer, to operate independently of one another at the same communications network, or to operate together using some or all of the same communications protocols, without interfering with the functioning of other devices on the network.

[95] Partnership to Advance Clean Energy - Deployment (PACE - D) Technical Assistance Program, "Smart Grids: A Roadmap for Communication and Application Interoperability in India", 2013.
[96] The Open Knowledge Initiative defines interoperability as "the measure of ease of integration between two systems or software components to achieve a functional goal. A highly interoperable integration is one that can be easily achieved by the individual who requires the result."

[97] "Smart Grid Interoperability Report", Global Smart Grid Federation, 2014.

- **Interconnectability** – the ability of two or more devices, regardless of manufacturer, to operate with one another using the same communication protocols, communication interface.
- **Interworkability** – the ability of two or more devices, regardless of manufacturer, to support transfer of device parameters between devices having the same communication interface and data types of the application data.
- **Interoperability** – the ability of two or more devices, regardless of manufacturer, to work together in one or more distributed applications. The application data, the semantic and application related functionality of each device is so defined that, should any device be replaced with a similar one of a different manufacturer, all distributed applications involving the replaced device will continue to operate as before.
- **Interchangeability** – the ability of two or more devices, regardless of manufacturer, to work together in one or more distributed applications using the same communications protocol and interface, with the data and functionality of each device so defined that, if any device is replaced, any distributed applications involving the replaced device will continue to operate as before the replacement, including identical dynamic responses of the distributed applications.

Interoperability is thus crucial to prevent vendor lock-in of any distributed system consisting of different entities or applications that need to work together to achieve a common objective. Interoperability is even more important in the context of Smart Grids, where the sheer number of entities that need to work together can be enormous.

The level of interoperability achieved will largely enable the level of functionality and commensurate benefits delivered by the future Smart Grid. Architecting the methodologies to establishing standards is essential to achieving high interoperability. Successful outcomes from standards development and selection can accelerate technology adoption by reducing costs and investment risk. On the other hand, lack of interoperability would hinder investment, restrict synergies, cause expensive redesigns and thus limit the eventual benefits of the Smart Grid.

7.4.2 Interoperability Developments

In many parts of the world, there are existing standards and on-going Smart Grid interoperability work and these are discussed below.

NIST – SGIP

The National Institute of Standards and Technology (NIST) is an agency of the U.S. Department of Commerce. NIST recently completed reviewing the NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0 and is presently incorporating public comments into the framework document.

The Framework lays out a plan for transforming the nation's ageing electric power system into an interoperable Smart Grid, a network that will integrate information and communication technologies with the power-delivery infrastructure, enabling two-way flows of energy and communications. The final version reflects input from a wide range of stakeholder groups, including representatives from trade associations, standards organizations, utilities, and industries associated with the power grid. The Smart Grid Interoperability Panel (SGIP) was created by NIST in November 2009 to provide an open forum for members to collaborate on standards development. Through the SGIP, NIST collaborates with the private sector in coordinating Smart Grid standards.

NIST's effort is aimed at creating a self-sustaining, on-going standards process to support continuous innovation as grid modernization continues to evolve. Grid modernization would need to ensure backward compatibility to the greatest extent practical and NIST envisions that the processes being put in place by the SGIP will provide the mechanism to evolve the Smart Grid standards framework as new requirements and technologies emerge.

CEN/CENELEC-ETSI[98]

The European Commission has issued a mandate (M/490) and requested the European Standards Organizations CEN, CENELEC and ETSI, to develop a framework and perform continuous standard enhancement and development in the field of Smart Grids, while maintaining consistency and promoting continuous innovation. The CEN/CENELEC-ETSI work, presented in January 2013, includes a first set of standards, Smart Grid reference architecture, and definitions of sustainable processes and Smart Grid information security. In December 2013, an intermediate report on interoperability – "Methodologies to achieve Smart Grid system interoperability through standardization, system design and testing" – from the Smart Grid Coordination Group/Mandate M/490 was published. In December 2014, the group published their report on Smart Grid interoperability. This report provides a methodology to reach the requisite level of interoperability for particular Smart Grid projects. It does so by focusing on three different aspects:

- Use case creation and system design.
- Creating interoperability profiles based on use cases, standards and specifications.
- Compliance, conformance and interoperability testing.

IEEE Smart Grid Standards

The IEEE is collaborating with other global standards bodies to effectively facilitate standards coordination and to ensure the intensifying Smart Grid movement's success. IEEE has more

---

[98] Cencenelec.eu, "Smart Grids - CEN-CENELEC", 2016. [Online]. Available: http://www.cencenelec.eu/standards/Sectors/SustainableEnergy/SmartGrids/Pages/default.aspx . [Accessed: 02- Jan- 2016].

than 100 existing standards and standards in development relevant to Smart Grid[99]. **National Smart Grid Standardization Promotion Group (China)**

In December 2010, the National Smart Grid Standardization Promotion Group was established under the joint leadership of the National Energy Administration and the Standardization Administration of China (SAC) with the aim of speeding up the standardization process. The focus of the Smart Grid Standardization Promotion Group is to draft strategic plans, formulate standard frameworks, and guide development of national and industrial standards. This group was further divided into three subgroups:

- Smart Grid standardization group
- Smart Grid equipment standardization group
- Smart Grid standardization international cooperation group

SGCC has developed a hierarchical system for strong Smart Grid standards which is expected to give guidance and instruction for research and development of Smart Grid standards. It consists of a number of layers, as described below:

- **The first layer is domain**. There are eight domains, including general and planning, generation, transmission, substation, distribution, utilization, dispatching, as well as ICT.
- **The second layer is technical fields**. There are a total of 26 technical fields, focusing on the overall direction of Smart Grid study and key areas of project construction. The division of different technical fields follows a series of SGCC's guidelines, including Planning of Smart State Grid, Smart Grid Key Technology Research and Study, Key Smart Grid Equipment (System) Development Planning.
- **The third layer is standard series**. There are a total of 92 series, covering "general", "engineering construction" (including design, refurbishment, acceptance and test), "operation and maintenance", and "equipment and material".
- **The fourth layer is specific standards**. This includes the actual specification of the standards which are to be implemented.

India – Bureau of Indian Standards[100]

The BIS Sectional Committee LITD10 had established seven panels for Smart Grid standards development for India. One among these is the interoperability working group (WG1) which aims to develop interoperability standards for power sector in India, covering the traditional value-chain, such as generation, transmission, distribution and newer elements of value-chain, such as availability based tariff, power exchange, renewable generation, risk management, home/office area networks, and system operations.

[99] IEEE.org, "IEEE focus on Smart Grid", 2016. [Online]. Available: https://www.ieee.org/publications_standards/publications/subscriptions/clientservices/ieee_focus_on_smartgrid.pdf [Accessed: 02-Jan- 2016].

[100] "Draft Indian Standards- Guidelines on standards for interoperability in power system communications", BIS) 2014.

In 2014, the panel released draft guidelines on standards for interoperability in power system communications. The levels of interoperability covered are broadly classified as communication technology, information technology and operation technology. An interoperability context setting framework suitable for addressing the unique requirements of India is also developed, and used for advancing the standardisation process. The report provides a mapping of the relevant standards across two areas, one the Application Domain being addressed and the other the appropriate Area of Interoperability.

The draft selection of areas covered for interoperable communication standards in the report include:

A. **Intra Substation Communication**: Communication happening within the boundary of a substation. Includes station bus and process bus communications.
   - Sending protection, samples, phasor measurements, and process control information between substations in real-time.

B. **Field Equipment Communication:** Represents communications that take place originating from and destined to devices outside control centers like a data concentrator gathering primary equipment monitoring data.

C. **Substation - Central System Communication:** Includes monitoring and control of substations, pole-top devices, generation plants or distributed energy resources. Exchange of critical and non-critical information to be considered.

D. **Inter Central System Communication:** Includes exchanging fault information for contingency analysis and emergency operations between control centers and data centers. Exchanging metering information from territorial boundaries to initialize state estimation or load distribution applications is another example. Communication may take place between levels of control centers within a utility, or between a Real-Time Operating System.

E. **Central System – DER Communication**: This includes communication between utility control centers and Energy Service Providers and Energy Market Participants like real-time pricing negotiations, aggregated customer metering and settlements. This environment also encompasses the communications between distributed energy resources and the organizations that must monitor and operate them.

F. **Central System - Enterprise System Communication**: Gathering weather data, communicating with regulators, auditors and vendors. May include passing historical data, specifications, network topologies, configuration files, debug traces. Enterprise applications like Billing systems and ERPs are also considered here.

G. **Central System - Consumer Communication**: This environment encompasses the communications between central system and devices in the consumer premises.

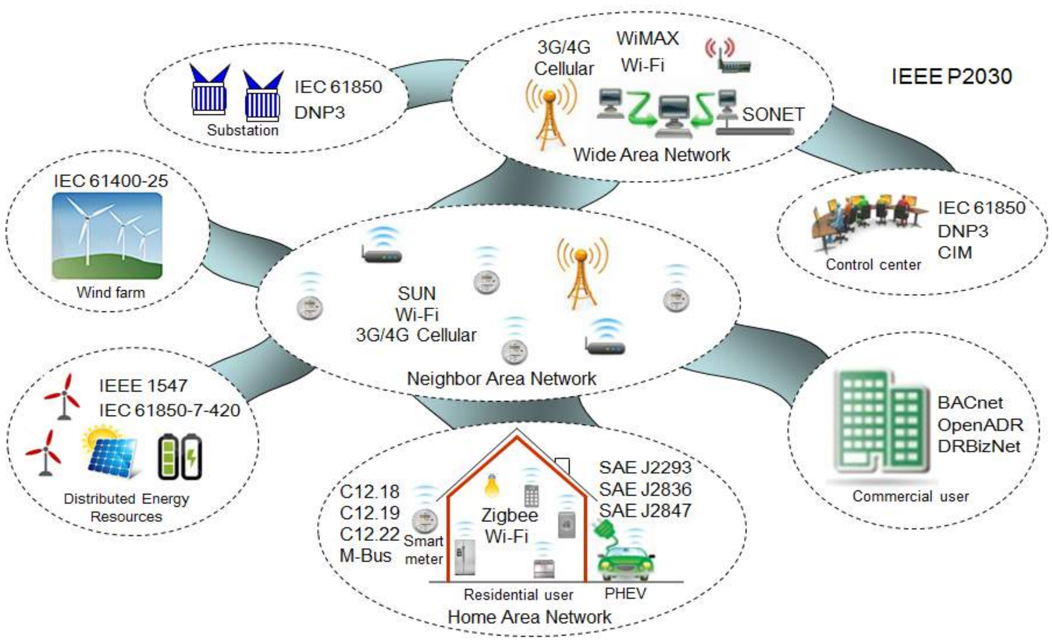
H. **Intra Consumer Premises Communication**: This Includes communication within the consumer premises between the smart meter, in-home display, smart appliances, etc.

The relevant standards selected in the report have been mapped across the areas of interoperability selected above for each application domain. The application domain includes:

- AMI
- Distribution Grid Management
- Network Communications
- Wide-Area Situational Awareness
- DR, DER and Consumer Energy Efficiency
- Cyber Security
- Electric Transportation

A snapshot of the various global standards used for Smart Grids is provided in Figure 7.3.

Figure 7.3: Representative SG communication standards[101]



To achieve interoperability, Internet Protocol (IP)-based systems offer a viable solution. This is discussed in detail in Section 7.5.

7.5 Role of IP in Smart Grid

The IP is the principal communications protocol in the Internet protocol suite for relaying datagram across network boundaries. Its routing function enables internetworking, and essentially establishes the Internet. IP has the task of delivering packets from the source host to the destination host solely based on the IP addresses in the packet headers. For this purpose, IP defines packet structures that encapsulate the data to be delivered. It also defines

[101] M. Obaidat, A. Anpalagan and I. Woungang, *Handbook of green information and communication systems*. Oxford: Academic Press Inc., 2012.

addressing methods that are used to label the datagram with source and destination information.

IP is a communications foundation that was developed for helping data networks talk to each other, and it helps to answer some of the issues faced by the Smart Grid. It has been proven in some of the largest networks in the world and provides practically unlimited scalability. Its original purpose was to help unrelated network systems communicate, so it was designed with flexibility in terms of protocols as well as the underlying physical connections, whether wired or wireless.
Today IP allows multiple types of physical equipment to operate transparently from end to end over a wide variety of communication media without adding the burden of conversion of protocols.

Because of the inherent design of the IP, the Internet architecture addresses many of the goals set for the Smart Grid[102].

- **Transmitting data over multiple media**: IP can run over any link layer network, including Ethernet, wireless radio networks, and serial lines, providing a common and flexible way to use and manage a network composed of disparate parts.
- **Changing and growing with the industry**: One of the principal benefits of IP is its ability to add a capability such as a new application without having to change IP itself. That is why IP can run applications it was not originally designed to support, such as secure Internet commerce, voice, collaboration, and Web 2.0 applications.
- **Connecting large numbers of devices**: One of the main challenges with connecting large numbers of devices is providing a unique identifier, or address, for each device. Unlike a lot of other architectures, IP version 6 (IPv6) offers straightforward addressing and routing for a huge network such as the Smart Grid.
- **Maintaining reliability**: IP already has more tools and applications to help manage the network and maintain reliability than any other communication protocol.
- **Connecting multiple types of systems**: IP is device independent. This means that it can identify any type of system to which data is addressed and deliver it to its destination. IP can also identify the system from which the data came, so it enables the receiving device to respond back to the sending device to let it know the data has arrived.
- **Ensuring security**: Although IP was designed to be open and flexible, over the years more and more tools have been built to provide security in the communications that travel over an IP network. In fact, of all communications protocols, IP has the most tools for securing and managing the transport of data. Therefore, while all the communications systems in Smart Grid will be able to utilize IP as a communications pipeline, IP has state-of-the-art tools to ensure the information travels as privately as needed, sending the information to the right destination while ensuring that it is not intercepted or accessed by unauthorized users.
- **Providing smooth migration**: IP provides a way to migrate in phases from multiple monitoring and control networks to a single converged network without disrupting service.

[102] Cisco Systems Inc., "Why IP is the Right Foundation for the Smart Grid," 2010.

This enables utilities to receive all the benefits of IP without having to undergo a massive “forklift” implementation.

Because of all these benefits that IP provides, it is prudent choice for interoperable end-to-end Smart Grid networks.

7.5.1 IPV6 Roadmap in India

IPv6 is the most recent version of the IP, the communications protocol that provides an identification and location system for computers on networks and routes traffic across the Internet. IPv6 was developed by the Internet Engineering Task Force (IETF) to deal with the long-anticipated problem of IPv4 address exhaustion. IPv6 is intended to replace IPv4.

The Indian government released an IPv6 Roadmap Ver-1 in 2010 that laid out some policies to help both the government and the private sector gear up for the transition. Institutional support was extended from the Indian Registry for Internet Names and Numbers and a new Centre for Innovation for IPv6.

Important objectives of the policy included:

- All major service providers (having at least 10,000 Internet customers or STM-1 bandwidth) will target to handle IPv6 traffic and offer IPv6 services by 2011.
- All central and State government ministries and departments, including its PSUs, shall start using IPv6 services by March-2012.
- Achieve substantial transition to new IPv6 in the country in a phased and time bound manner by 2020 and encourage an ecosystem for provision of a significantly large bouquet of services on IP platform.

A roadmap version-2 was released by the government in 2013 which was written on the foundation laid down by the National IPv6 Deployment Roadmap-I. Some key recommendations included:

- Enable IPv6 services at all new enterprise customers (connecting to the Internet after Jan 2014).
- Enable IPv6 services at all new retail wire line customers (connecting to the Internet after July 2014).
- Enable IPv6 services for LTE customers (connecting to the Internet after June 2013).
- All content and application providers to adopt iPv6 for new contents and applications by June 2014.
- All new “.in” domains to be compulsorily on dual stack from Jan 2014.
- All governments complete transition to IPv6 by Dec 2017.
- The Government organizations should move to IPv6-based innovative applications in their respective areas like smart metering, Smart Grid, smart building, Smart City, etc.

To complement the roadmap, DOT also released 'Compendium on IPv6-based Solutions/ Architecture/Case Studies for Different Industry Verticals' which among other use cases, enumerates the advantages of implementation of Smart Grid on IPv6-based infrastructure in the power sector. In the current scenario when we talk about IPv6 systems, it is basically MDM system/head end and enterprise systems being on IPV6.

The DOT's technical report on M2M enablement also provides a possible case for enabling of IPv6 for Smart Grid. This case is presented in Box 7.1.

Box 7.1 IP Based solution use case: A local mesh with remote application server[103]

In this case, there are multiple meters in vicinity and they need to communicate to a remote application server. The two communication methodologies depicted below for LAN and WAN are 6LoWPAN to and GSM (GPRS) respectively. The solution shall consist of 3 components, viz. a smart meter, a Data Concentrator Unit (DCU)/gateway, and the MDAS that is part of the Utility Head End System (HES). The DCU/gateway acts as a coordinating entity and facilitates 2-way communication between the smart meter and the HES. The smart meter in this case supports 6LoWPAN-based RF-mesh communication technology. Thus, the DCU/gateway handles both short-range and long-range communications. The DCU is responsible for maintaining a group of meters. However, if a gateway is used, it will only relay packets to the HES.

The network architecture for this use case is depicted in the figure above. The gateway/DCU has 6LoWPAN and GPRS modules, which interact with the end nodes over 6LoWPAN and to the HES over GPRS. From the Telco Core Network, data is typically sent to the utility via a leased line or a wireless link

7.6 Smart Grid Communication Considerations

The communication infrastructure in Smart Grid requires two-way communications, inter-operability between advanced applications and end-to-end reliable and secure communications with low-latencies and sufficient bandwidth. Moreover, the system security should be robust enough to prevent cyber-attacks and provide system stability and reliability with advanced controls. In the following sections, major Smart Grid communication requirements are presented[104].

[103] Department of Telecommunication, Government of India, Technical Report, M2M Enablement in Power Sector, http://tec.gov.in/pdf/M2M/M2M%20Enablement%20in%20Power%20Sector.pdf [last accessed on 01-04-2016]

[104] Source: V. C. Gungor, D. Sahin, T. Kocak, S. Ergüt, C. Buccella, C. Cecati and G. P. Hancke, "Smart Grid technologies: communication technologies and standards," Industrial informatics, IEEE transactions , pp. 529-539, 7 April 2011.

7.6.1 Security

Secure information storage and transportation are vital for utilities, especially for billing purposes and grid control. To avoid cyber-attacks, efficient security mechanisms should be developed and standardization efforts regarding the security of the power grid should be made.

7.6.2 Network Latency

Network latency defines the maximum time in which a particular message should reach its destination through a communication network. The messages communicated between various points within the Smart Grid, may have different latency requirements. For example, the information and commands exchanged between IEDs will require lower network latency than the SCADA information messages exchanged between electrical sensors and control centres. The network communication medium must therefore support the varied requirements. Similarly, the data rates supported by the communication medium also decide how quickly a device can communicate an event observed.

7.6.3 Data Delivery Criticality

The communication protocol used for a particular Smart Grid system application must provide different levels of data delivery criticality depending on the needs of the application. The following levels of data delivery criticality may be used:

(a) High is used where the confirmation of end-to-end data delivery is a must and absence of confirmation is followed by a retry;
(b) Medium is used where end-to-end confirmation is not required but the receiver is able to detect data loss, e.g., measured current and voltage values and disturbance recorder data;
(c) Non-critical is used where data loss is acceptable to the receiver.

7.6.4 Reliability

In Smart Grid, it is extremely important for the communication backbone to be reliable for successful and timely exchange of messages. The communication backbone reliability can be affected by a number of possible failures, including time-out failures[105], network failures[106], and resource failures[107].

7.6.5 Scalability

A Smart Grid should be scalable enough to facilitate the operation of the power grid. Many smart meters, smart sensor nodes, smart data collectors, and RE resources are joining the

---

[105] A time-out failure occurs if the time spent in detecting, assembling, delivering and taking action in response to a control message exceeds the timing requirements.

[106] A network failure occurs when there is a failure in one of the layers of the protocol suite used for communication

[107] A resource failure implies failure of the end node which initiates communications or receives messages

communications network. Hence, Smart Grid should handle the scalability with the integration of advanced web services, reliable protocols with advanced functionalities, such as self-configuration and security aspects.

A representative view of the typical communication requirement for the various Smart Grid applications is provided in the Table 7.5[108].

Table 7.5: Communication considerations for Smart Grid applications[109]

Application	Security	Bandwidth	Reliability	Latency
Advanced Metering Infrastructure	High	14-100 kbps per node	99.0-99.99%	2000 ms
AMI Network Management	High	56-100 kbps	99.00%	1000-2000 ms
Automated Feeder Switching	High	9.6-56 kbps	99.0-99.99%	300-2000 ms
Capacitor Bank Control	Medium	9.6-100 kbps	96.0-99.00%	500-2000 ms
Charging Plug-In Electric Vehicles	Medium	9.6-56 kbps	99.0-99.90%	2000 ms-5 min.
Demand Response	High	56 kbps	99.00%	2000 ms
Direct Load Control	High	14-100 kbps per node	99.0-99.99%	2000 ms
Distributed Generation	High	9.6-56 kbps	99.0-99.99%	300-2000 ms
Distribution Asset Management	High	56 kbps	99.00%	2000 ms
Emergency Response	Medium	45-250 kbps	99.99%	500 ms
Fault Current Indicator	Medium	9.6 kbps	99.00-99.999%	500-2000 ms
In-home Displays	High	9.6-56 kbps	99.0-99.99%	300-2000 ms
Meter Data Management	High	56 kbps	99.00%	2000 ms
Network Protection Monitoring	Medium - High	56-100 kbps	99.00-99.999%	2000-5000 ms
Outage Management	High	56 kbps	99.00%	2000 ms
Price Signaling	Medium	9.6-56 kbps	99.0-99.90%	2000 ms-5 min.
Real-time Pricing	High	14-100 kbps per node	99.0-99.99%	2000 ms
Remote Connect/Disconnect	High	56-100 kbps	99.00%	2000-5000 ms
Routine Dispatch	Medium	9.6-64 kbps	99.99%	500 ms
Transformer Monitoring	Medium	56 kbps	99.00-99.999%	500-2000 ms
Voltage and Current Monitoring	Medium	56-100 kbps	99.00-99.999%	2000-5000 ms
Workforce Automation	Medium	256-300 kbps	99.90%	500 ms

Traditionally utilities have relied on private time-division multiplexing (TDM)-based solutions such as Synchronous Optical Networking/Synchronous Digital Hierarchy (SONET/SDH). But these technologies deliver carrier-class performance and support the deterministic traffic critical for grid operations, and initial deployment is relatively straightforward[110].

[108] Energy.gov, "US D.O.E: NBP RFI: communications requirements- Comments of Utilities Telecom Council", 2010. [Online]. Available: http://energy.gov/sites/prod/files/gcprod/documents/UtilitiesTelecom_Comments_CommsReqs.pdf [Accessed: 02- Jan- 2016].

[109] M. Kuzlu, M. Pipattanasomporn and S. Rahman, "Communication network requirements for major Smart Grid applications in HAN, NAN and WAN", *Computer Networks*, vol. 67, pp. 74-88, 2014.

[110] Source: Teleprotection Over MPLS Wide-Area Networks, White Paper, Cisco, 2014

However, because of changing system requirements as described above, TDM infrastructures no longer adequately support long-term needs of Smart Grid. Many Smart Grid applications would use Packaged Switched Networks (PSNs) for communicating information and control signals. Examples include SCADA, workforce management, AMI, DMS, etc. Packet-based networks also provide more flexible network topology and multipoint communications.

Thus, when migrating to Smart Grid networks, utilities may need to choose which technology to employ, with available packet-based options including carrier-grade Ethernet, IP, vanilla Multi-Protocol Label Switching (MPLS), Multi-Protocol Label Switching - Traffic Engineering (MPLS-TE), and the newest variant – MPLS-TP[111].

- **Internet Protocol:** The IP suite does not define lower layers, and thus must run over Ethernet, SDH/SONET (POS – Packet over SDH/SONET), etc. IP leveraging its native routing protocol; however, these are not always rapid enough to meet stringent availability requirements. IP has a strong security component called IPsec, which can provide authentication, integrity, and confidentiality mechanisms, but at a relatively high operational cost.
- **MPLS:** This was originally devised as a method to accelerate IP forwarding, and to enable provisioning of QOS and VPN services for IP traffic. Being a part of the IP suite, MPLS does not define lower layers, relying (like IP) on Ethernet, OTN, POS, etc. MPLS did not originally have the Operations, Administration, and Maintenance (OAM) mechanisms needed for a transport network, but these have been recently developed as part of the MPLS transport profile, known as MPLS-TP. MPLS was designed as a core network technology, and thus, like SDH/SONET and OTN, has very few security mechanisms.
- **Ethernet:** This was originally a LAN technology but has developed into a carrier-grade network with OAM features. While Ethernet defines a native physical layer from 10 Mbps up to 100 Gbps, Ethernet frames can also be transported over other physical layers (e.g., OTN) and over MPLS via pseudo wires. Ethernet has several security-specific features, including the widely implemented IEEE 802.1X and emerging MACsec.

The decision on which packet technology to implement depends on a number of factors, among which are the number of sites to be connected and their size, as well as on the ability of the selected solution to ensure consistent performance across the different access media available at each site.

[111] Source: Carrier-Grade Ethernet for Power Utilities, Ensuring Reliable Communications in the Smart Grid, RAD, 20120

7.7 References

[1] Maurice Martin;Rick A. Schmidt, "Communications: The Smart Grid’s Enabling Technology," National Rural Electric Cooperative Association & DOE, 2014.

[2] W. Wang, Y. Xu and M. Khanna, "A survey on the communication architectures in Smart Grid," Computer Networks, pp. 55(15), 3604-3629, 2011.

[3] V. C. Gungor, D. Sahin, T. Kocak, S. Ergüt, C. Buccella, C. Cecati and G. P. Hancke, "Smart Grid technologies: communication technologies and standards," Industrial informatics, IEEE transactions , pp. 529-539, 7 April 2011.

[4] NIST PAP 01, "The Role of the Internet Protocol (IP) in AMI Networks for Smart Grid," National Institute of Standards and Technology, 2009.

[5] US ,Department of Energy , "Communication Requirements of Smart Grid Technology," 2010.

[6] M. Kuzlu, M. Pipattanasomporn and S. Rahman, "Communication network requirements for major Smart Grid applications in HAN, NAN and WAN," Computer Networls, pp. 74-88, 2013.

[7] S. Elyengui, R. Bouhouch and T. Ezzedine, "The Enhancement of Communication Technologies and Networks for Smart Grid Applications," International Journal of Emerging Trends & Technology in Computer Science (IJETTCS), pp. 107-115, 2013.

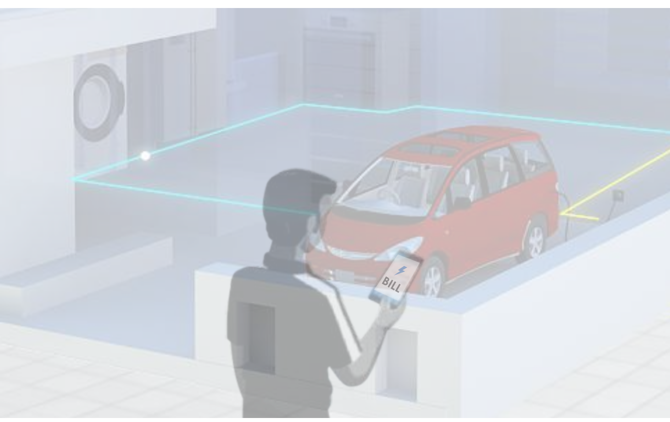
[8] Cisco Systems Inc., "Why IP is the Right Foundation for the Smart Grid," 2010.

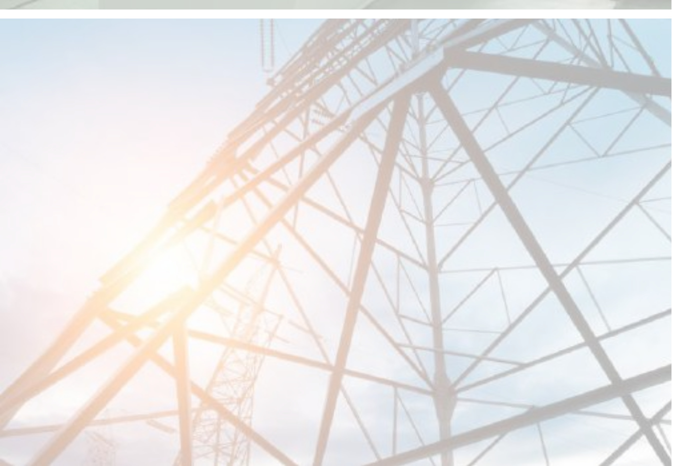
[9] NIST, "NIST Framework and Roadmap for Smart Grid Interoperability Standards,Release 3.0," 2014.

[10] Partnership to Advance Clean Energy - Deployment (PACE - D) Technical Assistance Program, "Smart Grids: A Roadmap for Communication and Application Interoperability in India," 2013.

[11] Department of Telecommunications (India), "National IPv6 Deployment Roadmap Version-II," 2013. [Online]. Available: http://dot.gov.in/sites/default/files/Roadmap%20Version-II%20English%20_1.pdf.

[12] "Smart Grid Interoperability Report", Global Smart Grid Federation, 2014.

Module - 8

Cyber Security in Power Systems

8.1 Cyber Security Definition and Objective for Smart Grid

8.1.1 Definition

Cyber-security is the ability to protect or defend the illegal use of data and prevent cyber-attacks.

Cyber-attacks are attacks, via cyberspace, targeting an enterprise's use of cyberspace for the purpose of disrupting, disabling, destroying, or maliciously controlling a computing environment, infrastructure, or destroying the integrity of the data or stealing controlled information[112].

Traditionally, cyber security for IT focuses on the protection of information and information systems from unauthorized access, use, disclosure, disruption, modification, or destruction in order to provide confidentiality, integrity, and availability. Cyber-security for the Smart Grid requires an expansion of this focus to address the combined power system, IT, and communication systems in order to maintain the reliability and the security of the Smart Grid to reduce the impact of coordinated cyber-physical attacks, and to protect the privacy of consumers.

Compared with traditional power systems, a Smart Grid would fully integrate two-way communication technologies into millions of power equipment, which poses increased cyber risk to power systems as they are exposed to potential vulnerabilities associated with communications and networking systems. As a result, cyber security issues in Smart Grids are of critical importance and have to be considered as one of the priorities in Smart Grid design[113].

8.1.2 Cyber Security Objectives

To ensure secure and reliable operation of Smart Grid, it is essential to understand the security objectives and requirements before providing a comprehensive treatment of cyber security in the context of energy delivery and management.

In this context the NIST has released a comprehensive list of Smart Grid security objectives which is summarized below:

- **Availability:** Ensuring timely and reliable access to information and its usage is most important in a Smart Grid. The disruption of access to information or use of information is a loss of availability and may affect the power delivery and related response.
- **Integrity:** Improper information modification or destruction is to ensure information non-repudiation and authenticity. Loss of integrity is considered as unauthorized modification or destruction of information. To protect information integrity is to ensure non-rejection of

[112] As per Committee on National Security Systems (CNSS), U.S.

[113] W. Wenye and L. Zhuo, "Cyber security in the Smart Grid: Survey and challenges," Computer Networks, 2013; Pages 1344-11371.

information and its authenticity. Loss of integrity can lead to serious consequences such as induce incorrect decision making in power management tasks.

- **Confidentiality:** A loss of confidentiality is unauthorized disclosure of information that is not open for public viewing. Authorized restrictions on information access and disclosure are required to protect personal privacy and proprietary information.

The following features are desirable to increase security levels to higher levels[114]:

- **Attack detection and resilience operations:** Compared with legacy power systems, the Smart Grid features a relatively open communication network over large geographical areas. Accordingly, it is almost impossible to ensure that every part or node in the Smart Grid be invulnerable to network attacks. Therefore, the communication network needs to consistently perform profiling, testing and comparison to monitor network traffic status. The aim of this monitoring is to detect and identify abnormal incidents due to attacks. Moreover, the network must also have the self-healing ability to continue network operations in the presence of attacks.
- **Identification, authentication and access control:** The Smart Grid network infrastructure incorporates millions of electronic devices and users. Identification and authentication is the key process of verifying the identity of a device or user. The focus of access control is to ensure that resources are accessed only after successful authentication of personnel. Strict access control must be enforced to prevent unauthorized users from accessing sensitive information and controlling critical infrastructure.
- **Secure and efficient communication protocols:** Differing from conventional networks, message delivery requires both time-criticality and security in the Smart Grid. The two objectives, however, usually contradict with each other. Networks in the Smart Grid cannot always use secure, physically-protected and high-bandwidth communication channels. Thus, optimal tradeoffs are required to balance communication efficiency and information security in the design of communication protocols and architecture for the Smart Grid.

From the above discussion it can be concluded that cyber security in Smart Grid is highly important as the grid reliability, data privacy and security are at stake. Before strategizing for protection of grid against threats it is required to assess in detail the possible types of cyber-attacks and security threats.

The following sub-sections describe in detail the nature and type of cyber security threats that Smart Grid systems can experience and possible mitigation strategies.

[114] W. Wenye and L. Zhuo, "Cyber security in the Smart Grid: Survey and challenges," Computer Networks, 2013; Pages 1344-11371.

8.2 Cyber Security Threats for Smart Grid

As security challenges mainly come from malicious cyber-attacks via communication networks, it is essential to understand potential vulnerabilities in the Smart Grid under network attacks. The cyber-attacks can generally be classified into three broad categories:

- **Availability attacks**: Attacks targeting availability, also called denial-of-service (DOS) attacks. They attempt to delay, block or corrupt the communication in the Smart Grid.
- **Integrity attacks**: Attacks targeting integrity aim at deliberately and illegally modifying or disrupting data exchange in the Smart Grid.
- **Confidentiality attacks**: Attacks targeting confidentiality intended to acquire unauthorized information from network resources in the Smart Grid.

These are discussed in more detail in the following sections[115].

8.2.1 Denial-Of-Service Attacks

In general, existing DOS attacks can happen at a variety of communication layers in the Smart Grid. The strategy of attacks and their implication will differ in each layer which is summarized below:

- **Physical layer:** This layer is concerned with transmission and reception of data stream. As wireless technologies are widely used in a Smart Grid's LAN, wireless jamming becomes the primary physical-layer attack in such networks. Jamming is a type of attack that attempts to interfere with the reception of broadcast communications and can lead to damages from delayed delivery of time-critical messages to complete DOS.

- **Media Access Control (MAC) Layer:** MAC layer is responsible for reliable point-to-point communication. An attacker may modify its MAC parameters to gain unauthorized access to the network. This type of attack will lead to performance degradation.

  Another harmful type of attack is spoofing which is the creation of IP packets using somebody else's IP address and targets both availability and integrity of the network. A spoofing attacker can present itself as one of the device to send fake information to other connected devices. For example, in a power substation network, a malicious attack can broadcast forged address resolution protocol packets to shut down connections of all IEDs to the substation gateway node.

- **Network and transport layers:** These two layers need to provide reliability control for information delivery over multi-hop communication networks. In computer networking, a hop is one portion of the path between source and destination. Data packets pass

[115] W. Wenye and L. Zhuo, "Cyber security in the Smart Grid: Survey and challenges," Computer Networks, 2013; Pages 1344-11371.

through bridges, routers and gateways on the way. Each time packets are passed to the next device, a hop occurs.

DOS attacks at both these layers can severely degrade the end-to-end communication performance. A recent study[116] also investigated the impact of a buffer-flooding attack. It is a method of overloading a predefined amount of space in a buffer, which can potentially overwrite and corrupt data in memory. Its impact was assessed on the DNP3-based SCADA network with real SCADA system hardware and software. The results concluded that the SCADA system they were using was vulnerable to DOS attack.

- **Application layer**: Application-layer DOS attacks intend to exhaust resources of a computer, such as CPU or I/O bandwidth. Application layer attacks can easily overwhelm a computer with limited computing resources by flooding computationally intensive requests. As millions of computing and communication devices in the Smart Grid are equipped with limited computational abilities, they can be potential victims of application-layer DOS attacks.

8.2.2 Attacks Targeting Integrity and Confidentiality

Attacks targeting integrity and confidentiality in general occur at the application layer, since they attempt to acquire or manipulate data information in the Smart Grid.

Such attacks attempt to secretly modify data in order to corrupt critical information pertaining to Smart Grid. The target can be either customers' information (e.g., pricing information and account balance) or power systems data (e.g., voltage readings and device running status). Because such information in power systems is valuable to both end users and utility companies, integrity-check methods are deployed in power systems to protect data integrity. Following are some of the attacks targeting data integrity of power systems:

- **False data injection attack**: It was initially designed to impact the state estimation for the SCADA system. Based on the assumption that an attacker has already compromised one or several meters, research[117] has pointed out that the attacker can successfully inject falsified data to the SCADA center, and at the same time pass the data integrity check used in current state estimation process.
- **Load redistribution attack**: It is another special type of false data injection attacks, in which only load bus injection measurements and line power flow measurements are attackable.

Attackers targeting confidentiality on the other hand have no intent to modify information transmitted over power networks. They eavesdrop on communication channels in power

[116] D. Jin, D.M.Nicol, G. Yan, An event buffer flooding attack in DNP3 controlled SCADA systems, in: Proceedings of the 2011 Winter Simulation Conference, 2011.
[117] Y. Liu, P. Ning, M. Reiter, False data injection attacks against state estimation in electric power grids, in: Proc. of ACM Computer and Communication Security (CCS), 2009.

networks to acquire desired information, such as a customer's account number and electricity usage. Typical examples include wire tappers and traffic analyzers. Such attacks can be considered to have negligible effects on the functionality of communication networks in the Smart Grid. However, with the increasing awareness and importance of customer privacy, the social impacts due to confidentiality attacks have received more and more attention in recent years.

In the case of attacks against integrity and confidentiality, attackers try to get authentication to the communication networks or the grid, and thus acquire access to sensitive information. Hence, authentication and access control are essential to preventing the Smart Grid from such attacks.

8.2.3 List of Cyber Attacks

In Smart Grid, the communication networks and IEDs are susceptible to a variety of cyber-attacks. Following is a list[118] of cyber-attacks that could potentially endanger the safety of Smart Grids.

- **Direct-access attack:** A direct-access attack means gaining physical access to the computer or its part and performing various functions or installing various types of devices to compromise security. The attacker can install software loaded with malware or download important data, using portable devices.
- **Eavesdropping:** Eavesdropping means secretly listening to a conversation between the hosts on a network.
- **Spoofing:** Spoofing is a cyber-attack where a person or a program impersonates another by creating false data in order to gain illegal access to a system.
- **Tampering:** Tampering is a web-based attack where certain parameters in the Uniform Resource Locator (URL) are changed without the customer's knowledge; and when the customer keys in that URL, it looks and appears exactly the same. Tampering is basically done by hackers and criminals to steal the identity and obtain illegal access to information.
- **Repudiation attack:** A repudiation attack occurs when the user denies the fact that he or she has performed a certain action or has initiated a transaction. A user can simply deny having knowledge of the transaction or communication and later claim that such transaction or communication never took place.
- **Exploits:** An exploit attack is basically software designed to take advantage of a flaw in the system. The attacker plans to gain easy access to a computer system and gain control, allows privilege escalation or creates a DOS attack.
- **Malware:** Malware refers to malicious software that is being designed to damage or perform unwanted actions into the system. Malware is of many types like viruses, worms, Trojan horses, etc., which can cause havoc on a computer's hard drive. They can either delete some files or a directory or simply gather data without the actual knowledge of the user.

[118] http://www.cybersecuritycrimes.com/types-of-cyber-attacks/

- **Bots:** Bots is a software application that runs automated tasks which are simple and repetitive in nature. Bots may or may not be malicious, but they are usually found to initiate a DOS attack or a click fraud while using the Internet.
- **Rootkits:** A rootkit is a malicious software designed in such a way that it hides certain process or programs from normal anti-virus scan detection and continues to enjoy a privilege access to your system. It is that software which runs and gets activated each time you boot your system and is difficult to detect. This software can install various files and processes in the system.
- **Spyware:** Spyware, as the name suggests, is software which typically spies and gathers information from the system through a user's Internet connection without the user's knowledge. Spyware software is majorly a hidden component of a freeware program which can be downloaded from the Internet.
- **Phishing:** Phishing is a cyber-threat which makes an attempt to gain sensitive information like passwords, usernames and other details for malicious reasons. It is basically an email fraud where the perpetrator sends a legitimate looking email and attempts to gain personal information.
- **Identity theft:** Identity theft is a crime wherein your personal details are stolen and these details are used to commit a fraud. An identity theft is committed when a criminal impersonates individuals and use the information for some financial gain.
- **Password attacks:** Password attack is a form of a threat to your system security where attackers usually try ways to gain access to your system password. They either simply guess the password or use an automated program to find the correct password and gain an entry into the system.
- **Key logger:** A key logger is a spyware that has the capability to spy on the happenings on the computer system. It has the capability to record every stroke on the keyboard, web sites visited and information available on the system. This recorded log is then sent to a specified receiver.

The above discussion highlights the broad categories of security threats which are possible in a Smart Grid environment. A detailed assessment of component-wise security risks is provided in Annexure 8 A. Section 8.3 discusses the strategies that can be adopted for threat detection and its mitigation.

8.3 Threat Detection And Mitigation Strategies

8.3.1 Threats Targeting Smart Grid Availability

DOS is a major type of attack which targets the availability objective of Smart Grid security. Even a weak DOS which disrupts the timing of critical signals is sufficient to create havoc. Thus, timely identification and mitigation of DOS threats are important for seamless functioning of Smart Grid.

8.3.2 DOS Attack Detection Methodology

The primary objective of keeping a Smart Grid infrastructure cyber-secure is to ensure system availability. Cyber-attacks like DOS attack, which have an immediate impact on the availability of communication systems and control systems, become the primary network security threats in the Smart Grid. Thus, it is essential to provide effective network approaches against DOS attacks. The mitigation strategies for DOS attack are summarized below:

- **Signal-based selection**: At the physical layer level, a DOS attack detector can measure the received signal strength information (RSSI) to detect an attacker. If the received signal information is greater than the threshold but the packet decoder outputs error, the detector can raise an alarm about a potential DOS attacker.
- **Packet based selection**: Under this detection strategy, the packets transmission results are analyzed by the detector. If there are significant numbers of transmission failures then it can be attributed to the presence of an attacker. This detection strategy can be implemented at each layer of the network and it is found to be effective in DOS attacks which degrade the network performance due to packet loss.

The above two strategies are passive strategies because they continuously monitor the network for any anomaly, and as it is detected an alarm is raised for subsequent action. These detection methodologies can be directly applied to communication networks in Smart Grids.

Other strategies for DOS attack detection include proactive and hybrid methods.

- **Proactive method**: In this a probe or test packet is sent to test or determine the status of potential attacker. Thus, the network takes an initiative to root out potential attackers as soon as possible. Since the involvement of a probe packet creates communication overhead for the network, the applications of proactive methods are limited to non-time critical networks.
- **Hybrid method**: It is also possible to adopt a hybrid method which involves the positives of other methods to improve the detection accuracy. Research work in this regard has proposed the use of both signal-based and packet-based detection to effectively identify jamming attacks in wireless networks.

DOS Attack Mitigation Strategies

Attack mitigation strategies can be deployed in addition to attack detection strategies. DOS attack mitigation schemes mainly include two lines of work: (1) physical-layer mitigation for jamming attacks with the intent to disrupt any wireless communications; and (2) network-layer mitigation for DOS attacks with the intent to exhaust a target's resources. Following is the description of each of the mitigation strategies in Smart Grid.

Physical layer mitigation of DOS: Widely used DOS attack at physical layer in wireless networks is wireless jamming. Thus, Smart Grid networks are required to be strengthened with anti-jamming strategies so that continuity of information delivery is ensured. The jamming-resilient schemes can be designed either in a coordinated or uncoordinated manner.

- **Coordinated** methods are conventional anti-jamming transmission schemes. They can be categorized as frequency hopping spread spectrum, direct sequence spread spectrum, and chirp spread spectrum. In this strategy, it is assumed that a pre-known secret key is known only to the communication parties and not the attackers. However, in open communication standards, this strategy can be easily compromised if the attacker finds the secret key.
- **Uncoordinated** protocols are promising for secure wireless communications in a distributed environment. They do not need sharing of a pre-known secret key with communicating parties. A secret key is randomly generated before the actual communication thus preventing attackers from acquiring sufficient knowledge to disrupt the communication. This resilience is achieved at the cost of delay in communication on account of sharing of key just before initiating the communication.

Network layer mitigation of DOS: The commonly used mitigation strategies against DOS attacks in network layer are summarized below.

- **Rate-limiting:** In the scenarios where detection strategies are unable to accurately identify malicious packets injected by attackers and the false positives rate is high, rate limiting mitigation strategy is applicable. Under this strategy, a rate limit is imposed on a set of packets that have been characterized as possibly malicious by the detection mechanism. Thus, an attacker will be identified and blocked if threshold limit of its malicious packets is met.
- **Filtering:** The attackers are identified and blocked for further communication if their source address is found in the blacklist provided by attack detectors. Upon detection, packets from attackers will not be forwarded or routed to victims.
- **Reconfiguration:** This solution is to reconfigure network architecture, such as changing the topology of the victim or the intermediate network to either add more resources to the victim or to isolate the attack machines.

For applying the above strategies in the context of Smart Grid, it is important to first understand the network topology used in Smart Grids.

8.3.3 Integrity and Confidentiality Attacks Mitigation

Different types of cyber-attacks threaten the integrity and confidentiality of Smart Grid and attempt to take control of the devices in Smart Grid system. The strategy used for gaining unauthorized access has been discussed in the previous sections. In order to safeguard Smart Grid, cryptographic approach becomes a robust counter-measure. Three major cryptographic counter-measures for managing data integrity and confidentiality in power systems are encryption, authentication and key management[119].

Encryption

Encryption is one of the most effective ways to ensure data security. A file or a data is called an encrypted data if we require a secret key or a passcode for reading it. To read an encrypted data using a secret key or a passcode is called decryption. Unencrypted data is called plain text while encrypted data is called cypher text. In a Smart Grid, the devices that are used are expected to have least basic cryptographic capabilities including the ability to support symmetric cyphers. The design of the encryption scheme is one of the most important ways of protecting data confidentiality and integrity in Smart Grid. The encryption scheme can be broadly divided into two types:

- **Symmetric key cryptography**: This type of encryption uses same key for encryption as well as decryption of the message at the sender's and receiver's end respectively.
- **Asymmetric key cryptography**: This type of encryption requires different keys for encryption as well as decryption of data message at the sender's and receiver's end respectively. Asymmetric key cryptography requires more computational resources than symmetric key cryptography.

Authentication

Authentication protocol for Smart Grid must ensure full security to protect data integrity. In addition, it should also meet the following requirements from the communication network perspective.

- **High efficiency:** Efficiency is crucial to achieve the high availability requirement in real-time Smart Grid applications. The indication of high efficiency is two-fold. First, it is always desirable to balance a good trade-off between redundancy and security. Second, computation involved in authentication (e.g., digital signature and verification) must be fast enough to meet timing requirements of messages in the Smart Grid.
- **Tolerance to faults and attacks:** Authentication schemes can offer strong protection against attacks targeting data integrity, but cannot by themselves provide all the necessary security in an operational environment, especially under DOS attacks. Hence, authentication schemes are required to detect malicious attacks, and collaborate with attack detection and response systems.
- **Support of multicast:** Multicast has wide applications in the Smart Grid, including monitoring, protection, and information dissemination. Time critical messages such as tripping circuit breakers can be sent efficiently in a short span of time if multicasting is used.

[119] W. Wenye and L. Zhuo, "Cyber security in the Smart Grid: Survey and challenges," Computer Networks, 2013; Pages 1344-11371.

Public key-based authentication protocols are communication efficient but lack computational efficiency. In contrast, symmetric key-based protocols are computationally efficient but security is uncertain because an attacker can easily obtain shared key from any of the compromised node. Therefore some evolved forms of protocol designs which use asymmetric keys and provide fast and efficient multicast authentication are required. Following are some of the protocols for authentication:

- **Secret-information asymmetry:** Each receiver is associated with a unique key. While transmitting the message, the sender appends authentication information belonging to each receiver. Upon receiving the message, each receiver uses its own secret to verify the authenticity of the message and access information.
- **Time asymmetry:** Each receiver has the same secret key but it is valid for a limited time interval only. The sender discloses a key to all receivers after they have received and buffered the message. The sender and receivers are needed to be synchronized with each other for this protocol to work.
- **Hybrid asymmetry:** Secret-information asymmetry can verify packets as soon as they are received but needs to balance a trade-off between security and scalability. Time asymmetry has low overhead and is robust since a single key is used in a short time period, but has the problem of packet buffering. The main idea of hybrid asymmetry is to combine these two asymmetry mechanisms together to achieve time efficiency, scalability, and security at the same time.

Key Management[120]

The Smart Grid consists of heterogeneous communication networks, including time-critical (e.g. for protection) and non-real-time (e.g., for maintenance) networks, small-scale (e.g., a substation system) and large-scale (e.g., the AMI system) networks, wireless and wire-line networks. It is not practical to design a single key management infrastructure to generate and distribute keys for all networks in the Smart Grid. Therefore, key management schemes should be carefully chosen to meet the network and security requirements of various systems in the Smart Grid. In the following sections, existing key management frameworks for power systems are summarized.

- **Single symmetric** key can be shared among all users, which is the most efficient yet the least secure way to provide secure communication. If an attacker obtains the key by compromising a device, it can easily inject falsified information to the entire network. Unfortunately, it is indeed used in existing metering systems, where the same symmetric key is shared across all meters and even in different states. If tamper-proof devices are deployed, the single symmetric key scheme can be very efficient to exchange information secretly.

[120] W. Wenye and L. Zhuo, "Cyber security in the Smart Grid: Survey and challenges," Computer Networks, 2013; Pages 1344-11371.

- **SCADA Key Establishment (SKE)**: It divides SCADA communication into two categories: master–slave and peer-to-peer, which use symmetric key and public key schemes, respectively. SKE is an elementary key management scheme for the SCADA system with low-cost security. It neither includes a full-fledged key management infrastructure, nor supports efficient multicast and broadcast that are essential in power systems.
- **SCADA Key Management Architecture (SKMA)**: A key distribution center (KDC) is used to maintain a long term key for each node. In SKMA, a node must maintain two types of long terms keys: node-to-KDC and node-to-node. The former is manually installed on a node; and the latter is obtained from the KDC. A session key is generated using the node-to-node key when two nodes communicate with each other. However, SKMA still does not support multicast. Key update and revocation are also issues of SKMA.
- **Advanced SCADA Key Management Architecture (ASKMA)**: It uses a Logical Key Hierarchy (LKH) to achieve efficient key management among all nodes. ASKMA has two major advantages compared with SKE and SKMA: (1) it supports multicast and broadcast, and (2) it is computationally efficient for node-to-node communication. However, it is less efficient during the multicast communication process.
- **ASKMA+**: In this method the key structure is divided into two classes applying the Iolus framework and constructed each class as a LKH structure. ASKMA+ was shown to be both multicast-efficient and storage-efficient compared with ASKMA.
- **Scalable Method of Cryptographic Key Management (SMOCK)**: It is a scalable method of cryptographic key management. It was designed to achieve light-weight key management for mission-critical wireless networks with application to electric grids. It entails almost zero communication overhead for authentication, offers high service availability and good scalability. Whereas, SMOCK is not fully designed with multicast and is more computationally cumbersome, thereby increasing the burden of embedded devices in power systems.

8.3.4 Approach for Cyber Resilience

Smart Grid is a complex ecosystem of interconnected power systems and convergence of various technologies like IT and communication with electrical grid. For such a complex techno-system, the utility should engage all stakeholders to develop a comprehensive cyber security framework that is all encompassing, interoperable, and robust in nature. Organizations such as NIST and the European Network and Information Security Agency have developed guidelines to deal with Smart Grid cyber security and provide a cohesive cyber strategy. According to NIST, the Smart Grid cyber strategy should be designed in such a way that it addresses prevention, detection, response, and recovery processes to counter any existing and potential threats. Some of the key points that a utility needs to consider while developing an approach to cyber resilience are:

Risk Assessment

For calculating risk, utilities have traditionally used the following formula:
Risk = Threat x Vulnerability x Impact[121]

This same formula can be used for measuring the risks posed by cyber threats with the following explanations for the variables:

- **Threat:** The spread of cyber-attacks is expected to continue to increase across all sectors of the digitally connected economy. The more electric power systems become interconnected with each other and with other domains, the greater the exposure to potential attack.
- **Vulnerability:** With the advent of Smart Grid and other ICT improvements, attackers no longer need to bypass physical security protections or risk personal injury. Highly networked systems provide new digital pathways for hackers to reach critical operational systems. Thus, vulnerability is no longer specific to locations and equipment used by the utility, and attacks can be launched from anywhere in the world with just an Internet connection.
- **Impact:** For electrical utilities, the potential impact from any kind of security threat has always been quite high. In the past, cyber threats were not much of a concern, but today, the impact to critical systems from a cyber-security breach increase exponentially as electrical system operations become more automated and interconnected.

While performing risk assessment, it is recommended that all utilities take a realistic view of the threats and work with national authorities as needed to assemble the required information. It is anticipated that no single utility or stakeholder would be able to analyze this information on its own. In the risk assessment practice, the utilities should include the following processes with the overall objective to determine the risks that are applicable to their assets:

- **Asset Identification:** Utilities need to identify the assets that need to be protected. Assets include everything from energy resources, power generators, transmission towers, distribution channels, transformers, voltage regulators, circuit breakers, and smart meters. Utilities need to create a detailed network diagram identifying all the above assets and their locations.
- **Categorize Assets:** The assets defined above should be categorized by risk of attack. The categorization should correlate to the level of impact on the grid: low, medium, and high. The impact levels are decided based on their impact on organizational operations, organizational assets and individuals. In addition, the potential effects of asset attacks or failures on the grid should be documented in detail.

The NIST model for categorizing asset risk is provided below:

[121] Best practices for cyber security in the electric power sector, IBM, white paper, Energy and Utilities

- **Asset Risk Identification:** Assets risks should be categorized into physical or logical risks.
    - **Physical Risks**: Physical attacks, including natural disasters and sabotage. In the past, most terrorist attacks have been physical, not logical.
    - **Logical**: Types of cyber and computer system attacks. Logical risks should be identified at every point of access to the system, whether external or internal. Logical risk identification can prevent a hacker who gains access to the internal network of the power utility from causing disastrous effects to the grid.
- **Asset Risk Analysis:** Risk analysis involves determining the probability of occurrence of a particular risk. Every possible risk should be evaluated with respect to the systems involved. The data extracted from risk analysis should be used to identify potential issues that could have any negative impact on the electric grid.
- **Asset Risk Management:** It includes the following actions:
    - **Avoidance:** The focus of risk management is to proceed with caution when determining if any upgrades or new systems are required. Assuming that new upgrades are required, they can increase risk by creating more access points in the system which could be breached.
    - **Transference:** Risk transference attempts to shift the consequences of a risk to a third party along with the responsibility of responding to the risk. For example, utilities can purchase insurance to cover the cost of the risk. However, risk transference does not eliminate the risk completely.
    - **Mitigation:** Mitigation seeks to reduce the probability of an adverse risk to an acceptable level by taking actions ahead of time. If done appropriately, mitigation measures can decrease the likelihood of occurrence of a problem.
    - **Acceptance:** The final technique for dealing with risk is to respond to the risk item with a contingency plan, should a problem occur. For example, if a task is at risk of being delayed, in the case of transformer repair, then the plan should be to add additional resources to the task. Contingency plans should include any work that must be done ahead of time to enable a successful contingency plan response.

Cyber Security Policy

Utilities need to develop a cyber security policy to secure its critical assets. The policy must be available to all personnel who are required to comply with its requirements and must be reviewed periodically. As a reference, the cyber security policy should ideally address the following issues:

- Purpose
- Scope and applicability
- Roles and responsibilities
- Topics addressed
- Compliance and exceptions
- Training and awareness
- Points of contact

The policy should also include details on information protection. Protection of information associated with critical cyber assets is a foundational security practice. Proper information protection of such information must be defined in the context of organizational security policy and include provisions for identifying, classifying, and protecting such information.

In addition, utilities should ensure that they meet the required security standards from the existing reference security standards for Smart Grids (Refer Annexure 8 B).

From the above discussion, it is clear that several detection and mitigation strategies can be adopted by utilities to thwart off cyber-attacks. Simultaneously, initiatives towards cyber resilience will make the electric grids less susceptible to cyber-attacks. In the Section 8.4, case studies and policies undertaken by countries across the globe are provided.

8.4 Case Studies

Several countries have formulated robust policy structures and response protocols in order to avoid damages from cyber-attacks. Policy initiatives in the U.S., Japan and France provide a brief account of measures undertaken for cyber-security in their respective countries. Case studies of cyber-attacks targeting industrial processes and data systems of various companies are given in Annexure 8 C.

8.4.1 Case Study: U.S[122]

Cyber security policies of the U.S. are based on preserving the best of cyber space and adhering to the principles viz. fundamental freedoms, privacy, and the free flow of information. The U.S. will work internationally to promote open, interoperable, secure, and reliable information and communications infrastructure that supports international trade and commerce, strengthens international security, and fosters free expression and innovation. For realizing this goal, it has developed policies to guide state's action and support rule of law in cyberspace. Following are the basis of norms or polices:

- Upholding fundamental freedoms: States must respect fundamental freedoms of expression and association, online as well as offline.
- Respect for property: States should in their undertakings and through domestic laws respect intellectual property rights, including patents, trade secrets, trademarks, and copyrights.
- Valuing privacy: Individuals should be protected from arbitrary or unlawful state interference with their privacy when they use the Internet.
- Protection from crime: States must identify and prosecute cybercriminals, to ensure laws and practices deny criminals safe havens, and cooperate with international criminal investigations in a timely manner.

[122] International Strategy For Cyberspace, 2011

- Right of self-defense: Consistent with the United Nations Charter, states have an inherent right to self-defense that may be triggered by certain aggressive acts in cyberspace.

Following are the policy priorities as set by the U.S. by making the cyber space secure and reliable:

- Promoting cyberspace cooperation, particularly on norms of behavior for states and cyber security, bilaterally and in a range of multilateral organizations and multinational partnerships.
- Ensuring robust incident management, resiliency, and recovery capabilities for information infrastructure.
- Encouraging international cooperation for effective commercial data privacy protections.
- Developing relationships with policymakers to enhance technical capacity building, providing regular and ongoing contact with experts and their U.S. Government counterparts.
- Developing and regularly share international cyber-security best practices.
- Providing assistance to other countries looking to build technical and cyber security capabilities.
- Strengthening current military alliances and building new ones to confront potential threats in cyber space.

8.4.2 Case Study: Japan[123]

In Japan, the National Information Security Center (NISC) was established in April 2005 within the Cabinet Secretariat as the command post for information security policy, to carry out the planning, proposal and general coordination related to planning of basic strategy and other centralized, cross-cutting promotion of information security measures for the public and private sectors. In addition, the Information Security Policy Council was established in the Strategic Headquarters for the Promotion of an Advanced Information and Telecommunications Network Society in May of the same year for centralized and cross-cutting promotion of information security measures for the public and private sectors, and works towards improving the level of information security and strengthening ability to deal with cyber-attacks for government institutions and critical infrastructure providers.

In order to construct a resilient cyberspace, and realize a cyber-secure nation, the Japanese government is undertaking the following efforts:

- Measures in government institutions: The level of information security related to information and information systems will be improved by adopting preventive measures. At first risk, profiling of the government institutions will be done and appropriate security measures will be suggested which will be integrated with diverse working arrangements of the employees.

[123] Cyber security strategy, Information Security Policy Council, June 2013

- Strengthening and enhancement of preparations to cope with cyber-attacks: For sustaining cyber-attacks it is necessary that a strong defensive system is built which can assure information security. Such assurance system will require intensified cooperation with foreign institutions while greatly promoting measures for gathering, analysis and sharing of counter-intelligence related information in cyberspace with each government institution working closely.
- Measures in critical infrastructure providers: Protection of critical infrastructures is essential for stability in people's lives, socioeconomic activities, government activities etc. Collation of potential risks across industries and their analysis will help in developing security standards in each field or domain. In this context, policy measures are promoting information sharing and cyber exercises between critical infrastructure providers, cyberspace-related operators and other private organizations.
- Human resource development: Due to the expanding cyberspace of Japan, it is necessary to employ skilled workforce of security professionals. The deficiency of trained professionals is increasing with increasing size of cyberspace to be managed. Moreover, it is required to raise the skill level of cyber security professionals within Japan, and to discover and cultivate exceptional personnel in the field, a framework is necessary for practical application of training throughout society.

8.4.3 Case Study: France[124]

An initial cyber security strategy was developed in early 2010 and published in early 2011 shortly after the discovery of a cyber-attack. The intention of this attack was to spy on finance and economic ministries. Other types of attacks include disabling information in demand for ransom and intruding in computer systems with the aim of stealing information. The degree of risk which was identified in 2010 has intensified by the increase in the capabilities of attackers, the proliferation of techniques of attack and the development of organized crime in cyberspace. As a means of counteracting these risks, a national agency was created as of 2009 to address cyber-attack and to protect the state information systems and critical infrastructures. The current cyber security approach of France is based on fulfillment of 5 strategic objectives which are as follows:

- Fundamental interests, defense and security of state information systems and critical infrastructures, major cyber security crisis:
    - An Expert Panel for Digital Trust will be created, under the aegis of the State Secretariat for Digital Technology and the National Authority for the Security of Information Systems. This panel will regularly conduct meetings of administrators from government and private sectors as well as academicians. The mission of this panel is to identify the key technologies for which in-depth knowledge is required for cyber security professions and in general for the development of a trustworthy digital environment.

[124] French National Data Security Strategy, 2015

- The National Authority for Information Systems Security will actively monitor the emerging technologies and their potential risks, and inform government institutions, private enterprises and citizens regarding them.
    - To raise the level of security of state information systems, a State Information Systems Security Policy was developed. Its effectiveness is evaluated annually.
- Digital trust, privacy, personal data, cyber malevolence:
    - Ensuring individual's right of freedom of speech in offline as well as online medium.
    - It has been proposed to establish a national system as of 2016 to provide assistance for victims of cyber malevolence.
    - Ministry of Interior will implement new instruments to monitor the development of cybercrime in order to guide public action. Such action will make available statistics on cyber-crimes which will help in implementation of adequate measures.
    - An identification system will be established by 2016 which will inform the French people on the use made of their data entrusted to digital services.
- Awareness raising, initial training, continuing education:
    - Government will undertake awareness campaigns for all French people in digital education.
- Environment of digital technology businesses, industrial policy, export and internationalization:
    - With the launch of new industrial France cyber security plan in 2013, support was provided to sector and businesses developing trustworthy cyber security products and services.
    - For supporting economic developing cyber security industrial sector, France will endeavor to facilitate better visibility, competitiveness and access to international markets for small and medium enterprises and startups companies.
    - Ensuring that the digital products and services or those that involve digital technology, which are designed, developed and produced in France, are among the safest in the world.
- Europe, digital strategic autonomy, cyberspace stability:
    - France will assist other countries which are keen to increase the resilience and security of their information systems, notably in terms of the protection of critical infrastructures and to combat against cybercrime.
    - France will play an active role in establishing a road-map that will determine the key factors of success of the short-term implementation of the policies that are adequate for the emergence of a European digital strategic autonomy. This autonomy will be in terms of regulations, standardization and certification, research and development, trust in digital technology. The important elements that will be taken into consideration while establishing this road-map is respect of Member States' sovereignty and protection of privacy as well as of personal data.

It can be concluded from the above discussion that development of policy norms by countries in the area of cyber security are motivated by incidents of cyber-attacks and hacking attempts. The formulated policies recommend preventive measures for future cyber-attacks and improving resiliency of cyber ecosystem. In the following section, key Indian and international developments in cyber security are discussed.

8.5 Cyber Security Developments

8.5.1 International Developments

The countries that are in advanced stages of Smart Grid development have also progressed rapidly in areas related to cyber security. Following are some of the key international developments:

- Intel Security and Wind River, a company that provides end-to-end Internet of Things (IOT) solutions, recently announced their new technology platform, Intel Security Critical Infrastructure Protection, for securing both legacy and new capabilities of the Smart Grid. A key feature of this solution is that it works by separating the security management functions of the platform from the operational applications, allowing the operational layer to be secured.
- Dell Security recently reported that attacks on SCADA systems increased by 100 percent in 2014 as compared to 2013. The majority of these attacks happened in Finland, UK and the U.S. and the likely factor could be connectivity to the Internet. Buffer overflows continue to be the most common attack vector, accounting for 25 percent of the attacks. Lack of information sharing and ageing industrial infrastructure are the major challenges in today's scenario.
- The Obama Administration released the first installation of a Quadrennial Energy Review, which includes initiatives to promote grid modernization. The USDOE has put in a request in the 2016 budget for USD 3.5 billion over the next 10 years for investment in Smart Grid foundational technology development, enhanced security capabilities, and greater institutional support and stakeholder engagement.
- Leading IT companies including Kaspersky Lab, IO Active, Bastille, and the Cloud Security Alliance have partnered and created a not-for-profit global initiative called 'Securing Smart Cities'. The objective of this initiative is to create awareness among Smart City planners regarding importance and cost benefits of cyber security and its integration at the project planning stage itself.
- The Online Trust Alliance (OTA), a non-profit organization and think-tank, recently released a draft framework for addressing the cyber security of the IOT initiative. The framework contains best practices and recommendations focusing on home automation and wearable technologies. In addition, OTA is developing testing tools and methodologies to formalize this framework with scoring criteria.

8.5.2 Developments in India

The GOI has taken significant steps in deployment of Smart Grids in India through Smart Grid pilot projects and Smart Cities. Realizing the importance of cyber security in Smart Grid, there have been some major developments around cyber security in India, some of which are listed in the Table 8.1.

Table 8.1: Key developments in cyber security in Indian context

Chief Information Security Officer	GOI has appointed Chief Information Security Officer[125] of India.
Cyber security disclosure norms	GOI is planning to bring a legislation that would ensure strict cyber security disclosure norms[126]. If a company faces cyber-attack or cracking incidence, the company would be required to disclose to its clients and government the impact of such an incident on the safety of their data and information.
Sectional Committee LITD-10	Guidelines for cyber security frame work, issues and standards are being prepared by the BIS in association with CPRI under Sectional Committee LITD-10. LITD 10 (Power System Control and Associated Communications) will prepare Indian Standards relating to: • Power system control equipment and systems including EMS (Energy Management System) • DMS (Distribution Management System) • SCADA (Supervisory Control and Data Acquisition) • Distribution automation, Smart Grid, tele-protection and associated communications used in planning, operation and maintenance of power systems.
Crisis Management Plan	Cyber security is also being included in the Crisis Management Plan of Power Sector being revised by the CEA.
ISGTF, Working Group 5	As part of the working groups constituted under the ISGTF, Working Group 5 i.e. "Physical cyber security, standards and spectrum" covers the following activities: • Creation and finalization of cyber security standards for Smart Grid deployment; • Suggest modifications in the Electricity Act 2003 to address cyber security issues; • Capacity building on issues related to cyber security.
National Critical Information Infrastructure Protection Center	The national nodal agency for protection of critical information infrastructure, has released a framework for evaluating cyber security in critical information infrastructure.

[125] http://economictimes.indiatimes.com/
[126] http://perry4law.org/cecsrdi

ISGF working group	ISGF working along with the ISGTF also has a working group on cyber security with the objective of developing Smart Grid cyber security requirement in Indian context, and to propose a risk assessment framework to evaluate risk of each Smart Grid element through its lifecycle.
Computer Emergency Response Team–India	A Computer Emergency Response Team-India (CERT-In) has been set up and is operational as the national agency for dealing with cyber security threats. It operates a 24x7 Incident Response Help Desk to help users in responding to cyber security incidents.
Department of Electronics and Information Technology	The DeitY was constituted under the Ministry of Communications and IT with a mission to promote e-Governance for empowering citizens, promoting the inclusive and sustainable growth of the Electronics, IT & ITeS industries, enhancing India's role in Internet Governance, and ensuring a secure cyber space. Some of the key functions of DeitY include: • Policy matters relating to information technology, electronics and Internet. • Matters relating to Cyber Laws, administration of the Information Technology Act. 2000 (21 of 2000) and other IT-related laws. A National Cyber Security Policy -2013 has also been released by the department. • Promotion of Standardization, Testing and Quality in IT and standardization of procedure for IT application and tasks.

8.6 References

[1] Bureau of Indian Standards, "Technical Committee: LITD 10, Draft Standards," 2013.

[2] W. Wenye and L. Zhuo, "Cyber security in the Smart Grid: Survey and challenges," Computer Networks, 2013; Pages 1344-11371

[3] World Economic Forum, "Accelerating Successful Smart Grid Pilots," 2010.

[4] IBM, Best practices for cyber security in the electric power sector, August 2012

[5] NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0, February 2012

[6] NISTIR 7628 Revision 1, Guidelines for Smart Grid Cyber-security, September 2014

[7] NISTIR 7298, "Glossary of Key Information Security Terms," National Institute of Standards and Technology, 2013.

[8] I. Ghansah, "Smart Grid Cyber Security Potential Threats, Vulnerabilities and Risks," California State University Sacramento, PIER Energy-Related Environmental Research Program., 2009.

[9] IBM, "Best practices for cyber security in the electric power sector," 2012, "Department of Electronics and Information Technology," [Online]. Available: http://deity.gov.in/.

Annex 8 A: Security Vulnerabilities In Smart Grid

To facilitate research on Smart Grid security, NIST recommends a series of key use cases for security consideration. This section details potential security threat use cases for (1) AMI and (2) DR-based on the NIST report which would serve as a reference for identifying security issues in other Smart Grid assets.

1 AMI Security Issues

The AMI system is an essential system in the Smart Grid because it deploys communication networks to connect each customer's home-area network with utility companies, and consistently interacts with smart meters in home-area networks for scheduled energy management or demand and request response in customers' homes. This interaction presents a number of vulnerabilities in the AMI system and some of these issues are discussed in Table 8.2.

Table 8.2: Analysis of issues in AMI systems

Security Issue	Description	Security goal compromised (Threat Level)
Listening Table 8.2: Analysis of issues in AMI systems	Unauthorized people listening to the AMI communication. • **Eavesdropping**: It is unauthorized real-time interception of a private communication. • **Traffic Analysis**: It is the process of intercepting and examining messages in order to deduce information from patterns in communication. • **Electromagnetic/Radio Frequency (EM/RF) Interception**: EM/RF interception to perform unauthorized interception of private communication. **Indiscretions by Personnel**: Lack of discretion of personnel could lead to unauthorized interception of private communication.	Confidentiality (High)
Modification	Unauthorized modification of the AMI data. • **Intercept, Alter**: Unauthorized people may intercept and alter the AMI data. • **Repudiation**: People, including public authorities, may modify the AMI data and thus refuse to acknowledge an action that took place.	Integrity (High)
Interactions	Interactions of AMI components with the environment could lead to unauthorized access to AMI communication information, modification of AMI data, denial of service to authorized users,	Confidentiality Availability Integrity Accountability

Security Issue	Description	Security goal compromised (Threat Level)
	and non-repudiation. • **Masquerade**: It is a type of attack where the attacker pretends to be an authorized user of a system in order to gain access to it or to gain greater privileges than they are authorized for. • **Bypassing Controls**: People may bypass security controls to get access to the confidential data and make unauthorized modifications. • **Authorization Violation**: People may violate the authorization of AMI system to perform unauthorized actions. • **Physical Intrusion**: People may physically intrude into AMI system components like Smart Meter to perform unauthorized actions. • **Man-in-the-Middle**: It is a form of active eavesdropping in which the attacker makes independent connections with the victims and relays messages between them, making them believe that they are talking directly to each other over a private connection when in fact the entire conversation is controlled by the attacker. • **Theft:** Physical theft of the AMI components could lead to unauthorized actions being performed.	(High)
Planted in Systems	Malicious code/components planted in the system could lead to unauthorized access to AMI communication information, modification of AMI data, denial of service to authorized users, and non-repudiation. • **Virus/Worms**: A computer virus is a computer program that can copy itself and infect a computer. A computer worm is a self-replicating computer program. It uses a network to send copies of itself to other nodes (computers on the network) and it may do so without any user intervention. • **Trojan Horse**: It is a term used to describe malware that appears, to the user, to perform a desirable function but, in fact, facilitates unauthorized access to the user's computer system. • **Trapdoor**: An undocumented entry point into a computer program, which is generally inserted	Confidentiality Availability Integrity Accountability (High)

Security Issue	Description	Security goal compromised (Threat Level)
	by a programmer to allow discreet access to the program. • **Service Spoofing**: It is a situation in which one person or program successfully masquerades as another by falsifying data and thereby gaining an illegitimate advantage.	
Denial of Service	It is an attempt to make AMI system resources unavailable to its intended users. • **Resource Exhaustion:** Hackers may use up all available facilities so no real work can be accomplished and thus AMI system resources become unavailable to the intended users. • **Integrity Violations**: Integrity is violated when someone accidentally or with malicious intent modifies the AMI data and thus prevents intended users from using the AMI system resources.	Availability (High)
Insider Attack	• The insider attack would take advantage of access to systems at the opposite end of the AMI system from the customer endpoint.	Confidentiality Availability Integrity Accountability (Low to High)
Unauthorized Access from Customer Endpoint	There is a potential for AMI to allow access to the bulk electric grid from the residential or small business customer endpoint. The adversary can take control of the customer endpoint, crack wireless communications between the AMI meter and other endpoint equipment, or crack wireless communications from the AMI meter to the local concentrator. These attacks will expose the head end equipment and systems to which the head end are connected.	Confidentiality Availability Integrity Accountability (High)
Cheating Customer	The customer at an endpoint would attack to achieve the goal of reduced cost of electric and/or natural gas use. They would use information freely available from the AMI meter vendor or a standard associated with AMI meters to reset the meter and reprogram it to report false information. If the information is not freely available, the attacker would reverse-engineer a meter to develop a way to modify it.	Confidentiality Availability Integrity Accountability (Low to High)

2 DR Security Issues

In DR, customers are provided with pricing information so that the customers or the energy-management and control system at the customer's sites may respond based on electricity prices or demand during some period of time. Since DR pricing information could be transmitted electronically or fixed for long period and could be accessed by the participants of the DR program, the customer's security and privacy needs to be addressed. Also, the integrity of the pricing signal is critical because if it can be manipulated, it could lead to financial impacts on the organization or customers. Thus, most of the DR functions in the Smart Grid, such as load shedding, TOU pricing, dynamic pricing, etc. require data integrity and confidentiality to maintain the reliability of the grid and prevent adversaries to manipulate the information in the system. Failure to provide integrity and/or confidentiality could result in the exposure of customer's information, unauthorized modification and manipulation of the information.

In this context the use cases for security vulnerabilities focusing on information transmitted between the utility and DRAS client are discussed in Table 8.3 and Table 8.4.

Table 8.3: Security vulnerabilities in utility operator interface

Utility Operator Interface		
Purpose	**Information Transmitted**	**Security Concern**
To initiate or update DR event information in DRAS	Program type, date & time of the event, date & time issued, geographic location, customer list (account numbers) and load shed event information.	**Confidentiality (L):** Eavesdropping on this formation is not of concern since the information may not be sent regularly. However, the information needs to be protected from unauthorized access. **Integrity (H):** Attacker modifies configuration data in the DRAS, such as DR program data, customer list and shed event information, affecting the DR program behavior. Attacker issues false or malicious DR events in DRAS, causing blackouts and instability of the grid. Also, this may lead to the financial impacts on customers. **Availability (L):** Failure in communication between utility and DRAS.
To initiate bid request in DRAS	Program type, date & time of the event, date & time issued, geographic location, customer list (account numbers), request for a bid (RFB) issue date & time, RFB close time, price offered for load reduction per time block.	**Confidentiality (H):** Eavesdropping on this formation could result in the leaking of bidding and also pricing information to the attacker. **Integrity (H):** Unauthorized manipulation on this information could affect the bidding program behavior. Attacker issues false bidding information, causing the false behavior of the bidding program and the financial impacts on customer.

Utility Operator Interface		
Purpose	**Information Transmitted**	**Security Concern**
		Availability (L): Failure in communication between utility and DRAS**.**
To set accepted bids in DRAS	Participant list (account numbers), accept or reject, load reduction bids per time block (for verification).	**Confidentiality (H):** Eavesdropping on this formation could lead to the invasion of participant's privacy. **Integrity (H):** Attacker modifies participant list or load reduction per time block, accepted or rejected bid, causing instability of the grid and having financial impacts on participants. Attacker issues accepted/rejected bids to DRAS clients which may make an inappropriate response, such as increase the loads, according to the false accepted or rejected bids received. **Availability (L):** Failure in communication between utility and DRAS.

Table 8.4: Security vulnerabilities in DRAS interface

DRAS Client Interface		
Purpose	**Information Transmitted**	**Security Concern**
To send shed or event information to trigger the event, client to shed or shift loads at participant sites, facilities or aggregator sites	Utility event information for smart DRAS clients, such as date & time of the event, date & time issued mode and pending signals. Mode and pending signals for simple clients. Event pending signals for simple clients.	**Confidentiality (H):** Attacker intercepts information sent between DRAS and DRAS client to gain knowledge of DR events, pricing information, customer information. Loss of confidentiality on this information can lead to the exposure of customer data, unauthorized modification of information, manipulation of information, malicious attacks, etc. causing the instability of grid and financial impacts on customers. **Integrity (H):** Attacker issues false/malicious DR events. Attacker may be able to turn on air conditioning or heater units in a large commercial building which can cause excessive loads to the gird and blackouts may take place, resulting in the instability of the grid and financial impacts on customers. Attacker may be able to shut down all air conditioning units which can cause annoyance and possible health concerns in some customers. Attacker issues false time synchronization, causing events to occur sooner or later than they normally would have. The signals need to be authenticated that they actually came from the DRAS. Inability

DRAS Client Interface		
Purpose	**Information Transmitted**	**Security Concern**
		to authenticate DRAS, DRAS client and UIS can lead to a number of attacks, such as authentication sniffing, denial of service (DOS), man-in-the-middle attack, etc. Attacker captures an authentic signal, prevents the required reduction in load forcing utilities to take other measures such as buying energy at higher costs, and blackouts could occur. **Availability (H):** Attacker prevents the reduction of the load by disabling DRAS clients from receiving the incoming DR signals using denial of service attacks. Attacker floods the DRAS communications channel with non-DR related Internet traffic. Failure in communication between DRAS and DRAS clients. **Accountability (M):** Participant denies receiving DR events. Participant denies receiving bidding information.
To send request for bid to participant or facility manager or aggregator.	This information comes in the form of an email, phone call or page.	**Integrity (L):** An adversary may manually send an email, make a phone call or submit a page to the participant or facility manager so that the manager may respond to the adversary instead of to DRAS or the manager may take a wrong action in response to the bid request.
To notify the acceptance or rejection notification to the participant or facility manager or aggregator	This information comes in the form of an email, phone call or page.	**Integrity (L):** An adversary may manually send an email, make a phone call or submit a page to the participant or facility manager so that the manager may respond to the adversary instead of to DRAS or the manager may take a wrong action in response to the notification.

ANNEX 8 B: SMART GRID SECURITY STANDARDS

Some of the standards that have been developed internationally for cyber security in Smart Grid are given below:

- ASAP-SG Security Profiles for – Third Party Data Access – Advanced Metering Infrastructure (AMI) – Distribution Management – Wide-Area Monitoring, Protection, and Control – Substation Automation (under development)
- CIGRE B5/D2.46 Application and management of cyber security measures for Protection & Control systems
- CIGRE D2.31 Security architecture principles for digital systems in Electric Power Utilities EPUs
- Department of Homeland Security (DHS) Catalog of Control Systems Security
- DHS Cyber Security Procurement Language for Control Systems
- USDOE/DHS Cyber security Capability Maturity Model for the Electricity Subsector
- USDOE/NIST/ North American Electric Reliability Corporation (NERC) Electricity Subsector Cyber security Risk Management Process Guideline
- USDOE/DHS Electric Sector Cyber security Risk Management Maturity Initiative
- USDOE Roadmap to Achieve Energy Delivery Systems Cyber security
- IEC 62351 Parts 1-11 Power systems management and associated information exchange – Data and communications security (Parts 9, 10, & 11 still under development)
- IEC 62443 series on Security for industrial process measurement and control (work in process)
- IEEE 1686 Substation Intelligent Electronic Devices (IEDs) Cyber Security Capabilities (being updated)
- IEEE 802 series – IEEE 802.11i Wireless security – IEEE 802.1X Port Based Network Access Control – IEEE 802.1AE MAC security
- IEEE 802.1AR Secure Device Identity IETF Cyber security RFCs, including: – RFC 5246 Transport Layer Security (TLS) – RFC 6407 Group Domain of Interpretation – RFC 4101, RFC 4102, RFC 4103 Base standards for IP Security (IPSec) – RFC 6347 Datagram Transport Layer Security – RFC 3711 Secure Real-time Transport Protocol (SRTP) – RFC 4962 Authentication, Authorization, and Accounting – RFC 5247 Extensible Authentication Protocol Key Management Framework – RFC 5746 Transport Layer Security (TLS) Renegotiation Indication Extension
- IETF RFC 6272 Internet Protocols for the Smart Grid (identifies RFCs used in the Smart Grid)
- ISA SP99 Cyber security mitigation for industrial and bulk power generation stations (work in process)
- ISO 27000 Information Security Standards (many standards)
- NERC Critical Infrastructure Protection 002-009 (multiple versions)
- NIST FIPS 140-2 Cryptographic Security
- NIST SP 500-267 Security Profile for IPv6

- NIST SP 800-131A Transitions: Recommendation for Transitioning the Use of Cryptographic Algorithms and Key Lengths (draft)
- NIST SP 800-53 Recommended Security Controls for Federal Information Systems and Organizations (rev 4 as draft)
- NIST SP 800-82 Guide to Industrial Control Systems Security
- NIST Special Publication 1108: NIST Framework and Roadmap for Smart Grid Interoperability Standards
- NIST Special Publication 800-39: Managing Information Security Risk: Organization, Mission, and Information System View
- NIST Special Publication 800-53: Recommended Security Controls for Federal Information Systems
- NISTIR 7628 Vol. 1 thru 3 Guidelines for Smart Grid Cyber Security
- NISTIR 7823: Advanced Metering Infrastructure Smart Meter Upgradeability Test Framework (draft)

ANNEX 8 C: REAL LIFE EXAMPLES OF CYBER ATTACKS

Cyber-attacks targeting the industrial processes and data integrity of reputed companies across the globe have been documented in detail. These attacks are highly relevant in Smart Grid because these attacks can be modified to target the Smart Grid components. Following are three of the documented attacks which have been widely analyzed for their sophisticated methodology and impact on the target organization.

1 SHAMOON Virus

Shamoon, also known as W32.Disttrack, is a modular computer virus which was discovered by Seculert in 2012. It targets recent NT kernel-based versions of Microsoft Windows. The affected parties were energy companies in middle-east namely Saudi Aramco, Qatar's RasGas, etc. The motive behind the virus was to overwrite and remove the information on hard drives of workstations in the mentioned companies. The affected workstations ranged from 30,000 to 55,000[127] in number in Saudi Aramco itself and it could be more considering workstations numbers of other companies. The motive of Shamoon is in complete contrast of its predecessors which had similar destructive capabilities but aimed at disrupting industrial process (Stuxnet) or secretly stealing information (Flame, Duqu).

As suggested by Kaspersky Labs and Seculert, the virus was introduced by a previous employee (having full system access) of the company Saudi Aramco. It took control of an Internet-connected computer and used that computer to communicate back to an external Command and Control server. It also infected other computers running Microsoft Windows that were not Internet-connected.

The virus has three major components[128]:

- Dropper: the main component and source of the original infection. It drops a number of other modules.
- Wiper: this module is responsible for the destructive functionality of the threat.
- Reporter: this module is responsible for reporting infection information back to the attacker.

As indicated by the studies on Shamoon, there was no impact on SCADA or ICS systems of the affected parties. But the analysis of motives of recent cyber-attacks suggests that energy companies or utilities are under threat from these attacks. It is necessary on the part of utilities and companies to perform a comprehensive risk assessment and adopt mitigation strategies to thwart attack attempts.

[127] https://www.tofinosecurity.com/blog/shamoon-malware-and-scada-security-%E2%80%93-what-are-impacts

[128] http://www.symantec.com/connect/blogs/shamoon-attacks

2 Aurora Generator Test

Aurora Generator test was conducted in 2007 by Idaho National Laboratory. The purpose of this test was to show capability of a cyber-attack to destroy physical components of an electric grid. Under the test, a computer program was used to rapidly open and close a diesel generator's circuit breakers out of phase from the rest of the grid and explode. This kind of vulnerability in which complete control can be taken of a grid's component by an external entity in order to malfunction, disrupt or destroy the services is referred to as Aurora Vulnerability.

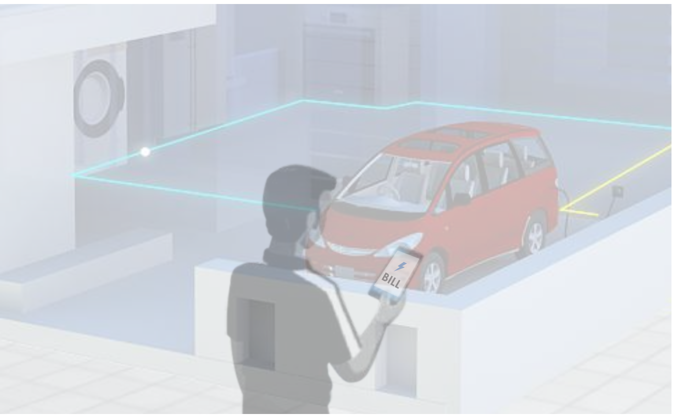
This vulnerability has become a big concern for electrical utility as they rely on publicly available equipment and common communication protocols (DNP, Modbus, IEC 60870-5-103, IEC 61850, Telnet, QUIC4/QUIN, and Cooper 2179)[129] to handle links between different parts in their systems. Usage of these protocols makes the maintenance process easier but it comes at a cost of increased vulnerability. These protocols are devoid of authentication, confidentiality, or replay protection which allows a malicious attacker to take control of the component. Even a single compromised component in the network can have a cascading effect which might lead to breakdown of more components or even complete blackouts. Moreover, if the single component takeover during an attack is not able to cause outages, it may lead to second attack or complete failure of component.

The Aurora vulnerability is caused by the out-of-sync closing of the protective relays. As such, any mechanism that prevents the out-of-sync closing would mitigate the vulnerability. One mitigation technique is to add a synchronism-check function to all protective relays that potentially connect two systems together. To implement this, the function must prevent the relay from closing unless the voltage and frequency are within a pre-set range. Additionally, the synchronism-check could monitor the rate of change of the frequency and prevent closing above a set rate[130].

3 STRUXNET

Struxnet is a computer malware program which was designed to sabotage industrial controls and real-time systems. Struxnet specifically targets PLCs, which allow the automation of electromechanical processes. Its design and architecture are not domain-specific and it could be tailored as a platform for attacking modern SCADA and PLC systems. It has three modules: a worm that executes all routines related to the main payload of the attack; a link file that automatically executes the propagated copies of the worm; and a rootkit component responsible for hiding all malicious files and processes, preventing detection of the presence of Struxnet. It is typically introduced to the target environment via an infected USB flash drive. Upon meeting the necessary conditions, it launches itself and creates havoc in the system while reporting normal operating parameters to the user. In other case, the malware lies dormant in the computing system. This example of Struxnet shows that the ultimate aim of a control system attack is to manipulate or control a critical edge device, i.e. the device sitting at the edge of the network interfacing with the real-world such as a programmable logic controller.

[129] http://www.defenseone.com/technology/2014/12/forget-sony-hack-could-be-he-biggest-cyber-attack-2015/101727/
[130] https://en.wikipedia.org/wiki/Aurora_Generator_Test



Module - 9

Consumer Engagement and Participation

9.1 Role of Customers in Smart Grid

Customer engagement is the key for successful deployment of Smart Grid technologies. With the advent of two way communication enabled by Smart Grid, it now becomes possible to engage customers more actively.

Smart Grid technologies and applications have direct impact on customers, enabling them to become active participants in the electrical ecosystem. The aim of these applications is to make customers more informed, aware of energy usage and participate in utility programs for mutual benefits. According to the USDOE:

In the Smart Grid, consumers will be an integral part of the electric power system. They will help balance supply and demand and ensure reliability by modifying the way they use and purchase electricity. These modifications will come as a result of consumers having choices that will motivate different purchasing patterns and behaviour. These choices will involve new technologies, new information about their electricity use, and new forms of electricity pricing and incentives.

Figure 9.1: Customer access points in Smart Grid environment

In a Smart Grid scenario, there are various customer access points which go way beyond those available in a traditional utility. Figure 9.1 summarizes the customer access points available in Smart Grid environment. Customer involvement with respect to each of the Smart Grid applications has been detailed in Table 9.1.

Table 9.1: Customer involvement in Smart Grid applications

Smart Grid Application	Description	Customer involvement and benefit
Interval meter data recording	Smart meters possess the capability of recording interval meter data for different durations i.e. 1 hour, 30 min, 15 min as required.	All types of customers whether residential, commercial, industrial receive benefits from this data. Customers can avail the facilities of energy management tools which import usage data to analyze and provide actionable insights. These insights include usage optimization and energy saving tips leading to a value for money scenario for customers.
Remote power connect, disconnect	AMI infrastructure will enable utility to remotely connect, disconnect the user's power connection.	Customers can choose energy packages according to their needs and utility can manage the connection remotely.
DR/ADR System	Enables peak load management for the utility when the wholesale prices are high or grid reliability is threatened.	Customers will have convenient and multiple options to register for such programs. Customers receive benefits for their participation.
Home Area Network	HAN provides the required communication network for linking smart appliances, in-home displays (IHD)[131] etc. to utility systems.	Customers can receive information on TOU tariff rates, incentives, penalties, energy consumption, etc.
Power Quality	Smart Grid technologies help in taking corrective as well as preventive actions by monitoring power quality parameters.	Customers do not require investment on voltage stabilizing equipment. Customers receive grid outage and restoration information from utility.
Prepaid Metering[132]	Smart Grid systems will enable prepaid metering where customers can switch from post payment of bills to pre -payment.	Customers gain control over their energy consumption.
Distributed Generation	Smart Grid facilitates integration of renewable energy in the grid. Smart metering infrastructure is capable of recording energy flows in both directions.	Customers can avail benefits of gross or net metering.
Customer portal	A web-based information access	Customers can avail the benefit of

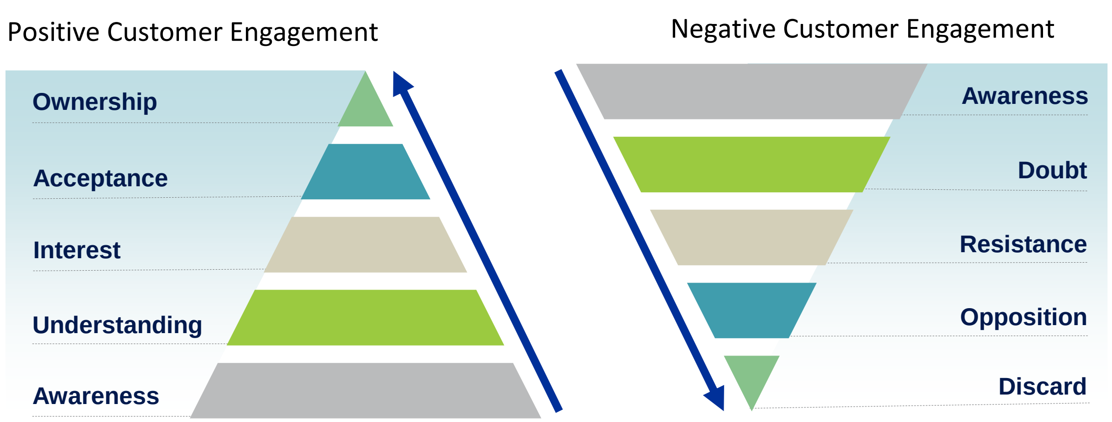
[131] SmartSacramento, Customer Applications, Lupe Strickland, SMUD, May 2012

[132] Smart Grid Customer Education Symposium Eric Lightner Director, Federal Smart Grid Task Force May 16, 2012

Smart Grid Application	Description	Customer involvement and benefit
	system. Customers can view near real time energy consumption, usage patterns, payment history, billing history, tariff plan details, etc.	online profile management by getting an accurate near real time view of its usage.

From Table 9.1, it can be observed that customers' interaction with Smart Grid technology is far more evolved and intense than traditional electrical grids. Also, the benefits realized from Smart Grid technologies by customers are unprecedented. The following section discusses customer behaviour and dynamics and how its understanding can help in successful Smart Grid technology deployment.

Figure 9.2: Customer behavior patterns affected by nature of customer engagement



9.2 Understanding Customer Behaviour and Dynamics

Smart Grid deployment requires huge investments and it is important to garner customer support and acceptability at every stage of technology deployment. Smart Grid represents an essential change in the relationship between the utility and its customer, and therefore, necessitates a new level of customer commitment. This commitment needs deep understanding of customer behaviour. Any action or inaction of utility to engage with customer can either positively or negatively impact consumer behaviour (Refer Figure 9.2).

Whenever a new service or a product is launched it leads to awareness among the customer. The awareness may lead to either understanding or doubt about the product depending on positive or negative influences. The understanding leads to customer interest in the product or service followed by acceptance. Once it is accepted, it leads to an inclination to own the product, service by the customer.

Similarly, creation of doubt among the customers about the product/service at the initial stage leads to resistance followed by opposition by the customer. This ultimately leads to discarding of such product/service.

Therefore, it is important to understand that a highly positive, customer-centric approach will ensure successful execution while a negative, lacklustre, one-size-fits-all approach will create undue resistance in customers ultimately leading to discarding of Smart Grid project. A case study is presented in Box 9.1 detailing on the strategy adopted by San Diego Gas and Electric Strategy for effectively engaging the customers.

Box 9.1 Case Study: San Diego Gas and Electric Strategy for engaging the customers

SDG&E is a regulated public utility which serves customers in the region of San Diego and Orange counties. The customer base is around 3.4 million and service area spans 4100 sq. miles.

Starting from 2009, the Stakeholder Education Group at SDG&E is responsible for customer engagement activities. SDG&E began installation of smart meters as part of its Smart Grid efforts. It employed a 90-60-30 day implementation protocol for engaging customers in the smart meters installation process. The strategy was highly successful as out of 2.3 million meter installations, it received complaints from only about 1,200 customers or 0.16 percent. The field visits helped in building trust among customers. Approximately 15 percent of customers provided feedback and concerns during these visits which were captured and addressed. Following is a brief overview of implementation protocol deployed by SDG&E:

- 90 days prior to installation: Presentations were given to community leaders and elected officials by Stakeholder Education Group members.
- 60 days prior to installation: Utility representatives participated in community events and discussed about smart meters which could help in better understanding of the cost of energy usage.
- 15-30 days prior to installation: Letters were mailed to customers providing the information on timeframe of smart meters installation at their residence.
- 2 days prior to installation: A phone call was made, announcing the installation as well as communicating the timings when the installer would be on site.
- On Installation Day: Installers interacted with customers to make a personal connection prior to installation and survey their experience.
- 2 weeks after installation: Field representatives consisting of recent retirees conducted a personal visit to answer questions.

Other notable initiatives in customer engagement deployed by SDG&E are:

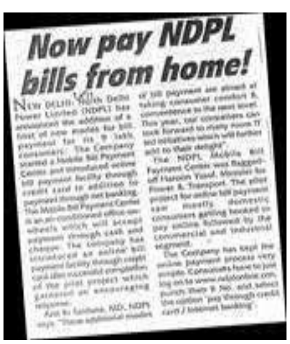
- Reduce your energy use: In the summer season, SDGE launched a reward-based program where consumers were notified in advance about forthcoming event days. On these specific days and during specific hours, consumers will earn bill credits for using less electricity. This program witnessed huge participation from approximately 50,000 customers and more than 40 percentage of eligible ones received bill credits on each of the event days.
- Engaging contests: SDG&E launched Biggest Energy Saver contest in 2011 followed by San Diego Energy Challenge in 2012. Both these contests were highly successful and created awareness among consumers regarding significant amount of energy and money.
- Power usage monitoring devices: Since 2013, customers have been able to install HAN devices (approved by SDG&E) which enables customers to monitor their overall power usage as well as appliance wise usage. In addition to HANs, SDG&E has also enabled web and mobile based application such as Power-Tools. These advanced tools interpret Green Button data and transforms it into action-able insights for consumers. These insights help customers identify ways to make smarter choices in their energy use habits and decisions, improve efficiency, and lower costs.

Box 9.2 Case Study: TPDDL consumer engagement during reform[133]

Background: At the time of privatization of power distribution in Delhi, there were significant apprehensions in the minds of every stakeholder. Earlier privatization efforts in some states were reportedly unsuccessful. The utility realized that in such a challenging situation, it was imperative to establish open and transparent communication channels with all stakeholders to win over their trust and support. Thus, one of the priorities of TPDDL was to transform the erstwhile monopolistic utility into a consumer friendly organization and to revamp its consumer's experience.

Consumer engagement initiatives: Following initiatives were undertaken by the utility during the reform process:

1. Initiated periodic engagement meets with Resident Welfare Associations (RWA)/Indian Welfare Associations (IWAs) within its area every month, wherein consumers could freely express their needs and requirements to the distributed leadership team of the company.
2. These meetings also became effective platforms to sensitize the consumers on various social actions such as climate change, energy conservation, safety, electricity theft, etc.
3. 'E Sampark' newsletter was introduced to communicate all key initiatives, new services to RWAs/IWAs which in turn helped them to sensitize their community members.
4. TPDDL engaged eminent citizens who were opinion makers in the society as "Brand Ambassadors" to act as bridge between the consumers and TPDDL. The main function of these Brand Ambassadors was to represent public concerns to TPDDL and at the same time spread the change message to the masses regarding the new initiatives and innovative services launched by TPDDL.
5. TPDDL also institutionalized segmented relationship approaches for its consumers through Client Managers (for Xpresss and Key Consumers > 100 KW load and G&I consumers), Account Managers (for High Revenue consumers > 10 KW load), CROs (for consumers <10 kW load) to provide dedicated services.
6. Engaging with consumers at various forums has provided useful insights to launch new initiatives and services for enhancing consumer satisfaction e.g. SMS-based services, video conferencing, etc. The utility also made effective use of media to reach out to its consumers and provide information regarding new initiatives, planned outages, high profile power thefts, energy conservation, safety, etc. In addition to the above, several Nukkad Nataks (street plays) were organized to make consumers aware of the hazards of theft of electricity.


Now pay NDPL bills from home!

133 https://www.tatapower-ddl.com/UploadedDocuments/TPDDL%20Case%20Study.pdf [Last Accessed: 01-Apr-2016]

It may be noted that lack of customer involvement may lead to low participation or decreasing participation over time leading to failure of Smart Grid project. Further, non-involvement may generate misconceptions and concerns about the Smart Grid project related to safety, health, privacy, cost, etc. Though these concerns can be easily alleviated through proper education and guidance, ignorance on part of utility will lead to increased unrest among customers. This is corroborated from the international experiences (Refer Table 9.2) on the above subject.

Table 9.2: Case studies of utilities failing to engage customers

Description of project	Challenges faced in engaging customers	Corrective actions taken by utility
In 2006, Pacific Gas and electric began installing smart meters in northern and central California for its nearly 5 million electric customers. **Impact**[134] The project got delayed till 2013 and exceeded its initial budget.	Throughout 2009 and into early 2010, PG&E received approx. 1,378 customer complaints regarding electrical bills and meter accuracy. Customers expressed concerns regarding severe lack of communication on part of utility. Moreover, the utility treated smart meter replacement as an infrastructure overhaul initiative. Concerns were raised regarding PG&E customer service and complaint resolution process. Customers were not adequately informed about reasons of billing inaccuracies leading to their decreased confidence. As per utility's 2011 report, two prime issues were identified for delay project. Firstly, increasing number of customers refused to grant access to PG&E for meter installation. Secondly, around 1600 residential customers were impacted by a meter defect which created a bad publicity for the project.	In cases where meters were not connected properly and calibrated as required, PG&E issued an apology to the customers and corrected the billing information. After media reports of negative customer reaction, PG&E strengthened its customer outreach efforts. Utility staff provided maximum information about smart meters at the installation point and made extra efforts in making customers understand smart meter's benefits in case of refusal. Utilities decided to use multiple communication channels to educate customers. Meter defect affected customers were given full refunds of over-billed amounts, plus interest, and a USD 25 inconvenience payment and an offer of a free in-home energy audit.
Central Maine Power (CMP) began installing smart meters in 2010 in	There was widespread negative feedback from customers regarding smart meter deployment since	Before PUC, CMP presented its case stating that due to the opt-out policy it will face financial

134 http://www.pge.com/web/includes/docs/ppt/myhome/customerservice/meter/smartmeter/april2013_report.ppt

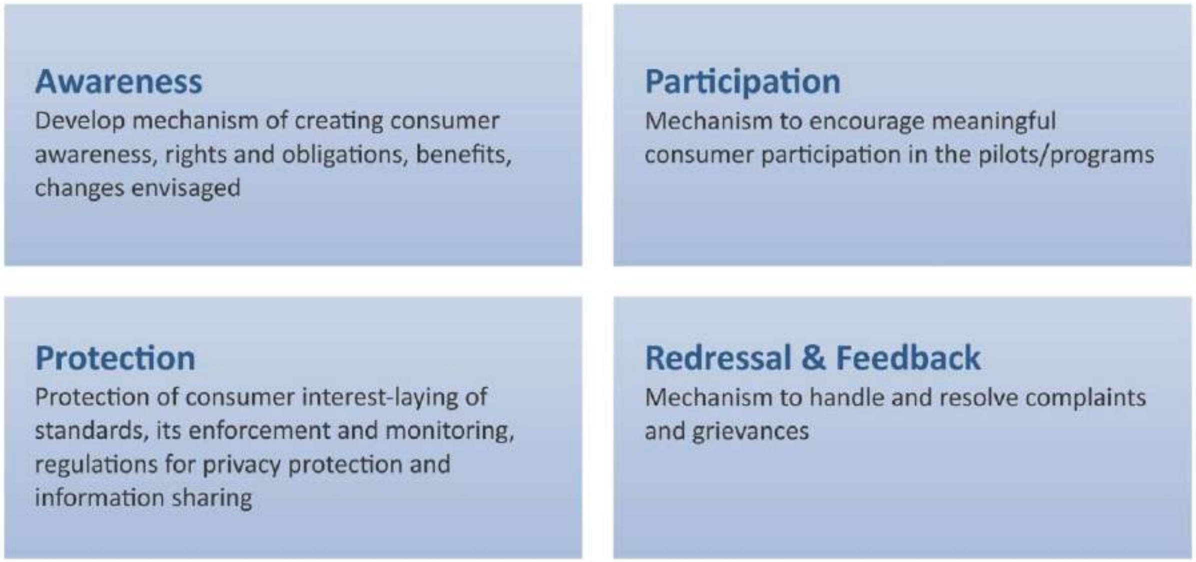
Description of project	Challenges faced in engaging customers	Corrective actions taken by utility
the state of Maine. Assuming high satisfaction levels of its customers, CMP did not launch any customer outreach program[135]. **Impact** Due to this negligence delays in project implementation were faced.	customer buy-in was not the priority of CMP. In early 2011, customers appealed before Maine Public Utilities Commission (PUC) regarding smart meter program, claiming that their property ownership rights were violated. However, PUC ruled in favor of CMP but directed CMP to provide an opt-out choice for customers. Unsatisfied with the PUC ruling, customers appealed in the Supreme Court stating that the opt-out fee violated the customers' rights under the Fourth and Fifth Amendments of the U.S. Constitution. However, Supreme Court ruled in favor of PUC. Finally, customers again appealed against smart meters installation on ground of health impact due to exposure of radio frequency waves.	losses. Thus, PUC approved opt-out fees which will be levied on customers. As a result, CMP implemented a tiered opt-out fee structure for customers refusing to install smart meters.

9.3 Critical Dimensions For Customer Engagement

This section describes four key dimensions (Figure 9.3) that should be considered by the utilities while preparing their customer engagement strategy. These are discussed in the following sections.

[135] http://www.infolawgroup.com/2012/08/articles/smart-grid-1/maine-supreme-court-affirms-validity-of-smart-meter-opTOUt-program/

Figure 9.3: Critical dimensions for customer engagement strategy



9.3.1 Awareness

Awareness implies providing the right information to consumers at the right time and developing programs and services that provide value to consumers. From the utility's perspective, it means investing time and resources in marketing and education, to ensure that consumers understand and take advantage of the opportunities to participate in the Smart Grid. Some of the key tools and awareness mediums that can be adopted by the utilities are presented below:

- **Dissemination of educational material in print:** Utility should distribute visually appealing brochure, pamphlet, and leaflets for information dissemination. These materials should be concise and engaging from the consumers' perspective. The contents of these materials can range from policy descriptions, rewards, contest announcements and customer reviews, industry expert's comments and much more.
- **Computerized calls**: Automated calls could be made to these consumers regarding current progress, giving information on different schemes and future events in Smart Grid implementations. At the end of these calls, feedback from the consumers could also be collected helping in gauging the effectiveness of this initiative.
- **Social media**: Social media channels such as Facebook, Twitter, and LinkedIn provide enhanced reach to the utility for creating awareness regarding Smart Grids.

Figure 9.4: Social media channels

- **Publications of white papers and newsletter[136]**: Utility can utilize in-house experts as well as collaborate with other experts to publish white papers on Smart Grid technology deployment experience, learnings, and best practices. The project team should release e-newsletter detailing achievements, work in progress, challenges, and expert's views on a monthly basis. Utility should promote customer subscription of these materials for igniting interest among customers.

  A case study on the strategy employed by a U.S.-based utility on improving consumer awareness is presented in Box 9.3.

Box 9.3 Case Study: Southern California Edison (SCE) strategy for engaging the customers effectively

Southern California Edison (SCE) is one of the U.S.' largest electric utilities with a customer base of more than 14 million people. Its service territory includes central, coastal and Southern California, excluding the city of Los Angeles and some other cities. Its service area spans about 50,000 sq. miles. During the period of 2009-2012, SCE began replacing traditional electric meters with smart meters as part of Edison Smart-Connect program. This program was highly successful as SCE installed more than 5 million smart meters in its service area. Moreover, several customer engagement initiatives of SCE witnessed huge number of participation making them a success. Following are some of the SCE most notable customer engagement initiatives.

- My Account program: SCE provides its customer the facility of My Account which enables online tracking of energy usage with custom usage reports. It helps customer in electricity bill management, online billing and payment of bills. This program saw registration of more than 350,000 customers.
- Budget Assistant: This free and smart meter-enabled tool was provided by SCE to help customers better manage their monthly bills. Through this tool, customers can set monthly spending goals, track their progress and get automated alerts to stay within monthly budget. By the end of 2012, nearly 349,000 customers signed up and started using this tool.

[136] Smart Grid Customer Education Symposium Eric Lightner Director, Federal Smart Grid Task Force May 16, 2012

- Save Power Days: This is an incentive-based load reduction program for residential customers initiated by SCE. The success of this program can be measured by nearly 820,000 customer registration as of December 2012. Moreover, SCE paid approx. USD 4.4 million in incentives to its enrolled customers during November 2012.
- YouTube Channels: SCE developed a variety of informatory video playlists for targeting its customer group. These YouTube videos educate customers about latest service offerings as well as technology, reliability and safety measures. Also included in these videos are customer stories.
- Other activities of SCE's customer engagement model include community events, targeted media relations announcements, print and television ads, radio spots, and just-in-time letters.

9.3.2 Participation

Full potential of Smart Grid technologies can only be realised if customers effectively participate in programs designed for such purposes. Utilities can incorporate activities in their customer engagement program to increase customer participation for programs such as DR, brownout implementation, net metering, etc., where customer action is required for success of the program. Following are some of the activities:

- **Revamping of utility website**: An updated and user-friendly version of utility website could be launched. This website should act as a one-stop solution for all the online activities such as payment of bills, bill history, form submission, etc.
- **Smart Grid project specific website**[137]: Smart Grid project specific website could be launched which should contain conceptual as well as technical knowledge about the Smart Grid project, frequently asked questions, common myths and the reality. The aim should be to create awareness in a user-friendly way without use of any technical jargon.
- **Organizing energy saving contests**[138]: Several contests can be organized such as awards for homes with highest reduction in their monthly bills, best performance in DR programs, etc. The winners' profile should be showcased on utility website which will serve as inspiration for other customers.
- **Online customer account management**[139]: Utility should notify customers regarding upcoming DR/DSM events through email, SMS, phone depending on the customer's preferences. Afterwards, customers need to commit their participation by logging-in to their online account and complete the necessary documentation. Only registered customers would be eligible for participation in the program. This online customer account management facility makes the registration process quick and user-friendly.
- **Digital communication**[140]: Digital communication channels encompass email, Internet, and social media platforms. Advanced mobile technology has made it possible for customers to remain connected to Internet, email, and social media round the clock. Creating access points on these channels will help customers participate in utility programs anytime and at any location. These channels can be used for one-on-one, group or mass communication.

[137] The Smart Meter Deployment Handbook, NV Energy, March 2013
[138] Smart Meters, Risa Baron, SDG&E
[139] Smart Grid Symposium 11 October 2011
[140] Transforming the Customer Experience, Chris Schein Senior Director, Communications, May 2012

Figure 9.5: Various modes of digital communication

A compendium of case studies highlighting the best practices in increasing consumer participation is presented in Box 9.4, Box 9.5 and Box 9.6

Box 9.4 Case Study: Baltimore Gas and Electric (BGE) strategy for engaging the customers effectively

Baltimore Gas and Electric (BGE) is Maryland's largest utility which serves around 1.2 million electricity customers. Its service encompasses 2,300 sq. miles area of Baltimore City and all or part of 10 Central Maryland counties.

Some of the highlights of customer engagement initiatives by BGE are proper communication and feedback on savings. Each of the customer group received a customized welcome brochure containing all the necessary information. Also, after completion of every saving initiative by BGE, a savings report was sent to the customer with-in days. Due to these measures and several others, high customer satisfaction and participation level was achieved.

Figure 9.6: Illustration of BGE's customer side mobile application and website

Few of the successful programs from BGE which deployed innovative customer engagement are highlighted below:

- **Smart Energy Manager**: This application helps AMI meters-installed customers to view their energy consumption on BGE website and provide energy savings tips. It was launched in October 2012 and accessible once the meter is certified. Additional features of this manager include estimated bills, unusual usage alerts, printed and electronic home energy reports, access to interval usage data, etc.
- **SER Program:** This peak time rebate program was launched in July 2013 and it is available to all BGE's customers with smart meter installed. Results from four summers of pilot programs show that peak demand was reduced by 15-25 percent and customers saved over USD 100 each year on an average. The customer engagement strategy for this initiative was divided into three phases which are explained below:
    - **Create awareness:** Educational mails and program overview video, educational E-mail and community meetings were some measures adopted for creating customer awareness.
    - **Generate engagement:** Opportunity for customers to learn about SER and ask questions was created by initiating programs such as 'Preview' Postcard and E-mail, 'What to do' video and outbound telemarketing campaign.
    - **Encourage action:** To encourage action among customers, program information was disseminated with the help of welcome kit direct mail (SER and SER/PR versions), Move-in and Move-out Direct Mail (SER and SER/PR versions), and event notifications: phone, Email and/or text.

Box 9.5 Oklahoma Gas & Electric (OG&E) strategy for engaging the customers effectively

Oklahoma Gas & Electric (OG&E) is a regulated electric utility which has a customer base of more than 801,000 in Oklahoma and western Arkansas region. The service area of OG&E spans around 30,000 sq. miles.

In 2008, OG&E began rolling smart meters in phases and presently has installed more than 823,000 smart meters in its service area. Also, in 2010, it launched "Smart Hours" program in Norman, Oklahoma. Due to the diligent efforts of OG&E, more than 44,000 customers enrolled in the Smart Hours program by the end of 2012 summer cooling season. This huge participation resulted in 70 MW of load reduction.

OG&E complemented the AMI deployment and load reduction programs with strong customer engagement strategy. Following is the brief overview of strategies adopted for effective customer engagement.

- **Web Portal**: "myOGEpower" is the utility's website where tools are available for customers use which helps in analysis of energy bill, power consumption and its costs, dynamic pricing and best-suited rate plan. In order to quickly resolve customer's queries, a set of Frequently Asked Questions have also been provided on the website.

- **Best Bill Guarantee**: Prices per unit of electricity increases from standard rates in high peak and critical peak hours of Smart Hours program. Thus, some of the OG&E customers were skeptical in enrolling for Smart Hours. In order to reduce this perceived risk, OG&E provides best bill guarantee for the first 12 months to the enrolled customers. Under this guarantee, customers will not pay more than the bill amount based on standard rates of per unit of electricity. Any extra amount paid by the customer at the end of 12 months will be credited back to the customer's account.

- **Smart Hours Plus**: Under this program, OG&E offers its customers a technologically advanced thermostat. This thermostat is synchronized with time-based rates of Smart Hours programs and can help customers take better advantage of time-based pricing.

- Other remarkable efforts for customer engagement include email advertisements of OG&E's web portal and video tutorials to supplement printed material.

Box 9.6 Case Study: Green button initiative

Green button initiative[141] is based on the concept that customers should be able to view, download their past energy usage data in a standard consumer-friendly and computer-friendly format. In order to ensure consumer privacy, this data can only be downloaded from utility's website after authentication. This initiative is in accordance with policy objectives in the Obama Administration's Blueprint for a Secure Energy Future and Policy Framework for the 21st Century Grid.

Figure 9.7: Illustration of green button initiative's customer interface

As far as progress of this initiative is concerned, utilities and electricity suppliers in 34 states and DC have committed to this initiative while 48 utilities have already implemented the same. Under Green Button, there are two options for consumers to access power usage data for analysis:

- **Download My Data**: In this option, past energy data can be downloaded by the consumer in a single file of XML format which can be shared with third party application developers for availing enhanced functionalities.
- **Connect My Data**: This option enables consumers to voluntarily share their usage data with third party applications on a recurring basis. Although, an initial setup process is required but after that no further action on consumer's part is required for data sharing.

Among the foremost advantage of Green Button data from consumers' perspective is availability of insights which can lead to cost savings. After understanding their consumption pattern and energy efficiency of home appliances, consumers can reduce their monthly electricity bills. Because of the consumer centric approach of Green Button initiative, it plays an important role in engaging customers.

9.3.3 Protection[142]

The basic infrastructure and architecture of Smart Grid technologies poses significant privacy issues as the Smart Grid relies on AMI, two-way communication network and data management that enables active information exchange between the utilities and the consumer. As an example, personal energy consumption data could reveal personal details about the lives of consumers, such as their daily schedules, whether their homes are equipped with alarm

[141] http://energy.gov/data/green-button
[142] Voluntary Code of Conduct final concepts and principles, USDOE, January 12, 2015

systems or whether they own expensive electronic equipment, etc. The proprietary business information of non-residential customers could also be revealed through the release of energy consumption data, resulting in competitive harm.

Therefore, data privacy becomes a key issue in the context of Smart Grids. The key for protecting privacy of information stored on computers or exchanged on communication networks is determining whether data is or is not personally identifiable information (PII). Classification of consumer data can be done at two levels:

1. **PII,** which consists of consumer names, addresses, numbers, and other information that specifically identifies the person or entity to which it applies; and
2. **Consumer-Specific Energy Usage Data (CEUD),** which, in most cases, does not identify an individual consumer but includes detailed information about the utility service provided to the consumer.

Based on the classification the utilities can set guidelines that can protect PII. A number of such Smart Grid privacy guidelines have been developed around the globe as well. The USDOE, in its October 2010 report on data access and privacy issues related to Smart Grid technologies, identified privacy issues related to third party access as one of the most critical and difficult issues in Smart Grid technologies. Similar to the lines prescribed by the USDOE based on the Federal Trade Commission (FTC, U.S.) report on protecting consumer privacy, utilities could incorporate the following principles for data privacy protection[143]:

- **Privacy by design:** Utilities should incorporate substantive privacy protections into their practices, such as data security, reasonable collection limits, sound retention and disposal practices, and data accuracy.
- **Data minimization and limited retention:** Utilities should limit data collection to that which is consistent with the context of a particular transaction or the consumer's relationship with the business, or as required or specifically authorized by law. In addition, personal information should be kept only as long as is necessary to fulfill the purposes for which it was collected. When no longer necessary, consistent with data retention and destruction requirements, the data and information should be irreversibly destroyed.
- **Data security:** Utilities should maintain comprehensive data management procedures throughout the life cycle of their products and services.
- **Simplified choice:** For practices requiring choice, companies should offer the choice at a time and in a context in which the consumer is making a decision about his or her data. Companies should obtain affirmative express consent before using consumer data in a materially different manner than claimed when the data was collected; or collecting sensitive data for certain purposes.

[143] "Protecting Consumer Privacy in an Era of Rapid Change", FTC, U.S. 2012.

- **Transparency (Notice and Access):** Privacy notices should be clearer, shorter, and more standardized to enable better comprehension and comparison of privacy practices. The notice should provide a detailed description of all purposes for which consumer data will be used, including any purposes for which affiliates and third parties will use the data, and how long the data will be maintained.

9.3.4 Redressal and Feedback

Smart Grid deployment and operation may involve situations like customers dissent to smart meter installation, unsatisfactory service, concerns on privacy and information access, poor complaint resolution and response. It is important to resolve customer concerns especially during the early stages of project, as this could negatively affect the credibility of Smart Grid efforts.

- **Anticipation of problems and their countermeasures**: Utilities should invest time in pre-deployment anticipation of likely customer concerns. Pre-deployment education programs to alleviate customer concerns could be one of the options. Consumers may be unable to understand the nuances of Smart Grid but they can surely develop an appreciation of these through education.
- **Trained customer service representative (CSR) workforce**: CSRs are the first point contact for customers in case of any concerns. The staff should thus be trained to provide a positive customer experience, and to address concerns to the maximum extent possible. CSRs should be receptive to all feedback, and treat all customer complaints as important.
- **Personalized attention to dissented customers groups**: Even after persistent efforts of the utility, it might be the case that a minority group of people still remain deeply concerned. A personalized awareness program should be adopted by utility to avoid the transition of these groups into more vocal concerned customers.
- **Existing legislative and regulatory framework for complaint redressal**: The existing Legislative and Regulatory Framework is permissive enough to provide for consumer complaint redressal. At first, attempt is made by utility to resolve the issue at the first point of contact through Internal Grievance Redressal Cell. If not satisfied, customer can submit the grievance to the Consumer Grievance Redressal Forum (CGRF) within 2 months. As per the Electricity Act, every licensee has to establish one CGRF having jurisdiction over its area of supply. Again if the customer is not satisfied, grievance can be filed before the Ombudsman.
- **Opt-out policy**[144]: The consumer engagement in advanced metering can also be based on opt-out policy wherein the customers who have objection to installation of smart meters may be given an option to opt out of the Smart Grid program. However, it becomes the responsibility of utilities to make sure that smart meters' benefits and risks of opting-out are properly communicated to the consumer.

[144] Smart Grid Customer Education Symposium Eric Lightner Director, Federal Smart Grid Task Force May 16, 2012

In conclusion, customer engagement is about working openly, pro-actively and collaboratively with customers and providing opportunities for their views and preferences to be heard. The feedback could then be analyzed to derive actionable insights influencing utilities' decisions. Also, effective consumer engagement requires commitment from both utilities and consumers. Collaboration of utilities and customers drive Smart Grid success to new heights.

9.4 References

[1] I. S. Consulting, “Smart Grid Consumer Engagement: lessons for North American Utilities,” National Resources Canada, 2013.

[2] SAIC, “Smart Grid Legislative and Regulatory Policies and Case Studies,” U. S. Department of Energy, Washington D. C., 2011.

[3] F. B. LLC, “Smart Grid Consumer Education Program Report,” 2013.

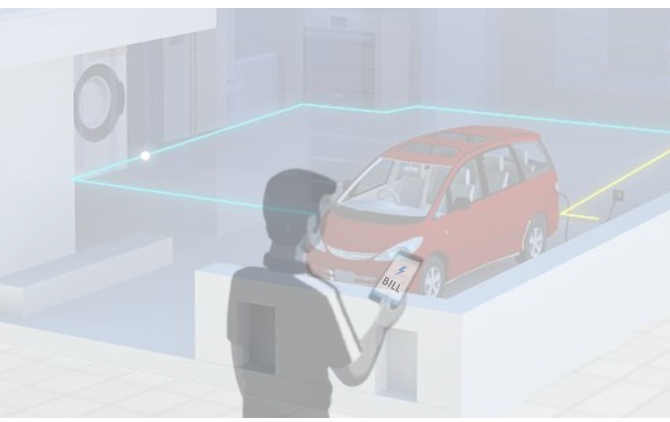
[4] S. G. C. COLLABORATIVE, “Smart Grid Customer Engagement Success Stories,” 2013.

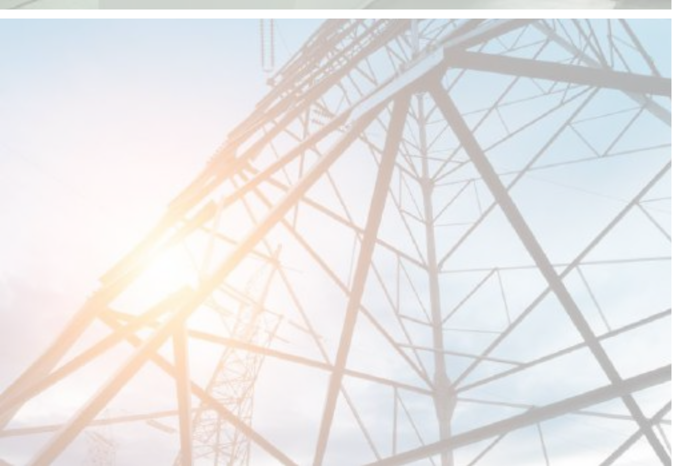
[5] N. R. E. Laboratory, “Voices of Experience: Insights on Smart Grid Customer Engagement,” U. S. Department of Energy. 2011

[6] BGE, “BGE Smart Grid and Demand Side Management,” 2014.

[7] “Consumer Engagement Workshop,” Ronald Reagan Building, Washington, D.C., 2013.

[8] “Model Smart Grid Regulations,” Forum of Regulators, [Online]. Available: http://www.forumofregulators.gov.in/Data/study/SG.pdf.2015





Module - 10

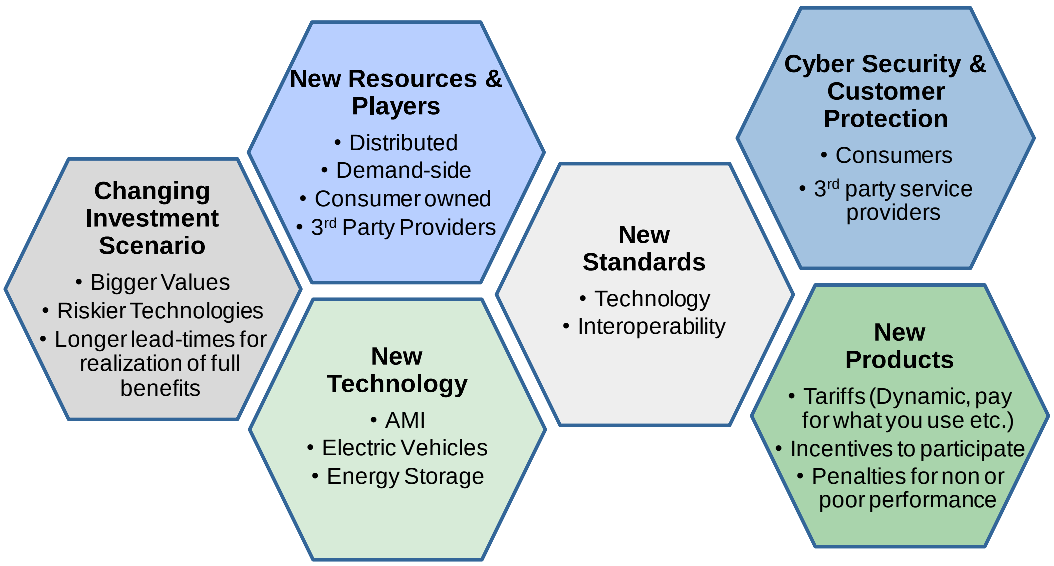
Regulatory Considerations in Smart Grid Projects

10.1 Need for regulatory framework for Smart Grid

Regulatory decisions drive the overall Smart Grid business approval of Smart Grid investments, recovery of these investments through different modes, provision of incentives and penalties to promote adoption of such solutions by the utilities, and deployment at the consumer end, and protection of consumer interest and ensuring value delivery, all of these require regulatory approval Smart Grids, hence cannot evolve without dynamic and flexible regulation.

Specifically, regulatory framework for Smart Grid is necessitated on account of the following aspects as presented in Figure 10.1:

Figure 10.1: Need for Smart Grid regulations



Each of the above aspect is explained below.

- **Changing investment scenario:** Smart Grid Technologies are evolving and hence riskier in nature. The utilities on one hand need to be motivated to adopt such investment, and on the other hand need to be protected from risk of obsolescence. In addition, certain investment may have much longer lead time than conventional investments. For instance, creation of backbone infrastructure may result in upfront capital investment, wherein the full benefits are phased out over longer period of time. AMI, communication backbone, etc. are common examples that come under such categorization.
- **New resources and players**: Smart Grid will involve an integrated system comprising consumers, distributed generation, aggregators and other third parties, energy storage devices, systems, storage banks, etc. functioning together. Several of these entities are new in nature which will necessitate clear principles that will govern such interaction and transactions. This will be particularly true for new market entrants and third party service providers such as DR or EV charging aggregators, energy efficiency service providers, micro-grid owners and operators, etc.

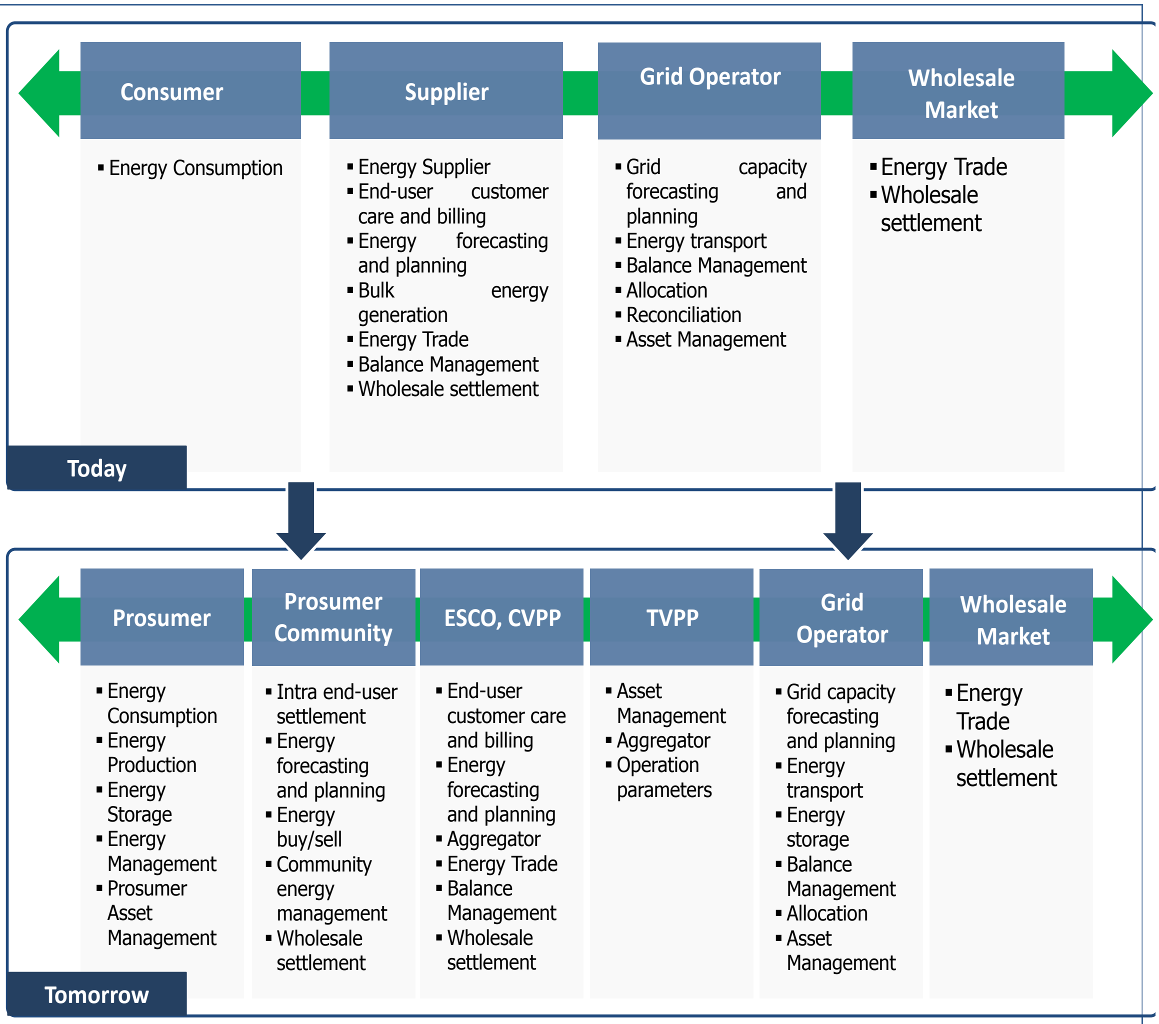
Box 10.1 Defining new concepts emerging through use of Smart Grid

Aggregators

Design of specific Smart Grid application may require the licensees to transact with large number of users. Dealing with such large number of consumers besides being an expensive activity also makes limited operational rationale for the licensee, since an individual user is unlikely to impact the licensee operations. In such cases, aggregators are introduced who act as intermediaries between the licensee and the individual consumer. In such a model, the licensee seeks to minimize its operational cost and offers incentives, fixed fee to the aggregators to achieve certain goals and provide specific services. The aggregators in order to maximize their profits work towards promoting deployment, creating awareness and encouraging users to adopt the scheme. The concept of aggregators is common in applications like DR and provisions of grid-based storage services.

Prosumers

Prosumer is an emerging concept in the electricity market that applies to a consumer that also produces energy. In a Smart Grid, a prosumer can be characterized by distributed generation technologies, energy storing equipment, smart meters and equipment to monitor, control and operate. Advanced metering and communication technologies enable consumers to become more actively involved in the whole energy system and have higher footprint in the system as 'prosumers'. Enablement and advanced usage and deployment of this require the utilities and the regulators to define new rules that govern such interaction of prosumer with the grid. From a structural perspective, adding prosumers to the value chain significantly changes its whole structure and underlying functionalities:



Source: A Prosumer-oriented Energy Market - Developments and future outlooks for Smart Grid oriented energy markets, IMPROSUME Publication Series #3, NCE Smart Energy Markets, Halden, 2012

Legend: CVPP - Commercial Virtual Power Plant (commercial aggregator); TVPP - Technical Virtual Power Plant; ESCO - Energy Service Company

The structural transition above also leads to change in the business characterstics and ways transactions happen in the electricity markets.

Transition of roles and actors in prosumer-based power system

- **New technology:** Smart Grid applications also involve dealing with new technologies such as AMI, advance metering and communication equipment, EVs and storage devices, etc. which may have a different life and recovery period. Such equipment might also run risk of obsolescence due to rapidly evolving technology.

- **New standards:** Smart Grid applications will involve communication across multiple entities that need to follow new protocols, and network and communication standards. Standards are required at both the application and communication level to ensure seamless communication among large number of entities involved, prevent vendor lock-in and ensure scalability systems. Regulatory framework must interface with the existing and evolving standards for Smart Grid applications.
- **Cyber security and consumer protection:** Rules for consumer data privacy and protection will also need to be laid out since consumers will be interacting directly with the grid. The change will also pave way for new market entrants and third party service providers such as DR or EV charging aggregators, energy efficiency service providers, micro-grid owners and operators, etc.
- **New products**: Smart Grid deployment will also result in newer products such as dynamic tariff mechanism, incentive and penalty framework governing transaction of consumers, utilities and involved third parties.

A regulatory framework that clearly spells out the above aspects is thus necessary for promoting Smart Grid deployment. The model Smart Grid regulations, issued by the FOR in India recently, provide an enabling framework for introducing several of the above aspects.

10.2 Key Regulatory Considerations for Smart Grid Projects

While formulating Smart Grid projects, following aspects should be taken into consideration:

10.2.1 Smart Grid Investment Approval

Traditionally, capital investments by utilities are considered by SERCs through submission of an Annual Revenue Requirement (ARR) and tariff revision proposal by the utility. The SERCs decide whether the investment will be prudently incurred and whether to add the investment amount to rate base. While some Smart Grid investments may be handled in this traditional manner, there are several reasons to rely on alternative methods. For instance, several Smart Grid projects aim at creating foundation infrastructure such as AMI or communication backbone that will require approval of capex upfront; however the benefits may be realized later. Such plans may require special treatment. Another reason is that number of investments may lead to indirect benefits, not quantifiable directly. For instance, improved data regimes, monitoring and alerts system results in initiating actions for loss reduction which benefit the utilities immensely. However, the direct benefit from Smart Grid investment is improved information and system visibility, while loss reduction is a consequential benefit.

Globally there have been different approaches to approval of Smart Grids projects. Until recently, the majority of projects have been in the demonstration phase and a portion of the funding has been provided centrally or through specific ‘green’ or efficiency-related initiatives. For example in the U.S., USD 4 billion was awarded to Smart Grids projects that were selected on the basis that they would help to foster homegrown technology development, provide employment and assist in the recovery of the economy. In Europe, projects of strategic regional or national interest that would help to achieve the EU2020 energy policy targets and in line with the European Strategic Energy Technology Plan or strategic energy targets received approval and funding. However, innovative approaches are now being adopted by the regulators worldwide to deal with Smart Grid investments. In some cases, Smart Grids have been dealt altogether differently, while in other cases, a differentiated approach within the same regulatory process has been adopted. In all the cases, the standards of review have been atleast the following three components: (i) reliability impacts; (ii) cost-effectiveness of the investment (relative to alternatives); and (iii) impacts on consumers. Table 10.1 maps out the regulatory approaches adopted across European countries.

Table 10.1: Regulatory approaches for approval of Smart Grid investments[145]

Country	Action by	Description of Action
Austria	National Regulatory Authority (E-Control)	Implicitly treated within incentive regulation model, total expenditure or TOTEX benchmarking and resulting individual and general productivity offsets guarantee cost-efficient solutions.
Cyprus	National Regulatory Authority	The regulator monitors and controls the work of the network operators and obliges them to operate in the most economical and efficient way and to process with the most cost-effective solutions.
Denmark	Several parties	Several Smart Grid-related activities are currently going on and have been going on in recent years. Grid companies are generally well aware of advantages and economics of various incentives within the umbrella. Grid companies are well consolidated and will be able to invest. Whether investments, decisions will be taken depends primarily on each company's strategy.
Finland	National Regulatory Authority	Incentive for (smart) grid investments. All network investments (standard network components) are accepted in network valuation (regulated asset base) by using standard unit prices, thus encouraging Smart Grid investments (e.g. smart metering, automation, protection, and systems).
Great Britain	National Regulatory Authority (OFGEM)	The fundamental structure of the price control mechanisms is designed to achieve this objective. The new Regulation, Innovation, Incentive leading to Outputs mechanism is now being employed.
Ireland	National Regulatory Authority	While this has not been identified as a barrier, the existing revenue controls cover this for all investments. The revenue controls for the system operators include 5-year retention of efficiency gains by the system operators. This would

145 Council of European Regulators (CEER) status review of regulatory approaches to smart electricity grids, July 2011

Country	Action by	Description of Action
		serve as an incentive to choose investment solutions that offer a cost effective solution.
Italy	National Regulatory Authority (AEEG), the Italian Government	For the transmission operator: An incentive was set by Regulatory Order 87/10, which refers to an indicator B/C, therefore promoting higher benefits and/or lower costs. For the distribution operators: The legislative decree of 3 March 2011 introduces an economic incentive (WACC extra-remuneration) for modernizing distribution networks "by the Smart Grid concept". The prioritized solutions are control, regulation and management of load and generating units, including recharging systems for electric vehicles. The NRA is mandated to define the characteristics of the solutions above.
Lithuania	National Regulatory Authority (PUC)	The applied price cap principle requires the effective use of financial resources, which are defined by the X-factor. In addition, the cost of unreasonable investment plans is not included in the network price according to the Rules of Investment Approval Procedure.

For regulatory evaluation of proposed Smart Grid investments, utilities should quantify the benefits and costs of proposed project(s) to the extent reasonably possible. Some of the regulatory practices that could be adopted by utility for submitting Smart Grid investments for approval and review by state commissions in India are:

- Include clear cost benefit analysis covering all stakeholders including consumers and prosumers in the Detailed Project Report (DPR).
- Align Smart Grid investment approval process with the current existing capex approval project through development of a multi-year Smart Grid plan. These plans could then be evaluated on the basis of the objective that the national and state level roadmaps have set to achieve.
- Take into cognizance that Smart Grid is at early stages of development in India, and incentives and allowances need to be included to promote Smart Grid investments. These could include approval for higher levels of contingent expenditure, returns, depreciation for tariff determination purposes, etc.
- Focus on adequate visualization and analytics. Deployment of AMI and intelligent SCADA system is aimed at improving the amount (frequency and granularity) and quality of data that utilities maintain. Huge amount of data generated will need smart analytics to analyze such data and derive meaningful actions out of it. Therefore such analytics can be considered to be a required part of any project proposals that are submitted for approval.

- Include training to ensure that employees and consumers alike are empowered with the right knowledge which is critical for the success of the project. Therefore, allocation of cost for such activities should also be considered as part of the project proposal.

It is worthwhile to mention that Smart Grid investments can also be encouraged through new business models that encourage vendors to bring in upfront capital investments and be paid through the benefits achieved through deployment. Several models like build-operate-own, pay for service, pay from savings, etc. can be structured to achieve this.

Investment Cost Recovery

Many of the technologies that are part of the Smart Grid are yet to mature completely and need to climb significant learning curves. There is therefore a risk of stranded costs, due to high cost investments being made in an immature technology at a very early stage.

For many decades, once a utility plant was constructed or equipment installed, it could be reliably expected to remain in service for its estimated useful life. Many of these ranged from 10 to 40 years. Meters, for example, had useful lives of 10 to 15 years. However, advanced meters and metering systems employ computing technology. The technological and cost curves for computers may be very different from the equipment historically used in the electric utility industry. If advanced metering systems exhibit technological and cost behaviors that are similar to those of computers, then their useful lives may turn out to be shorter than estimated. Smart Grid technology is classified among the high-technology systems and hence requires faster depreciation than traditional meters.

A new approach to cost recovery is required to address these challenges. The various approaches through which the utilities can provide for recovery of Smart Grid investments are discussed below:

Modes of Cost Recovery			
Through ARR process (Socialization)	Specific Tariff schemes & designs	Design of Surcharges	Pricing of new services

A. Through the ARR process (Socialization)

This process involves recovery of investments through the regular ARR process. Such a recovery model leads to socialization of expenses wherein the incremental expenditure is spread over a wider consumer base. One benefit of this method is that the impact of large investment is minimized with entire consumer base sharing the burden of investments.

Both utilities and regulators are more familiar investing in equipment and plants with operation life of 20 to 30 years. Smart Grid investments however involve software and hardware which have shorter life cycle and are changing rapidly. Hence, applying long regulatory depreciation lives to short lived equipment may face the risk of stranded investment. A case example of how depreciation rates were modified to create incentive for Smart Grid investment is presented in Box 10.2 and cost recovery through tariffs is presented in Box 10.3

Box 10.2 Cost recovery through accelerated depreciation periods

Higher Depreciation Periods

Illinois Commission approved a 10-year amortization for smart meters in a Commonwealth Edison case. The Texas PUC approved a seven-year depreciation period for both Oncor Electric Delivery and CenterPoint Energy[146].

Further, the U.S. Smart Grid tax provisions have reduced the depreciation rate for Smart Grid technologies from 20 years to 10 years, bringing Smart Grid tax treatment in line with other high-technology systems. Accelerated depreciation allows utilities to take larger tax deductions on investments in Smart Grid technology each year, creating incentives for increased spending on smart meters and related equipment as well as reducing the risk of future stranded assets due to technology advancement.

Box 10.3 Cost recovery through tariffs

Recovery from tariffs

To promote demonstration projects, the regulatory model in Finland (applies from 2012 to 2015) includes an innovation incentive allowing a proportion of research and development (R&D) costs (that covers pilot schemes) to be passed through to consumers. This is currently the position in Great Britain where up to 90 percent of the cost of certain projects can be funded from network tariffs. However, the network company still has to consider the balance between costs, benefits and risks before initiating a project. The situation is similar in Italy where there is a regulatory scheme for the promotion of demonstration projects, which are assessed by the National Regulatory Authority on the basis of their starting date.

B. Specific tariff schemes and designs

This recovery method involves introduction of specific schemes to incentivize users for promoting a particular application that is likely to benefit the stakeholders. Some examples include CPP, RTP and incentives for interruptible load. Few examples of these tariff schemes are provided in Box 10.4, Box 10.5, and Box 10.6.

[146] "State Regulatory Update: Smart Grid Cost Recovery", Edison Electric Institute, 2016.

Box 10.4 Specific tariff scheme: CPP

Specific tariff scheme: CPP
System operators such as PJM Interconnector publish CPP rates, (normally during times of stress for a period of two weeks and related to summer cooling load) that encourage downstream-connected entities to reduce consumption during this time.

Box 10.5 Specific tariff scheme: RTP

Specific tariff scheme: RTP
RTP programs are offered by Ameren Illinois and ComEd in Illinois, U.S. where consumers pay electricity supply rates that vary by the hour. The fixed-priced electric supply rate is reflected in the Price to Compare table and in addition the utilities also charge for the costs of purchasing the electric supply without any mark-up or profit. Unlike the utilities' fixed-priced electric supply rate, the utilities charge residential consumers real-time pricing for the electricity they consume each hour based on the corresponding wholesale hourly market price of electricity. With Ameren's residential real-time pricing program, hourly prices for the next day are set the night before and can be communicated to consumers so they can determine the best time of day to use major appliances.

Box 10.6 EnerNoc innovative incentive scheme for cost recovery[147]

EnerNoc incentive scheme for cost recovery
Through a third party service provider (EnerNoc), Midwest Energy in the U.S. targets consumers with peak summer demand of more than 30 kW, which includes more than 2,000 accounts. For accounts having 40 hp motors at pumping sites, there is no charge for participation and sites with a 25 hp motor can participate by paying a USD 500 installation fee. For participation, Midwest Energy pays USD 20 per kW of interrupted capacity, with the rate escalating higher in subsequent years of participation. In this case EnerNoc is paid a fee by Midwest Energy relative to the service they provide and the savings Midwest makes.

C. Design of Surcharges

System improvement surcharges are designed to provide consumers with improved service quality; greater rate stability; fewer service interruptions; increased safety; and lower levels of unaccounted for energy. In light of today's difficult financial markets, system improvement charges are one of the few types of innovative regulatory policies that are expected to provide access to capital markets at reasonable terms.

[147] http://www.enernoc.com/our-resources/case-studies/547-midwest-energy-grows-new-energy-supply-with-enernoc-agricultural-demand-response [Last Accessed Online: 10-Feb-2016]

A system improvement charge would normally appear as a surcharge on consumers' bills. The surcharge amount is expressed as a percentage and applied to the total amount billed to consumers under normal rates and charges.

The system improvement charges enable utilities to:

- Accelerate investment in new plant to replace ageing infrastructure.
- Recover fixed costs (depreciation and pre-tax return) of certain non-revenue producing, non-expense reducing infrastructure improvement costs placed into service between control periods.
- Better absorb increases in other costs for a longer period of time, particularly during times of relatively low interest rates.
- Facilitate compliance with evolving regulatory requirements.

Projects are limited to revenue neutral projects, consisting principally of infrastructure replacement. The costs of additional infrastructure required to serve new consumers is generally not to be recoverable through this method. Some examples of the same are presented in Box 10.7.

Box 10.7 Examples of surcharges for cost recovery

In Germany, all domestic consumers pay a green surcharge to cover the costs of investing and integrating RE including the balancing costs.

In the U.S., based on experience in the water industry, the Pennsylvania Public Utility Commission (PUC) recently approved the use of system improvement charges to allow electric companies to use a surcharge on consumers' bills to accelerate the replacement of aging infrastructure that could normally only be replaced at the end of its recovery period.

Instances of application of surcharges do exist in the Indian context as well. The Maharashtra Electricity Regulatory Commission introduced reliability surcharge for withdrawal of load shedding for specific consumer categories in specific areas. Similarly, surplus power from captive power generating plants was supplied to consumers in Pune for payment of additional charges clubbed along with the tariffs.

D. Pricing of new services

Similar to surcharges, new services provided through Smart Grids can be recovered through specific pricing of such services. For instance, regular alerts to consumers for load management may come as specific service provided through utility designated third parties. In such cases, the SERCs may permit recovery of charges through different modes.

Box 10.8 Pennsylvania Public Utility Commission – system improvement charges[148]

Based on experience in the water industry, the Pennsylvania Public Utility Commission (PUC) urges the use of system improvement charges to allow electric companies (distribution system improvement charge – DSIC) to use a surcharge on consumers' bills to accelerate the replacement of existing ageing facilities that otherwise will occur if the utility waits until the completion of a rate case to begin receiving a return on its investment. System improvement charges reduce the frequency and the associated costs of base rate cases while maintaining a high level of consumer protection through better reliability and service.

10.2.2 Tariff Design to Support Recovery of Smart Grid Investments (By Promoting Deployment)

A common practice across several Indian states has been to encourage consumers to shift their consumption from peak to off-peak times through adoption of TOD tariffs. However, in the emerging scenario, the pricing design has to be differentiated from conventional TOD pricing since the peaks are more volatile than in the past and the prices can vary radically between days of the month and between seasons.

The conventional tariff regimes will need to change with deployment of Smart Grid technologies that redefine the way the consumers and other related stakeholders interact, understand and manage energy consumption. Technology-enabled and consumer-driven DR will not take occur unless the two key regulatory issues are addressed:

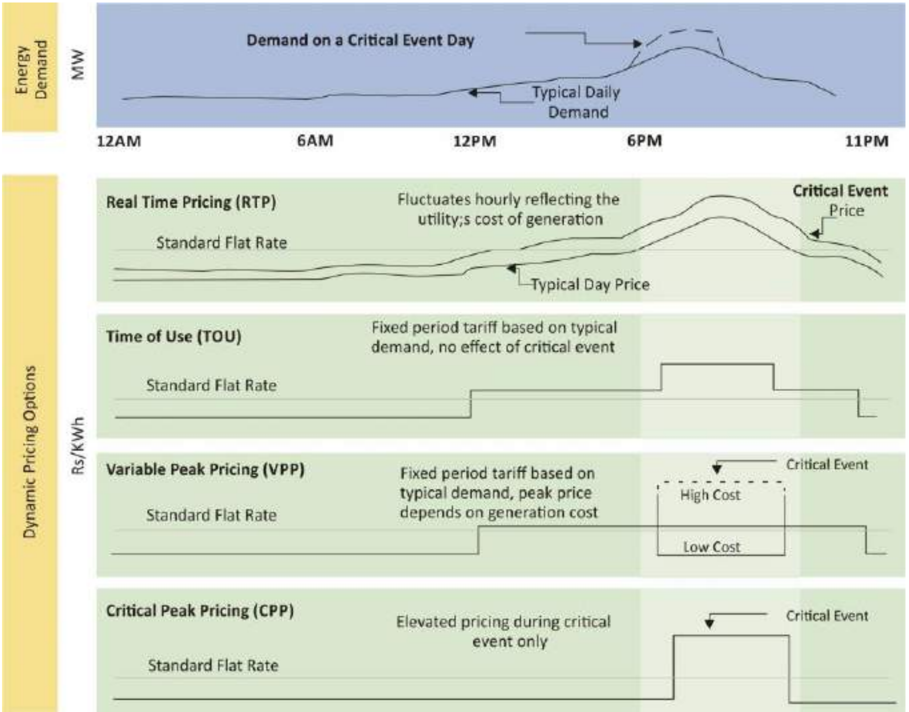
- Provide consumers economic incentives to reduce peak demand through dynamic pricing programs. Increasing price volatility and high costs of peak power makes it necessary to communicate the price signals to consumers who are otherwise insured from them. Such signals through dynamic pricing are likely to create benefits in the form of avoided generation, transmission and distribution costs.
- Readable, simple and understandable consumption and pricing information which is accessible in real time to consumers and other third parties.

Dynamic pricing framework as and when notified would in effect complement the utility programs on DR. The key difference between DR and dynamic pricing is that while DR targets relatively fewer but large consumption consumers, the target of dynamic pricing would be a larger body of consumers with lesser consumption. There are spectrums of dynamic pricing strategies (as presented in Figure 10.2) like TOU, CPP, Critical Peak Rebate (CPR) and Real Time Pricing (RTP) which can be explored in India.

These are explained below:

[148] http://www.puc.state.pa.us/general/consumer_ed/pdf/dsic_fs.pdf [Last Accessed Online: 10-02-2016]

Figure 10.2: Dynamic pricing options



- **TOU:** Prices vary by rate period and day of week, but do not change based on system conditions (technically, not a dynamic rate option). TOU prices and time periods are generally fixed at least a year in advance. TOU offers consumers the least potential reward at the lowest risk.
- **RTP:** Prices change on an hourly or sub-hourly basis to reflect the true cost of supply in the wholesale market. The volatile nature of RTP can harm consumers and may discourage participation in voluntary dynamic pricing programs although RTP offers consumers potentially the highest reward compared to traditional flat-rate pricing, but at the highest risk.
- **CPP:** CPP captures the true cost of power generation during the period when the demand reaches its peak (i.e., top 100 to 200 hours a year). In exchange for paying very high prices during those peak hours, consumers receive a discounted rate for all remaining hours of the year. The actual times in which the CPP will be in effect are identified on a day-ahead (and sometimes day-of) basis, depending on the demand–supply balance.
- **CPR:** CPR is similar to CPP, but instead of higher prices during peak periods on selected days, consumers are paid to reduce load (technically, not a rate, but a pay-for-performance program). CPR allows consumers to remain on their current flat rate while receiving a cash rebate for each kilowatt hour (kWh) of energy usage they reduce from their baseline usage during the peak hours. Thus, CPR provides an opportunity to consumers to save money on their monthly bill.

Internationally, several countries have experimented and benefitted from dynamic pricing regimes. Two such examples of use of dynamic pricing in South Dakota and Minnesota are mentioned in Box 10.9 and 10.10.

Box 10.9 Case examples of implementation of dynamic pricing regimes[149]

Sioux Valley Energy (SVE) is an electric cooperative serving approximately 21,000 consumers in seven counties in South Dakota and Minnesota. During the summer of 2011, SVE offered CPP to about 600 consumers to participate in a pilot program to reduce their electricity consumption on those days and times when hot weather and air conditioner use would normally push SVE into buying more expensive power from suppliers.

Of the consumers participating in the CPP pilot, some volunteered (opt-in), while a larger number of others were included in the program but were allowed to leave (opt-out) if they were not interested in participating. Those consumers who chose to opt-out were placed back on the standard rate. A third group of program participants consisted of consumers who were not placed on the CPP rate but were encouraged to monitor their consumption through a web portal or an in-home display. As a part of the program, SVE wanted to learn whether giving consumers access to information on their consumption and costs alone would have an effect on peak demand.

The CPP rate went into effect on days identified by SVE when system electricity demand would reach peak levels and result in higher wholesale power costs. Participating consumers were notified of the critical peak event one day in advance using phone calls, email, text messages, or in-home displays. SVE could have announced up to 35 critical peak events over the summer, but chose to be cautious and called only 13 critical peak events. When called, the critical peak events covered a four-hour period between 4:00 p.m. and 8:00 p.m.

When the rate was in effect, CPP participants paid fifty cents per kilowatt-hour, compared to less than seven cents during all other times. SVE consumers on standard rates paid more than nine cents per kilowatt-hour, so the CPP participants could save money (about two cents per kilowatt-hour), particularly if they were able to reduce electricity use during critical peak events. The CPP of fifty cents per kilowatt-hour provided a financial incentive for participants to shift optional activities, such as clothes washing and drying and dish washing, to times other than critical peak periods.

Impacts varied by type of SVE CPP pilot participant class and whether they were placed on CPP or just had access to a web portal or in-home display.

Results from SVE's pilot program demonstrated that the CPP strategy was successful in lowering peak demand. Residential consumers in the pilot reduced their consumption during peak periods by about 5 to 25 percent, depending on whether they were in opt-in, opt-out, or technology-only groups. Findings for farms and other rural residential consumers in these same groups were tallied separately; they also reduced their consumption during peak periods, but by somewhat lower amounts.

[149] https://www.smartgrid.gov/files/Sioux_Valley_Energy_Case_Study.pdf [Last Accessed Online: 6-Feb-16]

Box 10.10 Case examples of TOD implementation in MSEDCL[150]

Most of the SERCs in India have implemented TOD tariffs, generally for large industrial and commercial category consumers in the country. As one such example, Maharashtra State Electricity Distribution Co. Ltd., according to the tariff order dated 26-June-2015, follows the following TOD tariff for consumer categories with consumption of more than 20KW:

Time Slot	TOD Tariff (INR per KWh)
2200 Hrs-0600 Hrs	-1.50
0600 Hrs-0900 Hrs & 1200 Hrs-1800 Hrs	0.00
0900 Hrs-1200 Hrs	0.80
1800 Hrs-2200 Hrs	1.10

In addition to the above, it is critical to harness all local generation or distributed generation resources, especially RE through supportive tariff regimes. Therefore, consumers owning generation or 'prosumers', need to be incentivized to provide their resources to the grid. In most cases net metering or Feed-in-Tariff models have been introduced.

Box 10.11 Case of use of net metering for distributed generation[151]

A recent study of net metering in California using actual data from 10,000 solar systems and analytic models from the California Public Utilities Commission (CPUC) found that when California reaches its current net metering cap of 5 percent of non-coincident peak load (at about 5.2 GW of solar), the benefits of net-metered projects will exceed the costs by about USD 92 million annually, across the three large investor-owned utility territories in the state. With the introduction of smart meters, it is now possible for licensees to push price signal to consumers and allocate costs according to the time of use and state of the grid or true cost of supply during that time. Smart meters also have the facility to calculate net units in and out from the consumer to enable any net metering programs.

Box 10.12 Net Metering use case in Delhi[152]

In 2014, the Delhi Electricity Regulatory Commission came out with a rooftop solar 'net metering' policy to promote RE. Since then, BSES DISCOMs have promoted the concept among their consumers about the benefits of this initiative. BSES Rajdhani Power Limited (BRPL) has energized five rooftop solar 'net metering' arrangements in South and South West Delhi. Out of these, 4 are domestic (in Kailash Colony, Pushpanjali, G K 3 and Pushp Vihar) and one is commercial (Pushp Vihar). Between them, they have an existing sanctioned load of 287 KW. These five connections total 66 KW of roof top solar net metering load. They are expected to save the respective consumers between 360 units and 3600 units per month. In monetary terms, this translates into monthly savings of between INR 3,000 (USD 45) to INR 32,000 (USD 478).

[150] http://www.mahadiscom.in/tariff/Order-121of2014-26062015.pdf [Last Accessed Online: 1-April-16]

[151] http://votesolar.org/wp-content/uploads/2013/07/Crossborder-Energy-CA-Net-Metering-Cost-Benefit-Jan-2013-final.pdf [Last Accessed Online: 6-Feb-16]

[152] http://www.bsesdelhi.com/HTML/press/2015/Net_Metering_Eng.pdf [Last Accessed Online: 1-April-16]

Therefore, it is important that the utilities seek to incorporate incentives for consumers owning generation to supply excess capacity to the grid.

Further, utilities may choose to implement DR programs, under which incentive is paid to the consumers to curtail their consumption as part of an agreed arrangement (which pays an incentive for number of units curtailed over a period of time and number of events over a given period). Whereas dynamic tariff programs encourage consumers to adjust their consumption behavior in response to price signals pushed by the utility to smart meters, DR programs may pay incentives for interruptible load, curtailment services provided by third party service providers such as EnerNoc and Viridity Energy in the U.S., Kiwi power in the UK and VTrium Energy in Singapore.

10.2.3 Customer Participation and Grievance Redressal

Traditionally energy efficiency programs have focused on improving the end uses like aggregating savings from installation of CFLs or installation of building management systems, etc. Such schemes are generally simple to evaluate, monitor and verify, with clear and tangible benefits. Implementation of Smart Grid enables utilities and the consumers to achieve more than traditional static demand management programs, by bringing in behavioral changes that do not lend themselves to simple measurement and monitoring.

Smart Grid technologies and tools can enable consumers to understand their electricity use, manage their electricity bills, and sell power back to the grid. Adequate consumer awareness and involvement is critical for successful deployment of Smart Grid programs and applications.

In line with the above, the Model Smart Grid regulations also provide for creation of adequate awareness, and hence promote consumer participation and involvement in Smart Grid initiatives and programs. It also should emphasize the need for each Smart Grid program proposal to have a clear strategy for consumer involvement.

Further, prosumer is an emerging concept in the power market that applies to consumers of energy that can also be producers. In a Smart Grid, a prosumer can be a new and active participant in balancing the electricity system. A prosumer can be characterized by distributed generation technologies, energy storing equipment, smart meters and equipment to monitor, control and operate. The Smart Grid creates the basis for intelligent integration of user-actions in securing a continuing high supply security while integrating more fluctuating RE into the electricity supply system. An important requirement is acceptance and active adoption of the new possibilities by the prosumer. Thus, with prosumers becoming an integral part of electric system, new set of directives will be needed to resolve any dispute that may arise under such interaction.

It is thus important in case of Smart Grid to have new set of directives to resolve any dispute that may arise for the emerging prosumer.

Having mentioned this, it is also important to maintain alignment with the existing grievance redressal mechanism already present across different states. In view of this, the standard practice that can be applied by the regulatory framework can be to allow the utility to attempt to resolve the issue at the first point of contact before it reaches the grievance redressal mechanism. An Internal Grievance Redressal Cell to deal with such issues should be maintained by the utilities.

In the event that a consumer or prosumer is not satisfied with the remedy provided by the internal cell the consumer could have the option to submit the grievance to the CGRF. As per the Electricity Act, every licensee has to establish one CGRF having jurisdiction over its area of supply. If the consumer is still not satisfied by the order of the forum, then he may file representation before the Ombudsman.

While such provisions are required, the systems may also need further strengthening to deal with new kinds of issues that may emerge with Smart Grid applications such as prosumer issues, issues to deal with third parties, etc.

10.2.4 Evaluation, Measurement and Verification (EM&V)

EM&V will become increasingly important as the utilities, third parties and consumers move towards advance level of deployment of Smart Grid applications. EM&V will be necessary for baseline setting, goal setting, introducing focused initiatives and assessing cost-effectiveness of programs.

The EM&V Planning should be intended to address the following key issues:

- The proper allocation of EM&V costs.
- The proper attribution of savings, when results from multiple evaluations have to be credibly tabulated into a collective total by following common rules and processes.
- The details of desired stakeholder input into the various aspects of the overall EM&V and reporting process.
- Procedures to identify and prevent duplication of evaluation efforts and prevent both the duplication of research towards the development of ex-ante measures and what happens when measures are not yet researched, but needed, must be clearly defined up-front.
- The realization of economies of scale by evaluating similar initiatives and efficiency projects together; such that fewer individual and potentially inconsistent sets of results emerge at the end of a program cycle.

Smart Grid will enable a vibrant platform for implementing new business models and applications. Analyzing different market model scenarios will be crucial in order to demonstrate the benefits of Smart Grid. The output parameters of the various applications will need to be measured by baseline metrics or indicators known as KPI.

10.2.5 Safety and Standards Related to Smart Grid

The power sector can be seen as a logical information network where nodes, representing information sources and sinks, are interconnected with information links. Information travels from source nodes to destination nodes over information links across devices belonging to different systems, organizations, people, information representation formats, and communication protocols. To facilitate seamless communication between these nodes, a set of Interoperability Standards are required. A highly interoperable integration is one that can be easily achieved by the individual who requires the result[153].

Adherence to relevant standards is critical from multiple dimensions:

- To ensure an interoperable system that involves seamless communication across multiple entities involved;
- To prevent vendor lock-in and proliferation of proprietary standards; and
- To ensure scalability of the systems installed.

Considering that Smart Grid encompasses a wide variety of network participants, standards are required at various levels.

Product Standards

The introduction of new technologies such as smart meters and AMI leads to the requirement for new product standards to ensure that the best fit technology, with safety in mind is introduced in India. In India, the responsibility for development of product standards lies with the BIS. For example, BIS in 2015 has released the standard for smart meter (IS 16444: Static Direct Connected Watt-hour Smart Meter Class 1 and 2 – Specification).

System Standards

Similar to the North American Electric Reliability Corporation in the U.S., the CEA[154] is responsible for prescribing standards on matters such as construction of electrical plants, electric lines and connectivity to the grid, installation and operation of meters and safety and grid standards in India. Some key relevant standards notified by the CEA are mentioned in Box 10.13.

[153] Partnership to Advance Clean Energy - Deployment (PACE - D) Technical Assistance Program, "Smart Grids: A Roadmap for Communication and Application Interoperability in India", 2013.

[154] The Central Electricity Authority of India is a statutory organization constituted under section 3(1) of Electricity Supply Act 1948, which has been superseded by section 70(1) of the Electricity Act 2003.

Box 10.13 Key standards notified by CEA

Some of the key standards already notified by the CEA are as follows:

Connectivity Standards

Technical standard for Connectivity to the Grid (Amendment) Regulation, 2013

Technical standard for Connectivity of the Distributed Generation Resources

Technical standard for Connectivity to the Grid Regulation, 2007

Operation Standards

Central Electricity Authority (Grid Standards) Regulations, 2010

Metering Regulations

Central Electricity Authority (Installation and Operation of meters) (Amendment) Regulations, 2010

Central Electricity Authority (Installation and Operation of meters) Regulations, 2006

Similarly, at the central level, the CERC specifies the Indian Electricity Grid Code (IEGC). The IEGC also lays down the rules, guidelines and standards to be followed by various persons and participants in the system to plan, develop, maintain and operate the power system, in the most secure, reliable, economic and efficient manner, while facilitating healthy competition in the generation and supply of electricity. The SERCs are also mandated to notify the State Grid Code consistent with the provisions of the IECG.

All of the above regulations are critical to ensure reliable and safe grid operation, both at the transmission and the distribution level and should be interfaced within the Smart Grid regulatory framework.

Network and communication standards

As stated earlier, the Smart Grid business opportunity is substantial and the business model is expansive. There are several challenges in integrating technologies and industries, and ensuring seamless communication and information flow across multiple entities. There is thus a need for uniform and harmonized set of standards.

Box 10.14 Network and communication standards

Within India, a Panel on Digital Architecture has been constituted by BIS under Power System Control and Associated Communications Sectional Committee LITD 10 to formulate Guidelines on Standards for Interoperability in Power System Communications. The Panel has released draft guidelines in 2014[155].

For matters relating to cyber security, the DeitY has specified the National Cyber Security Policy.

[155] Can be accessed online at http://www.bis.org.in/sf/ltd/LITD_10_3299.pdf [Last Accessed on 6-Feb-2016]

Performance Standards

Currently, several SERCs in India have specified the Standards of Performance (SOP) regulations. These regulations specify the minimum and overall standards for several parameters that reflect a utility's performance as a whole including the interface with consumers. The regulations also specify penalties for under or non-performance.

In several cases, the utilities lack proper systems to accurately measure these parameters; as a result the compliance levels have been low. Smart Grid aims to provide foundation infrastructure that enable accurate measurement of such parameters; and coupled with adequate analytics facilitate introduction of focused measures to improve performance.

Consumer data protection standards

The basic infrastructure and architecture of Smart Grid technologies poses significant privacy issues as the Smart Grid relies on AMI, two-way communication network and data management that enables active information exchange between the utilities and the consumer.

In the U.S., a Regulator's Privacy Guide to Third-Party Data Access for Energy Efficiency[156] was developed as a product of the State and Local Energy Efficiency Action Network (SEE Action), facilitated by the USDOE and the U.S. Environmental Protection Agency.

Similar on the lines prescribed by the USDOE, following regulatory practices presented in Box 10.15, can be adopted for an effective regulatory framework on consumer data protection:

Box 10.15 Consumer data protection framework by USDOE

- **Privacy by design-** Utilities should incorporate substantive privacy protections into their practices, such as data security, reasonable collection limits, sound retention and disposal practices, and data accuracy.
- **Data minimization and limited retention-** Utilities should limit data collection to that which is consistent with the context of a particular transaction or the consumer's relationship with the business, or as required or specifically authorized by law.
- **Data security-** Utilities should maintain comprehensive data management procedures throughout the life cycle of their products and services.
- **Simplified choice-** For practices requiring choice, utilities should offer the choice at a time and in a context in which the consumer is making a decision about his or her data. Utilities should obtain affirmative express consent before-
    - Using consumer data in a materially different manner than claimed when the data was collected, or

[156] http://web.mit.edu/cron/project/EESP-Cambridge/Articles/SEEA%20-%202013%20-%20cib_regulator_privacy_guide.pdf [Last Accessed Online: 10-Feb-2016]

- Collecting sensitive data for certain purposes.

- **Transparency (Notice and Access) -** Privacy notices should be clearer, shorter, and more standardized to enable better comprehension and comparison of privacy practices.

Basis the above principles, classification of consumer data can be done to set clear regulatory rules on data access with third parties. There can be broadly two categories:

1. PII, which consists of consumer names, addresses, numbers, and other information that specifically identifies the person or entity to which it applies;
2. CEUD, which, in most cases, does not identify an individual consumer but includes detailed information about the utility service provided to the consumer.

The lack of protocols and standards currently for the new "smart" components means that there is a risk that investments may be made in equipment that is unable to interact with other critical components. Secure and safe IT communication and advanced software is essential for the current power system and will be significantly more important in Smart Grids. Using public networks for data transfer will lower investment costs, but will also significantly increase the vulnerability of power grids to cyber-attacks. The public risk picture is also important and highly uncertain.

To mitigate these risks it is required that the regulations put into place interoperability standards, appropriate incentive/penalty mechanisms and data protection standards for utilities. Some of the regulatory approaches are discussed below in terms of relevant examples:

- NIST initiated the Smart Grid Interoperability Panel (SGIP) to coordinate standards development for the Smart Grid. NIST has already released the NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0. The documents describe the reference model, standards, gaps, and action plans for developing a secure and interoperable Smart Grid. It also states that Smart Grid will continually evolve as new requirements and technologies emerge. The processes established by the SGIP, engaging the diverse community of Smart Grid stakeholders, provide a robust ongoing mechanism to develop requirements to guide the standardization efforts now spanning more than 20 standards-setting organizations.

- In Europe and the U.S., regulators have demanded accurate performance data from utilities related to service to consumers. Hence, a lot of effort has been accorded to integration of business processes and analytics of applications such as workforce and asset management which record outage information to automatically provide information on levels of service to consumers.

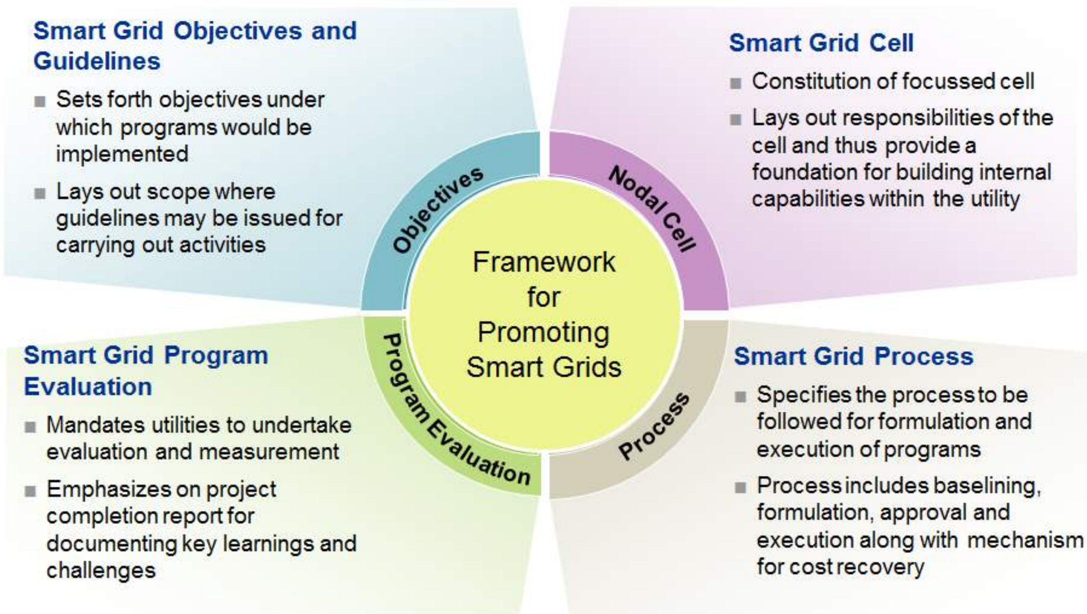
- The UK Energy watchdog monitors performance of all of the UK utilities and issues fines to utilities according to the inconvenience to the consumer. This compensation mechanism provides an incentive for utilities to ensure power to consumers. If the power cut is caused by a fault on the network, consumers may be entitled to a compensation payment. The amount compensated is exponential and is according to the duration of the outage.

10.3 Regulatory Development In India to Support Smart Grid Deployment

In order to provide regulatory impetus to Smart Grid investments, model Smart Grid regulations have been approved by the Forum of Regulators in 2015[157]. These model regulations provide a framework for SERCs to adopt these regulations in their respective states according to their needs and priorities.

The overall framework consists of broadly four sections: Smart Grid Objectives; Smart Grid Cell; Smart Grid Process; Smart Grid Program Evaluation. These are described briefly in Figure 10.3.

Figure 10.3: Model Smart Grid regulations – framework



10.3.1 Smart Grid Objectives

The model Smart Grid regulations specify that the objectives of the Smart Grid project may be:

- Improve efficiency in licensee operations
- Manage T&D network effectively
- Enhance network security
- Integrate renewable and clean energy into the grid
- Enhance network visibility and access
- Improve customer and prosumer service level
- Promote optimal asset utilization

[157] Draft Smart Grid Regulations have already been issued by Regulatory Commissions of Assam, Tripura, Karnataka, Madhya Pradesh and Haryana as on 31-March-2016

10.3.2 Smart Grid Cell

Since the Smart Grid activities cut across different functions in the utility, ensuring successful implementation and operation could require creation of Smart Grid cell within the utility. The responsibilities may include:

- Baseline study and development of data
- Formulation of Smart Grid plans, programs, and projects
- Design and development of Smart Grid projects including cost benefit analysis, plans for implementation, monitoring and reporting, and for measurement and verification
- Implementation of Smart Grid programs

In order to staff the Smart Grid Cell, the utilities would need to undertake capacity building initiatives to provide its engineers and managers with basic knowledge of Smart Grid technologies and various aspects of planning and deployment for undertaking a Smart Grid project.

10.3.3 Smart Grid Process

Baseline Study

Smart Grid will enable vibrant platform for implementing new business models and applications. Analyzing different market model scenarios will be crucial in order to demonstrate the benefits of Smart Grid. In order to gauge the metrics it would be crucial to develop baseline metrics for the required parameters or key performance indicators. In this regard, the model regulations call for utilities to undertake:

- Baseline study to identify the targets and final outcomes for Smart Grid project programs; and
- Study to estimate potential for employment of specific efficiency technologies and applications, establish key performance indicators, and determine existing baseline technical conditions.

Formulation of Smart Grid Plan

The regulations call for utilities to submit an integrated multi-year Smart Grid plan along with multi-year tariff petition or ARR petition. The proposal for Smart Grid Projects should include:

- DPR
- Customer engagement and participation plan
- Training and capacity building plan

The DPR would include inter alia description of:

Project objective	Technical feasibility study	Projected financial implications	Target stakeholders	Detailed cost benefit – all costs qualitative & quantitative	Proposed mechanism for recovery of costs
Delivery strategy	Implementation mechanism	Implementation schedule	Monitoring and evaluation plan	Plan for increasing awareness among the stakeholders	

Project Approval

In the matter of approval, the regulations call for:

- Projects to be in line with the objectives stated in the regulations; and
- Provision of incentive, dis-incentive mechanism linked to the execution, implementation and performance during the life of the project by the commission.

Cost Recovery

For cost recovery, the regulations specify that:

- Utility need to identify the net incremental costs, if any, associated with planning, design and implementation of programs; and
- Utilities should propose methodology for recovery of net incremental costs through tariff or any other mechanism.

Project Execution

In order to address the key challenge of standards, the regulation mentions the following key points:

- Utilities to normally adopt system standards as per regulations notified by the CEA;
- Network, communication, products, interoperability and cyber security standards as provided by the BIS;
- SOP as notified by the Commission will apply. Assessment of performance of projects would be carried out for incentivizing, penalizing of utilities; and
- Utilities need to ensure that protection of consumer data and privacy is accorded highest level of priority.

A broad philosophy that has been adopted while framing these regulations is to interface the standards already published by designated authorities and wherever, relevant standards are not available alignment with the international standards by the IEC, IEEE and the American National Standards Institute is considered.

10.3.4 Smart Grid Project Evaluation

Evaluation, Measurement and Verification

In the context of EM&V, the model Smart Grid regulations specify the following:

- Smart Grid program to be monitored and evaluated based on appropriate methodology including Key Performance Indicators as decided by the Commission; and
- Utility to submit an evaluation report to the Commission, which inter alia will include outcomes, benefits, lessons learnt and way forward.

Smart Grid Project Completion

For completion of the Smart Grid project undertaken, the regulations specify the following:

- Utilities to prepare and submit a detailed program, Project Completion Report within one month of completion of such program;
- The report should cover the program, project expenses, physical achievements, constraints and difficulties faced, and deviations, if any; and
- Utilities to place the completion report in public domain through its website.

In summary, a facilitative framework has been specified to promote and enable Smart Grids in India. Specific and more prescription regulations will evolve once results of the initial deployments and pilots are available. Several states have already taken note of this and have either notified or in process of notifying regulation for their respective states.

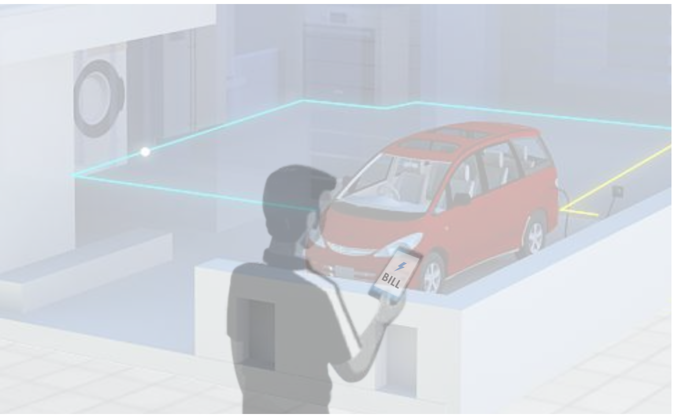
10.4 References

[1] "CEER Status Review of Regulatory Approaches to Smart Electricity Grids," CEER, Council of European Energy Regulators, C11-EQS-45-04, 6 Jul 2011.

[2] "Model Smart Grid Regulations", Forum of Regulators, 2015.

[3] I. Shandurkova, B. Bremdal, R. Bacher, S. Ottesen and A. Nilsen, "A Prosumer Oriented Energy Market", IMPROSUME Publication Series #3, NCE Smart Energy Markets, Halden, 2012.

[4] World Alliance for Thai Decentralized Energy Association (WADE THAI), "Smart/Intelligent Grid Systems Development and Deployment," European Union, 2013.



Module - 11

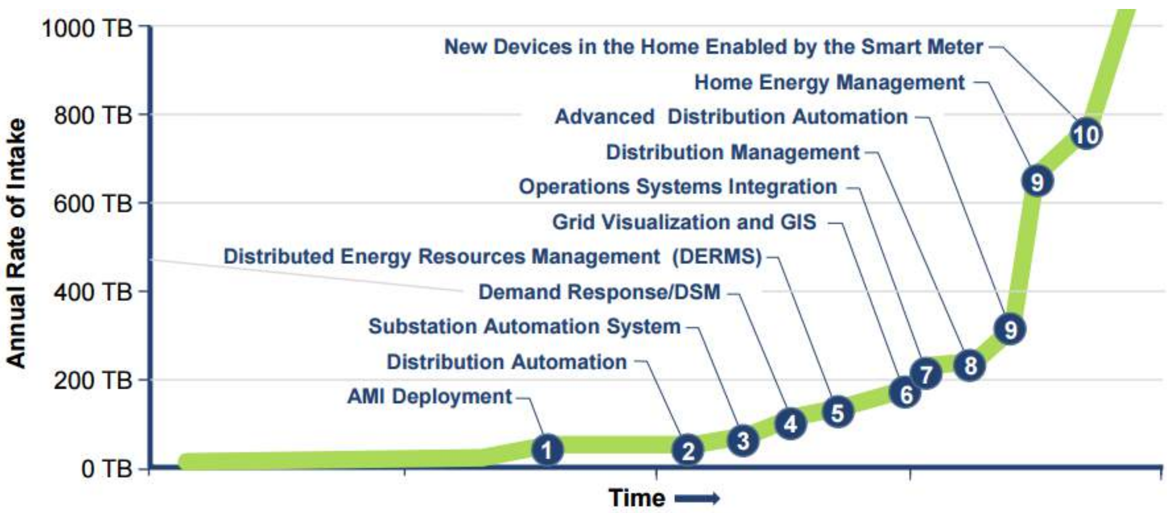
Smart Grid Analytics

11.1 Data Analytics in Smart Grid

With the adoption of Smart Grid, a number of new data sources are being added into the system that have the potential to provide distinct opportunities to drive increased operational efficiency and reliability, improved customer service, and greatly enhanced customer relationships for the utilities. It also offers distinct opportunities to drive better and more efficient operations and maintenance spending, including predictive maintenance rather than run-to-failure operations, load forecasting and balancing, asset optimization and failure analysis, better economies of scale, and more.

Without Smart Grid, the data that a utility usually collects from its customers mainly constitutes a monthly meter reading, i.e., one data point a month per customer. But with the implementation of AMI, the level of data collection would grow manifold with readings being taken at frequent intervals (ex. 10-15 minutes). AMI is just one of the many elements of Smart Grid that would lead to generation of what is termed as 'Big Data'[158]. Some of the sources of big data for utilities in a Smart Grid environment are represented in Figure 11.1[159]:

Figure 11.1: Smart Grid 'Big Data' sources[160]



As detailed in Figure 11.1, even the most basic of Smart Grid infrastructure, i.e., AMI produces data in few Terabytes and as we move towards advanced Smart Grid implementation over time, the amount of data would grow by exponential amounts and thus a shift towards analytics becomes essential for utilities.

[158] Industry Analyst firm Gartner defines Big Data as : *"Big Data is high volume, high velocity and high variety information assets that demand cost-effective, innovative forms of information processing for enhanced insight and decision making".*

[159] Source: EPRI Intelligrid Via Lockheed Martin Presentation, "Solving Big Data Challenges US Electric Utility Industry", July 2014

[160] Source: EPRI Intelligrid Via Lockheed Martin Presentation, "Solving Big Data Challenges US Electric Utility Industry", July 2014

Analytics Definition

Analytics can be defined as a process of transforming raw data into meaningful information which assist in deriving conclusions and facilitate decision making. This transformation includes four key areas:

- **Collecting, managing, cleaning and storing data**: Data is collected from a variety of sources, e.g., smart sensors, AMI, SCADA, etc. Data initially is obtained in a raw form which must be processed or organized for analysis, as an example, the data may first be organised into a specific table format for further analysis. Processed data may still contain duplicates, missing data or contain errors. This, therefore, lends the need for data cleaning. Data cleaning is the process of preventing and correcting these errors.
- **Extracting and analysing data**: Variety of techniques, statistical algorithms can be applied to analyse the clean data and understand the messages contained in it. Statistical models may also be applied to the data to identify relationships among the variables, such as correlation or causation.
- **Reporting analysis results**: Once the data is analysed, it may be reported in many user friendly formats to the users. Data visualization techniques can be employed to clearly and efficiently communicate the message to the stakeholders. Data visualization uses information displays such as tables and charts in the form of dashboards to help communicate key messages contained in the data.
- **Making decisions and taking action:** Analysing big data thus enables the business users to make better and faster decisions using data that was previously inaccessible or unusable.

For the purposes of Smart Grid data analytics, four analytical model categories can be used: descriptive, diagnostic, predictive, and prescriptive.

Analytics Model	Description
Descriptive	What happened or what is happening now?
Diagnostic	Why did it happen or why is it happening now?
Predictive	What will happen next? What will happen under various conditions?
Prescriptive	What are the options to create the most optimal or high-value outcome?

While currently most utilities can analyze data, mostly historical, on an ad hoc basis through manual entries, spreadsheets and business intelligence reports, Smart Grid data analytics enables utilities to move to a more pro-active analysis (both descriptive and diagnostic) by incorporating a much higher volume of historical data along with real time data, with more complexity, and analyzing it much more quickly. Also, with historical and real-time data at hand, utilities can look to predictive and prescriptive analytics for building real value to mitigate potential problems before they arise. By using analytics, utilities can now better improve customer satisfaction through segmentation and personalization; improve operational reliability through predictive maintenance; and increase operational efficiencies through improved forecasting and execution.

Key Drivers of Data Analytics for Utilities

Some key drivers of smart analytics capabilities include[161]:

Improved customer satisfaction through segmentation and personalization: Customer data analytics, encompassing both meter data and other customer data (such as social media and customer relationship data), will provide the utility with a means to provide its customers with information about their usage patterns and target them with more effective DR and DSM programs that enable energy cost savings for the customer. Customer rating and segmentation analysis can enable utilities to develop personalized services and marketing campaigns for consumers as well as analyze credit history of consumers to improve collections.

Improved revenue optimization and operational efficiency: Use of analytics improves utility revenues and operational efficiency through information on thefts, reduction in billing errors, accurate energy accounting, timely detection of faults and control, better system-wide resource planning, etc.

Improved grid reliability and load management: Use of Smart Grid technologies will provide geo-spatial intelligence to visualize grid operations which improves grid resilience. Data analytics insights (including predictive analytics) lead to better grid operations management in extreme weather, including reduced outages and reduced faster recovery from grid outages.

Asset Management (Repair, maintenance and replacement): Power distribution, being an asset-intensive industry, requires proper asset management as a top priority. With Smart Grid, the grid assets would increasingly be monitored and provide significant data for analysis. Advanced analytics can then be employed to improve uptimes, performance and availability of crucial assets while reducing the amount of unscheduled maintenance to minimize maintenance-related costs and disruptions of the operation.

Integration of renewable and distributed generation: Renewable sources of energy generation have inherent uncertainty regarding their availability which adversely affects the grid operations. Usage of data analytics in a distributed generation environment enables improved forecasting and consequent impact on the grid thereby enabling better RE integration with grid operations.

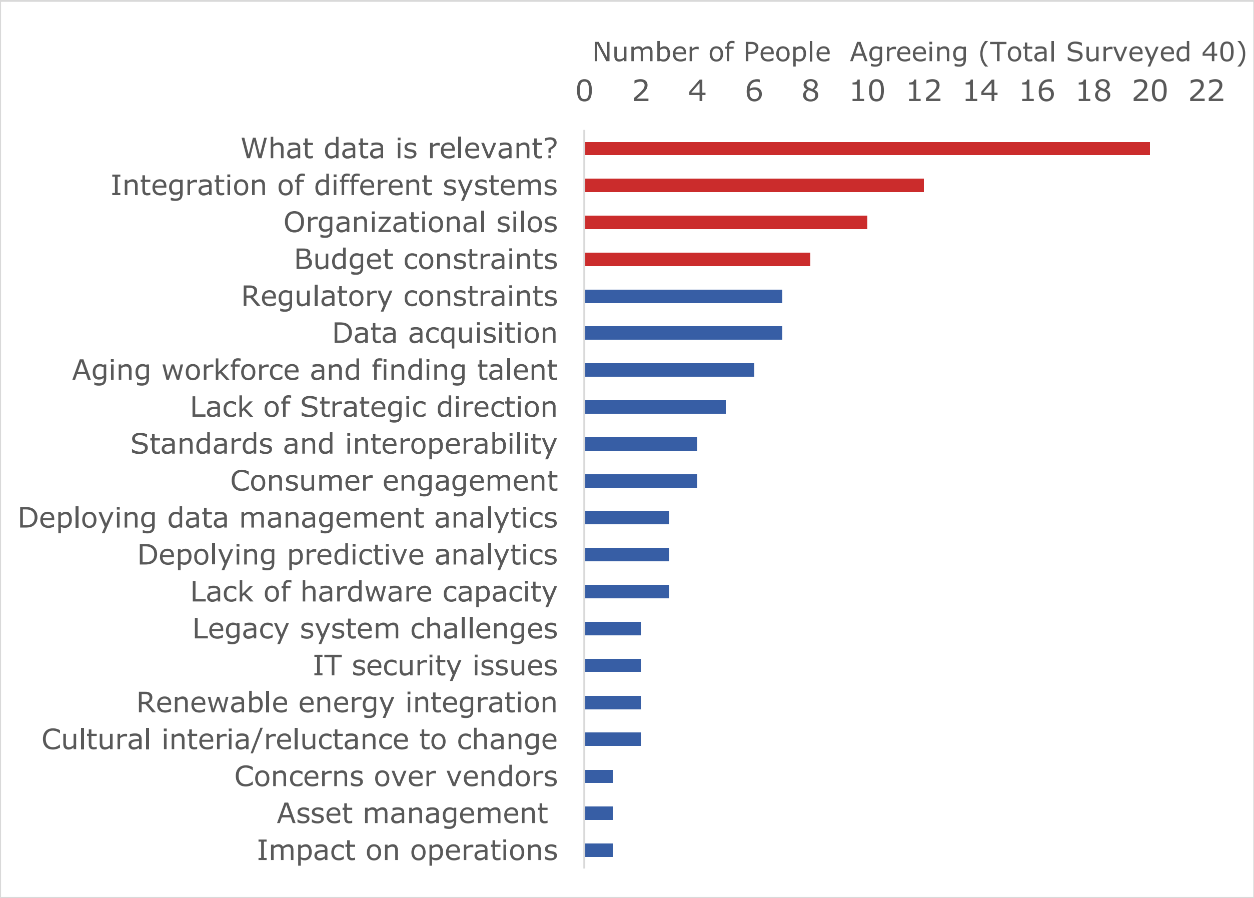
[161] Oracle Utilities, "Utilities and Big Data: A Seismic Shift is Beginning", Orac006Ce, 2013.

Barriers for Implementing Data Analytics for Utilities

In spite of the benefits of data analytics, there are significant barriers to data management.

'Smart Grid Update', a research-driven news, market analysis, online networking portal and conference producer in the UK, conducted an industrial survey among 40 plus professionals from utilities and suppliers ranging from engineers to CEOs[162] to find out what they felt were the three most pressing challenges they faced regarding data management. The survey results are shown in Figure 11.2.

Figure 11.2: Survey Results: challenges faced by top management regarding data management



As per the survey results, most crucial concerns relate to data and its acquisition, aggregation and processing. Other important concerns are integration, skilled workforce and budgetary constraints. In order to institutionalize data analytics in the utility operations, it is essential to understand some of these barriers and understand implications and possible solutions to overcome them, some of these aspects are discussed in Table 11.1.

---

[162] Available online at http://www.smartgridupdate.com/dataforutilities/pdf/DataManagementWhitePaper.pdf [Last Accessed Online: 20-Feb-2016]

Table 11.1: Smart Grid analytics: challenges and solutions

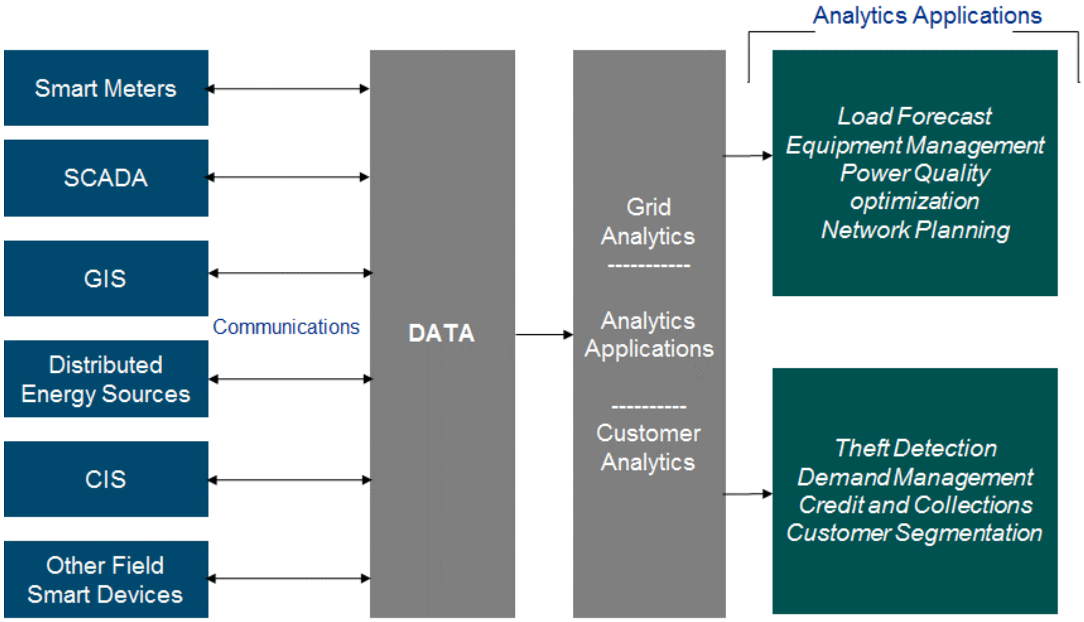
	Challenges	Implications and Solutions
Data concerns	What type of data to be collected? Whether it is relevant for the purpose of analysis? How it can be used for analysis?	Real value of Smart Grid can only be realized once these concerns are resolved and utility understands how different data points can be used to resolve practical issues at their end.
Budget and funding requirements	Lack of clear cost benefit analysis hampers investment decisions in such tools. Without clear understanding of the benefits (both qualitative and quantitative) obtaining regulatory approvals might be difficult.	Quantification of Benefits is a must to drive investments. Important to parameterize benefits related to fault prediction, theft reduction, improved billing services etc. to quantify benefits vis-à-vis cost.
Interoperability	With a multitude of hardware and software, utilities have concerns ranging from ability of technology to effectively communicate, software discrepancies and standards formats for data exchange.	A solution capable of recognizing various Smart Grid data classes and their characteristics to develop comprehensive Smart Grid data management and governance capabilities. A comprehensive interoperability guideline is an urgent requirement for advancing the standardization process in Smart Grid.
Skilled workforce	Ageing workforce in the operational department are needed to be replaced, talented IT experts are required as many utilities lack a dedicated analytics center.	Instead of costly in-house data analytics capabilities utilities can outsource the application software to third party companies or can hire specialized agencies to support to train existing workforce.
Silo based operations	Current data management strategies use multiple data formats stored in multiple databases; moreover operational teams are working in groups, silos. This makes communication among groups and sharing of data difficult.	Convergence of IT and OT processes is required. IT and OT convergence can enable utilities to reduce costs across the software management landscape, including enterprise architecture and information and process integration and can be a significant driver in helping utilities cut operational expenses by

	Challenges	Implications and Solutions
		improving their asset management capabilities.
Reluctance to change	Business operations in the utilities were established 30-40 years ago and in order to bring utility-wide data management changes, the rewards must exceed the inherent risks.	Change management coupled with adequate capacity building key to such transformation. Further, to give utilities more confidence over the analytical investments, an analytics solutions provider with years of experience in utility operational working should be chosen.
Technological complexity	Learning for utilities to apply new analytics tools, open standards for interoperability, and architectures to manage grid data at scale is an uphill task.	Selecting a data analytics specialist partner will help utility in mitigating the technological risks. With due time capacity building programs for the employees can be organized.
Security and privacy	Future homes will be interconnected to intelligent Smart Grid which will make it a high potential target for hackers.	Privacy laws have to be established in order to prevent exploitation consumer profiles, energy usage data, etc.

11.2 Smart Grid Data Analytics Applications

Smart Grid analytics facilitates utilities to gain tremendous business value from the huge volume of data generated through Smart Grid. The business value of analytics can be derived from both the grid side and consumer side. Both grid and consumer side analytics are explained in detail in Figure 11.3.

Figure 11.3: Smart Grid analytics applications[163]

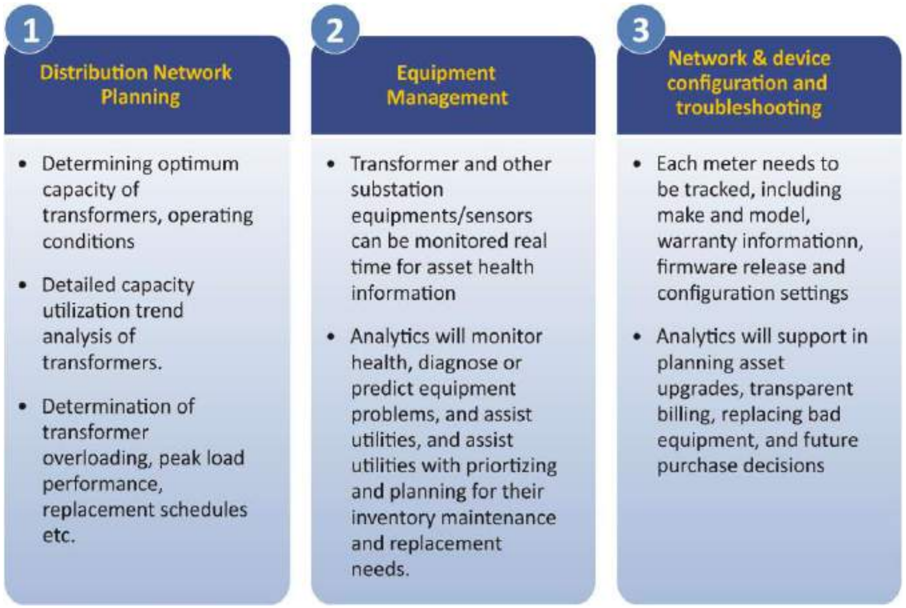


11.2.1 Grid Analytics

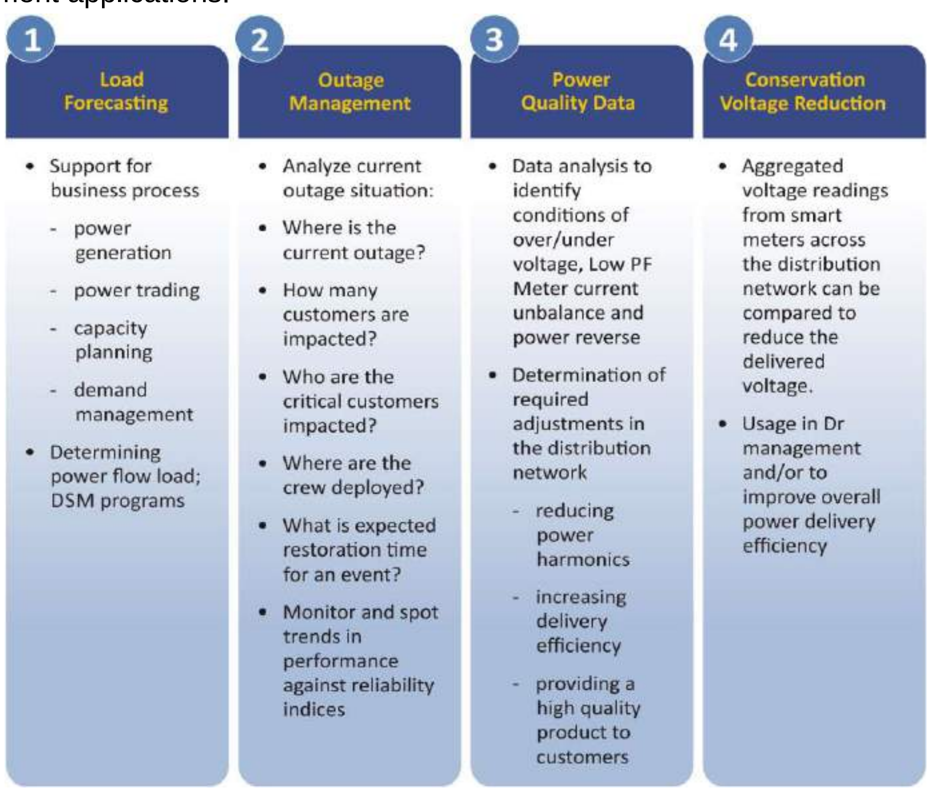
Grid-side analytics enables utilities to ensure better planning, optimum configuration and operation and maintenance of utility distribution networks. Grid analytics includes:

- **Asset optimization:** These are set of analytics that assist utilities with optimizing the performance and reliability of grid assets. This area includes categories such as, substation equipment management, network troubleshooting and overall distribution network planning.

[163] Image Source: M. Smith, "Utility Analytics: The Road from Data to an Intelligence Revolution", UtilityAnalytics Institute, 2012.



- **Network optimization:** Analytics that assist with optimizing the operation of the grid network to minimize power losses and maximize efficiency and quality. This area includes categories such as outage management, power quality optimization and advance distribution management applications.



An example of predictive grid analytics by taking advantage of smart sensor data is presented in Bo 11.1.

Box 11.1 DTE Energy, Detroit, U.S.: Sensors for a predictive grid in the motor city[164]

Project Objective:

DTE Energy wanted to move away from traditional Fault Current Indicators and instead bring back real-time fault data with waveform capture that could be analyzed to predict grid outages, provide notifications of momentaries and alert crews to line disturbances.

Project Description:

DTE Energy deployed Smart Grid Sensors and Predictive Grid Analytics platform at key substations and feeders within its extensive distribution network. This solution offered real-time data to be gathered from the sensors to the analytics software which could be used to predict faults respond to outages and monitor assets to more strategically plan their capital investments.

Data from the Smart Grid Sensors is sent to Sensor Management System (SMS) software for analysis and then pushed to DTE Energy's Data Historian, GIS and DMS to provide crews with live, situational awareness about grid conditions.

Benefits:

With this data, crews can get real-time diagnostics about what caused the faults. They can also get ahead of outages by investigating equipment failures, momentaries and line disturbances (e.g. trees brushing against power lines) before they cause a power failure. All of this data is captured, classified and analyzed by the SMS software first and this gives DTE Energy information to avoid future outages.

DTE has seen tremendous cost savings from this deployment, not only in reduced drive times and crew overtime, but in other unexpected ways as well. For example, instead of long lead time and costly substation upgrade, now with the analytics solution it takes only a couple of thousand dollars to monitor a substation remotely. Additionally, by using the Predictive Grid Analytics capabilities of the solution, they can begin to avoid outages, saving an estimated USD 10,000 per event.

11.2.2 Customer Analytics

Customer analytics enables utilities to analyze various customer and business process data in order to better serve its customers. Customer analytics includes:

- **Customer operations**: Analytics which focus on improving the internal efficiency and effectiveness of a utility's customer operations. This area includes meter data analytics, credit and collections, theft detection, campaign management, customer segmentation, rate planning modelling, and other customer operations.

[164] "DTE Energy: Sensors for a Predictive Grid in the Motor City", Institute for Electric Innovation, 2014.

1 Theft Detection	2 Rate Plan Modelling	3 Campaign Management	4 Customer Segmentation	5 Credit and Collections
• Eliminates faults/tampers of electro-mechanical meters • Potential theft can be detected by analyzing meter • Analytics can flag customers by analyzing data such as drop in customer consumption, history of irregularity in load violation, default payment	• Effectively designing and structuring dynamic price and time of use plans • Targeting specific consumer segments and reducing marketing costs	• Analytics that provide support for planning and tracking capabilities for customer marketing campaigns to enable utilities to effectively allocate marketing resources.	• Analytics that assist utilities with segmenting customers into discrete groups that share similar characteristic s to enable utilities to effectively serve and interact with those groups.	• Analytics that analyze consumer credit and payment history to optimize the cash flow of utility companies, including billing collections, and low-income customer programs

A practical international and national case study highlighting the benefits of employing analytics software solution to determine theft and tamper cases is presented in Box 11.2 and Box 11.3.

Box 11.2 Revenue Protection Software: Sacramento municipal utility district Smart Grid demonstration[165]

Project Objective

The Sacramento Municipal Utility District (SMUD) implemented data analytics software to identify instances when a meter had been tampered with, by-passed, or had simply malfunctioned.

Traditionally, SMUD meter readers would identify such issues while reading the meters each month. In order to meet or exceed the standard set by this manual inspection process, SMUD installed revenue protection software. This software generates leads for on-site investigation based on results from theft detection algorithms that process numerous datasets from different utility systems as well as external sources. The primary purpose of this project is to replace physical inspections with data analytics in order to achieve numerous objectives, including:

- Protect the customer and SMUD employees from potentially unsafe conditions due to someone tampering with the meter.
- Reduce annual revenue loss from theft.

Project Description

The utility data used by the software includes datasets from the advanced metering infrastructure (kWh, voltage, register, alarm, event, and other alert data), the customer information system (customer, premises, billing, and service notifications) and from the GIS. External or third party datasets, such as county assessor property information, weather data, and demographic data, are also utilized. Almost all of the datasets are updated daily with the exception of the GIS and county assessor datasets which are updated weekly and quarterly, respectively.

The software identifies and prioritizes the most likely theft cases. The rich datasets enable SMUD's revenue protection analysts to generate leads for investigation, using 20+ theft detection algorithms. Simple leads, such as a "zero usage" that match disconnection orders, are usually viewed and closed without a field inspection. The leads requiring field inspection are prioritized based on weighting criteria defined by the analysts.

The revenue protection software processes the data to rank probable tamper and theft cases. The ranking relies on a combination of algorithms. The weight given to each algorithm result can be configured. This permits refinement of the total weighted score used to rank each case. Some of the algorithms utilized in the software are listed below.

- Consumption drop score – looks for decrease in consumption over past two years.
- Drop on tamper flag – looks for consumption drop immediately following a tamper or power down event.
- Frequent tamper alert – looks for a pattern of multiple tamper flags and a repeatable pattern.
- Load factor score – targets businesses with low consumption relative to their demand, a possible indication of intermittent tampering.
- Local chain business comparison – compares usage of customer to usage of similar customers.
- Max monthly usage – records the highest monthly energy consumption for comparison.
- Meter set score – compares the seasonal interval consumption before and after the meter set.
- Minimum consumption score – assigns a score to the minimum energy use by the customer.
- Neighbor score – measures deviation from expected consumption based on nearby residences.

[165] EPRI, "A Case Study on the Revenue Protection Software: Sacramento Municipal Utility District Smart Grid Demonstration," 2014.

- Reverse power alert – records when power flow through the meter is from the customer to the utility.
- Slope percent – slope component of the linear regression over past two years.
- Total score – combines resultant scores of other algorithms to determine the likelihood of theft.
- Unauthorized use alert – records and flags energy consumption on an idle meter.
- YP score – identifies location of the customer based on phone number of customer.
- Zero use alert – registers zero energy consumption.

Results

The revenue protection software permitted SMUD to move from a reactive response, relying on tips from the public and from SMUD employees, to a proactive response, using statistical analyses to make inferences of the data and identify possible theft. SMUD has benefited from the technology and reduced revenue loss. SMUD does assign the following benefits to the detection software, and is starting to see trends, such as increases in the kWh billed and dollars collected, as shown in the following table.

Summary of the Billed vs Collected Amounts with and without the Revenue Protection Software

	2011	2012	2013	12 Months prior to detection	12 Months after detection
$ Billed	$1,752,820	$1,120,860	$2,953,334	$1.36M	$3.11M
KWh Billed	9,912,680	5,009,350	13,738,497	-	-
$ Collected	$138,020	$337,030	$653,418	$334k	$723k

Benefits to the customer:

- Improves customer safety by better identifying meter tampering.
- Reduces revenue loss that would negatively impact customers by contributing to future rate increases.

Benefits to the utility:

- Improves employee safety.
- Prioritizes leads based on ones with the highest probability of theft.
- Provides efficient use of SMUD resources (labor, fuel, investigation costs, and software).

Box 11.3 BSES: Smart Grid analytics for theft detection[166]

Project Overview:

Modern analytics is playing a big-role in crackdown by BSES against power-theft. It is helping BSES unearth even the most ingeniously planned meter tampering cases.

Smart meters installed by BSES have intelligent logic and software modules. Any deviation, sudden power interruption and abnormal event logging is recorded. Apart from the smart meters, energy input data from the over 11,000 distribution transformers is routinely being collated. Both types of data are analyzed using sophisticated tools by a centralized team and power-theft locations narrowed-down significantly with active use of technology.

Solution Overview:

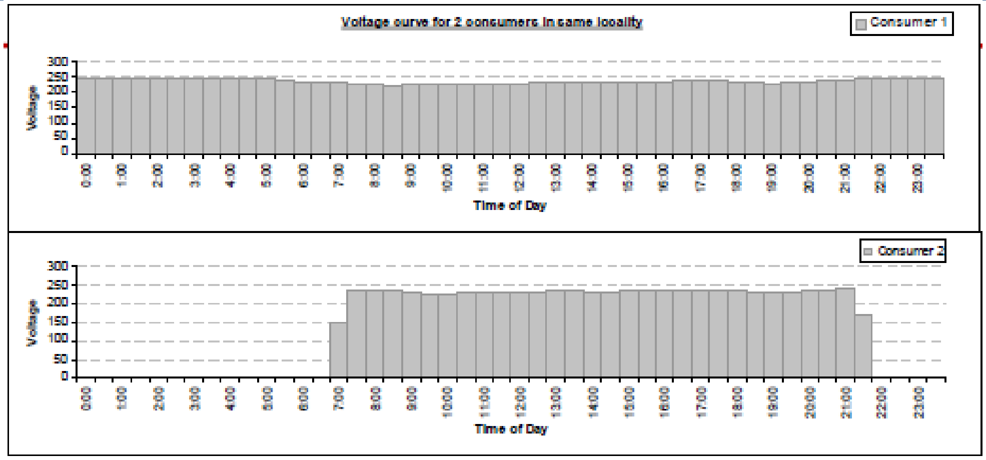
BSES has identified that successful theft creates abnormalities related to:

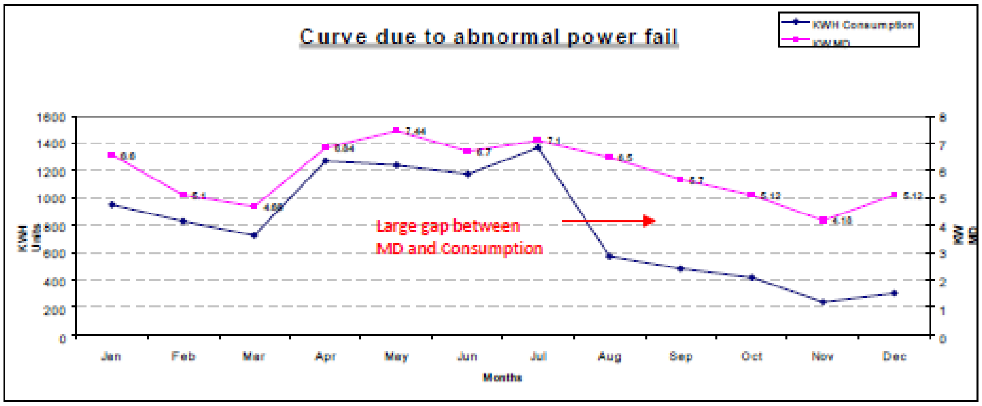
- Basic electrical, voltage principal
- Load abnormalities
- Consumption pattern
- Power availabilities
- Other sensor observations
- Meter memory data related
- Other meter parameters
- Behavior

Using analytics BSES is identifying such abnormalities to detect theft. Four maturity levels of analytics are in place:

- **Level 1: Consumption based analysis** - Simplest analysis but cannot be treated as evidence of threat.
- **Level 2: Consumption with survey data** - Other information obtained from secondary source (e.g. activity, operating hours, premise size, etc.) and similar consumers are analyzed by comparing these data.
- **Level 3: Tamper events** - Programmed the meter so as to identify abnormalities and log events. Analyzed logged events and consumption pattern to identify theft. This leads to high strike rate, but can only identify theft according to predefined criteria.
- **Level 4: Instantaneous parameter** - Meters log instantaneous parameters such as voltage, current, PF, power on/off, etc. These instantaneous parameters are analyzed for patterns and variations to identify theft. Key to such analytics is 'Logics', i.e., relation between theft method and its impact on meter parameters. Once relations are established, then cases of theft are filtered accordingly. This method has a very high strike rate and also wider acceptance by judiciary. BSES has employed about 125 logics to its analytics solution.

[166] http://www.bsesdelhi.com/HTML/press/2014/BSES_Meter_Tampering_Cases_Nov-21_english.pdf [Last accessed:01-04-2016]
http://www.esi-africa.com/wp-content/uploads/i/p/Rajesh-Bansal_Metering2.pdf [Last accessed:01-04-2016]





Result:

From April to November, 2014, over 15,000 cases of meter tampering have been detected by BSES and over 83,000 KW of power-theft load unearthed across South, West, East and Central Delhi.

- **Customer engagement:** Analytics which support utility interactions with customers and improve their relationship with the utility through improved service, lower costs and better customer experiences. This area includes categories such as DR, energy efficiency, prepayment, and other customer engagement.

1 Conservation tips and suggestions	2 Rate plan selection	3 Efficiency measurement & planing	4 Prepay	5 Demand Management
• Consumer specific energy conservation recommendations • Optimizing baseline power consumption by monitoring usage of pcs, set-top boxes charges which consumes power even when not in use	• Customer analytics tools to help choose best suited energy rate plan • A "best plan selector tool" can recommend best plan with estimated amountof energy savings. • Interface will be easy to grasp backed by powerful analytical algorithms	• Data analytics can effectively measure the success of energy efficiency programs by aggregating and analyzing all the data	• Well established in emerging markets where electrification is high with low consumer credit levels • Pro active notifications to consumers regarding recharging of plans before service interruption	• Analysis and tracking of consumer consumption under a monetary reward based DR program to prevent exploitation • Validating demand reductions claimed by third party DR service providers and DRA

Box 11.4 Utility Data Analytics Case Study: Oklahoma Gas & Electric (OGE)[167]

Project background

OG&E's "2020 Initiative" prohibits it from building any new fossil-based generation plants until the year 2020. OG&E was looking to fill the gaps via targeted residential and small commercial DR programs, and in this respect started to use dynamic customer segmentation analytics to target best bets. The utility's chief challenge was to leverage greater value and energy savings out of the 800,000 control points (i.e., smart meters) which were recently rolled out. OG&E project also emphasized on "break down departmental silos" by implementing a comprehensive and holistic data strategy that would provide the utility with actionable intelligence about its consumers and grid operations.

OG&E's project goal

The utility forecasts daily system demand of 5,864 MW in 2020, a reduction of more than 500 MW. A reduction of 70 MW was slated to take place over the course of 2012, with 60 MW being saved via DR and 10 MW via integrated volt/VAR.

Project description:

Analytics that OGE was implementing included:

- Consumer analytics and customer segmentation
- Peak load management/load shed (via DSM analytics)
- Grid optimization (voltage control and conservation)
- Geospatial and visual analytics for centralized view of multiple systems

OGE was to receive data from 52 million meter reads per day, a figure that was expected to double in the years ahead. To deal with the influx of data, OGE was implementing integrated operations center which the utility expects will receive approximately two million event messages per day from AMI, data networks, meter alarms and outage management systems. Other areas in which OGE is driving big-data adoption include the planned deployment of a new DMS, as well as an OMS and an integrated volt/VAR control program.

Benefits:

OGE's 2020 Initiative will require the utility to shed substantial load. To achieve this goal, the utility has developed a strategy that relies on segmentation analytics, which will allow it to gain visibility into individual customers' responses to price signals, and as well as to identify the best customers to target with specific marketing campaigns. It will also allow the utility to perform the measurement and verification tasks necessary to develop and offer the most optimal rate structures. The utility's Smart Grid investments in both smart meters and ZigBee-controlled

[167] Greentechmedia.com, "Utility Case Study: OGE's Data Analytics Deployment", 2016. [Online]. Available: http://www.greentechmedia.com/articles/read/utility-case-study-oge-data-analytics-deployment. [Accessed: 25- Jan- 2016].

thermostats have facilitated this dynamic segmentation capability.

OGE believes that it is important to break down organizational silos because correlations of time-synched data from multiple inputs (MDM, CRM, billing/CIS, asset management and outage management) all provide valuable data that can contribute to the process of developing effective DR programs and rate structures.

The Analytics platform used by OGE provides the backbone for smart meter data, and also helps the utility gain a clearer understanding of customer behaviors and preferences from an enterprise perspective.

All these smart analytics applications thus highlight the huge value that can be extracted from Smart Grid data by utilities. While the data can be used to derive financial value, it is also important to note that some of the data generated can reveal personal information of consumers and hence may lead to privacy issues. Therefore, data privacy considerations and policies should be an important part of planning while using Smart Grid data.

11.3 References

[1] SAS, "Innovate and Optimize: The Power of Analytics in Today's Utility," 2011.

[2] Oracle Utilities, "Utilities and Big Data: A Seismic Shift is Beginning", Oracle, 2013.

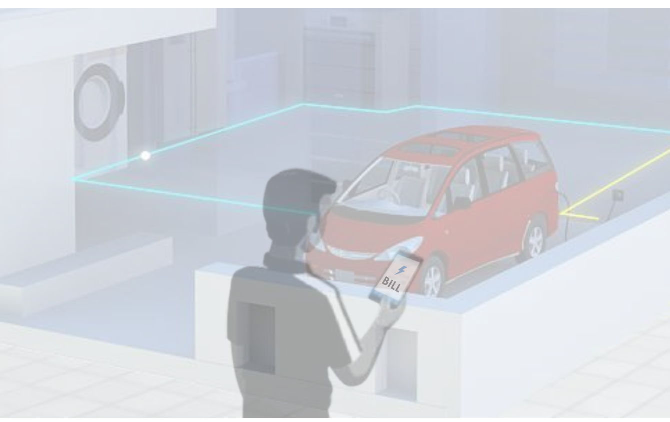
[3] UtilityAnalytics Institute, "Annual Grid Analytics Report" 2012.

[4] UtilityAnalytics Institute, "Annual Customer Analytics Report" 2012.

[5] EPRI, "A Case Study on the Revenue Protection Software: Sacramento Municipal Utility District Smart Grid Demonstration," 2014.

[6] "DTE Energy: Sensors for a Predictive Grid in the Motor City", Institute for Electric Innovation, 2014.

[7] Greentechmedia.com, "Utility Case Study: OGE's Data Analytics Deployment", 2016. [Online]. Available: http://www.greentechmedia.com/articles/read/utility-case-study-oge-data-analytics-deployment. [Accessed: 25- Jan- 2016].



Module - 12

Smart Grid and Smart City

12.1 Defining Smart Cities

The rise of cities has grown over millennia and has evolved over time as places where the entirety of human activities and services concentrate, spanning multiple modes of transportation, water supply, electricity, telecommunication and Internet, schools and colleges, hospitals, markets and businesses, other resources and services across people with varied skills. As cities evolved with more and more facilities and services, they became more and more attractive to people from rural areas leading to even faster urbanization. Rapid growth of cities has led to the creation of metropolitan regions, clusters of cities in a region.

As cities around the world experience this exploding growth, the need to ensure that they can expand sustainably, operate efficiently and maintain high quality of life for residents becomes even greater today. Smart Cities is part of the strategic response by the Governments to challenges and opportunities of increasing urbanization, and rise of cities as a nexus of societal development.

There is no universally accepted definition of a Smart City. It means different things to different countries depending on the priorities, the current and future (desired) state. The conceptualization of Smart City, therefore, varies from city to city and country to country, depending on the level of development, willingness to change and reform, resources and aspirations of the city residents. A Smart City would have a different connotation in India than, say, in Europe.

Some of the definitions being employed globally are as follows:

“A city well performing in a forward-looking way in economy, people, governance, mobility, environment, and living, built on the smart combination of endowments and activities of self-decisive independent and aware citizens”, Giffinger et al., 2007

“A city that monitors and integrates conditions of all of its critical infrastructures including roads, bridges, tunnels, rail, sea-ports, subways, airways, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens”, R Hall, 2000

“The effective integration of physical, digital and human systems in the built environment to deliver sustainable, prosperous and inclusive future of its citizen”, British Standards Institute

“One that makes optimum us of all interconnected information available today to better understand and control its operations and optimize the use of internal resources”, IBM

In the approach to the Smart Cities Mission, the GOI defines the objective as ‘to promote cities that provide core infrastructure and give a decent quality of life to its citizens, a clean and sustainable environment and application of ‘Smart’ Solutions’. The focus is on sustainable and inclusive development and the idea is to look at compact areas, create a replicable model which will act like a light house to other aspiring cities.

Fundamentally across all definitions, in Smart City initiatives, ICT becomes an enabler for improvements, which spans better measurements, better analysis, and better action leading to better quality of life for its citizen.

12.2 Smart City Architecture

Some of the core infrastructure elements in a Smart City as listed by GOI's 'Smart City Mission Statement and Guideline' document include:

i. Adequate water supply;
ii. Assured electricity supply;
iii. Sanitation, including solid waste management;
iv. Efficient urban mobility and public transport;
v. Affordable housing, especially for the poor;
vi. Robust IT connectivity and digitalization;
vii. Good governance, especially e-governance and citizen participation;
viii. Sustainable environment;
ix. Safety and security of citizens, particularly women, children and the elderly; and
x. Health and education.

Reliable, adequate and high quality utility services are thus critical in a Smart City. 24x7 services are considered a necessary part of a Smart City. It should be the right of every citizen to get these facilities on demand. Similarly, municipal services such as water supply, drainage, solid waste management need to deliver high quality and be available 24x7. To achieve this, Smart Cities would require the implementation of smart solutions across the utilities.

Figure 12.1: Smart City solution framework (as defined by the MOUD, Govt. of India)[168]

Some of the solutions for developing Smart City systems as mentioned in Figure 12.1 are discussed below:

- **Water supply**: Safe and adequate water supply is a public good as it has positive externalities. Access to water supply improves the productive working hours of urban poor by 1.5 to 2 hours. Smart Cities should therefore have adequate availability of piped water supply that meets the quality standards across the city. Adoption of new methodology, especially smart metering and sensor networks for reducing loss and energy consumption and identifying leaks in water networks, would thus be needed.

- **Sanitation:** Sanitation is important for all residents. Lack of sanitation causes epidemics; and health disorders keep the mortality rates high in general. It is essential that cities should have area wide sanitation plans for all parts of the city. It may be based on Decentralized Sewage and Solid Waste Management System. Each and every citizen should have access to toilets. There should be 100 percent recycling in the sanitation system.

  Waste Management forms an essential part of sanitation system. Most of the cities are facing many issues with regard to waste management. A Smart City solution would thus incorporate segregation of recyclable and non-recyclable waste, technology for waste

[168] "Smart City: Mission Statement and Guidlines", MOUD, Government of India, 2015.

management, collection and disposal system and promote use of products based on recycled solid waste (e.g. power, compost, etc.).

- **Communication**: a high level of telephone and Internet penetration will be essential in a Smart City which requires a highly reliable network. This would need collaboration among various departments and municipal authorities.

- **Urban mobility**: rapid urbanization of cities has resulted in unplanned development. Most of the cities are marred by congestion and deteriorating city core. It is therefore essential that while planning for the Smart Cities, emphasis must be given to planned development and decongestion. Adaptive and synchronized traffic signals for traffic management and smart parking are some solutions that smart cities would incorporate.

- **Health:** The aim of Smart Cities would be to provide world class medical infrastructure and high quality of healthcare service at affordable cost which is accessible to each and every section of society. Provisions like electronic health record for all the citizen visiting hospitals, telemedicine and online (video-based) medical consultation will be encouraged in Smart Cities.

- **Electricity**: Smart Cities need to have universal access to electricity (24x7) and increased RE generation. This requires investments and shift towards smart metering, establishment of Smart Grids, its integration with RE sources, to meet the demand. Existing transmission and distribution system would need to be strengthened and energy storage needs to be established. Further, the focus would be on optimization of electricity consumption and green initiatives.

Smart Grid as an enabler for Smart Cities

The energy infrastructure is one of the most important features in any city. Almost all city functions depend upon reliable supply of electricity.

A Smart Grid thus forms the backbone of any Smart City initiative. Smart Grid modernizes power systems through self-healing designs, automation, remote monitoring and control, and establishment of micro-grids. It makes the consumer an active stakeholder in energy management by informing and educating them about their energy usage, costs and alternative options, to enable them to make decisions autonomously about how and when to use electricity and fuels. It also provides safe, secure and reliable integration of distributed and RE resources. All these promote an energy infrastructure that is more reliable, more sustainable and more resilient. Thus, a Smart Grid is at the heart of the Smart City, which cannot exist without it.

Smart Cities thus depend on a Smart Grid to ensure resilient delivery of energy to supply their many functions and improve system efficiencies.

Smart Grid brings with it significant levels of automation, communications and information technology on the electrical distribution systems. Some of the key Smart Grid infrastructure also finds applications across the city utilities. These include:

GIS: GIS in city context is an invaluable tool for strategic planning of land use and for development of transportation plan to ensure that there will be sufficient land to meet the anticipated population and economic growth, and provide a good living environment.

GIS finds applications across services from checking inflow and infiltration of rainwater and groundwater into sewer systems to improving emergency responses to leaks, breaks and downed utility networks. GIS also supports Asset Management by storing, managing and maintaining accurate asset records that can be shared utility wide. GIS can help track the performance of one or multiple infrastructure projects, identification of bus routes, road capacity and condition, landfill and recycling sites and many other such applications.

SCADA: Distribution utilities are already implementing SCADA systems for monitoring and controlling the real-time power flows, this infrastructure and bandwidth can be leveraged to monitor and control other areas of city like water and gas networks using smart field sensors for these utilities.

ICT: ICT forms the backbone of most smart utility applications from intelligent waste containers that detect level of load and allow for an optimization of the collector trucks route, mobile application-driven citizen services like bill payments for utilities, monitoring of energy consumption and emissions across sectors, use of driverless trains, improved video surveillance, connected personal health monitoring devices, etc.

Therefore, a wide variety of infrastructure being deployed for smart electricity grid is common across sectors and city services, which puts distribution utilities at the forefront of leveraging synergies with Smart City initiatives. The following section discusses in detail the various synergies that exist between Smart Grid and Smart Cities.

12.3 Synergies Between Smart Grid and Smart City

The implementation of Smart Grid offers Smart Cities the basic ICT and sensor-based infrastructures that is common across services like water, gas, transport, waste management, etc. Thus, utilities developing Smart Grid projects provide a platform for both the city administrators and DISCOM to provide expanded city wide services that span beyond the traditional distribution utility boundaries.

These synergies (in terms of GIS, SCADA, communication network, etc.) point towards an opportunity for utilities to partner with the municipalities in which they operate for mutually beneficial sharing of infrastructure that are either already in place or quickly being deployed for smart assets that they own and operate.

Some of these physical infrastructures which offer synergies between Smart Grid and Smart City are discussed in the following sections.

12.3.1 Geographic Information System

In electrical grids, many utilities have employed GIS to map consumers and electrical assets as a means to visualization of the entire electrical network. While GIS is an important infrastructure for electrical utilities, location and hence GIS is a common denominator in every aspect of Smart City development and thus provides a strong synergistic opportunity for an integrated GIS approach to city planning.

Smart Cities are a complex landscape supported by infrastructure backbone for power, roads, water, drainage and sewage among others. To enable integration and synergistic functioning of different participants of the Smart City ecosystem, a centralized information system based on GIS would provide an IT framework which would integrate not only every stakeholder but also every aspect of Smart City process, starting from conceptualization, planning, and development to maintenance.

The integrated city-wide GIS system can map all the city assets including the roads, traffic lights, communication network, sewerage lines, water supply, electric supply infrastructure, education institutes, police stations, hospitals, etc. This centralized GIS would then enable maintaining and deploying data and applications throughout every aspect of the city development life cycle, which include:

Acquiring: GIS can help find the right areas for city development, view legal boundaries, and arrive at right valuation of existing and new sites.

Planning and Design: Integrated GIS with most design tools, brings greater analytics and cost-estimation capabilities to city infrastructure design process.

Selling: Analyse demographics and market conditions to provide a more accurate picture of a property's suitability to needs.

Maintenance: Easily manage disparate assets. Integrate city asset inventory with inspection history and work order management to maintain critical investments in a cost-effective manner.

GIS mapping which is already employed by distribution utilities as part of the R-APDRP initiative can thus be effectively used by other infrastructure services providers for planning as well as operation and maintenance of their systems. This would require regular updating as well as mechanism of cost sharing for use of such infrastructure by multiple sectors.

12.3.2 Metering and Billing

While smart metering has been promoted in the context of electrical grid in India, a Smart City would require implementation of smart meter and AMI for other utilities like water and gas as well.

A common ICT infrastructure for Internet of Meters is thus an innovative way of creating common information highway of machines-sensors-meters to connect to the web and get integrated services to consumers. An integrated solution of smart meters (electricity, water and gas) for automated collection of meter data can provide operational and cost efficiencies for utilities through integrated metering of electric, water and gas in its service territory. Customers will also benefit by having access to more data about their energy consumption and resources to help them better manage their usage.

The integrated metering infrastructure can also employ a centralized MDMS and billing and CIS system to generate common platform for bill payment across utilities. This has to significantly bring down the overall collection costs and IT-based billing system already implemented by various electrical utilities can be synergized for this effect. The city of Tallahassee, U.S. has successfully employed such a solution, the case of which is presented in Box 12.1.

Box 12.1 City of Tallahassee combined smart metering project[169]

Project Background: Tallahassee, U.S. has a population of 182,000. Its municipal utility services 87,000 residential customers and 14,000 commercial customers with electric service. The city also serves 26,800 gas customers and 75,600 water customers with some overlap among the three utilities.

The city is completing its smart metering project to roll out a single Smart Grid platform for its electric, water and gas utilities to create real-time communications that can enable a number of programs that encourage conservation and off-peak usage of resources.

Project Highlights:

There are two main parts of the system: AMI and the MDMS.

1. **AMI**: The AMI includes utility smart meters, a backhaul network to transmit the meter data and a central head-end system that collects the data. The program involves installing nearly 213,000 new meters. Each home or business was installed with separate water, gas and electric meters. The gas and water meters communicated wirelessly to the electric meters. Each water and gas meter is identified with a unique serial number that prevents customers from being accidentally charged for a neighbour's usage.

   The electric meters track electric usage and act as repeaters that accept the data from the

[169] Elp.com, "Combining Utility Efforts for a Single Smart Grid Platform", 2016. [Online]. Available: http://www.elp.com/articles/powergrid_international/print/volume-18/issue-7/features/combining-utility-efforts-for-a-single-smart-grid-platform.html. [Accessed: 24- Feb- 2016].

water and gas meters and transmit all the data through the network to the head end. They can transmit data on a regular schedule or on demand. Some enable the city to connect or disconnect service remotely. The meters also can link to central thermostats or other home automation systems and provide digital information displays that customers can read.

Benefits: There is a significant direct cost savings that comes with replacing independent repeaters with the electric smart meters. Each independent repeater costs USD 1,100 and another USD 3,500 for installation.

2. **MDMS** is a separate computer system responsible for maintaining the metering data, analysing it and reporting on the data. It integrates with other computer systems and a centralized billing system.

   It is the key point for connection to the web portal. It also will include advanced meter theft analytics. The web portal, called e+ Online, allows customers to view their current and historical bills and usage for all three utility services plus sewer, solid waste, fire and storm water services. From this portal, customers can also pay their bills, use a rate comparison tool to choose the best rate for their lifestyles and look at weather data and consumption. Meter data is available in 30-minute increments. Gas and water data are available in hourly increments.

12.3.3 Communication Backbone

The Smart City uses digital technologies to enhance performance and comfort, to reduce costs and resource utilization, and to engage more effectively and actively with its citizens. To achieve this, it is important to establish a two way communication between the infrastructure and public systems.

Smart Cities will thus require high speed and high-bandwidth communication networks for transportation, security and energy and other vital city services. Applications and technologies like location-based services, analytics, and IOT and M2M communications will also be essential tools for setting up an interconnected Smart City. Some of the applications employing communications as the backbone would include:

- Municipal utility (water, gas, electricity): distribution automation, advanced metering infrastructure and SCADA;
- Intelligent transportation systems: traffic signal management, and red light enforcement cameras; and
- Video surveillance: safety as well as crime prevention and prosecution.

City communication backbone will thus be an essential ingredient of Smart Cities or enabling services such as Smart E-Governance for citizen, public surveillance systems, Transport Management, Smart Utility/Energy, Smart Education, and Smart Health.

A common communication network (also referred to as communication canopy infrastructure) employed across utilities can be utilized to provide public Internet access, offering a valuable service to the community as well as fostering economic development.

In this aspect, a common wireless, fibre-optic communications networks can deliver broadband for all of these city services on the same platform. It offers a fast, secure, reliable and easily scalable platform, securely partitioned to enable differentiated quality of service standards for different users. As a result, communications for vital services such as fire, police and ambulance can reliably run on the same network as smart metering monitoring and data backhaul, public lighting and a host of other services. This makes the communications infrastructure more cost efficient and easier to manage. Additionally, new revenue streams such as the provision of public wireless Internet can also be delivered. Some case examples of integrated communication infrastructure are discussed in Box 12.2, Box 12.3 and Box 12.4.

Box 12.2 Oklahoma City, Pan-city broadband infrastructure[170]

The wireless broadband network in Oklahoma City, U.S. had been designed as an extension of the City's IT infrastructure with the initial goal to improve the city's public safety information system, enable new applications, reduce costs and improve services to the community. With time, it is now being used by mobile workers including police, fire, building inspectors and public works personnel. Additional city services and high-value applications are gradually being added. The network covers 555 square miles of the city, making it the world's largest contiguous metro-scale Wi-Fi deployment, operating more than 200 municipal applications.

Box 12.3 Stratford, Canada smart meter network for citywide wireless broadband connectivity[171]

Background: Early in 2010, the Province of Ontario enacted its Green Energy and Green Economy Act, setting specific goals for energy conservation in municipalities like Stratford. The city itself had its own goal of providing broadband access for its residents and business communities, and stimulating economic development through its Smart City initiative. Stratford officials sought a safe, secure, cost-effective, high-performance network that would support a smart metering program and at the same time help enhance community-wide communications.

Solution: To meet this dual objective, the city utility opted for a citywide wireless network using the latest broadband technology. The system consisted of wireless mesh infrastructure using 802.11n outdoor mesh access points and a system to transmit encrypted smart meter data and backhaul it to the city fibre optic network. The system also made the entire city a high-speed wireless broadband hot spot, enabling residents, businesses and visitors to enjoy instant Internet access from virtually anywhere in Stratford.

Result: With deployment completed in 2010, Stratford is reaping the benefits of its dual-purpose

[170] "ABB Power and Automation: Solid Foundations for Smart Cities", ABB.
[171] [Online]. Available: https://www.zebra.com/content/dam/msi-new/assets/web/Business/_Documents/Case%20studies/_Static%20files/Stratford%20CS%20FINAL.pdf [Accessed: 24- Feb-2016].

network strategy. Its smart metering initiative is in full swing, helping the city and its customers reduce both electricity consumption and utility bills. At the same time, the network offers ultra-high-speed Internet access to every resident and business. Stratford has adopted a managed service model that offers access via local carriers that rent capacity on the wireless network, providing the city with an additional revenue stream. Stratford is also using the mesh infrastructure to provide mobile access for public works and municipal employees.

Box 12.4 Florida Power and Light, US street light network for extended city application[172]

Project highlights: Florida Power and Light, a power distribution company, is deploying North America's largest networked street lighting program to connect and control more than 500,000 street lights. Their approach include:

- **An IPv6-based multi-application network** – this leveraged the same network for multiple applications, including advanced metering, distribution automation and smart street lights.
- **A streetlight vision software** – this controlled and managed street lights with adaptive lighting approaches that adjusted light levels based on motion or presence levels.
- **Efficient operations** – by automation, the load on call centre is reduced thus enabling faster outage response and restoration, better asset management and network performance.

Smart Grid-Smart City synergies: While this project creates the largest smart IP-networked street light deployment under contract in the U.S., it leverages the same network that FPL was already using for its Smart Grid program.

This project also establishes a city-wide network canopy upon which additional Smart City services can quickly and cost-effectively be deployed in the future, allowing cities to recoup their investment and speedily deliver additional value to citizens.

Significantly, these networks can extend to connecting other Smart City assets including Smart Water networks, pollution and environmental sensors, EV chargers, parking meters, and traffic lights, among many others. Intelligent traffic systems can now detect vehicle volume in all directions and immediately adjust themselves to allow the most efficient flow. Some estimates say 70 percent of all wasted fuel results from sitting at traffic lights in a city, so using this intelligent, interconnected system could significantly cut pollution and waste.

12.3.4 Control Center

With Smart Grid projects, centralized command and control centres are being setup to visualize the electric network in real time and based on the system analysis, event indications take quick response actions like network switching, workforce dispatch, etc. all from a single centralized location.

This is a concept that can be extended to the Smart City context where an integrated control network with common data transmission infrastructure can monitor all the municipal and supply

[172] "Opening the Door to the Smart City Key Priorities and Proven Best Practices from Major Cities Worldwide", Silver Spring Network, 2015.

networks of the service companies involved in the city. The goal of this centralized city control centre would be thus to manage and find about the ordinary consumption, incidents and emergencies in these networks. In addition, the networks would have alert devices and monitor consumptions, flows, intrusions, etc., making it possible to act in the event of system leaks in near real time. The integrated control centre could include supply network, drainage network, rainwater network, public lighting, Closed Circuit Television (CCTV), pneumatic waste collection, climatology, electrical network among others.

A centralized city command and control center is also under construction in the Gujarat International Finance Tec-City (GIFT), the details of which are presented in Box 12.5.

Box 12.5 Gujarat International Finance Tec-City command and control center[173]

Background: The GIFT City is being developed as a global financial and IT, ITeS hub in the state of Gujarat, a first of its kind in India. GIFT has been planned as a Smart City with next class infrastructure using latest ICT.

Being a Smart City, GIFT City authorities are expected to proactively monitor and manage the city's infrastructure using ITC for ensuring better services to the citizens. The infrastructure which needs to be monitored consists of multiple utilities (water management system, electrical infrastructure, automatic waste collection and recycling system, district cooling system, city occupiers' safety, security and surveillance, traffic management, etc.). GIFT City is planning to carry out city infrastructure monitoring and maintenance by integration of all these utilities on a single platform which is called City Command and Control Center (C-4).

Project highlights: The first part (platform) will connect all the utilities and provide a complete view of the city infrastructure; the second part will host CCTV surveillance, integration of BMS of various buildings and track critical parameters like fire and safety, intelligent traffic management system and Public Address (PA) system for handling law and order in the city. By integrating various infrastructure and utilities by connecting them on a single fiber optic-based ICT network spread across the city and by building intelligence in every upcoming building and utility, GIFT City is trying to achieve the following:

1. Monitor and manage the city infrastructure proactively.
2. Water supply distribution and monitoring system by using sensors and automation built at various places across the water distribution system, all of these sensors and automation will be connected to City Command and Control Center. This connected water system will ensure zero discharge for GIFT city.
3. Ensuring zero water discharge city by effectively monitoring the water systems by implementing sensors and integrating them with city-wide ICT infrastructure.
4. Managing traffic across the city by using cameras, PA system, digital signage and touch panel-based information kiosk.
5. Any disaster can be addressed by using the analytics placed on GIS-based city management system which is connected to every utility, building and infrastructure by city-wide fiber optic network.
6. Better and advance healthcare facilities for citizens.

[173] Nceg.gov.in, "Nominations received under 18th National Conference of e-Governance | 19th National conference on e-Governance", 2016. [Online]. Available: http://nceg.gov.in/nomination-received-18th-nceg. [Accessed: 24- Feb- 2016].

7. Monitoring of electrical infrastructure will ensure zero theft and highest uptime required for offices, business units and residents of the GIFT City.

Box 12.6 Rio, Brazil Citywide operation control center[174]

Background: Establishment of the Rio Operations Center grew out of catastrophic flooding and landslides that occurred in Rio de Janeiro, Brazil, in 2010. The Center was formed to integrate information from multiple government agencies and private sources to improve city safety and incident response. Incidents that it manages range from public utility problems and public transit issues to emergencies and disasters. It also acts as an operational hub for coordinating safety and security at large events, such as Carnival, the 2014 World Cup, and the upcoming 2016 Summer Olympics.

Operating Principle: Started in 2010, the initiative is based on three pillars:

- Collection of information from sensors such as rain gauges, radar sensors, GPS systems, images, social networks, and other sources;
- Analysis of information to make operational decisions; and
- Dissemination of information to the population, alerting citizens of disasters or other problems.

The Center collects layers of data from multiple sources to monitor events in the city. Sources of incoming data include security cameras, water and rain gauges, private maps, traffic signal data, the electricity grid, traffic controls, public transit vehicles, and social media feeds such as Twitter and Waze. The Center employs more than 400 staff, and operates 24x7.

Event Communication: Connecting agencies and data sources centrally allows Rio to coordinate communications and actions to events that affect the public. It uses social media, news outlets, and

[174] "IoE-Based Rio Operations Center Improves Safety, Traffic Flow, Emergency Response Capabilities", CISCO, 2014.

sirens located throughout the city to give emergency instructions. It also provides routine information services such as traffic flow and vehicle accident information, as well as updated commuter wait times.

Radio stations transmit directly from the Center, and the Center has a Twitter handle to disseminate pertinent incident information in real time. Citizens can also Tweet requests for information from the Center. All final information is made publicly available. This media and Operations Center outreach means that citizens of Rio de Janeiro can see the direct, day-to-day impact of the Center on their own lives, both from an emergency response perspective and as a tool to aid travel within the city.

Project Impact: More than 50 city agencies are now connected with this system, and pertinent data from the agencies integrated, due to the Operations Center. This allows more cooperative and efficient relationships among city agencies. The Center has also connected the city to commuters in new ways. Because of the center's relationship with the press, traffic and transit information can be disseminated quickly. Commuters can also access real-time updates via social media, and the city can respond to metro train delays by alerting buses and taxis in affected areas to converge on locations to pick up commuters.

12.3.5 Citizens Connect and Forum

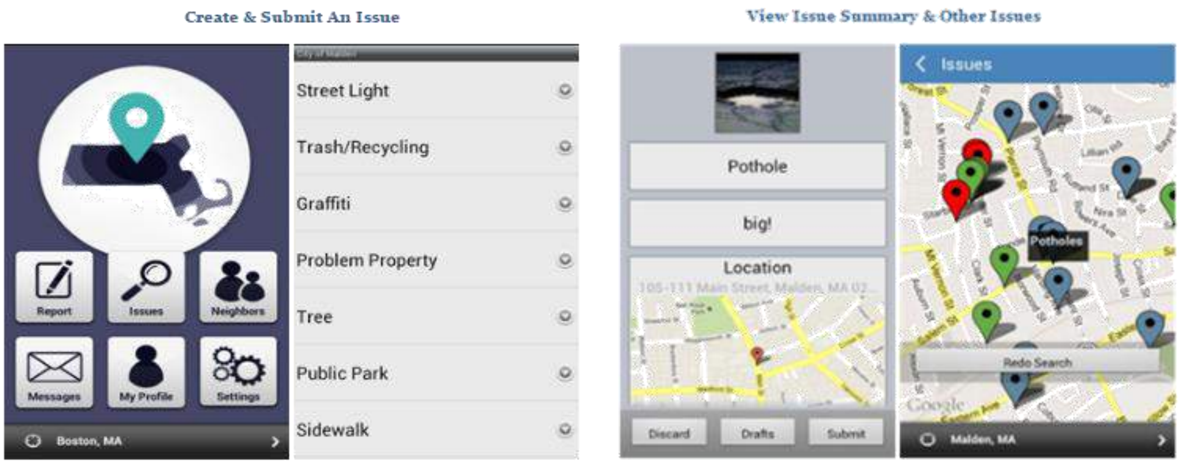
To develop a successful Smart City, citizens also need to be engaged and enlisted in various aspects of city planning and design. The concept of Smart Cities envisages bidirectional communication of city administration with its citizens via the medium of citizen's forum.

A citizen's forum can connect data, people and knowledge to create a participatory citizen process. The forum platform can be utilized for building productive new ideas, effectively disseminating new procedures, promoting and discussing initiatives and creating consumer buy-in and awareness. This can also cover specific threads to create opinions, obtain feedback and create an overall culture of collaborative learning.

Consumer care centres and consumer portals are present across many DISCOMs which deal with consumer issues in terms of billing, collection, complaint resolution on planned outages, etc. A number of consumers are using the consumer portals and this can be expanded for the scope of Smart Cities citizen connect program. A case of city-wide citizen's forum deployed in the city of Boston, U.S. is presented in Box 12.7.

Box 12.7 Boston City, U.S. citizen connect application[175]

In 2009, the Boston Mayor’s Office of New Urban Mechanics developed a smartphone app called Citizens Connect that allows residents to quickly report public works and service needs. Bostonians can inform officials of infrastructure and service problems such as potholes, streetlight failures, or graffiti via their phones, allowing the city to be far more responsive to its citizens’ needs and eliminating paperwork. As workers finish projects they record the date and time of completion, allowing residents to verify the city’s responsiveness to their requests.



The digital platform allows citizens to easily and swiftly tailor government resources to their needs; it acts as a more convenient, responsive, and engaging form of the 311 system (the traditional government information system) or physically traveling to City Hall. Citizens Connect reduces barriers to interaction with government, allowing city residents to actively engage their government for assistance rather than being reduced to passively waiting for services to eventually materialize. The program transforms what was once a drawn-out and discouraging process into one that inspires active involvement, improving the value of government services by encouraging citizen-produced input.

By December of 2012, over 35,000 problems had been reported and remedied and more than 20 percent of all “quality of life” notifications that the city receives pass through the app.

12.3.6 Supervisory Control and Data Acquisition

SCADA systems facilitate remote monitoring and control of electrical networks. SCADA applications also extend to other energy related networks, i.e., water and gas. To leverage existing SCADA network in a city context, a multi-utility specific SCADA application can be developed to access all process control information at an enterprise level.

Utility-specific applications, such as leak detection, pipeline simulation, and outage and leakage management can be easily integrated in a common SCADA network, giving city municipalities a single source of truth for its entire energy network.

[175] Data-Smart City Solutions, "Citizens, Connected | Data-Smart City Solutions", 2013. [Online]. Available: http://datasmart.ash.harvard.edu/news/article/citizens-connected-245 [Accessed: 24- Feb- 2016].

Box 12.8 Multi-Utility SCADA deployment in Germany[176]

NVV Niederrheinische Versorgung und Verkehr Aktiengesellschaft in Mönchengladbach, West Germany, supplies approximately 350,000 inhabitants in the city of Mönchengladbach and its surroundings with electricity, gas and water. A multi-utility SCADA system is used for the central monitoring and control of the power grid (3,650 km), the natural gas network (1,150 km), the drinking water network (950) and the sewer network (1,300 km). The power, gas, drinking water and wastewater networks are controlled via the IDS HIGH-LEIT control system. Apart from SCADA functions and a topology module, the system also features a simulation module which enables the simulation of switching operations and their impact on the power grid. Separate grid calculations can be executed via an independent application server, including the calculation of load flow, short-circuit current, compensation current and distance protection for the power grid.

12.4 Developments in India to Promote Smart City-Smart Grid Integration

12.4.1 Smart Cities Mission Convergence with Smart Grid Initiatives

The GOI has launched the Smart Cities Mission - an urban renewal and retrofitting program with a mission to develop 100 cities all over the country making them citizen friendly and sustainable. The Union Ministry of Urban Development (MOUD) is responsible for implementing the mission in collaboration with the state governments of the respective cities and the relevant line ministries.

For the Smart Cities mission, INR 480 billion (USD 7.1 billion) funding has been approved by the Cabinet. The Smart Cities mission provides for a common solution framework that binds key areas of city like electricity, water, waste management, e-governance, mobility and health to work in unison to achieve a common goal of making a city more liveable, sustainable and efficient for its residents.

Application of smart solutions will enable cities to use technology, information and data to improve infrastructure and services. Comprehensive development in this way will improve quality of life, create employment and enhance income for all.

Smart Cities is therefore a combined effort across ministries, sectors and municipalities and for a comprehensive development of cities, integration of the physical, institutional, social and economic infrastructure is required. In this context, many of the sectoral schemes and programs across ministries of the Government converge in this goal of Smart Cities and need to be leveraged at the planning stage of Smart Cities itself.

---

176 Ids-schweiz-ag.ch, "NVV AG: www.ids-schweiz-ag.ch", 2016. [Online]. Available: http://www.ids-schweiz-ag.ch/en/references/bereich-strom/nvv-ag.html. [Accessed: 24- Feb- 2016].

Specific to the energy goals/solutions for Smart Cities (Figure 12.2), there is a strong complementarity between IPDS, NSGM and related schemes with the Smart Cities Mission for achieving urban transformation. The synergies of these schemes with respect to some of the goals of Smart City are discussed in the following sections.

Figure 12.2: Smart City energy management solution[177]

Smart Metering

Smart Metering is a common infrastructure requirement for Smart Cities across electricity, water and gas. In India, the smart metering implementation is gaining momentum particularly in electricity sector due to various initiatives undertaken by the GOI.

A. The IPDS has been launched by GOI with a focus on improving power supply quality and availability in urban areas. The IPDS Scheme cost is INR 32,612 crore (USD 4867 million) including budgetary support of INR 25,354 crore (USD 3784 million) and provides for numerous opportunities linked to the smart metering including:

   - Installation of prepaid, smart meters in government establishments;
   - AMI, smart meters in the towns where SCADA is being established under R-APDRP;
   - Completion of optical fibre missing links under the establishment of National Optical Fiber Network; and
   - Provisioning of net metering.

B. With the recently launched UDAY scheme, the GOI proposes to install 35 million smart meters across India in a bid to reduce utility losses.

C. In 2015, the GOI approved the NSGM, an institutional mechanism for planning, monitoring and implementation of policies and programs related to Smart Grid activities. The mission estimates a planned outlay of INR 890 crore (USD 133 million) for the 12^{th} Plan period with a budgetary support of INR 267 crore (USD 40 million) for development of Smart Grid in Smart Cities. One of the key components of Smart Grid activity under the NSGM includes deployment of smart meter and AMI.

[177] "Smart City: Mission Statement and Guidlines", MOUD, Government of India, 2015.

D. The National Tariff Policy was amended in 2016, which ensures the 4Es of Electricity for all, Efficiency to ensure affordable tariffs, Environment for a sustainable future, Ease of doing business to attract investments and ensure financial viability. The policy also requires faster installation of smart meters to enable “TOD metering, reduce theft and allow net metering.

RE Integration

The Smart City Mission requires greater integration of renewables into the electrical grid. One of the objectives of the mission is of assured electricity supply with at least 10 percent of the Smart City’s energy requirement coming from solar and development of green buildings. Some of the schemes converging in this regard include:

A. The Ministry of New and Renewable Energy has recently launched a program on “Development of Solar Cities”. The program assists urban local governments in:

- Preparation of a master plan for increasing energy efficiency and RE supply in the city;
- Setting-up institutional arrangements for the implementation of the master plan; and
- Awareness generation and capacity building activities.

The Solar City aims at minimum 10 percent reduction in projected demand of conventional energy at the end of five years, through a combination of enhancing supply from RE sources in the city and energy efficiency measures. The basic aim is to motivate the local governments for adopting RE technologies and energy efficiency measures. In a Solar City, all types of RE-based projects like solar, wind, biomass, small hydro, waste to energy, etc. may be installed along with possible energy efficiency measures depending on the need and resource availability in the city.

B. The IPDS scheme envisages outlay for provisioning of solar panels on government buildings including net metering.

C. One of the activities envisaged by the NSGM is development of medium sized micro-grid (INR 27 crore (USD 4 million) outlay is estimated for the same), development of distributed generation in form of rooftop PV and creation of EV charging infrastructure.

Convergence of Power Sector Schemes with Other Smart City Infrastructure:

A. Replacement of overhead wiring to underground wiring is required for Smart Cities as a measure to provide visual aesthetics. As a part of strengthening of sub-transmission and distribution network, IPDS requires under-ground cables in densely populated areas and areas of tourism and religious importance.
B. IPDS scheme provides for GPS-based GIS survey of assets and a similar initiative is present in the NSGM which includes substation renovation and modernization with deployment of GIS. These measures therefore provide a convergence opportunity for implementing city-wide GIS implementation for asset mapping.

In conclusion, the various digital assets that are being created under the R-APDRP, IPDS, NSGM or other Smart Grid initiatives can thus be extended to other city infrastructure domains at marginal cost to the utility.

12.5 References

[1] K. Geisler, "The Relationship Between Smart Grids and Smart Cities", IEEE, 2013.

[2] "Smart City: Mission Statement and Guidlines", Ministry of Urban Department, Government of India, 2015.

[3] "GIS for Smart Cities", Esri India, 2015.

[4] "Integrated ICT and Geospatial Technologies: Framework for 100 Smart Cities Mission", NASSCOM, 2015.

[5] "IPDS in Smart Cities", Ministry of Power, 2015.

ANNEX - MODEL ROAD MAP FOR SMART GRID IMPLEMENTATION

As utilities embark on the Smart Grid journey, each utility would need to understand the goals it wants to achieve using Smart Grid, how it can leverage legacy/existing solution for transition to a Smart Grid, and what are the new technologies it needs to implement. To help utilities find answers to these questions, a model road map is presented in Figure 1 which details out the activities that a utility would need to undertake in order to embark on its Smart Grid implementation path.

The transition to the Smart Grid is a journey driven by the objectives and needs of the primary beneficiaries—utilities, individual consumers, and society in general. The implementation guideline defined here is based on common principles of designing projects. This framework can be adopted by utilities to take forward their Smart Grid activities and to realize organizational goals. Figure 1 depicts a reference framework which needs to be customized for each utility based on the starting points and goals of the utility.

Figure 1: Road map for Smart Grid implementation

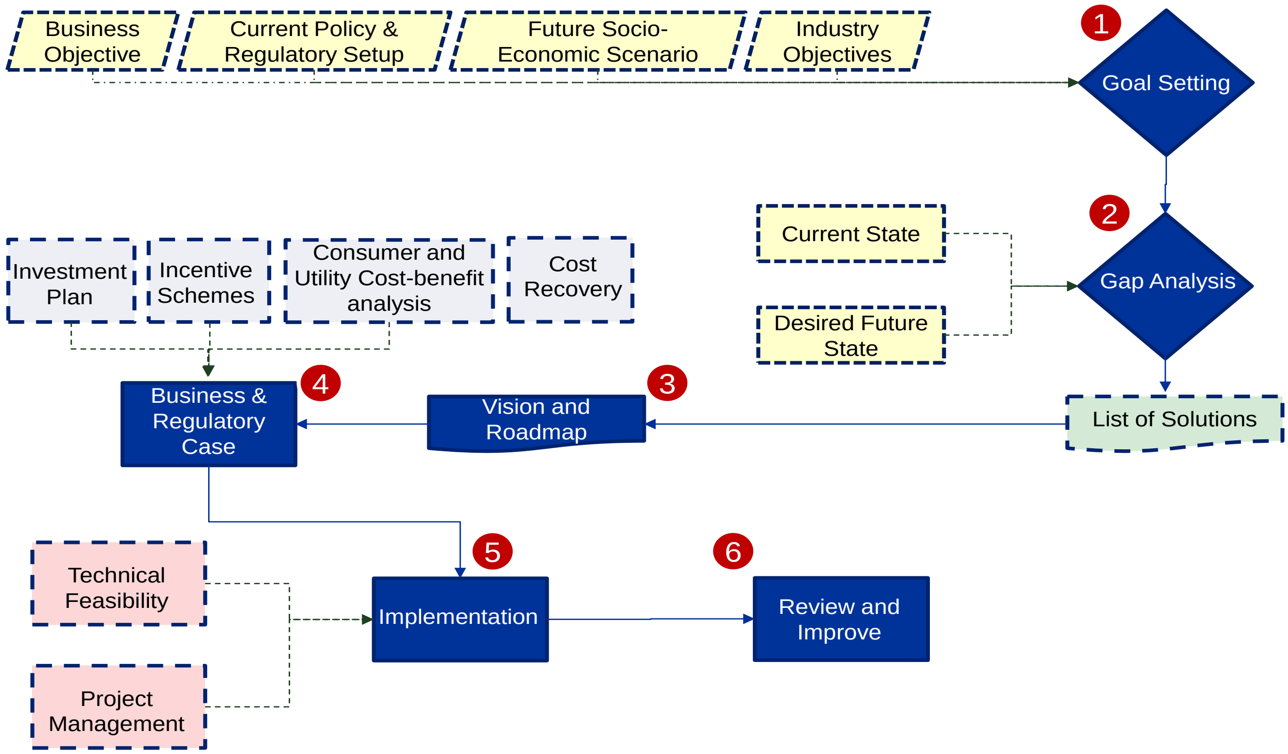
- **Define Goals -** setting goals that are specific to the DISCOM's business objectives and regulatory and policy obligations of the DISCOM.
- **Gap Analysis -** analyzing the gap between goals and current status and identifying infrastructure/upgrades to meet the goals.
- **Defining Roadmap -** developing a roadmap for the transition between current status and the business goals.
- **Business and Regulatory Case -** developing a quantitative cost-benefit analysis and building a case for regulatory approval of Smart Grid investments.
- **Implementation -** developing an implementation strategy that includes project management, technology selection and risk assessment and management.
- **Review and correct -** focusing on review and corrective action. Identifying what went wrong and how it can be corrected.

A large part of implementing a Smart Grid project is based on understanding the current position and output of the business applications and processes implemented under existing initiatives such as R-APDRP, IPDS, DDUGJY, etc. to check what is available and what can be replicated.

From the gap analysis it is easy to understand where the area of focus should be and accordingly prioritize the activities. This leads to definition of a DISCOM-specific Smart Grid roadmap especially for technology and business processes. This will also enable the DISCOM to understand the required regulatory changes and identify the technology, manpower and funding resources required to implement its projects.

A detailed flow representing various phases required for implementing Smart Grid by utilities is shown in Figure 2.

Figure 2: Activity flow for Smart Grid implementation



Each of the above six phases is explained along with detailed guidance.

Phase 1: Setting the right Smart Grids goals

This phase defines the vision of the utilities and their priorities. In order to understand the readiness of the business, their ability to move towards Smart Grids or to take benefit of technology implementation under other government schemes (IPDS, R-APDRP, etc.), it is necessary to understand what the benchmark is, “where does the business need to be”, what needs to be done to make the business financially stable and more customer-oriented. Goals therefore should be based on business objectives, industry objectives, the requirements of the India Electricity Act 2003 (EA 03), the current policy and regulatory requirements, national Smart Grid roadmap objectives and the emerging sector dynamics such as targets to be achieved under schemes like UDAY.

An illustrative example of Smart Grid goals is presented in Table 1.

Table 1: Smart Grid goal setting example

Business Objective/Smart Goals	Translation into Smart Grids	How Much	By When	Measurement Criteria
Reduce supply losses	• AMI Implementation • Theft Analytics	-10 percent	2018	• Reduced commercial losses. • Reduced technical line losses.
Reduce the cost of supplying Electricity	Intelligent load management	-10 percent	2017	• Reduced peak time demand. • Reduced cost of power purchase.
Increase revenue from regulated assets	Optimized asset utilization	-50 percent	2018	• Reduction in number of hours of load shedding. • Increase in number of units supplied.
Increased percentage of RE	• Integration of Renewable Energy Sources (RES)/DERs • Promotion of Micro-grids	+15 percent	2020	• Percent increase in number of units supplied from RES/DERs. • Percent increase in number of units supplied from decentralized solar generation.
Reduced outage time and frequency	Outage Management System (OMS)	-30 percent	2017	• Reduce time taken to identify and rectify outages. • Improvement in reliability indices.

Once the objectives of the Smart Grid project are defined, it is necessary to prioritize the goals that are to be addressed. This can be carried out based on the immediate need of the utility or the current level of readiness/preparedness. For example, in areas with high-losses, accurate energy accounting and identification of theft and loss points is desired. Similarly, in areas with poor reliability, reducing outages may be more important.

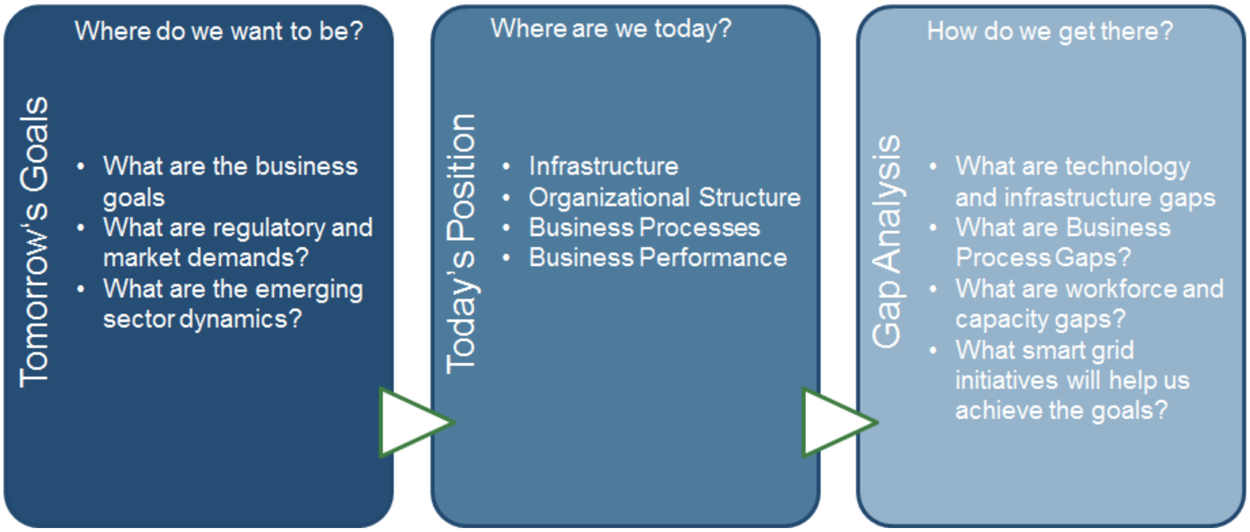
Setting goals[178] will facilitate the DISCOM to identify specific Smart Grid initiatives that can help achieve its goals.

Phase 2: Gap analysis

The Smart Grid vision defined in the desired future-state assessment is compared to the present-state assessment results to identify the gaps in technology, business processes, and consumer acceptance areas. Gap analysis helps identify the actions/specific solutions that would be needed to reduce or eliminate them. These solutions would include new applications, technologies, business processes, regulatory policy, and consumer outreach.

[178]This is also accompanied by setting of a clear baseline against which progress and outcomes will be measured

Figure 3: Gap analysis process



Present state assessment

The Smart Grid strategy should leverage the electric distribution utility's existing assets to the fullest extent possible. This will help ensure that the modernization plan is practical and possible using available resources. Therefore, having a thorough understanding of the current status of the organization is an important first step toward Smart Grid implementation.

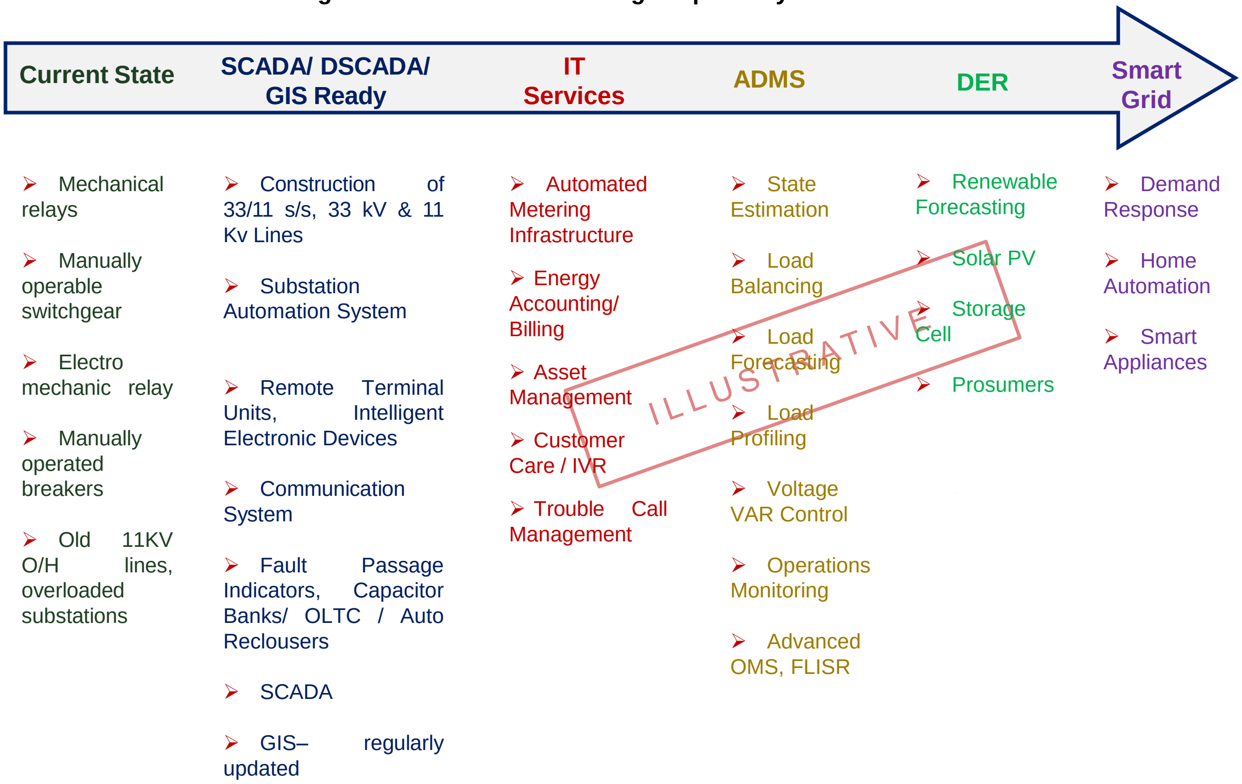
The current state could be evaluated from the following perspectives:

- **Technical**: This would include identification of the technologies, applications, processes, and systems currently deployed and in use, as well as currently approved plans for future investments in government schemes (e.g. IPDS and R-APDRP) that contribute towards the identified Smart Grid goals.

  An electrical system study including load growth analysis should be undertaken to understand level augmentation of sub stations required and assess whether the equipment installed currently are adequately rated and capable of remote operation.

  In the current state, a number of utilities would find after this analysis that their existing technological state comprises of mechanical relays, operable switch gear, electro mechanic relays, manually operated breaker, old 11KV lines, overloaded substations, etc. To reach from such a state to a Smart Grid status, a phased introduction of technologies towards achieving Smart Grid automation level would be required. An illustrative pathway for achieving this is shown in Figure 4.

Figure 4: Illustrative technological pathway to Smart Grid



- **Regulatory**: This would address policies that impact Smart Grid deployment and the current regulatory climate for Smart Grid investments.

- **Organization and Structure**: This represents the organizational capabilities, business processes and characteristics that enable an organization to align and operate as required to achieve its desired Smart Grid transformation. The assessment focuses on current state of utility in terms of culture, structure, training and education, and knowledge management within the organization. As an example, with implementation of GIS, business process for regularly updating of GIS database, which are labor intensive, needs to be put in place to effectively utilize the benefits of GIS.

- **Consumer**: This identifies the current consumer attitudes toward the Smart Grid and their level of participation (active or passive) in energy management.

A representative example of utility gap analysis for outage management is presented in Table 2.

Table 2: Details of processes and gaps for OMS, contribution from existing infrastructure and additional upgrades required

OMS Functionality and Requirement		Present Status	Gap to be addressed to accomplish Smart Goals
Network Visibility	Visibility of entire network	GIS Asset Mapping & Consumer Indexing	
Real time fault location	Real-time remote fault location to consumer level.	SCADA at substation level. (for qualifying towns)	No option for remote fault location at consumer level. Relies on calls into call center and crew locating fault based on data received from call center. AMI at consumer level will support this requirement.
Near real-time fault isolation	Real-time remote fault location to consumer level.	Fault isolation to substation/11kV level through substation automation provided as part of R-APDRP Part B	No option for remote fault isolation beyond substation level (distribution transformer (DT)/Feeder/Consumer). Relies on crew manually isolation fault. AMI at consumer level and FLISR application using advanced DMS can enable this.
Near real-time system restoration.	Immediate restoration of unaffected network	Automatic remote restoration not possible	Full network automation required plus ring circuits, sectionalizers, auto-re-closers, etc. AMI and advanced DMS application to be implemented.
	Crew dispatch and fault repair	In some instances this function (Workforce and Asset Management) exists within the ERP	W&AM/ERP to be integrated with OMS.

The above mapping thus enables the utility to clearly understand the current status and identify the solutions required for overcoming gaps with the desired state.

To undertake this activity, the Smart Grid Maturity Model (SGMM) tool could be utilized by utilities. The SGMM is a management tool developed by the Software Engineering Institute at Carnegie Mellon University. The model provides a framework for understanding the current state of Smart Grid deployment and capability within an electric utility and provides a context for establishing future strategies and work plans as they pertain to Smart Grid implementations.

Phase 3: Definition of road map

This phase defines the guidelines required for the migration towards Smart Grid and will lead to the development of a priority-based action plan/implementation roadmap, including technology and capacity requirements, high-level budget and timeline based on achieving the targets agreed in the phase.

The outcome of gap analysis process is a Smart Grid road map, which connects the goals in the Smart Grid vision with the investments needed to achieve the target. The roadmap would enable the management to communicate clearly its Smart Grid vision to employees, customers, regulators and vendors.

The road map would indicate the stages of Smart Grid deployment, first of which is generally AMI/smart meter deployment. The next step in deploying the Smart Grid roadmap is to build a business case for each of the Smart Grid applications to be implemented.

Figure 5: Illustrative Smart Grid roadmap

	Phase-1 2016-2017	Phase-2 2017-2019	Phase-3 2019-2022	Future Phase beyond 2022
Technology	• Communication Infrastructure • Supervisory Control and Data Acquisition • Geographical Information System (GIS) • Automated Metering Infrastructure (AMI)	• Distribution Management System (DMS) • Distribution Automation (DA) • Outage Management System (OMS) • CRM & Billing	• Demand Side Management • Distributed Generation (DG) • Enterprise Application Integration (EAI) • Mobile Workforce Management	• Advanced Metering Infrastructure (AMI) • Green Grid implementation • Business Analytics • Distributed Energy resources (DER) Integration
Consumer & Regulatory	• Initiation of Customer Outreach and Engagement Programs • Implementation of Dynamic Tariffs	• Mandatory Demand Response programs for larger sections of consumers • Enablement of Prosumers in select areas	• Active Participation of "Prosumers"	
Organizational	• Form & charter smart grid teams involving employees from every department. • Research & Development, Training & Capacity Building	• Link employee compensation to smart grid success. • Optimize business processes leveraging the enterprise IT architecture	• Integrate real-time analysis with integrated resource planning.	• Advance training for distribution engineers for state estimator and real-time engineering analysis tools/applications enabling dynamic management

ILLUSTRATIVE

Phase 4: Building business and regulatory case

Business Case

Using the identified solution set and the quantities and phase approach assumed in the initial road map document, a business case is developed by estimating costs and benefits and the results evaluated using specific financial metrics. The final financial metrics to be used for the business case should be based on what is needed by the overall Smart Grid decision-making process. Some suggested metrics include net present value, benefit-to-cost ratio, and payback period. The business model thus developed would be used to determine if the Smart Grid meets the financial barriers.

I. Cost estimation

For estimating costs, some of the major forms of costing to be considered for a Smart Grid project are as follows:

- Infrastructure cost, which includes capital investments for up grading and for new installations.
- Operational and maintenance cost of equipment (hardware and software).
- Recurring costs for communication systems as technology advancements involve exponential growth in contrast to hardware/equipment, which has linear growth
- Capacity building programs for employees.
- Consumer awareness programs to elicit effective participation.

II. Benefit estimation

The utility needs to establish the benefits, both direct and indirect, at the planning phase of the project and they need to be estimated according to the benefits accruing to various stakeholders. For example,

- Utilities: The major benefit could be reduction in operational losses due to increased collection efficiency, reduction in power theft or better load, infrastructure and asset management.
- Consumers*:* Enhanced reliability and power quality and lower tariffs are the key benefits for consumers. Moreover, the presence of some programs such as DR could even help consumers to earn revenue for supporting grid operations.
- Society: Integration of a higher level of RE sources and reducing losses will help in reducing CO_2 emissions. Better load and power management will improve access to power, per capita consumption of electricity and productivity.

The goals defined in the roadmap could form the basis from which the specific Smart Grid benefits are determined and their values estimated. For example, if one goal is to improve reliability by 30 percent relative to the baseline reference then that goal implies a specific reduction in the number and frequency of outages and perhaps an improvement in power quality. The challenge is to estimate the value of these specific benefits from the perspective of the primary beneficiaries the utility, the consumer, and the society.

Regulatory case

The analysis of business impact of Smart Grid technologies would have a substantial impact, specifically on gaining regulatory approval and cost-recovery approach. In order to ensure the complete support of regulatory authorities during project implementation, the following measures should be undertaken:

- **Benefits assessment**: Customer and utility-focused cost to benefits analysis will provide a clear picture of the commercial aspect of the project as well as tangible/intangible benefits and any expected impact on tariffs.
- **Risk assessment**: Undertake sensitivity analysis on business model assumptions, to enable regulators to understand the risk associated with the project. Additional analysis will be required to reduce the uncertainty of any assumptions that significantly impact the end result.
- **Project monitoring**: A structure for monitoring through KPIs and reporting will provide transparency in terms of the project's progress.
- **Detailed project report**: Having a standard format DPR.
- **Incentives**: Designing the program in such a way that there is an incentive for all stakeholders.
- **Cost recovery**: There are various modes through which the regulatory framework could provide for recovery of Smart Grid investments which include:

  I. Through ARR process (Socialization)
  II. Specific tariff schemes and designs
  III. Design of surcharges
  IV. Pricing of new services

Phase 5: Implementation

This phase is focused on the implementation of the action plan/road map. During this phase it is important to have a well-structured project team comprising relevant competencies, a well-structured project charter defining roles and responsibilities and a methodology for project monitoring, reporting and corrective action and a well-defined communication strategy to ensure buy-in from all stakeholders.

The following practices could be employed for successful execution of Smart Grid projects:

Creation of a Smart Grid project team

The Smart Grid projects and evolution need to be institutionalized within a DISCOM. Since the Smart Grid activities cut across different functions in the utility, ensuring successful implementation and operation could require creation of dedicated Smart Grid teams to coordinate various activities[179].

- Formulation of Smart Grid plans, programs, and projects
- Design and development of Smart Grid projects including cost benefit analysis, plans for implementation, monitoring and reporting, and measurement and verification
- Seeking necessary approvals for Smart Grid plans, programs, and projects
- Formulation of customer engagement plans

It is critical for all projects to have a project charter with clear and concise roles, responsibilities, deliverables and deadlines, agreed by all stakeholders and approved at committee level. It is also important to analyze the institutional requirements and take the necessary actions required to deliver the program. For example, some of the institutional requirements for a DR program can be addressed by forming specific teams such as:

- A transverse central team responsible for program design including members from power management, metering and customer service.
- An analytics team responsible for identifying potential DR events such as high cost of obtaining power, power outages, etc.
- A metering team responsible for customer profiling from meter data management and based on type of customer such as: industrial, residential or commercial, class of customer whether rural or urban and type of load including seasonal variations.

Project evaluation, monitoring and verification

To ensure that projects remain on track, it is important to have a system for monitoring at a central level which reviews the whole program. A program can be successful only if there are adequate M&V tools in place to monitor the performance of the project. Otherwise it would be impossible to ascertain the impact of the program. The output of the M&V process will facilitate continuous improvement. A typical example would be KPIs to compare monthly metering, billing and collection efficiency.

Risk mitigation

In addition to the M&V framework, it is also necessary to have a threat mitigation plan in place to identify any foreseen and unforeseen challenges during the implementation of the project. The following is an example of a threat mitigation strategy:

- Streamlining vendors for critical infrastructure (metering, communication, etc.) to avoid complex troubleshooting.
- Moving towards open protocol standards to address interoperability issues.

[179] Constitution of a Smart Grid cell is also detailed out in the model Smart Grid regulations issued by Forum of Regulators

- Building adequate cyber security measures to thwart any attempts of cyber-attacks.
- Inviting large-scale consumer participation through various demonstrable benefits.

During the course of project implementation the project team should review progress and implement corrective action or adjust activity to adhere to the project milestones. This will also help in scaling up activities in the future. Therefore the following could be considered:

- Coordination with all the stakeholders to identify any mid-course correction and possible alternatives needed to resolve issues.
- Coordination with senior management on any corrective measures to be taken.
- Monitoring and coordinating and budget adjustments to keep the project financially positive.
- Documentation of lessons learnt from the pilot projects and dissemination to all other stakeholders.

Selection of technology

While selecting technology and considering leveraging existing infrastructure, the following points need to be considered by the utility:

- Mapping existing infrastructure vs. new infrastructure and developing a process for integration whilst ensuring future interoperability.
- New technology should be based on interoperable standards to avoid future technical obstacles.
- Technical specification, cost comparison and live demonstration, use cases and proven track record should all be considered before selecting technology.

Integration of ITs and OTs

As utilities incorporate more smart devices into their operational environment on a continuous basis, the case for integration of IT-OT grows stronger to get the maximum benefits from these system upgrades. An integrated approach that shares standards and platforms across IT and OT can enable utilities to reduce costs across the software management landscape, including enterprise architecture and information and process integration. Integration of IT and OT will bring together real time systems such as SCADA, EMS and DMS with corporate applications such as EAM, EOM, CIS, MWFM and DRMS and this can be a significant driver in helping utilities cut operational expenses by improving their asset management capabilities.

Phase 6: Review and Improve

This phase determines whether the goals have been achieved as outlined in the 1st phase, if not then what went wrong and how it can be rectified; if yes, then what can be leveraged and utilized in the future. This phase does not mean the end but a continuation of the process and leads into revisiting the targets/position, etc. Thus the emphasis here is on continuous improvement and not maintenance of status quo.

There are many procedures for managing corrective actions but they all evolve around the same theme: Plan, Do, Check, Act and a process should be designed according to each project/business.

The guidelines enlisted above form a basis for project implementation and the guiding framework can be used by utilities to effectively implement Smart Grid projects and leverage existing infrastructure created under R-APDRP, IPDS and other similar initiatives.

Notes

Notes

Notes

National Smart Grid Mission Project Management Unit
Power Grid Corporation of India Limited
'SAUDAMINI', Plot No. - 2, Sector - 29,
Gurgaon - 122 001 (Haryana)