SMART GRID OF BANGLADESH

POSSIBILITY AND FUTURE

A Project and Thesis submitted in partial fulfillment of the requirements for the Award of Degree of Bachelor of Science in Electrical and Electronic Engineering

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Certification

This is to certify that this project and thesis entitled "**Smart Grid of Bangladesh Possibility and Future**" is done by the following students under my direct supervision and this work has been carried out by them in the laboratories of the Department of Electrical and Electronic Engineering under the Faculty of Engineering of Daffodil International University in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering. The presentation of the work was held on 30 January 2021.

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The project and thesis entitled **"Smart Grid of Bangladesh Possibility and Future,"** submitted by **Md. Fazlee Rabbi,** ID #: 172-33-488**, Md. Arman Hossain Sagar,** ID #: 172-33-480, Session: Summer 2017 has been accepted as satisfactory in partial fulfillment of the requirements for the degree of **Bachelor of Science in Electrical and Electronic Engineering** on ----------- 2021.

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This thesis is dedicated to my parents & teacher's

For their endless love, support and encouragement…

CONTENTS

List of Tables

List of Figure

LIST OF ABBREVIATIONS

CAIDI	Customer Average Interruption Duration Index
CHP	Combined Heat and Power
DG	Distributed Generation
DR	Demand Response
MAIFI	Momentary Average Interruption Frequency Index
MW	Megawatts
MWh	Megawatt Hours
RE	Renewable Energy
SAIDI	System average Interruption Index Duration Index
SAIFI	System Average Interruption Frequency Index
T&D	Transmission and Distribution

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ABSTRACT

In the upcoming years, electricity's share of entire global energy is forecasted to continue to increase, and even more intelligent systems are going to be introduced into the electric power delivery (transmission and distribution) networks. It is expected that the grid will shift from an electromechanically controlled system to an advanced electronically controlled network known as Smart Power grid within the next two decades. A vital constraint is how to remodel, retrofit, and also upgrade the current electromechanically regulated system into a smart self-healing power grid which is powered by a properly planned market strategy. Ground-breaking advancements in information technology, material science and engineering guarantee vital progress in the security and safety, reliability, efficiency, and also cost effectiveness of electric power delivery systems.

Both theoretically and practically, Smart grid is more complex, larger and more effective than its older counterpart. This thesis addresses the perspective of Smart grid in Bangladesh with the basic introduction of Smart grid technologies. The key target of this thesis is to provide current condition of the electrical grid of Bangladesh as well as discussing the possibilities of Smart grid in this developing country. It is anticipated that this thesis will provide a positive way to address the challenges of the energy sector of Bangladesh by implementing Smart grid technology.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Nowadays people are more conscious about their environment and sources of electrical energy as they're aware about global warming, energy efficiency, energy conservation, rationale use of energy etc. The sources of energy have an important impact on the global climate change . People have realized the need of green energy sources. Huge amount of fossil fuels are burnt to provide the tremendous amount of daily electricity, as a result the GHG emission is increasing and polluting the climate. to enhance the system efficiency and utilize the energy precisely, new concepts have evolved considering the stress of the people also as use of energy in most effective way. 'Smart Grid' is one among the foremost remarkable and sustainable concepts nowadays to provide secured, reliable, clean and high quality electricity supply. As differing types of consumers demand, the utilities got to provide better quality, more reliable electricity at a good cost. Smart Grid is an ongoing development process which supports the innovation in technology, conservation and efficiency of energy use and therefore the total management of electrical energy. It are often referred because the use of recent developed communication and knowledge system which links a spread of customer equipments and assets along side sensors to make a sensible system. Smart Grid is more intelligent, efficient, accommodating, motivating, opportunistic, quality focused, resilient and green compared to our mainstream power system.

Bangladesh, the 43rd largest economy within the world in 2010 features a vast and sophisticated power distribution network. With many problems during this sector, the implementation of Smart Grid within the distribution sector may be a challenging task.

The electric power industry needs to be upgraded in order to cope with the needs of modern digital society. In this thesis, we discussed about Smart Grid as a possible solution. This thesis paper is divided into six chapters. Chapter 1 introduces us with Smart Grid, with brief description of history, goal, characteristics etc. Chapter 2 emphasizes on driving factors, development and progress of Smart Grid. Chapter 3 describes various technological aspects of Smart Grid. Chapter 4 discusses the benefits and challenges. Chapter 5 focuses on the potential of Smart Grid in Bangladesh. Finally chapter 6 wraps up the thesis paper with discussion on the overall work along with the future recommendations.

A quick discussion about the benefits and importance of smart distribution system has been presented in section two. The distribution system of Bangladesh has been presented and analyzed in section three. Section four and five will present the potential benefits of Smart Grid in distribution system and therefore the progress & prospects in Bangladesh power distribution system. Section six is that the concluding remarks.

1.2 Historical Development of the Electricity Grid

Electricity was first sold to consumers about 130 years ago and since then the electrical industry has reached a stage where it encompasses so many branches and specialties that the range of career opportunities seems limitless.

Immediately following the publication of the results of Faraday's famous 1831 experiments, many practical generators were constructed by inventors. Their aim was to produce a supply of direct current that would take the place of the battery as a source of electrical energy. The first D.C. generators, also known as dynamos, were produced for experimental purposes. Later, dynamos were produced for electroplating and for supplying the arc lamp. Used for lighting, the arc lamp produces an intense light from an arc created between two carbon electrodes. Some of the first machines in Britain were specifically designed to supply the energy required for the arc lamps used in lighthouses, but it was not long before the arc lamp was being used for lighting public places. The design of larger, more efficient dynamos continued. To give some indication of size, Edison's famous Jumbo dynamo of 1881 was rated at 1500 light 110 volt and was driven by a 150 horsepower engine, equivalent to about 112 kW. By contrast, the larger generators in a base-load power station today are rated up to 650 000 kW. Before 1880, the primary purpose of most electrical sources was to supply the electrical energy for arc lamps.

However, the open arc of these lamps produced gases that were a fire hazard and the arc carbons and control gear required constant maintenance. They were made only in high ratings; accordingly, when the enclosed, small and low-rated incandescent electric lamp became a practical proposition, it quickly replaced the arc lamp in most lighting applications. Modern day alternating current power grid evolved after 1896, based in part on Nikola Tesla's design published in 1888. In those days, the grid was designed as a centralized unidirectional system of electric power transmission, electricity distribution, and demand-driven control. In the twentieth century electrical grids originated as local grids that developed over time, and were ultimately interconnected for economic as well as reliability reasons. By the 1960s, the electrical grids of developed countries had become very large, mature and highly interconnected, with thousands of 'central' generation power stations delivering power to major load centers via high capacity power lines which were then branched and divided to provide power to smaller industrial and domestic users over the entire supply area. The topology of the 1960s grid was a result of the strong economies of scale of the current generation technology. By the late 1960s, the electricity grid reached the overwhelming majority of the population of developed countries, with only outlying regional areas remaining 'off-grid'. Through the 1970s to the 1990s, growing demand led to increasing numbers of power stations. In some areas, supply of electricity, especially at peak times, could not keep up with this demand, resulting in poor power quality including blackouts, power cuts, and brownouts. Increasingly, electricity was depended on for industry, heating, communication, lighting, and entertainment, and consumers demanded ever higher levels of reliability.

Towards the end of the 20th century, electricity demand patterns were established: domestic consumptions led to daily peaks in demand that were met by an array of 'peaking power generators' that would only be turned in for short periods each the day. The relatively low utilization of these peaking generators (commonly, gas turbines were used due to their relatively lower capital cost and faster start-up times), together with the necessary redundancy in the electricity grid, resulted in high costs to the electricity companies, which were passed on in the form of increased tariffs.

1.3 The Concept of Smart Grid

A Smart grid is an umbrella term that covers modernization of both the transmission and distribution grids. It is the integration of Electrical & Digital Technologies, Information and communication which facilitates integration of business processes and systems to yield real measurable value across the power delivery chain. It is an intelligent future electricity system that connects all supply, grid and demand elements through a communication system. Smart grid delivers electricity to consumers using two-way digital technology that enable the efficient management of consumers, efficient use of the grid to identify and correct supply- demand imbalances. It brings a 'digital upgrade' of distribution and long distance transmission grids to both optimize current operations by reducing the losses, as well as open up new markets for alternative energy production. Figure 1.1 below shows the different aspects of a Smart grid network as a general concept.

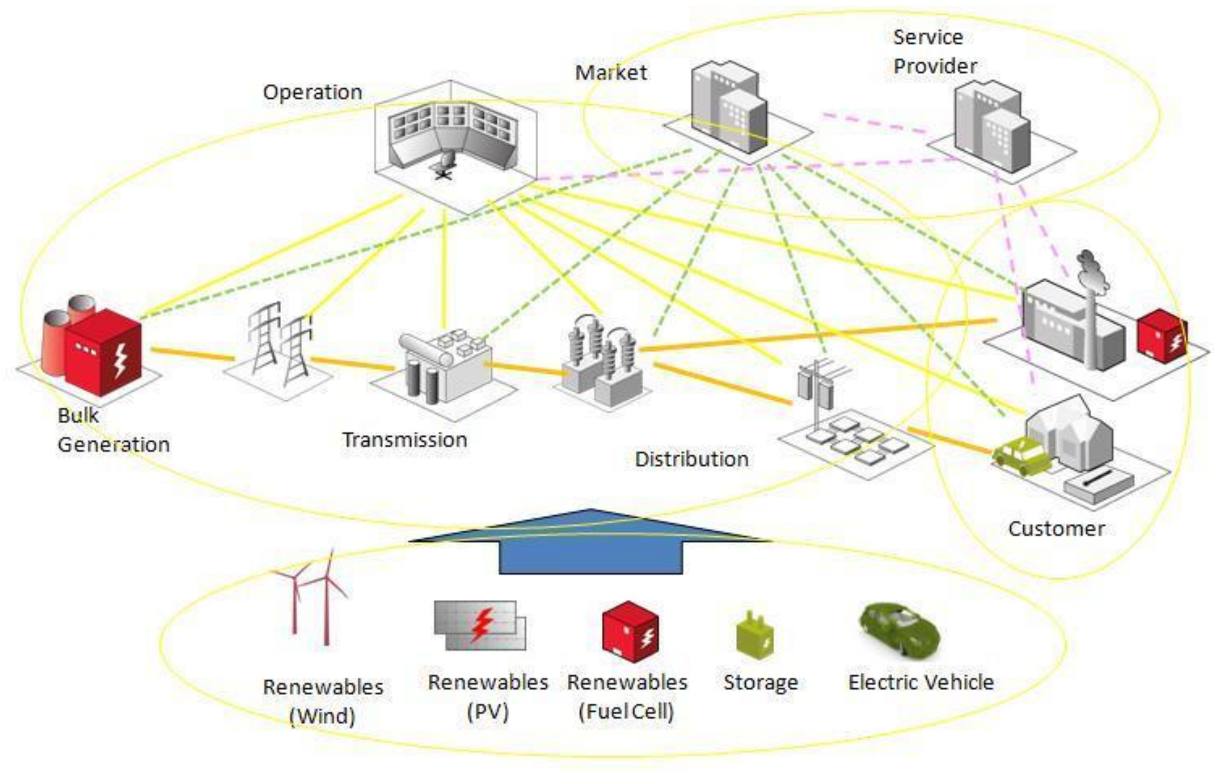

Fig. 1.1: Smart Grid Network

There are many definitions of Smart Grid and different people have different views on defining it. The brief definition of Smart Grid, as proposed by the European Technology Platform, is- "A Smart Grid is an electricity network that can intelligently integrate the action of all users connected to it—generators, consumers and those that do both—in order to efficiently deliver sustainable, economic and secure electricity supplies". National Institute of Standard and Technology (NIST) defines it as- "a modernized grid that enables bidirectional flows of energy and uses two-way communication and control capabilities that will lead to an array of new functionalities and applications." According to USA Department of Energy's modern grid initiative, a Smart grid is the technology that incorporates advanced sensing technologies, control systems and integrated communications into the existing electricity grid.

After analyzing the definitions stated above, the following characteristics of the Smart Grids can be distinguished:

- Optimized for best resource and equipment utilization
- Distributed by its structure (assets and information)
- Interactive (customers, retailers, markets)
- Adaptive and scalable (for changing situations)
- Proactive rather than reactive (to prevent emergencies)
- Self-healing (can predict/distinguish/bypass abnormal situations)
- Reliable and secure (from threats and external disturbance)
- Efficient and reliable
- Open for all types and sizes of generation
- Environment-friendly (using renewable energy resources)
- Integrated (monitoring, control, protection, maintenance, EMS, DMS, AMI)

1.4 Current Power Grid vs. Smart Grid

Compared to the traditional power grid, Smart grid has obvious advantages and characteristics in all aspects of power system. Table 1.1 provides the comparison between the current grid and smart grid.

Table 1.1: Comparison between Existing Power Grid & Smart Grid

Features	Current Grid	Smart Grid
Communication	One way	Two way

Interaction with user side	Limited	Extensive
Instrument type	Electrical	Numerical
Flow control	Limited	Universal
Reliability	Prone to failure and cascading outages	Pro-active, real-time protection and islanding
Power restoration	Manual	Self healing
Topology	Radial	Network
Generation	Centralized	Distributed
Operation & Maintenance	Manual equipment checks, time-based maintenance	Remote monitoring, predictive and condition based maintenance
Metering	Electromechanical	Digital
Customer participation	Limited	Extensive

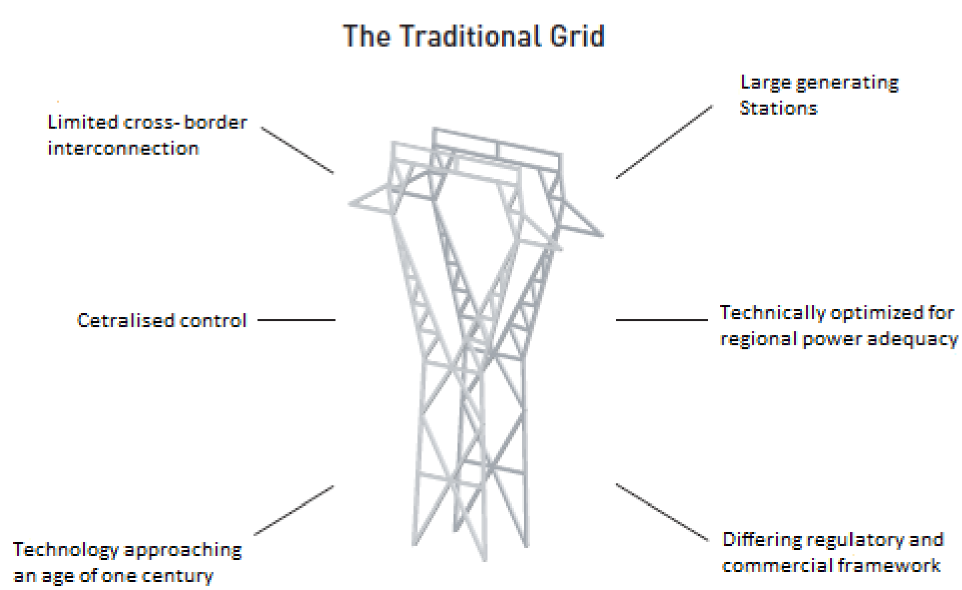

Fig. 1.2: Current Power Grid

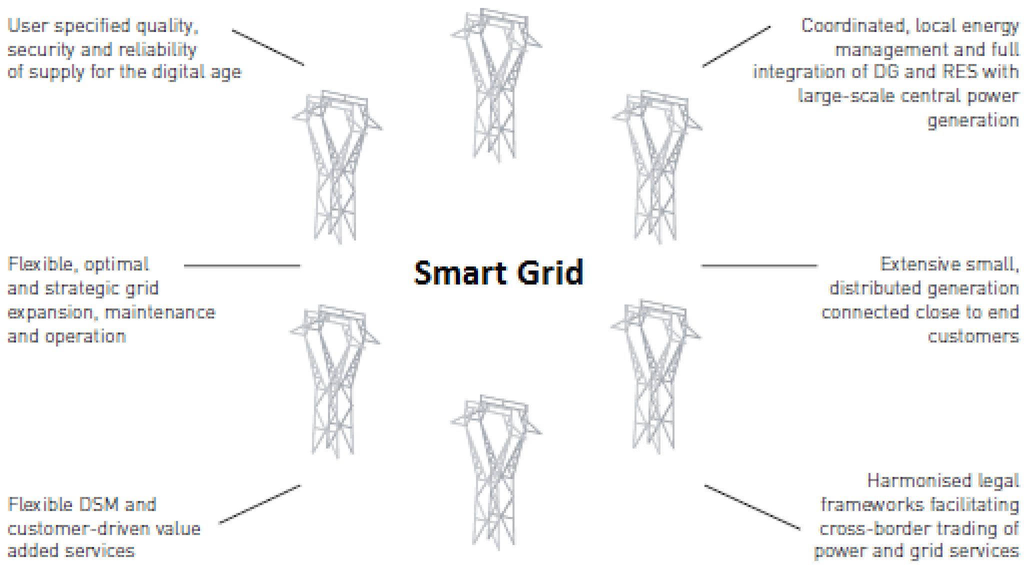

Fig. 1.3: Smart Grid

1.5 Significant of smart Grid/ Study

Because regarding 2005, there's been growing interest within the Smart Grid. The popularity that ICT offers significant opportunities so as to modernize the particular procedure related to the electrical networks has coincided with an understanding that the facility sector may end up being decarbonizes during a practical price if it's supervised also as managed successfully. Additionally, numerous far more factors have coincided so as to market interest within the Smart Grid. In several areas of the earth (for instance, the us and lots of nations within European countries like Bangladesh), the particular power grid broadened quickly within the 1950s also because the transmission and distribution gear which was found out then has become past it's style existence also as trying to find alternative. The necessity to refurbish the transmission and distribution circuits is a clear opportunity so as to innovate alongside fresh styles also as operating practices. Consequently a couple of the prevailing power transmission and distribution lines are operating near their capacity and a few renewable generation cannot be linked. This particular requires far more smart ways of growing the facility transfer capacity of circuits dynamically and rerouting the facility flows via much less loaded circuits. Any quite power grid operates within prescribed voltage and frequency limitations. When the voltage exceeds it's top restrict, the particular padding related to aspects of the facility system and consumer equipment could also be damaged, leading to short-circuit problems. As well reduced the voltage might cause malfunctions of customer equipment also as end in excess current and tripping of some lines and machines. Modern society requires an increasingly reliable electricity supply because far more also as more critical loads are connected. Conventional method of enhancing dependability had been to line up extra repetitive circuits, through substantial capital price also as environment effect. The Smart Grid strategy is by using smart post-fault reconfiguration to make sure following a (inevitable) difficulties within the power system, the actual materials so as to clients tend to be taken care related to nevertheless to avoid the worth connected with several circuits which can be just partially packed regarding tons of their very own existence. Much less repetitive circuits end in much better using home nevertheless higher electrical losses.

1.6 Scope of Smart Grid

Power lack is basically a globally issue. At the present, quite 40 countries show power grid instability also as load-shedding thanks to electricity shortage. Us also as Western businesses tend to be at the present that specialize in creating 'smart electric grid' systems so as to enhance energy circulation utilizing electronic radios with reference to better electrical grid manage as well as energy conservation. The need to construct Smart Grid systems is really increasing globally also as Bangladesh may become the leader during this region related to technologies improvement. Because energy need is really growing annually within Bangladesh, it isn't feasible to construct energy channels quickly. Smart Grid system can minimize this problem. just in case of load-shedding, brought on by electric energy lack within the country, the particular Smart Grid may instantly recalculate also as deliver electric power The basic must implement Smart Grid are digital radios, circuit breakers then on. Each electronic radios also as circuit breakers need to update the particular procedure related to country's electrical grid, which can be created also as manufactured in Bangladesh in large scale. With the assistance of expatriate Bangladeshi engineers, Bangladesh can start designing and manufacturing the electrical parts required to up-grade the electricity grid in Bangladesh to ensure that, Bangladesh are often an early developer and adopter of the Smart Grid technology.

1.7 Methodology

The study was conducted mainly supported the info collected from the various secondary sources like Bangladesh power development board, power division, and power cell, U.S Department of Energy (DoE), Smart Grids European Technology Platform etc. Different statistical reports, relevant research papers, books and lots of national and international journals have also been reviewed for this study.

1.8 Thesis diagram

The study of this thesis is organized as follows –

Chapter-1 introduces historical development of the electricity grid, the concept of smart grid, current power grid vs. smart grid, significant of smart grid/ study, scope of smart grid, methodology and this thesis study.

Chapter-2 The Road to Smart Grid

Chapter-3 Smart Grid Technologies

Chapter-4 Benefits and Challenges

Chapter-5 Development of Smart Grid in Bangladesh

Chapter-6 concludes with some recommendations and future scopes of the work

CHAPTER 2
THE ROAD TO SMART GRID

2.1 Introduction

We are in a rapid, global rollout of smart grid standards. With the smart grid's promise dependent on crossing the various geographic, operational and technological boundaries that have historically defined electricity delivery around the world, standards serve as bridges for two-way power and information flow end-to-end across an infrastructure that more closely connects energy generation, distribution, delivery and consumption.

So fast is standards development for the smart grid around the world, in fact, that the utilities on the vanguard of real-world rollout may feel a little befuddled in trying to make sense of what is and is not possible today. Thanks to key development activities over the past decade and a new era of smart grid-driven coordination among standards development organizations (SDOs), a standards-based approach to integrating utility applications is, indeed, possible.

2.2 What Makes a Smart Grid “Smart”?

The answer is Intelligent Energy Transfer. It is smart to not waste energy and not waste money in power generation capacity, but it takes some intelligent technology and control to make it happen. Electricity energy storage is one of those key technologies to minimize transmission losses and enhance grid stability while adding more renewable energy.

A common interpretation of the smart grid is that it is the combination of the electric power and communication infrastructures, characterized by two-way communication and two-way energy flow. However, this interpretation sometimes gives a wrong impression that the deployment of the advanced metering infrastructure (AMI) and phasor measurement units (PMUs) equals a smart grid. It is true that advanced sensing and communication systems are indispensable parts of a smart grid, since they provide channels for monitoring critical data and sending back control commands. However, they don’t provide the smartness for data analysis and decision making.

2.3 Smart Grid Standards

There are many applications and technologies for Smart grid that have been developed. Most of them are still in the development phase. But, the important task is to find widely accepted standards for the overall system without inhibiting the integration of advanced applications, smart meters, smart devices and renewable energy sources. Smooth inter-operability, comprehensive decision support, robust data security, product safety are also need to be concerned.

According to The Energy Independence and Security Act of 2007 (EISA), the National Institute of Standard and Technology (NIST) has been assigned the “primary responsibility to coordinate development of a framework that includes protocols and model standards for information management to achieve interoperability of Smart Grid devices and systems" [Energy Independence and Security Act of 2007 [Public Law No: 110-140], Sec. 1305]

To carry out its EISA-assigned responsibilities, NIST devised a three-phase plan to rapidly identify an initial set of standards, while providing a robust process for continued development and implementation of standards as needs and opportunities arise and as technology advances.

The Smart Grid will ultimately require hundreds of standards. Some are more urgently needed than others. To prioritize its work, NIST chose to focus on six key functionalities plus cyber security and network communications.

- **Demand response and consumer energy efficiency:** Mechanisms and incentives for utilities, business, industrial, and residential customers to cut energy use during times of peak demand or when power reliability is at risk. Demand response is necessary for optimizing the balance of power supply and demand. With increased access to detailed energy consumption information, consumers can also save energy with efficiency behavior and investments that achieve measurable results. In addition, they can learn where they may benefit with additional energy efficiency investments.
- **Wide-area situational awareness:** Monitoring and display of power-system components and performance across interconnections and over large geographic areas in near real time. The goals of situational awareness are to understand and ultimately optimize the management of power-network components, behavior, and performance, as well as to anticipate, prevent, or respond to problems before disruptions arise.
- **Energy storage:** Means of storing energy, directly or indirectly. The most common bulk energy storage technology used today is pumped hydroelectric storage technology. New storage capabilities- especially for distributed storage- would benefit the entire grid, from generation to end use.
- **Electric transportation:** Refers primarily to enabling large-scale integration of plug-in electric vehicles (PEVs). Electric transportation could significantly reduce U.S. dependence on foreign oil, increase use of renewable sources of energy, and dramatically reduce the nation's carbon footprint.

- **Network communications:** Refers to a variety of public and private communication networks, both wired and wireless, that will be used for Smart Grid domains and sub domains. Given this variety of networking environments, the identification of performance metrics and core operational requirements of different applications, actors, and domains—in addition to the development, implementation, and maintenance of appropriate security and access controls—is critical to the Smart Grid. FERC notes, a "… cross-cutting issue is the need for a common semantic framework (i.e., agreement as to meaning) and software models for enabling effective communication and coordination across inter-system interfaces. An interface is a point where two systems need to exchange data with each other; effective communication and coordination occurs when each of the systems understands and can respond to the data provided by the other system, even if the internal workings of the system are quite different."
- **Advanced metering infrastructure (AMI):** Provides near real-time monitoring of power usage, and is a current focus of utilities. These advanced metering networks are of many different designs and could also be used to implement residential demand response including dynamic pricing. AMI consists of the communications hardware and software, and the associated system and data management software, that together create a two-way network between advanced meters and utility business systems, enabling collection and distribution of information to customers and other parties, such as the competitive retail supplier or the utility itself. Because the networks do not share a common format, NIST is helping to coordinate the development of standard information data models.

- **Distribution grid management:** Focuses on maximizing performance of feeders, transformers, and other components of networked distribution systems and integrating them with transmission systems and customer operations. As Smart Grid capabilities, such as AMI and demand response are developed, and as large numbers of distributed energy resources and plug-in electric vehicles (PEVs) are deployed, the automation of distribution systems becomes increasingly more important to the efficient and reliable operation of the overall power system. The anticipated benefits of distribution grid management include increased reliability, reductions in peak loads, increased efficiency of the distribution system, and improved capabilities for managing distributed sources of renewable energy.

- **Cyber security:** Encompasses measures to ensure the confidentiality, integrity, and availability of the electronic information communication systems and the control systems necessary for the management, operation, and protection of the Smart Grid's energy, information technology, and telecommunications infrastructures.

2.4 Technical Composition of Smart Grid

Smart grid mainly consists of four parts:

2.4.1 Advanced Metering Infrastructure (AMI)

AMI is a critical infrastructure for its development, its main function is to empower the user, allowing the system to establish contact with the load, and allowing users to support the power grid operation. It includes smart meters, wide-area network facilities, home networking, marking the data management systems, operating checkpoints and so on. Figure 2 describes the interface between the AMI technology and several other technologies.

2.4.2 Advanced Distribution Operation (ADO)

The traditional power distribution automation focuses on automatic control of power distribution circuit switch, but ADO Is a complete automation of all control devices and function, with the purpose of achieving self healing capabilities of smart grid. Its main function will be real-time monitoring of distribution information and automatic demand response; predict and control the real-time status of power distribution system; automatic voltage and reactive power control and power management.

2.4.3 Advanced Transmission Operation (ATO)

The goal is to achieve intelligent transmission, and focus on congestion management and reducing the risk of large-scale outages. Its technology components are transmission network compatibility technology and advanced grid monitoring technology. Among them, transmission network compatibility technology includes special high-voltage transmission technology, superconducting power transmission technology and dynamic fixed transmission line technology and the transmission network monitoring technology includes wide-area measurement systems and the state detection technology of transmission equipment.

2.4.4 Advanced Asset Management (AAM)

Mainly to achieve the power asset management, significantly improving the power grid operation mode and efficiency. It is mainly divided into four layers:

- user layer
- logic layer
- application service layer
- system service layer

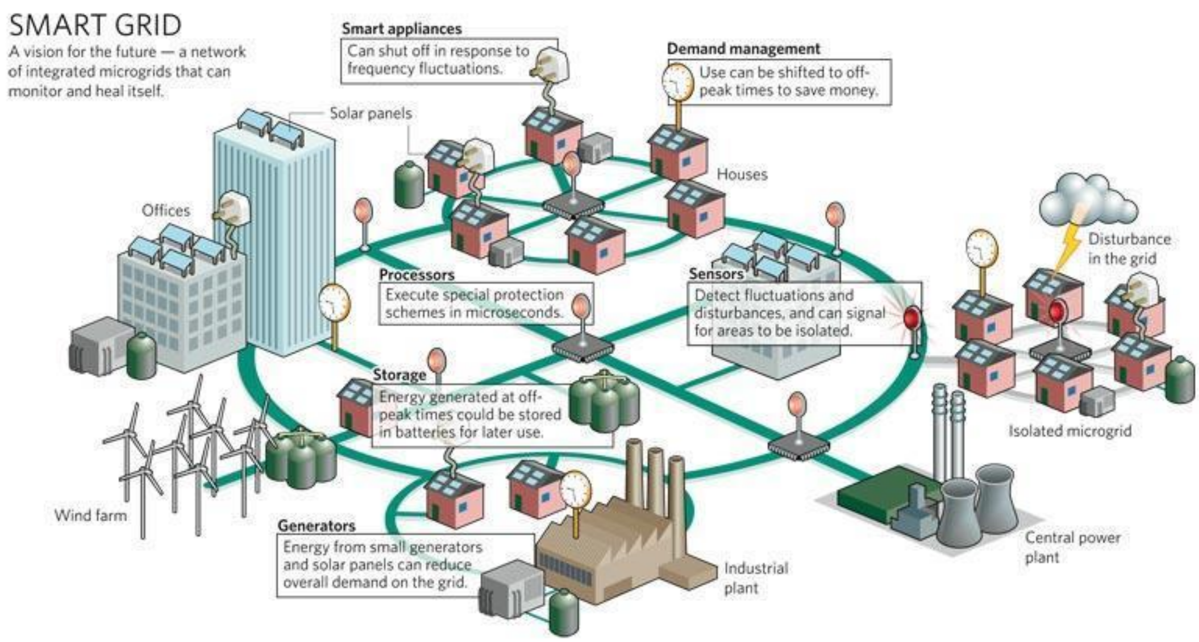

Fig. 2.1: Model set up for Smart Grid Network

2.5 Driving Factors

The current climate demands change in the way electricity is supplied. As the internal market develops, consumers will start to benefit from greater choice and lower costs. Fossil fuels are running out and the security of electricity supplies is under threat. Environmental issues have moved to the fore and the world must meet targets set. There are three major driving factors towards making the future grids smarter.

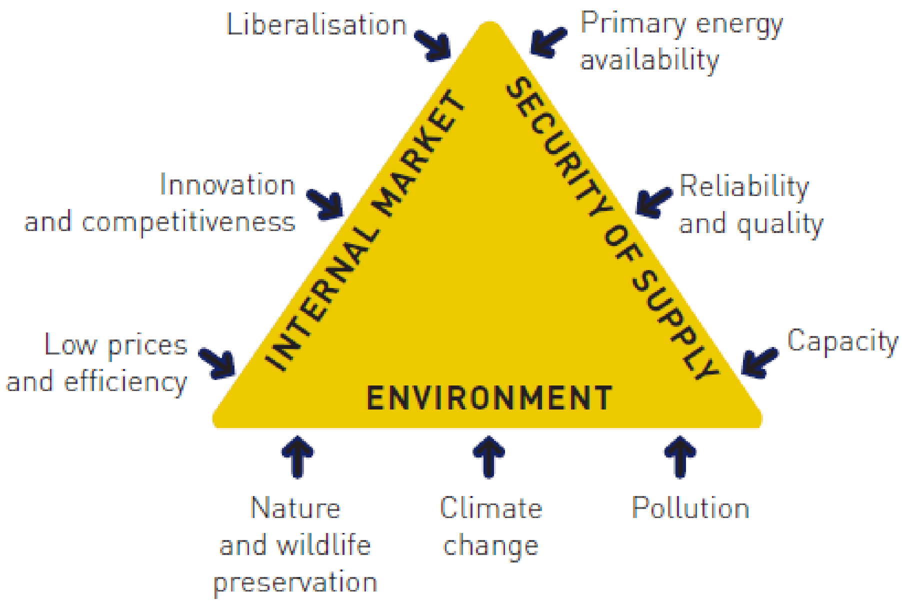

Figure 2.2: Driving Factors of Smart Grid

2.5.1 Internal Market

The Internal market has evolved to be liberal and market driven structure by deregulating the industries. This allows other utilities to generate and sell their product on a free market, which in theory should promote competition between the utilities, driving prices down. This market evolution, associated with an efficient regulatory framework, will promote economic growth and play a key role in nation's competitiveness strategy. Increasing competition will encourage efficiency and spur on technological progress and innovation. As a result, the internal market is expected to provide such as a wider choice of services and downward pressure on electricity prices.

2.5.2 Security and Quality of Supply

Modern society depends critically on a secure supply of energy. Growth partnership company Frost & Sullivan reports that at a global level, electricity consumption is set to increase from 10543 billion kilowatt hours in 1990 to over 30116 billion kilowatt hours in 2030 at a compound annual growth rate of 3.6%. Countries without adequate reserves of fossil fuels are facing increasing concerns for primary energy availability. Furthermore, the ageing infrastructure of electricity transmission and distribution networks is increasingly threatening security, reliability and quality of supply. Power outages also cost significant economical consequences as today's society is heavily based on electricity. The US loose at least $150 billion each year due to power outages, even though the power system is 99.97% reliable. A recent survey reveals that power outages result in a loss of industrial output worth $1 billion a year which reduces the GDP growth by about half a percentage point in Bangladesh. A major hurdle in efficiently delivering power is caused by the inefficient distribution system. It is estimated that the total transmission and distribution losses in Bangladesh amount to one-third of the total generation, the value of which is equal to US $247 million per year. It is time to redesign electricity grids which take account of new roles and challenges. Significant investment will be required to develop and renew these infrastructures. The most efficient way to achieve this is by incorporating innovative solutions, technologies and grid architectures.

2.5.3 The Environment

Besides issues of primary energy supply, the major disadvantage of fossil fuels is that they emit CO_2, SO_2, NO_X and other pollutants when burnt to generate electricity. The greenhouse gases contribute to climate change, which is recognized to be one of the greatest environmental and economic challenges facing humanity. In the US, power generation is responsible for 40% of carbon emission of the country and making the power plant just 5% more efficient, it is possible to reduce 262.1 billion pounds of CO_2. Research is needed to help identify the most cost-effective technologies and measures that will enable meet targets under the Kyoto Protocol and beyond.

A recent research by Powel Company in Norway shows that the majority of European utilities consider technology as a main driver for Smart Grids. According to David J. Leeds of GMT research, the major driving factors of smart grid are given below.

2.5.4 Technology Advancement

- Smart Grid can be seen as the convergence of IT, telecom, and energy markets
- New products and solutions through technology advancement
- Significant amounts of venture capital investment in Smart Grid technologies and solutions

2.5.5 Higher Efficiency With the Help of Grid Optimization

- Multiple integration points for intelligent grid hardware and software from transmission to consumption
- Embedded sensors and monitoring capabilities
- Deployment of advanced two-way communications networks
- Growing Supply of Renewable and Distributed Power Generation and Storage
- Network and systems architecture to support many forms of distributed generation and storage
- Intelligent support for multiple forms of intermittent renewable power sources (centralized and/or distributed)

2.5.6 Advanced Customer Services

- Robust, simple consumer energy management platforms
- Networked devices within the "smart home"
- New, efficient pricing models for electricity usage

2.5.7 Infrastructure Reliability and Security

- Networks/systems tolerant of attack or natural disaster
- Ability to anticipate and automatically respond to system disturbances

2.5.8 21st Century Power Quality

Power quality determines the fitness of electrical power to consumer devices. The set of limits of electrical properties allows electrical systems to function in their intended manner without significant loss of performance or life.

The quality of electrical power may be described as a set of values of parameters, such as:

- Continuity of service
- Variation in voltage magnitude

- Transient voltages and currents
- Harmonic content in the waveforms for AC power

  Modern systems use sensors called phasor measurement units (PMU) distributed throughout their network to monitor power quality and in some cases respond automatically to them. Using such smart grids features of rapid sensing and automated self healing of anomalies in the network promises to bring higher quality power and less downtime while

2.6 Summary

New energy conservation technologies are needed for Smart Grids. As such technologies may reduce the need for reserve power plants and can cut the costs of power failures. Energy conservation technologies may also help to smooth out the variability of renewable energy generation, such as wind and solar.

CHAPTER 3
SMART GRID TECHNOLOGIES

3.1 Introduction

The many smart grid technology areas – each consisting of sets of individual technologies – span the entire grid, from generation through transmission and distribution to various types of electricity consumers. Some of the technologies are actively being deployed and are considered mature in both their development and application, while others require further development and demonstration. A fully optimized electricity system will deploy all the technology areas described here. However, not all technology areas need to be installed to increase the "smartness" of the grid.

3.2 Advanced Metering Infrastructure (AMI)

3.2.1 Introduction

Advanced metering infrastructure (AMI) refers a system that collects, measures and analyzes energy usage by enabling data to be sent back and forth over a two-way communications network connecting advanced meters ("smart meters") and the utility's control systems. AMI provides utilities unprecedented system management capabilities, allowing for the first time the possibility of having consumers/end-users make informed, real-time choices about their energy usage (acting as a gateway technology to the "smart home"). Millions of smart meters are currently being deployed around the globe. There are two main components of any AMI system:

- The physical smart meter itself, which replaces older mechanical meters unable to communicate
- The communications network necessary to transport the data that the meter generates

AMI can be explained as having two distinct layers: the application layer and the transport layer. The application layer is concerned with data collection, monitoring and operational control, related to effectively managing the over-all electric grid. At the application layer, data analysis is also performed; the goal is that information sent from millions of end points is converted into "actionable intelligence" able to help grid operators achieve an efficient and adaptive delivery and utilization of power, as well as ensuring reliability and security.

The transport layer is concerned with moving information back and forth from the utility to the energy user; this is done by moving data across a series of interconnected networks. It should be noted that the reason AMI receives so much attention (apart from smart meters being an easy technology to understand) is because the build-out of the transport layer will allow many other advanced applications to operate, as there will now be a communications network infrastructure in place between the end-user and the utility.

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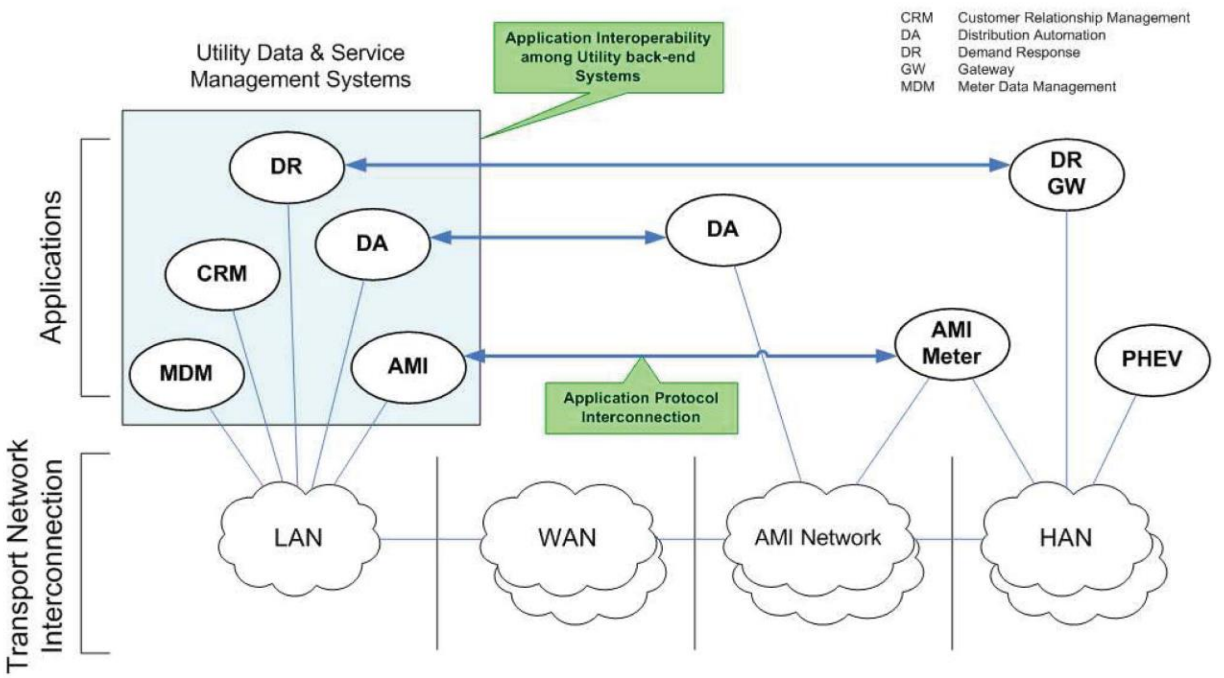

One of the most exciting applications that AMI allows for is demand-response, which gives the utilities the ability to turn off/down grid endpoints in real-time (thermostats, HVACs, lighting systems, etc.), based on pre-arranged contractual agreements with customers, in order to curb peak demand.

3.2.2 Smart Metering

Throughout the day Smart Meter records the electricity usage and securely stores it within its memory, until it receives a request to send information. The data is then securely routed meter to meter, until it is received by a collection device. The Smart Meters form a mesh network, ensuring the utility receives data in a reliable and cost effective way. If there is an interruption in communication anywhere along the path, the self-healing network automatically redirects the consumption information to a nearby meter or to a collection device. The fully protected data then relayed to the utility using the existing communication network.

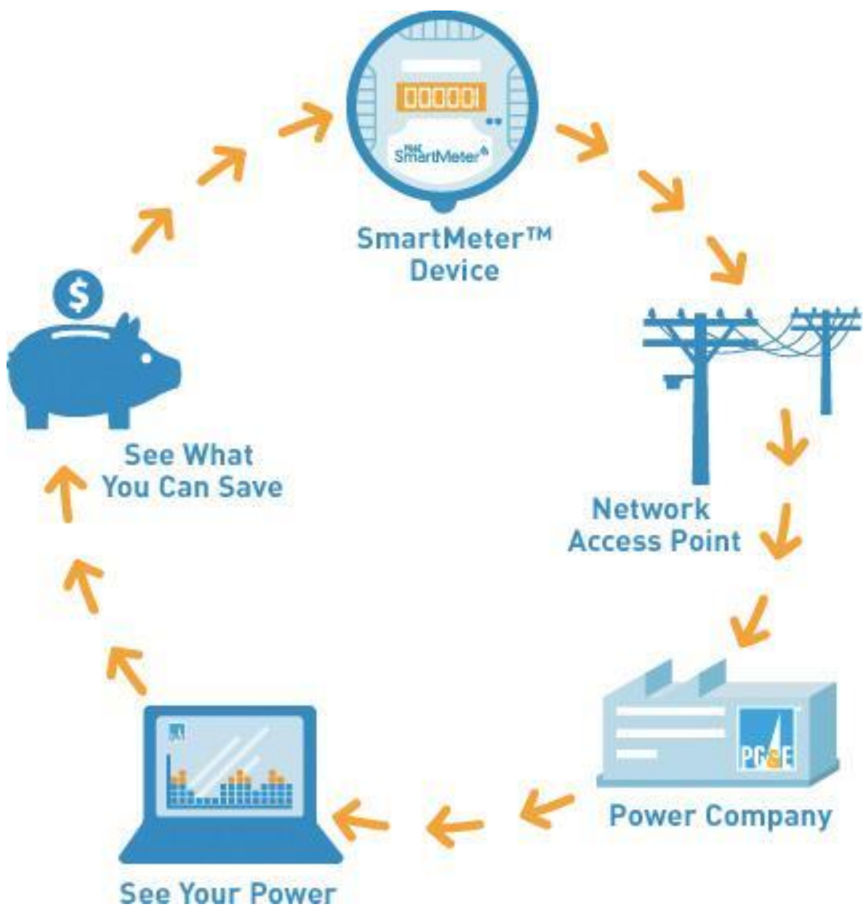

Fig. 3.2: Smart Meter- How It Works

3.2.3 Smart Meter and Smart Grid

Sometimes people get confused between smart meters and Smart Grids. The short answer is that, just as meters are part of the power grid, smart meters are a part of Smart Grids.

Smart meters have six primary features: two-way communications, recording of interval data on energy usage, delivery of data to the utility at least daily, a disconnect switch, power quality sensing (voltage), and a two-way communications module to talk to smart thermostats, in-home displays, smart appliances and smart equipment in customer homes and businesses. These features empower consumers with time-based pricing options, such as Peak Time Rebates and Time-of-Use prices, and detailed energy usage, cost, and carbon information, including monthly usage and bill to date. These features also enable utilities to manage better their line voltage and line losses.

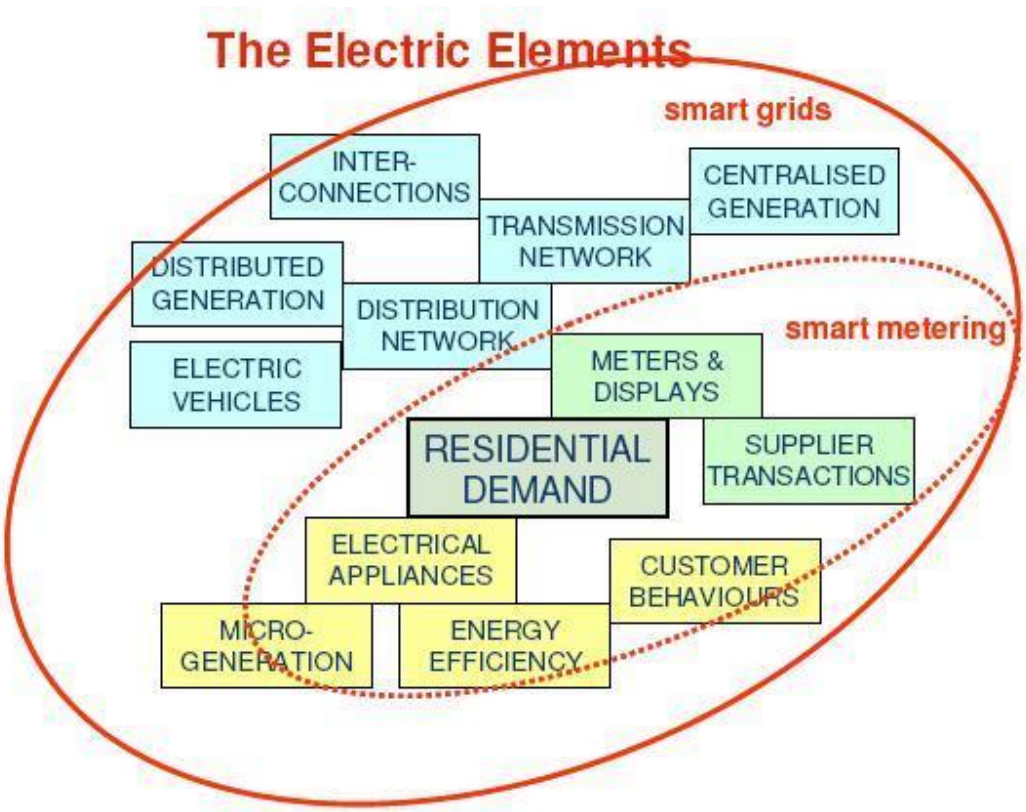

Fig. 3.3: Smart Meter and Smart Grid

Smart Grids start by automating meters and continue with automating the power delivery system. The latter means adding automated sensors and devices on power lines and in substations (the transmission and distribution grid). This automation allows for remote monitoring and control of the grid, more efficient operations, greater reliability through automatic restoration after outages ("self-healing"), and other benefits. In using the term, "Smart Grid," many people are focusing on the wires, transformers, and other devices on the power delivery side. While automating the power system sounds impressive, automating the meters actually delivers more benefits to both consumers and utilities, something for policymakers to keep in mind.

3.2.4 Advantages

There are many advantages. Smart meters provide additional information to help customers track and better manage their homes' energy consumption. For example, with a smart meter a consumer can monitor his daily usage online at his account and make consumption changes early in a bill cycle to better manage the amount of your electric bill. One can also elect to receive e-mails and text messages with weekly estimates of your monthly electric bill, to help plan and budget.

Power can be remotely started and stopped to support timely completion of customer service orders for turn-ons and turnoffs. Field meter reading is no longer required. By reducing labor and transportation costs, SRP is able to keep its prices lower. Traffic and vehicle emissions are also reduced in our community.

Smart meters record usage in real time, so real time collection and transfer of information is very much possible. It's a very important feature of Smart Meter, as it allows customers to track their real-time usage.

Customers may view their daily energy usage on the Web and also on the display of the meter.

Since meter readers will no longer need to read every meter each month, which will reduce pollution, fuel consumption and traffic. Additionally, the information a consumer will be able to access can help him to make decisions on reducing energy consumption, which can reduce the amount of electricity demand and the environmental impacts associated with power generation.

3.3 Demand Response/Demand Side Management

3.3.1 Introduction

Demand Response manages peak electrical demand providing incentives to utility to customers to reduce load on demand. In electricity grids, demand response (DR) is similar to dynamic demand mechanisms to manage customer consumption of electricity in response to supply conditions, for example, having electricity customers reduce their consumption at critical times or in response to market prices. The difference is that demand response mechanisms respond to explicit requests to shut off, whereas dynamic demand devices passively shut off when stress in the grid is sensed.

Demand response can involve actually curtailing power used or by starting on-site generation which may or may not be connected in parallel with the grid.

Demand response is a relatively simple concept. Utilities incentivize electricity customers to reduce their consumption at critical, "peak" times, on demand. Contracts, made in advance, specifically determine both how and when the utility (or an acting third-party intermediary) can reduce an end user's load. To date, most demand response efforts in North America have been coordinated with the larger users of energy – commercial and industrial users. Now, with the advancement of Smart Grid communications and technology, residential users will increasingly have the option to enroll in DR programs, giving DR "reach" to a substantial portion of the overall system. In fact, many industry observers has expressed that any true vision of a comprehensive Smart Grid is incomplete without demand response included.

3.3.2 The problem with peak

While supply and demand is a bedrock concept in virtually all other industries, it is one with which the current grid struggles mightily because, as noted, electricity must be consumed the moment it's generated. Without being able to ascertain demand precisely, at a given time, having the 'right' supply available to deal with every contingency is problematic at best. This is particularly true during episodes of peak demand, those times of greatest need for electricity during a particular period.

Imagine that it is a blisteringly hot summer afternoon. With countless commercial and residential air conditioners cycling up to maximum, demand for electricity is being driven substantially higher, to its "peak." Without a greater ability to anticipate, without knowing precisely when demand will peak or how high it will go, grid operators and utilities must bring generation assets called peaker plants online to ensure reliability and meet peak demand. Sometimes older and always difficult to site, peakers are expensive to operate – requiring fuel bought on the more volatile "spot" market. But old or not, additional peakers generate additional greenhouse gases, degrading the region's air quality. Compounding the inefficiency of this scenario is the fact that peaker plants are generation assets that typically sit idle for most of the year without generating revenue but must be paid for nevertheless.

In making real-time grid response a reality, a smarter grid makes it possible to reduce the high cost of meeting peak demand. It gives grid operators far greater visibility into the system at a finer "granularity," enabling them to control loads in a way that minimizes the need for traditional peak capacity. In addition to driving down costs, it may even eliminate the need to use existing peaker plants or build new ones – to save everyone money and give our planet a breather.

3.3.3 Benefits

The most important benefit of demand response is improved resource-efficiency of electricity production due to closer alignment between customers' electricity prices and the value they place on electricity. This increased efficiency creates a variety of benefits, which fall into four groups:

- Participant financial benefits are the bill savings and incentive payments earned by customers that adjust their electricity demand in response to time-varying electricity rates or incentive-based programs.
- Market-wide financial benefits are the lower wholesale market prices that result because demand response averts the need to use the most costly-to-run power plants during periods of otherwise high demand, driving production costs and prices down for all wholesale electricity purchasers. Over the longer term, sustained demand response lowers aggregate system capacity requirements, allowing load-serving entities (utilities and other retail suppliers) to purchase or build less new capacity. Eventually these savings may be passed onto most retail customers as bill savings.
- Reliability benefits are the operational security and adequacy savings that result because demand response lowers the likelihood and consequences of forced outages that impose financial costs and inconvenience on customers.
- Market performance benefits refer to demand response's value in mitigating suppliers' ability to exercise market power by raising power prices significantly above production costs.

3.3.4 Continuing Challenges

There are three primary challenges that could limit opportunities for continued growth in demand response solutions:

- The limited number of retail customers on time-based rates (which provides the necessary incentive to respond/react to market prices.
- Limitations on the number of customers that have access to meter data (who lack not only home energy management systems or "portals" to read the data, but in majority of cases the smart meters needed to generate and share that information.
- The scale of infrastructure investment needed to deploy enabling technologies during an economic downturn.

While there is a bit of a "Big Brother" concern to having utilities control consumer appliances and assets, the transition to real-time pricing (RTP) signals from their utilities along with the advancement of Smart Grid technologies (such as home energy management systems) will set the stage for consumers to dynamically adjust their own energy consumption profiles to minimize costs; this solution will preserve customer autonomy and mitigate privacy issues.

3.4 Grid Optimization and Distribution Automation

The term "smart grid" has been used to describe a broad range of technologies, design concepts and operating practices that collectively paint an exciting picture of what our electric power infrastructure might look like in ten or twenty years. But what about the grid we have today? Certainly one of the most important attributes of a smart grid is the ability to wring more out of the assets currently deployed throughout our electricity delivery system. That is the essence of optimization.

Grid optimization entails a wide array of potential advances that will give utilities and grid operators digital control of the power delivery network. The addition of sensor technology, communication infrastructure and IT will help optimize the performance of the grid in real-time, improving the reliability, efficiency and security. Grid operators will gain improved situational awareness as fundamental system-wide visibility and analytics will now be in place. While AMI deployments lay the foundation for utilities having control of millions of end user devices, real-time command and control of higher-level grid devices is of equal, if not greater, value in the current push for overall grid efficiency.

The deployment of wide-spread sensor technologies can be considered analogous to adding a central nervous system to the electric grid. It's worth noting, that in the human body, the brain does not provide all the intelligence; the nervous system gives the body wider, distributive intelligence. A true Smart Grid will have intelligence embedded at virtually every critical node, and just as the human brain can sense and respond to damaged nerves throughout the body, a Smart Grid will immediately react to disturbances throughout the power network. The communication infrastructure is vital to sensing grid activity and issuing control signals for improved grid performance and security. Information technologies will take data generated from millions of end points (such sensors embedded on equipment ranging from capacitor banks to transformers), and convert that into actionable intelligence. Ultimately, the grid will behave much like airplane's autopilot system (with many operational systems operating in the background). A Smart Grid will self-correct, self-optimize, call attention to any pertinent issues, and instruct operators if a manual override is necessary.

The benefits of grid optimization are fairly straightforward:

- To get more out of the existing infrastructure and thus defer investments in new generation, transmission and distribution facilities
- To reduce the overall cost of delivering power to end users
- To improve reliable delivery of power to end users
- To reduce resource usage and by extension, emissions of CO_2 and other pollutants

XCEL Energy's view of a smart and intelligent power grid

Utilities can expect to enhance and ref ne their distribution and generation management with the help of real-time system information. As a result, they will be able to respond to peak demand loads more efficiently; identify outages and their related causes more precisely (enabling faster restoration); dispatch a more cost effective mix of fuel sources (while minimizing environment impacts); and automatically re-route energy as needed to meet consumer demands and avoid unnecessary strain on the power grid.

Perceived Advances:

- Up to 30 percent reduction in distribution losses from optimal power factor performance and system balancing

- Expected deferral of capital spends for distribution and transmission projects based on improved load estimates and reduction in peak load from enhanced demand management
- Potential carbon footprint reduction as a result of lowered residential peak demand and energy consumption, improved distribution losses and increased conservation options
- Possible reductions in the number of customer minutes out as a result of improved abilities to predict and/or prevent potential outages, and more effective responses to outages and restoration
- Potential utility cost savings from remote and automated disconnects and reconnects, elimination of unneeded field trips

3.5 Distributed Generation and Integration of Renewable Energy

3.5.1 Distributed Generation

For the last 5-6 years, a number of customers have been installing stand alone distributed generation for their needs in small units. This trend indicates that distributed generation applications have gained more interest, due to the continued advancement of distributed generation technologies and their effectiveness as a local power source, where generation is in close proximity to the load or consumer. Distributed generation provides power from a few watts (W) to ten megawatts (MW) and offers several benefits compared to conventional power generation. Society‘s awareness of green energy utilization also leads to the increase of distributed generation installation and operation. Moreover, constraints on new construction of bulk power generation and transmission or distribution lines have created the conditions for utilizing this small-scale generation coupled to local transmission or distribution networks.

In a Jan. 11, 2011, press release, Bloomberg New Energy Finance stated that "Investment in small-scale, distributed generation projects surged by 91% last year to $59.6bn, with the dominant element rooftop and other small-scale solar projects, notably in Germany but also in the US, the Czech Republic, Italy and elsewhere."

3.5.2 What is Distributed Generation

Distributed generation is an approach that employs small-scale technologies to produce electricity close to the end users of power. DG technologies often consist of modular (and sometimes renewable-energy) generators, and they offer a number of potential benefits. In many cases, distributed generators can provide lower-cost electricity and higher power reliability and security with fewer environmental consequences than can traditional power generators.

In contrast to the use of a few large-scale generating stations located far from load centers--the approach used in the traditional electric power paradigm--DG systems employ numerous, but small plants and can provide power onsite with little reliance on the distribution and transmission grid. DG technologies yield power in capacities that range from a fraction of a kilowatt [kW] to about 100 megawatts [MW]. Utility-scale generation units generate power in capacities that often reach beyond 1,000 MW.

3.5.3 Distributed Generation Benefits

Increasing power system reliability expectations have evolved into the growth of distributed generation. The main drivers of that growth can be divided into three categories, which are environmental concerns, commercial policies and energy policies. These factors have been contributing to the high interest and penetration of distributed generation utilization. Issues related to the operation and interconnection of distributed generation into power system networks, such as power quality, reliability, stability and protections have been the focus of stakeholders, including power operators, designers, policy makers, engineers and consumers. However, in spite of triggering these issues, distributed generation also offers several advantages.

Table 3.1: Matrix of Distributed Generation Benefits and Services.

		Benefit Categories							
		Energy Cost Savings	Savings in T&D Losses and Congestion Costs	Deferred Generation Capacity	Deferred T&D Capacity	System Reliability Benefits	Power Quality Benefits	Land Use Effects	Reduced Vulnerability to Terrorism
DG Servi	Reduce in Peak Power Requirements								
	Provision of Ancillary Services - Operating Reserves - Regulation - Black start								

c e	- Reactive Power								
	Emergency Power Supply	□	□			□	□		

3.5.4 Distributed Generation and Power Quality

The term “power quality” can be associated with the reliability of power supply. However, engineers and power providers define it differently according to the parameter characteristic being measured, such as voltage, current or frequency. Adding distributed generation to power systems generally increases system reliability and power quality, for instance as a voltage support. In this case, distributed generation assists the central generation when overload occurs on the system, consequently avoiding voltage drop and accordingly improving the system voltage profile. However, there is a possibility of unexpected events that influence the system‘s power quality, such as reactive power absorptions, over injection of the current and the variability of renewable distributed generation source. Power quality related issues are very important and should not become a major obstacle against distributed generation deployment and RES utilization. However, it should be a challenge for novel approaches in power quality management and monitoring. Particularly with the co-existence of advanced power system utilities and information technologies, it can establish new techniques to address this case.

3.5.1.4 How Much DG Can the Grid Take

How much DG any particular grid system can integrate depends on how advanced it is and on how we define DG. On January 2010 California Public Utility Commission (CPUC) report notes that "Perhaps the most useful definition of distributed generation is one that focuses on connection and location rather than generation capacity. Based on comparisons of different characteristics and impacts of electric generating systems, researchers from the Swedish Royal Institute of Technology's Department of Electric Power Engineering defined distributed generation as "an electric power source connected directly to the distribution network or on the customer side of the meter". That definition includes generation from all sources. However, different countries, governmental and regulatory bodies, and reports define DG in different ways, so straightforward answers to the "how much" question are hard to come by.

3.5.1.5 How Much DG Do We Have

One 2009 study found that Denmark produces more than 45% of its power with DG. We need to keep in mind, though, that in Europe, DG often also includes demand response and renewable power projects of any size. According to one European source (Improgres—Improvement of the Social Optimal Outcome of Market Integration of Distributed Generation and renewable energy resources in European Electricity Markets), power generation from distributed sources/renewable energy will rise from 490 TWh/year in 2005 to about 1,280 TWh/year in 2030. DG's proportionate share of generation will also increase—from about 15% to about 26% in the same timeframe.

3.6 Integrated Communication

A variety of communications media are used in today's electric grid, including copper wiring, optical fiber, power line carrier technologies, and wireless technologies. Using these media, it is possible to deploy Substation Automation (SA), an excellent first step in integrating grid communications. However, SA does not yet fully integrate with the other features that will modernize our power grid.

Limited deployment of distribution automation (DA) has also occurred. Low speed transmission supervisory control and data acquisition (SCADA) and energy management system (EMS) applications have been successfully integrated among regional transmission organizations, generators, and transmission providers. But these applications still lack full utilization of the integrated, high-speed communications system required by the modern grid.

Power line carrier technology has been in use for many years in the utility industry. Recently, BPL carrier technologies have been developed and successfully demonstrated on a pilot basis. Also, wireless technologies are currently being developed and demonstrated, but they are not yet used in the grid communications infrastructure on either the system or the user side.
The current state of communications technologies described in the three tables below is in various stages of availability, deployment, or development.

3.6.1 Broadband over Power Line

Originally focused on Internet access and voice over Internet protocol for consumers, BPL is increasingly being deployed to meet utility needs for distributed energy resources (DER), AMR, DR, and consumer portal applications, as well as DA and video monitoring (primarily for security) applications and other high-speed data needs on the system side.

Table 3.2: Broadband over Power Line (BPL)

Broadband over Power Line	
Name	**Description**
Broadband over power line	• Meets some utility needs for AMR, DER, DR, and consumer portal applications, as well as DA, video monitoring, and other high-speed data applications • Deployable only over low- and medium-voltage distribution • Facilities • Demonstrated in over 30 pilots and trials • Has not penetrated the communications market as the lead • candidate for supporting the modern grid's communications infrastructure

Broadband over power line	• Deployment and integration with distribution facilities currently • Limited • Numerous vendors are aggressively marketing these products • Next-generation systems now under development promise lower cost, improved performance, higher speed, and utility applicability • Application at transmission voltages may also be viable Radio frequency interference with ham radio identified in some • BPL technologies; however, techniques have been developed and appear effective in eliminating the interference

Name	Description

3.6.2 Wireless Technologies

Various wireless technologies are emerging as possible candidates for the communications infrastructure of the modern grid. To date, few of them have made significant market penetration in either system or user side applications.

Table 3.3: Different types of Wireless Technologies

Technology	Description
Multiple address system radio	• Consists of a master radio transmitter/receiver and multiple remote transmitters/receivers • Master can access multiple units • Can be used as a repeater radio to transmit signals over or around obstructions • Used widely by utilities for SCADA systems and DA systems • Flexible, reliable, and compact

	• Radio systems that deliver short messages to small
Paging networks	• remote mobile terminals • One-way messaging is cost effective, but two-way is generally cost prohibitive • Some paging standards exist, but many systems remain proprietary
Spread spectrum radio systems	• Used in point-to-multipoint radio systems • Can operate unlicensed in 902-928 MHz band but must continually hop over a range of frequencies • Line of sight is needed for optimal coverage • Often used as last-mile connection to a main communications system
Technology	**Description**
Wi-Fi	• Utilizes IEEE 802.11b and IEEE 802.11g • Data transfer rates range from 5 – 10 Mbps for 802.11b and up to 54 Mbps for 802.11g • Effective for in-office or in-home use • Range is only about 100 meters
WiMax	• Utilizes IEEE 802.16 • Provides longer distance communications (10 – 30 miles) with data transfer rates of 75 Mbps • May be used as the spine of a transmission and distribution communications system that will support Wi-Fi applications for SA or DA • Can communicate out-of-sight using IEEE 802.16e and can communicate with moving vehicles • Communicates point-to-point with different vendors

3G	• Can be applied as a low-cost solution for SA to control and monitor substation performance when small bursts of information are needed • May not meet the quality needs of online substation control and monitoring • Expected to be cost effective and quickly implemented • Coverage may not be 100% (some dead zones)
Time division multiple access (TDMA) Wireless	• Digital cellular communication technology that allocates unique time slots to each user in each channel • Utilizes IS-136 standard • Two major (competing) systems split the cellular market: TDMA and CDMA (see below); third-generation wireless networks will use CDMA
Code division multiple access (CDMA) wireless	• Has become the technology of choice for the future generation of wireless systems because network capacity does not directly limit the number of active radios; this is a significant economic advantage over TDMA • Has been widely deployed in the United States • Utilizes the IS-95 standard which is being supplanted by IS-2000 for 3G cellular systems

3.6.3 Other Technologies

Table 3.3 below includes other communication technologies that support, or could support, the modern grid.

Table 3.4: Other Technologies supporting the modern grid

Technology	Description
Internet2	• Next-generation high-speed internet backbone • More than 200 universities are working to develop and deploy advanced network applications
Power-line carrier	• Supports advanced metering infrastructure (AMI) deployments and grid control functions, such as load shedding • Communicates over electric power lines • Provides low-cost, reliable, low- to medium-speed, two-way communications between utility and consumer
Fiber to the home (FTTH)	• Provides a broadband fiber-optic connection to customer sites • Costs of installation and associated electronics prohibitive • For decades, has been the "Holy Grail" of the telecommunications industry, promising nearly unlimited bandwidth to the home user • To be cost-effective, needs passive optical network, which permits a single fiber to be split up to 128 times without active electronic repeaters; general decrease in cost of electronics is also helpful
Hybrid fiber coax (HFC) architecture	• Uses fiber to carry voice, video, and data from the central office (head end) to the optical node serving a neighborhood • Cable operators have begun plant upgrades using HFC to provide bi-directional services, such as

	video-on-demand, high-speed Internet, and voice-over-Internet protocol
Technology	**Description**
Radio frequency identification (RFID)	• Uses radio frequency communication to identify objects • Provides an alternative to bar codes • Does not require direct contact or line-of-sight scanning • Low-frequency systems have short ranges (generally less than six feet); high-frequency systems have ranges of more than 90 feet

3.7 Phasor Measurement Unit

A phasor measurement unit (PMU) is a device which measures the electrical waves on an electricity grid, using a common time source for synchronization. Time synchronization allows synchronized real-time measurements of multiple remote measurement points on the grid. In power engineering, these are also commonly referred to as synchrophasors and are considered one of the most important measuring devices in the future of power systems (like Smart Grid). A PMU can be a dedicated device, or the PMU function can be incorporated into a protective relay or other device.

Power system parameters are represented as complex numbers. A phase vector, or phasor, is a representation of a sine wave whose amplitude (A) and angular frequency (ω) are time-invariant. Conventional instruments measure only magnitudes of phasors. With PMU we can measure both magnitude and angle of the phasor.

In the past, a lack of adequate computing power and the huge difficulties involved in collecting, coordinating and synchronizing the grid data made this impossible. However, new technology now available has radically changed this situation.

To make life even easier, engineers have simplified the mathematics they use. This was done to circumvent familiar difficulties with differential equations and long terms that included expressions such as ‘Asin ($\omega t+\varphi$)’ – which are typical of sinusoidal waveforms, like the AC mains power, that vary with time.

Figure 3.4 below shows the block diagram of a PMU relating different parts.

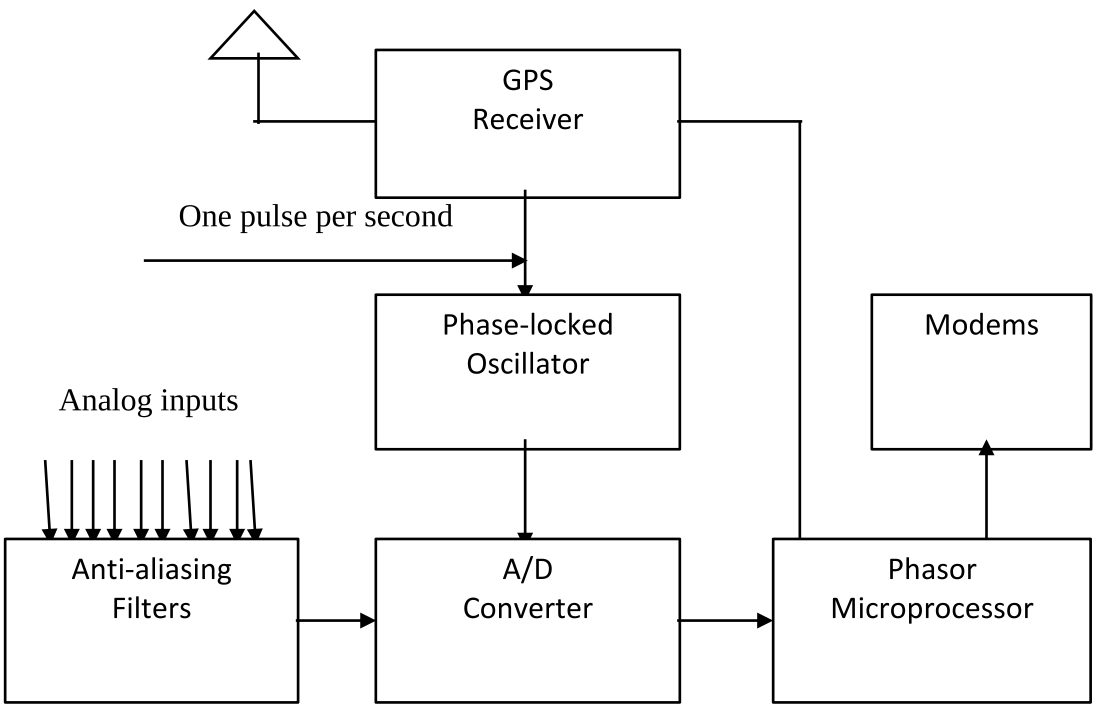

Fig.3.4: Block diagram of a PMU

3.7.1 PMU in Smart Grid

The concept of the Smart Grid begins with the fundamental need to increase the reliability and efficiency of the nation’s transmission systems and centralized generating assets. The integration of phasor measurement units and other advanced sensors into comprehensive wide area monitoring networks will enhance the situational awareness of the national grid and enable system operators to react to system disturbances and anomalies more accurately and expeditiously. Popularly referred to as the power system's 'health meter', Phasor Measurement Units (PMU) sample voltage and current many times a second at a given location, providing an 'MRI' of the power system compared to the 'X-Ray' quality available from earlier Supervisory Control and Data Acquisition (SCADA) technology. Offering wide-area situational awareness, phasors work to ease congestion and bottlenecks and mitigate – or even prevent – blackouts. Typically, measurements are taken once every 2 or 4 seconds offering a steady state view into the power system behavior. Equipped with Smart Grid communications technologies, measurements taken are precisely time-synchronized and taken many times a second (i.e., 10-60 samples/second) offering dynamic visibility into the power system. The accuracy, speed and reliability of PMUs are critical to fulfilling the promise of the Smart Grid. However, the current standard that governs PMU performance is quite broad, and testing by NIST has shown that PMUs from various manufacturers can report dynamic conditions very differently. For example, the primary transducer that converts high line voltages to the smaller voltages used by the measuring system can introduce inaccuracies. From the primary transducer, signals pass through an anti-aliasing filter that also generates some level of error. Next, the signal goes through an analog to digital (A/D) converter that can introduce magnitude or gain error and channel phase shift. Signal processing is carried out to evaluate the phasor magnitude and phase angle which may create additional error. The phase is reported with respect to the global time reference so errors in the global positioning system (GPS) source and cable delays may introduce synchronization errors.

3.7.2 Limitations of SCADA

- Measurements obtained at slower rate (1 sample/1-4s)
- Measurements are not time synchronised
- Does not provide dynamic behaviour of system
- Limited situational awareness conveyed to the operator
- SCADA is 'X-ray' of power grid where PMU is 'MRI'

3.7.3 PMU Applications

Table 3.5: PMU Deployment in Different Parts of the World

PMU Applications	North America	Europe	China	India	Brazil	Russia
Post-Disturbance Analysis	□	□	□	**P**	**T**	□
Stability monitoring	□	□	□	**P**	**P**	□
Thermal Overload Monitoring	□	□	□	**P**	**P**	□
Power System Restoration	□	□	□	**P**	**P**	**P**
Model Validation	□	□	□	**P**	**T**	□
State Estimation	**P**	**P**	**P**	**P**	**P**	**P**
Real-time Control	**T**	**T**	**T**	**P**	**P**	**P**
Adaptive Protection	**P**	**P**	**P**	**P**	**P**	**P**
Wide Area Stabilizer	**T**	**T**	**T**	**P**	**P**	**P**

P= Planning Stage; T= Testing Stage

3.7.4 Challenges

- Consistent performance required for a multi vendor PMU system
- Diverse requirements from all utilities
    - Different application requirements
    - Difference in infrastructure
    -
- WAMS architecture
    - Present architecture not suitable for large system
- High investment
    - Initial high investment requirement acts as an deterrent
    - Clear roadmap is needed
- Lack of related products
    - Not enough related products (PDC, application software)

- PMU placements
    - Non-linear optimization problem
    - currently one can get sub-optimal solution
- Visualization of PMU data
    - Difficult to visualise the voluminous data
- Communication of PMU data
    - Expensive communication network required
- Communication delays
    - leads to delay in generating proper control signals
- Low frequency oscillation monitoring
    - algorithms are computationally heavy
    - all modes may not be captured
    - distorted power system waveforms make it difficult

3.8 Smart Home and Home Area Networks

3.8.1 Smart Home

At the turn of the century, electricity improved everyday life by supplying light after dark and providing power to machines. Today, the traditional home has appliances that are operated locally and manually, usually by flipping a switch or pushing a button. These devices have limited controls, and managing the energy they use can be difficult.

Consumers receive electricity bills once a month. The customer has no way to correlate the amount of money spent on electricity with how it was used. Furthermore, for those customers who have purchased renewable energy systems, there's no ability to measure (and receive credit for) the value of energy produced from renewable resources.

The smart home represents the convergence of energy efficient, controllable appliances and real-time access to energy usage data. This integration of smart devices and smart grid enables customers to proactively manage energy use in ways that are convenient, cost effective, and good for the environment.

Smart home technology is the technology used to make all electronic devices around a house act "smart" or more automated. Nearly all major appliances in the future will take advantage of this technology through home networks and the Internet. Smart home technology is a way for ordinary electronics and appliances to communicate with each other, consumers, and even manufacturers. Many consider a smart home to be one that is networked. Others feel it is a home that has appliances that will allow the consumer to do little to no work, but a smart home really is all of that combined, and more. Not only will all consumer products be networked, but they will also make life easier on people. Smart home technology is currently being developed and implemented for all rooms in the house.

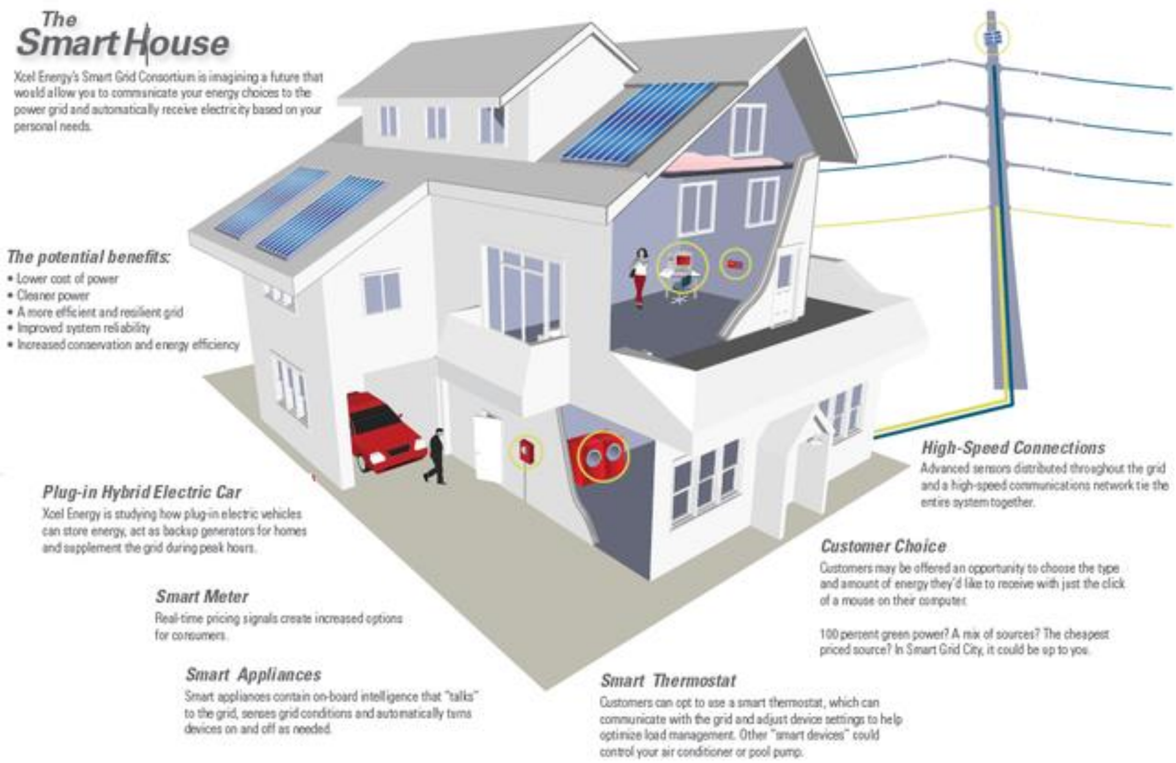

Fig. 3.5: Smart Home

3.8.2 Home Area Network

Home Area Networks (HAN) are the fun part of Smart Grid. A network within the home that enables devices and major appliances to communicate with each other and dynamically respond to price (and carbon) signals sent from the utility, relaying whether or not electricity is currently expensive. Who doesn't want their dishwasher to realize that if it waits three hours to run its cycle, it will save 50 percent for that particular energy transaction? For that matter, who doesn't want a "smart home," outfitted with rooftop panels, micro wind turbines, advanced storage and smart charging capabilities for the electric car in the driveway, where each of these applications is visibly traceable and remotely controllable in real time via a web-based home energy management system? Who doesn't want the capabilities to learn their energy usage and energy generation on their iPhone, and discover that the utility is actually paying them for the excess solar energy which they recently generated, or had available in storage? Perhaps HAN is so much fun because it doesn't actually exist in any meaningful way (beyond demonstration pilots) – but for the first time ever it's entirely reasonable to expect that it will soon arrive at mass scale. While HAN remains in the realm of great promise, speculation, debate and uncertainty – it is often referred to as a bleeding-edge.

3.9 PHEV Smart Charging and V2G

One of the most discussed and anticipated "applications" of Smart Grid is the introduction of the plug-in hybrid electric vehicle (PHEV). PHEV's larger battery, relative to the previous generation (plug-less) hybrids, will allow for both the possibility of storing electricity, which might otherwise go unused (ideally from renewable, intermittent sources), and of feeding stored energy back into the electric grid, in periods of high demand, serving as a back-up source of power for the electric grid. While the market fundamentals to support what will be a revolutionary advancement in both the automobile and energy industries are not fully in place as 2010, PHEVs are about to be marketed and sold by virtually every major automobile manufacturer in world in the next two to five years, and as such utilities are now scrambling to ready themselves for what could be a truly disruptive technology.

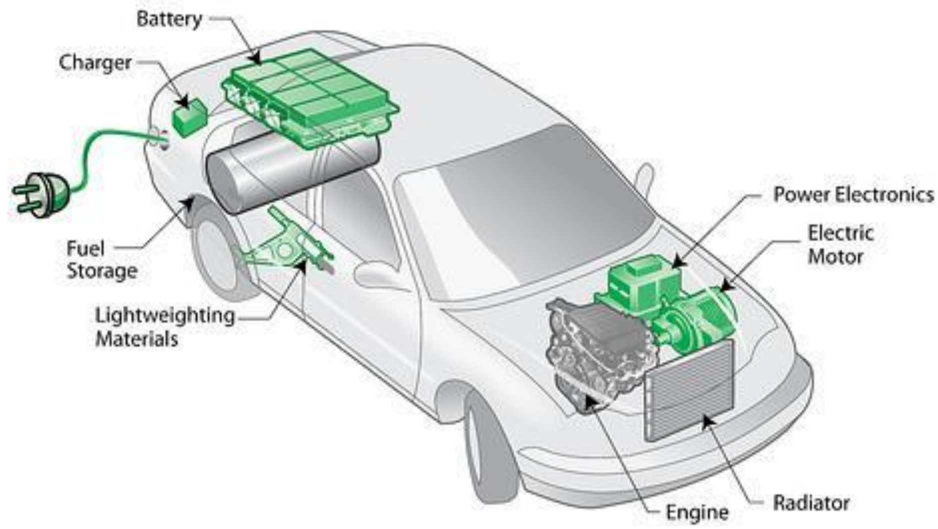

Fig. 3.6: Plug-in Hybrid Electric Vehicle

Politicians on both sides of the aisle support electric vehicles, as they are both environmentally friendly (a concern of the left) and reduce the need for foreign sources of oil (a concern of the right). The Stimulus Package announced by the Obama administration in early 2009 gives citizens a $7,500 U.S. federal tax credit on battery powered cars, effectively bridging the price gap between these more expensive vehicles and the traditional cars. In our view, in general there are two remaining barriers to mass PHEV penetration: cheaper and better performing batteries (and hence, cheaper cars) and an electric grid that can support their introduction at scale – a Smart Grid. As PHEVs ramp up, there will be two very interesting challenges/opportunities they will present:

1. Smart charging
2. Vehicle to grid (V2G)

3.10 Energy Storage

As the electrical grid is integrated with more renewable energy sources, energy storage will be instrumental for micro grids and smart grids. Adding digital intelligence to the power grid is getting all the attention right now from Congress, investors and entrepreneurs, but a next-generation smart grid without energy storage is like a computer without a hard drive- severely limited. Energy stored throughout the grid can provide dispatchable power to address peak power needs, decreasing the use of expensive plants that utilities power up as a last resort when demand spikes, making the network less volatile. Energy storage will also be crucial for making the most of variable renewable energy sources (the sun shines and the wind blows only at certain times) once they're connected to the grid. In the way that computers and the infrastructure of the Internet have built up around storage as a key component, so the power grid eventually will rely on energy storage technology as a pivotal piece.

These nine are among the most promising:

3.10.1 Compressed Air

Compressed air is a decades-old technology which takes excess energy from a power plant or renewable energy and uses it to run air compressors, which pump air into an underground cave or container where it's stored under pressure. When the air is released, it powers a turbine, creating electricity. Utilities like PG&E are starting to investigate this technology because it is one of the lowest-cost and simplest energy storage technologies.

3.10.2 Pumped Hydro

Pumped hydro storage is the most widespread energy storage technology used in the world, according to the Energy Storage Association. There are about 90 GW of pumped storage in operation in the US, which equals about 3 percent of worldwide generation capacity. The system works by pumping water from a lower reservoir to a higher reservoir and then letting the water move downhill to produce electricity when needed. Traditional iterations of the technology are ideal for populations that live close to high altitude terrain, like Switzerland, where pumped hydro has been used for a century.

CHAPTER 4

BENEFITS AND CHALLENGES

4.1 Introduction

There are two reasons to create a national smart grid. First, today's grid needs to be upgraded because it is aging, inadequate, and outdated in many respects—investment is needed to improve its material condition, ensure adequate capacity exists, and enable it to address the 21st-century power supply challenges. Status quo is not an option. Secondly, the benefits of the smart grid are substantial.

4.2 The Seven Principal Characteristics of the Smart Grid

- Enables active participation by consumers— Consumer choices and increased interaction with the grid bring tangible benefits to both the grid and the environment, while reducing the cost of delivered electricity.
- Accommodates all generation and storage options— Diverse resources with "plug-and-play" connections multiply the options for electrical generation and storage, including new opportunities for more efficient, cleaner power production.
- Enables new products, services, and markets— The grid's open-access market reveals waste and inefficiency and helps drive them out of the system while offering new consumer choices such as green power products and a new generation of electric vehicles. Reduced transmission congestion also leads to more efficient electricity markets.
- Provides power quality for the digital economy— Digital-grade power quality for those who need it avoids production and productivity losses, especially in digital-device environments.

- Optimizes asset utilization and operates efficiently— Desired functionality at minimum cost guides operations and allows fuller utilization of assets. More targeted and efficient grid maintenance programs result in fewer equipment failures and safer operations.
- Anticipates and responds to system disturbances (self-heals) — the smart grid will perform continuous self-assessments to detect, analyze, respond to, and as needed, restore grid components or network sections.
- Operates resiliently against attack and natural disaster— the grid deters or withstands physical or cyber attack and improves public safety.

4.3 Benefits

The smart grid presents a wide range of potential benefits, which include-

4.3.1 Self-healing and Resilient

Smart grid, with combination of implanted real time sensor, computerized control, is able to anticipate, detect and react to troubles like power outages and distribution interruptions. The system should be able to automatically search for solution to either completely avoid or diminish these problems. Smart centers placed along power lines and substation can detect trouble and can communicate real time information to automatically diagnose the problems on the line and reroute the power supply.

Technology such as Fault Detection Isolation and Restoration (FDIR) can be used in conjunction with protective relays to automatically detect and isolate a fault, and then restore power to as many customers as possible. This will greatly improve the reliability of the electrical distribution network. As applied to distribution networks, there is no such thing as a "self healing" network. If there is a failure of an overhead power line, given that these tend to operate on a radial basis (for the most part) there is an inevitable loss of power. In the case of urban/city networks that for the most part are fed using underground cables, networks can be designed (through the use of interconnected topologies) such that failure of one part of the network will result in no loss of supply to end users.

4.3.2 Asset Optimization

A smart grid will enable better asset utilization from generation to the consumer end points. It will enable condition and performance based maintenance. Smart grids will also improve efficiency through reduction in technical and non-technical line losses.

4.3.3 Enable Demand Response

Extending the smart grid within the home, consumer appliances and devices can be controlled remotely, allowing for demand response. In the event of peak in demand, a central system operator would potentially be able to control both the amount of power generation feeding into the system and the amount of demand drawing from the system.

4.3.4 Integration of Advanced and Low-carbon Technologies

A smart grid will exhibit "plug and play" scalable and interoperable capabilities. It permits a higher transmission and distribution system penetration of renewable generation, distributed generation and energy storage .It allows the society to optimize the use of low-carbon energy sources, support the efforts to reduce the carbon intensity and minimize the collective environmental footprint. Smarter Grid helps the customers to lower the carbon footprints, without having to compromise on the lifestyle, usage requirements.

4.3.5 Power Quality

A smart grid will have high quality of power and reduces the occurrence of distortions of power supply. As the load demands increase on an exponential path, there would be power quality degradation, in turn requiring distributed monitoring and proactive mediation.

4.3.6 Market Empowerment

A smart grid will provide greater transparency and availability of energy market information. It will enable more efficient, automated management of market parameters, such as changes of capacity, and enable a plethora of new products and services. New sources of supply and enhanced control of demand will expand markets and bring together buyers and sellers and remove inefficiencies. It will shift the utility from a commodity provider to a service provider.

4.3.7 Customer Inclusion

A smart grid involves consumers by engaging them as active participants in the electricity market. It will help empower utilities to match evolving consumer expectation and deliver greater visibility and choice in energy purchasing. It will generate demand, for cost-saving and energy-saving products. Smart grids will help educate the average consumer, foster innovation in new energy management services and reduce the costs and environmental impact of the delivery of electricity.

4.3.8 Reliable

Generally, a reliable grid is one that delivers electricity to consumers when they desire or need it and it is of a quality that supports the consumers' requirements. Improvements in reliability can generally be measured by a reduction in the frequency and duration of outages, a reduction in the number of disturbances due to poor power quality, and virtual elimination of widespread blackouts. Improvements in reliability would create a number of benefits.

4.3.8.1 Delivery Company Benefits

- Reduced operational costs due to fewer truck rolls, and less demand on call center operations, engineering, and outage response resources
- Improved employee safety as employees are subjected to hazardous conditions less frequently
- Increased revenues as electricity sales are interrupted less frequently and for shorter durations
- Higher customer satisfaction ratings and improved relations with the regulator, the community, etc.
- Reduced capital costs as fewer devices fail in service
- The monetized value of these benefits depends on the current state of the delivery company. Some companies will see substantial value while others who may have previously invested in reliability improvements may benefit less. All delivery companies, however, are expected to see some reduction in their costs, and cost reduction keeps downward pressure on future rates—that's good for all consumers.

4.3.8.2 Electricity Supplier Benefits

Improved reliability reduces the down time for some generators. When the customer is "off," the generator is selling less of its product. Additionally, a reduction in system transients will reduce the wear and tear on generators and can reduce the time plants are in a forced outage due to system reliability issues.

4.3.8.3 Residential Consumer Benefits

- Improved level of service with fewer inconveniences caused by outages and poor power quality (resetting electronic devices, no lights, refrigeration, etc.)
- Reduced out-of-pocket costs resulting from loss of sump pumps, spoiled perishables, etc.

4.3.9 Smart Grid and Environment

The energy conservation and improvements in end-use efficiency enabled by the smart grid reduce half of the emissions. Environmental improvements can be obtained by managing the peak load through demand response rather than spinning reserves. It can reduce T&D losses by 30%. Smart grid system gives a continuous feedback on electricity use, which enables the consumers to adjust the usage in response to pricing and consumption and thereby reduce annual CO_2 emissions. Optimized use of existing generation, transmission and distribution through this system reduces the new infrastructure constructions.

4.3.10 Improved Economics

Improvements in economics are realized when energy and delivery bills paid by consumers are lower than they otherwise would have been. The creation of opportunities for new products and services, the stimulation of economic development and the U.S. GDP, and the creation of new jobs are all elements of improved grid economics.

4.3.10.1 Delivery Company Benefits

- Numerous opportunities to leverage its resources and enter new markets created by the smart grid such as demand response, micro grid deployment and operations, DER, and others
- Increased revenues as theft of service is reduced, from improved metering accuracy of smart meters over traditional ones, and from shorter power outages

- Improved cash flow from more efficient management of billing and revenue management processes

4.3.10.2 Electricity Supplier Benefits

- New market opportunities for distributed generation and storage will be created.
- The demand for lower cost, environmentally friendly distributed generation and storage will give energy suppliers new options for DER businesses.
- A more robust transmission grid will accommodate larger increases in wind and solar generation.
- A flatter load profile will reduce operating and maintenance (O&M) costs at base-load generating plants. Unfortunately, a flatter load profile will reduce the opportunity for higher priced peaking units to operate, creating the potential for some stranded assets. One stakeholder's benefit can be another one's liability.

4.3.10.3 Residential Consumer Benefits

- Downward pressure on energy prices and total customer bills
- Increased capability, opportunity, and motivation to reduce consumption
- Opportunity to interact with the electricity markets through home area network and smart meter connectivity
- Opportunity to reduce transportation costs by using electric vehicles in lieu of conventional vehicles
- Opportunity to sell consumer-produced electricity back to the grid

4.3.11 Improved Efficiency

Efficiency improvements will reduce the cost of producing, delivering and consuming electricity. Reducing the O&M and capital investment costs, as well as the amount of energy used by consumers, will keep downward pressure on future prices and will help the United States more effectively utilize its precious resources.

4.3.11.1 Delivery Company Benefits

- Increase asset utilization —"getting more through existing assets"

- Reduction in lines losses on both transmission and distribution
- Reduction in transmission congestion costs
- Reductions in peak load and energy consumption leading to deferral of future capital investments
- Increased asset data and intelligence enabling advanced control and improved operator understanding
- Reduction in capital expenditures due to improved utilization of existing assets
- Extended life of system assets through improved asset "health" management
- Improved employee productivity through the use of smart grid information that improves O&M processes
- Improved load forecasting enabling more accurate predictions on when new capital investments are needed
- Reduced use of inefficient generation to meet system peaks

4.3.11.2 Electricity Supplier Benefits

- Reduced transmission congestion gives more competitive generators greater access to markets.
- Efficiency of generation is improved due to flatter load curves.
- Opportunity to expand green power portfolio is due to a more robust transmission grid.
- Fewer forced outages due to a more reliable and efficient transmission system increase unit capacity factors.
-

4.3.11.3 Residential Consumer Benefits

- Increased capability, opportunity, and motivation to be more efficient on the consumption end of the value chain
- Increased influence on the electricity market
- Ability to switch from gasoline to electricity for transportation

4.3.12 Improvement in Security and Safety

Improvements in security increase the robustness and resiliency of the grid from a physical perspective and a cyber perspective, thereby reducing the probability and consequences of manmade attacks and natural disasters. In addition, reductions in oil imports made possible by the smart grid enhance national security by increasing U.S. energy independence. Improvements in safety reduce the hazards inherent in an energized electric system as well as the time of exposure to those hazards.

Depending on the type of Smart Grid application, it would have different types of benefits. Not all applications have all types of benefits. Furthermore, consistent with the idea that the framework provides flexibility, a project might suggest other types of benefits which it might provide. Electric Power Research Institute (EPRI) ran a project and published a document about different benefits of different applications of Smart Grid and their sources.

Table 4.1: Benefit Categories and Sources of benefit

Benefit Category	Benefit	Source of Benefit
Economic	Electricity cost savings – Lower electricity cost to consumers	• Flatter load curve (from load shifted to off-peak periods, e.g., from consumer behavior and smart appliances that can respond to price signals) • Dynamic pricing and/or lower electricity rates (reflecting reduced generation costs with flatter load curve) • Lower electricity consumption
Benefit Category	**Information Reported by Project, with and without the Smart Grid Deployment**	
Economic	• Hourly load data, by customer • Monthly electricity cost, by cust3omer • Tariff description, by customer • Demographic and other information affecting demand	

<table>
<tr><td rowspan="8"></td><td colspan="2">For firms, square footage and SIC code
Types of smart appliances in use</td></tr>
<tr><td>Benefit</td><td>Source of Benefit</td></tr>
<tr><td>Reduced generation costs from improved asset utilization</td><td>Flatter load curve (from load shifted to off-peak periods, e.g., from consumer behavior and smart appliances that can respond to price signals)
Dynamic pricing and/or lower electricity rates (reflecting reduced generation costs with flatter load curve)
Lower total electricity consumption</td></tr>
<tr><td colspan="2">Information Reported by Project, with and without the Smart Grid Deployment</td></tr>
<tr><td colspan="2">Generation costs (that reflect optimized generator operation)
Deferred generation capacity investments
Reduced ancillary service cost</td></tr>
<tr><td>Benefit</td><td>Source of Benefit</td></tr>
<tr><td>T&D capital savings</td><td>Deferred transmission and distribution capacity investments
Reduced equipment failures</td></tr>
<tr><td colspan="2">Information Reported by Project, with and without the Smart Grid Deployment</td></tr>
</table>

	• Deferred T&D capital investments	
	Benefit	**Source of Benefit**
	T&D O&M savings	• Reduced O&M operations costs • Reduced meter reading cost
	Information Reported by Project, with and without the Smart Grid Deployment	
	• Activity-based O&M costs • Equipment failure incidents	
Benefit Category	**Benefit**	**Source of Benefit**
Economic	Reduced transmission congestion costs	• Increased transmission transfer • capability without building additional transmission capacity
	Information Reported by Project, with and without the Smart Grid Deployment	
	• Actual real-time capability of key transmission lines	
	Reduced T&D losses	• Optimized T&D network efficiency • Generation closer to load [from distributed generation (DG)
	Information Reported by Project, with and without the Smart Grid Deployment	
	• T&D system losses (MWh)	

	• % of MWh served by DG	
	Benefit	**Source of Benefit**
	Theft reduction	• Reduced electricity theft
	Information Reported by Project, with and without the Smart Grid Deployment	
	• Estimated T&D system losses from theft (MWh)	
Reliability and Power Quality	**Benefit**	**Source of Benefit**
	Reduced cost of power interruptions	• Fewer sustained outages • Shorter outages (reduced duration) • Fewer major outages
	Information Reported by Project, with and without the Smart Grid Deployment	
	• SAIFI • SAIDI or CAIDI	
	Benefit	**Source of Benefit**
	Reduced costs from better power quality	• Fewer momentary outages • Fewer severe sags and swells • Lower harmonic distortion
	Information Reported by Project, with and without the Smart Grid Deployment	
	• MAIFI	
Benefit Category	**Benefit**	**Source of Benefit**

<table>
<tr>
<td rowspan="3">Environmental</td>
<td>Reduced damages as a result of lower GHG/carbon emissions
Reduced damages as a result of lower SOx, NOx, and PM emissions</td>
<td>From the mechanisms below:
− Lower electricity consumption from:
Intelligent appliances
− Lower T&D losses from:
Optimized T&D network
Generation closer to load (DG)
− Lower emissions from generation from:
Combined heat and power (CHP)
Renewable energy (RE)
Operating generators more efficiently
Avoiding additional generator dispatch with demand response</td>
</tr>
<tr>
<td colspan="2">Information Reported by Project, with and without the Smart Grid Deployment</td>
</tr>
<tr>
<td colspan="2">Reduced CO2 emissions
Reduced SOx, NOx, and PM emissions
Hourly consumption by fuel type, compared
to baseline/control group
% of MWh served by DG
T&D system losses (MWh)
MW of CHP installed
% of MWh served by RE
% of feeder peak load served by RE</td>
</tr>
</table>

	○ Average heat rate of supply (or similar information)	
Energy Security	**Benefit**	**Source of Benefit**
	Greater energy security from reduced oil consumption	● Electricity substituting for oil by "smart-grid enabled" electric vehicles
	Information Reported by Project, with and without the Smart Grid Deployment	
	● MWh of electricity consumed by electric vehicles	
	Benefit	**Source of Benefit**
	Reduced widespread damage from wide-scale blackouts	● Reduced wide-scale blackouts
	Information Reported by Project, with and without the Smart Grid Deployment	
	● Number of wide-scale blackouts	

The following Table 4.2 presents the calculations and inputs required to monetize each of the benefits. The detailed methodology for quantifying and monetizing each benefit is further described below.

Table 4.2: Summary of benefit input parameters and calculations

Benefit	Functions & Enabled Energy Resources	Input Parameters
Optimized Generator Operation	● Wide Area Monitoring, Visualization, & Control ● Distributed Generation	● Annual Generation cost($) ● Optional Inputs ● Average Hourly Generation Cost($/MWh) ● Avoided Annual Generator Dispatch (MWh)

	• Stationary Electricity Storage • Plug-in Electric Vehicles	• Annual Energy Storage Efficiency (%) • Annual PEV Efficiency (%)
	Monetization Calculation	
	Standard Calculation: **Value ($)** = [Annual Generation Cost ($)]Baseline - [Annual Generation Cost ($)]Project **Optional Calculation:** **Value ($)** = [Average Hourly Generation Cost ($/MWh) * Avoided Annual Generator Dispatch (MWh) * Average Efficiency (%)]Project – [Average Hourly Generation Cost ($/MWh) * Avoided Annual Generator Dispatch (MWh) *Average Efficiency (%)]Baseline Average Efficiency (%) = For projects that yield this benefit as a result of Wide Area Monitoring, Visualization, and Control, the value will be 100%. For projects that just support Stationary Electricity Storage or Plug-in Electric Vehicles this value will be equal to the Annual Efficiency of these technologies.	
Benefit	**Functions & Enabled Energy Resources**	**Input Parameters**
Deferred Generation Capacity Investments	• Customer Electricity Use Optimization • Distributed Generation • Stationary Electricity Storage • Plug-in Electric Vehicles	• Total Customer Peak Demand(MW) • Energy Storage Use at Annual Peak Time(MW) • Distributed Generation Use at Annual Peak Time(MW)-Impact • PEV Use at Annual Peak Time(MW)-Impact

		• Price at Capacity at Annual Peak($/MW) **Optional Inputs** • Capital Carrying Charge of New Generation($/yr) • Generation Investment Time Deferred(yrs)
	Monetization Calculation	
	Standard Calculation: **Value ($)** = [Price of Capacity at Annual Peak ($/MW) * {Total Customer Peak Demand (MW) – Energy Storage Use at Annual Peak Time (MW) – Distributed Generation Use at Annual Peak Time (MW) – PEV Use at Annual Peak Time (MW)}]Baseline - [Price of Capacity at Annual Peak ($/MW) * {Total Customer Peak Demand (MW) – Energy Storage Use at Annual Peak Time (MW) – Distributed Generation Use at Annual Peak Time (MW) – PEV Use at Annual Peak Time (MW)}]$_{Project}$ **Optional Calculation:** **Value ($)**= [Capital Carrying Charge of New Generation ($) *(1-(1-Discount rate (%))^Time Deferred (yrs))]$_{Project}$ -[Capital Carrying Charge of New Generation ($) *(1-(1-Discount rate (%))^Time Deferred (yrs))]$_{Baseline}$	
Benefit	**Functions & Enabled Energy Resources**	**Input Parameters**
Reduced Ancillary Service Cost	• Wide Area Monitoring, Visualization, & Control • Automated Voltage & VAR Control	• Ancillary Services Cost($) **Optional Inputs** • Average Price of Reserves($/MW) • Reserve Purchases(MW)

Benefit	• Real-time Load Measurement & Management • Distributed Generation **Functions & Enabled Energy Resources**	• Average Price of Frequency Regulation($/MW) • Frequency Regulation Purchases(MW) **Input Parameters**
	• Stationary Electricity • Storage • Plug-in Electric Vehicles • Customer Electricity Use Optimization	• Average Price of Voltage Control($/MVAR) • Voltage Control Purchases(MVAR)

Benefit	**Monetization Calculation**
Reduced Ancillary Service	**Standard Calculation:** **Value ($)** = [Ancillary Services Cost ($)]Baseline - [Ancillary Services Cost ($)]Project **Optional Calculation:** **Value ($)** = [Σ (Price of Ancillary Service ($/MW) * Purchases (MW))]Baseline - [Σ (Price of Ancillary Service ($/MW) *Purchases (MW))]Project

Benefit	**Functions & Enabled Energy Resources**	**Input Parameters**
Reduced Congestion Cost	• Wide Area Monitoring, Visualization, & Control • Dynamic Capability Rating	• Congestion Cost ($) **Optional Inputs** • Congestion(MW) • Average Price of Congestion($/MW)

	• Power Flow Control • Distributed Generation • Stationary Electricity Storage • Plug-in Electric Vehicles	
	Monetization Calculation	
	Standard Calculation: **Value ($)** = [Congestion Cost($)]Baseline - [Congestion Cost($)]Project **Optional Calculation:** **Value ($)** = [Congestion (MW) * Average Price of Congestion ($/MW)]Baseline - [Congestion (MW) * Average Price of Congestion ($/MW)]Project	
Benefit	**Functions & Enabled Energy Resources**	**Input Parameters**
Deferred Transmission Capacity Investments	• Fault Current Limiting • Wide Area Monitoring, Visualization, & Control • Dynamic Capability Rating • Power Flow Control	• Capital Carrying Charge of Transmission Upgrade ($) • Transmission Investment Time Deferred (yrs)

<table>
<tr><td rowspan="3"></td><td>Customer Electricity Use Optimization
Distributed Generation
Stationary Electricity Storage
Plug-in Electric Vehicles</td><td></td></tr>
<tr><td colspan="2">Monetization Calculation</td></tr>
<tr><td colspan="2">Value ($)= [Capital Carrying Charge of Transmission Upgrade ($) *(1-(1-Discount rate (%))^Time Deferred(yrs))]$_{\text{Project}}$ - [Capital Carrying Charge of Transmission Upgrade ($) *(1-(1-Discount rate (%))^Time Deferred(yrs))]$_{\text{Baseline}}$

Note: this should only be calculated once since all years of deferral are included</td></tr>
<tr><th>Benefit</th><th>Functions & Enabled Energy Resources</th><th>Input Parameters</th></tr>
<tr><td>Deferred Distribution Capacity Investments</td><td>Dynamic Capability Rating
Real-Time Load Measurement & Management
Real-Time Load Transfer
Customer Electricity Use Optimization
Distributed Generation</td><td>Capital Carrying Charge of Distribution Upgrade ($/yr)
Distribution Investment Time Deferred (yrs)</td></tr>
</table>

Benefit	Functions & Enabled Energy Resources	Input Parameters
	• Stationary Electricity Storage • Plug-in Electric Vehicles	
	Monetization Calculation	
	**Value ($)=** [Capital Carrying Charge of Distribution Upgrade ($) *(1-(1-Discount rate (%))^Time Deferred(yrs))]Project - [Capital Carrying Charge of Distribution Upgrade ($) *(1-(1-Discount rate (%))^Time Deferred(yrs))]Baseline Note: this should only be calculated once since all years of deferral are included	
Benefit	**Functions & Enabled Energy Resources**	**Input Parameters**
Reduced Equipment Failures	• Fault Current Limiting • Dynamic Capability Rating • Diagnosis & Notification of Equipment Condition • Enhanced Fault Protection	• Capital Replacement of Failed Equipment ($) • Portion Caused by Fault Current or Overloaded Equipment (%) • Portion Caused by Lack of Condition Diagnosis (%)
	Monetization Calculation	
	For Fault Current Limiting, Dynamic Capability Rating, & Enhanced Fault Protection: **Value ($)** = [Capital Replacement of Failed Equipment ($) * Portion Caused by Fault Current or Overloaded Equipment (%)]$_{Baseline}$ -	

	[Capital Replacement of Failed Equipment ($) * Portion Caused by Fault Current or Overloaded Equipment (%)]$_{Project}$ For Diagnosis & Notification of Equipment Condition: **Value ($)** = [Capital Replacement of Failed Equipment ($) * Portion Caused by Lack of Condition Diagnosis(%)]$_{Baseline}$ - [Capital Replacement of Failed Equipment ($) * Portion Caused by Lack of Condition Diagnosis (%)]$_{Project}$	
Benefit	**Functions & Enabled Energy Resources**	**Input Parameters**
Reduced Transmission & Distribution Equipment Maintenance Cost	• Diagnosis & Notification of Equipment Condition	• Total Transmission Maintenance Cost($) • Total Distribution Maintenance Cost($)
	Monetization Calculation	
	Value ($) = [Total Distribution Equipment Maintenance Cost ($) + Total Transmission Equipment Maintenance Cost ($)]$_{Baseline}$ –[Total Distribution Equipment Maintenance Cost ($) + Total Transmission Equipment Maintenance Cost ($)]$_{Project}$	
Benefit	**Functions & Enabled Energy Resources**	**Input Parameters**
Reduced Transmission & Distribution Operations Cost	• Automated Feeder & Line Switching Automated Voltage & VAR Control	• Transmission Operations Cost ($) • Distribution Operations Cost ($) **Optional Inputs** • Distribution Feeder Switching Operations ($)

		• Distribution Capacitor Switching Operations ($) • Other Distribution Operations Cost ($)
	Monetization Calculation	
	Standard Calculation: **Value ($)** = [Distribution Operations Cost ($) + Transmission Operations Cost ($)]$_{Baseline}$ - [Distribution Operations Cost ($) + Transmission Operations Cost ($)]$_{Project}$ **Optional Calculation:** **Value ($)** = [Distribution Feeder Switching Operations ($) + Distribution Capacitor Switching Operations ($) +Other Distribution Operations Cost ($) + Transmission Operations Cost ($)]$_{Baseline}$ - [= Distribution Feeder Switching Operations ($) + Distribution Capacitor Switching Operations ($) + Other Distribution Operations Cost ($) +Transmission Operations Cost ($)]$_{Project}$	
Benefit	**Functions & Enabled Energy Resources**	**Input Parameters**
Reduced Meter Reading Cost	• Real-time Load Measurement & Management	• Meter Operations Cost($)
	Monetization Calculation	
	Value ($) = [Meter Operations Cost ($)]$_{Baseline}$ - [Meter Operations Cost ($)]$_{Project}$	
Benefit	**Functions & Enabled Energy Resources**	**Input Parameters**
Reduced Electricity Theft	• Real-time Load Measurement & Management	• Number of Meter Tamper Detections- Residential

Benefit		● Number of Meter Tamper Detections – ● Commercial ● Number of Meter Tamper Detections – Industrial ● Average Annual Customer Electricity Usage – ● Residential, Commercial, Industrial
	Monetization Calculation	
	Value ($)** = [Σ{ Number of Meter Tamper Detections by class (#) * Average Annual Customer Electricity Usage by class (kWh) * Average Percentage of Load not Measured by class (%) * Average Duration of Theft by class (% of year) * Average Retail Electricity Rate by class ($/kWh)}]$_{\text{Baseline}}$ - [Σ{ Number of Meter Tamper Detections by class (#)* Average Annual Customer Electricity Usage by class (kWh) * Average Percentage of Load not Measured by class(%) * Average Duration of Theft by class (% of year) * Average Retail Electricity Rate by class ($/kWh)}]$_{\text{Project}}$ **Average Percentage of Load not Measured by class (%) = This is a DOE assumption that varies by class **Average Duration of Theft by class (% of year)** = This is a DOE assumption that varies by class **Average Retail Electricity Rate by class ($/kWh)** = Weighted Average of electricity rate by customer class	

Benefit	Functions & Enabled Energy Resources	Input Parameters
Reduced Electricity Losses	• Power Flow Control • Automated Voltage and VAR Control • Real-Time Load Measurement & Management • Real-Time Load Transfer • Customer Electricity Use Optimization • Distributed Generation Stationary Electricity Storage	• Distribution Feeder Load (MW) • Distribution Losses (%) • Transmission Line Load (MW) • Transmission Losses (%) Average Price of Wholesale Energy ($/MWh)
Benefit	**Monetization Calculation**	
Reduced Electricity Losses	**Value ($)** = [(Distribution feeder load (MW) * Distribution losses (%) + Transmission line load (MW) * Transmission losses (%)) * 8760 (hr/yr)* Average Price of Wholesale Energy ($/MWh)]$_{Baseline}$ - [(Distribution feeder load (MW) *Distribution losses (%) + Transmission line load (MW) * Transmission losses (%)) * 8760 (hr/yr)* Average Price of Wholesale Energy ($/MWh)]$_{Project}$	
Benefit	**Functions & Enabled Energy Resources**	**Input Parameters**
Reduced Electricity Cost	• Customer Electricity Use Optimization	• Total Residential Electricity Cost ($)

	• Distributed Generation • Stationary Electricity Storage Plug-in Electric Vehicles	• Total Commercial Electricity Cost ($) • Total Industrial Electricity Cost ($)
	Monetization Calculation	
	Value ($) = [Total Residential Electricity Cost ($) + Total Commercial Electricity Cost ($) + Total Industrial Electricity Cost ($)]$_{Baseline}$ - [Total Residential Electricity Cost ($) + Total Commercial Electricity Cost ($) + Total Industrial Electricity Cost ($)]$_{Project}$	
Benefit	**Functions & Enabled Energy Resources**	**Input Parameters**
Reduced Sustained Outages	• Adaptive Protection • Automated Feeder and Line Switching • Automated Islanding and Reconnection • Diagnosis & Notification of Equipment Condition • Enhanced Fault Protection • Real-Time Load Measurement & Management • Distributed Generation	• SAIDI (System) • Value of Service (VOS) ($/kWh) – Residential, Commercial, Industrial • Average Hourly Load Not Served During Outage per Customer by class (kW) **Optional Inputs** • SAIDI (Impacted Feeders or Lines) • Total Customers Served by Impacted Feeders or Lines (#) – Residential, Commercial

<table>
<tr><td rowspan="3">Benefit</td><td>• Stationary Electricity Storage Plug-in Electric Vehicles</td><td></td></tr>
<tr><td colspan="2">Monetization Calculation</td></tr>
<tr><td colspan="2">Standard Calculation:
Value ($) = Σ{ [SAIDI (System) * Total Customers Served within a class (#) * Average Hourly Load Not Served During Outage per Customer by class (kW) * VOS by class ($/kWh)]$_{Baseline}$ - [SAIDI (System) * Total Customers Served within a class (#) * Average Hourly Load Not Served During Outage per Customer by class (kW) * VOS by class ($/kWh)]$_{Project}$
Monetization Calculation</td></tr>
<tr><td>Reduced Sustained Outages</td><td colspan="2">Optional Calculation:
Value ($) = Σ{ [SAIDI (Impacted Feeders or Lines) * Total Customers Served by Impacted Feeders or Lines (#) *Average Hourly Load Not Served During Outage per Customer by class (kW) * VOS by class ($/kWh)]$_{Baseline}$ -[SAIDI (Impacted Feeders or Lines) * Total Customers Served by Impacted Feeders or Lines (#) * Average Hourly Load Not Served During Outage per Customer by class (kW) * VOS by class ($/kWh)]$_{Project}$</td></tr>
<tr><td>Benefit</td><td>Functions & Enabled Energy Resources</td><td>Input Parameters</td></tr>
<tr><td>Reduced Major Outages</td><td>• Wide area Monitoring, Visualization & Control
• Automated Islanding and Reconnection
• Real-Time Load Measurement &</td><td>• Outage Time of Major Outage (hr) – Residential, Commercial, Industrial
• Average Hourly Load Not Served During Outage per Customer by class (kW)</td></tr>
</table>

	Management Real-Time Load Transfer	• Value of Service (VOS) ($/kWh) – Residential, Commercial, Industrial
	Monetization Calculation	
	**Value ($)** = Σ{ [Outage Time of Major Outage by class(hr) * Average Hourly Load Not Served During Outage per Customer by class (kW) * VOS by class ($/kWh)]$_{\text{Baseline}}$ - [Outage Time of Major Outage by class(hr) * Average Hourly Load Not Served During Outage per Customer by class (kW) * VOS by class ($/kWh)]$_{\text{Project}}$}	
Benefit	**Functions & Enabled Energy Resources**	**Input Parameters**
Reduced Restoration Cost	• Adaptive Protection • Automated Feeder and Line Switching • Automated Islanding and Reconnection • Diagnosis & Notification of Equipment Condition • Enhanced Fault Protection Real-Time Load Measurement & Management	• Distribution Restoration Cost ($) • Transmission Restoration Cost ($) **Optional Inputs** • Number of Outage Events (#) • Restoration Cost per Event ($/event)
	Monetization Calculation	
	Standard Calculation: **Value ($)** = [Distribution Restoration Cost ($) + Transmission Restoration Cost ($)]$_{\text{Baseline}}$ - [Distribution Restoration Cost ($) + Transmission Restoration Cost ($)]$_{\text{Project}}$	

<table>
<tr><th>Benefit</th><th>Functions & Enabled Energy Resources</th><th>Input Parameters</th></tr>
<tr><td rowspan="4">Reduced Momentary Outages</td><td>● Enhanced Fault Protection
● Stationary Electricity Storage</td><td>● MAIFI (System)
● Value of Service (VOS) – Power Quality ($/interruption)
Optional Inputs
● MAIFI (Impacted Feeders)
● Total Customers Served on Impacted Feeders (momentary) (#) – Residential, Commercial, Industrial</td></tr>
<tr><td colspan="2">Monetization Calculation</td></tr>
<tr><td colspan="2">Standard Calculation:
Value ($) = [Momentary Interruptions (# of interruptions) * VOS – Power Quality ($ per interruption)]$_{Baseline}$ -[Momentary Interruptions (# of interruptions) * VOS ($ per interruption)]$_{Project}$
Momentary Interruptions (# of interruptions) = MAIFI (Index) * Σ{Total Customers Served by class (#)}</td></tr>
<tr><td colspan="2">Optional Calculation:
Value ($) = [Momentary Interruptions (# of interruptions) * VOS – Power Quality ($ per interruption)]$_{Baseline}$ -[Momentary Interruptions (# of interruptions) * VOS ($ per interruption)]$_{Project}$
Momentary Interruptions (# of interruptions) = MAIFI of Impacted Feeders (Index) * Σ{Total Customers Served by class on the Impacted Feeders (#)}</td></tr>
<tr><th>Benefit</th><th>Functions & Enabled Energy Resources</th><th>Input Parameters</th></tr>
<tr><td>Reduced Sags & Swells</td><td>● Enhanced Fault Protection</td><td>● Number of High-Impedance Faults Cleared(# of Events)</td></tr>
</table>

	• Stationary Electricity Storage	• Value of Service(VOS)-Sags & Swells($/event)
	Monetization Calculation	
	Value ($) = [Number of High Impedance Faults Cleared (# of events) * VOS – Sags and Swells ($/event)]$_{Project}$ -[Number of High Impedance Faults Cleared (# of events) * VOS – Sags and Swells ($/event)]$_{Baseline}$	
Benefit	**Functions & Enabled Energy Resources**	**Input Parameters**
Reduced Oil Usage	• Automated Feeder and Line Switching • Diagnosis & Notification of Equipment Condition	For PEVs (with reduced gasoline consumption mechanism): • kWh of Electricity Consumed by PEVs (kWh) • Electricity to Fuel Conversion Factor (gallons/kWh)
Benefit	**Functions & Enabled Energy Resources**	**Input Parameters**
	• Real-Time Load • Measurement & Management • Plug-in Electric Vehicles	• For all other Functions • Truck Rolls (# of events)
Benefit	**Monetization Calculation**	
Reduced Oil Usage	**Value (gallons of oil)** = Net Avoided Fuel Use (gallons)* Fuel to Oil Conversion Factor (gallons oil/gallon fuel) Net Avoided Fuel Use (gallons) = [Fuel Use (gallons)]Baseline - [Fuel Use (gallons)] Project Net Avoided Fuel Use (gallons) = [Avoided Fuel Use (gallons)]Project - [Avoided Fuel Use (gallons)] Baseline	

	For PEVs (with reduced gasoline consumption mechanism): Avoided Fuel Use (gallons) = kWh of Electricity Consumed by PEVs (kWh) * Electricity to Fuel Conversion Factor(gallons/kWh) For all other Functions: Fuel Use (gallons) = Truck Rolls (# of events) * Average Miles Travelled per Truck Roll (miles/event) ÷ Average Fuel Efficiency for Truck Roll Vehicle (miles/gallon) **Optional Calculation:** Fuel Use (gallons) = Σ{Number of Operations Completed(# of events) * Average Miles Traveled per Operation(miles/event) ÷ Average Fuel Efficiency for Service Vehicle (miles/gallon)}	
Benefit	**Functions & Enabled Energy Resources**	**Input Parameters**
Reduced Wide-scale Blackouts	• Wide-area Monitoring & Visualization • Dynamic Capability Rating	• Number of Wide-scale Blackouts(# of events) • Estimated cost of each Wide-scale Blackout($/event)
	Monetization Calculation	
	Value ($) = [Number of Wide-scale Blackouts (# of events) * Estimated Cost of each Wide-scale Blackout($/event)]$_{Baseline}$ - [Number of Wide-scale Blackouts (# of events) * Estimated Cost each Wide-scale Blackout($/event)]$_{Project}$	

4.4 Challenges

Several challenges present themselves for smart grid development-

4.4.1 Financial resources

The self-healing characteristic of grid is good, particularly if it includes societal benefits. But regulators will require extensive proof before authorizing major investments based heavily on societal benefits.

4.4.2 Government support

The industry may not have the financial capacity to fund new technologies without the aid of government. The utility industry is capital-intensive, but has been sustaining exorbitant losses due to thefts and subsidization.

4.4.3 Compatible equipment

Some older equipment must be replaced as it cannot be compatible with smart grid technologies. This may present a problem for utilities and regulators as keeping equipment beyond its depreciated life minimizes the capital cost to consumers.

4.4.4 Lack of policy and regulation

No defined standards and guidelines exist for the regulation of smart grid initiatives in most of the countries.

4.4.5 Capacity to absorb advanced technology

Most of the distribution companies have limited experience with basic information and communications technology and, as a result, they have weak internal skills to manage critical component of smart grids.

4.4.6 Consumer education

Consumer education & participation is an important component of the successful implementation of the Smart Grid. A portion of the Smart Meter benefits rely upon consumer engagement. To facilitate consumer engagement, utilities must provide consumers with clear & accurate information about programs & services available both prior to & throughout the deployment of Smart Meters.

The transition to Smart Meters & related infrastructure will provide consumers access to current data about their energy usage, creating an opportunity to better control energy consumption. Smart Meters also provide the basic infrastructure for aggregate benefits related to reliability, outage identification, & reduced peak demand. These benefits have a positive effect on all consumers including those who choose to opt-out.

A smooth transition to Smart Meters, thus Smart Grid, can be accomplished only through consumer education. A well thought-out education strategy allows consumers to develop a sense of trust with the utility & an understanding of the available benefits.

The consumers should be provided with education on some common topics of their concerns, which include—

- Health & safety measures
- Privacy/data security
- Cyber security & bill impacts

The education should be divided in some resources in response to consumer concerns about Smart Grid. The resources fall into one or more of the following categories:

- Technical in nature
- Relevant to Smart Meter technology
- Research focused
- Science based
- Peer reviewed
- Commentary and/or opinion

Consumers fear about the environmental effects of Smart Grid such as house-fires & radio-frequency hazard. Education should be given on the impacts of this on environment, so that consumers can realize & make use of this new grid technology better.

Consumer education about time-of-use tariffs will be crucial to consumers receiving benefits from this new technology. However, consumers who are not able or not willing to shift their use of electricity away from peak periods will likely face higher bills.

Since peak demand for electricity usually occurs during extremely hot or cold weather this potentially will have impacts on equity between customers – those who can & those who cannot afford extra cooling or heating. A voluntary take-up by consumers may be the most effective way of managing these issues.

4.4.7 Cost assessment

Costs could be higher than projected because the standards and protocols needed to design and operate an advanced metering infrastructure are still in a state of flux. Thus, investments made now, before the standards are settled, have a higher risk of obsolescence. Failure to include estimates of the costs for the control equipment customers will install to automate their response to time-differentiated pricing could put smart grid investments at risk.

4.4.8 Cyber security and data privacy

Digital communication networks and more granular and frequent information on consumption patterns raise concerns in cyber-insecurity and potential for misuse of private data.

4.4.9 Strengthening the Grid

The Smart grid is a new kind of deployment foe us. This grid system is almost wholly controlled through programming & information technologies. Thus, this grid will be much more expensive, sophisticated & sensitive when compared to our existing power grid. So, after planting the grid on the base, we should have to pay attention to the task of strengthening the grid, so that it stands firmly & take the burden of the huge demand capacity of this country.

The Smart grid, although a revolutionary being, has to have some weak spots, which should be of our utmost concern. The companies and manpower working behind the setup of the grid, has to deal with some unexpected occurrences and hazards the grid has to overcome. These are—

- Attacks of cyber thieves
- Weak Base

- Inefficient Control System
- Corrosion
- Smart Meter Authentication
- Blackouts

The basic electrical power system in use today has evolved over about 120 years. The main components of this power system are generation, transmission, distribution & loads. The power is generated by large central generators & fed into a high-voltage interconnected transmission network. The generation & transmission network has some degree of automation with supervisory control & data acquisition (SCADA) system connecting various components through good communication links that maintain security & facilitate integrated operation.

4.4.10 Compatible Equipments

The smart grid is a very complex & sophisticated system. The control of smart grid in a country like ours is really a mammoth task. To cover the controlling program of the whole grid system, a lot of equipments are required, which are compatible with the system. So, we should know about the equipments to enhance our idea on smart grid architecture.

4.11 Summary

The Smart Grid is designed to be the perfect power transmission & distribution system for the upgraded demand of the 21st century citizens. This is a modernized sophisticated grid, so it is abided to face some major challenges, from security & protection from hacking to the assurance of its capability of decentralized distribution of power. It has vast benefits, from controlling the internal market to ensuring the reliability, efficiency & safety of the electrical system. It’s up to our realization that we give total importance to these issues for proper conduct of the grid.

CHAPTER 5

DEVELOPMENT OF SMART GRID IN BANGLADESH

5.1 Introduction

Bangladesh is one of the world's most densely populated countries with total population of around 160 million in an area of 147,570 sq. Km. The scarcity of energy is anticipated to endure for the next 50 years; as electricity demand is increasing every year surpassing generation capacity and distribution capabilities. New power stations cannot be built hastily enough. Moreover, there is lack of fuel energy in Bangladesh and power stations need wide amount of fuel every hour. This insufficiency of fuel will continue unless the nuclear power station becomes operational. When the neighbors have advanced much, Bangladesh is still at the elementary level in developing a smart grid. The country has only one national load dispatch center and a distribution load dispatch center, which is not working properly.

The electrification rate in Bangladesh is low and approximately 49%, but reliable and quality power supply is still a faraway. The power network of Bangladesh has its installed capacity of 8876 MW and maximum generation has not yet exceeded 6279 **MW (as on 25/07/2012)** MW and the present peak demand is said to be around 7,000 MW. The electricity generation, transmission & distribution infrastructure is quite old, small and poorly managed. Ample and reliable supply of electricity is an important pre-requisite for attracting both domestic and foreign investment. Per capita electricity consumption in Bangladesh (252 kWh) is one of the lowest in the world and is due to failure to manage the assets in a proper way which leads to planned load shedding in the urban as well as rural areas.

The government has given top priority to the development of the power sector considering its importance in overall development of the country and has set the goal of providing electricity to all citizens by 2020. The problems in Bangladesh electric power sector include many aged infrastructures, high system losses, delays in completion of new plants, low plant efficiencies, erratic power supply, electricity theft, blackouts, land crisis, overloading of system components, inefficient planning, corruption and shortages of funds for power plant operation and maintenance etc. These leads to extensive load shedding resulting in severe disruption in all important and economic activities. Fuel mixes in the power sector and different statistics of distribution system of Bangladesh are presented in Figure 1 and Table 1 & 2.

A recent survey reveals that power outages result in a loss of industrial output worth USD$1 billion a year which reduces the GDP growth by about half a percentage point in Bangladesh. A major hurdle in the efficiently delivering power is inefficient generation, transmission and distribution system. It is estimated that the total transmission and distribution losses in Bangladesh amount to one-third of the total generation, the value of which is around USD$247 million per year. Bangladesh can reduce electricity crises by minimizing technical and non technical losses of the present electrical system. These losses if effectively reduced can save around 250 MW which is a significant amount of the total demand. Assuming 1 MW plant cost Tk 4 Crore, it will save at least 1000 Crore and construction period of 3-4 years.

In the public sector, a good number of generation units have become very old and has been operating at a much-reduced capacity. As a result, their reliability and productivity are also poor. For the last few years, actual demand could not be supplied due to shortage of available generation capacity.

Figure 5.1 below shows the capacity of the fuel components with respect to the total installed capacity. Table 5.1 & 5.2 shows the service voltage level of distribution system and general information of distribution system respectively.

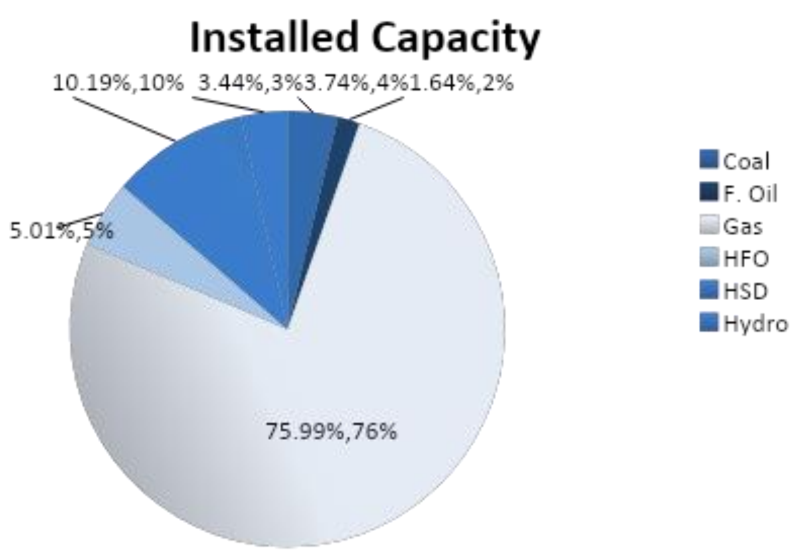

Fig 5.1: Fuel Mix Ratio in the total Installed Capacity of Power in National Grid of Bangladesh as on August 1, 2019

Table 5.1

Service Voltage Level in Distribution System of Bangladesh

Demand Range	Supply Voltage
Less than 50kW	230/400 V
50kW – 5MW	11 kV
5MW – 15MW	33 kV
More than 15MW	132 kV

Table 5.2

General Information of Distribution System of Bangladesh

Item	Number
Total No. of Customer	More than 12 Million
Total Dist. Line Length	2,70,000 km
Distribution Loss (Feb"11)	12.25%
T&D Loss (Feb"11)	14.37%

5.2 System Loss

System loss has been reducing in recent years, but it is still significantly high. The latest DESCO fiscal year system loss is shown below in Table 5.3:

Table 5.3

Fiscal Year System Loss (DESCO)

Fiscal Year	System Loss (%)
2013-14	8.41%
2014-2015	8.37%
2015-2016	8.03%
2016-2017	7.24%
2017-2018	7.18%

Figure 5.2 below shows the system losses by years graphically:

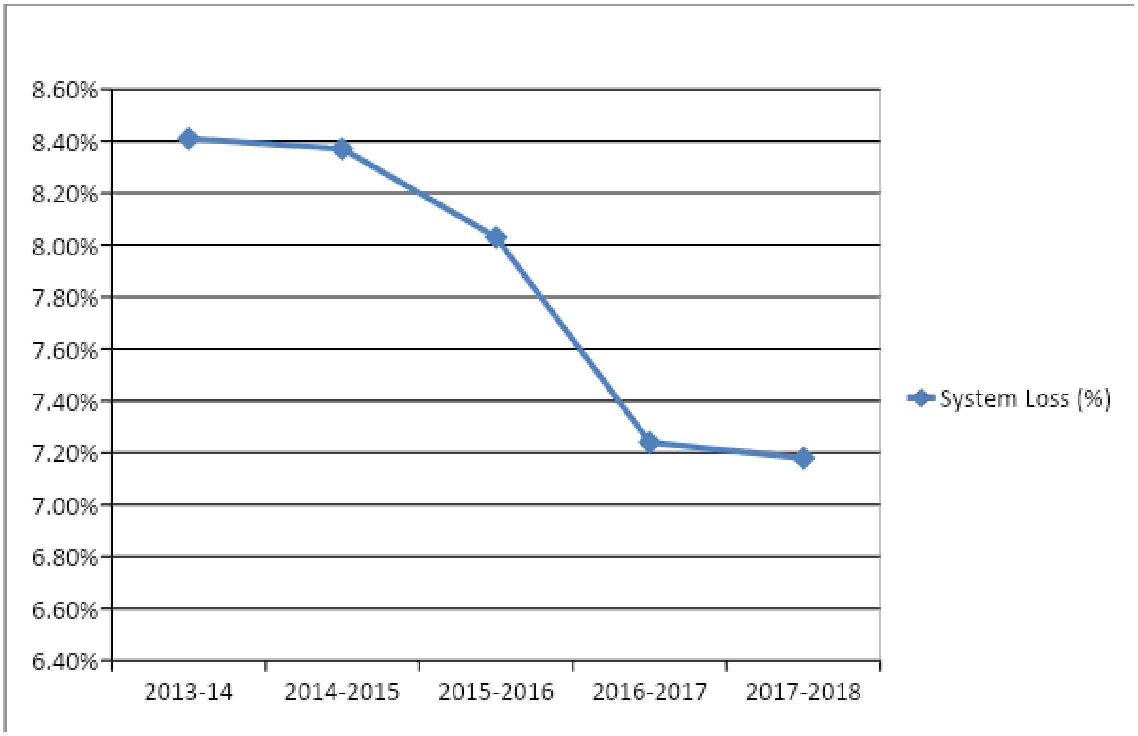

Fig 5.2: System loss

5.3 Demand Forecast

In the Power System Master Plan (PSMP) -2010 study is now underway. The preliminary demand forecast was made based on 7 % GDP growth rate. The actual demand could not be supplied for the last few years. The maximum demand served so far is 5244 MW (2. The electricity development is required to be accelerated to increase access and attain economic development. The desirable economic growth rate would be about 7% p.a. Based upon this preliminary study the anticipated peak demand would be about 10,283 MW in FY2015, 17,304 MW in FY2020 and 25,199 MW in 2025. According to PSMP- 2010 Study year-wise peak demand forecast is given below in Table 5.4:

Table 5.4

Demand Forecast (BPDB)

Fiscal Year	Peak Demand (MW)

2010	6,454
2011	6,765
2012	7,518
2013	8,349
2014	9,268
2015	10,283
2016	11,405
2017	12,644
2018	14,014
2019	15,527
2020	17,304
2021	18,838
2022	20,443
2023	21,993
2024	23,581
2025	25,199
2026	26,838
2027	28,487
2028	30,134
2029	31,873
2030	33,708

5.4 Advantages of Smart Grid in Bangladesh

For Bangladesh to maintain its economic growth there is an urgent need to build a modern, intelligent grid. To provide a stable environment in electric infrastructure through fixing the fundamental problems, an intelligent Smart grid is needed for the country. Without this, Bangladesh will not be able to keep pace with the growing electricity needs of its industries, and will fail to create the required environment for growth.

If a Smart Grid can be constructed, Bangladesh will enjoy all the benefits of Smart Grid stated before. During peak time in summer, total load demand exceeds the maximum generation limit, so structured load shedding is a regular occurrence. Power engineers and experts say that, the demand deficiencies can be met up in urban areas with peak load shaving and proper coordinated utilization of existing supplied power.

5.4.1 Rapid Industrialization and Economic Growth Require a Stable, Reliable, Efficient Power Supply

Industrialization and economy will remain high-growth in the future. Non agricultural products were the main sources of income for Bangladesh for the last few years. To attract foreign investments in future, stable, efficient, reliable and economic power supply is a crying need. Thus, the existing grid should be modified towards the Smart Grid. Power cut due to unexpected faults is a common incident in Bangladesh. With the fast switching characteristics of Smart Grid, the faults can be fixed automatically, thus it reduces the outage time and other related costs. Consequently reactive power support and voltage profile maintenance can also be managed.

5.4.2 Improved Load Factor

In actual practice it is impossible to achieve 100% load factor, but we still desire it to be 100%. A consumer is characterized by his maximum demand and energy consumed in kWh. To supply the energy requirements of a customer, it is necessary to install a power plant which will be able to supply his maximum demand. If the consumer’s maximum demand equals his average load, his load factor is 100% and he makes use of the total capacity all the time. So the cost of the energy would be minimum.

Operationally, the Smart Grid will improve load factors, lower system losses, and dramatically improve outage management performance. It encourages consumers to consume less power and supply more during the peaks due to smart pricing scheme. So we will not face a significant peak or off-peak hours, which will improve the load factor significantly.

5.4.3 Secured and Support with Self Healing Facility

With its intelligent control system, power theft and other losses will be reduced. The sensors and other intelligent equipments will react quickly enough to measure any unusual activities in the grid. Power theft is one of the main reasons for the inefficient system in Bangladesh. Smart Grid technology is a solid solution to this problem.

5.4.4 Metering Infrastructure

Smart meter ensures the proper utilization of power by reducing the power theft, sending emergency information to customer, managing the dynamic electricity rate, peak load shaving, controlling the smart home appliances efficiently etc. This will create huge amount of power savings and ensure the overall security and safety of the distribution system. Without the advanced metering infrastructure (AMI), demand side management (DSM) is very difficult. Smart meter will decrease the hazards of manual billing procedure too.

5.4.5 Improved Protection System

With the improved control and protection system, any emergency power cut or disturbances would not affect a huge geographical area. The micro grid concept may come into action in this period. Thus the massive blackout can be prevented. Distribution and substation automation provides the power distribution system with very effective protection system. Distribution Automation includes fault location, fault identification and service restoration, remote monitoring of faulted circuit indicators, remote activation of “fuse saving” features in recluses and circuit breakers, integrated volt/var control, peak feeder load management, equipment condition monitoring, etc.

5.4.6 Distributed Energy Resources

Distributed generation (DG) is becoming popular mainly because of loss reduction, cost saving from transmission & distribution network expansion as it is located near the load centers and scarcity of conventional energy resources. Bangladesh government has set up various rules for the DGs, since November 2010 mandated the installation of roof-top solar panels on all new high-rise buildings. To meet the power crisis and resource scarcity, applications of either stand-alone or grid connected PV systems would be very effective and realistic for power addition. Near about 300MW of power can easily be generated from solar energy to feed the national grid if solar PV systems are installed on rooftops of 20,000 multistoried buildings in capital city, Dhaka.

5.4.7 Automatic Load Shifting and Switching

Substation automation and distribution automation will make the load shifting and switching easier and automatic. Furthermore, other applications of Smart Grid will facilitate for efficient planning for electricity routing and load shifting.

5.4.8 Deregulated Market

Currently there is no electricity market concept existing in Bangladesh power system. Developing Smart Grid in Bangladesh will create a deregulated and modern power market. Thus new competition, business and research areas will be created and add benefit to its customers.

5.4.9 Economic Benefit

Because of these several above mentioned reasons, extra investment and maintenance cost that could be needed to install extra power generation and distribution facilities will be reduced, which means less economic investment and civil works. This savings may be utilized to further improve the existing system.

5.4.10 Digitization

Steps to implement Smart Grid by the Govt. of Bangladesh will be a strong approach to make a "Digital Bangladesh". The government has declared the "Vision 2021" which targets establishment of a resourceful and modern country by 2021 through effective use of information and communication technology - a "Digital Bangladesh".

5.4.11 Future Expansion Planning

The big cities of Bangladesh are over populated with less options available for establishing required facilities by electric utilities in due time in a right place. There are many applications of Smart Grid which will ease the procedure of decision making for a network planner.

5.4.12 Environment Protection

Bangladesh is a signatory of both the Kyoto Protocol and United Nations Framework Convention on Climate Change (UNFCCC). In the year 2009 Bangladesh was liable for the emission of around

50.7 million tonnes of CO_2 into the air from where 22.2 million tonnes came from electricity production. In the same year, Bangladesh, one of the most climate change vulnerable countries, produced 0.312 tonnes of CO_2/capita from all sectors which indicates an increase of 166.2% of tonnes of CO_2/capita compared to the amount of 1990 and it is a pretty high amount compared to similar types of countries in Asia. Bangladesh emitted around 0.137 tonnes CO_2/capita from electricity sector itself. It is proven that Smart Grid is an initiative towards the green and pollution free environment, reducing the emission of harmful GHG gases from electricity sector. Thus to help save the environment and earth, Smart Grid is an obvious choice for Bangladesh.

As the customers want a reliable, cheap and quality power supply in an environment friendly manner, it can be stated that Smart Grid is an inevitable choice for Bangladesh power system. Figure 3 presents the possible interaction of the power and communication infrastructure for developing Smart Grid in Bangladesh.

5.5 New Challenges to Power System Planning and Operation

The development of Smart Grid in Bangladesh will face many new challenges and requirements for power system planning and operation in many technical aspects. Some of these are:

5.5.1 Integration of Various Types of Sources in Power System

Smart Grid development in Bangladesh requires a study on security, stability, reliability, control measures of power system. As there are varieties of sources to be connected to the grid, the proper coordination should be studied and applied. As the nuclear power station in Ruppur, Bangladesh is going to be added with its present generating stations, the smart integration is must for proper function of Smart Grid.

5.5.2 Distributed Generation and Synchronized Development of T&D Network

The operating characteristics of many distributed generations and the interaction mechanism between the grid and various sources need to be studied. It needs planning methods for the coordinated development of the T&D network, improvement of the safety and reliability of the power supply, and optimization of the network resources.

5.5.3 Study on Smart Grid Planning and Developing Strategy

As many of the engineers are not yet familiar with modern grid concept, they need the knowledge of the Smart Grid. After going through various cases of implementation of Smart Grid in different countries, the deficiencies in Bangladesh power system needs to be pointed out. The problems should be analyzed, investigated and researched further to identify barriers for development of Smart Grid with specific national condition. Strategies and development plans need to be applied for preparing the roadmap of Bangladesh Smart Grid. The final goal of the study is to propose the concept and configuration of the modern power grid, to propose the planning methods for overall improvement and promote the facilities of the grid.

5.5.4 Power Grid Improvement with Modern Technologies

To increase the controllability, adaptability, flexibility, observability and intelligence, the grid should be configured with modern electronic devices such as power electronic devices, semiconductor devices etc. Power system stability, energy storage with control methods, protection system, advanced superconducting power equipments etc. should be studied and applied for better performance.

5.5.5 Security Monitoring, Fast Simulation, Intelligent Decision-Making

Monitoring the generator and power grid status, construction and adjustment of the grid, arrangement and adjusting the operation should be safe and secured. The network security and defense system, intelligent decision making, fast simulation should be studied and analyzed. This will launch a network monitoring system with complete security and protection function that can meet the requirements of the Smart Grid.

5.5.6 Recovery Control Technology

Control technologies for complex and difficult power failures, the adaptive optimization, instant decision making technology, technique of self healing recovery system should be studied by the planners and engineers. The emergency control and command system should be developed for proper emergency management system. Extreme weather is very much common in the southern part of Bangladesh. Black start technology under extreme weather, should be taken into account for proper coordination. Another target of this study is to set up the reserve system and mechanism at different levels step by step that can avoid large-scale blackout.

5.6 Prospects of Smart Grid in Bangladesh

With a huge pressure of daily increased power demand, presently the utilities are adding many new generation facilities with small capacities to its power grid in a quick rental basis to cope up the present power shortage problem. But in the long run, Bangladesh needs a power system restructuring and a sustainable solution to the problems. This restructuring must be in a way which would satisfy the expectations of power plant in the 21st century. In order to reach this goal, the Smart Grid is a certain choice for Bangladesh. In this section some of the activities to achieve the power system modernization and Smart Grid establishment are mentioned below:

5.6.1 Renovation of Old Power Plants

The government has taken initiative to renovate a number of old power plants in the country. With the help of memorandum of understanding (MoU) with foreign and domestic companies, overhauling and maintenance of at least 10 power plants, having a combined capacity of 833MW, those stopped electricity generation due to lack of maintenance and overhauling is under process.

5.6.2 Smart Meter Implementation

One of the preliminary steps to transfer to Smart Grid is to install the smart meters. Recently power distribution authorities in the capital city Dhaka are going to install „Digital Programmable Energy Meters" with remote data communication facilities for billing, energy auditing, demand side management, data acquisition, load disconnection/reconnection, data monitoring and analysis etc. Basic equipments as well as automated meter reading (AMR) softwares' are also included in this system. At first this metering infrastructure will be installed in some selected areas of Dhaka city as a pilot project. Later on, all other areas and other cities will be under this facility.

5.6.3 Communication Infrastructure

A secured and reliable communication network along with the power network will ensure the proper control and management of the system. Because of the enormous development in the telecommunication sector in Bangladesh, the communication backbone is quite well developed. A Home Area Network (HAN) can be used through different communication protocol technologies. Several wireless and wired home networking technologies are currently available to customers. For example, electrical wiring, telephone line, coaxial cable, optical fiber, etc. But it is cumbersome to set up wired network in an existing home. Therefore it is preferable to use wireless network. Some wireless communication standards using RF signal are Wi-Fi {IEEE 802.11}, Bluetooth {IEEE 802.15.1 (v1.1 only)}, ZigBee / ZigBee Pro {IEEE 802.15.4 (radio-layer only, not protocol)}, Z-Wave. Considering the speed and the sensitivity, Wi-Fi and ZigBee are promising.

5.6.4 Distributed Generation

The national power grid in Bangladesh is not much capable for massive integration of renewable energy sources to its system. With huge potential for solar PV generation in Bangladesh it is likely that the utilities starting research on the integration to the grid. Research is going on with other distributed generation sources like biomass, micro hydro, wind etc. Major renovation of the power infrastructure is needed to support the bi-directional energy flow with smart control functions. This will improve the reliability and resiliency of the power grid, especially in the state of emergency or in the peak load. Bangladesh government has set targets for developing renewable energy resources to 5% of total power demand by 2015 and 10% by 2020. Government has set target of generating 500MW of green energy, almost ten times the current amount by 2015, in an attempt to narrow the gap between current supplies of grid electricity.

5.6.5 Supervisory Control and Data Acquisition System (SCADA)

SCADA is a Smart Grid technology which is already been used in Dhaka city power distribution system which performs the operation and control of 132 kV and 33 kV electrical networks to supply about 1300 MW of energy through different grid and power sub-stations. This system improves the monitoring and control of the power system, reliability and efficient operation of the distribution system. SCADA performs the jobs in co-ordination with all divisional control room, grid control rooms of Dhaka Power Distribution Company Limited and the National Load Dispatch

Center of Power Grid Company of Bangladesh. The existing SCADA system which is facing lots of drawbacks due to many issues should be equipped with more modern equipments to support all the facilities provided by the system.

5.6.6 Automated Switching

Automated switching prevents massive blackout and helps to isolate the faulted portion of the network and restore power to unfaulted area quickly with proper switching action. Blackout is a major power problem in Bangladesh and thus installation of intelligent terminal units and intelligent switches into network, problems can be solved effectively.

5.6.7 Geographic Information Systems (GIS)

Geographic Information Systems (GIS) tools can also be used in this smart platform by the utility operators, designers, planners and engineers to facilitate the distribution system with more benefits. Application of GIS, one of the components of Smart Grid will ease the procedure of decision making for a network planner. GIS can be used to improve the ability to keep the records of customers and other assets geographically. Though its not been started yet but, GIS can be used in Bangladesh power sector in the electricity routing network for several purposes such as automated route selection for the construction of new power lines, asset management, proper land use, future expansion planning, decision making on new establishments etc.

5.6.8 Customer's Dilemma

Inadequate knowledge of customers on power systems and energy can put a barrier for having some programs to make them participate in the energy management of the Smart Grid. So, knowledge sharing programs for consumers have to be achieved before the introduction of the Smart Grid in Bangladesh. Customers are one of the pillars for Smart Grid, so without their proper knowledge and agreeing to bear the extra expenses for the Smart Grid it will be difficult to materialize Smart Grid in Bangladesh.

5.6.9 Policies and Rules

For the financing, planning, design, implementation, operation & maintenance of Smart Grid, the govt. could form policies, rules & regulations and well defined and experienced body under the supervision of “Ministry of Power, Energy and Minerals" of the Govt. of People’s Republic of Bangladesh. Necessary training sessions could be arranged and expert exchange programs should be maintained on a regular basis.

5.6.10 Rapid changes in Technology

The electro-mechanical meters at homes last 20-30 years easily. But we cannot say the same for Smart Meters. We know the field of technology is very fast and dynamic one. What is a modern device today may well be out of date within a few years. Not only will the Smart Meters, the other vital component of sensing, measurement and control go through rapid changes. We must be able to handle these changes.

5.6.11 Financial Investment

The government is giving its best effort to reach the goal of providing electricity service to all the people by the year 2020. Along with the reform programs, government has taken a number of time bound development plans. By the year 2020, installed capacity has been planned to increase to 17,765 MW. There will be huge expansion of transmission and distribution lines. All these need investment requirement of USD$4.5 billion and USD$7.0 billion during 2007-2012 and 2012-2020 time periods respectively. Only around one third of rural residents have access to electricity. Some 16 million homes have yet to be connected to the grid. It is changing rapidly with help from the World Bank. The World Bank’s International Development Association (IDA) has approved a USD$172 million credit facility to support installation of solar power and other renewable energy “mini-grid" systems for as many as 630,000 more homes in rural Bangladesh. The funds add to the IDA’s Rural Electrification and Renewable Energy Development Project (RERED) in Bangladesh, which aims to install solar power systems on more than 1 million rural Bangladeshi homes and businesses by 2012. This latest financing follows an additional USD$130 million the World Bank awarded RERED in December, 2009. With this specific investment plan, the govt. should try to establish the Smart Grid that could be a role model for others to follow.

Development of Smart Grid in Bangladesh is not possible neglecting the national needs and issues. With specific national consideration, the road map towards the Smart Grid of Bangladesh should be developed as soon as possible. A lot of systematic research and infrastructural developments are needed to avail all the facilities to the power system.

5.7 Summary

This chapter upholds the bright future perspective of establishment of Smart Grid in our country. Ours is a developing country, so this mammoth project is a one too much for us till now. At first we have to look at our existing power system and determine its loss, line fault and respective cost or consumer bills. Then our target will be to identify the challenges posed by our authorities & the surrounding environment. We should be well aware of the differences between the Smart Grid & our present grid system. It has to be ensured the Smart Grid meets the capacity demand of the people of this country. Bangladesh will be benefited from the Smart Grid in the upcoming future if the roadmap is in the right direction.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Discussion

This thesis tries to define the smart grid concept and explains where it is going in near future. It does so by providing an outlook on the electricity market and its players, explaining the smart grid drivers, applications, challenges, benefits etc. As a part of this enterprise power engineers, for example, are investigating efficient and intelligent ways of energy distribution and load management; IT specialists are researching cyber security issues for reliable sharing of information across the grid, the signal community is looking into advancing instrumentation facilities for detailed grid monitoring; renewable energy experts are studying efficient integration of renewable energy to the smart grid while business administrators are reforming power system market policies to adapt to these new changes to the system. To make a power system smart requires modeling, identification, estimation, robustness, optimal control and decision making. With the combination of all these factors we can move towards smart grid- the power grid of the future.

6.2 Future Opportunities and Challenges

To highlight further opportunities where science and technology from other industries could possibly be identified to fill these gaps, the following issues must be addressed:

- Low-cost, practical electric and thermal energy storage;
- Micro grids, ac and dc, including both self-contained, cellular, and universal energy systems and larger building- or campus-sized systems;
- Advanced (post-silicon) power electronics devices (valves) to be embedded into flexible ac and dc transmission and distribution circuit breakers, short-circuit current limiters, and power electronics-based transformers;
- Power electronic-based distribution network devices with integrated sensors and communications;
- Fail-safe communications that are transparent and integrated into the power system;
- Cost-competitive fuel cell;
- Low-cost sensors to monitor system components and to provide the basis for state estimation in real time;
- Cost-effective integrated thermal storage (heating and cooling) devices;
- Thermal appliances that provide "plug-and-play" capability with distributed generation devices;
- High-efficiency lighting, refrigerators, motors, and cooling;
- Enhanced portability through improved storage and power conversion devices;
- Efficient, reliable, cost-effective plug-in hybrid electric vehicles (PHEVs);
- Technologies and systems that enable "hardened" end-use devices;
- Conductors that enable greatly increased power flow capability;
- Smart, green, zero-energy buildings; and
- Thermoelectric devices that convert heat directly to electricity.

However, these technologies will require sustained funding and commitment to research, development, and demonstration. Given the state of the art in electricity infrastructure security and control, creating a smart grid with self-healing capabilities is no longer a distant dream; considerable progress has been made toward this goal.

However, considerable technical challenges and several economic and policy issues remain to be addressed. At the core of the power infrastructure investment problem lie two paradoxes of restructuring, one technical and one economic.

Technically, the fact that electricity supply and demand must be in instantaneous balance at all times must be resolved with the fact that new power infrastructure is extraordinarily complex, time-consuming, and expensive to construct. Economically, the theory of deregulation aims to achieve the lowest price through increased competition. However, the market reality of electricity deregulation has often resulted in a business-focused drive for maximum efficiency to achieve the highest profit from existing assets rather than in lower prices or improved reliability.

Both the technical and economic paradoxes can be resolved through knowledge and technology. Given economic, societal, and quality-of-life issues and the ever-increasing interdependencies among infrastructures, a key challenge before us is whether the electricity infrastructure will evolve to become the primary support for the 21st century's digital society—a smart grid with self-healing capabilities—or be left behind as a 20th century industrial relic.

6.3 Recommendations

The nature of the transition to Smart Grids has been discussed previously: it is an evolutionary process for which there is no single blue print, and therefore there is no 'costed plan'. This does not of course mean that the financial aspects should be treated on a laissez faire basis. Indeed, special financial attention is required to evaluate the likely costs and benefits of emerging technologies, and manage investments as they take place. In view of the potentially high costs involved for network infrastructure, and its long life of typically 20/40 years, it is a priority to ensure the effective and efficient use of funds and to avoid poor utilization or stranded assets. Cost uncertainty is problematic for developing business cases in this area of work. It can be anticipated that there will there be a price premium for first-application devices (there will typically be a single supplier, it involves bespoke specialist work, and there are no scale-production benefits available at that stage).

Four broad actions in parallel would ensure that the smart grid's design and implementation will fully enable markets for electrical power.

1. Modify existing and create new policies and regulations that remove the economic and political barriers to integrated markets. It will take a systems view and, most likely, federal directives to align policies toward integrated markets that benefit all consumers. For example, retail markets can perform well around TOU rates (real-time or not). The underlying requirements are that (1) market rate design needs to have rates that fairly represent costs at any TOU, and (2) consumers need access to the market. There are complex issues to be undertaken and, as in any political process, no one wants to end up with a disadvantage.

2. Provide widespread market education to all stakeholders in the smart grid, especially distribution-level consumers. Thousands of consumers may join a DR group that gives incentives participation, including selling the aggregated DR in the real-time market to offset energy costs. Knowing the potential gain and potential liability of such a venture is a must for consumers.

3. Standardize the communication of market information throughout the design of the smart grid with equipment, software processes, and protocols. Having a broker of market information is to the advantage of all market participants, like the reporting of stock values. Any consumer should have access through non-proprietary equipment.

4. Provide incentives for capital investment in new technology and the integration of existing advanced technologies. Regulators wish to have access to competitive markets to lower prices, yet are reluctant to (or prohibited to) authorize investments that spread benefits outside their regulatory jurisdiction or to utilize new technology. Options for resolution require some managed risk.

6.4 Conclusions

This thesis has dealt with the evolution of Smart Power Grid System. It is still in it nascent stage. The whole power community is busy now in understanding and developing smart power grid system which is no longer a theme of future. This introductory thesis is a small but a very vital step towards achieving the ultimate goal of making a “National Grid” a reality.

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