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Smart Grid: Technologies, applications and research challenges

B.Sc. Thesis

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Preface

The term "Smart Grid" is used for the integration and the synergy of infrastructure at the site of electricity to the Information and Communication Technologies (ICT).

Already, the European Union, with specific recommendations invites national agencies to begin to plan the National Energy Informational Strategy.

This thesis provides a detailed description of what a "Smart Grid" is, its features, the conceptual model and the communications media related to it. Also, it analyzes the Smart Grid applications, the security and network issues as well as the future development plans about Smart Grid.

A part of the current thesis has been published as a book chapter (P. Chatzimisios, D. Stratogiannis, G. Tsiropoulos and G. Stavrou, “Survey on Smart Grid communications: from an overview, architecture and models to standardization efforts to interoperability and coexistence issues”, chapter in the book entitled “Handbook on Green Information and Communication Systems”, Elsevier, 2013).

Περίληψη

Σκοπός της πτυχιακής εργασίας είναι η αναλυτική περιγραφή, η μελέτη, οι εφαρμογές και οι ερευνητικές προτάσεις που αφορούν ένα Έξυπνο Ηλεκτρικό Δίκτυο (Smart Grid) .

Ο όρος «Smart» αναφέρεται στην προσπάθεια εκσυγχρονισμού του υπάρχοντος ηλεκτρικού δικτύου και στη μετατροπή του σε ένα μοντέρνο, διαλειτουργικό δίκτυο που θα ενσωματώνει τεχνολογίες πληροφοριών και επικοινωνιών στην υποδομή και στη διανομή ενέργειας. Τα στοιχεία που το καθορίζουν, εντοπίζονται σε όλα τα στάδια από την παραγωγή, τη μεταφορά και τη διανομή, έως την κατανάλωση και την εμπορία.

Τα χαρακτηριστικά του Smart Grid καθιστούν το δίκτυο πιο αποδοτικό, προσαρμοστικό, εύρωστο, οικολογικό και εύκολα διαχειρίσιμο, ενώ ταυτόχρονα διευκολύνουν τον έλεγχο σε όλα τα στάδια του δικτύου. Χαρακτηριστικό γνώρισμα της λειτουργίας του αποτελεί η αμφίδρομη ροή της ενέργειας και των πληροφοριών στα στάδια που το απαρτίζουν.

Abstract

The aim of the thesis is to provide a detailed description and study as well as information about the applications and research proposals for a Smart electrical Grid (Smart Grid).

The term «Smart» refers to the attempt to modernize the existing electricity network and its transformation into a modern, interoperable network that integrates information and communication technology infrastructure and distribution.

The elements that define Smart Grid are identified at all stages of the production, transmission and distribution to consumption and marketing. These elements will make the network more efficient, adaptive, robust, ecological and easily manageable, and will facilitate the control at all stages of the network. A characteristic feature of the operation of the Smart Grid is the two-way flow of energy and information in its component stages.

Acknowledgments

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Also, I thank Mrs. Karakasi Panagiota for editorial and orthographic custody.

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List of Abbreviations and Acronyms

European Standard's Organization (ESO's)		
CEN	**European Committee for Standardization**	www.cen.eu/cen/Sectors/Sectors/UtilitiesAndEnergy/SmartGrids/Pages/default.aspx
CENELEC	**European Committee for Electrotechnical Standardization**	www.cenelec.eu/aboutcenelec/whatwedo/ technologysectors/SmartGrids.html
ETSI	**European Telecommunications Standardization**	www.etsi.org/website/Technologies/SmartGrids.aspx

FOR UTILITY INDUSTRY NORTH AMERICA'S STANDARDS DEVELOPMENT ORGANIZATIONS (SDO´s)		
ANSI	**American National Standards Institute**	www.ansi.org

DIN	***Deutsches Institut für Normung*, German Standards Institute**	www.din.de
IEC	**International Electrotechnical Commission**	www.iec.ch
IEEE	**Institute of Electrical and Electronics Engineers**	www.ieee.org
ISO	**International Organization for Standardization**	www.iso.org
ITU	**International Telecommunication Union**	www.itu.int

Abbreviations and Acronyms	
American Recovery and Reinvestment Act	ARRA
Advanced Metering Infrastructure	AMI
Advanced Encryption Standard	AES
Business as usual	BAU
Business Area Networks	BAN
Consumer Premises Networks	CPNs
Control capability of graphical user interface	GUI

Demand-response	DR
Direct Sequence Spread Spectrum	DSSS
Distributed Energy Resources	DER
Distribution Automation	DA
Distribution Management Systems	DMS
Department of Energy	DOE
Energy Independence and Security Act	EISA
Energy Management Systems	EMS
European Standardisation Organisations	ESO
Fault Detection Isolation and Restoration	FDIR™
Federal Energy Regulatory Commission	FERC
Frequency Hopping Spread Spectrum	FHSS
Government Accountability Office (USA)	GAO
Greenhouse gases	GHG
Home Area Networks	HAN
Information and Communication Technologies	ICT

intelligent electronic devices	IEDs
Industrial Area Networks	IAN
Light emitting diode	LED
Merseyside and North Wales Electricity Board	MANWEB
Mobile Broadband Wireless Access	MBWA
Multiple Input Multiple Output	MIMO
Neighborhood Area Network	NAN
National Rural Electric Cooperative Association (USA)	NARECA
National Association ofRegulatory Utility Commissioners	NARUC
North American Electric Reliability Corporation	NERC
National Energy Technology Laboratory	NETL
National Institute of Standards and Technology	NIST
Quality-of-Service	QoS
Plug-In Electric Vehicle	PEV
proportional/integral/derivative	PID
Remote terminal units	RTUs

Supervisory Control and Data Acquisition	SCADA
Standards Development Organizations	SDO
Wide-Area Situational Awareness	WASA

Chapter 1: Introduction

Energy is a structural factor in the field of economy and facilitating conditions of life. Any period of human creation requires energy expenditure. Initially, power consumption was mainly limited to physical work. Gradually, human beings seeking more and more production discover energy reserves such as oil, coal etc.

However, whether for economic or environmental reasons or due to the risk for progressive lack of coverage of energy needs and, consequently, the degradation of lifestyle, as it has shaped the last half century, efforts are directed either towards new, renewable energy (solar, wind) or to better management of their energy forces.

In human being's energy quest, the effort to create a Smart network that will manage any kind of energy in such a way as to achieve not only saving energy, but also successful and effective distribution is apparent. Successful distribution leads to multiple benefits: economic, energy, productive. For this reason there are many sectors (economy, energy production, energy industry, information technology, engineering, etc.) that are involved in this new venture.

Smart Grid is a proposal for a new era in electrical power system and works by using communication and information technology in the three phases of power industry (generation, delivery and consumption of electrical energy). Computer science and engineering are two disciplines that are invited to seek, cooperate and sign the best possible proposal to implement a Smart Grid. This will achieve the utilization of information technologies and create the basis for the development of intelligent infrastructure and "green" development.

In this thesis, an effort to present Smart Grid is made. The first chapter presents an outline definition of Smart Grid. It refers to its characteristics that distinguish it from the current Grid in terms of functionality, the differences from the conventional networks, and application domains in the existing Grid and its benefits.

The second chapter refers to the scope of Smart Grid and the domains of which its conceptual model is consisted such as Customers, Bulk Generation, Operations, Service Providers, Markets, Transmission distribution.

The third chapter refers to the communication structure of a Smart Grid that is composed essentially of six areas of networking (external Access, Core, Backhaul, Access Area, Neighborhood Area Network (NAN), and Consumer Premises Networks. The Challenges for a communication system that Smart Grid provides, and the requirements needed for the communication system are mentioned. Also, the architecture of Network Communications as HAN, WAN, etc, the supporting network technologies and other potential wireless technologies such as Mobile Broadband Wireless Access (MBWA) are included**.**

The expectations of the applications of Smart Grid are hopeful. In the fourth chapter, the expected benefits are discussed. Also, the impediments of the adoption of Smart Grid technologies because of the variety of Smart Grid applications, which are many and therefore utilities have to choose the ones that will provide the best return on investment. The immediate adoption of Smart Grid has its difficulties, since utilities must transform their business and operations to utilize Smart Grid technologies. However, Smart Grid Applications are presented like Wide-Area Situational Awareness (WASA) that represents the monitoring of the power system across wide geographic areas. The Demand Response system, the electric storage benefits of energy storage to generation and other technical applications of electric energy storage are referred and their benefits for both the companies and the customers. Also, SCADA system and its components such as instrumentation, remote stations, communication networks, and MTU the central control station, or central station, or SCADA master are mentioned.

Challenges and security are discussed in the fifth chapter**.** Smart Grid poses many procedural and technical challenges as society turns from the current Grid with its one-way power flows from central generation to dispersed loads, toward a new Grid with two-way power flows, two-way and peer to peer customer interactions, and distributed generation. Complexity of the Smart Grid, transition to Smart Grid, ensuring cyber security of systems, consensus on standards, development and support of standards cannot be taken lightly.

In the sixth chapter, the Smart Grid's perspective seems to be a dynamic process for future management of energy. Cities and countries that make an effort to invest and to try this new proposal are referred (some of countries investing in Smart Grid, as China, USA, Italy, Greece in the future) are presented.

Finally, the thesis discusses the clients' concerns about the information of their consumption habits, their privacy, computer security, concerns over giving the government mechanisms to control the use of all power using activities, etc.

Conclusively, one could say that Smart Grid is expected to benefit not only the consumers and utilities, but also the countries' economies, the power industry and the environment. For this reason, it deserves a careful study.

Chapter 2 “Smart Grid”

2.1 Definitions of “Smart Grid”

The new social, economic and environmental trends, having evolved worldwide such as the increasing demand for increased productivity and effectiveness of power Grid along with the protection of the environment standards, have created the need for advanced exploitation of the existing energy distribution network by integrating advanced sensing technologies, control methods and communications networks into it.

The convergence of the existing power delivery infrastructure with the information communications technology leads to an innovative energy distribution Grid that will provide new capabilities and significant advantages to participating entities. The evolution of next generation electric power systems also seems as a promising solution for energy problem along with the constraints of Tokyo convention regarding carbon emission and the compliance of each country with it. Thus, energy providers, policy makers, regulation authorities and various enterprises have shown great interest on opportunities arousing by the development of Smart Grid technology in the fields of automation, advanced data collection, control, broadband telecommunications, intelligent appliance interoperability, security, distributed power generation and renewable effective integration.

Smart Grid is a proposal to modernize the transportation and distribution of electricity. Specifically, the application of technology in electricity consumption at home in the 21st century is programmed to operate automatically using remote controls.

Smart Grid is a new term that has been used recently and a formal, precise definition of it does not yet exist [43]. The term was first used in the US Energy Independence and Security Act (EISA) of 2007 [52], and although there are many definitions (DOE, 2008), there is not a clear one [52]. Reference [51] defines Smart Grid as a network of computers that controls the traffic flow and delivers it between individual clients and control centers. Smart Grid as an automated power network gives the opportunity to user and node to be in real-time monitored providing two-way flow of the current consumption and information from the power stations to the client. Through the extensive use of distributed intelligence, broadband communications and the integration of automatic control system, Smart Grid can ensure the market transactions -online in real time- as seamless connectivity and real-time interaction between all members of power system [46]. Sissine in [44] refers to a distributive system that allows the flow of information from a customer meter in two directions around the home to the thermostats, Smart appliances and other applications and from home to the provider. Smart Grid includes a variety of functional and energy measures such as Smart metering and renewable energy sources [44]. According to [45] the system architecture of the Smart Grid will shift from large sources and centralized control in a system with many other smaller sources and decentralized intelligence.

Basically, Smart Grid's proposal is to provide the convergence of electric distribution systems and modern digital technology. Whereas current electric grid works at one-way flow of energy, Smart Grid will provide bidirectional energy flow and two-way digital communication over the same distribution system. So, customers will have real-time information on energy use, and will be informed about the price according to energy supply and demand. Smart devices and appliances will give consumers the opportunity to avoid higher energy prizes.

As referred above, there isn't only one definition about what Smart Grid is. Below, some global organizations's definitions about Smart Grid by their point of view are quoted.

The European Technology Platform defines “Smart Grid” as :

An electricity network that can intelligently integrate the actions of all users connected to it -producers, consumers and those they do both- to the efficient delivery of sustainable, economic and safe electrical supplies.

The Department of Energy of the U.S.A defines Smart Grid as:

A Grid that uses digital technology to improve reliability, safety and efficiency (both economic and energy) of the power system, from large production through transmission systems to consumers, and a growing number of media Storage and Distributed Generation.

The N.I.S.T refers to it as:

A modernization of the electricity delivery system which monitors, protects and automatically optimizes the operation of its interconnected elements – from the central and distributed generator through the high-voltage transmission network and the distribution system, to industrial users and building automation systems, to energy storage installations and to end-use consumers and their thermostats, electric vehicles, appliances and other household devices.

In my opinion, Smart Grid is the energy management information at all stages from production to distribution and consumption in order to achieve / accomplish a rational, prudent and well-organized distribution of energy resources. Ideally, Smart Grid is also a digital network that unites electrical providers, power-delivery systems and customers, and allows two-way communication between the utility and its customers.

2.2. Smart Grid Characteristics

According to the definition of what is a Smart Grid, there are characteristics that distinguish it from the current Grid in terms of functionality rather than in terms of specific technologies that may be needed. Considerable efforts have developed and articulated the vision statements, architectural principles, barriers, benefits, technologies and applications, policies, and frameworks that help define what the Smart Grid is. The characteristics interconnected by a close causal effect are challenges that must be taken into account in the design of an intelligent network.

Some of the widely accepted principle characteristics that will be the basis for the future Grid will be described below.

According to DOE, NIST, EISA, and many other organizations and people these characteristics are:

- Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid.
- Optimize Asset Utilization and Operate Efficiently.
- Development and incorporation of demand response, demand-side resources, and energy-efficiency resources.
- Provide Power Quality for the Digital Economy
- Measurability - Predictive
- Deployment and integration of advanced electricity storage and peak-shaving technologies.
- Provision to consumers of timely information and control options.
- Operate Resiliently to Attack and Natural Disaster
- Anticipate and Respond to System Disturbances (Self-heal)
- Enable Active Participation by Consumers
- Enables New Products, Services, and Markets

2.2.1 Analytically:

- **Digitalization – Controllability**

Smart Grid will use a unique digital platform for fast and reliable detection, measurement, communication, computing, control, protection, visualization and maintenance of the entire transmission system. This is a fundamental feature that will facilitate the implementation of other Smart features. This platform is characterized by user-friendly display of information fragility and a high tolerance to anthropogenic mistakes. There should be some degree of observability and transparency to ensure effective analysis, management, and anticipating and responding to changing network state. The wealth of information data, which essentially makes the Smart network should also be measurable, observable and manageable.

- **Optimization**

Optimization of the operation and assets of the Smart Grid is imperative. It can be achieved with the help of advanced technologies and Smart appliances (Intelligent Electronic Devices - IEDs), intelligent management and automation, while balancing a diversity variables and tradeoffs. A Smart Grid applies the latest technologies to optimize the use of its assets. Operationally, Smart Grid will improve load factors, lower system losses, and it will improve dramatically outage management performance. The availability of additional Grid intelligence will give planners and engineers the knowledge to build what is needed when it is needed, extend the life of assets, repair equipment before it fails unexpectedly, and more effectively manage the work force that maintains the Grid. Operational, maintenance, and capital costs will be reduced thereby keeping downward pressure on electricity prices.

- **Demand- Response (DR)**

Demand-response programs will satisfy a basic consumer need — greater choice in energy purchases. The ability to reduce or shift peak demand allows utilities to minimize capital expenditures and operating expenses while also providing substantial environmental benefits by reducing line losses and minimizing the operation of inefficient peaking power plants. In addition, emerging products like the plug-in hybrid vehicle will result in substantially improved load factors while also providing significant environmental benefits

- **Provision of Power Quality for the Digital Economy**

Smart Grid provides reliable power that is relatively interruption-free. Reliability refers to the ability of a system or data to perform the required functions under given conditions for a specified time in general lines. Smart Grid will interpret the operational function and the degree of volatility of all system. Moreover, it will show the high-consistency, repeatability solvency and the Smart Grid will be maintained in accordance with effective measurements and assessments. It will monitor, diagnose, and respond to power quality deficiencies, leading to a dramatic reduction in the business losses currently experienced by consumers due to insufficient power quality. New power quality standards will balance load sensitivity with delivered power quality. Additionally, power quality events that originate in the transmission and distribution elements of the electrical power system will be minimized and irregularities caused by certain consumer loads will be buffered to prevent impacting the electrical system and other consumers.

- **Measurability - Prediction**

The service interruption and damage incidents are serious and very likely to occur. It is important to be measurable so that appropriate assessments and evaluations can be made. The Smart Grid will be able to detect and correct functional disorders through dynamic measurements and real-time monitoring. Predictive use of machine learning, weather impact projections, and stochastic analysis to provide predictions of the next most likely events so that appropriate actions are taken to reconfigure the system before next worst events can happen.

- **Accommodation of All Generation and Storage Options**

The Smart Grid accommodates all generation and storage options. It will seamlessly integrate all types and sizes of electrical generation and storage systems as well as Distributed Energy Resources (DER) using simplified interconnection processes and universal interoperability standards to support a “plug-and-play” level of convenience. Large central power plants including environmentally friendly sources, such as wind and solar farms and advanced nuclear plants, will continue to play a major role even as large numbers of smaller Distributed Energy Resources. The Smart Grid various capacities from small to large will be interconnected at essentially all voltage levels and will include distributed energy resources such as photovoltaic, wind, advanced batteries. The Smart Grid supports all generation options. The same is true of storage, and as storage technologies mature, they will be an integral part of the overall Smart Grid solution set.

- **Real-Time Information**

The active participation of consumers in electricity markets will bring tangible benefits to both the Grid and the environment. The Smart Grid will provide consumers real-time information, control, and options that allow them to engage in new “electricity markets.” Grid operators will treat willing consumers as resources in the day-to-day operation of the Grid. Well-informed consumers will have the ability to modify consumption based on balancing their demands and resources with the electric system’s capability to meet those demands.

- **Resilient operation to attack and natural disaster**

The Smart Grid will incorporate a system-wide solution that reduces physical and cyber vulnerabilities and enables a rapid recovery from disruptions. Resiliency refers to the ability of a system to react to events so that problematic elements are isolated while the rest of the system is restored to normal operation. The Smart Grid resists attacks on both the physical infrastructure (substations, transformers, etc.) and the cyber-structure (markets, systems, software, communications). Its decentralized operating model and self healing features will also make it less vulnerable to natural disasters than today’s Grid. Sensors, cameras, automated switches, and intelligence are built into the infrastructure to observe, react, and alert when threats are recognized within the system. Security protocols will contain elements of deterrence, detection, response, and mitigation to minimize impact on the Grid and the economy.Constant monitoring and self-testing are conducted against the system to mitigate malware and hackers

- **Anticipation and response to system disturbances (Self-heal)**

The Smart Grid will identify independently and react to system disturbances and performs mitigation efforts to correct them. It will incorporate an engineering design that will enable problems to be isolated, analyzed, and restored with little or no human interaction. It will heal itself by performing continuous self-assessments to detect and analyze issues, take corrective action to mitigate them and, if needed, rapidly restore Grid components or network sections. It will also handle problems too large or too fast-moving for human intervention. Acting as the Grid's "immune system," self-healing will help maintain Grid reliability, security, affordability, power quality and efficiency. The self-healing Grid will minimize disruption of service by employing modern technologies that can acquire data, execute decision-support algorithms, avert or limit interruptions, dynamically control the flow of power, and restore service quickly. Probabilistic risk assessments based on real-time measurements will identify the equipment, power plants, and lines most likely to fail. Real-time contingency analyses will determine overall Grid health, trigger early warnings of trends that could result in Grid failure, and identify the need for immediate investigation and action. Communications with local and remote devices will help analyze faults, low voltage, poor power quality, overloads, and other undesirable system conditions. Then appropriate control actions will be taken, automatically or manually as the need determines, based on these analyses.

- **Active Participation by Consumers**

From the consumer's perspective, electricity consumption in the Smart Grid is an economic choice that recognizes both the variable cost of electricity and its value to the consumer under a range of times, places, and circumstances. Consumers have access to new information, control and options to engage in electricity markets, they see what they use, when they use it, and how much it costs.

- **New Products, Services, and Markets**

Correctly-designed and -operated markets efficiently reveal cost-benefit tradeoffs to consumers by creating an opportunity for competing services to bid. A Smart Grid accounts for all of the fundamental dynamics of the value cost relationship. Some of the independent Grid variables that must be explicitly managed are energy, capacity, location, time, rate of change, and quality.

The Smart Grid will link buyers and sellers together — from the consumer to the Regional Transmission Organization (RTO) — and all those in between. It will support the creation of new electricity markets ranging from the home energy management system at the consumers' premises to the technologies that allow consumers and third parties to bid their energy resources into the electricity market.

The Smart Grid will support consistent market operation across regions. It will enable more market participation through increased transmission paths, aggregated demand response initiatives, and the placement of energy resources including storage within a more reliable distribution system located closer to the consumer. Markets can play a major role in the management of these variables. Regulators, owners/operators, and consumers need the flexibility to modify the rules of business to suit operating and market conditions.

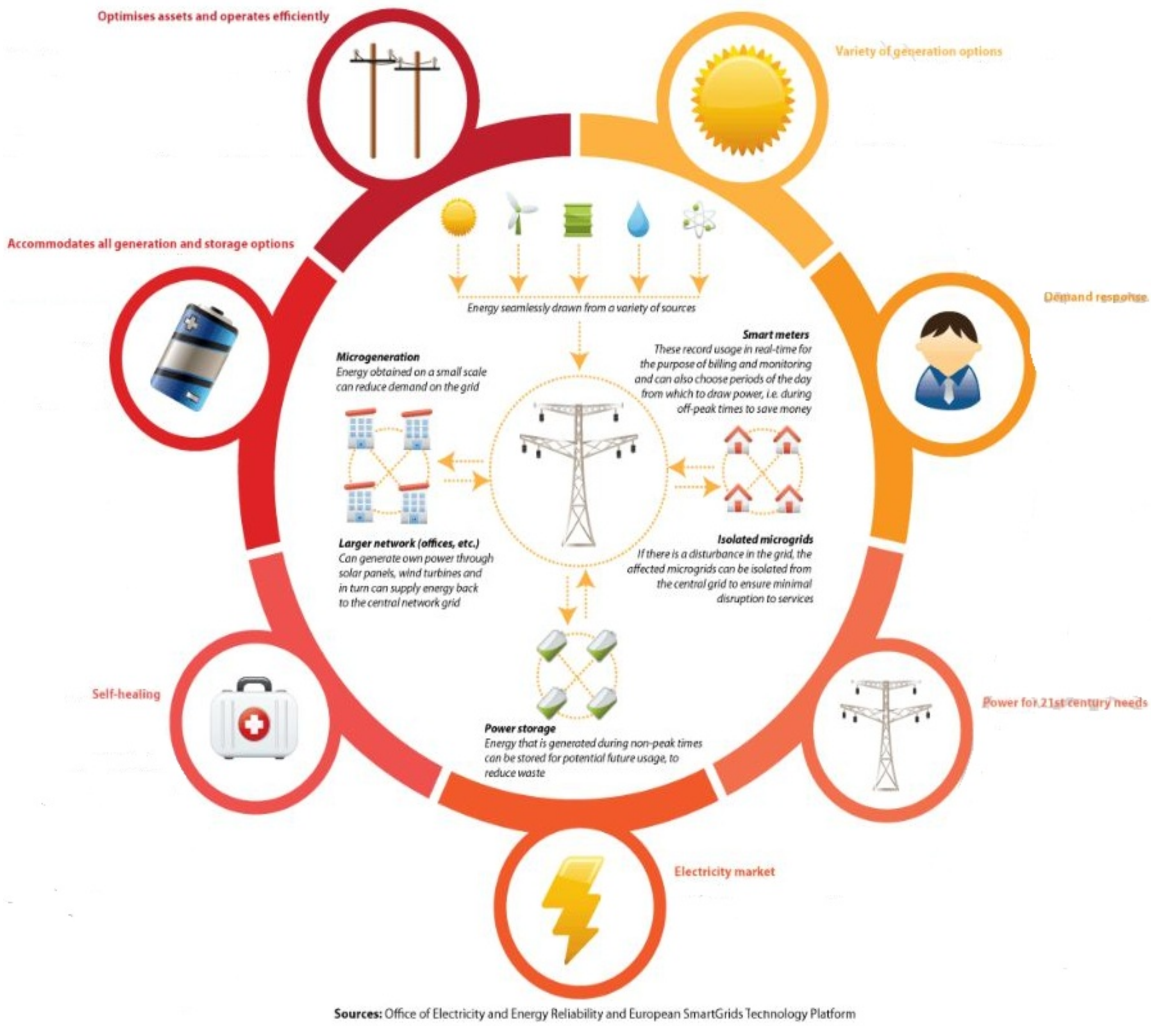

Figure 1 Smart Grid Characteristics Source: Office of Electric and Energy Reliability and European SmartGrids Technology Platform.

2.3. Differences between current power and Smart Grid

The power Grid is aging and congested and faces new challenges and stresses like:

- Growth in demand
- Constraints on capacity expansion
- Shifts in generation sources
- Transmission congestion
- Distribution

- Demand management
- Regulatory policy
- Environmental impact

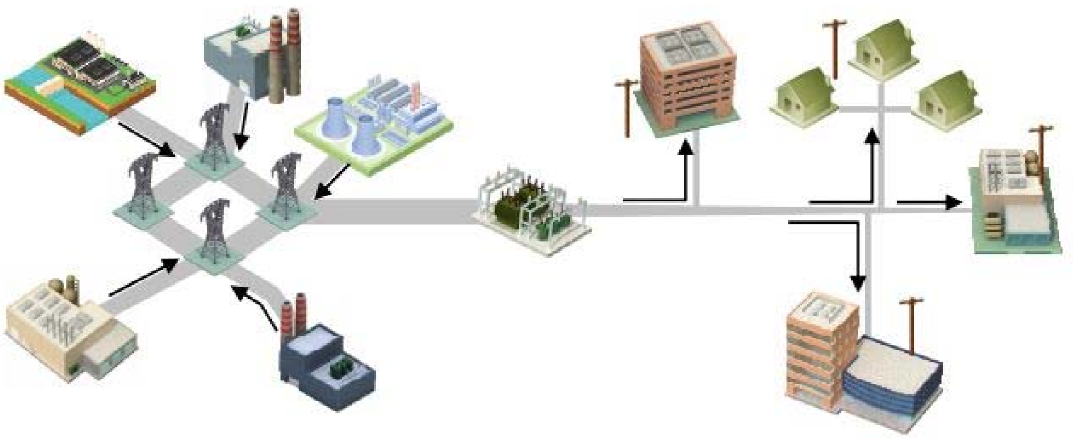

Figure 2 Today`s power Grid Source:Retrieved from http://www.dalkia.ie/media/energy_bulletins/Smart-Grids.htm 28/2/2013

These challenges put risk in its ability to reliably deliver power to an economy that is increasingly dependent on electricity. A growing recognition of the need to modernize the Grid to meet tomorrow's challenges has found articulation in the vision of a Smart Grid. In the United States and many other countries, modernization of the electric power Grid is central to national efforts to increase reliability and energy efficiency, transition to renewable sources of energy, reduce greenhouse gas emissions, and build a sustainable economy that ensures prosperity for future generations. Globally, billions of dollars are spent to build elements of what ultimately will be "Smart" electric power Grids. Today's electric grid was designed to operate as a vertical structure consisting of generation, transmission, and distribution and supported with controls and devices to maintain reliability, stability, and efficiency. However, system operators are now facing new challenges including the penetration of RER in the legacy system, rapid technological change, and different types of market players and end users. The essence of this vision is "a fully-automated power delivery network that can ensure a two-way flow of electricity and information between the power plants and appliances and all points in between". The next iteration, the Smart Grid, will be equipped with communication support schemes and real - time measurement techniques to enhance resiliency and forecasting as well as to protect against internal and external threats. The design framework of the Smart Grid is based upon unbundling and restructuring the power sector and optimizing its assets.

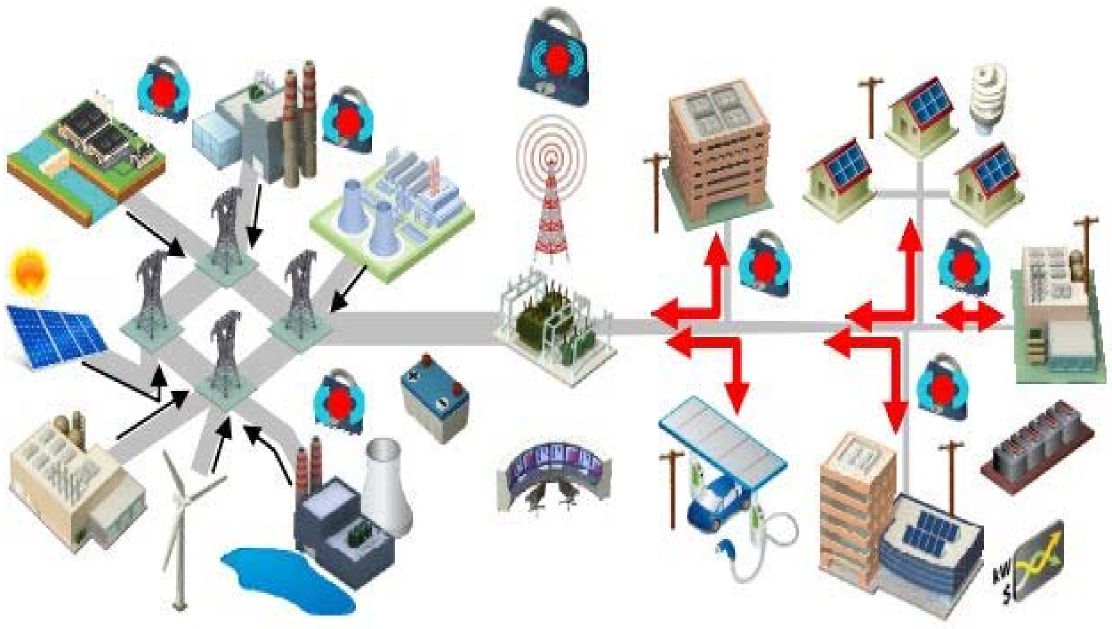

Figure 3 Tommorow`s power System
(Source: Retrieved from http://www.dalkia.ie/media/energy_bulletins/Smart-Grids.html, 28/2/20013)

The new Grid will be capable of:

- Providing utilities to monitor and manage their power delivery in real time.
- Enabling utilities will be able to offer multiple rate tructures to manage demand peak and offer demand management services to encourage efficiency.
- Accommodating renewable energy to maximize their environmental benefits and operational value.
- Handling uncertainties in schedules and power transfers across regions.
- Optimizing the transfer capability of the transmission and distribution networks and meeting the demand for increased quality and reliable supply.
- Managing and resolving unpredictable events and uncertainties in operations.

Table 1 Comparison of today`s Grid vs Smart Grid

	"Current Grid"	"Smart Grid"
Enables Consumer Participation	Consumers are uninformed and do not participate	Informed, involved consumers demand response and distributed energy resources and options to buy and sell
Accommodates All Generation & Storage Options	Dominated by central generation - many obstacles exist for distributed energy resources interconnection	Many distributed energy resources with plug - and - play convenience focus on renewable
Enables New Markets	Limited wholesale markets, not well integrated	Mature, well-integrated wholesale markets, growth of new electricity markets
Meets PQ Needs	Focus on outages slow response to power quality issues	Power quality a priority with a variety of quality/price options - rapid resolution of issues
Optimizes Assets & Operates Efficiently	Little integration of operational data with asset management - business process silos	Greatly expanded data acquisition of Grid parameters focus on prevention, minimizing impact to consumers

Self Heals	Responds to prevent further Damage - focus on protecting assets following a fault	Automatically detects and responds to problems; focus on prevention, minimizing impact to consumers
Resists Attack	Vulnerable to malicious acts of terror and natural disasters -slow response	Resilient to cyber attack and natural disasters- rapid restoration capabilities
Topology	Radial	Reticular
Instrument Type	Electrical	Numerical

2.4. Benefits of the Smart Grid

Although the transition to the Smart Grid may unfold over many years, incremental progress along the way can yield significant benefits. The Smart Grid's ability to improve safety and efficiency, make better use of existing assets, enhance reliability and power quality, reduce dependence on imported energy, and minimize costly environmental impacts are all market forces that have substantial economic value. In general terms, the Smart Grid will assure that consumers are provided with reliable, high quality digital-grade power, increased electricity-related services and an improved environment. Recognizing these many attributes, the American Recovery and Reinvestment Act of 2009 (ARRA) was designed to provide additional stimulus, to accelerate the Smart Grid transition, and thereby realize the benefits sooner. The opportunities are many and the returns can be sizable. As a result, the momentum for a Smart Grid is large and growing, but if it is to be sustained, the Smart Grid's value must become crystal clear to all stakeholders, especially to residential consumers.

Without the development of the Smart Grid, the full value of a lot of individual technologies like Electric Vehicles, Electric Energy Storage, Demand Response, Distributed Resources, and large central station Renewables such as wind and solar will not be fully realized.

Smart Grid benefits can be categorized as following types:

(According to NIST,IEEE, DOE, and other organizations, institutes, peoples)

- **Power reliability and power quality.**

A reliable Grid provides power, when and where its users need it and of the quality they value. A Smart Grid can create benefits through improvements in Grid reliability by reducing the frequency and duration of power outages and the number of power quality disturbances, including reducing the probability of regional blackouts with the contribution of self-healing power systems, through the use of digital information, automated control, and autonomous systems.

- **Safety and cyber security benefits**

The Smart Grid will continuously monitor itself to detect unsafe or insecure situations that could detract from its high reliability and safe operation. Higher cyber security is built in to all systems and operations including physical plant monitoring, cyber security, and privacy protection of all users and customers. The use of the Smart Grid policies will improve security and safety by reducing the vulnerability of the Grid to unexpected hazards and promoting a safer system for both workers and the general public. A secure Grid withstands physical and cyber attacks without suffering massive blackouts or exorbitant recovery costs. It is also less vulnerable to natural disasters and recovers quickly from disturbances.

- **Energy efficiency benefits**

An efficient Grid employs strategies that lead to cost control, minimal transmission and distribution losses, efficient power production, and optimal asset utilization while providing consumers with options for managing their energy usage. The Smart Grid will be more efficient, providing reduced total energy use, reduced peak demand, reduced energy losses, and the ability to induce end-users to reduce electricity use instead of relying upon new generation.

- **Environmental and conservation benefits**

The Smart Grid is "green". An environmentally responsible Grid reduces environmental impacts thorough improvements in efficiency and by enabling the integration of a larger percentage of intermittent renewable resources than could otherwise be reliably supported. The Smart Grid will help Green House Gases (GHG) to be reduced and other pollutants by allowing customers to purchase cleaner, lower-carbon-emitting generation and enabling the replacement of gasoline-powered vehicles with plug-in electric vehicles.

- **Direct financial benefits**

The Smart Grid offers direct economic benefits. An economic Grid operates under the basic laws of supply and demand, resulting in fair prices and adequate supplies. Operations costs are reduced or avoided. Customers have pricing choices and access to energy information by keeping downward prices on electricity prices, reducing the amount paid by consumers as compared to the "Business As Usual" (BAU) Grid, creating new jobs, and stimulating the Gross Domestic Product (GDP). Entrepreneurs accelerate technology introduction into the generation, distribution, storage, and coordination of energy.

- **New products and services**

Smart Grids can also create a platform on which retailers can create and offer new products and services that give consumers greater choice and flexibility in energy consumption and create value for end users.

Various stakeholder groups will benefit from the Smart Grid in different ways. A benefit to any one of these stakeholders can in turn benefit the others. Those benefits that reduce costs for utilities lower prices, or prevent price increases, to customers. Lower costs and decreased infrastructure requirements enhance the value of electricity to consumers. Reduced costs increase economic activity which benefits society. Societal benefits of the Smart Grid can be indirect and hard to quantify, but cannot be overlooked. The primary stakeholder groups that will benefit from the Smart Grid are:

- **Consumers**

Consumers will be able to balance their energy consumption with the real-time supply of energy according to the needs and the money they can spend. Variable pricing will provide consumer incentives to install their own infrastructure that supports the Smart Grid. Smart Grid information infrastructure will support additional services not available today. Smart Grid can provide a new set of tools for consumers to manage their usage and total energy bills.

- **Utilities**

Utilities can provide more reliable energy, particularly during challenging emergency conditions, while managing their costs more effectively through efficiency and information. Grid operators will benefit from direct cost reductions, and higher customer satisfaction. Direct cost reductions can come in the form of lower meter reading and servicing costs. Other benefits include reductions in theft and energy losses, improved and more efficient customer service, more efficient planning and maintenance of the system, and more efficient use of back office resources.

- **Society – Local Governments**

Society will have benefits from more reliable power for governmental services, businesses, and consumers sensitive to power outage. Renewable energy, increased efficiencies, and Plug-In Electric Vehicle (PEV) support will reduce environmental costs, including carbon footprint. Local governments can benefit from higher reliability and lower duration of outages which will reduce the burden on local fire, police and other city resources that must help with such events. Greater information and control over the distribution system will also allow Grid operators to assist with emergency situations, by turning off power selectively or by restoring power faster and more efficiently. Local governments are also consumers of electricity and can take advantage of the consumer-related benefits of Smart Grids.

- **Local Economies**

Benefits can arise from increasing the reliability of the power system, creating a modern infrastructure for the 21st century commerce and attracting or retaining new and innovative businesses providing new jobs and income. Most importantly, a modern electricity infrastructure can protect the economic and environmental viability of communities that are essential to creating a truly sustainable economy. In addition, the environmental benefits of a Smart Grid can reduce health-care-related costs.

2.5 What a Smart Grid Isn't

The term «Smart Grid» was used for some years to express a variety of concepts, solutions and products. Stakeholders who referred to this term very often, evolve the concept, something which often leads to different interpretations and possible misuses of the term (European Regulators Group for Electricity & Gas, 2009). Some points to [1]note.

- The Intelligent Energy Network is a network of electricity supply only, no gas and both levels of transport and distribution.
- Intelligent networks are not some new form of 'super network'. They will not have visually significant difference from current conventional networks. However, they will lead to improved efficiency and effectiveness.
- The intelligent network is not presented as a technological revolution; on the contrary it is an evolution or a process through which the networks electricity

[1] http://www.smartgrids.eu/?q=node/163

continuously improved to meet the needs of consumers in the present and the future.

- Although sometimes the concepts are combined, the intelligent network is not Smart metering. The Intelligent Network is a rather wider range of technologies and solutions.
- While many providers have focused their attention on smart metering, they are not a necessary condition for Smart Grids. It is possible to have intelligent network without Smart metering.

Chapter 3 “Conceptual Model”

3.1 Scope of a Smart Grid

A Smart Grid will use digital technology to improve the reliability, security, and efficiency of the electricity system from large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources (DOE/OEDER 2008a).

Due to the vast number of stakeholders and their various perspectives, there has been debate on a definition of a Smart Grid that addresses the special emphasis desired by each participant. The information networks that are transforming economy in other areas are also being applied to applications for dynamic optimization of electric system operations, maintenance, and planning. Resources and services that were separately managed are being integrated and rebounded as traditional problems are addressed in new ways, adapt the system to tackle new challenges, and discover new benefits that have transformational potential. The following areas arguably represent a reasonable partitioning of the electric system that covers the scope of Smart Grid concerns. To describe the progress being made in moving toward a Smart Grid, one must also consider the interfaces between elements within each area and the systemic issues that transcend areas.

Areas/domains of the electric system that cover the scope of a Smart Grid

The areas/domains of the electric system that cover the scope of a Smart Grid include the following (according to NIST, IEEE, DOE):

- Customers: The end users of electricity. May also generate, store, and manage the use of energy. Three customer types are discussed, each with its own domain: residential, commercial, and industrial.

- Bulk Generation: The generators of electricity in bulk quantities. May also store energy for later distribution.
- Transmission: The carriers of bulk electricity over long distances. May also store and generate electricity.
- Distribution: The distributors of electricity to and from customers. May also store and generate electricity.
- Markets: The operators and participants in electricity markets.
- Service Providers: The organizations providing services to electrical customers and to utilities.
- Operations: The managers of the movement of electricity.

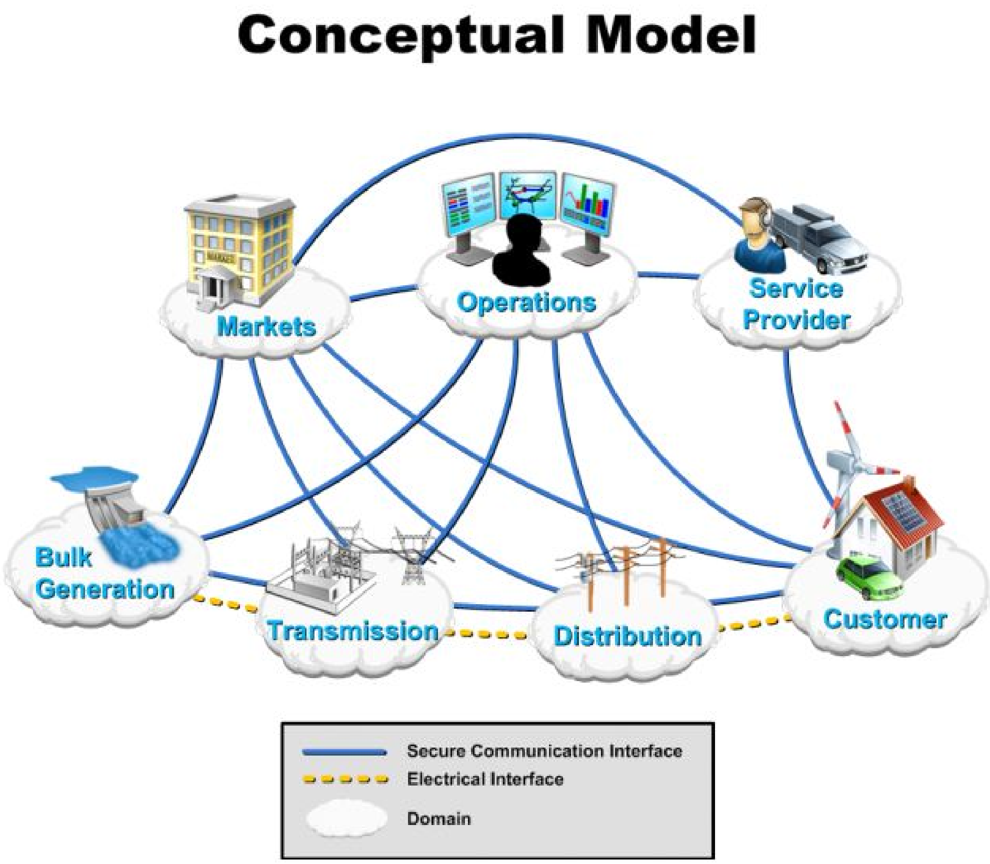

Figure 4 following conceptual model highlights interactivity of the Domains of Smart Grid (Source : NIST Framework and roadmap for Smart Grid Interoperability Standards, Release 2.0)

The NIST Conceptual Reference Model is descriptive, and is intended to be high-level. The NIST conceptual Model can serve as a tool for identifying actors and possible communication paths in the Smart Grid. The figure above provides a high-level grouping of what NIST has deemed as the Smart Grid domain.

The conceptual model consists of several domains, each of which contains many applications and actors that are connected by associations, which have interfaces at each end. Analyzing each of the domains it is important to note that actors in a particular domain often interact with actors in other domains. Moreover particular domains may also contain components of other domains.

3.1.1. Customers

The Customer domain of the Smart Grid is where the end-users of electricity (home, commercial/building and industrial) are connected to the electric distribution network through the Smart meters. It communicates with the Distribution, Operations, Markets, and Service Provider domains.

Actors in the Customer domain typically enable customers to manage their energy usage and generation. These actors also provide control and manage the flow of electricity to and from the customers and provide energy information about energy usage and patterns. The boundaries of the Customer domain are typically considered to be the utility meter and/or an additional communication gateway to the utility at the premises. Each customer has a discrete domain comprised of electricity premise and two-way communications' networks.

There are three types of customers within the Customer domain: industrial, commercial/building and home. The gateway is the primary communications interface to the Customer domains. It may communicate with other domains via AMI (Advanced Metering Infrastructure) or another method such as the Internet. It typically communicates to devices within the customer premises using a home area network or other local area network. The gateway enables applications such as remote load control, monitoring and control of distributed generation, in-home display of customer usage, reading of non-energy meters, and integration with building management systems. It may also provide auditing/logging for security purposes.

Table 2 Typical Applications within the Customer Domain

Application	Description
Home/Industrial Automation	A System that is capable of controlling and processing various functions within the Home/Industrial building
Solar/Wind Generation	Harnesses solar/wind for electricity at the customers location.

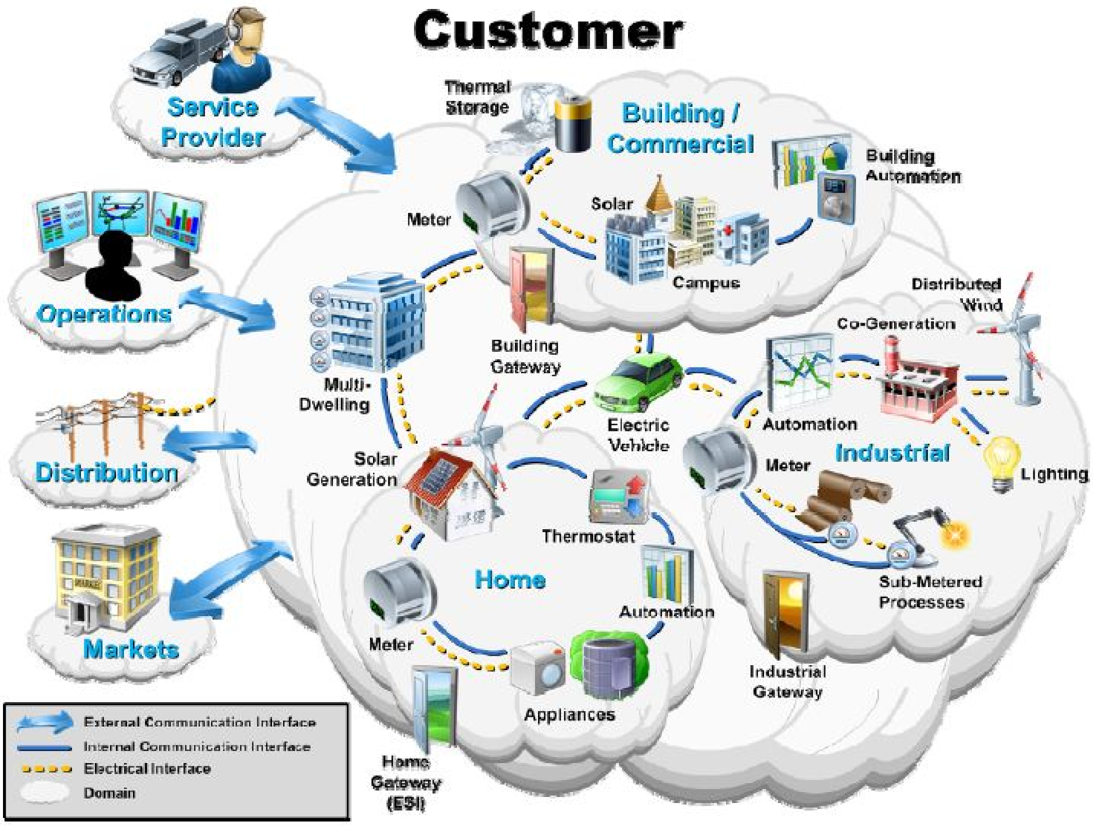

Figure 5 Overview of the Customer Domain
(Source : NIST Framework and roadmap for Smart Grid Interoperability Standards, Release 2.0)

3.1.2 Bulk Generation

Applications in the Bulk Generation domain are the first processes in the delivery of electricity to customers. Electricity generation is the process of creating electricity from renewable and non-renewable energy sources in bulk quantities. These sources can also be classified as renewable, variable sources, such as solar and wind; renewable, non-variable, such as hydro, biomass, geothermal and pump storage; or non-renewable, non-variable, such as nuclear, coal and gas. Energy that is stored for later distribution may also be included in this domain. The boundary of the Generation domain is typically the Transmission domain.

The Bulk Generation domain is electrically connected to the Transmission domains and shares interfaces with the Operations, Markets and Transmission domains.

Communication with the Transmission domain is the most critical because without transmission, customers cannot be served. The Bulk Generation domain must communicate key performance and quality of service issues such as scarcity (especially for wind and sun) and generator failure. These communications may cause the routing of electricity onto the transmission system from other sources. A lack of sufficient supply may be addressed directly (via Operations) or indirectly (via Markets).New requirements for the Bulk Generation domain include green house gas emissions controls, increases in renewable energy sources, provision of storage to manage the variability of renewable generation. [NIST, Gunther, et al.).

Table 3 Generation Categories (According to NIST)

Category	Description
Variable	Generation from wind, sun, wave power, etc. that can vary with time.
Non-Variable	Generation from continuous process, coal, uranium, water.
Renewable	Generation from a source that can be replenished.
Non-Renewable	Generation from a source that cannot be replenished.

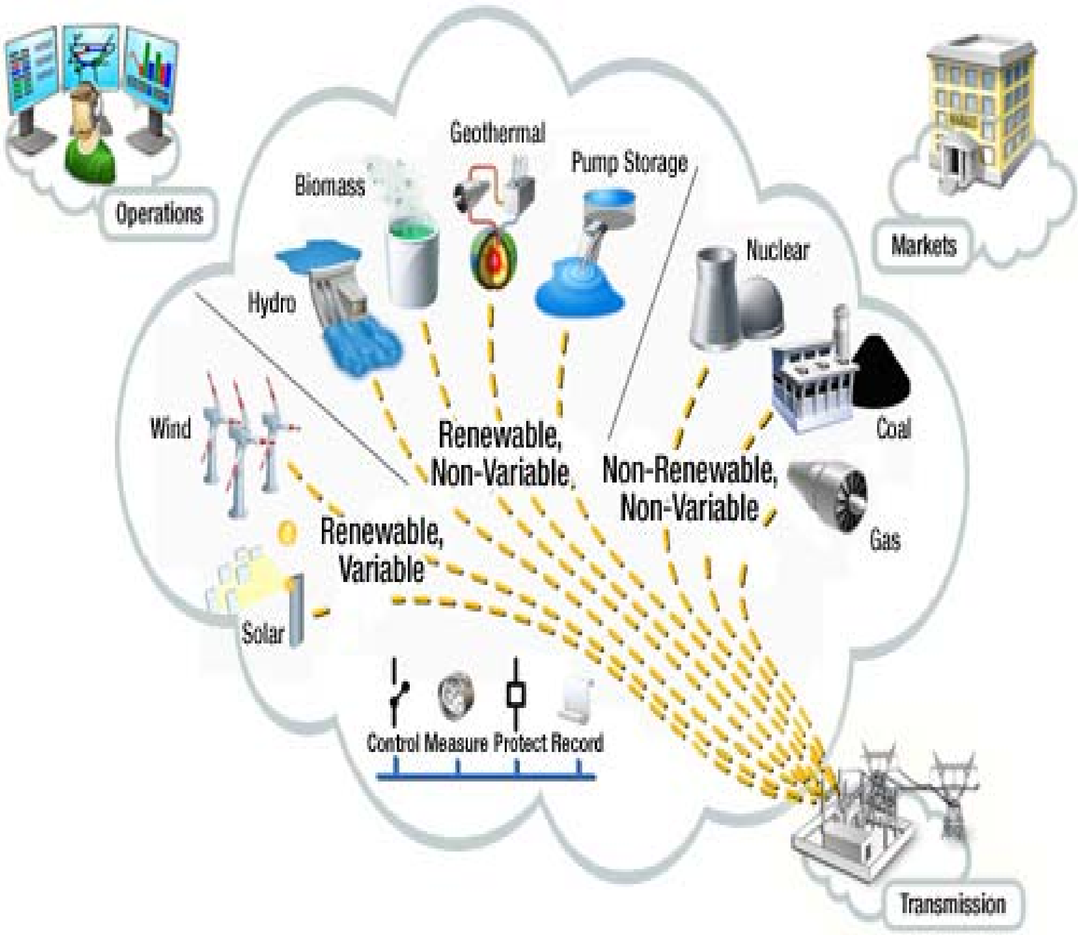

Figure 6 Bulk Generation Domain
(Source : NIST Framework and roadmap for Smart Grid Interoperability Standards, Release 2.0)

Table 4 Common Applications in Bulk Generation, Transmission, and Distribution Domains (According To NIST)

Applications	Descriptions
Control	Performed by actors that permit the Operations domain to manage the flow of power and reliability of the system.

Measure	Performed by actors that provide visibility into the flow of power and the condition of the systems in the field. In the future measurement might be found in built into meters, transformers, feeders, switches and other devices in the Grid. An example would be the digital and analog measurements collected through the SCADA system from a remote terminal unit (RTU) and provide to a Grid control center in the Operations domain.
Protect	Performed by Actors that react rapidly to faults and other events in the system that might cause power outages, brownouts, or the destruction of equipment. Performed to maintain high levels of reliability and power quality. May work locally or on a wide scale.
Record	Performed by actors that permit other domains to review what has happened on the Grid for financial, engineering, operational, and forecasting purposes.
Asset Management	Performed by actors that work together to determine when equipment should have maintenance, calculate the life expectancy of the device, and record its history of operations and maintenance so it can be reviewed in the future for operational and engineering decisions.
Stabilize and Optimize	Performed by actors that ensure the network is operating with the appropriate tolerances across the system. They may gather information to make control decisions that ensure reliable and proper operations (stability) or more efficient operations (optimization). Measurement and control form a feedback loop that allows Grid operators to stabilize the flow of energy across the electric network or safely increase the load on a transmission path.

3.1.3. Transmission

Transmission is the bulk transfer of electrical power from generation sources to distribution through multiple substations. A transmission network is typically operated by a Regional Transmission Operator or Independent System Operator whose primary responsibility is to maintain stability on the electric grid by balancing generation (supply) with load (demand) across the transmission network.

The Transmission domain is electrically connected to the Bulk Generation and Distribution domains, as well as communicating with the Operations, and Markets domains. The transmission domain may contain Distributed Energy Resources such as electrical storage or peaking generation units. Energy and supporting ancillary services (capacity that can be dispatched when needed) are procured through the Markets domain and scheduled and operated from the Operations domain, and finally delivered through the Transmission domain to the distribution system and finally to the Customer Domain. Most activity in the Transmission domain is in a substation. An electrical substation uses transformers to change voltage from high to low or the reverse across the electric supply chain. Substations also contain switching, protection and control equipment. The figure depicts both step-up and step down sub-stations connecting generation (including peaking units) and storage with distribution. Substations may also connect two or more transmission lines. Transmission towers, power lines and field telemetry such as the line sag detector shown make up the balance of the transmission network infrastructure.

The transmission network is typically monitored and controlled through a Supervisory Control and Data Acquisition (SCADA) system composed of a communication network, monitoring devices and control devices.

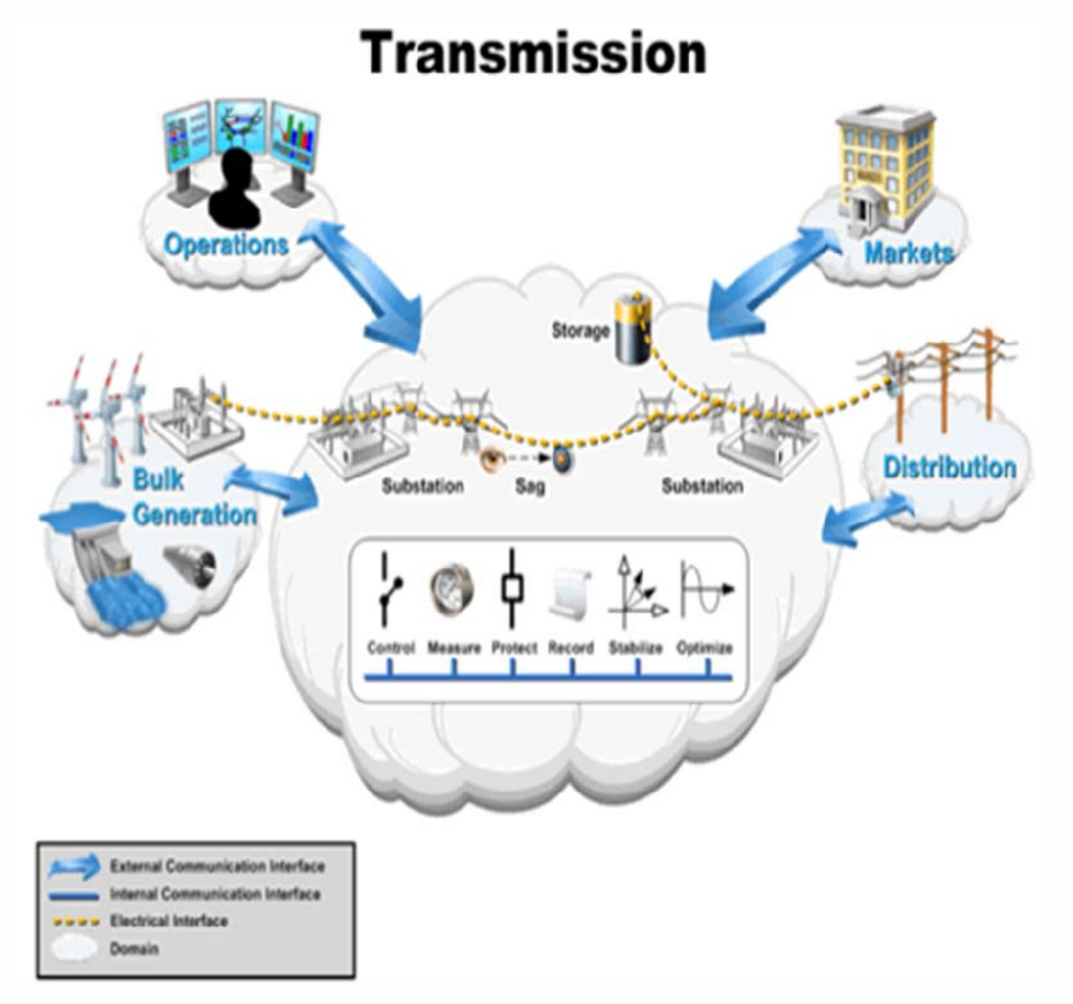

Figure 7 Transmission Domain
(Source : NIST Framework and roadmap for Smart Grid Interoperability Standards, Release 2.0)

3.1.4 Distribution

The Distribution domain is the electrical interconnection between the Transmission domain, the Customer domain and the metering points for consumption, distributed storage, and distributed generation. Basically, it distributes the electricity to and from the end customers in the Smart Grid. .The Distribution domain also communicates with the Operations and Markets domains. The electrical distribution system may be arranged in a variety of structures, including radial, looped or meshed.

The reliability of the distribution system varies depending on its structure, the types of actors that are deployed, and the degree to which they communicate with each other and with the actors in other domains. Historically distribution networks have little instrumentation installed, and there was very little communication within this domain whicht was not manually done by humans (Gunther, et al.). Many communications interfaces within this domain were hierarchical and unidirectional, although they now generally can be considered to work in both directions, even as the electrical connections are beginning to do. With the advancement of distributed storage, distributed generation, demand response and load control, the ability of the Customer domain to improve the reliability of the Distribution domain exists. Distribution networks are now being built with much interconnection, extensive monitoring and control devices, and distributed energy resources capable of storing and generating power. . Such distribution networks may be able to break into self-supporting "micro-Grids" when a problem occurs and customers may not even be aware of it.

The distribution network connects the Smart meters and all intelligent field devices, managing and controlling them through a two-way wireless or wireline communication network. It may also connect to energy storage facilities and alternative distributed energy resources at the distribution level.

Distribution actors may have local inter-device (peer-to-peer) communication or a more centralized communication methodology. Domain in real-time to manage the power flows associated with a more dynamic Markets domain and other environmental and security-based factors.

The Markets domain will communicate with Distribution in ways that will effect localized consumption and generation. In turn, these behavioral changes due to market forces may have electrical and structural impacts on the Distribution domain and the larger Grid. Under some models, third party Customer Service Providers may communicate with the Customer domain using the infrastructure of the Distribution domain; such a change would change the communications infrastructure selected for use within the Domain.

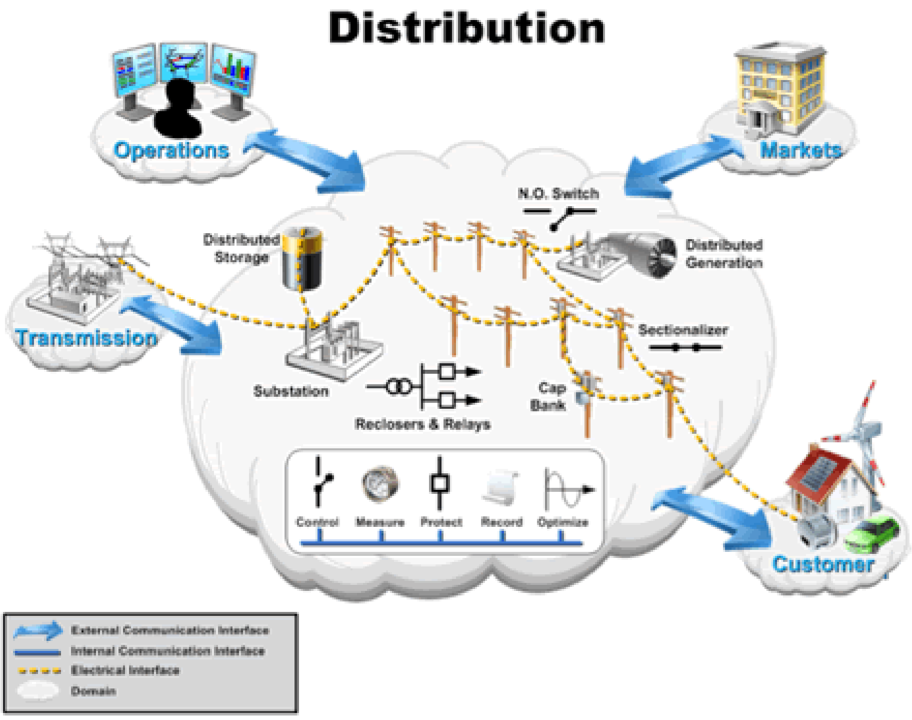

Figure 8 Distribution Domain
(Source : NIST Framework and roadmap for Smart Grid Interoperability Standards, Release 2.0)

3.1. 5. Markets

The Markets domain operates and coordinates all the participants in electricity markets within the Smart Grid. It provides the market management, wholesaling, retailing and trading of energy services. The Markets domain interfaces with all other domains and makes sure they are coordinated in a competitive market environment. It also handles energy information clearinghouse operations and information exchange with third-party service providers. For example, roaming billing information for inter-utility plug-in-vehicles falls under this domain [5].

Actors in the Markets domain typically perform pricing or balance supply and demand within the power system. The boundaries of the Markets domain are typically considered to be at the edge of the Operations domain where control happens, and at the domains containing physical assets (e.g. generation, transmission, etc).

Communication between the Market domain and the domains supplying energy are critical because efficient matching of production with consumption is dependent on markets. Market interactions must be reliable. They must be traceable and auditable. They must support e-commerce standards for integrity and non-repudiation. As the percentage of energy supplied by small DER increases, the allowed latency in communications with these resources must be reduced. Energy supply domains include the Bulk Generation domain and Distributed Energy Resources (DER) [5].

The high-priority challenges in the Markets domain are: extension of price and DER signals to each of the Customer sub-domains; simplification of market rules; expanding the capabilities of aggregators; interoperability across all providers and consumers of market information; managing the growth (and regulation) of retailing and wholesaling of energy, and evolving communication mechanisms for prices and energy characteristics between and throughout the Market and Customer domains

Figure 9 Market Domain
(Source : NIST Framework and roadmap for Smart Grid Interoperability Standards, Release 2.0)

Table 5 Typical Applications in the Markets Domain (According to NIST)

Example	Description
Market Management	Market managers include ISOs for wholesale markets or NYMEX for forward markets in many ISO/RTO regions. There are transmission and services and demand response markets as well. Some DER Curtailment resources are treated today as dispatchable generation.
Retailing	Retailers sell power to end customers and may in the future aggregate or broker DER between customers or into the market. Most are connected to a trading organization to allow participation in the wholesale market.
DER Aggregation	Aggregators combine smaller participants (as providers or customers or curtailment) to enable distributed resources to play in the larger markets.
Trading	Traders are participants in markets, which include aggregators for provision and consumption and curtailment, and other qualified entities. There are a number of companies whose primary business is the buying and selling of energy.
Market Operations	Make a particular market function smoothly. Functions include financial and goods sold clearing, price quotation streams, audit, balancing, and more.

3.1.6 Service Providers

The Service Provider domain of the Smart Grid handles all third-party operations among the domains. These might include web portals that provide energy efficiency management services to end-customers, data exchange between the customer and the utilities regarding energy management, and regarding the electricity supplied to homes and buildings. It may also manage other processes for the utilities, such as demand response programs, outage management and field services.

Actors in the Service Provider domain include the organizations providing services to electrical customers and utilities. That is, the actors in this domain typically perform a variety of functions that support the business processes of power system producers, distributors and customers. These business processes range from traditional utility services such as billing and customer account management to enhanced customer services such as management of energy use and home energy generation.

Service providers will create new and innovative services and products to meet the new requirements and opportunities presented by the evolving Smart Grid. The boundaries of the Service Provider domain are typically considered to be the power transmission and distribution network controlled by the Operations domain. Services provided must not compromise the security, reliability, stability, integrity and safety of the electrical power network.

The service provider must not compromise the cyber security, reliability, stability, integrity and safety of the electrical power network when delivering existing or emerging services.

The Service Provider domain shares interfaces with the Market, Operations and Customer domains. Communications with the Operations domain are critical for system control and situational awareness; communications with the Market and Customer domains are critical for enabling economic growth through the development of “Smart” services. For example, the Service Provider domain may provide the interface enabling the customer to interact with the market(s).

The priority challenge in the Service Provider domain is to develop the key interfaces and standards that will enable a dynamic market-driven ecosystem while protecting the critical power infrastructure. These interfaces must be able to operate over a variety of networking technologies [5][6].

Some benefits of the Service Provider domain from the deployment of the Smart Grid include:

- The development of a growing market for 3rd parties to provide value-added services and products to customers, utilities and other stakeholders at competitive costs.
- The decrease in cost of business services for other Smart Grid domains.
- A decrease in power consumption and an increase in power generation as customers become active participants in the power supply chain.

Figure 10 Service Provider Domain
(Source : NIST Framework and roadmap for Smart Grid Interoperability Standards, Release 2.0)

Table 6 Applications in the Service Provider Domain (According to NIST)

Example	Category	Description
Customer Management	Core Customer Services	Managing customer relationships by providing point-of-contact and resolution for customer issues and problems.
Installation & Maintenance	Core Customer Services	Installing and maintaining premises equipment that interacts with the Smart Grid.
Building Management	Enhanced Customer Services	Monitoring and controlling building energy and responding to Smart Grid signals while minimizing impact on building occupants.
Home Management	Enhanced Customer Services	Monitoring and controlling home energy and responding to Smart Grid signals while minimizing impact on home occupants.
Billing	Core Business Services	Managing customer billing information, sending billing statements and processing received payments.
Account Management	Core Business Services	Managing the supplier and customer business accounts.
Others	Emerging Services	All of the services and innovations that have yet to be created.

3.1.7 Operations

The Operations domain manages and controls the electricity flow of all other domains in the Smart Grid. It uses a two-way communications network to connect to substations, customer premises networks and other intelligent field devices. It provides monitoring, reporting, controlling and supervision status and important process information and decisions. Business intelligence processes gather data from the customer and network, and provide intelligence to support the decision-making.

Actors in the Operations domain perform the ongoing management functions necessary for the smooth operation of the power system. While the majority of these functions are typically the responsibility of a regulated utility, many of them may be outsourced to service providers and some may evolve over time. For instance, it is common for some customer service functions to be part of the Service Provider domain or Markets domains. No matter how the Service Provider and Markets domains evolve, there will still be basic functions needed for planning and operating the service delivery points of a “wires” company. In transmission operations, Energy Management Systems (EMS) are used to analyze and operate the transmission power system reliably and efficiently, while in distribution operations, similar Distribution Management Systems (DMS) are used for analyzing and operating the distribution system [5][6].

The typical applications performed within the Operations domain may include: network operation, network operation monitoring, network control, fault management, operation feedback analysis, operational statistics and reporting, real-time network calculation, dispatcher training.

Table 7 Applications in the Operations Domain (According to NIST)

Application	Description
Network Operations	The Network Operations domain (actually a sub-domain) within Operations includes the applications:
Monitoring	Network Operation Monitoring actors supervise network topology, connectivity and loading conditions, including breaker and switch states, and control equipment status. They locate customer telephone complaints and field crews.
Control	Network control is coordinated by actors in this domain, although they may only supervise wide area, substation, and local automatic or manual control.
Fault Management	Fault Management actors enhance the speed at which faults can be located, identified, and sectionalized and service can be restored. They provide information for customers, coordinate with workforce dispatch and compile information for statistics.
Analysis	Operation Feedback Analysis actors compare records taken from real-time operation related with information on network incidents, connectivity and loading to optimize periodic maintenance.
Reporting and Stats	Operational Statistics and Reporting actors archive on-line data and to perform feedback analysis about system efficiency and reliability.
Calculations	Real-time Network Calculations actors (not shown) provide system operators with the ability to assess the reliability and security of the power system.
Training	Dispatcher Training actors provide facilities for dispatchers that simulate the actual system they will be using. (not shown on diagram)

Records and Assets	The Records and Asset Management actors track and report on the substation and network equipment inventory, provide geospatial data and geographic displays, maintain records on non-electrical assets, and perform asset investment planning.
Operational Planning	Operational Planning and Optimization actors perform simulation of network operations, schedule switching actions, dispatch repair crews, inform affected customers, and schedule the importing of power. They keep the cost of imported power low through peak generation, switching, load shedding or demand response.
Maintenance and Construction	Maintenance and Construction actors coordinate inspection, cleaning and adjustment of equipment, organize construction and design, dispatch and schedule maintenance and construction work, capture records gathered by field personnel and permit them to view necessary information to perform their tasks.
Extension Planning	Network Extension planning actors develop long term plans for power system reliability, monitor the cost, performance and schedule of construction, and define projects to extend the network such as new lines, feeders or switchgear.
Customer Support	Customer Support actors help customers to purchase, provision, install and troubleshoot power system services, and relay and record customer trouble reports.
Meter Reading and Control	Meter Reading and Control actors perform a variety of functions on the metering system including data collection, disconnect/reconnect, outage management, prepayment point of sale, power quality and reliability monitoring, meter maintenance and asset management, meter data management including validation, estimation and editing (VEE), customer billing, and load management, including load analysis and control, demand

	response, and risk management.
Supply Chain and Logistics	Supply Chain and Logistics actors manage the processes for acquiring necessary supplies; tracking acquired and ordered supplies; and allocating them.
Financial	Financial actors measure performance across the whole organization, including the evaluation of investments in capital projects, maintenance, or operations. They track risk, benefits, costs and impact on levels of service.
Communications Network	The planning, operations and maintenance of all communications network asset that are required to support Operations.
Security Management	The management of security policies, distribution and maintenance of security credentials, and centralized authentication and authorization as appropriate.
Premises	Information regarding the location of a service. This set of functions includes: Address management; Right of ways, easements, grants; and Real estate management.
Human Resources	Human Resources actors manage personnel information and activities including safety, training, benefits, performance, review, compensation, recruiting and expenses.
Business Planning and Reporting	These actors perform strategic business modeling, manpower planning, reporting, account management, and both assess and report on risk, performance and business impact.
Stakeholder Planning and Management	These actors perform track and manage the needs and concerns of various utility stakeholders by monitoring customer input, regulators, service standards, and legal proceedings.

Figure 11 Operation Domain
(Source : NIST Framework and roadmap for Smart Grid Interoperability Standards, Release 2.0)

Chapter 4: Communication technologies and Smart Grids

A communication system is the key component of the Smart Grid infrastructure. Its role is one of the major factors that are transforming the traditional Grid into Smart Grid. With the integration of advanced technologies and applications for achieving a Smarter electricity Grid infrastructure, a huge amount of data from different applications will be generated for further analysis, control and real-time pricing methods. Hence, it is very critical for electric utilities to define the communications requirements and find the best communications infrastructure to handle the output data and deliver a reliable, secure and cost-effective service throughout the total system. Electric utilities attempt to get customer's attention to participate in the Smart Grid system, in order to improve services and efficiency. Demand side management and customer participation for efficient electricity usage are well understood, furthermore, the outages after disasters in existing power structure also focus the attention on the importance of the relationship between electric grids and communications systems.

The Smart Grid is a network of networks comprising many systems and subsystems. That is, many systems with various ownership and management boundaries interconnect to provide end-to-end services between and among stakeholders as well as between and among intelligent devices.

The Smart Grid information technology layer consists of computing platforms, operational systems, business applications and business services. Energy management, transmission operations, distribution operations, Independent System Operator, Regional Transmission Organization operations are among the major functions that constitute the role of the IT layer.

The communication structure of a Smart Grid is composed essentially of six areas of networking: External Access, Core, Backhaul, Access Area, Neighborhood Area Network (NAN), and last Consumer Premises Networks. The figure below shows the typical layers for Smart communications networks and their Technologies standards layers. The four areas, which are interconnected with one another, are supported by various technologies and substantially raise the communication infrastructure of the Smart Network.

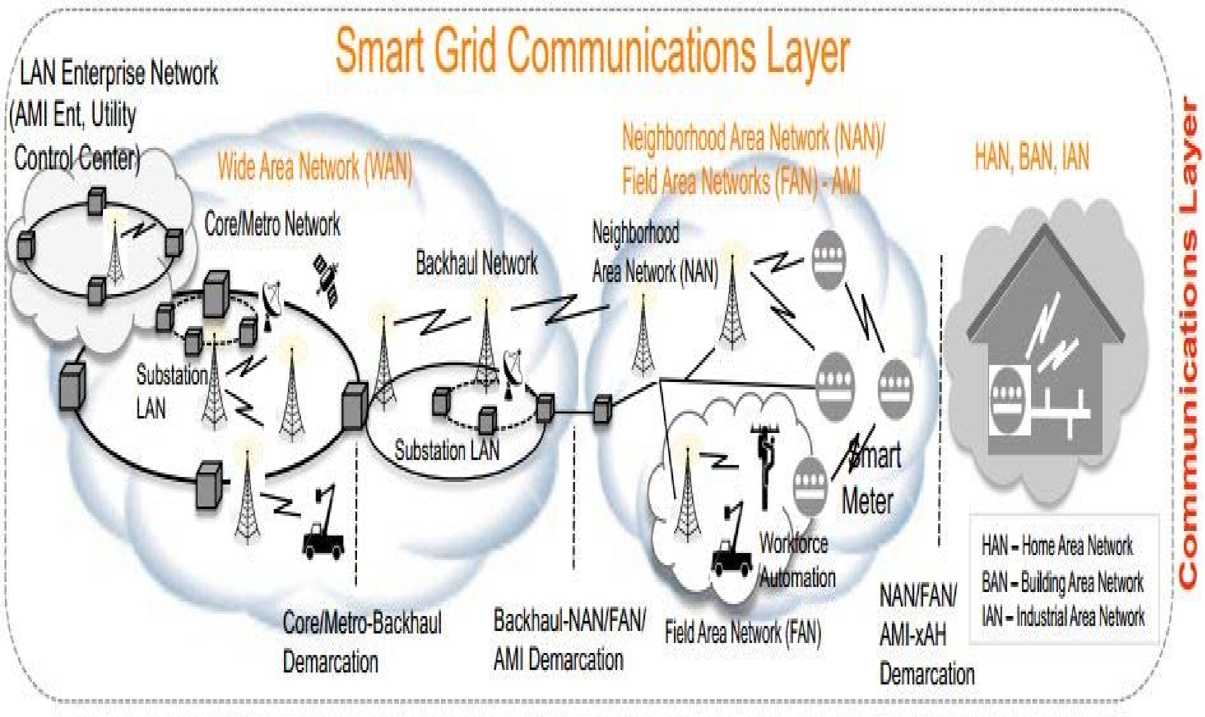

Figure 12 Communication Layers (By IEEE)

Consumer Premises Networks (CPNs) are part of the AMR networks. They provide the communication between the appliances and equipment with the consumers' premises. Based on the consumer's consumption profile, these networks can be divided into three different networks namely; Home Area Networks (HAN), Business Area Networks (BAN) and Industrial Area Networks (IAN). The communication technologies that are utilized in these networks are wired and wireless networks. Examples of such networks are Zigbee, Xbee, Bluetooth, Z-Wave, Wi-Fi, Home Plug, 6-lowPAN, BACnet and SAEJ2847. The devices that are served by these networks can be:

- Smart home appliances, in-home display, home computing devices.
- Load control devices, demand side management, power measurements

- Electrical vehicles outlets, renewable energy integration

Neighborhood Area Networks are networks that are also part of the AMR and AMI network. They collect the information from the consumers' devices through CPNs via the Smart meter and pass it to the utility data centre for further processing and feedback actions. The communication technologies that are utilized in these networks are wired and wireless networks. Examples of such networks are RF Mesh, RF Radio point-to-multiple point, Wi-Fi, WiMAX, LTE, GPRS/EDGE, PLC/BPLC, and FTTP/FTTH/Ethernet. The devices that are served by these networks can be utilized for:

- Advanced Smart meters such energy consumption and RTMP, load control relays.
- Concentrators (collection point for meters from all neighborhoods).

Access Area Network are responsible for Grid connected at the distribution level. The communication technologies that are utilized in these networks are wired and wireless networks; examples of such networks are WiMAX, LTE, GSM-CDMA, 3G/LTE Public, BPLC and FTTP/FTTH/Ethernet. The devices that are served by this network can be:

- Voltage Regulators, re-closers and remotely operable switches.
- Capacitors banks and active power factor connection, distance to fault relays and line fault indicators.
- Phasor measurement and distributed RTUs, line sag indicators and maximum demand indicators.
- Renewable energy resources

Backhaul Network is responsible for Grid connected at the distribution level. This network connects the data concentrators in AMI with automation, substation / distribution and control centers associated with the operation of public utilities. This domain does not only need to provide broadband media, but requires the installation of the network be as easy as possible and cost effective. In addition, routes and connections through which flow data should be flexible and seamless. The most important is that the overall performance is predictable for reliable data transfer before the entrance to the barrel. The communication technologies that are utilized in this network are wired and wireless networks. Examples of such networks are LTE/ LTE Public, WiMAX, Microwave, Fiber, BPLC and FTTP/FTTH/Ethernet. The devices that are served by this network can be:

- SCADA –RTUs substations, Intelligent Electronics Devices (IDE)
- Protection Relays, Oil level, Pressure and Temperature Sensors, Monitoring Cameras

Core Network supports linking numerous substations and seats utilities. The network requires high capacity WAN availability and bandwidth to manage the "mountains" of data transferred from other areas, as well as by multiple mediators. The communication technologies that are utilized in this network are wired and wireless networks. Examples of such networks are Leased Line Circuits, GPRS and LTE, Fiber and FTTP/FTTH/Ethernet Core Network is responsible to corporate communications for services such as:

- Corporate communications-Voice and Data.
- Corporate communication-Planning and QoS.

External Access Networks are the public access networks that give access to the ecosystems providers' and access to some of the above networks. The external networks mostly utilize public access networks.

4.1 Requirements for the communication system

The communication infrastructure between energy generation, transmission, and distribution and consumption requires two-way communications, interoperability between advanced applications and end-to-end reliable and secure communications with low-latencies and sufficient bandwidth. Moreover, the system security should be robust enough to pre-vent cyber-attacks and provide system stability and reliability with advanced controls. Appropriate communication networks for energy management applications need to provide special features and services that are closely related to application requirements and separate them from other networks.

In the following, major Smart Grid communication requirements are presented.

- **Communication Security.** Data related to energy distribution are considered critical, in particular, when they are relevant for billing purposes or Grid control. Secure communication is therefore important. To avoid cyber attacks, efficient security mechanisms should be developed and standardization efforts regarding the security of the power Grid should be made. Surveys among utilities showed that integrity (no malicious modification) and authenticity (origin and access rights are guaranteed) are the most important security goals for energy distribution networks, whereas the confidentiality aspect is not considered to be an issue ([48][49])
- **Ease of deployment and maintenance.** For any distributed communication system, mechanisms must before seen which facilitate not only the initial installation but particularly the maintenance of the infrastructure during the operation. Features like error mode analysis and error localization, easy update of firm- and software and remote configuration are essential.
- **Appropriate communication delay and system responsiveness**. The communication between the power supplier and power customers is a key issue of the Smart Grid. Performance degradation like delay or outage may compromise stability, therefore, a Quality-of-Service (QoS) mechanism must be provided to satisfy the communications requirements (for example high-speed routing) and a QoS routing protocol must be applied in the communications net-work. The QoS management needs to take care of different data classes such as metering, control, or alarm data. Even if the predominant communication relationship is client/server (i.e., an application server polls the meter data or issues control commands), it may be necessary to foresee something like a fast event channel to transmit, e.g., alarms from the meters to the control room [13].

- **High reliability and availability are standard requirements for nearly every communication system**. The availability of the communication structure is based on preferred communication technology. Wireless technologies with constrained bandwidth and security and reduced installation costs can be a good choice for large-scale Smart Grid deployments [49].
- **On the other hand, power line technologies or wired technologies with increased capacity, reliability and security can be costly**. To provide system reliability, robustness and availability at the same time with appropriate installation costs, a hybrid communication technology mixed with wired and wireless solutions can be used. In the particular case of power line systems, such a change may be introduced by distribution network management which balances the power consumption load on the power Grid, particularly on the medium-voltage (MV) level. Switching actions are initiated via various SCADA and controlling systems (or even manually) using specific communication protocols that may not be modified. Therefore, there is no straightforward way to simply inform the communication system management about topology changes that are about to occur. Rather, the communication system itself must be designed for robustness. Providing the system reliability has become one of the most prioritized requirements for power utilities. Aging power infrastructure and increasing energy consumption and peak demand are some of the reasons that create unreliability issues for the power Grid ([50]). Harnessing the modern and secure communication protocols, the communication and information technologies, faster and more robust control devices, embedded intelligent devices for the entire Grid from substation and feeder to customer resources, will significantly strengthen the system reliability and robustness [50].
- **Automatic management of redundancies is closely related to the previous requirement**. As some applications are time critical, real-time properties of the network have to be maintained even during topology changes. As stated before, such changes must not be regarded as exceptional situations due to error conditions but occur in normal operation.

- **High coverage and distances**. Evidently, the nodes to be connected by the communication network are distributed in a wide area. Network concepts based on telecommunication systems or power lines have the potential to fulfill this requirement.
- **Large number of communication nodes**. If we assume that only one energy meter per customer is connected, a primary station can supply up to tens of thousands of nodes, particularly in areas of large apartment block concentration. Even though the commands and data packets are usually short, total data volume to be transferred in the network is substantial, and communication overheads can become an issue.

4.2 Challenges for a communication system

While communications technology is seen as an essential enabling component of future Smart Grids, there are a number of challenges that must be addressed in order to have fully robust, secure and functional Smart Grid networks. It is important to note that these challenges are very much intertwined, i.e. they affect each other and must be considered as parts of a bigger problem/challenge.

- **Interoperability:** The Smart Grid will connect a large number of elements dissimilar transmission and distribution, generation sources and consumers. further, Smart Network will consist of heterogeneous network architectures, technologies and standards. For example, short-range wireless (e.g. Bluetooth, UWB, Wi-Fi, ZigBee) and wired networks (e.g. PLC, Ethernet) may be used for interconnection devices on a local level (e.g. providing communications for home automation, Smart metering, substation automation or production control systems force), and the cellular (e.g. GPRS), the 4G technologies (e.g. 802.16m and LTE) or wired broadband (e.g. xDSL, HFC, FTTH) can be used for networking wide area. Achieving interoperability of communications systems and architectures that support Smart Grid requires agreement on the use, an interpretation of the interfaces and messages that can bridge combines the various standards and technologies.

- **Security and privacy**: Increased interconnection and integration also introduce cyber vulnerabilities into the Grid. Failure to address these problems will hinder the modernization of the existing power system. Security issues include unauthorized Smart metering data access, distributed turning off all devices by an attacker, Smart metering data repudiation, stealing power without notice, attacking Smart Grid infrastructure to cause power outage, etc. There are also some concerns about privacy issues in Smart Grids, e.g., metering data can leak sensitive and private information.
- **Interdisciplinary**: Smart Grids include many different organizations and societies so that the research areas are interdisciplinary in nature, e.g., integration of sensor networks, actuation, and power systems, integration of communication/networking with power systems and control systems, and integration of security and power systems, etc
- **Scalability:** Since a Smart Grid involves millions of users, scalability becomes an issue. A technical sound solution in a small scale may not be scalable when applying into such a huge scale. Internetworking between heterogeneous wired and wireless networks with seamless mobility and quality of service requirements become important.
- **Performance:** First, Smart Grid communication is very complex due to heterogeneous systems, large scale deployments, interdisciplinary areas (such as control, communication, power, etc.), and dynamic and non-deterministic systems. Second, efficiency is important for better, fast, secure, and robust controls and communication.

4.3 Architecture of Network Communications

The communication infrastructure in Smart Grid must support the expected Smart Grid functionalities and meet the performance requirements above. As the infrastructure connects an enormous number of electric devices and manages the complicated device communications, it is constructed in a hierarchical architecture with interconnected individual sub networks.

In order to describe the architecture network, the network can be categorized into several logical components based on their coverage, such as Home Area Network, Local Area Network, Neighborhood Area Network, Wide Area Network, and Access Network. This does not imply that physical implementation must divide the network this way, nor that network companies must structure their network in a similar way and limit their services to some specific components. The general meaning of these components is listed in below. Note that the areas covered by these components may overlap, but should be obvious in the context being discussed.

Table 8 Major Components of Smart Grid Networks

Term	**Definition**
Wide Area Network	A Wide Area Network is a communication network that covers a wide geographical area and accommodates terminals and LANs. This is typically called "Back Haul" network in Smart Grid environment.
Local Area Network	A Local Area Network is a network that connects computers and devices in a limited geographical area such as home, computer laboratory, office building, and closely positioned group of buildings.
Home Area Network	In the Smart Grid applications, a Home Area Network refers to the networks in the homes that interconnect energy devices, including appliances, energy management station, plug-in electrical vehicle chargers, energy sources.
Access Network	An access network refers to a network which connects subscribers to their immediate service provider. It is contrasted with the core (or transport) network in wide area network.
Neighborhood Area Network (NAN)	A Neighborhood area network is an access network that allows Smart Grid end-device and home area networks to connect to wide area network.

4.3.1 Home Area Networks

Home networks are required in the consumer sector, to monitor and control of Smart devices in the field of customer and to implement new functions such as DR and AMI.

Home area networks emerged in earnest in the late 1990s and early 2000s fueled by the growth of the Internet. Now with the onset and development of the Smart Grid, other players are entering the HAN market where their key differences revolve around data rates and power consumption. The Internet and the technologies surrounding it are developed to move large amounts of data quickly through a network at somewhat intermittent intervals. The needs of the Smart Grid are significantly different; requiring relatively low bandwidth but regular communications. These different needs open the door for other players to enter the HAN market.

Achieving a vision of the Smart Grid at the consumer level to allow homeowners to better understand and manage their energy consumption will require many new types of devices with lower bandwidth but regular and consistent data stream requirements. Devices such as thermostats, HVAC systems, major appliances, home automation systems, home energy management systems, lighting, gas meters, water meters, and electric meters will all be networked and communicating information that allows the homeowner to better understand and manage energy use.

There are myriad standards and protocols vying for dominance in the Smart Grid market. With so many devices needing to be connected to the network it is in the consumers and manufacturers best interests to identify the most worthy candidates and settle on those for purposes of interoperability, economies of scale and ease of adoption. There are three leading standards: HomePlug Green PHY, ZigBee, and IEEE 802.11n and briefly identify competing technologies.

With such a diverse and large number of devices to be incorporated into Smart Grid networks, it is important to understand the technologies and architectural models being used. So how are we going to connect all these devices together? There appear to be two distinct trains of thought with variations of the HAN architecture as it relates to the utility. The first is that the utility, which has traditionally controlled the majority if not all the electrical infrastructure, will be able to control all the appliances within the home to better manage the Grid. This is currently in use in some areas where consumers opt-in to allow the utility to shut off their Air Conditioning units during peak demand. The other camp sees the utility having access to a gateway within the home and then the consumer controls what happens in the home or delegates that to a third party. The gateway architecture fits well for both the consumer who is uneasy with a utility being able to control devices within his or her home as well as the vendor and manufacturers concerned with interoperability.

The HAN standards are often categorized into three bins, new wires, no new wires, and wireless. Each category has distinct strengths and weaknesses. Though there is not a clearly defined best option it is certain the standards most likely to be adopted will interoperate with other standards. As it would be expected, the leading standards are mature and widely understood.

4.3.2 Field Area Network

Field area networks form the communication facility for the electricity distribution systems. The electrical sensors on the distribution feeders and transformers, IED devices capable of carrying out control commands from DMS, DERs in the distribution systems, PEV charging stations and Smart meters at customer premises form the main sources of information to be monitored and controlled by the DMS at the control centers. The power system applications operating in the distribution domain utilize field area net-works to share and exchange information.

These applications can be categorized as either field based (related to transmission lines, sensors, voltage regulators, etc.) or customer based (related to end customers, like houses, buildings, industrial users, etc.). Field based applications include OMS, SCADA applications, DER monitoring and control, etc. Customer based applications include AMI, DR, LMS, MDMS, etc. These two classes of applications operating in the distribution domain have different critical requirements. For example, customer based applications require the communication network between the utility and the customer to be highly scalable. This would allow addition of more applications and customers in future. Time sensitivity is not much of an issue for such applications. Field based applications on the other hand are more time sensitive in nature. Hence the utilities have a choice in adopting either communication networks dedicated to each class of applications or a single shared communication network for both classes. A shared field area network will be able to minimize development cost and issues while a dedicated network will have advantages of real-time communication capability and additional security.

4.3.3 Wide Area Networks

Wide area networks form the communication backbone to connect the highly distributed smaller area networks that serve the power systems at different locations. When the control centres are located far from the substations or the end consumers, the real-time measurements taken at the electric devices are transported to the control centres through the wide area networks and, in the reverse direction, the wide area networks undertake the instruction communications from control centres to the electric devices. For enhanced wide area situational awareness, RTOs re-quire a lot of information about the state of the power Grid. This is achieved by using fast, time-stamped and real-time information about the system from specialized electrical sensors (PMUs) at substations (Lee, L.. Lai 2007). The PMU devices capture current and voltage phasor information from the electrical buses at the substations at sample rates up to 60 Hz. The information received from PMUs is used by the EMS systems at control centers for improved state estimation, monitoring, control, and protection. The wide area networks also convey communications between the IEDs and the control centers. The IEDs are in-stalled along transmission lines and in substations to capture local SCADA information and act upon the control and protection commands from the control centers. Moreover, to support the reception of high speed PMU data at the control centers, a high bandwidth network is required.

Currently, the substations communicate with the control centers using point to point telephone or microwave links. Thus, in the absence of high speed network, the sensed dig-ital data from PMUs is only limited inside substations and cannot be effectively utilized by the control centers [8]. This underscores the need of a high bandwidth wide area network in the Smart Grid system.

4.4 Supporting network technologies

The requirements of the telecommunication network in Smart Grid can sometimes be difficult to define, especially in applications that are now emerging such as Smart energy networks. The two most important factors you need to consider are performance channel (throughput), often referred to as speed or bandwidth and channel delay (latency). If the goals set for these factors are not achieved, the system has no chance of success. Factors follow but also important is the reliability and security. The yield of channel determines how much information can be sent from one point to another at a given time. In analog systems the performance is proportional to the bandwidth and is usually given in Hertz, while in digital systems is usually calculated in bits per minute (bps).

Many network technologies can be used in a Smart Grid to areas of transportation, distribution and end-consumer level, but none of them are suited to all applications. Some technology or even better a subset of technologies to suit most applications particular sector or in applications that have similar communication needs.

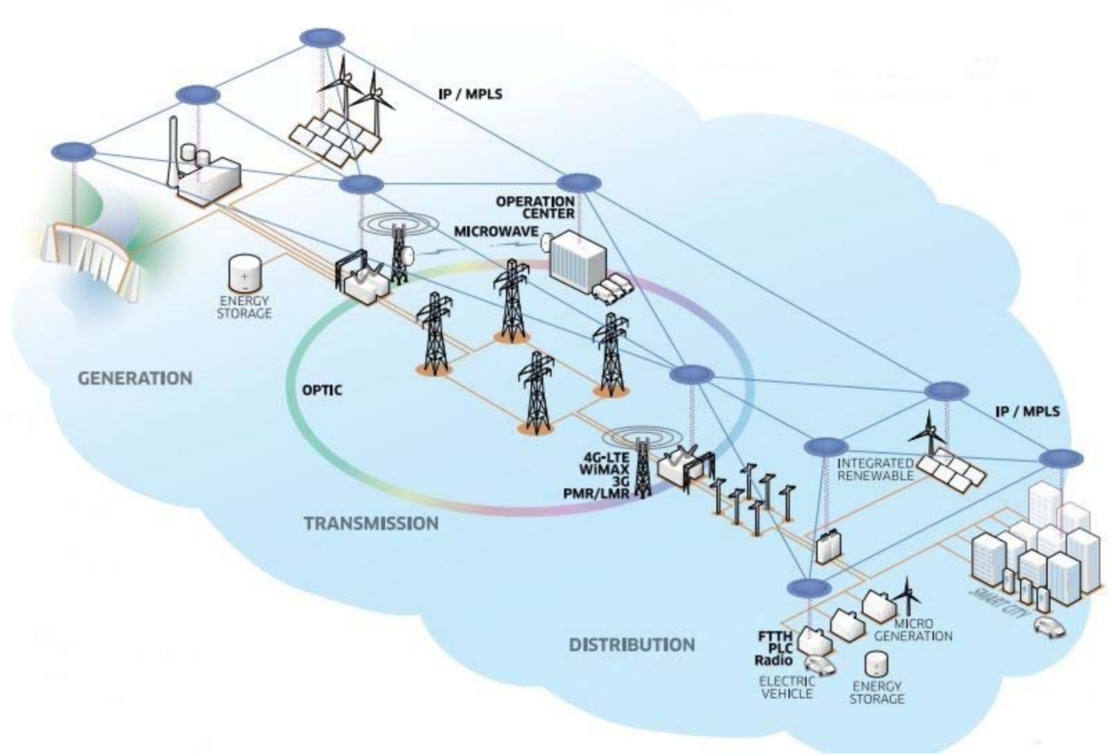

Figure 13 Communication Model
(Source: Retrieved from http://www2.alcatel-lucent.com/power-utilities)

The adoption of different technologies for Smart Grid communications will ultimately depend on the characteristics of the network and the fixed requirements. Small utilities, for example, can exploit the advantages of existing cellular networks and to work with others to reduce capital and operating costs. In contrast, large firms will be able to build their own network to avoid sharing bandwidth in order to make higher profits from capital invested. Moreover, the geographical needs, project objectives and the applications and services that will be available to consumers would affect choice of technologies to be implemented.

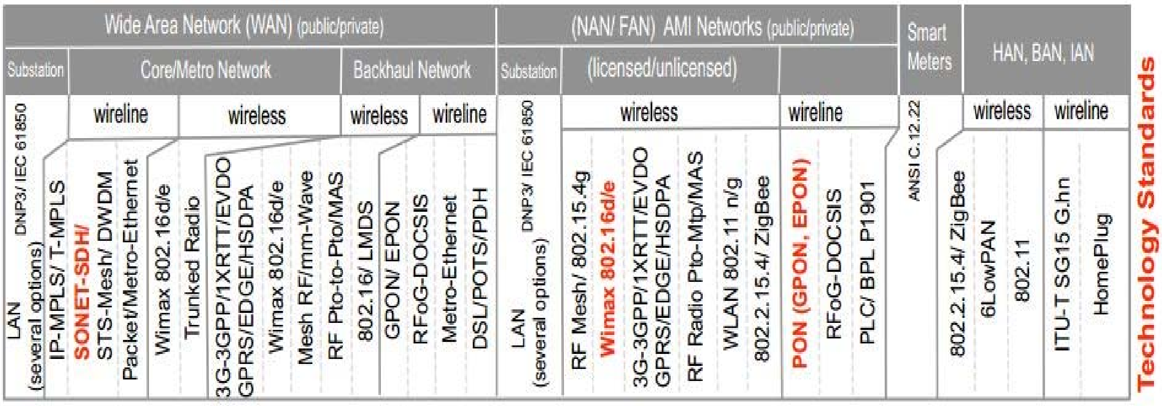

Figure 14 Telecommunications Technologies (By IEEE)

4.5. Wireless Technologies

Generally, the signals in wireless communications are significant attenuation such as transmission and address interference from the environment. Consequently, the Wireless networks often provide connections with comparatively short low data rates.

The implementation of wireless technology offers several advantages over the wired as a low cost installation, mobility, coverage of remote areas, rapid installation, etc. However, in any technology there are some challenges to be addressed before its use in the Smart environment Network. Some common concerns about wireless technologies are: 1) Wireless technologies operating in unlicensed frequency spectrum is more vulnerable to noise and interference phenomena, 2) Wireless technologies licensed range encounter less interference, but it is a relatively expensive option, 3) the security for wireless media are inherently less.

4.5.1 Wireless LAN

IEEE 802.11 based wireless LAN provides robust, high speed point-to-point and point-to-multipoint communication [2]. The spread spectrum technology was adopted in IEEE 802.11, because it allowed multiple users to occupy the same frequency band with a minimum interference to the other users. IEEE 802.11 legacy standard proposes the standard for wireless Local Area Networks (LANs) covering three non-interoperable technologies: Frequency Hopping Spread Spectrum (FHSS), Direct Sequence Spread Spectrum (DSSS) and Infrared (IR) at 1 & 2 Mbps data rates. IEEE 802.11b, also known as Wi-Fi, offers a maximum data rate of 11Mbps. It operates on 2.4GHz frequency band with DSSS modulation technique. Further, currently available technologies based on IEEE 802.11a and IEEE 802.11g can provide data rates up to 54 Mbps. IEEE 802.11a operated on 5.8GHz frequency band with Orthogonal Frequency Division Multiplexing (OFDM) modulation; whereas, 802.11g, also known as enhanced Wi-Fi, operates on 2.4 GHz frequency bands with DSSS modulation technique. IEEE 802.11n based on Multiple Input Multiple Output (MIMO) technology is intended to increase data rates further, up to 600 Mbps. IEEE 802.11i (known as WPA-2) enhances the cyber security in wireless LANs using Advanced Encryption Standard (AES) [3], [4]. Deployment of wireless LAN offers various benefits over wired LAN, as it is easy to install, provides mobility of devices, less expensive.

Wireless LAN can be considered for various Smart Grid applications, such as distribution substation automation and protection, and monitoring and control of distributed energy resources, especially for remotely located small substation and DERs, where data rate requirements and radio interferences are comparatively less.

Some of the benefits that Wireless LAN can provide are: high reliability and availability of wireless communications and with the huge expansion of wireless communications the industry strengthens the Wireless LAN equipment.

4.5.2 WiMAX

Worldwide inter-operability for Microwave Access (WiMAX) technology is a part of 802.16 series standards for Wireless Metropolitan Area Network (WMAN) [16]. The main objective of WiMAX is to achieve worldwide interoperability for microwave access. In 2001, when the first draft of IEEE 802.16 standard was released, it defined the wide operating range of 10-66GHz for communication infrastructure. WiMAX forum has published a subset of the range for interoperability. For fixed communication 3.5 and 5.8GHz bands have been dedicated, while for mobile communication frequency bands 2.3, 2.5 and 3.5 GHz have been assigned. The spectrums 2.3, 2.5, 3.5GHz are licensed; whereas 5.8GHz is unlicensed spectrum. It provides data rate up to 70Mbps and distance up to 48km [EPRI Tech. Rep.,2008.]. However, distance and network speed are inversely proportional to each other. Licensed spectrums allow higher power and longer distance transmission, which is more suitable for long distance communication. The bandwidth and the range of WiMAX provide the alternative of cable, DSL and T1 communication channel for last-mile access.

As Wireless LAN can be considered for various Smart Grid applications, so does WiMAX. Some of its applications are: 1) Wireless Automatic Meter Reading (WMAR), 2) Real Time Pricing, 3) Outage Detection and Restoration

1. Large distance coverage and sufficiently high data rates make WiMAX technology more suitable for Wireless Automatic Meter Reading (WMAR) as a part of utility Automatic Metering Infrastructure (AMI).
2. WiMAX network for AMI can be used to provide real-time pricing models based on real-time energy consumption of the customers.
3. With the help of two-way communication using WiMAX, fast outage detection and restoration can be implemented.

The advantages of WiMAX technology today include the lower cost of development and operation, smooth communication, high rates transmission (as the 75Mbps), the sufficient bandwidth and scalability.

One of the negatives of WiMAX is that bandwidth is shared with users. This is explained by the fact that the frequencies over 10GHz can not be disseminated through obstacles. Thus, particularly for urban areas, the lower frequencies are more useful, however, they have already been licensed. So, the most likely way for providers to use Smart Grid technology is the lease from another. Also, WiMAX presents an asymmetry in the velocities couplings anode and cathode, while the trade off between distance and transmission rate is another weakness.

4.5.3 Cellular network Communication

Existing cellular networks can be a good option for communicating between Smart meters and the utility and between far nodes. The existing communications infrastructure avoids utilities from spending operational costs and additional time for building a dedicated communications infrastructure. Cellular network solutions also enable Smart metering deployments spreading to a wide area environment.

The 3G (3rd Generation) / 4G (4th Generation) cellular technology operates on the spectrum range of 824-894MHz/1900MHz [7]. These are the licensed frequency bands. Data transmission rate of this technology is 60-240Kbps, and distance converge depends upon the availability of cellular service [EPRI Tech. Rep.,200811]. This cellular network topology consists of cells, which are formed by many low power wireless transmitters. From the moment of mobile devices having cellular modem, transmission of data is also exchanged between cell to cell, which facilitates non interrupted data flow. This way it forms a point to point architecture. It can also receive data from serial or Ethernet interface and transmit data on a second interface over cellular network, to enable normally wired components to become wireless. This technology offers extensive data coverage, no maintainance costs and network fully maintained by carrier[[47]).

The advantage ofcellular technology is that the existing infrastructure can be used at some extent. Therefore, utilities do not have to incur extra cost for building the communications infrastructure required for a Smart Grid. Widespread and cost-effective benefits make cellular communication one of the leading communications technologies in the market. Due to data gathering at smaller intervals, a huge amount of data will be generated and the cellular networks will provide sufficient bandwidth for such applications. When security comes into discussion, cellular networks are ready to secure the data transmissions with strong security controls. Also, with the recent growth in 3G / 4G cellular technology, the data rate and Quality of Service (QoS) are improving very fast.

On the other hand, some critical Smart Grid applications require uninterrupted availability of communications. However, the cellular network will be used in parallel with the consumer market, which may lead to congested network or degradation of performance in emergency situations. Furthermore, the cellular communications are likely unsuitable for applications involving many data and require very high bandwidth.

4.5.4 ZigBee

ZigBee is a wireless communications technology that is relatively low in power usage, data rate, complexity, and cost of deployment. It is an ideal technology for Smart lighting, energy monitoring, home automation, and automatic meter reading, etc. ZigBee and ZigBee Smart Energy Profile (SEP) have been realized as the most suitable communication standards for Smart Grid residential network domain by the U.S. National Institute for Standards and Technology (NIST[2]) [1].

The communication between Smart meters, as well as among intelligent home appliances and in home displays, is very important. Many AMI vendors, such as Itron, Elster, and Landis Gyr, prefer Smart meters, where the ZigBee protocol can be integrated into . ZigBee integrated Smart meters can communicate with the ZigBee inte-grated devices and control them. ZigBee SEP provides utilities to send messages to the home owners, and home owners can reach the information of their real-time energy consumption.

Operates in the unlicensed 868MHz band in Europe, 915MHz in North America and worldwide 2.4GHz. In the zone of 2.4GHz, the transceivers operating more frequently, have 16 channels width 5MHz each and use OQPSK modulation technique. It selects this shape, which is a variant of classical QPSK, because it

[2] http://www.itu.int/home/imt.html

requires less power compared to similar designs, while achieving the same or better performance (throughput). ZigBee offers data rates of 20-250Kbps coverage and 10-100m and ZigBee employs 128-bit AES encryption for security [9]

Considered very good choice for measurement and management of energy. It is ideal for Control of home appliances due to simplicity, mobility it provides, robustness, low bandwidth requirements, low power consumption, low cost, and operating in unlicensed spectrum and has easy install of application.

But there are some limitations to the use of ZigBee in practical applications such as small manufacturing, small memory size, small delay requirements and interference from other devices that share the same transmission medium.

4.5.5 Wireless Mesh

A mesh network is a flexible network consisting of a group of nodes, where new nodes can join the group and each node can act as an independent router. The WMN often consists of mesh clients, mesh routers and gates. Clients are often laptops, cell phones and other wireless devices while the mesh routers forward traffic to and from the gates, which may, but need not, be connected to the Internet. The coverage area of the radio nodes working as a single network is sometimes called a mesh cloud. These networks are reliable and offer redundancy. Such networks also have the property of self-healing, characteristic that enables the communication signals to find an-other route via the active nodes, if any node should drop out of the network.

Wireless mesh networks and networks of low-power and low-speed (low-power and low-rate, LPLR) play an important role in the communication infrastructure of Smart Grids. The WMN, originally designed for communication in community or neighbourhood, is considered one of the prescribed approaches to support Smart Grids. Principally based on the IEEE 802.11 standard to provide reliable and cost-effective mesh networking, easy to install and implement and are an affordable investment. Able to effectively manage applications Smart Grid, among other uses not related to Smart Grids. On the other, the LPLR networks apply generally, the IEEE 802.15.4 and consist of numerous devices, which are based on sensors.

Mesh networking is a cost effective solution with dynamic self-organization, self-healing, self-configuration, high scalability services, which provide many advantages, such as improving the network performance, balancing the load on the network, extending the network coverage range [10]. Good coverage can be provided in urban and suburban areas with the ability of multi hop routing. Also, the nature of a mesh network allows meters to act as signal repeaters and adding more repeaters to the network can extend the coverage and capacity of the network. Advanced metering infrastructures and home energy management are some of the applications that wireless mesh technology can be used for.

On the other hand network capacity, fading and interference can be counted as the major challenges of wireless mesh networking systems. In urban areas, mesh networks have been faced with a coverage challenge since the meter density cannot provide complete coverage of the communications network.

Providing the balance between reliable and flexible routing, a sufficient number of Smart nodes, taking into account node cost, are very critical for mesh networks. Furthermore, a third party company is required to manage the network, and since the metering information passes through every access point, some encryption techniques are applied to the data for security purposes. In addition, while data packets travel around many neighbours, there can be loop problems causing additional overheads in the communications channel that would result in a reduction of the available bandwidth [22a].

4.5.6 Satellites Communications

Satellite communications is a good solution for remote control and monitoring, they provide global coverage and fast installation. In some scenarios where there is no communication infrastructure, especially in remote substations and generation, satellite communications is a cost effective solution. Such communication can be easily installed and requires only the purchase of the necessary equipment satellite communications. Here it should be noted that some utilities have already installed such equipment for the monitoring of rural substations.

In addition, a dedicated terrestrial architecture is vulnerable to disasters or system failures of communication. Consequently, in order to ensure safe operation and delivery of critical data in case of traffic disaster or damage of terrestrial communication systems, satellites can be used as a backup system for existing networks.

However, two disadvantages of satellite communications, should be mentioned. First, a satellite communication system has a significantly higher delay than a terrestrial system. This makes some protocols eg TCP, which were originally designed for terrestrial communication, unfit for satellite communications. Secondly, the characteristics of a satellite channel vary with the influence of attenuation and the weather conditions. This property can greatly reduce the performance of the entire communication system.

4.5.7 Other Potential Wireless Technologies

4.5.7.1 Mobile Broadband Wireless Access (MBWA)

IEEE 802.20 standard for MBWA provides high bandwidth, high mobility and low latency in the licensed frequency bands below 3.5 GHz, by utilizing the positive features of both IEEE 802.11 WLANs and IEEE 802.16

WMANs. It is also known as MobileFi. It offers real time peak data rate of 1Mbps to high speed data rate of 20Mbps. This standard is optimized for full mobility up to vehicular speed of 250km/h [11].

IEEE 802.20 may be used for Smart Grid applications, such as broadband communication for plug-in electric vehicles, wireless backhaul for electric grid monitoring and SCADA systems. IEEE 802.20 (MBWA) is new emerging technology, and hence, communication infrastructures for this technology are not readily available. Currently, use of this technology may be a costly solution compared to cellular technology

4.5.7.2 Digital Microwave Technology

Digital microwave operates on licensed frequency band of 2-40GHz, and provides the data rate up to 155Mbps. Microwave technology provides very long distance coverage up to 60 kilometres. It accepts data from Ethernet or ATM port and transmits it to the other as microwave radio. Digital microwave can support point to point communication for Smart Grid applications, e.g. transfer trip between DER and distribution substation feeder protection relay. Microwave radio is susceptible to two types of signal fading, precipitation and multi-path interference. Encryption for security may result in additional latency as it takes larger message sizes [14].

4.5.7.3 Free-space optical communication

The optical free space communication is a technology of optical communication which can use the light transmitted in the free space for the transmission of data from point to point. It provides high data rates with low error rate bit. Additionally, it is very safe because of the high directivity and tight radii. A part from providing long-distance point-to-point communication in remote or rural areas, wireless optical technologies also provide solutions to point-to-point for use in densely populated urban areas, where microwave solutions are not practical in terms of interference. However, the free-space optical communication, like microwave technology is visual technologies (line-of-sight, LOS). Therefore, the characteristics and the quality of communication is greatly influenced by obstacles (e.g. buildings and hills) and environmental constraints (e.g. rain).

4.5.7.4 Bluetooth

Bluetooth is part of wireless personal area network standard, IEEE 802.15.1. It is low power, short range radio frequency communication standard. It operates on 2.4–2.4835GHz unlicensed ISM band. It offers a data rate of 721Kbps [9]. Devices with Bluetooth configuration consists of complete OSI 7 layer communication stack. It can facilitate both point to point, and point to multipoint communication configuration. Depending upon the communication configuration it offers distance coverage between 1m – 100m. Bluetooth technology can be used for local online monitoring applications as a part of substation automation systems [12].

These devices are highly influenced by surrounding communication link and may interfere with IEEE 802.11 based wireless LAN network. The Bluetooth offers weak security compared to other standards.

Table 9 Wireless Communications Features

Wireless Technology	Data Rate	Approx. Coverage	Potential Smart Grid Applications
Wireless LAN	1-54Mbps	100m	distribution protection and automation
WiMAX	70Mbps	48Km	Wireless Automatic Meter Reading (WMAR)
Cellular	60-240Kbps	10-50km	SCADA and monitoring for remote distribution

ZigBee	20-250Kbps	10-100m	Direct load control of home appliances
MobileFi	20Mbps	Vehicular Std.	communication for PEVs and remote monitoring
Digital Microwave	155Mbps	60 km	transfer trip (point-to-point)
Bluetooth	721Kbps	1-100m	local online monitoring applications

4.5.7.5 Wire line /Wired Technologies

The wired technologies, such as fiber optic and BPL (Broadband over Power lines), may be preferred by utilities when they are already available in areas served when they can meet the performance requirements. Course, may be used for the construction of communication networks and dedicated wires are different from the electrical lines. These specially dedicated networks require additional investment for the installation of cables, but can offer higher capacity and less delay for communication.

Depending on the transmission medium used, wired networks include SONET / SDH, Ethernet, DSL and coaxial cable access networks. DSL and coaxial cables can be used to access the Internet. The currently available technology allows data transfer via DSL and coaxial cable rate as 10Mbps.

The technologies and fiber optic networks, including next-generation Synchronous Optical Network and Synchronous Digital Hierarchy (SONET / SDH), are able to provide different data rates on access levels, ranging between 155Mbps and 160Gbps. Offer platforms that provide multiple services, which support IP-based applications and Ethernet. As a result of the simplicity of Ethernet and efficiency on costs, the adoption of IP with MPLS (Multi Protocol Label Switching) to achieve transport over SONET / SDH existing packet-switched networks (known as carrier Ethernet) will enhance the credibility , quality of service and security for critical applications of Smart Grids. Ethernet is now able to offer speeds to one Gbps Gigabit Ethernet (GbE) and 10 Gbps to 10GbE. The pop 40GbE/100GbE with ample capacity would be beneficial for the overall data traffic Smart Grid.

Similarly, Ethernet and Gigabit passive optical networks (EPON / GPON) using optical-electrical approaches to providing adequate capacity for the delivery of large data and high-speed transmission in access networks. Advantage of the wavelength division multiplexing (Wavelength Division Multiplexing - WDM). H using different wavelengths, both for traffic growth (upstream) and downstream (downstream), allows for great flexibility in routing and switching optical signals

4.5.8 Powerline Communication (PLC)

The power lines are mainly used for electrical power transmissions, but they can also be utilized for data transmissions. The power line communication systems operate by sending modulated carrier signals on the power transmission wires. Typically data signals cannot propagate through transformers and hence the power line communication is limited within each line segment between transformers. Data rates on power lines vary from a few hundred of bits per second to millions of bits per second, in a reverse proportional relation to the power line distance. Hence, power line communication is mainly used for in-door environment to provide an alternative broadband networking infrastructure without installing dedicated network wires.

Powerline communication (PLC) is a technique that uses the existing powerlines to transmit high-speed (2–3 Mb/s) data signals from one device to the other. PLC has been the first choice for communication with the electricity meter due to the direct connection with the meter [8] and successful implementations of AMI in urban areas where other solutions struggle to meet the needs of utilities. PLC systems based on the LV distribution network have been one of the research topics for Smart Grid applications in China [9]. In a typical PLC network, Smart meters are connected to the data concentrator through powerlines and data is transferred to the data center via cellular network technologies. For example, any electrical device, such as a powerline Smart transceiver-based meter, can be connected to the power-line and used to transmit the metering data to a central loca-tion [15]. France has launched the “Linky meter project” that includes updating 35 million traditional meters to Linky Smart meters. PLC technology is chosen for data communication be-tween the Smart meters and the data concentrator, while GPRS technology is used for transferring the data from the data con-centrator to the utility’s data center [15]. ENEL, the Italian elec-tric utility, chose PLC technology to transfer Smart meter data to the nearest data concentrator and GSM technology to send the data to data centers

Chapter 5: Smart Grid Applications

Smart Grid' s applications will benefit the existing system. Yet, there are some impediments to the adoption of Smart Grid technologies. At first the variety of Smart Grid applications are quite many, so utilities have to identity the ones that will provide the best return on investment. Also, to adopt Smart Grid immediately is not simple, because utilities must transform their business and operations to utilize Smart Grid technologies.

However, since it does not seem that the rapid development in energy sector will slow down any time soon, it is necessary for every utility to have a clear and concise plan for future investments. Geographical position may affect the short-term goals that utilities are trying to accomplish, but some commonalities can be seen across the countries. There are several major challenges that utilities are facing. Yet, there are some common parts of the framework that all utilities should implement.

5.1 Wide-Area Situational Awareness (WASA)

Wide Area Situational Awareness (WASA) represents the monitoring of the power system across wide geographic areas. These broad area perspectives are necessary to maintain system knowledge and decisions that go beyond conventions of individual companies or even regional transmission organization boundaries. The requirements for WASA are architecturally significant from the standpoint of requiring uniformity across traditional systems operation boundaries. Enabling WASA based applications brings forward unique requirements and challenges for the Smart Grid infrastructure.

Modern power systems are extremely large and complex physical objects to control. They, in turn, consist of a number of also large and complex components, such as bulk generation, transmission, distribution, and customer systems. These systems are interconnected and have strong interrelationships. With the significant advances of active components in the customer systems (DER, PEV, etc), the customer component will also significantly impact transmission system. The situational understanding of the transmission system cannot be comprehensive without information from the distribution and customer systems.

In order to properly define the requirements for the WASA there is need to find the optimal proportion of the information, which should be provided to the automated monitoring and control systems and to the operator, which is always the “person in charge”. In the sense of the volume of data, the automated systems will process the bulk of data, and the operators should be provided by concise and optimally visualized information to be able to direct the automated systems to the changing operational objectives within changing optimization constraints, remaining outside of the loop that is fast processing huge amount of data.

The following use cases are representative of architecturally-significant samples for WASA.

- **Contingency Analysis**
  Contingency analysis (CA) is an Energy Management System (EMS) application that analyzes the security of a power system. It calculates, identifies, and prioritizes: current and power flow overloads in equipment, voltage violations at buses, and system stability problems that would occur if contingency events happen in the future. Contingency analysis simulates the effects of removing equipment and calculates the results using a model of the power system.
- **Inter-Area Oscillation Damping**
  Low frequency Inter-area oscillations are detrimental to the goals of maximum power transfer and optimal power flow. An available solution to this problem is the addition of power system stabilizers to the automatic voltage regulators on the generators. The damping provided by this technique provides a means to minimize the effects of the oscillations. If an oscillation exists, a control signal

is sent to the generator's voltage regulator that effectively modulates the voltage and effectively damps out the oscillations.

- **Wide Area Control System for Self Healing Grid Applications**

  The objective of the Wide Area Control applications is to evaluate power system behaviour in real-time, prepare the power system for withstanding credible combinations of contingencies, prevent wide-area blackouts, and accommodate fast recovery from emergency state to normal state. The Wide area control system functions comprise a set of computing applications for information gathering, modelling , decision-making, and controlling actions.

- **Voltage Security**

  The Voltage Security function is designed to detect severe low voltage conditions based on phasor measurements of Power and Voltage and upon detection, initiate corrective action such as load shed.

- **Monitoring Distribution Operations as a Part of WASA**

  The objectives of this function as a component of WASA are to monitor in the near-real time and in close look-ahead time the behavior of distribution operations under normal and emergency operating conditions, analyze the operations, and provide the transmission automated management systems and the transmission operator with the results of the analysis aggregated at the demarcation lines between distribution and transmission.

- **Voltage, Var, and Watt Control (VVWC)**

  The following objectives, relevant to WASA are supported by the application: Reduce load while respecting given voltage tolerance (normal and emergency); Conserve energy; Reduce or eliminate overload in transmission lines; Reduce or eliminate voltage violations on transmission lines; Provide reactive power support for transmission/distribution bus; Provide spinning reserve support; Minimize cost of energy.

5.2 Demand Response

The Demand Response system temporarily changes the electricity consumption by loading on the distribution Grid in response to market (e.g., high electricity tariff due to high demand) or by maintaining the reliability on the Grid. The customer Demand Response system may also contribute towards demand response by supporting the electricity demand temporarily. Implementation of a Demand Response system is beneficial for both the utility companies and the customer. The Demand Response system allow the utility companies to control the peak power conditions on the Grid and flatten the consumption curves by shifting consumption times. The utility is therefore able to avoid a short term peak by delaying some of the existing usages and buy itself time to start off additional power plants. This avoids the inefficient operation of running backup power plants to cover the peak loads on the Grid. Based on consumption curves, the utility companies can provide dynamic Real-Time Pricing information to the customers, thereby encouraging them to shift their usage to times of lower electricity demand. This will maximize the use of available power and increase overall system efficiency. Customers on the other hand can use an energy management interface and Smart appliances (which communicate with a Smart meter) and schedule their electricity usage in synchronization with the low price signals. The process can also be automated and controlled by the utility as per the customer preferences. Moreover, by setting up DERs and energy storage devices at their premises, customers can sell the excess electricity back to the utility. The DR systems use the AMI infrastructure and field area networks of the customer domain to implement their functionalities.

The following use cases are representative of architecturally-significant samples for Demand Response (DR).

- **Direct Load Control**

  The DR solution shall provide the ability to manage direct load control programs. It accomplishes this by managing the transmission of direct load control actions to direct load control enabled devices as , HAN device, and

Smart appliances. This solution will also provide interactions with customers to convey direct load control information.

- **Demand Response Management System Manages Demand in Response to Pricing Signal**
  Studies indicate that customers who understand the cost of electricity reduce their usage, especially when prices are high. The DR solution shall provide the ability to manage pricing signal programs designed to reduce load. It accomplishes this by managing the transmission of price signal information to DR-enabled devices. This solution shall also provide interactions with customers to convey price signal information; communication is shown via the meter or the Facility EMS/Gateway.
- **Customers Reduce Their Usage in Response to Pricing or Voluntary Load Reduction Events**
  Customer awareness of energy scarcity and customer attention to energy use, each maintained by economic signals, are key benefits of the Smart Grid. The most expensive use of the Grid is to cover short term shortages in energy supply. The Grid can share responsibility for peak load management with customers by sharing economic incentives to reduce load. These incentives may be shared in advance by day-ahead pricing or in real time during a critical event. Energy customers will develop a variety of strategies to respond once the economic incentives are in place.
- **External Clients Use the AMI to Interact With Devices at Customer Site**
  The Smart Grid will enable third parties, such as energy management companies, to use the communication infrastructure as a gateway to monitor and control customer equipment located at the customer's premise. The communication will be required to enable on-demand requests and support a secure environment for the transmission of customer confidential information, and would take place via an AMI or communication through the Facility EMS/Gateway
- **Customer Uses an Energy Management System (EMS) or In-Home Display (IHD)**

The Smart Grid will facilitate customers becoming actively involved in changing their energy consumption habits by connecting their personal control and display devices to the utility Grid. This technology also makes it possible for the utility to obtain vital information to maintain power quality and reliability on their systems. Providing customers with the means to visually monitor information about their energy use from their residence or business helps them to make more educated energy related decisions. Customers with access to EMS and IHD are more inclined to install energy efficient equipment on their premises and participate in load reduction programs. This use case describes how customers and the utility use these new technologies for improved load management.

- **Utility procures energy and settles wholesale transactions**

  Operations for the Retail Market receive and prepare bids and offers into the wholesale energy market and evaluate the incoming bids from the wholesale market against the needs and the cost of operation. To facilitate this process, the Retail Market needs to know what resources, such as distributed generation or demand response, are available and for how long. Some time after a wholesale transaction has been completed, the Retail Market settles the transaction using actual usage data gathered by the metering system during the period specified in the transaction. The data is used to prepare bills and invoices to multiple parties involved in the transaction based on contracts and tariffs.

- **Dynamic Pricing— Energy Service Provider Energy and Ancillary Services Aggregation**

  A Demand Response Service Provider collects energy and ancillary services bids and offers from Dynamic Pricing and other DER subscribing customers. The Service Provider combines those bids into an aggregate bid into the market operations bid/offer system. When accepted, the Service Provider notifies the end customer of the status and requests scheduling of the services

- **Customer Uses Smart Appliances**

The Smart Grid allows customers to become actively involved in changing their energy consumption habits by connecting their personal Smart Appliances to the utility Grid. This use case describes how the customer installs and begins using Smart Appliances to manage their energy usage and costs. Communication is through the Facility EMS/Gateway or the metering system.

- **VVWC with DR, DER, PEV, and ES**

  The application calculates the optimal settings of voltage controller of LTCs, voltage regulators, DER, power electronic devices, capacitor statuses, and may enable Demand Response to amplify the effect of load-reducing volt/var control.

5.3 Electric Storage

To date, the only significant bulk electricity storage technology has been pumped storage hydroelectric technology. Distributed storage exists (e.g. local storage for UPS systems, etc.) but it is not aggregated or available for any system benefits. New storage technologies are under development and in some cases are being deployed, and could also potentially provide substantial value to the electric grid. Electric storage is recognized to have value at all levels in the modern power system, from central generation to point of use. Examples of storage functionalities are:

- At Generation level – frequency control, spinning reserve, supply-ramping, demand leveling, minimum loading

- At Transmission level – stability, VAR support, power quality and transfer leveling, and reliability

- At Substation/Distribution – peak shaving, voltage support, power quality, capacity investment deferral, and reliability

- At End-Use level – demand control, interruption protection, voltage support and power quality

5.3.1 Benefits of Energy Storage to Generation.

The value of energy storage on electric power systems has been recognized for more than 50 years. It was obvious that if storage was available to store the coal and nuclear produced energy during the nights, it would create significant savings. In spite of these potential advantages and considerable research, the only significant energy storage system developed for electric power systems was pumped storage plants.

Fifty years ago, energy storage was considered the potential “handmaiden” for base-load nuclear and coal generation. Now, the national emphasis is on development and use of renewable technologies, such as wind and solar, technologies that often do not produce power when it is needed. The net result is that the significant portion of the generating capacity in the wind and solar generation has to be duplicated on the power system with some form of peaking generation that can be operated to provide the reliability needed by the system. It is becoming increasingly evident that energy storage could be an alternative to this peaking capacity and become the “handmaiden” of solar and wind power as well as enabling us to fully utilize our base-load nuclear and coal capacity.

5.3.2 Benefits of Energy Storage to Transmission and Distribution

Energy storage applications offer potential benefits to the transmission and distribution system because of the ability of modern power electronics, and some electro chemistries , to change from full discharge to full charge, or vice versa, extremely rapidly. These characteristics enable energy storage to be considered as a means of improving transmission Grid reliability or increasing effective transmission capacity. At the distribution level, energy storage can be used in substation applications to improve system power factors and economics and can also be used as a reliability enhancement tool and a way to defer capital expansion by accommodating peak load conditions. Energy storage can also be used to alleviate diurnal or other congestion patters and, in effect, store energy until the transmission system is capable of delivering the energy to the location where it is needed.

Other technical applications of electric energy storage include:

Grid stabilization, Grid frequency support, Grid reserves, Grid voltage support, Black start.

5.3.3 Some of the use cases Electric Storages are:

- Energy Storage (ES) Owners Store Energy from the Power System ES owners store energy when it is at its lowest cost and when it has least possibility to be detrimental to the power system operations.

- Energy Storage (ES) Owners Discharge Energy into the Power System

ES owners discharge energy when it is economically advantageous to do so and/or when it can improve reliability, efficiency, or power quality of the power system operations.

- **Building Energy Usage Optimization using Electric Storage**
  Energy storage is used as one mechanism to optimize building energy usage in response to realtime pricing (RTP) signals. The RTP system provides the pricing schedule through email or direct transfer to the Building Automation System (BAS) that can perform the necessary activities to optimize the building energy usage.

- **RTO/ISO Directly Dispatches Electric Storage to Meet Power Demand**
  Using either market-based energy scheduling or emergency control capabilities, the RTO/ISO directly dispatches stored electric energy to meet local or regional power demand. The market based energy schedule would include the electric storage devices that are under dispatch control of the

RTO/ISO for the purpose of meeting scheduled demand. Separately, depending upon the structure of the electric market, the RTO/ISO could also schedule and control the charging of the electric storage devices. The devices could also be controlled to provide for scheduled VAR demand.

- **Utility Dispatches Electric Storage to Support Intentional Islanding**
  A utility determines that an electric island (microGrid) could be intentionally established and dispatches electric storage as well as other DER generation and load management capabilities to support this islanding.
- **Electric Storage Used to Provide Fast Voltage Sag Correction**
  Electric storage provides fast voltage sag correction.
- **Impact on Distribution Operations of Plug-in Electric Vehicles as Electric Storage**
  The objectives of this use case are to demonstrate that the distribution monitoring and controlling functions a) take into account the near-real time behavior of the ES as loads and as Source of Energy and b) have the needed input information for the close look-ahead times reflecting the behaviour of the ES as loads and as Source of Energy.

The Future for Energy Storage

At the present time, the U.S. Government is funding significant research in energy storage and the possibilities for new energy storage technologies being developed and being applied in the system are better than at any time in recent years. Most people feel that development of energy storage should be the top priority for new technologies in our electric power systems.

Specific needs of the future are:

- Identification of the potential effect of energy storage on the fu-ture electric utility systems of the United States

- Determination of the feasibility of commercialization of various energy storage systems and establishing the required key technical, cost, and environmental characteristics

5.4 Electric Transportation

Electric transportation is a key area of focus for the Smart Grid community. Electric transportation could significantly reduce dependency on foreign oil, increase the use of renewable sources of energy, and also dramatically reduce carbon footprint. The current Grid and market infrastructure cannot support mass deployments of PEVs. There are very special issues to consider when designing for massive PEV support. The introduction of millions of mobile electricity charging and discharging devices provides unique challenges to every domain on the Smart Grid. A thorough and careful analysis of PEV introduction is necessary, and the Smart Grid architects and standards organizations must take special care to consider it in their designs. Transportation accounts for more than 30 percent of the world's energy consumption and nearly 72 percent of global oil demand. Given the volatility of oil prices over the past decade, the political instability of oil producing nations, and the environmental damage caused by internal combustion engines, governments are increasingly coming to view electric transport as essential to economic growth, energy independence, and greenhouse gas reduction. Three factors, in particular, are driving the United States and other countries toward transportation electrification:

High and volatile oil prices: Oil prices have been highly volatile over the past decade, rising from roughly $25 per barrel in 2000 to $75 in 2006 and soaring to an all-time high of $147 per barrel in 2008 before settling back to around$80 in early 2010. Naturally, gasoline prices have fluctuated widely as well. In addition, every recession over the past 35 years has been preceded by or occurred concurrently with an oil price spike. In contrast, electricity prices have been relatively stable with the price per MegaWatt hour (MWh) tracking between $50 and $75 and retail rates rising an average of less than 2 percent per year.

Energy independence and security: Growing worldwide competition for oil creates economic risks. For example countries as United States, with China's oil demand growing at double digit growth rates to over 8 million barrels per day (versus the US's 20mm bpd consumption) cause more dependence on imports from volatile Middle Eastern, African, and South American countries. This creates concerns over security and oil availability. Securing foreign oil supplies exacts a high price according to the RAND Corp., whose research suggests that between 12 and 15 percent of the U.S. defence budget, or some $67 to $83 billion annually, is spent patrolling oil transit routes and protecting infrastructure in hostile regions to ensure a continued flow of oil.

Environmental benefits: According to the U.S. Department of Energy (DOE), transportation is the largest emitter of carbon dioxide in the United States, accounting for roughly one third of all CO2 emissions. Inherently clean electric motors are more than three times as efficient as gasoline engines; transport electrification will cut greenhouse gases significantly. The environmental advantages of electric transport are such that even if EVs were initially powered by electricity generated solely from today's relatively dirty coal power plants, EVs would still reduce carbon emissions compared to gas-based vehicles, according to a study by the Natural Resources Defense Council and Electric Power Research Institute.

5.4.1 Electric Vehicles in Smart Grids

The next decade will bring a significant shift toward the electrification of transportation around the globe. Worldwide, more than 20 automakers plan to bring electric vehicles (EVs) to market starting in late 2010, and researchers expect sales of EVs to grow from 1 percent of the global market, or just under one million vehicles per year, to six percent by 2020. This sea change in transportation applies a new urgency to a wide variety of business, technical, and regulatory issues that must be addressed if the electrification of transportation is to succeed.

EVs will fundamentally change how electric utilities do business. Although full electrification of the U.S. transportation system will take several decades, most utilities are well aware that even low levels of EV adoption can strain their existing infrastructure. Some are proactively preparing to address EV integration issues, while others will be reactively dealing with Grid reliability problems as they arise.

Utilities are best positioned to manage the impact high-capacity EV charging will have on the Grid. Either significant new infrastructure needs to be added to the distribution infrastructure (an EV can consume as much energy as an air-conditioned home—potentially doubling peak residential electricity demand) or these new EV loads need to be managed to avoid overlapping with existing residential usage patterns. Utilities taking an active role in planning and implementing an EV charging management solution will be well-positioned to benefit from the coming massive change in transportation.

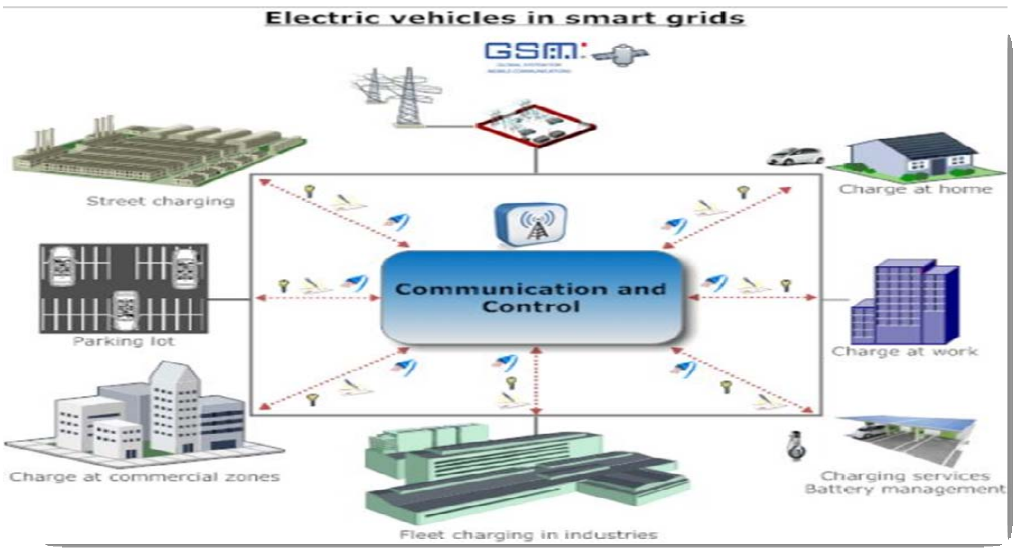

Figure 15 Electric vehicles in Smart Grids context
(Source: http://www.silverspringnet.com/pdfs/whitepapers/SilverSpring-Whitepaper-ElectricVehicles.pdf)

5.4.2 Challenges to EV Adoption for Consumer

To succeed as an industry, the EV community—including automakers, utilities, EVSE providers, and government agencies such as PUCs and city agencies—must overcome a number of barriers to adoption. One major hurdle is the integration of charging stations into the electric grid. Consumers driving their EV away from a dealership won't find charging stations, which are critical to timely charging, on numerous street corners as they do today with gas stations [38-42].

Among the consumer challenges that must be addressed are:

High cost: Depending on the battery size, EVs can be more expensive than vehicles with traditional gas engines. Hybrid EVs, including PHEVs, are more expensive than gas-powered vehicles because they have both an electric motor and an internal combustion engine. McKinsey & Co. estimates that by 2015 a PHEV with a range of 40 miles will cost $11,800 more than a standard car with a gas fuelled internal combustion engine, while an EV with a range of 100 miles will cost $24,100 more.[v]

Potentially long charging times: It can take from half an hour to a day or more to charge EVs, depending on battery capacity, state of charge, and the type of charging infrastructure or EVSE used. Three levels of charging technologies are being developed, supplying different amounts of power. AC Level 1 (L1) charging and Level 2 (L2) EVSEs are designed for use in individual residences, multi-dwelling units, and similar structures. DC Fast Charging is designed for commercial installations, such as commercial charging stations (think gas station equivalents), and these devices charge the battery using direct current. This technology and market is in its infancy, and few DC fast chargers are available in the United States.

EV Charging Times

		Time to charge[2]	
Charger type	Capacity[1] (kW)	Chevy Volt (8kWh)	Nissan LEAF (24kWh)
AC Level 1	1.3	~6 hrs	~16-18 hrs
AC Level 2	3.3	~3 hrs	6-8 hrs
	6.6	~1.5 hrs	~3 hrs
DC Fast Charger	~60	<10 min	~30 min

Figure 16 EV Charging Times
(Source: http://www.silverspringnet.com/pdfs/whitepapers/SilverSpring-Whitepaper-ElectricVehicles.pdf)

Range anxiety: Because of the lack of public rapid charging infrastructure, anxiety about being stranded is a concern for potential EV buyers. Many EVs can go only a limited distance, such as 40 miles, before recharging. While this range is sufficient for the 80 percent of the people who commute fewer than 40 miles per day, research by Frost & Sullivan indicates that drivers have a strong preference for range-extended PHEVs like the Volt.

Long permitting process for L2 chargers: Consumers are used to buying a car and driving it home. Consumers will demand the convenience of the faster L2 chargers, which require permits and must be installed by a licensed electrician. With L2 EVSEs, they may wait one or two months before their charger is installed at their home. Obtaining a permit may involve both the city and local utility, which must be informed about the additional power requirements [38-42].

Administrative impacts: Regardless of who installs, operates, or owns charging infrastructure, utilities must be included in the permitting process so they can plan and budget for the necessary network upgrades. If service panel upgrades are required for L2 EVSE installation, the consumer will not be able to install the EVSE until the utility has ensured the Grid is capable of supporting the additional demand. This process will place an additional administrative burden on utilities and creates significant pressure on them to avoid being a bottleneck to EV adoption [38-42]..

Billing issues: Business models for providing charging services have yet to be worked out. For example, how will utilities be compensated for the power used by charging stations that are owned and operated by third parties? What happens when a driver charges at a public station? How can a utility keep track of which resident in an apartment complex plugged into a charging station and bill them accordingly? Will utilities need to develop transfer pricing agreements, like cell phone operators did, to accommodate “roaming” and/or develop parking meter-like pay stations to accommodate the 50-cent or $1.00 transactions per battery charge [38-42].

Benefits from embracing the EV

While the electrification of the transportation sector poses numerous challenges, it also presents utilities with a significant opportunity. Since only utilities can mitigate the impact of charging stations on the Grid, by planning now for EVs, utilities provide many benefits such as:

Maximizing utilization of infrastructure:

Utilities are gaining experience today with the tools and techniques that will be required to control the inevitable increase in demand for electricity that even early EV adoption will bring. Pilots involving price incentives to consumers have resulted in significant peak shifting; off-peak EV charging will be critical to enabling utilities to shift peak demand and defer capacity upgrades to their distribution network. In the future, creating an active load through EV charging can help utilities integrate renewable energy sources and avoid having to build new peak generating capacity, acting like energy storage without actually needing to overcome the challenges of drawing power from batteries [38-42]..

Transport electrification also boosts electricity sales, which can help utilities reduce the rate impact of bringing renewable energy sources online and implementing efficiency programs by helping utilities lower the amortization of their fixed costs of infrastructure. By slowing the pace of rate increases, the United States can achieve its energy goals without overly burdening consumers. And by anticipating L2 EVSE installations, utilities can put processes in place to cut administrative overhead and streamline permitting, as well as take the lead in defining billing models [38-42].

Creating closer customer relationships:

Transportation electrification presents an opportunity for utilities to have greater contact with customers, creating a stronger relationship. Not only will utilities enable vehicle “fueling” through EV charging, they’ll also be able to communicate greenhouse gas reductions and energy savings to customers (and regulators) through web portals and monthly bills, empowering customers as partners in energy efficiency.

Reducing greenhouse gases

By proactively working to support EVSEs, utilities can play a major role in cutting GHG emissions. It’s likely that future legislation will levy limitations on carbon emissions; utilities that actively support EVSE will be well positioned to manage the impact and help determine the proper allocation of GHG credits.

Leveraging EVSE communications for other energy initiatives:

Utilities that want to derive the benefits of measuring the electricity used for EVs will need revenue grade metering and communications to the EVSE. With these capabilities, the utility can measure EVSE usage and quantify GHG savings, effectively manage the electricity flow by enrolling customer in a demand response (DR) program, and offer customers special rates for EVSE charging [38-42]..

5.5 Advanced Metering Infrastructure

AMI integrates meters(including water, gas, etc.), communication networks and software to measure, collect, storage, analyze and use data on electricity consuming as well as system operation [18]. From power company's aspect, AMI not only provides communication networks and facilities throughout the whole system, but also provides measurement points and observability in system level. It is always considered to be the first step in Smart Grid construction [19]. Generally, AMI system consists of Smart meters installed in user side, metering data management system located in power company, and communication networks connect them[20]. In order to strengthen demand side management, the system extends to user's home area network, as figure 17 shows.

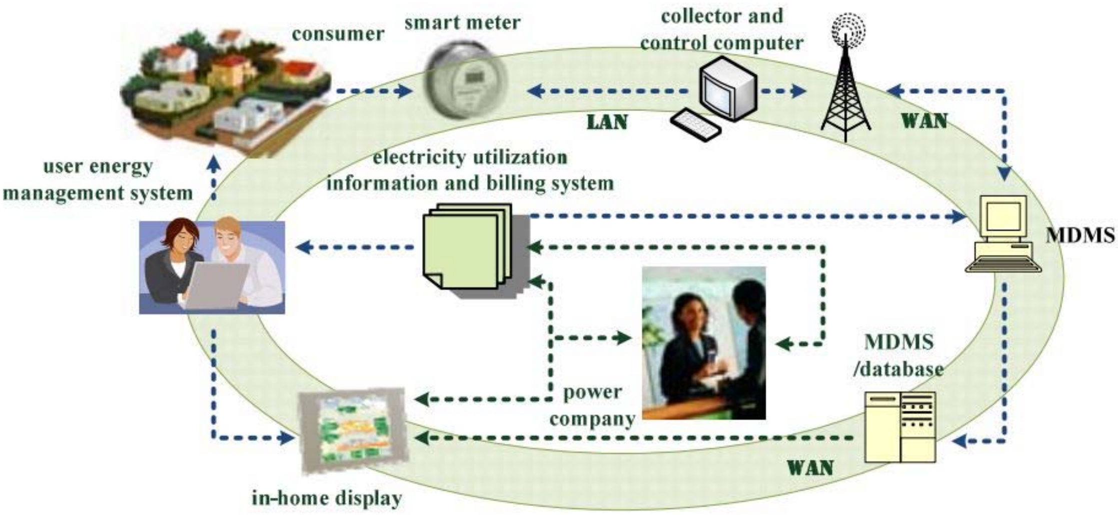

Figure 17 AMI composition, structure and data flow diagram
(Source: Functional Analysis of Advanced Metering Infrastructure in Smart Grid)

Smart meter, which is a digital instrument based on microcontroller to achieve energy measurement, monitoring and control capabilities, is an important component of AMI. Smart meter collects detailed real time data on energy consuming, deliver the raw data through two-way communication networks to MDMS. The raw data is analyzed and processed in MDMS in order to achieve a number of complex functions of AMI. As collecting many electrical parameters measurements with time scales, Smart meter becomes a system sensor and measuring point distributed all over the Grid.

An advanced two-way communication network forms a high speed channel to exchange power flow and information flow between consumer and the Grid. This can be realized by a variety of communication media. Two-way communication provides a means of improving energy efficiency and reliability of the Grid. It also make user participate system operation actively and friendly, interact between user's resources and the Grid deeply and co-ordinately. On the contrary, these capabilities put forward higher demands to the communication network. Therefore, combining specific needs of Smart Grid, data amount, real time requirement, communication means and so on should be studied [37].

MDMS (Metering Data Management System) is a database system for acquisition, processing and storing measured values of meters, acts as an analytical tools to interact with other information systems. It can manage all meters, transmit data other than tariff, turn on/off electricity, manage data on fault detection and recover from failure, generate and process worksheet in filed work automatically, show as figure 18. In addition, MDMS can integrate operation system of the Grid in order to achieve coordinating system fault management, scheduling system operation, completing load research and forecasting management, etc.

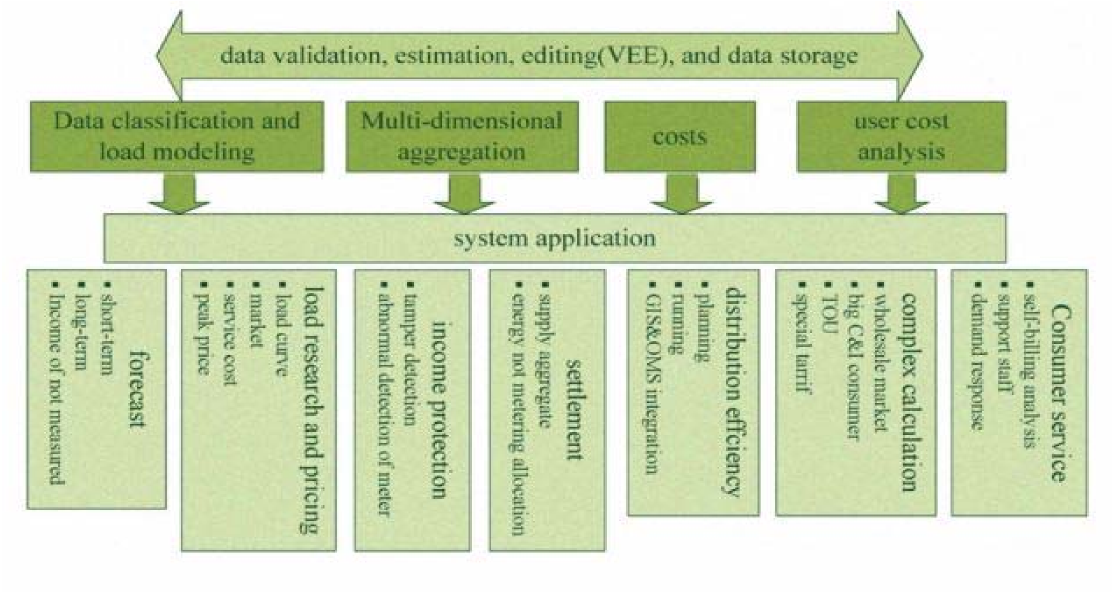

Figure 18 Main functions of metering data management system
(Source: Functional Analysis of Advanced Metering Infrastructure in Smart Grid)

The end points connect to Smart meters, In-home Display (IHD) Programmable Communicating Thermostat (PCT) and/or other energy consumption display and control end devices. An AMI system with Smart meters, IHDs and PCTs enables consumers to assist in using energy more efficiently and adjust their behaviour to reduce peak capacity required.[22] [23] [24]

Home area network(HAN) coordinates user's energy management system and portal, connects Smart meter and other user's controllable intelligent electric equipments to achieve more efficient load management with the help of price signal(voltage, frequency) or combination signal as incentive automatically. Usually, intelligent nodes in HAN connected by wireless ZigBee or power line carrier.

Requirements for Smart Grid AMI Communication Network

The requirements for a communication network between the Smart meters and a utility's MDM system will be under the umbrella of the requirements for communication infrastructure for the Smart Grid [26]. This communication network is an IP-based network. Nevertheless, the structure of the IP protocol suite, with its OSI layers and features of the upper layer protocols, needs to take account of the specific requirements for the Smart Grid. Some of the requirements for this IP-based communication network are as follows:

- Standards-based—the IP suite and upper layer protocols should be standards-based to ensure interoperability and to support diverse applications.
- Open—the open standards provide the widest possible range of devices that can be employed, and the development of new devices and entry by new vendors has to be encouraged.
- Interactive—interactive applications enable active participation by consumers in demand response.
- Interoperable—the communications network will be composed of segments using different networking technologies and protocols. It is vitally important that these segments can interoperate with each other to provide end-to-end services.
- Manageable—supports network management tools for network performance monitoring and management.
- Scalable—support for scaling to large deployments is a must for a Smart Grid communications network; 120 million IP nodes, in US alone, are required for the Smart Grid in the future.
- Extensible—extensibility facilitates support for new applications and services of Smart Grid.
- Upgradable—support for easy and gradual upgrade of different segments of the communications network is necessary to protect the investment in legacy components.

- Future-proof—enables new products, services, and markets; provides broad investment protection over the network's long lifetime.

- Resilient and Self-healing—high reliability and self-healing requirements demand that the network be resilient and capable of continued operation, even in the presence of localized faults, and moreover be capable of self-healing from power disturbance events to minimize the effects of, and reduce recovery time from, network outages.

- Real-time—Smart Grid AMI applications, including demand response and dynamic pricing, require the communications network to provide metering data in near real-time.

- Cost-effective—the benefits of Smart Grid AMI load control and dynamic pricing programs could be outweighed by the increased cost of implementing a comprehensive Smart Grid AMI system. It is essential to implement a cost-effective Smart Grid AMI system.

- Supporting traffic differentiation—packets delivered on the Smart Grid AMI network are generated for different applications, such as more critical load control messages, and less delay-sensitive metering data. The AMI communications system needs to support traffic differentiation and prioritization in order to maximize the overall satisfaction for all purposes.

- Secure—the Smart Grid components have critical features, such as Smart meters that accept utility commands to turn on and off, or in-home energy management systems and appliances that accept signals to turn down or off during peak energy demand times, all of which could be used in malicious ways. With the transmission of data through a public network, which hackers have easy access to for eavesdropping or tampering ,ensuring an end-to-end secure transmission is a critical and challenging problem to tackle [27] [28].

Functional Analysis of AMI in Smart Grid

A functional analysis of AMI is necessary, cause Smart Grid goals is to meet future power Grid development (which may involve variable price, improve power quality, increase real power Grid utilization coefficient, provide a variety of options for consumer, reduce power consuming and lower loss and so on). These capabilities are achieved by virtue of advanced technologies to make AMI play a better role in Smart Grid.

The development of energy metering system has experienced three phases which are: AMR, automatic meter management(AMM), and AMI. AMM is a transitional form from AMR to AMI. AMR only permits to deliver information on unique direction, its automatic meter reading makes power staff get rid of heavy manual labor, and greatly improve reading accuracy. However, AMR has little amount of information available, has no or only a simple monitoring capabilities. It cannot meet requirements to flexible interaction. AMI has added complex monitoring functions besides advanced two-way communication capability, and integrated user side controllable resources to complete demand response based on specific incentive signal. For example, Smart home should be taken into consideration [29]

- **Offer a variety of measurement information**
  Data collection and storage is a basic function of Smart meter. Smart meter can measure many electrical parameters, such as active power, apparent power, power factor, voltage/current RMS etc. In addition, it can provides voltage and current waveform sampling data to realize (remote)power quality monitoring. AMI can read meters at a specified time or any time in terms of orders delivered from upper control center.
- Detailed measurement data provides an accurate basis for power system scheduling, planning and operation. In addition, power company through anti-tamper, delayed investment and intelligent device maintenance,

monitors and uses distribution equipments more efficient, and distributes energy to its customers more reliable.

- **Achieve demand side management**

  Demand side management requires electricity users to respond to incentive pay or price change, to transfer or reduce load by changing their original consumption mode for shifting peak load [16]. Power Grid changes operation strategy from traditional model that follows with load changing into load shift mode, and demand side resources used to balance power generation and power supply all the time. Demand management can be realized by direct load control, variable price and other means to improve utilization efficiency of the Grid, avoid or mitigate investments on power plant, transmission and distribution Grid.

- **A variety of event alarms and protection function**

  Smart meter issues a variety of alarm signals, including meter malfunction alarm, power-down alarm, theft/tamper alarm etc., and sent alarm information to MDMS for further analysis. With the help of GPRS or other intelligent systems, power company can accurately identify the alarming meter and its location, dispatch staff in time without user calling or the staff inspecting spot periodically.

- **Data security issues**

  Data security is mainly to prohibit non-authorized operations. In one hand, measurement data as well as working parameters should not be changed as a result of illegal operation or interference (electromagnetic interference, electrostatic, etc.) in any case. On the other hand, data encryption should be done in public networks to prevent disclosure, even be modified of important data to reduce security risks and avoid significant economic losses. Data security measures both involve software and hardware. Software measures include data backup, different level access rights management. Hardware measures include built-in switch, sealed buttons, etc.

- **A variety of remote service capabilities**

MDMS manages meters and their measure values, including adds/deletes meters, modifies or sets parameters of meters, and remote updates software of meters. Therefore, Smart meter can be applied in broader context because of this kind of flexible design. Remote calibration feature allows the staff easily correcting measure values to improve measure accuracy of meters in the control center [14] AMI enables remote software and hardware fault diagnosis, and returns diagnostic results back to MOMS, locates fault and response quickly.

- **Business expand and value-added services**

  User energy management system is integrated into home automation systems, which makes customer has a better electricity service. Meanwhile, communication networks of AMI can be fully utilized (Xiao-min et al.,2010). With further development of two-way communication facilities, customer will enjoy home automation and a variety of value-added services that has nothing to do with electricity supply as well, such as home shopping, home banking, security system(home security, alarm for the elder and the weaker), multimedia applications etc.

5.6 Distribution Grid Management

The existing distribution power systems consist of hundreds of distribution feeders, thousands of distribution transformers supplying millions of customers and contain a large number of locally and remotely controllable devices. Even now, they present large and complex objects to control.

With significant penetration of AMI, Demand Response, Distributed Energy Resources, and PEVs, the distribution systems become active participant in the overall power system operations and can become capable energy market participants.

In order to maximally utilize the potentials of the advanced distribution operation applications and their integration with customer and transmission systems operations, a large amount of information should be exchanged between the field

IEDs, transmission SCADA/EMS, Distribution SCADA/DMS, and customer systems (AMI, DER, DR, PEV, and Electric Storage). A large amount of input data comes from corporate databases and models. Most of the DMS Advanced Applications are integrated in a system based on a common DMS database, which, in turns is integrated with corporate databases, Utility SCADA/EMS and interfaced with AMI and other customer EMS, including DER systems.

Close functional integration with Transmission/Generation Operations via corresponding EMS will significantly enhance the efficiency and reliability of both distribution and transmission Grids and will provide a comprehensive Wide-Area Situational Awareness.

5.6.1 Distribution Automation (DA)

It is important to recognize the difference between the traditional distribution systems and the distribution systems of the future. The existing distribution systems were designed to deliver electrical energy to end-users only, while the future distribution systems will deliver both energy and information. An automated distribution system will incorporate a flexible electrical architecture that will allow the easy addition of DA applications, with an open communication architecture that will enable information flow between system components, operators and customers. Distribution automation will require the installation of controls, switches, and monitors as well as the communication channels that will support this new infrastructure. Based on the current infrastructure evaluation, utilities should develop a long-term plan to automate their distribution circuits. As noted, circuit automation will involve the installation of some of the following devices:

- Automatic reclosers with communications and control - these will minimize the outage times and help isolate the fault to the minimum number of customers.

- Sectionalizers - work in conjunction with reclosers thus further reducing the number of customers affected by the outage.
- Motor operated tie switches - used to automatically transfer the source to a different circuit after the fault isolation.
- Capacitor banks - help maintain the voltage at predetermined levels and help in power factor correction.
- Voltage regulator controls - voltage monitoring and control is important because of the reduced losses on the distribution system.
- Integrated Voltage Control - provides flat voltage profile across the whole feeder, while minimizing the power loss on the system;.
- Single phase load sensors - these sensors monitor the load at different parts of the distribution system, which can lead to reduced outage times;
- Pole replacement - installation of new equipment will require new poles.
- SCADA improvements - the addition of new equipment and devices will require more powerful SCADA system in order to accommodate new data points.
- Communication network improvements - new devices will communicate with SCADA, so improved communication network is required in order to support new devices [30].

6.6.2 Substation Automation

Substation automation involves installing microprocessor relays as well as communication processors and systems, which will enable fault isolation and load redistribution in association with distribution automation. As before, the long term plan will need to be developed to automate substations.

Substation automation will involve:

- Replacing electromechanical relays with microprocessor relays that can also store events, so that they can help solve any possible problems that take place.

- Replacement/upgrade of the existing communication processors in the substations for easier SCADA communications.
- Upgrade to fiber optics network.
- Communication gateways will be needed to provide connection between the distribution SCADA and Distribution Management System [30].

5.6.3 SCADA SYSTEMS

SCADA system stands for supervisory control and data acquisition system. It refers to the combination of telemetry and data acquisition. It commences with measurement of the data by specific devices in the field of application and collected via intelligent electronic devices (IEDs), then transferring these data to a master station to implement the necessary processing and control algorithms. The results of processing are displayed on a number of operator monitoring screens, while the control actions are conveyed back to the field of application in real time.

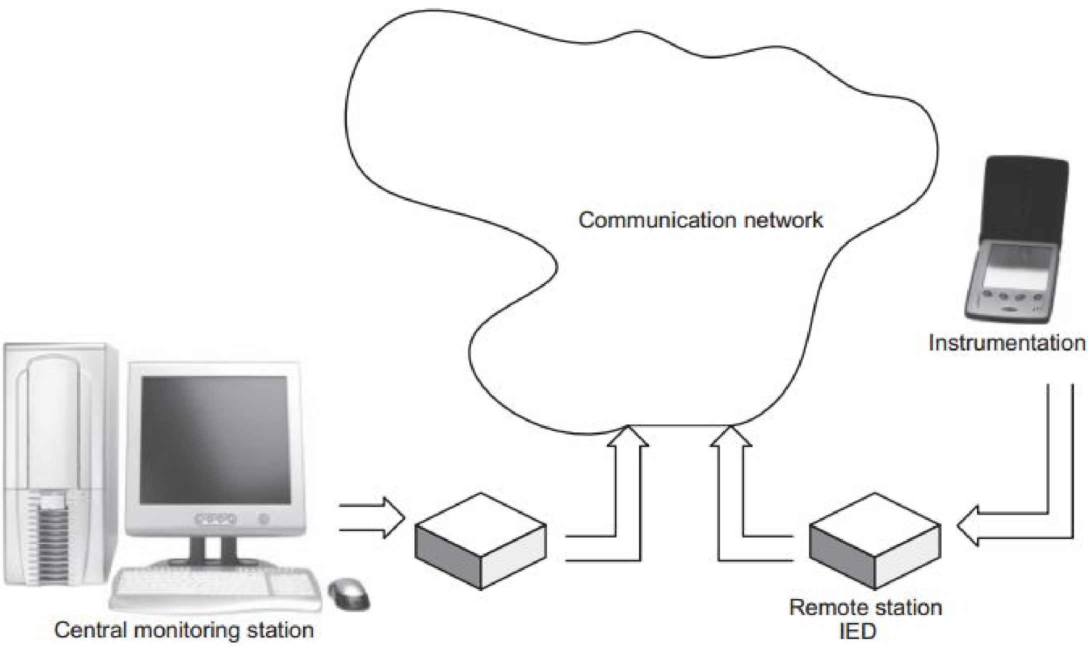

Figure 19 Elements of a SCADA system.
(Source: Electric Distribution Systems, First Edition. Abdelhay A. Sallam, Om P. Malik)

Disadvantages of the Relay System

- Complicated control systems
- Expensive systems
- Systems need more space
- Control relays consume more power, generating more heat
- Relays are used only for on/off control
- Any change in the control program needs rewiring of the relays
- It is difficult to troubleshoot and diagnose the fault for complicated control systems.

Advantages of the SCADA Systems

- Self – diagnosis,easily maintained
- Capability of arithmetic functions implementation
- Easy to program and reprogram
- Facility of communication with other controllers
- Industrial plant SCADA can be viewed as a distributed control system (DCS)
- Capability of graphical user interface (GUI) and visual display of system status.

Two major features are needed in implementing SCADA

- **Telemetry**
  Telemetry is the initial step in applying SCADA by defining the technique

used for measuring the data (voltage, current, speed, etc.) from different locations in the real - time process and transferring it to the IEDs such as remote terminal units (RTUs) or PLCs in another location through a communication circuit .

- **Data Acquisition**

  Data acquisition refers to the method used for accessing and collecting the data from the devices being controlled and monitored, and to be forwarded to a telemetry system ready for transfer to the various sites. The data may be analog or digital gathered by sensors such as ammeters, voltmeters, speedometer, and flow meter. It can also be data to control equipment such as actuators, relays, valves, and motors.

The SCADA system consists of four components as follows.

1. Instrumentation

This component refers to the devices used for monitoring certain parameters such as sensors and the devices used for controlling certain modules such as actuators. In general, these devices are connected to the equipment or machines being monitored or controlled by the SCADA system. Their main function is to convert the parameters from the physical form to electrical form as continuous (analog) or discrete (digital) signals readable by the remote station equipment (RTUs or PLCs).

2. Remote Stations

The measuring devices (first component) connected to the plant being monitored and controlled are interfaced to the remote station. Functions of remote stations are[36]:

- Gathering data from the different devices in the plant being monitored and controlled
- Holding the data gathered in its memory and waiting for a request from the master station (master terminal unit [MTU]) to transmit the data

- Receiving data and control signals from MTU and transmitting the control signals to the plant devices.

The remote station is either RTU or PLC. The RTU is used effectively in the event of difficult communications. Its inputs and outputs are shown in Figure 20. The RTU has digital/analog inputs and outputs with light emitting diode (LED) indication (selectable per channel), optically isolated for surge protection and also protected against short circuits. On the other hand, the PLC is usually expected to be already available in the plant processes, so it is of great worth to be used also in the SCADA systems. Both the RTU and PLC have been greatly improved recently.

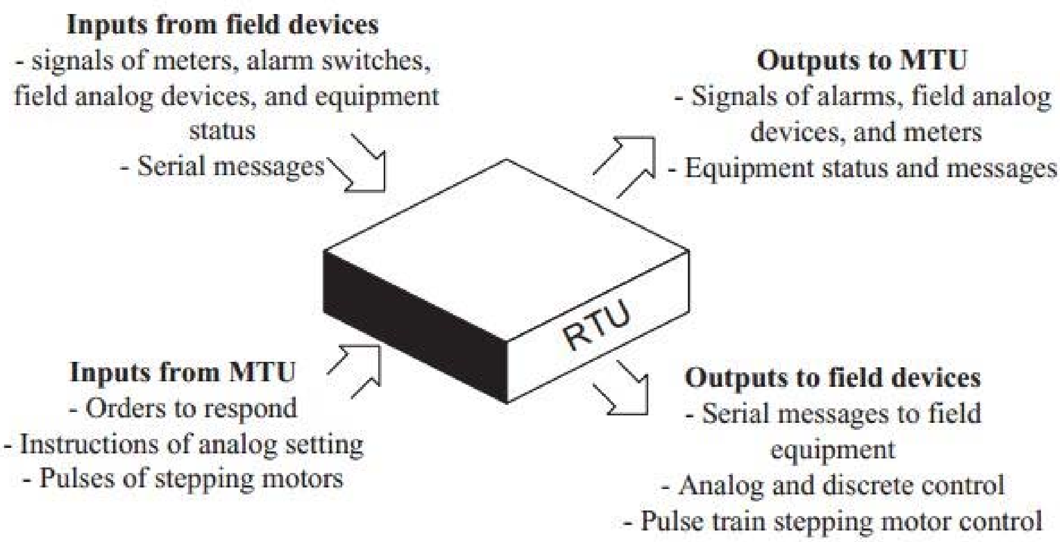

Figure 20 Remote terminal unit: inputs/outputs
(Source: Electric Distribution Systems, First Edition. Abdelhay A. Sallam, Om P. Malik)

3. Communication Networks

The geographically dispersed RTUs are connected to the MTU through a variety of communication channels, including radio links, leased lines, and fiber optics. The design of both RTUs and MTU is largely affected by the availability limitation and high cost of communication channels [36].

The hardware and software design of both MTU and RTUs must guarantee that the information is transferred correctly from the RTUs to the MTU and vice versa, and not affected by the noise occurring randomly on the communication channel.

The configuration of communication system depends on:

- Number and location of RTUs;
- Number of points at RTUs and required update rates; and
- Available communication equipment, techniques, and facilities.

The SCADA communication techniques include modulation, multiplexing, message format, and information transfer.

4. MTU

It is also called " central control station, or central station, or SCADA master. " It is considered as the heart of the system where its main functions are[36]:

- Making the communication, gathering data, storing information,
- Sending Information to other systems processing the data gathered by remote stations to generate the necessary actions
- Interfacing to the operators mainly via monitors and printers.

The inputs and outputs of the MTU are shown in the Figure.

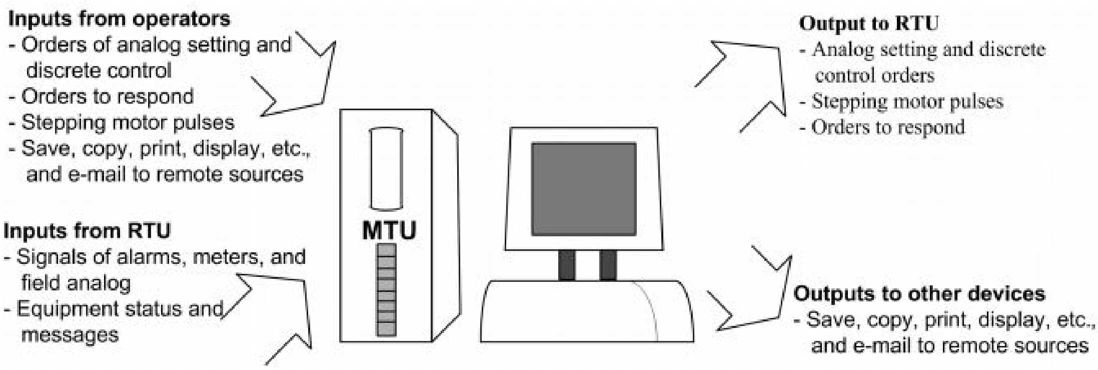

Figure 21 MTU inputs/outputs
(Source: Electric Distribution Systems, First Edition. Abdelhay A. Sallam, Om P. Malik)

Chapter 6: Challenges and Security

The Smart Grid poses many procedural and technical challenges as society migrates from the current Grid with its one-way power flows from central generation to dispersed loads, toward a new Grid with two-way power flows, two-way and peer to peer customer interactions, and distributed generation. These challenges cannot be taken lightly – the Smart Grid will entail a fundamentally different paradigm for energy generation, delivery, and use.

6.1 Procedural Challenges

It will be useful to prioritize the challenges that the Smart Grid needs to overcome first as a foundation for what is to come. The industry should collaborate to segregate the challenges into buckets to test a hypothesis under which to move forward. To address this problem, EPRI is working with several members to develop roadmaps for achieving the promise of the Smart Grid including the necessary decision trees, off ramps and schedules. The procedural challenges to the migration to a Smart Grid are enormous, and all need to be met as the Smart Grid evolves:

- **Broad Set of Stakeholders.** The Smart Grid will affect every person and every business. Although not every person will participate directly in the development of the Smart Grid, the need to understand and address the requirements of all these stakeholders will require significant efforts by utilities, system operators, third party electricity service providers and consumers themselves.

- **Complexity of the Smart Grid.** The Smart Grid is a vastly complex machine, with some parts racing at the speed of light. Some aspects of the Smart Grid will be sensitive to human response and interaction, while others need instantaneous, intelligent and automated responses. The Smart Grid will be driven by forces ranging from financial pressures to environmental requirements.

- **Transition to Smart Grid.** The transition to the Smart Grid will be lengthy. It is impossible (and unwise) to advocate that all the existing equipment and systems to be ripped out and replaced at once. The Smart Grid supports gradual transition and long coexistence of diverse technologies, not only as we transition from the legacy systems and equipment of today, but as we move to those of tomorrow. We must design to avoid unnecessary expenses and unwarranted decreases in reliability, safety, or cyber security.

- **Ensuring Cyber Security of Systems.** Every aspect of the Smart Grid must be secure. Cyber security technologies and compliance with standards alone are not enough to achieve secure operations without policies, on-going risk assessment, and training. The development of these human-focused procedures takes time—and needs to take time—to ensure that they are done correctly.

- **Consensus on Standards.** Standards are built on the consensus of many stakeholders over time; mandating technologies can appear to be an adequate short cut. Consensus-based standards deliver better results over.

- **Development and Support of Standards.** The open process of developing a standard benefits from the expertise and insights of a broad constituency. The work is challenging and time consuming but yields results more reflective of a broad group of stakeholders, rather than the narrow interests of a particular stakeholder group. Ongoing engagement by user groups and other organizations enables standards to meet broader evolving needs beyond those of industry stakeholders. Both activities are essential to the development of strong standards.

- **Research and Development**. The Smart Grid is an evolving goal; we cannot know all that the Smart Grid is or can do. The Smart Grid will demand continuing R&D to assess the evolving benefits and costs, and to anticipate the evolving requirements.

- **Having a Critical Mass.** It is unclear to the EPRI project team if the Smart Grid implementation is subject to considerations like those of critical mass needed, tipping points and penetration of implementation. There is some concern that early efforts must yield benefits in order to gather support for the development. That support may not accrue until a critical number of consumers are on board with the concepts. If everything the industry does in building the Smart Grid is amenable to a slow diffusion model for evolution as opposed to undertaking some elements in a concentrated way, those benefits may not be revealed quickly enough.

6.2 Technical Challenges to Achieving the Smart Grid

- **Smart equipment.** Smart equipment refers to all field equipment which is computer based or microprocessor-based, including controllers, remote terminal units (RTUs), intelligent electronic devices (IEDs). It includes the actual power equipment, such as switches, capacitor banks, or breakers. It also refers to the equipment inside homes, buildings and industrial facilities. Smart Equipment also includes previously electromechanical switches, reclosers, voltage controllers, and other actuated hardware that have been retrofitted with sensors and controls used to monitor state, transmit that state to an external analysis point, and execute control commands returned from that point. Some of these packages are outfitted with local intelligence, used to carry out analysis and instructions when remote analysis is unnecessary or not economical. This embedded computing equipment must be robust to handle future applications for many years without being replaced.

- **Communication systems.** Communication systems refer to the media and to the developing communication protocols. These technologies are in various stages of maturity. The Smart Grid must be robust enough to accommodate new media as they emerge from the communications industries and while preserving interoperable, secured systems.

- **Data management.** Data management refers to all aspects of collecting, analyzing, storing, and providing data to users and applications, including the issues of data identification, validation, accuracy, updating, time-tagging, consistency across databases, etc. Data management methods which work well for small amounts of data, often fail or become too burdensome for large amounts of data – and distribution automation and customer information generate lots of data. In many cases entirely new data models and techniques (such as data-warehousing and data-mining) are being applied in order to handle the immense amount of synchronization and reconciliation required between legacy and emerging databases. Data management is among the most time-consuming and difficult task in many of the functions and must be addressed in a way that will scale to immense size.

- **Cyber Security.** Cyber security addresses the prevention of damage to, unauthorized use of, exploitation of, and, if needed, the restoration of electronic information and communications systems and services (and the information contained therein) to ensure confidentiality, integrity, and availability.

- **Information and Data privacy.** The protection and stewardship of privacy is a significant concern in a widely interconnected system of systems that is represented by the Smart Grid. Data integrity and non-repudiation is needed for succinct, reliable communication across the Grid. Additionally, care must be taken to ensure that access to information is not an all or nothing at all choice since various stakeholders will have differing rights to information from the Smart Grid.

- **Software applications.** Software applications refer to programs, algorithms, calculations, and data analysis. Applications range from low level control algorithms to massive transaction processing. Application requirements are becoming more sophisticated to solve increasingly complex problems, are demanding ever more accurate and timely data, and must deliver results more quickly and accurately. One of the most prominent software development evolutions is shifting from a peer-to-peer integration environment to a services oriented architecture (SOA) built upon on a robust analysis, simulation, and data management infrastructure. Software engineering at this scale and rigor is still emerging as a discipline. Software applications are at the core of every function and node of the Smart Grid.

6.3 Additional Challenges

- **Self Healing Actions:** A Smart Grid has to be able to heal itself; meaning it should be able to take action in order to continue to deliver power after a contingency occurs. To do so, a microcontroller has to be associated to every asset of the Grid while tied through a reliable communication system linked to a central command center.

- **Renewable Energy Integration with the Grid***:* This is a very active research area. Renewable energy such as wind or solar-based generation systems when integrated with the electric grid faces a series of challenges such as:

    - Wind forecast: In order to predict the generation profile over a period of time, there is need to accurately predict the wind speed and direction and then compute the generated power from this wind. Because wind is intermittent in nature it is not easy to have accurate prediction of wind especially on the long-term.
    - Wind generation dispatch: The operation of a wind-based generation system can be considered as weather-dependent and therefore this will affect the generation dispatch.
    - Power flow optimization: Wind generation exists where there is wind blowing sites and these sites could be in different location from where

the load is. The main consequence is high transmission line congestions. Since building new lines is not economically feasible then ways to transmit this energy to different places over long distances represents a serious challenge.

    - Power system stability: The inverter in wind energy-based system decouples the wind generator from the rest of the Grid. This may have an adverse effect on system stability due to the reduced inertia especially for high level of wind penetration.

- **Energy Storage Systems***:* When relying on more renewable as energy generation systems it is essential to integrate more energy storage systems as the level of renewable-based energy generation system increases inthe electric power network in order to congest the variability and the availability of the wind. The challenges with energy storage systems are:

    - Costs: Energy storage systems are very expensive, further research is needed to reduce the cost of using those systems.

    - Complexity: The addition of storage systems is often followed by very complex analysis of the power systems. Each storage system has to be custom designed for the point of the network it is being connected. This increases even more the cost of those devices [31] .

    - Non-flexibility: the addition of a new energy storage system require a lot of studies and material which a often very costly. Every energy storage system is design for a specific network configuration and is thus not easily adaptable to changes in the network. Energy storage systems are thus often designed for a particular system and, hence, they are not flexible. With the future power Grid configuration, it becomes essential to start seeking new trends to make this technology more flexible and adaptable to various systems [32].

- **Consumers' Motivation***:* A key function of a Smart Grid is to motivate consumer to actively participate in the energy management of the Grid. This function also encounters two main challenges:

    - *Privacy:* Consumers need to communicate with utilities in order to participate in the management of their power consumption. This implies a sharing of data among the two entities. Utility can then be able to access private information about consumers since the Smart meters are always collecting data and sending them to the utility. Reference [32] raised these concerns and provided information on how to properly protect consumers from privacy invasion [32].

    - *Security:* Data collection is now being done by wireless devices. Data can then be easily intercepted and corrupted by malicious people. This can harm both consumer and utility. This issue has a bigger impact on the utility since now the consumer is able to generate and sell power to the Grid. Data corruption in this case can drive tremendous costs to the company [33].

    - *Consumer education:* The consumer still needs to be educated on why he should actively take a role in the management of his electric power consumption

- **Power Quality :** Smart Grid is required to provide power with a high quality level to consumers through the following features:

    - *Disturbance identification:* Smart Grid has to allow the proper cause of distortion in the Grid to determine if the disturbance is from the generation side or the load side. This topic is still in the early stage of research.

    - *Harmonics suppression:* In order to provide high quality power, harmonic mitigation techniques need to be developed such that harmonics are suppressed and any other power quality events such as sag, swell, spikes or variations such as over-voltage, under-voltage, voltage flicker, frequency deviations and voltage unbalance.

- **Reliability***:* Smart Grid is expected to deliver reliable power to customers. Power Grid reliability is assessed by the frequency and duration of outages. Smart Grid is required to reduce both numbers in order to improve the system reliability. The following are possible challenges facing improved reliability.
    - *Grid automation:* The power Grid has to, by itself, detect a fault, clear it, and resume the normal operating condition. Obviously, by suppressing the human interaction, repairing time is considerably reduced. But in order to achieve that, an important effort needs to be put into building a strong data routing system. Strong and reliable protection, control and communication network need to be put in place [33].
    - *Grid reconfiguration:* Another feature of the Smart Grid is its ability to break itself into smaller Grid that is autonomous during a contingency. Thus, the consumer, at the end (or start) point of the power line will experience less outages. This feature makes Smart Grid a very complex subject. Many more topics such as power system stability and generation-demand equilibrium in those smaller Grids have to be addressed in order to implement the ideal Smart Grid [33].

Chapter 7: Smart Grid Future

Smart Grid is the future of energy distribution and represent a significant field in the effort to lower global emissions. As mentioned, it creates a two-way communication between the Grid and appliances, in order to achieve a more efficient flow and consumption of electricity (reducing costs for consumers and providers, lowering waste, and making power distribution more scalable to meet growing demand).

Smart Grid seems to be a dynamic process for future management of energy. Already, last years countries have invested in this idea. For example, in 2010, China was the worldwide leader, having designated $7.32 billion for Smart Grid investment, based on data from Zpryme Research & Consulting, an Austin, Texas research and consulting firm that draws on stated federal spending figures. The U.S. was second at $7.09 billion; Japan was a distant third at $849 million and South Korea was fourth at $824 million. In Europe, Spain was first with $807 million (fifth). The other countries are in the diagram below:

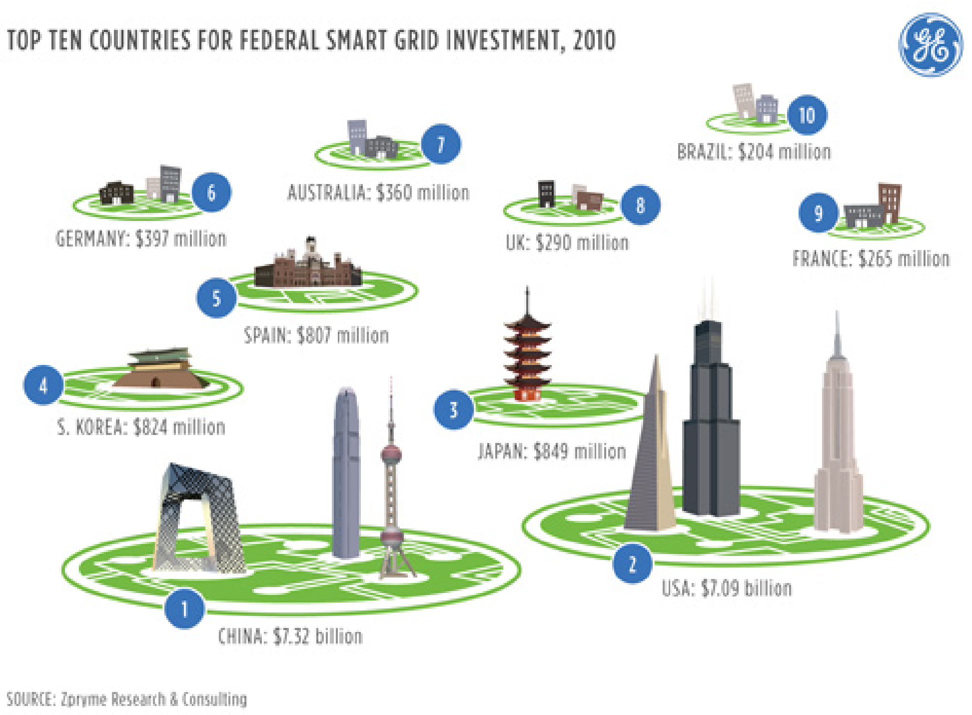

Figure 22 Top Ten Countries For Federal Smart Grid Investments

7.1 Future plans

In Asia, Smart Grid investments seem to dominate the industry over the next 10 years. According to recent industry reports, China, Japan, Korea, and India tend to be the leaders in terms of Smart Grid investments. In China Smart Grid investments will touch $99 billion and $7.18 billion in South Korea over the next decade. Japan and India are also expected to launch pilot Smart Grid programs.

Rising Smart Grid spending reflects Asia's pressing need to adopt Smart Grids to update outdated power infrastructure, meet unique power requirements, and address challenges including:

- Securing the Smarter Grids in adherence to regulations
- Increasing end-user (customer) buy in
- Establishing Interoperability between key Smart Grid stakeholders and service providers to enable seamless service

Power regulators are now actively seeking ideas, technology and strategic partnerships with the private sector to speed up the Smart Grid integration process in their respective countries.

Utilities worldwide will collectively invest more than US$378 billion in building electricity Smart Grids by 2030. But 80% of this capital spend will be concentrated in just ten countries, according to a new report by Innovation Observatory [34].

Competition to win contracts with utilities in these leading Smart Grid markets will be fierce, as the sheer scale of the investment is creating a huge appetite to supply. Technology suppliers will need to tailor their strategies for different geographic regions, and adopt different approaches depending upon their size, their legacy industry expertise and the specific part of the Smart Grid value chain they serve.

Crucial reading for metering manufacturers, distribution/substation automation equipment vendors, software vendors, communications technology suppliers, and investors, the 45-slide report is available from Innovation Observatory [35] priced at GBP1500 (plus applicable taxes.

A recent research report published by Innovation Observatory reveals that utilities worldwide will spend US$378 billion in Smart Grid technologies by 2030. However, the lion share (almost 80%) of the total investment will be taken by only 10 countries. The United States will be leading the Smart Grid investment for the next five years. By 2030, it will spend US$66 billion for intelligent Smart Grid infrastructure. Apart from Smart meters, the investment will be geared towards Grid automation, communication infrastructure, IT systems and hardware, home area network, and system integration. China, which will take over the US as the leading Smart Grid market by 2016, will supposedly spend US$99 billion by 2030, which includes roll-out of 360 million Smart Meters.

The two emerging nations India and Brazil also have massive Smart Grid investment plans and are among the top 10 list. India, which will be third largest Smart Grid investment market, is set to install 130 million Smart Meters by 2021. At present, the market in India is nascent with only few Smart meters roll out happy greened. But it seems gather the pace from 2012 onwards. During the same time period, Brazil, which will be the sixth largest Smart gird market, is set to replace 63 million Smart meters.

The other members of the top 10 includes leading European countries the UK, Germany, France, and Spain and Japan and South Korea from the Asia Pacific Region.

Top 10 List

1. China
2. USA
3. India
4. France
5. Germany
6. Brazil
7. Spain
8. UK
9. Japan
10. South Africa

6.2. Smart Grid’s cities appliance

First cities with Smart Grids

7.2.1 Italy

The earliest, and still largest, example of a Smart Grid is the Italian system installed by Enel S.p.A. of Italy. Completed in 2005, the Telegestore project was highly unusual in the utility world because the company designed and manufactured their own meters, acted as their own system integrator, and developed their own system software. The Telegestore project is widely regarded as the first commercial scale use of Smart Grid technology to the home, and delivers annual savings of 500 million euro at a project cost of 2.1 billion euro.

7.2.2 USA

In the US, the city of Austin, Texas has been working on building its Smart Grid since 2003, when its utility first replaced 1/3 of its manual meters with Smart meters that communicate via a wireless mesh network. It currently manages 200,000 devices real-time (Smart meters, Smart thermostats, and sensors across its service area), and expects to be supporting 500,000 devices real-time in 2009 servicing 1 million consumers and 43,000 businesses. Boulder, Colorado completed the first phase of its Smart Grid project in August 2008. Both systems use the Smart meter as a gateway to the home automation network (HAN) that controls Smart sockets and devices. Some HAN designers favor decoupling control functions from the meter, out of concern of future mismatches with new standards and technologies available from the fast moving business segment of home electronic devices.

7.2.3 Canada

Hydro One, in Ontario, Canada is in the midst of a large-scale Smart Grid initiative, deploying a standards-compliant communications infrastructure from Trilliant. By the end of 2010, the system served almost 1.3 million customers in the province of Ontario. The initiative won the "Best AMR Initiative in North America" award from the Utility Planning Network.

7.2.4 Germany

The City of Mannheim in Germany is using realtime Broadband Powerline (BPL) communications in its Model City Mannheim "MoMa" project.

7.2.5 Greece

In Greece, in five Aegean Islands (Lesvos, Limnos, Santorini, Milos and Kythnos) , an innovative project is planned to save energy, improve the quality of supply, succeed bill reduction, increasing penetration of Renewable Energy and automotive electrical connector to island electrical systems occurs in 5 islands.

In collaboration with RAE, PPC and NRP the Smart Grid program runs by the Network of Sustainable Aegean Islands (DAFNE) and the Aegean Energy Agency. The first stage of the project involves the study of technical and institutional issues, sponsored by the EU ELENA. The main work can begin construction in 2013 with an investment cost of more than 40 million €.

7.3 Smart Grid Projects

- **Iberdrola** is leading a three-year European initiative to study the impacts of integrating renewable energy on Grids. The Spanish energy company launched the iGREENGrid project along with 11 of the main electricity distribution companies and research institutions in Europe, with the ultimate goal being to define and pool procedures, technological advances and best practices that will contribute towards increasing the capacity of electricity Grids to receive distributed generation from renewable sources. Iberdrola points out that iGREENGrid reflects one of the most crucial lines of research in the area of Smart Grids due to the amount of renewables already connected to Grids in Germany and France
- **Duke Energy** just won an award from POWERGRID International magazine and PennWell Corp. for a similar initiative. Its battery installation at a North Carolina substation was named Project of the Year for integrating renewable energy into the Grid. At the Rankin Substation, a 402-kilowatt/282-kilowatt-hour sodium nickel chloride battery system is being used to smooth out large

minute-by-minute peaks and valleys in production from a nearby 1.2-megawatt solar facility at a local industrial complex. "We have to explore every avenue to make sure the Grid can handle the influx of more renewables," said Dan Sowder, Duke's senior project manager. "We want to see if a central battery installation at a substation can support the Grid. In the future, there may be neighborhoods full of rooftop solar. We need to be ready for that."

- **A Los Alamos National Laboratory** quantum cryptography (QC) team successfully completed what it says is the first-ever demonstration of securing control data for electric grids using QC. According to a news release from the lab: "Novel methods for controlling the electric grid are needed to accommodate new energy sources such as renewables whose availability can fluctuate on short time scales. This requires transmission of data to and from control centers; but for Grid-control use, data must be both trustworthy and delivered without delays. The simultaneous requirements of strong authentication and low latency are difficult to meet with standard cryptographic techniques. New technologies that further strengthen existing cybersecurity protections are needed. Quantum cryptography provides a means of detecting and defeating an adversary who might try to intercept or attack the communications."
- **Southern California Edison** (SCE) is moving closer to the June 30 launch of its stimulus-supported Irvine project designed to demonstrate Smart Grid solutions in the real world. SCE is working with GE and others on the project, which includes automation and communications in the substation and across power lines to Smart meters, Smart appliances, rooftop solar and plug-in electric vehicles in homes. “We’re moving the Smart Grid discussion from engineering and concepts on the drawing boards to our customers,” said Doug Kim, SCE director of Advanced Technology. “Consumers who have been hearing about a Smarter electric grid will now experience it firsthand. With increased insight, more options and greater control over their energy usage, consumers in this demonstration project will help us engineer a better energy future.” GE says the demonstration project will help participants fine-tune the

software, communications, automation, hardware and network management tools that will make an advanced energy infrastructure possible.

- **The Pacific Northwest Smart Grid Demonstration Project**, hailed as the **country's largest**, has released its 2012 Annual Report. "Our project completed its infrastructure design, development and deployment phase and is now well into end-to-end testing of transactive control in the crucial data collection and analysis phase," noted Project Director Ron Melton of Battelle in the report's introduction. Melton says this current phase may be the most important. "Initially, we will examine the performance of our transactive control system and improve the algorithms affecting the behavior of approximately 12,000 Smart Grid-responsive assets, which include solar panels, water heaters, Smart appliances, battery storage units, plug in hybrid vehicles and backup generators," Melton said. "We are also collecting data about the benefits of approximately 80,000 Smart Grid enabled assets, such as Smart meters, Smart transformers, and distribution automation equipment. We will be able to draw a few preliminary conclusions about how a Smart Grid on an even wider scale could look like." The five-year, $178-million project involves 60,000 electric consumers across five states Funded by DOE and project partners, it involves Battelle, the Bonneville Power Administration, 11 utilities and five technology partners.
- **PON technology in China**
  An interesting piece in the MIT Technology Review highlights a Smart Grid pilot that State Grid Corporation of China is rolling out to test passive optical networking (PON) technology, described as high-bandwidth data wiring that can be run inside electric power cables without interference. The thinking is that the technology can not only make the electric grid more efficient and reliable, but could also be a conduit for delivering high-speed Internet, TV and telephony. As the article points out, there's difference of opinion on whether it's something U.S. utilities would or should consider, but it's an interesting read either way.
- **Making energy storage more economical in Washington State**

A partnership between the Snohomish PUD in Washington State and 1 Energy Systems will develop and deploy an approach to energy storage aimed at helping electric utilities increase their use of renewable energy and improve overall reliability. Under the partnership, 1Energy will provide a one-megawatt battery energy storage system, built on a Modular Energy Storage Architecture (MESA). The system, based on commercially-available, advanced technology batteries, will be housed in a standard shipping container, which will be installed at a PUD substation. Alstom Grid and faculty at the University of Washington are also collaborating on the project.

- **Trialing Echelon control nodes in Concord, MA**

  Concord Municipal Light Plant (CLMP) recently completed an initial trial of Echelon's Edge Control Node (ECN) 7000 control nodes, which were deployed at strategic locations within the town of Concord, Massachusetts. According to Echelon, ECN’s open architecture enabled custom hardware and software expansion to automate the collection of data from legacy non-AMI meters, extending the useful life of these meters while offering a means for back office integration and meter data analysis. One node was placed next to a critical distribution transformer, enabling it to also monitor the transformer and provide near real-time measurements of power quality data. Turning such legacy transformers at key locations into “Smart transformers” without forklift replacement offers Concord a very cost-effective way to track the health of its distribution transformers.

- **Developing microGrids in remote areas of Argentina**

  A Duke Energy International project is bringing renewable electricity to a pair of remote areas of Argentina that have no reliable access to power. Developing each project as a microGrid -- providing power to two small towns that will remain unconnected to the nation’s Grid -- will not only help residents of the towns but also provide technical information about microGrid operations, says John Stowell, VP of international stakeholder relations in Duke’s sustainability department. The projects are small -- a 65-kilowatt hydroelectric dam and a 75-kilowatt wind project. Duke will operate them for two years, training local power company employees to eventually take over the operations. The project is through the Global Sustainable Energy Partnership.

- **Targeting hard-to-reach meters in Scotland**

  A trial in Scotland that targeted hard-to-reach meters in densely populated urban areas in Glasgow as well as rural locations to simulate GB-wide rollout conditions has been deemed a success. ScottishPower was able to connect over 99% of meters in the trial areas with a single installation visit to each home, using SmartReach's long-range radio communications solution alone. The trial covered meters located outside and deep inside buildings, in basements and in flats across rural and dense urban areas. SmartReach used Arqiva's existing tower infrastructure, the Sensus FlexNet Smart metering communications solution and Smart meters from EDMI for the trial.

- **MALTA**: Integrated Utilities Business Systems Organization: Enemalta Corporation and Water Services Corporation, (MT) Period: Sept 2008 - Sept 2013 Project category: Smart Meter and AMI Project Description: Replacement of 250,000 meters with Smart meters and implementation of remote management. SCADA for voltage levels 132kV, and 33kV. Reengineering of the utilities processes.

7.4 Concerns

The Smart Grid brings to utilities, consumers, and society a range of benefits and risks. It will help utilities reduce costs, better manage assets, and minimize the frequency and duration of outages. It will allow customers to lower their electric bills by planning their consumption in real time, by moving discretionary energy-intensive activities to off-peak periods and modifying or even eliminating the use of inefficient appliances to reduce costs and protect the environment. It will benefit society by improving the operation of the national energy Grid, lowering emissions from fossil fuel generation, and encouraging the use of renewables. But with these benefits comes the challenge of balancing the risks caused by the potential mishandling of the new, highly-granular consumer energy consumption data against the rewards of a robust Smart Grid.

Although Smart Grid derives from a vision about renewable energy, better life, economic benefits, there are a lot of concerns about the following:

1. customers wander who is going to collect their consumption habits, what for, and what about their privacy
2. if there is any prediction about computer security
3. concerns over giving the government mechanisms to control the use of all power using activities, and
4. social concerns over "fair" availability of electricity,
5. social concerns over Enron style abuses of information leverage,

The following table shows the reasons for concerns by clients [54].

Table 10Energy Data Disclosure Concerns

Appliance Use	Activity Disclosure Risk – Low	Activity Disclosure Risk – Medium	Activity Disclosure Risk – High
Hot water heater	Washing clothes		Bathing
Lights	At home and awake		Number of loads per day/week could reveal home occupancy levels
Microwave/stove/oven	cooking	Shows daily work schedule	
Hair dryer		Post shower-getting ready for work/other activity	On/off times may identify daily schedule

dishwasher	Washing dishes		No usage for long periods may signify vacation
TV	At home and watching		On/off times may identify daily schedule
Air conditioner/heat pump	Cooling/heating		On/off times may identify daily schedule
Computer	Working/surfing the net		Risk for theft
Alarm system	Home or away		
Medical equipment		Customers may not want others to know they are on oxygen, dialysis, or some other treatment regimen	Violation of HIPPA rules

7.5 Answers to concerns

7.5.1 Schedule, organisation and protection

About privacy, the National Association of State Utility Consumer Advocates (NASUCA) taking into account clients" concerns- comments to the U.S. DOE., NASUCA that consumers both generate the data transmitted over the Smart Grid and pay for the meters that transmit it (via their electric rates). Therefore, NASUCA asserts [53], the customer must: a) own her or his home energy usage data, b) have consistent access to that data for personal review in a usable format, c) be fully informed of what data is flowing to and from the meter, to whom the data is flowing, and with what frequency the data is communicated [53].

Also, regulators will determine who should receive any monetary compensation derived from the sale of Smart Grid data, through what process, and with what constraints and procedures. The National Association of Regulatory Utility Commissioners (NARUC) notes that Smart Grid poses significant privacy issues that need to be considered and resolved by regulators. It is proposed that four components of Smart Grid Policy Depend on Intent and Need such as: a) define with whom will be shared the information utilities will collect, for what purpose and what protection will be required, b) ensure that the customers understand what data will be shared and under what terms and conditions, c) require privacy training programs which will include yearly train utility employees, require certification and audit compliance, d) enforce and revise as report privacy breaches, amend processes to correct errors and review and evaluate [53] [54].

Yet, the electric industry incorporating with information technology (IT) systems tries to improve reliability and efficiency. There is concern that if these efforts are not implemented securely, the electric grid could become more vulnerable to attacks and loss of services. To address this concern, the Energy Independence and Security Act of 2007 (EISA) provided NIST and Federal Energy Regulatory Commission (FERC) with responsibilities related to coordinating the development and adoption of Smart Grid guidelines and standards.

GAO was asked to (1) assess the extent to which NIST has developed Smart Grid cybersecurity guidelines; (2) evaluate FERC’s approach for adopting and monitoring Smart Grid cybersecurity and other standards; and (3) identify challenges associated with Smart Grid cybersecurity. To do so, GAO analyzed agency documentation, interviewed responsible officials, and hosted an expert panel.

7.5.2 What GAO Recommends

GAO recommends that NIST finalize its plan and schedule for updating its cybersecurity guidelines to incorporate missing elements, and that FERC develop a coordinated approach to monitor voluntary standards and address any gaps in compliance. Both agencies agreed with these recommendations.

With respect to challenges to securing Smart Grid systems, GAO identified the following six key challenges:

Aspects of the regulatory environment may make it difficult to ensure Smart Grid systems' cybersecurity.	Consumers are not adequately informed about the benefits, costs, and risks associated with Smart Grid systems.
Utilities are focusing on regulatory compliance instead of comprehensive security.	There is a lack of security features being built into certain Smart Grid systems.
The electric industry does not have an effective mechanism for sharing information on cyber security.	The electricity industry does not have metrics for evaluating cyber security

Specifically, GAO recommends that the Commission develop an approach to coordinate with state regulators to (1) periodically evaluate the extent to which utilities and manufacturers are following voluntary interoperability and cyber security standards and (2) develop strategies for addressing any gaps in compliance with standards that are identified as a result of this evaluation. Further, to the extent that the Commission determines that it lacks authority to address any gaps in compliance, GAO recommends that the Chairman report this information to Congress. The report recommends that the Commission take these same measures with groups that represent municipal and cooperative utilities.

Conclusion

As a result of the new social, economic and environmental trends is the increasing demand for more productivity and effectiveness of power Grid. Caring about the protection of the environmental standards, the need for advanced exploitation of the existing energy distribution network by integrating advanced sensing technologies, control methods and communications networks into it, the idea for Smart Grid seems to be the best..

The convergence of the existing power delivery infrastructure with the information communications technology will lead to an innovative energy distribution Grid that will provide new capabilities and significant advantages to participating entities. The evolution of next generation electric power systems also seems as a promising solution for energy problem along with the constraints of Tokyo convention regarding carbon emission and the compliance of each country with it. Thus, energy providers, policy makers, regulation authorities and various enterprises have shown great interest on opportunities arousing by the development of Smart Grid technology in the fields of automation, advanced data collection, control, broadband telecommunications, intelligent appliance interoperability, security, distributed power generation and renewables effective integration

Energy dependence on foreign sources, in combination with the global warming consequences are the main motives for every country to develop a new independent, as possible, energy status.

Smart Grid effort is expected to benefit not only the pair consumers and utilities, but also countries' economies, the power industry and, of course, the environment. Energy concumers, utilities, device producers will have the possibility to use new tools, functions (e.g. automating distribution management with meter reading and trouble healing), charging electric vehicles (EV), monitoring and adjusting energy usage in —real time, delaying or even canceling the need for new generating capacity, and allowing remote service installation and management.

People expect many benefits from Smart Grid appliance—such as empowering greater consumer choice in energy use, improving the reliability of power generation and distribution e.t.c. Advantages seem to be many as it integrates information, communication, and intelligent control technology, in the electrical system, providing modern methods to maintain reliability and improve flexibility. Energy efficiency, peak reduction, efficiency of the appliances, reduction of the cost of energy usage are some of the goals of Smart Grid.

However, questions are raised about the kind of information utilities and others will gather about the customers, who is going to have that information, who will have access to it, if the consumer will be aware of it (about who knows his consumption data from his Smart metering and habits). The share of data among the consumers, the utilities and who others, is a very important privacy issue. NARUC (National Association of Regulatory Utility Commissioners) estimates that Smart Grid raises important privacy issues, that must be considered and pointed out by anyone involved.

The development of electricity networks and funding of research programs will be determined mainly by the energy policy of the countries. According to the figures to date intelligent networks are the future of electricity networks.

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