Smart Grid Capabilities, Infrastructure, Impact on Power Suppliers/Consumers and Concerns

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ABSTRACT

This paper dwells on the need to integrate existing traditional sources of supply and the renewable sources in order to establish a new energy system which is energy efficient, reliable, controllable, secure, compatible, economical and sustainable. Smart grid can overcome existing and future challenges in a cost effective manner. In this paper, the main focus is on the smart grid infrastructure, its capabilities, communication scenarios, technologies and energy management. The implementation of the vision of modernized intelligent smart grid can overcome problems and challenges of traditional electricity grids and utilities. The paper also focuses on the services and factors that attract the consumers and utilities to change the way they operate in order to improve the current services. Various measures are proposed to help in implementation and adoption of smart grid vision in Pakistan. Finally, paper presents smart grid research programs, deployments, issues and concerns.

KEYWORDS – smart grid, renewable sources, load patterns, infrastructure, utilities, compatible, sustainable, scenarios.

1. INTRODUCTION

The term smart grid refers to the next generation electrical power grid in which information, communication and control technologies are used to collect process and transfer data/information between utility companies and customers in an automated manner with negligible delays [1]. A fully automated smart grid as shown in figure-1 has the following benefits over a traditional electric grid:

- Power flow is bi-directional in smart grid while uni-directional in traditional grid [2].
- Power generation is distributed in smart grid while centralized in traditional grid.
- Customers participate in smart grid as against in the traditional grid.
- Smart grid accessibility is expandable while of traditional grid is limited. e.g., enabling transition to plug-in-vehicles [3]
- Smart grid is environmental friendly as against that traditional girds.
- Power storage is possible in case of smart grid.
- Smart grid offers real time communication between suppliers, consumers, smart devices and regulating authorities as compared to traditional grid.
- Reliability, stability, controllability, efficiency and economics of smart grid is higher than that of traditional grid.
- Smart grid uses sensors throughout the network as against in traditional grid.

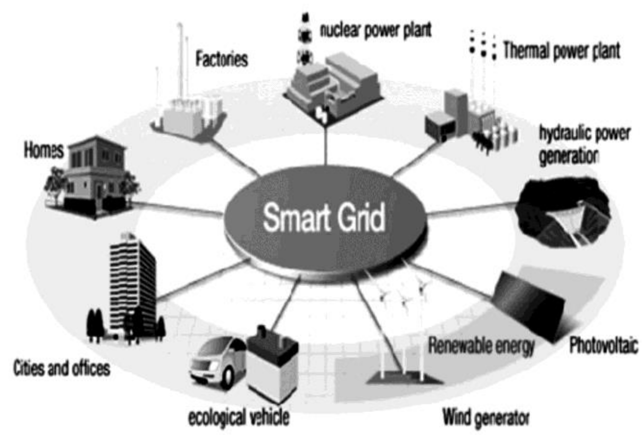

Figure-1: Pictorial Concept of Automated Smart Grid [4]

2. CAPABILITIES OF SMART GRID

Reliability: Smart grid ensures the reliability of the system. It detects and removes electrical faults automatically. Network Flexibility & Integration: Smart grid facilitates centralized as well as distributed energy sources. Traditional energy generation units and distributed generation units like solar systems, fuel cells, wind turbines, pumped hydroelectric power plants and superconducting magnetic coils may be integrated to improve system efficiency and flexibility [5].

Transmission Enhancement: : Smart grid uses FACTS (Flexible AC Transmission Systems), HVDC (High Voltage DC Systems), DLR (Dynamic Line Rating Technology) and HTS (High Temperature Superconductors) to improve transmission efficiency [6].FACTS and HVDC technologies are used to enhance the controllability of transmission line and optimize power transfer capability.DLR indentifies current carrying capability of a section of a network and optimizes utilization of existing transmission assets.HTS are used to reduce transmission losses and limit fault currents.

Load Management: In smart grid, efficiency of the power usage can be increased by managing the load at consumer side. Power plants do not need to produce extra energy during peak-load hours.

Demand Response Program: Smart devices installed at utility side and consumer side share information with each other using communications technologies and remote switching is made in accordance with the consumer choice.

Utility companies can reduce consumption by communicating directly to devices installed at consumer end in order to prevent system overloads [7].

Power Quality: Smart grid provides different grades and prices of power to different customers. Customers get uninterrupted supply with better rates. Faults can be cleared in short time.

Environmental Capabilities: Smart grid helps to reduce greenhouse gases and other pollutants by reducing generation from inefficient energy sources and supporting renewable energy resources. It also replaces gasoline-powered vehicles with plug-in-electric vehicles.

3. HARDWARE INFRASTRUCTURE

Advanced Metering Infrastructure (AMI): Smart meter is usually an electrical meter that records consumption of electric energy in intervals of hours or less and communicates that information at least daily back to the utility for monitoring and billing purposes. AMI performs the following functions:[8]

- Demand Response Program (DRP) to consumers to reduce energy bills
- Smart metering to collect, store and report customer energy consumption data to control centers for bill generation
- Detection of losses and thefts
- Connection and disconnection of supply

Distributed Energy Storage Infrastructure: Distributed energy sources like wind, solar, biomass etc are integrated with traditional energy sources. Energy of renewable sources is stored in batteries and used for dc as well as ac loads. Addition of this energy optimizes efficiency, reliability and stability of the power supply system. . Main obstacle for employing additional flexible storage solutions such as batteries or pumped storage is their relatively high cost.

Electric Vehicle (EV) Charging Infrastructure: EV infrastructure of smart grid handles charging, billing and scheduling of electric vehicles. An electric vehicle is defined as a vehicle with an electric battery that can be charged from the network, i.e. Plug-in-Hybrid electric vehicles.

Home Energy Management Systems (HEMS):Smart appliances such as refrigerators ,air-conditioners, fans, washing machines, etc offer great control and reduce overall electricity consumption. Digital signal controllers deliver precise control of all smart appliances. HEMS are the interface between smart grid and domestic energy objects. Home energy management collects real time energy consumption data from smart meter and from various house objects. Consumers can see how their energy usage affects their costs and they can change their behavior.

Communication Infrastructure: Communication infrastructure used in smart grid includes:

1. Wide Area Network

2. Field Area Network

3. Home Area Network

When control centers are located away from consumers and substations, then wide area network (WAN) is used to transport real-time measurements of electronic devices to/from control centers and between different IEDs (Intelligent Electronic Devices). Smart devices are installed along power transmission lines, distribution lines, intermediate stations and substations to get messages/information and activate control as well as protection commands received from control centers. IEDs are micro-processor based smart electronic devices used for protection, local and remote monitoring and controlling a power station.

Field area network (FAN) is used to share and exchange information between applications and control centers that cover distribution domain. Field based applications like transmission lines, transformers, circuit breakers, relays, sensors, voltage regulators, etc use SCADA for exchange of information or data.

Customer based applications (houses, buildings, industrial users, etc) use AMI, DR (Demand Response), LMS (Load Management System), MDMS (Metering Data Management System), etc. for information and data exchange [5].

Home area networks (HAN) monitor and control smart devices in the customer domain. In customer domain, ESI (Energy Service Interface) is used between the utility and the customers to share information. Customer devices like fan, refrigerator, air-conditioner, etc are connected to smart meter via ESI and smart meter communicates with the utility to exchange information.

4. COMMUNICATION TECHNOLOGIES

Different communication technologies are used for message and data transfer in transmission, distribution and customer domains of smart grid. The available network technologies are:

1. Power line communication technology
2. Dedicated wire line communication technology
3. Wireless communication technology

In power line communication, power lines are utilized for electrical power transmission as well as data transmission. Typically data signals cannot propagate through transformers and hence the power line communication is limited within each line segment between transformers.

Dedicated wire-line cables separate from electrical power lines are used for data transmission. Dedicated transmission medium may be copper wire, coaxial cable, SONET, SDH, Ethernet and DSL. SONET (Synchronous Optical Network) is the international transmission standard for optical networks which gives much more data rates. SONET speeds are classified as optical carriers 1 (OC-1) to optical carriers 192 (OC-192).

Wireless communication networks are generally employed for short distance communication and transfer data at low rate. A number of wireless network standards are available to transfer data from utility to consumer and vice versa. The standard802.11 is widely used for LAN which transfers data at 150 Mbps up to 250 m. The standard 802.16 is used for broadband wireless internet communication. It sends data packets at data rate of up to 100 Mbps and covers 50 Km area. WiFi and ZigBee networks are used for home applications [9].

5. COMMUNICATION SCENARIOS

Communication scenarios represent data flow in smart grid infrastructure that may help for energy management. Following communication scenarios are illustrated:

Substation Control Scenario: Real-time monitoring and control of substation is achieved using local area networks (LAN), wireless WAN and Ethernet as depicted in figure-2 [10]. Special sensors are installed to take the equipment status samples, these samples are processed, digitized and sent to control center of substation for appropriate action. Each switch processes information and sends processed message to control center. Network delay for maintenance purpose is about 1 sec, for real-time monitoring and control is about 10 ms and for equipment fault information is about 3 ms.

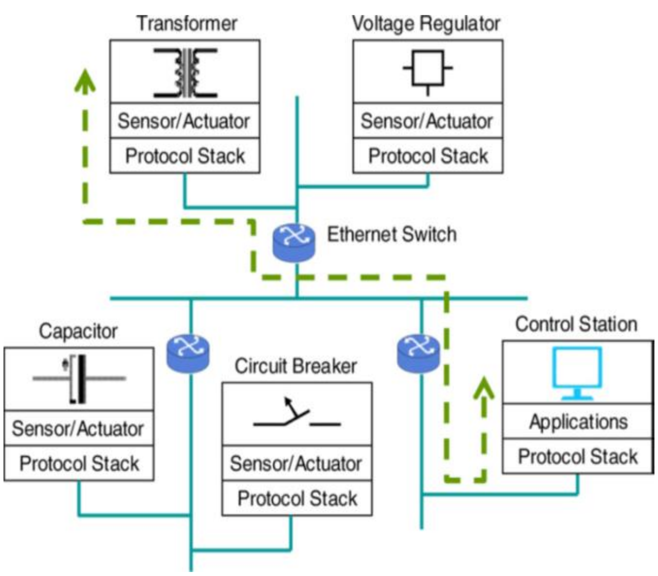

Figure-2: Substation Control Scenario

Transmission Line Monitoring Scenario: Sensors installed along power lines collect real-time data for line monitoring and control as laid out in figure-3 [10]. Data is digitized and transmitted to control center through wide area network. Transmission delay for fault message should not exceed 3 ms.

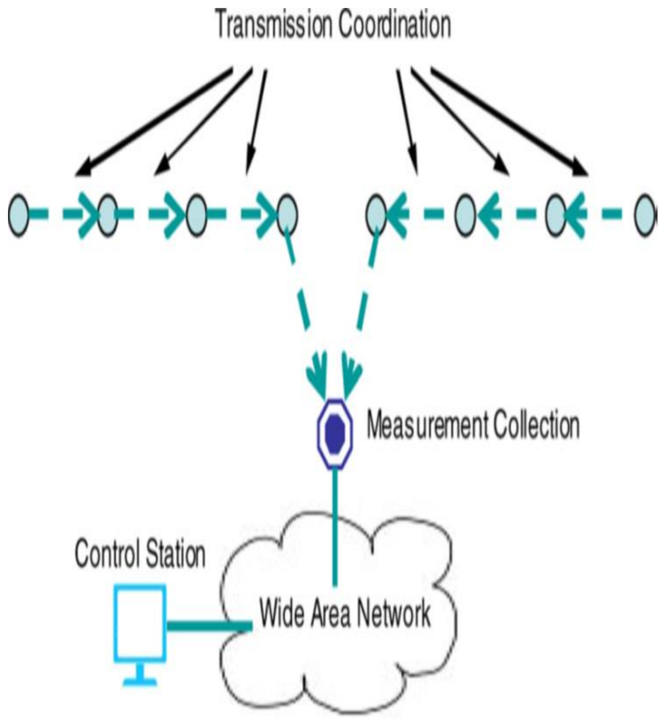

Figure-3: Transmission Line Monitoring Scenario

Automatic Meter Reading Scenario: Smart meters send meter readings automatically to utility companies over network for customer bill generation as shown in figure-4. Communication delay for meter readings is acceptable for few seconds.

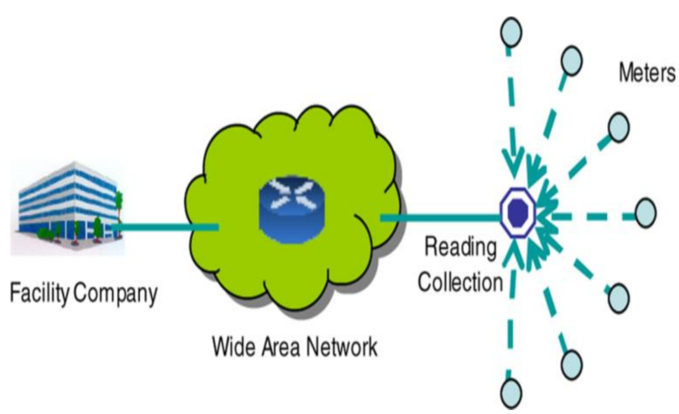

Figure-4: Automatic Meter Reading Scenario

Demand Response Decision Making Scenario: In smart grid, communication network will facilitate suppliers and customers for energy trading as shown in figure-5[10]. Network delay of a few seconds is acceptable to catch up with dynamic market states.

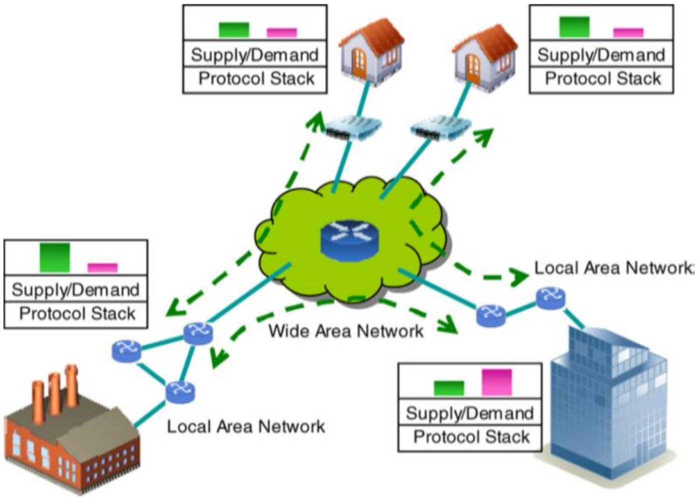

Figure-5: Demand Response Decision Making Scenario

Energy Usage Scheduling Scenario: Customers can take advantage of dynamic energy prices to reduce energy cost by scheduling time of low energy prices. Prices are low at night because demand of energy decreases when factories, schools, universities and office buildings are closed. Prices are high during daytime because electricity is largely used. This scenario is depicted below in figure-6 [10].

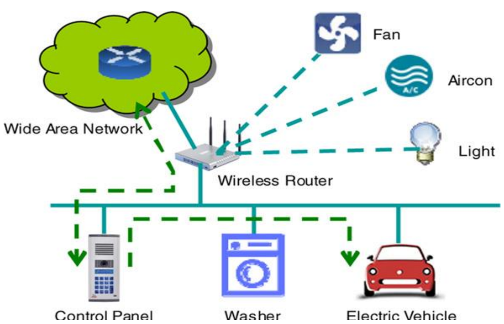

Figure-6: Energy Usage Scheduling Scenario

6. IMPACT OF OPTIMIZED AUTOMATED SMART GRID ON SUPPLY COMPANIES

- Real time status monitoring of network and smart devices
- Quick fault detection, location and troubleshooting
- Network self restoration and reconfiguration
- Direct reduction of energy usage having direct control on consumer appliances
- Increased capability of distributed generation
- Reduced transport losses
- Reduction of carbon emissions
- Usage of energy storage options
- Increasing network power load factors

7. IMPACT OF AUTOMATED SMART GRID ON POWER SUPPLY CONSUMERS

- Availability of uninterrupted quality supply
- Promotion of energy usage scheduling
- Plug-in-charging of hybrid vehicles
- Pollution free environment
- Mitigation of energy thefts

8. MAJOR RESEARCH PROGRAMS

IntelliGrid Program (U.S): Started by EPRI to replace traditional grid system by smart grid in order to improve quality, availability and controllability of supply delivery system. IntelliGrid provides funds worldwide to promote global research efforts and is also supplier of smart grid components [11].

MGI - Modern Grid Initiative(U.S): A number of bodies like DOE, NETL, utility companies, customers, and researchers are doing efforts to develop a fully automated modern smart grid [12].

Grid 2030 (U.S) Program: Joint program of government and non-government bodies to improve existing grids including generation, transmission, distribution and utilization. The vision of Grid 2030 program is to develop a more flexible, reliable, controllable and efficient electric power delivery system for United States. Universities, research laboratories, R&D departments, industries, government departments and investors are doing efforts to meet smart grid targets [13].

GridWise Program (U.S): This program facilitates utility companies and consumers to modernize electric power delivery system. It is a joint effort started by different government and non-government departments to implement the vision of smart grid in America. It provides funds, technology, software and hardware infrastructure and assistance to improve electric power delivery system [14].

GridWise Architecture Council (GWAC): Made by U.S, DEO to enhance interoperability between different smart devices in the electric supply system. GWAC provides consultancy to industry and utility companies regarding improvements in electric power delivery system [15].

GridWorks Program (U.S): The aim of this program is to improve efficiency, reliability, controllability, availability and safety of power electric system by optimizing the grid components. GridWorks emphasis on high quality cables, supper conductors, modern substations, reliable protective systems, harmonic free power electronic devices, flexible distribution systems, reliable transmission systems, distributed integrated technologies and energy storage technologies [16].

9. DEPLOYED SMART GRIDS

Enel (Italy) Smart Grid:1st smart grid project, Completed in 2005, project cost – 2.1 billion euro, annual saving – 500 million euro [17].

Austin, Texas (U.S) Smart Grid: Working since 2003, currently managing 500,000 real-time devices, servicing 1million consumers & 43000 businesses [18].

Boulder, Colorado Smart Grid:1st phase completed in August 2008 [19].

Hydro One Smart Grid: Ontario – Canada, servicing 1.3 million customers since 2010 [20].

10. ISSUES & CONCERNS

- New and immature technology
- Shortage of experts to implement smart grid
- High initial implementation cost
- No consumer privacy
- Complex (variable) rate systems
- Remotely-controlled supply concerns
- Emission of RF signals from smart meters

11. PROPOSALS FOR IMPLIMENTATION OF SMART GRID VISIONIN PAKISTAN

Government of Pakistan has initiated various projects on solar, wind and biomass power generation at different areas to meet demands of increasing loads and this distributed generation is to be added to national grid. In order to implement vision of smart grid, following points needs to be considered:

- Government must make effective and clear policies on future energy supply.
- National and international investors must be encouraged and facilitated in all respects to import infrastructure, technology and standards.
- Small projects regarding renewable energy (solar, wind, biomass, etc) be initiated and integrated to overcome existing and future power shortage crisis.
- Power energy departments be headed by qualified, eligible, dedicated, devoted and experienced persons to manage and implement vision of smart grid.
- Tax free import of hardware and technology be ensured.
- Universities, researchers and R&D departments be funded to carry out research projects to improve power delivery system using smart grids.

12. CONCLUSIONS

It is concluded that smart grid is expected to relieve the energy shortage problems by integrating renewable energy resources and two-way communication network may help for cost effective energy management.

Further, the issues of aging power infrastructure, work manpower, power theft, pollution free environment, electric power quality, availability, stability and controllability can be solved by deploying smart grids.

Smart grid infrastructure, communication technologies, communication scenarios, impact on utilities and consumers, research programs and smart grid deployments have produced new issues and concerns.

This work summarizes that fruitful collaborative efforts are still required from industrialist, transmission and distribution companies, power researchers, power monitoring bodies, government officials, power traders, policy makers, consumers, power equipment manufacturers and software experts to integrate and optimize emerging technologies for implementation of smart grid.

13. REFERENCES

[1] Ye Yan, “A survey on smart grid communication infrastructure: Motivations, Requirements and Challenges” IEEE communications surveys & tutorials, vol. 15, NO. 1, First Quarter 2013

[2] Xi Fang, “Smart Grid – The New and Improved Power Grid” IEEE communications surveys & tutorials, vol. 14, NO. 4, Fourth Quarter 2012

[3] Fangxing Li, “Smart Transmission Grid: Vision and Framework” IEEE transaction on smart grid, Vol.1, September 2010.

[4] Xiang Lu, “An Empirical Study of Communication Infrastructures towards the Smart Grid”, IEEE transaction on smart grid, Vol-4, NO. 1, March 2013

[5] Xi Fang, “Smart Grid – The New and Improved Power Grid” ” IEEE communications surveys & tutorials, vol. 14, NO. 4, Fourth Quarter 2012

[6] Chun-Hao Lo, “The Progressive Smart Grid System from Both Power and Communications Aspects” IEEE communications surveys & tutorials, vol. 14, NO. 3, Third Quarter 2012

[7] Chun-Hao Lo, “The Progressive Smart Grid System from Both Power and Communications Aspects” IEEE communications surveys & tutorials, vol. 14, NO. 3, Third Quarter 2012

[8] Daojing H, “An Enhanced Public Key Infrastructure to Secure Smart Grid Wireless Communication Networks” IEEE networks January/February 2014

[9] Zhong Fan “Smart Grid Communications: Overview of Research Challenges, Solutions, and Standardization Activities” IEEE communications surveys & tutorials, vol. 15, NO. 1, First Quarter 2013

[10] Wenye Wang, Yi Xu, Mohit Khanna "A survey on the communication architectures in smart grid", computer networks 55 (201) 3604-3629, www.elsevier.com

[11] "Electric Power Research Institute (EPRI)" www.epri.com/IntelliGrid(online)

[12] U.S. Department of Energy, National Energy Technology, Modern Grid Initiative, www.netl.doe.gov (online)

[13] U.S. Department of Energy, Office of Electric Transmission and Distribution, "Grid 2030" www.oe.energy.gov

[14] U.S. Department of Energy, Office of ElectricityDelivery and Energy Reliability, GridWorkswww.gridwise.org

[15] GridWise Architecture Council Interoperability Context Setting Framework, www.gridwiseac.org

[16] U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability, GridWorks www.oe.energy.gov

[17] NETL Modern Grid Initiative-Powering Our 21 st Century Economy, www.netl.doe.gov

[18] "Building for the future": Interview with Andres Carvallo, CIO-"Austin Energy Utility"www.nextgenpe.com

[19] Betsy Loeff (2008-03), "AMI Anatomy: Core Technologies in Advanced Metering" Ultrimetrics Newsletter, www.mvv.de

[20] Best Loeff, Demanding Standards: Hydro One aims to leverage AMI via interoperability www.elp.com

14. BIOGRAPHIES

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