Chapter - 1

INTRODUCTION

CHAPTER-1

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This chapter illustrates an introduction to Smart grid technology. Overview and motivation for this research are also discussed. This chapter also includes theoretical and experimental research methodologies implemented for prototype development. Chapter scheme is also illustrated to explore succeeding chapters.

1.1. OVERVIEW

The power grid around the world is going through a massive and radical transformation through Smart grid technology. Smart grid is the most inventive and imaginative technology of existent era. An existing power grid is lacking reliability, remote monitoring and control, automation, sensing, disaster recovery, security and efficiency. Smart grid technology is an integration of electrical and communication infrastructures with full duplex flow of energy and information. It ensures reliable power distribution through real time monitoring and control of generation, transmission and distribution parameters. Smart grid is designed to provide demand side management through implementation of smart meters, distribution automation, micro power generation, storage of electricity and SCADA.

Consumer has no role to play in an existing power grid. Smart grid necessitates active participation of consumers. Consumers can be a part of generation by energy generation through renewable energy resources. They can also alter their consumption pattern as well as sell excess energy to grid. Microgrid is an imperative feature of Smart grid technology to increase the penetration of renewable energy resources. Microgrid facilitates and expedites the use of renewable energy resources for reduction of carbon emissions.

IoT is an integral component of Smart power grid as it is a hierarchical network of interconnected networks and IEDs. Real time monitoring and control is facilitated by IoT as devices upload their near real time statistics and download the commands from utilities for reliable operation. IoT is inevitable to facilitate the key Smart grid features such as self-healing, disaster recovery, distribution automation, fault diagnosis and control, improved power quality and security. Bidirectional communication, distribution automation, advanced metering infrastructure (AMI), high penetration of renewables with

sufficient storage capacity, microgrid, Plug-in hybrid electric vehicle etc. are the pivotal features of Smart grid technology as shown in Fig.1.

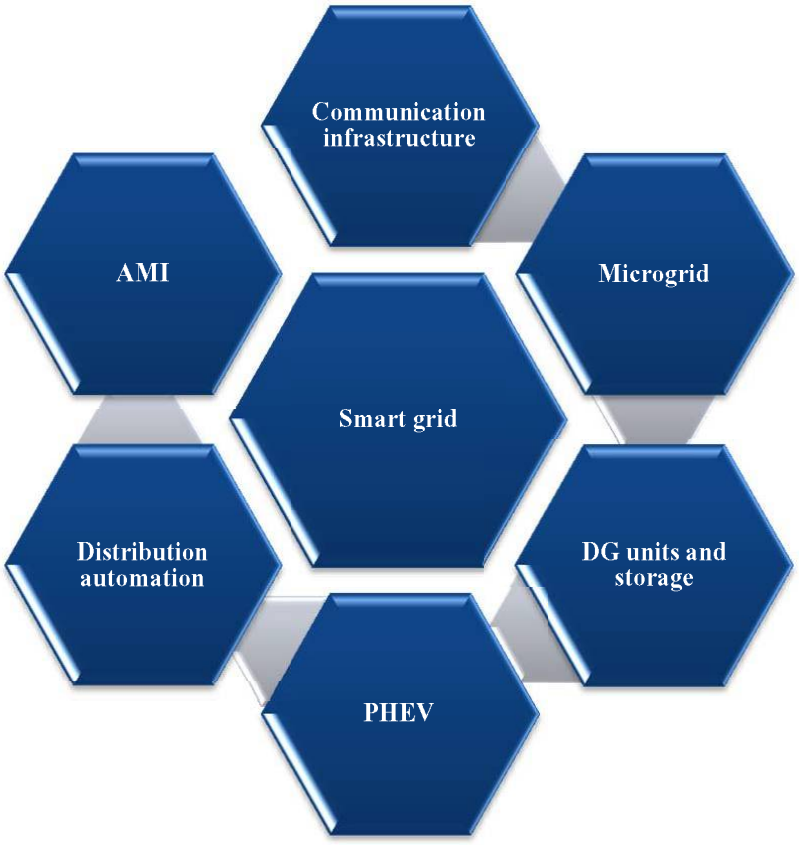

Fig.1.1. Pivotal features of Smart grid technology

Smart grid comprises of hierarchical and heterogeneous technologies and standards. Sensing, communication and automation are the core components of Smart grid infrastructure. Internet has paved the base of Smart grid design and deployment.

Standards and technologies for Smart grid infrastructure are being abstracted and developed by various organizations like IEC, IEEE, ETP, EPRI and NIST. Harmonization between standards is an unavoidable challenge in Smart grid deployment.

1.2. MOTIVATION

The true meaning of technology is realized when it is developed to fulfill the basic necessities of people and reaches to a grass root level. The most crucial and critical necessity of today's era is electricity. Smart grid technology is the most imaginative and

It aims to provide reliable, secured and clean power to the stakeholders. The following facts depict the current scenario of energy sector in India.

- The requirement of energy in the year 2016-17 is 1142092 MU while the total available energy is 1134631 MU. Thus, the deficit energy is 7461 MU which is around 0.6 percent of available energy [1].
- The most vital requirement of rural empowerment is energy. Microgrid enables and expedites the use of renewable energy sources. So, it can reach up to remote and unelectrified locations.
- According to the statistics provided by rural electrification corporation limited (REC), still around 6088 villages are unelectrified in various states of India [2].
- India is blessed with enormous amount of renewable energy sources. Potential of Solar energy is very high in the country. India being a tropical country, a clear sunshine is experienced for about 250 to 300 days in most of the regions. Annual radiation is around 1600 to 2200 KWh/m^2. The energy potential from this statistics is 6000 million GWh/year [3].
- There is a huge scope to address the problem of energy scarcity through distributed generation and distribution which is a prominent feature of smart microgrid technology.
- Primary and non-renewable resources such as coal and oil are limited, expensive and environmentally detrimental.
- An emission of carbon dioxide and other greenhouse gases from thermal power plants is higher in India in comparison with global standards due to inferior quality of coal. Higher cooling water and air temperature consumes more amount of coal.
- Aging of coal based power plants decreases their efficiency. Their upgradation requires a large amount of capital. Still 4116.5 MW of thermal units are to be retired in 2018-19 [4].
- The reserves of oil and gas are estimated to last for 45 years and the coal is estimated to last for 200 years in the world [5]. Thus the primary energy resources are very limited.
- In India, transmission and distribution losses such as theft loss, commercial loss and technical loss are approximately 23% of the total power generated which are

the highest in the world [6]. Smart grid technology can eliminate these losses through Advanced Metering Infrastructure (AMI) [6].

- There are enormous challenges in increasing the penetration of renewable and non-conventional energy sources due to their intermittent and non-dispatchable nature and reliability issues. This obstacle calls for innovative solution for high penetration of renewable energy resources. Smart grid can effectively address this problem through deployment of microgrid.
- Penetration of various communication technologies and networks is very progressive which can be used for automation and control.
- At present, there is a simplex flow of electricity from utilities to consumer premises. Due to which, consumers have no decisive role in energy usage. Smart grid ensures active involvement of users in energy consumption, billing and auxiliary power.
- The current system lacks remote monitoring and control of grid network. Smart grid facilitates complete monitoring and control of entire network through heterogeneous and hierarchical communication network.
- Disaster recovery is critical in the present power grid. Smart grid ensures self-healing and easier fault diagnosis.
- Plug-in hybrid electric vehicles (PHEVs) and Electric vehicles (EVs) can carve the pioneering path by replacing fuel based vehicles.

The above facts illustrates the current scenario of energy sector. Pervasive penetration of communication networks can facilitate rapid deployment of Smart grid network. Smart power grid is a multifaceted technology with enormous research areas. As it is an integration of electrical and ICT infrastructure, interoperability between standards and technologies is a major concern.

This research work explores design, implementation and optimization of communication infrastructure for Smart grid hierarchical layers.

1.3. PROBLEM STATEMENT

Energy is the most fundamental requirement of today's era. It is evident from the various statistics and realities depicted in section 1.2 that transformation of an existing grid is an inevitable requirement. Aging of coal based power plants, inadequacy of primary energy sources, distribution and theft losses, high penetration of communication technologies, enormous amount of renewable energy resources, grid reliability issues,

lack of remote monitoring and control etc. are the major factors which formulates a problem statement as ''Design, Optimization & Implementation of Secured Wireless Communication Infrastructure For Smart Microgrid''.

Problem statement elucidates the design of prototype developed on the basis of IEEE 802.15.1, IEEE 802.11 and IEEE 802.3 standards for PAN, HAN and WAN. It also includes cross layer optimization of Smart grid HAN and NAN using IEEE 802.11 standard.

1.4. OBJECTIVES

The objectives of the research work are listed below.

- Comparative analysis of different communication technologies for Smart microgrid.
- Design & Optimization of Smart Microgrid communication infrastructure.
- Validation through implementation of wireless monitoring and control of Smart microgrid power system.

1.5. RESEARCH METHODOLOGY

The theoretical and experimental framework of research methodology implemented for the research work are depicted below.

1.5.1. THEORETICAL FRAMEWORK

Theoretical framework includes the study of various aspects such as current energy scenario in India in terms of energy production, scarcity and aging of coal based power plants. As communication infrastructure is well established in our country, there is a huge scope of Smart grid deployment.

The thesis covers an architecture of Smart grid and Microgrid networks. Various communication standards can be used for hierarchical layers of Smart grid network. Various communication standards such as IEEE 802.3, IEEE 802.11, IEEE 802.15.1, IEEE 802.15.4 and IEEE 802.16 are included in the thesis. The research work includes review as well as comparative analysis of diverse set of communication protocols. Different parameters like frequency band, licensing of spectrum, coverage area, data throughput, advantages, disadvantages and potential applications are compared in the

context of heterogeneous Smart grid communication infrastructure. Various challenges in the deployment of Smart power grid are also illustrated.

Optimization is essential for design and deployment of various hierarchical and heterogeneous networks. As Smart grid is a completely innovative, ingenious and imaginative technology, the design of Smart grid network cannot be built upon existing grid network. The theoretical framework of this research work includes conceptual clarifications on necessity of cross layer optimization for complex Smart grid network. Apart from the network deployment aspects, safety and reliability of Smart grid infrastructure is also crucial for its consistent operation and management.

Smart grid comprises of various electrical equipment, power electronics converters, Sensors, actuators and communication transceivers which are vulnerable to EMI effects. The thesis also includes EMI threats and standardization for reliable operation of Smart grid infrastructure. An intelligent power grid is a network of hierarchical and heterogeneous networks which makes it vulnerable to cyber threats. An application of existing knowledge and techniques of cyber security used for Internet will not be enough for secured Smart grid network due to its complex architecture. For example, WSN security must be dealt with a completely different perspective because of its dissimilar vulnerabilities. The theoretical work comprises of Cyber security issues and challenges of Smart grid network which can be explored as a future research.

1.5.2. EXPERIMENTAL WORK

This research work explores an experimental investigation of various hierarchical network layers of Smart grid communication infrastructure. IoT is an integral component of Smart grid infrastructure. The prototypes are developed and tested to validate the theoretical and conceptual aspects of Smart grid architecture. The prototypes are designed for Home area network using IEEE 802.15.1, Local area network using IEEE 802.11 as well as Wide area network using IEEE 802.3 and IEEE 802.11 standards. An integrated development environment (IDE) 1.6.11 is used as a source code editor and debugger. An independent webserver and GUI are developed for home area network.

An independent web server works on an address **''192.168.1.177''** in LAN. The prototypes are tested using serial monitor as well as GUI. IDE serial monitor and CoolTerm softwares are used for real time monitoring, controlling and capturing of data.

The real time data with time stamps is captured for graphical representation. The GUI is developed using HTML-5. GUI is meant for remote wireless monitoring and control of designed prototype. A website for IoT exploration is developed and can be accessed on URL **''smartenergy.dlinkddns.com''.**

The website is developed for dynamic IP using port forwarding. This thesis includes design, implementation and experimental validation of Smart Microgrid communication infrastructure through development of local as well as global web server.

Apart from the development of prototypes, a network optimization perspective is also explored through simulation approach. Joint optimization of Physical as well as MAC layers of WLAN is performed using PAMVOTIS software. Cross layer optimization is performed for IEEE 802.11 standard using Riverbed Modeler-OPNET software. Parameter optimization is crucial to get higher throughputs and lower delays. This research work includes HAN as well as NAN optimization for Smart grid network. Parameter as well as protocol optimization are depicted using simulation results.

1.5.3. SOURCES OF DATA

- Data sheets of various vendors.

1.5.4. SOFTWARE TOOLS

- Serial Monitor – IDE
- Fritzing- Circuit maker software
- HTML for Web Page
- CoolTerm
- Riverbed modeler- OPNET
- Web hosting service for dynamic IP configuration

1.6. RESEARCH CONTRIBUTION

- The research work presents concept, design and architecture of Smart grid communication infrastructure.
- The research work illustrates analysis and comparative study of diverse set of communication protocols for Smart grid applications.
- The experimental research work depicted in this thesis validates design, implementation and testing of IoT based prototype. The prototype covers HAN,

NAN/LAN & WAN for Smart grid communications with interoperable backbone network. The same can be upgraded and commercialized with some modifications but with the same communication protocols.

- An independent website is developed for real time monitoring and control of energy sources using HTML based GUI.
- The research work includes a novel optimization approach based on joint or cross layer parameter optimization for performance enhancement. The network design and simulation results validate the theoretical concepts.
- Various cyber security and EMI threats are also analyzed and discussed for future research and design endeavors.

1.7. CHAPTER SCHEME

This thesis includes seven chapters including current chapter and they are structured as follows.

Chapter 1 covers an introduction part of the thesis. Overview, motivation behind the research work, objectives, research contribution and research methodology are depicted in this chapter. Research methodology is depicted in terms of theoretical as well as experimental research work carried out for design and implementation of Smart microgrid prototypes.

Chapter 2 includes literature review. Total 108 web links, review and research papers are referred to study and review the recent advancement in Smart grid technology. Gap areas are also identified from the referred papers.

Chapter 3 depicts the definitions and communication infrastructures of Smart grid and microgrid technologies. This chapter also depicts detailed review and comparative analysis of communication standards for Smart grid communication infrastructure. Various communication standards are compared on the basis of bandwidth, data throughput, licensing, coverage area, advantages, disadvantages and potential application in Smart grid communication infrastructure.

Chapter 4 describes communication network optimization using cross layer approach. A conceptual clarification on Cross layer optimization is depicted using various illustrations. This chapter presents an importance of joint optimization for complex Smart

grid communication network. The simulation results using PAMVOTIS and Riverbed-OPNET modeler are depicted using graphical representations.

Chapter 5 illustrates an implementation and testing of prototype designed for remote wireless management of smart microgrid energy system using PAN, LAN and WAN.

Design, implementation and testing of prototypes based on IEEE 802.15.1, IEEE 802.3 and IEEE 802.11 are depicted in this chapter. This chapter also includes snapshots of website, local server and graphical representation of real time data.

Realization of Smart grid technology is a completely novel and extremely complex task. Chapter 6 contains issues and challenges in Smart grid communications. Various issues such as EMI threats, cyber security challenges, WSN vulnerabilities and standardization activities are depicted in this chapter. This chapter can be explored for further research endeavors.

Chapter 7 incudes conclusion of the research work and future scope. Smart grid is an interdisciplinary technology. The significance of this research work and future research orientations are included in this chapter.

CHAPTER SUMMARY

An existing grid is being revolutionized through integration of electrical and ICT infrastructures. Aging of coal based power plants, losses and scarcity of primary energy sources necessitate the transformation of an existing passive grid. Smart grid is a heterogeneous and hierarchical network comprising of pervasive and complex architecture. This chapter includes need and motivation behind the research work and methodologies used for implementation of IoT based prototype.