CHAPTER-I

Introduction

1.1. Background

The importance of electricity in contemporary world is growing rapidly and showing exponential growth. The increased human-technology interface in modern technological era did necessitate demand of electricity for functioning of the technological gadgets. Electricity, a high-grade form of energy, generates from the various segments of low-grade energy sources like fossil fuels (coal, oil, and natural gases), hydro power, renewable energy sources (photovoltaic, solar thermal, wind turbine, biomass and geothermal) and nuclear energy. Major power generation comes from the conventional thermal power plants by using fossil fuels. With limited availability of fossil fuels and cause of environmental degradation, conventional power plants are facing the major setback. Owing to environmental concerns, the world identified alternative and sustainable energy sources like renewable energy for the sustainable development. The harnessing of the clean energy sources, utilization of renewable energy resources are increasing exponentially. The World is moving towards harnessing of renewable energy sources to reduce excessive carbon emission and using as the effective alternative energy sources. With regressive research and development work in renewable energy sector, it's getting day by day more economic and feasible one. Large capacities of renewable energy based power generation units are now being deployed to meet ambitious targets in India. India is increasing renewable energy capacities for getting more diversified energy sources as well as preventing ecological system.

However, India in particular lags behind the utilization of renewable energy sources in the world. India is working towards a target of renewable energy capacities providing 175 GW of energy demand by 2022 (MNRE-Ministry of New and Renewable Energy). The renewable energy sources in the projected energy mix include wind, Photovoltaic, concentrated solar power, biomass and geothermal. These renewable energy sources tend to be located in remote or inaccessible regions, and their integration into power grids typically occurs in the distribution network as decentralized power generation. This runs contrary to the conventional design philosophy of power system infrastructure, which favours large centralized power generation facilities with unidirectional power flow from source to load through reducing voltage levels. Also, a vision of making the smart city of India's major cities needs to install renewable distributed generation units at their residential and commercial buildings to meet their demand and promote green building concept. Renewable distributed generation system use decentralization of power generation with renewable energy sources.

The need to reduce greenhouse gases emissions and the liberalization of the electricity market has led to a large-scale development of renewable distributed generation technologies in electrical grids (Labis et al., 2011). Renewable distributed generation technologies, such as photovoltaic or wind power generators, are used to reduce fossil fuels consumption and carbon emissions. However, the uncertainty of output power fluctuation of renewable distributed generation may cause excess variations of the grid's voltage and frequency. In recent past, storage systems have been designed to provide energy reserve to match the demand variability and fluctuating output power (Borges and Cantarino, 2011). In the smart grid system, optimal planning of renewable distributed generation will neutralize demand-supply variability without any storage system.

1.1.1. Sustainable development of modern power generation system

Modern power sector has been motivated to develop sustainable power generation system with advanced technologies. Use of smart grid integrated renewable distributed generation is future of sustainable development of modern power generation system. As an example, Figure-1.1 shows a residential application of smart grid integrated renewable distributed generation with controllable loads and storage units. This home application may be a power producer or a consumer, also known as the "prosumer".

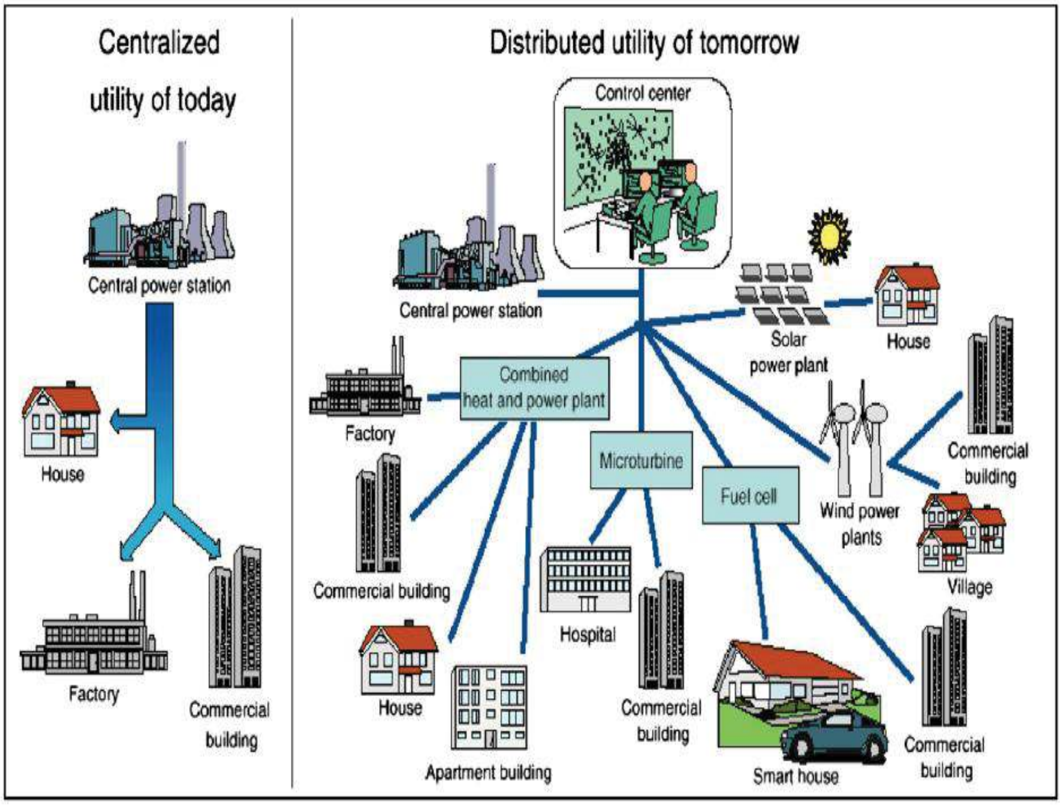

Figure 1.1: Penetration of renewable distributed generation in modern power distribution system (Viral and Khatod, 2012)

A few years ago, renewable distributed generation technologies were developed to follow the sustainable development of power sector (Abdullah et al., 2014). Research and development upgraded renewable distributed generation technologies to increase consumer satisfaction with option of the automatic control of some loads. Customer-enabled management provides opportunities for consumption adaptation to time pricing and new smart grid services for higher quality power supply. In this study, advanced smart grid integrated renewable distributed generation has been considered for the sustainable development of power sector. Considerable research activity is focused on the integration of large amounts of renewable distributed generation technologies in the power system (Hung et al., 2013). The attention is now oriented toward the use of renewable distributed generation technologies for improving grid operation by contributing to ancillary services, increasing the energy reserve, and reducing CO_2 emissions. In practice, new facilities are expected to reduce congestion, minimize the production cost, and maintain the frequency and voltage (Tan et al., 2013).

Wolsink (2012) found that the most technical studies apply implicit and largely unfounded assumptions about the participation in and contribution of actors to renewable distributed generation. This lack of understanding will have severe consequences: smart grids will not further renewable deployment when there are hardly actors that are willing to become part of them. This introduces first attempt to address the social construction of smart electricity grids. As institutional factors have proved to be the main determinants of acceptance, these will also be crucial for further renewable deployment in micro-grid communities. Elaboration of the institutional character of social acceptance and renewable energy innovation calls for an institutional theory approach involving common pool resources management because these socio-technical systems aim to optimise the exploitation of natural resources. Citizens/consumers and other end-users increasingly have the option to become more self-sufficient by becoming co-producers of electricity.

These developments require a fundamental redesign of the policy to increase penetration of renewable distributed generation technologies (Viral and Khatod, 2012). Here, an aggregated architecture of a power system is considered as a means to facilitate the integration of multiple prosumers both in the electrical system and in the market. They gather the "flexibilities" and the contributions provided by prosumers to form grid services, and they offer these services to the different power system participants through various markets. At the prosumers' premises and electrical appliances, renewable distributed generation can be controlled and optimized by the simulation. The global objective consists in matching the total power production with the demand in an optimal way. This concept is pertinent in the framework of smart grids through the combined use of an additional communication network within an intelligent energy management system and local controllers (Farhangi, 2010). This scheme is a step between the current grid requirements and the future smart grids. This work tackles the problem of the optimal operational planning of smart grids for the prosumers. A coordinated management of energy resources is proposed through a communication network.

Incorporating high volumes of renewable distributed generation in distribution networks introduces both technical and economic challenges that must be addressed, such as reverse power flow, local voltage rise, power quality, and increasing fault levels, among others. A common practice among network operators to connect renewable distributed generation on a first-come first-serve basis may also compound the issues by possibly ‘sterilising' portions of the network. Whilst these issues may be overcome by network reinforcement; such asset upgrades are not desirable due to the cost of financing investment in new infrastructure and sometimes impossible or slow to realization due to planning restrictions, environmental concerns, and public objections. Given these potential obstacles, it is desirable that any new renewable distributed generation technology development is carried out in a manner that maximizes the utilization of existing assets.

In seeking for alternative network options for renewable distributed generation integration, it is meaningful to leverage the recent technical development in the power industry. Smart grids have been put forward as a new dimension for future electricity networks. Smart grid may simply be defined as "smarter" electricity network; however, the explicit meaning of the term can be expressed in many different ways depending on the application. As the driver for advancing the electricity systems mainly involve significant changes to the generation and demand patterns, the development of smart grid to manage such changes are focused on five main purposes (Fang et al., 2012):

1) To enable the production and supply of electricity more cost-effectively;
2) To allow consumers to be informed with necessary information such as electricity price and their energy-use behavior to obtain the most efficient and economic energy consumption;
3) To encourage renewable distributed generation integration;
4) To enhance the electricity systems' security and reliability;
5) To support the growing use of electric vehicles in the coming decades to reduce dependence on gasoline.

Smart grid technologies are evolving and appear largely as under the term "active network management." The transition from historical practice to active management increases the "smartness" of the electricity network. Active network management may be compatible with automation of the network to speed supply restoration following an abnormal event, and increased visibility and control of the network to facilitate management practices" (Gemine et al., 2016).

While modern smart grid is intended to provide additional scope to connect renewable distributed generation without traditional reinforcements, the extent of its ability to relieve the network constraints is not fully understood. The limitations of the existing distribution network in a regime of high renewable distributed generation technologies penetration are becoming increasingly obvious, such as a lack of adaptive measures to tackle occurrences of violation of voltage, reliability and power quality limits due to the variability of renewable distribution generation sources?. Therefore, it is desirable for customers, developers of renewable, distribution network operators and regulators that the body of knowledge in the field of renewable distributed generation planning in the context of smart grid continues to grow to prevent the network from turning into a significant limiting factor for the increased deployment of renewable distributed generation technologies.

To leverage the benefits arising from the modern power sector planning and operating the network for connecting more renewable distributed generation, a large amount of work is going on the detailed control methodologies, but an emerging research area is the optimal planning of renewable distributed generation. Optimal planning of renewable distributed generation is an effective and flexible framework for investigating the cost minimization to accommodate generation and provide insights for distribution network operators and developers. Instead of a conventional approach to connect and integrate renewable energy, optimal planning offers a means of providing a more structured and planned integration. Some literature refers to it as optimal planning or allocation, but its use is potentially much wider as part of new planning approaches. While existing literature has outlined many useful advances there remain significant areas that require development to enable optimal planning of renewable distributed generation and the methodology on which it relies to be truly evolutionary optimization tool to get global optimal solutions useful for distribution network operators, regulators, and developers.

Simulation can provide a one-step analysis that indicates what capacity is feasible at a given location. This differs significantly from the existing literature of siting and sizing of decentralized power generation system. Integrating high volumes of renewable distributed generation means a great number of development schemes seek connection approval, which increases the complexity of analysis as many of their impacts are interrelated. Meanwhile, the variability of renewable distributed generation output means that analysis cannot be constrained to just maximum or minimum demand patterns.

Consideration of whole time series relation or ranges of conditions in analysis is much more time-consuming. It is desirable to be carried out by automated but repeatable approaches, so that analysis and engineering time can be released to more productive tasks. With the complicated impacts from intermittent decentralized power generation, it needs to be extendable to various aspects of concern. The methodologies used in this work grow the knowledge of modern renewable distributed generation system, especially in tackling of decentralized generation curtailment rules, uncertainty management, and energy sharing with grid supporting network management. Its extensions will allow us the use of hybrid technologies for decentralized power generation and cope up with the uncertainty of renewable energy sources.

1.1.2.Increasing renewable energy capacities

Development of renewable energy based power generation technologies in India was started in 1897 at Sidrapong, Darjeeling with first hydroelectric installation followed by commissioning of a hydropower station at Sivasamudram in Karnataka during 1902. In 1997 the Wind Turbines were installed and generated electricity in India. However, at that time, shortage of conventional energy resources and environmental pollution were not the major problem as compared to recent time. Recently global warming is the major threat to living species all over the world. At that time development of renewable energy in India mostly utilized hydropower and other modes of renewable energy sources were on trial basis. With location constraint hydropower having limited coverage areas in India, generates electricity centrally which causes transmission and distribution losses. On the other hand with the availability of abundant solar and wind potential in India made this considerable to generate power and increase their capacities.

Solar and wind-based technology also gives the flexibility to generate electricity at a small level which helps to reduce transmission and distribution losses and have more flexibility to reach over remote areas. A few years ago, renewable energy in India was a sector that is in its infancy compared to other partner countries. Recently, India has taken some major steps to have increased its renewable energy generation capacity. Now, India's electricity sector is amongst the world's most active players in renewable energy utilization, especially wind energy. As of 31st July 2015, India had grid-connected installed capacity of about 36.64 GW non-conventional renewable technologies-based electricity capacities, about 13.32% of its total (Physical Progress, January 2014). With increased capacity, currently India has the fifth position globally in the generation of renewable energy based electricity. In December 2011, over 300 million Indian citizens had no access to frequent electricity. Over one-third of India's rural population lacked electricity, as did 6% of the urban population. Of those who did have access to electricity in India, the supply was intermittent and unreliable. In 2010, blackouts and power shedding interrupted irrigation and manufacturing sectors across the country (Remme et al., 2011).

Global warming is the major cause of increased natural disasters in India like Uttarakhand and Chennai disasters which happened in recent past. Indian environment experts are claiming that burden of increased global warming from the developed country is shifted towards developing and poor countries. As per the expert statement developed country should equally penalize for the percentage of generating greenhouse gases globally. For this, the developed country should come forward and economically help poor countries for having utilization of renewable energy and cutting down the use of fossil fuels. India also amended its electricity act-2003 to increase the proportion of renewable energy. Recently India has major deals with some developed country to increase the capacity of renewable energy. From the beginning of the 21st century, the Indian government used market incentives, in addition to command and control management and direct subsidies, to stimulate renewable energy production. The Indian government started Department of Non-Conventional Energy Sources (DNES) in 1982, Ministry of Non-Conventional Energy Sources (MNES) in 1992. Ministry of Non-Conventional Energy Sources (MNES) renamed as Ministry of New and Renewable Energy (MNRE) in 2006. MNRE also started to give a green certificate and numerous research centers and research grants all over the country in recent past. The Indian Renewable Energy Development Agency (IREDA) is a Public Limited Government Company established as a Non-Banking Financial Institution in 1987 under the administrative control of MNRE to promote, develop and extend financial assistance for renewable energy and energy efficiency/conservation projects with the motto: "ENERGY FOREVER". The Jawaharlal Nehru National Solar Mission (JNNSM) was launched on the 11^{th} January 2010. Solar Energy Corporation of India (SECI) was set up on 20^{th} September 2011, as a not-for-profit company under Section-25 of the Companies Act-1956 as an implementation and facilitation institution dedicated to Solar Energy sector.

Renewable energy in India comes under the purview of the MNRE. India was the first country in the world to set up a ministry of non-conventional energy resources, in the early 1980s. India's cumulative grid-interactive or grid tied renewable energy capacity (excluding large hydro) has reached 33.8 GW, of which 66% comes from the wind, while solar PV contributed nearly 4.59% along with biomass and small hydro power of the renewable energy installed capacity in India (MNRE-Ministry of New and Renewable Energy). According to the national target, installed capacity of renewable energy will be 175 GW in India by 2022.

Table-1.1showspast fifteen years annual renewable energy installation capacity in Megawatt and total transmission and distribution (T&D) losses in India respectively. With the given data, we have analyzed its trend in Figure-1.2 and 1.3 for renewable energy installation capacity and transmission and distribution losses respectively. The Figure-1.2 is showing rapid growth in installation capacity of renewable energy in India. In the growth of renewable energy mainly solar and wind energy are growing rapidly compared to other renewable energy sources. While, Figure-1.3 is showing the continuous decline in transmission and distribution losses. From these two figures, we can see, by using renewable energy based distributed generation technology we can minimize our total transmission and distribution losses.

Table 1.1: Annual renewable energy installed capacity and percentage T&D losses in India (MNRE-Ministry of New and Renewable Energy)

Year	RE Installed Capacity (MW)	Percentage T&D Losses
2001-02	3518	33.96
2002-03	4880	32.54
2003-04	5311	32.53
2004-05	6161	31.25
2005-06	8088	30.42
2006-07	10257	28.65
2007-08	12403	27.2
2008-09	14792	25.47
2009-10	16817	25.39
2010-11	19974	23.97
2011-12	24914	23.65
2012-13	28067	23.4
2013-14	31702	22.7
2014-15	33791	21.17

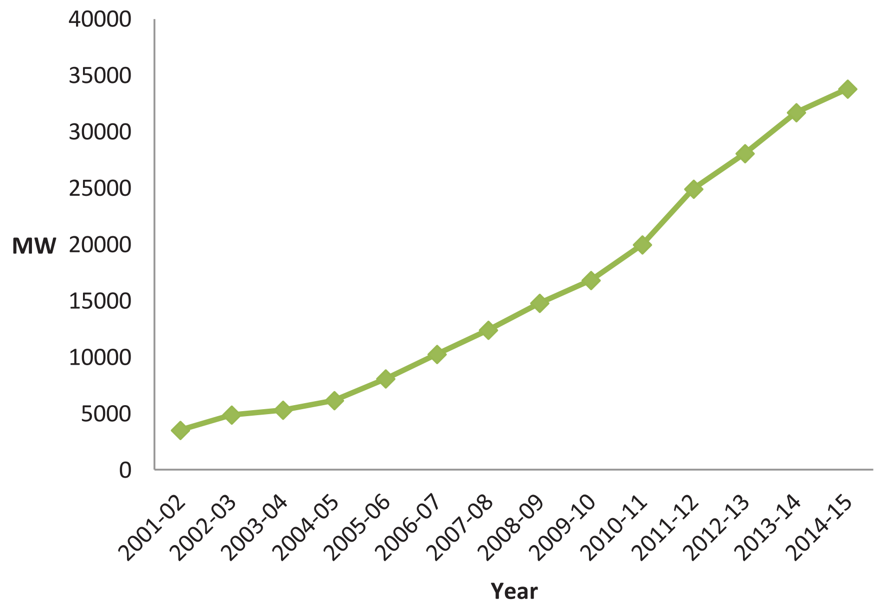

Figure 1.2: Yearly growth of installed renewable energy capacity in India

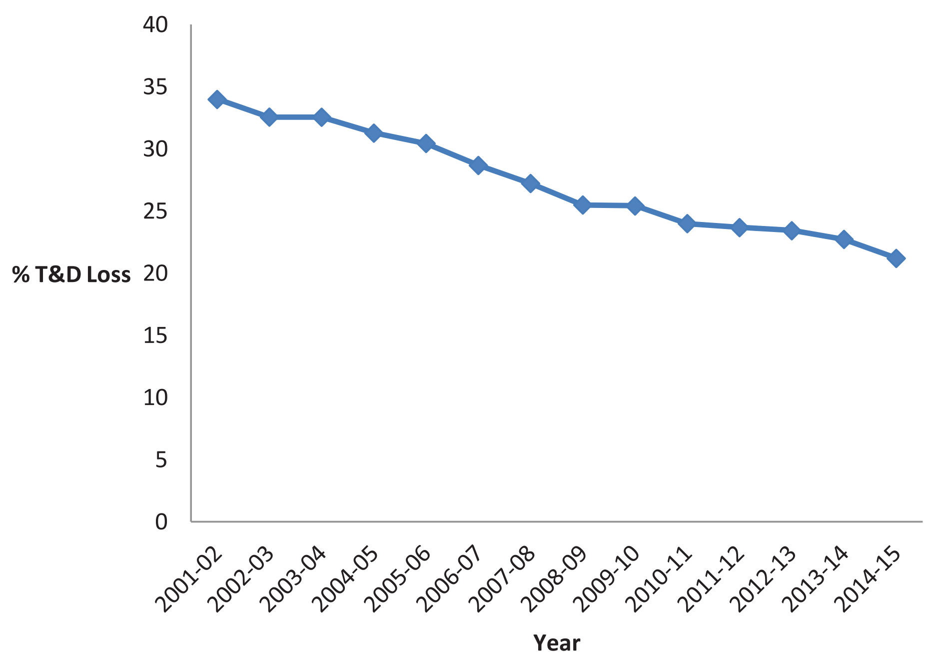

Figure 1.3: Annual percentage transmission and distribution losses in India

Liberalized markets and getting green electricity with shares of renewable distributed generation technology in the generation mix, today's India face a challenge to balance between centralized and decentralized electricity supply systems. One of the key changes in India has been the increasing weight that economic considerations have gained in the country's energy policy, especially since the Electricity Act-2003 and Act-2005. It has been suggested that India's energy policy during the 2000s has undergone a paradigm shift, with the security of supply and climate change gaining importance at the expense of the earlier focus on liberalization, privatization, and competition. Others, by contrast, have discussed that a defining characteristic of the Indian energy policy continues to be its strength, the majority considered its excessive reliance on a free market ideology. Regardless of whether a paradigm shift has occurred or not, it is clear that at least at the level of official discourse, the governments remain committed to tackling climate change and enhancing energy security, but doing this within competitive markets. Likewise, the governments declare their desire to promote the distributed generation of renewable energy sources, yet strong drivers push towards concentration and centralisation. In India, concerns about climate change and energy security helped renewable distributed generation on the policy agenda, and high hopes are being placed in large-scale of decentralized solar and wind generation. The challenge is to create systems able to accommodate both centralized and decentralized elements—with a diversity of generation sources and smart grid network architectures. The creation of such smart grid architectures poses particular challenges to electricity network control systems. Despite the largely common challenges, the solutions to network control continue to be different in India.

Introducing more renewable distributed generation into an essentially centralised system will require not only more advanced technologies but also hierarchical and nested control structures that combine centralised control of the entire system with decentralised and responsive control structures at various levels. The local level must be able to balance and control reactive power, and provide up-to-date information to the regional and central control levels at all times, and the local level must be able to continue operating in situations of system breakdown. In India, the rapid expansion of renewable distributed generation has already led to an acute need for drastically new control structures, whereas policy of the India is largely anticipatory, the government is assessing the likely future changes that more distributed generation structure would require, in a situation with a rapidly ageing asset base. Change in India is driven not only by the increasing customer demands for high-quality power and the policy objectives of greater renewable distributed generation technology penetration but also by the distribution network operators' desire to optimise asset utilisation, defer reinforcement and strategically plan the replacement of ageing assets. For the long period, India is managing to increase renewable distributed generation integration apparently with only minor changes in network control. It was not until the early 2000s that the reliability problems created by the sudden increase in wind generation, the blackouts in northern India in 2010 and 2012, were the wake-up call.

1.1.3. Importance of renewable distributed generation

Flexibility to install an environment-friendly power generation unit in remote areas and inaccessible region made renewable distributed generation more favourable alternative in developing nations (Karki et al., 2008). In developing nations like India, a majority of people are living in rural or remote areas without having the adequate amount of power supply. The majority of people are still either fully or partially living dark life in rural or remote areas of developing nations. Betterment of the whole nation, upliftment of deprived and poor people, and giving them a better life, should be the government priority.

Geographical issues aside, the current grid is facing difficulty in accommodating variable sources of power like wind and solar energy, the fastest-growing sources of renewable power for the grid (Domínguez and Amador, 2007). As these resources begin to supply increasing percentages of power to the grid, integrating them into grid operations is increase complexity. The smart grid will be able to make better use of these energy resources. It will give grid operators new tools to reduce power demand quickly when the wind or solar power dips, and it will have more energy storage capabilities to absorb excess wind and solar power when it isn't needed, then to release that energy when the wind and solar power dips (Moslehi and Kumar, 2010). In effect, energy storage will help to smooth out the variability in wind and solar resources, making them easier to use. Building the smart grid can help to solve the problem, as it will help to ship the power to where it needed (Amin and Wollenberg, 2005). Studies have shown that connecting wind resources from a diversity of geographic locations helps to balance out fluctuations in wind power (Atwa and El-Saadany, 2011). In other words, when the wind isn't blowing in one region, it may be blowing in some other region. Having such geographically diverse wind resources with a single national grid will result in a more steady supply of wind power to the nation's power grid, making it easier for grid operators to make full use of this resource.

With their advantages, this is top priority in making of energy policy in India. In India, many strategies and policies have been developed and developing to boost the utilization of renewable distributed generation technology.

1.1.3.1. Future growth of renewable distributed generation

India, a large country area-wise and world's second populist country, is growing rapidly and showing eagerness of the development with recent policies and visions. For the development, India is trying to reach out to every citizen with 24x7 electricity facility in coming few years. Use of renewable distributed generation with smart grid integration becoming results of the recent transformation in power sector (Guo et al., 2013). India is taking major steps to enhance the use of integrated and stand-alone power generation through renewable distributed generation technology. Modern smart grid concept is helping to maintain flexibility in the power supply and digital communication system to make transparency in billings. Renewable distributed generation gives flexibility of power sharing through microgrid and better control from the smart grid technology (Nadimi et al., 2016).

India has called to secure 175 GW of their electricity from clean, renewable resources by 2022 and yet, grid-connected installed capacity of about 36.64 GW non-conventional renewable technologies-based electricity capacities, about 13.32% of its total (Physical Progress, January 2014; and Power Generation from Various Renewable Energy Sources, December 2013). What's holding us back? Our grid is partly to blame. The role of renewable distributed generation is growing rapidly with the evolution of smart grid concept in the modern power sector. With the effect of the new reformation in Indian power sector, India reformed their power sector and moved inclined towards harnessing of renewable energy sources and increasing contribution of renewable distributed generation technology for reducing the demand-supply gap. Renewable distributed generation technology is helping India to electrify their rural areas with minimum transmission and distribution losses and giving more flexibility to match demand variability. Increasing renewable energy capacity in India also withstands their global commitment to help in reduction of carbon emissions and having sustainable future. In this work, we focused on availability, current status, economical benefits, technical advantage, and future potential of renewable distributed generation in India.

We discussed government's initiative and program to help in increasing utilization of renewable distributed generation in India.

1.1.3.1.1. Renewable distributed generation planning

Mainly renewable distributed generation works in two modes; first integrated with the power grid and second stand-alone. In the integrated renewable distributed generation system, surplus power either stored in power bank or supplied to the grid which helps to cash surplus power by supplying it to the grid. Stand-alone gives onsite power generation without having connectivity to the grid supply. For reducing generation uncertainty in renewable distributed generation system, we can use a hybrid system to overcome this issue.

1.1.3.1.1.1. Demand and supply

Indian power industry is normally not very developed regarding their capacities, accessibility of majority, power quality, and global interactions. In last few years, India has made some major policy revision to transform this sector. A result of this transformation is the total installed capacity of power in India in March 2016 crossed 300GW (Installed Capacity Reports, 2016). The contribution of different energy sources and their percentage growth rate in India in the past few years and projected for future is shown in Figure-1.4. This represents potential growth of renewable energy sector in coming years as compared to other energy sectors.

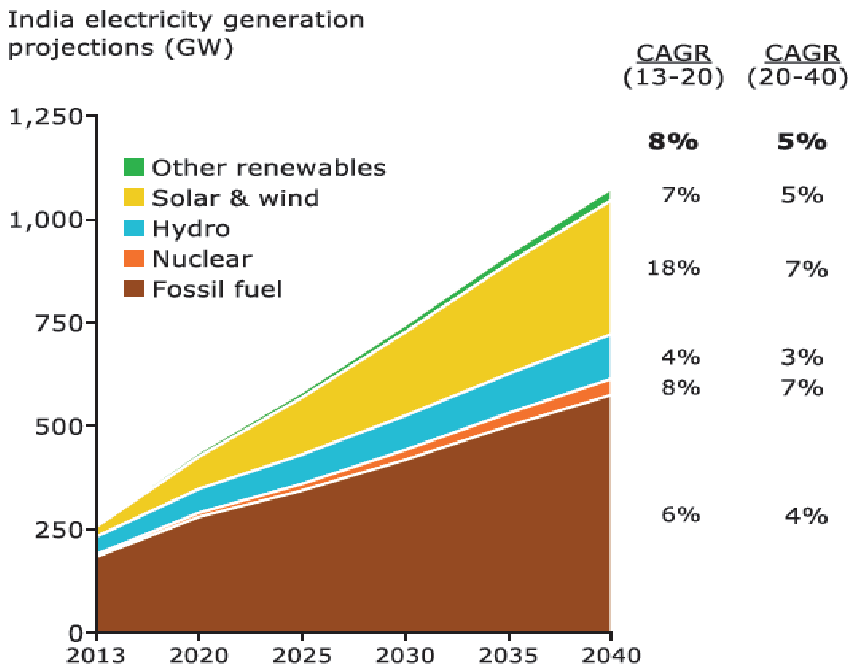

Figure 1.4: Future growth of renewable energy in India compared to other energy sources (World Economic Forum, 2016)

The disparity between states is quite significant for distribution of power supply in India. States like Gujarat (2,105 kWh) is at the top in per capita power consumptions, whereas states like Bihar (203 kWh) at a lower level in per capita power consumption, average per capita power consumption of India is 1,010 kWh for the year 2014-15 (Planning commission government of India, February 2014). In supply side, switch from conventional to renewable distributed generation affecting power distribution with geographical factor and government policies. Renewable distributed generation in different regions of India depends on the availability of the renewable energy sources and public awareness along with government support to harness maximum energy. With this new power generation system, India is reaching out to their poor population in rural and remote areas with subsidized cost. The flexibility of onsite generation is making this more feasible and favourable to reduce transmission and distribution losses. Uses of hybrid technology concept would also help to reduce the risk of uncertainty in power generation. The government is trying to fill up the gap between demand and supply, and growing demand for renewable distributed generation technology. In Indian renewable energy sector photovoltaic, wind and solar thermal are playing a major role and being the future with the recent changes in government policies, like make in India, which will demand huge potential of the power supply.

1.1.3.1.1.2. Financial support

Initial investment cost is a major challenge for penetration of the renewable distributed generation technologies in Indian power sector (India in Business, 2016). India is facing financial limitations to increase investment in this regard. Our government targeted to achieve a subtotal of 175 GW renewable energy capacities by 2022, which needs an investment of more than $200 billion and representing a five-fold in an increase on the currently installed total of 36 GW of renewable energy in coming years (Buckley, 2015). Another side, the Climate Policy Institute (CPI) has mentioned the importance of getting the cost of debt and equity finance down with having priority of renewable energy project in electricity generation. This issue is a constraint in India, especially, because of its closed financial markets and its high inflation and high-interest rate environment. Overcoming of this constraint is from the harnessing of more renewable energy sources with power transformation in India. India is working with German KfW Development Bank, the Asian Development Bank, and the World Bank to get financial support for the solar projects and with this India will reduce its current cost of debt from 12.5% to about 8.5% (Buckley, 2015).

Before passage of the Electricity Act-2003, the Indian power sector was rarely considered to be an investment destination for private capital. Globalization of market has attracted private interference in this sector because it is the most straightforward investment proposition. Thus the involvement of private sector capital would be a major objective as states in India desire to achieve the target of 24x7 electricity supply in coming few years.

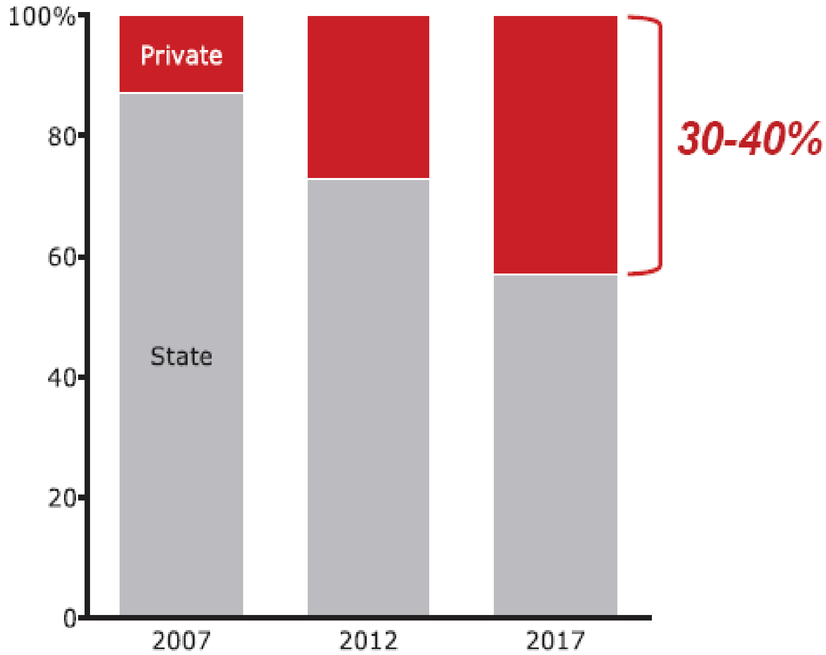

Figure 1.5: Last ten years growing contribution of Private sector in Indian electricity market (World Economic Forum, 2016)

After the liberalization of Indian power sector and making Electricity Act 2003, the involvement of multiple entities has been widely increased, and quality of performance has been assessed. A role of the private sector has been increased with the large extent and helping India to achieve its goal. Figure 1.5 shows the last ten years growing contribution of Private sector in Indian electricity market (World Economic Forum, 2016). The major factors which are playing a pivotal role in Indian power sector reformation are:

a) Efficiency improvement of existing companies

b) Subsidized renewable energy sectors

c) Decentralization of power generation for rural electrification

d) Increasing involvement of private industry for the rapid growth and getting more investment opportunity.

1.1.3.1.2. Government policies

The demand-supply gap has forced the authorities to look for the development of captive power plants at the load centres. The urban buildings such as universities, residential, and industries are generating onsite power generation to reduce the grid load. This gives an opportunity for customers to cash profit with sharing of surplus power through the microgrids.

India has abundant renewable energy sources availability for harnessing of the renewable energy sources. The MNRE has launched multiple policies to enhance the role of renewable energy in power generation. Earlier it has announced a goal of 20 GW solar energy installations by 2020, 100 GW by 2030, and 200 GW by 2050 (Vishnu, June 2008). Now it extended this with a 100 GW capacity of solar energy by 2022. With a transforming act, Electricity Act-2003, India has given a push to distributed energy generation specifically in the rural electrification. This implies the use of conventional and renewable energy sources for the distributed generation and power supply. With some additional features in the Electricity Act-2005, an extension of the Electricity Act-2003, India focused on the reliable power supply to its rural areas. It increased the contribution of decentralized power generation based on conventional and renewable energy sources; only renewable energy sources are being used, whereas reaching out with conventional power supply system is not feasible. India has announced attractive financial subsidy schemes for installation of renewable energy sources at the commercial and residential buildings. The MNRE is planning to launch some regulation over 'minimum renewable energy content' in commercial buildings very shortly. This bill would mandate installation of renewable distributed generation units for commercial distributions, universities, residential area, industries, and government buildings to harness renewable energy sources at the site and will promote the development of microgrid in India. Some initiatives of India to boost the use of renewable distributed generation are:

a) To protect renewable energy producers from payment delays by power distribution firms.
b) To support for stressed power assets and renewable energy projects in the country.
c) Shipping department planned to install 160.64 MW solar and wind power projects at all the major ports in India by 2017.
d) With 50 kW average capacities of 10,000 solar, wind and biomass projects would be installed in next five years.
e) Reaching towards affordable, clean and reliable power supply to every household.
f) Regulated its state partners to prepare year-wise action plans to achieve the target of 175 GW renewable energy capacity by 2022.

1.1.3.1.3. Government programmes

Commitment to achieve clean and affordable power supply to each household, India started multiple programs to boost the electricity sector. Major program has been launched for the increasing role of renewable energy to reduce carbon emissions and showing global commitment to reduce 30-35% carbon emissions by 2030. In technological advancement and penetration of renewable distributed generation in the electricity sector, India has launched multiple programs for promoting the renewable distributed generation technology. Recently started programs are:

1.1.3.1.3.1. Integrated Power Development Scheme (IPDS)

The concept of integrated renewable distributed generation under Integrated Power Development Scheme (IPDS) launched with the objectives:

a) Strengthening of sub-transmission and distribution networks in the urban areas.
b) Metering of distribution transformers/feeders/consumers in the urban areas.
c) Information Technology enablement of distribution sector and strengthening of the distribution network.
d) Completion of optical fiber missing links to connect all the 33 kV or 66 kV grid sub-stations.
e) National Power Data Hub development at Central Electricity Authority (CEA).
f) Training and Capacity Building.
g) Provisioning of Solar Panel.

1.1.3.1.3.2. National Smart Grid Mission (NSGM)

India started a National Smart Grid Mission (NSGM) initiative in power sector to plan and monitor implementation of policies and program related to smart grid activities. Up to 30% of the project cost of smart grid for most of the components will be provided by a grant from the NSGM budget. For certain selected components such as training and capacity building, consumer engagement, etc., the funding will be 100%.

Smart grid projects will cover the indicative components:

a) Deployment of smart meters and advanced metering infrastructure (AMI).

b) Renovation and modernisation of the substation with the feasible application of geographic information system (GIS).
c) Medium sized microgrids development.
d) Development of renewable distributed generation by using photovoltaics.
e) Real-time monitoring and control of distribution transformers.
f) Provision of power quality improvement measures like harmonic filters etc.
g) Infrastructure development for charging of the electric vehicle.

Because of underdevelopment of this new technology, this will have some modifications in future as per their operational work. This will develop a new dimension of power distribution system in India. It will give the opportunity to reduce tariff with optimal utilization of power distribution.

1.1.3.1.3.3. Programme on "Development of Solar Cities"

The MNRE has launched a program on "Development of Solar Cities." This gives installation of photovoltaic panels in urban areas and reduces grid supply.

This program assists the state government in the development of urban areas by three measures:

a) Developing a master plan for increasing energy efficiency and use of renewable distributed generation in urban regions.
b) Setting-up of an institution for proper implementation and regulation of the master plan.
c) Public awareness for the use of renewable distributed generation in residential buildings.

Aim to reduce 10% conventional power supply and use advance efficient technology like smart grid or microgrid to achieve this. Public involvement is the major part of this program to reduce dependence on conventional power sources.

1.1.3.1.3.4. Jawaharlal Nehru National Solar Mission (JNNSM)

The Jawaharlal Nehru National Solar Mission (JNNSM), also known as National Solar Mission, is one of the eight keys of National Missions which comprise India's National Action Plan on Climate Change (NAPCC). A mission of this program is to transform rural economy with decentralized power generation system.

The objective of this program is to the rapid installation of solar energy units throughout the nation to make India as a global super power in solar energy. The aim of the National Solar Mission is showing unexceptional growth in the solar energy sector to lighting rural population lives. The role of distributed generation in this program is very important.

Implementations of this program to achieve its target in multiple phases are:

a) Policy development for the deployment 100 GW by 2022 with composition of the 40 GW Rooftop and 60 GW large or medium scale grid integrated solar power projects.
b) Develop better environment for solar manufacturing, specifically solar thermal for indigenous production and market leadership.
c) Promoting installations of off-grid solar power units to reach out 1000 MW by 2017 and 2000 MW by 2022.
d) Development of the 15 million square meters area of the solar thermal collector by 2017 and achieve 20 million by 2022.

e) Deployment of the 20 million solar lighting systems in rural areas of India by 2022.

1.1.3.1.3.5. Wind Power Programme

The broad-based Wind Power Programme of India aims to catalyze the commercial use of grid interactive wind power. This program covers unknown windy areas for assessment of the wind energy potentials. Now the focus is wide and implementation of projects in new or uncovered areas. Further hundreds of private winds monitoring stations are also operational in this program. It is found that 237 stations have economically preferable wind power potential greater than 200 W/m^2 in India.

For this program, the India is providing fiscal and financial incentives, which includes rebates like 80% over accelerated depreciation, excise duty exemption, concessional customs duty on specified items, sales tax exemption, income tax exemption and the similar one for ten years. Also, State Electricity Regulatory Commissions (SERCs) are determining preferential tariffs. The Indian Renewable Energy Development Agency (IREDA) gives loan for installation of wind power projects. In 2009, the ministry of power introduced a Generation Based Incentive (GBI) Scheme for wind power projects, in which wind power projects are not availing the Accelerated Depreciation (AD) benefit are eligible for GBI incentive. Under GBI, industries will get incentive based on the outcome as compared to earlier investment based.

1.1.3.2. Regional management in renewable distributed generation

The local energy management allows the use of renewable distributed generation according to the grid operator requirement and also with the variation of renewable energy sources. When generation exceeds demand, surplus power can supply to grid or store in batteries. When generation is lower than demand, demand fulfills with either power purchased from the grid or use storage power. Hybrid technology gives better control over power generation variability from renewable energy sources.

Regional distributions of the renewable energy sources vary with geographical changes. Harnessing of the renewable energy sources in demand areas needs case-specific analysis to get the suitable mode of renewable distributed generation technology for the installation. In this work, we considered a case of BHU campus for installation of suitable renewable distributed generation units to reduce carbon emission levels and load over grid supply. This will help to achieve the vision of government of India to develop sustainable power generation system. BHU campus is located in the north India between 25.26^o N latitude and 82.99^o E longitude. It is one of the largest universities considering the campus area in India; BHU campus is a miniature representation of residential regions in the country spread over 1300 acres with approximate 35000 residents.

The benefits of expanding these energy sources would be enormous; renewable distributed generations would reduce BHU's dependency on grid supply and elevate the environmental hazards by depending on indigenous resources. The cost of electricity, which is dropping rapidly, when drawn from renewable energy sources, opens up the competition to many conventional technologies. Renewable technologies have no fuel costs, and they cannot be exhausted easily. In this context, this study proposes a scientific model to prioritize alternative renewable distributed generation technologies for a region-specific with their geographical factors. After that, manage the uncertainty of generation and load demand to optimally allocate renewable distributed generation units. Evolution of smart grid technology promotes decentralized power generation with optimal utilization of regional renewable energy resources.

1.2. Thesis objectives

The ultimate goal of the work adopted in this thesis, as shown in Figure-1.6, is to tackle the problem of renewable distributed generation planning and optimal allocation assessment under conditions of high penetration of renewable distributed generation. The proposed planning methodology takes into consideration the intermittent nature of the renewable energy sources, the annual load profile, and the technical constraints of the system. To assess optimal planning of renewable distributed generation in installation area during simulation of the model, the evolutionary genetic algorithm (GA) and Monte Carlo Simulation (MCS) techniques are proposed to model the random behaviour of the renewable distributed generations and system components. With regards to renewable distributed generation planning, the main focus of the proposed methodology is to optimally allocate renewable distributed generation units in distribution systems to maximize the utility benefits. Moreover, a novel model is proposed to optimally supply back surplus power to the grid when low demand and power purchased from the grid in higher demand with generation to mitigate the problems created by the high penetration of intermittent renewable distributed generation, and at the same time add value to the utility and the investors.

The objectives of this research are:

1. Selection of the appropriate renewable distributed generation technology. VIKOR method a novel multi-criteria decision-making technique has been chosen for the selection of best renewable distributed generation technology at BHU campus;
2. Statistically analyse the uncertainty of hourly wind speed distribution at BHU campus from the three continuous probability distributions with three goodness-of-fit tests by using modern statistical tool R programming language software;

3. Statistically analyse the uncertainty of hourly load demand distribution at BHU campus from the three continuous probability distributions with three goodness-of-fit tests by using R programming language software;

4. Optimal planning of renewable distributed generation at BHU campus with the objective of net project cost minimization and solving this with evolutionary genetic algorithm methodology to get the optimal solution.

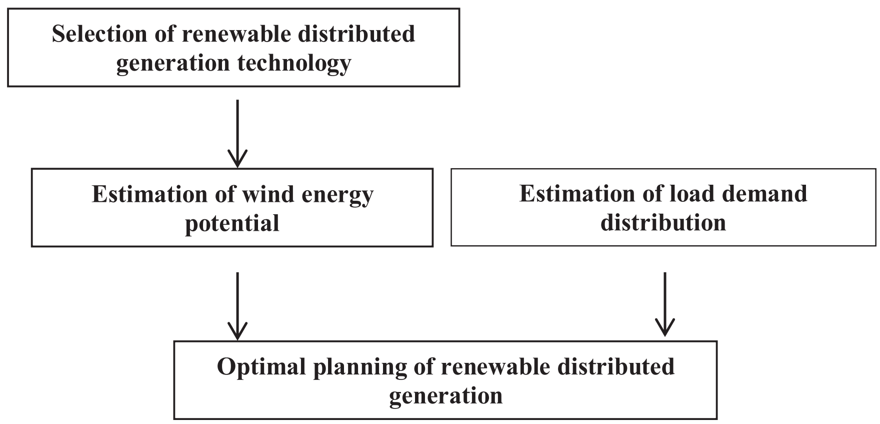

Figure 1.6: Objectives of the thesis

1.3. Hypothesis and Assumptions

The aim of this thesis is to concentrate on developing new models to extend the knowledge of renewable distributed generation planning and optimization, especially in the area of installing capacity analysis. The work in this thesis is essential to establish an accurate, extendable, cost-effective planning system to assist in increasing renewable distributed generation penetration effectively. The following summarizes the work in four sub-areas around installing capacity that is delivered in the thesis.

A novel multi-criteria decision making based VIKOR method approach is proposed in this thesis to determine the suitable renewable distributed generation technology at BHU campus. Using this method, different feasible renewable distributed generation alternatives are identified and prioritised, which helps appropriate renewable distributed generation developments to justify the investment from both technical and economic aspects. The knowledge of benefit of different priority settings could also form a basis of multiple criteria for selecting renewable distributed generation to provide economic incentives to facilitate the decentralized generation planning process.

The uncertainty of wind speed distribution has been predicted from the Lognormal, Gamma and Weibull probability distribution functions with Kolmogorov-Smirnov, Anderson-Darling and Cramer von Mises goodness-of-fit tests. Data has been computed in R programming language software. For better insight the uncertainty of wind speed distribution has been analysed, which helps to get optimal investment in installation of the renewable distributed generation units at BHU campus.

Another major contribution of the research reported in this thesis is to provide the estimation of load demand uncertainty. Lognormal, Gamma and Weibull probability distribution functions have been proposed with Kolmogorov-Smirnov, Anderson-Darling and Cramer von Mises goodness-of-fit tests to identify best suitable probability distribution function in estimation of the load demand uncertainty at BHU campus. R programming language has been used for the computation.

The optimal planning of renewable distributed generation is further supported by exploring the objective functions. Objective functions consist investment cost, operation and maintenance cost, cost of power purchased from grid, saving from the internal consumption and revenue of surplus power supplied to the grid. A mathematical model has been developed to get the optimal solutions. A well-known and effective methodology genetic algorithm has been used for getting the optimal solutions. By clearly demonstrating the benefits of adopting a particular genetic algorithm methodology in a renewable distributed generation planning cost reduction scheme, the method will facilitate the development of optimal allocation of renewable distributed generation units.

Apart from the progress in each topic that presents their own and unique contribution, the following benefits are expected to be achieved from this thesis:

- With modern smart grid technology, the increase in utilization of renewable energy sources will promote integrated renewable distributed generation, defer the network reinforcement, and also avoid the unnecessary replacement of assets;
- For renewable distributed generators, the growth in the installed capacity and annual generation without costly and time-consuming infrastructure upgrades will raise the financial return on their investments;
- For consumers, benefit from insuring appropriate levels of network capacity adequate to meet security and quality standards of the power supply.

Overall, the development of new optimization algorithms and models for improved renewable distributed generation planning is believed to facilitate the connection of new installed renewable distributed generation capacity in a cost-effective way, thus allowing the associated environmental and social benefits to be captured. The work presented in this thesis will be useful for the power distribution management and help to meet the changing needs of the transition of the BHU campus to grow with more sustainable and smart technologies.

1.4. Structure of the Thesis

The main content of this thesis consists of eight chapters and is structured as shown in Figure-1.7:

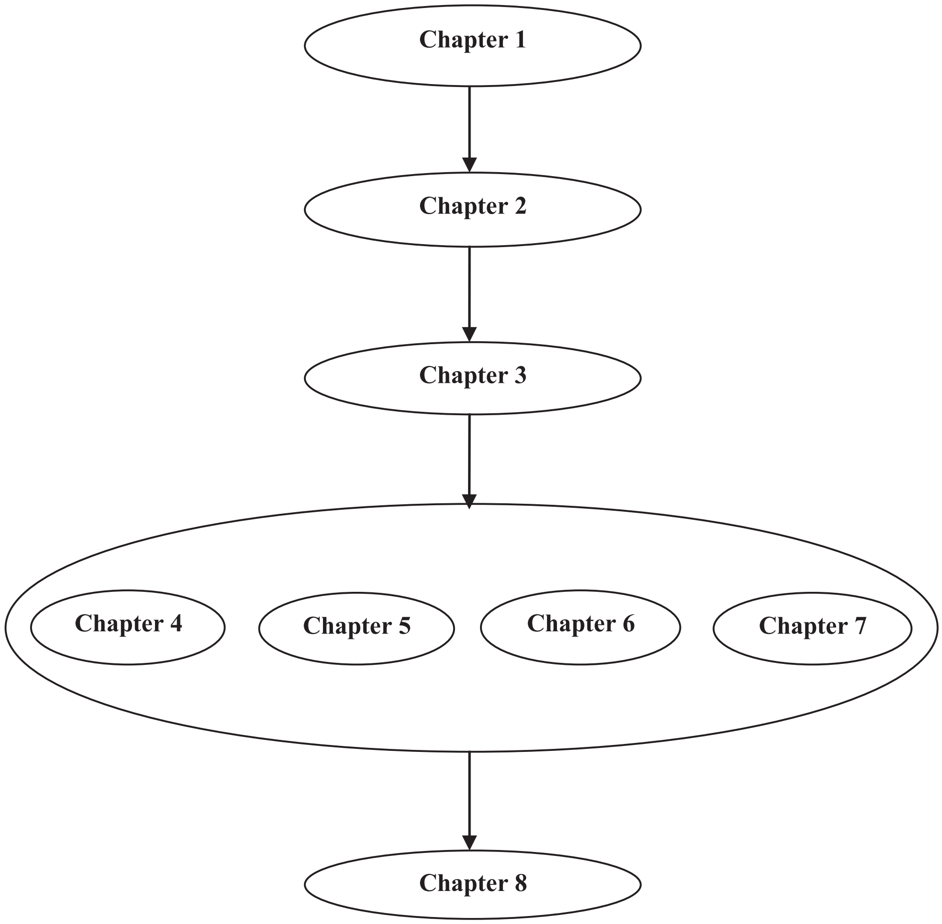

Figure 1.7: Thesis outline

Chapter-1 deals with the introduction of the thesis which consists of basic ideas about this thesis. A brief introduction to this research work has been discussed in this chapter followed by objectives of the thesis and hypothesis and assumptions used in this research work.

Chapter-2 describes literature review of the thesis. The literature review of the whole thesis has been segmented into four major work areas which have been presented in this thesis. Those work areas are the selection of best renewable distributed generation technology, estimation of wind energy potential, estimation of load demand distribution and optimal planning of renewable distributed generation. After the study of literature review, we identified the research gaps and discussed it.

Chapter-3 is the theoretical background of the thesis which shows multi-phase development in power generation system from its very initial stage. First, it overviews the conventional power generation and the different sources of distributed generation technologies. We explored the renewable distributed generation technologies that are available to facilitate the integration of renewable distributed generation. The contribution of different modern technologies to increase demand of renewable distributed generation systems is analyzed with the focus on the development of optimal planning methods for active integration. The planning philosophy under the transition to the smart grid is studied

Chapter-4 shows a novel multi-criteria decision making based VIKOR method approach is proposed to determine the suitable renewable distributed generation technology at BHU campus. Using this method, different feasible renewable distributed generation alternatives are identified and prioritized, which helped appropriate renewable distributed generation developments to justify the investment from both technical and economic aspects.

Chapter-5deals with the prediction of the random distribution of wind speed at BHU campus for the estimation of wind energy potential. The uncertainty of wind speed distribution has been predicted from the different continuous probability distribution functions with goodness-of-fit tests. Data has been computed from the R programming language software.

Chapter-6 studies the issue of estimating randomly distributed hourly load demand at BHU campus. Different probability distribution functions have been proposed with goodness-of-fit tests to identify best fitted probability distribution function in case of load demand distribution at BHU campus. R programming language has been used for the computation.

Chapter-7 represents the optimal planning of renewable distributed generation supported by exploring the objective functions. A mathematical model has been developed with constraints to get solutions. A well-known and effective methodology genetic algorithm has been opted for getting the optimal solutions.

Chapter-8 shows overall summary and conclusions of this thesis. This chapter also discusses the contributions and limitations of using the approaches developed. The potential directions of the future work are also addressed.