Chapter 1 : Introduction

1.1 Background of the work

Energy is crucial in supporting people's daily lives and for continued technological development. Over the past decades, energy supply as well as demand has been steadily increasing due to population growth, economic development and living standard improvement throughout the world. To meet rising energy demands, fossil fuels are being extensively used, which has led to continuous increase in greenhouse gas emission. It has been reported that 28% of greenhouse emission is produced during electricity generation, especially in developing countries worldwide (United States Environmental Protection Agency, 2016). Most of the electricity generation is centralized and generates power at large scale. These systems are usually situated away from end-user and connected to high-voltage transmission lines. The centralized power generation systems include conventional power plants, such as fossil fuel, nuclear and hydro. Conventional power plants lead to extensive usage of depleting fossil fuels for centralized power system. This practice heavily contributes to greenhouse emission and carbon footprint, which are not just local but a global concern. Moreover, in a centralized system, other difficulties are associated with extracting, processing, and transporting certain fuels, such as coal and natural gas. Further, large volumes of water are used for steam generation and cooling system, which finally discharge to the water source relatively at a higher temperature and reduced quantity, due to evaporation losses. In addition, enormous consumption of fossil fuel leads to shrinkage of its reserves and gradually rise in its costs.

To address these issues, research in clean energy as well as decentralized power generation, which is near to the end user is gaining importance amongst researchers worldwide in order to work towards sustainable future. Considering renewable energy as a promising alternate energy source and exploring the potential at the local level will help improve energy security as well as reduce the ill effects, such as climate change and global warming. The decentralized power generation also known as distributed generation includes various technologies, such as photovoltaic system, wind turbines and biomass systems, which generate electricity at/or closer to where it will be used. These technologies can be used to meet the individual demand, such as households, water pumping, small businesses, or these may be integrated into microgrid. The decentralized power generation, which relies only on Renewable Energy Sources (RES), also include either storage system or backup generator, such as diesel generator to provide electricity in case of power shortage or high demand. The decentralized power generation also reduces the transmission and distribution system losses by using local renewable energy sources.

In the last decade (2005-2015), growth in total energy consumption was 1.7%, whereas energy generation from renewable and fossil fuel were increased by 5.4% and 1.6%, respectively (Renewable Energy Policy Network for 21st Century (REN21), Renewables Global Status Report, 2018). In the year 2016, renewable energy resources (excluding traditional use of biomass) contributed approximately 10.4 % of total energy consumption globally. Among all renewable energy resources (wind, solar, biomass, geothermal, ocean power and hydropower), hydropower contributes major portion in power generation, which is about 3.7% out of 10.4% in total (REN21). Despite the fact that power generation from hydro is more, further expansion and new installation are very much restricted due to limited availability of viable sites. On the other hand, solar photovoltaic (PV) and wind are abundantly available in most of the countries. Thus, PV and wind technologies are growing at a higher rate among RES. As cost of PV panel decreased due to technological advancements, it became popular among the RES. Installed global capacity of PV plants in the year 2017 was 402 GW with an increase of 32.6% from the previous year. About 98 GW of PV capacity is added in the year 2017, which includes on-grid and off-grid plants. Major contributors to the new installation in the year 2017 were China, India, Japan, and the United States. China is on the top in installed capacity of PV (54% of total capacity), and India is sixth (9.3% of total capacity) in the world despite having huge PV potential. In the market of wind power, more than 52 GW were added globally in the year 2017 which is an increase of 11% from the previous year. The total installed global capacity of wind power in the year 2017 is 539 GW. India added 4.1 GW of wind power in 2017 and ranked fourth in the world with a total capacity of 32.8 GW. By the end of 2017, commercial wind power was seen in more than 90 countries and 30 new countries added more than 1 GW in operation. This shows the diversification of wind power market. Rapid decrease in the cost of wind power generation, both on-shore and off-shore, have made it a feasible option for power generation. Wind and solar power quickly became mature and cost competitive technology across the globe.

Due to economic development, especially in a developing country like India, gap in energy supply and demand of energy is more in some regions. Urbanization in India is taking place at a faster rate. Latest Census report indicates that 31.16% of total population lived in urban areas (Census, 2011). In 2017, it increased to 34% according to World Bank data. Also, due to steady population growth, there is a substantial increase in demand for electricity. "Growth of electricity sector in India from 1947-2018" report highlighted that in the last five years (from March, 2013 to March, 2018), energy demand has increased by 37.11% (Ministry of Power, 2018). As on date, India has a generation capacity of 225 GW and due to lower capacity additions over the years, supply has perpetually lagged behind demands. In the fiscal year 2017-18, the utility energy availability was 1,205 billion kWh with a deficit of requirement by 8 billion kWh and the peak load met was 160,752 MW with a deficit of requirement by 3,314 MW (Ministry of Power, 2018). However, in "Load generation balance report 2018-19 (LGBR, 2018 Report)", India's Central Electricity Authority anticipated energy surplus and peaking surplus to be 4.6% and 2.5%, respectively for 2018–19 fiscal year. In the LGBR 2018, it was reported that "*Surplus energy is anticipated of the order of 1.9%, 14.8% and 22.9% in the Western, Northern and North-Eastern Regions respectively. Eastern and Southern regions are likely to face an energy shortage of 4.2% and 0.7% respectively which can be compensated from surplus power in other regions. The peaking surplus of 9.3%, 4.9%, and 12.6% is anticipated in Western, Eastern and North-Eastern Regions respectively. Northern and Southern regions are likely to face peak deficit of 1.2% and 4.5% respectively*". Therefore, the LGBR 2018 report stated that "*States with the shortage of energy would need to arrange additional power from them to meet their peaking and/or energy shortages during 2018-19*".

The Power Grid Corporation of India Limited (PGCIL) is responsible for power transmission across the country. The PGCIL ensures efficient operation and maintenance of transmission systems and operates 1,51,380 circuit km of transmission lines, 3,53,344 MVA transformation capacity and 239 sub-stations as of January 2019. The power systems in India are divided into five regional grids namely: Northern, Eastern, Western, North Eastern and Southern region, for planning and operational purpose. Each regional grid is connected to all public sector power plants in that region and receives electricity generated by the power plants. The generated electricity from different power plants needs to be synchronized in order to combine into one grid. Regional grid then transfers the power to National Load Dispatch Centre (NLDC), India or to other regional grid, if required. The NLDC schedules and distributes it to the end users. There is variation in the frequency of electricity generated by each power plant, which is one of the difficulties faced by the regional grid while integrating and synchronizing. Each regional grid has some peculiarities in terms of capacity, nature of power generation and demand of energy. North region grid faces a deficit in supply/demand due to fluctuating loads, which is weather dependent (as high as 50ºC in Rajasthan verses -20ºC in Kashmir). At the same time, adverse weather conditions such as fog and dust make the maintenance of the transmission lines more difficult. Moreover, in snow conditions, feed water for hydropower plant goes runof-the-river. On the contrary, North Eastern region has less load and high hydro potential. However, the Western and the Southern region has high load due to the high demand of energy for industry and agriculture. In Southern region, the hydropower is monsoon dependent. Therefore, PGCIL faces difficulty in maintaining supply/demand mainly due to variation in hydro power, demand and frequency of electricity. In case of any unforeseen situation, such as heavy snowfall, blizzard or silt of hydropower, operation of national grid becomes challenging. For example, in February 2015, twelve-meter snowfall in Kashmir caused major operational difficulty in the regional grid. Other concerns for regional grid includes integration of new technologies, technological obsolescence, reliability of physical system, etc. These days, PGCIL focuses on integrating renewable energy technologies in their distribution network to improve efficiency by reducing inline losses, addressing environmental concerns by reducing CO_2 emission and to achieve reliability of supply. Renewable resources, such as wind and solar are generally available across India. However, wind and solar resources are variable and intermittent, which pose severe stresses to grid security system. In view of this, accurate assessment and development of an Energy Management System (EMS) for optimum utilization of RES are desired, which can be easily used by energy planner under multiple spatial scales.

The high interest in power generation using RES demands a new power network which has capability to integrate RES with other distributed generators like diesel generator. Decentralized generation of power has the potential to integrate clean power resources within microgrid with high penetration of RES, which can be operated stand-alone or grid-connected mode with the help of EMS (Figure 1.1). Microgrid as a sustainable energy system, not only reduces the greenhouse emissions but also has several other advantages. Advantages of microgrid are discussed by Lasseter (2002) and Chris and Giri (2006). They have highlighted that introducing microgrid can improve local reliability, minimize feeder load, electrify remote locations, reduce transmission loss and provide cost-effective power to end-user. Microgrid can be operated either stand-alone mode, which is also known as islanding mode, or grid-connected mode. When it operates as stand-alone, the storage system is a must component to normalize the variability in RES. Microgrid consists of five components; Distributed Generators (DGs), loads, storage devices, controls, and point of common coupling.

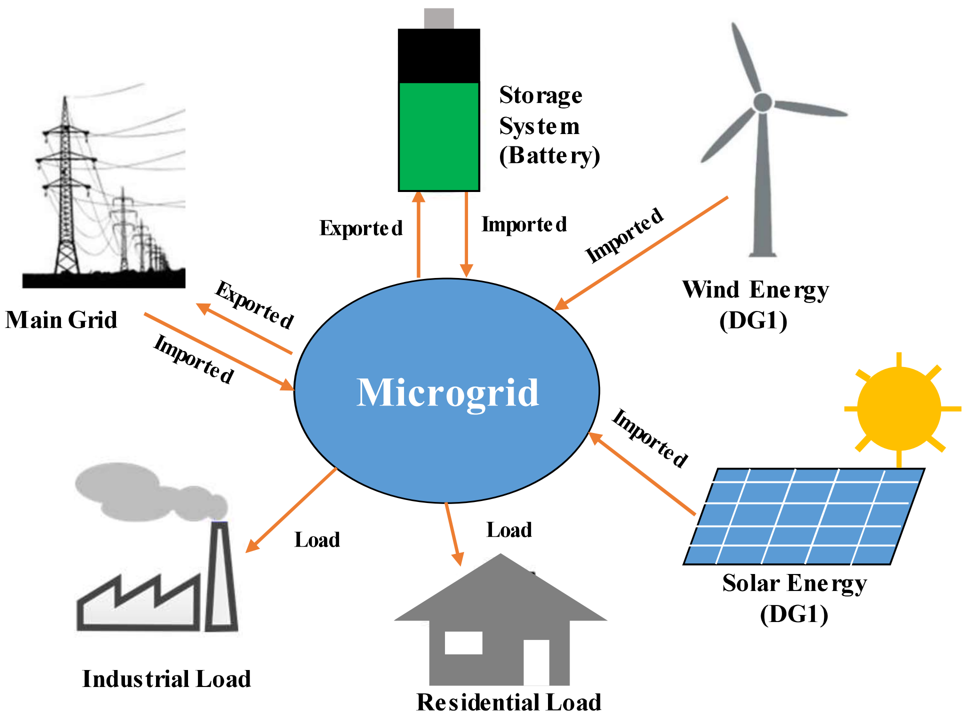

Figure 1.1. Typical schematic diagram of a microgrid (Ref: Gu *et. al*., 2014).

Microgrid is expected to generate sufficient power to meet the local demand. It is, therefore, necessary to efficiently estimate DGs including RES. India has an estimated renewable energy potential of about 900 GW, out of which more than 850 GW comes from solar and wind (MNRE Report, 2016-17). Andhra Pradesh (AP) and Telangana state (TS) are the states with high potential of wind and solar energy. However, the installed capacity is far less than the estimated capacity. AP and TS have total installed capacity including renewable energy of 23.22 GW out of which more than 5.85 GW is from renewable energy which is about 25% (MoP, 2018). Addition of renewable energy capacity is growing fast, especially power generation from solar and wind. Even though AP and TS had anticipated for energy surplus generation, yet only 107,330 MU requirement could be met with a deficit of 56 MU in the year 2016-17 (Load Generation Balance Report, 2017-18). This power deficit is increased in the year 2017-18 to 175 MU and the requirement was 118,702 MU (Load Generation Balance Report, 2018-19). It can be noticed that increase in requirement in one year was 10.6% whereas increase in deficit was 212.5% (more than 200%). The anticipated power shortage for the year 2018-19 in TS is more than the previous year, deficit anticipated in energy and peak are 88372 MU and 1443 MU, respectively. At the same time, AP is among the top three states in India with maximum capacity of solar park. In the near future, AP and TS are aiming to become a surplus energy generating states with increased renewable energy harvesting. It is, therefore, the need of the day to have accurate evaluation and exploitation of RES in AP and TS. As of now, there are only a few locations where measured data is available, which limits the exact estimation of wind and solar potential. Thereby an efficient methodology needs to be developed for accurate prediction of the solar and wind potential at the local level using reference measured data. Besides, overall mapping of wind and solar potential will increase the visibility of potential and help to locate areas with high potential.

Furthermore, efficient utilization of RES like wind and solar at the local level depends upon three factors; accurate perdition of RES, estimation of demand and integration of sources into EMS. Available measured data can be used as reference for prediction and evaluation of wind and solar potential at the local level using efficient mathematical or prediction techniques. In order to predict the solar and wind potential accurately at a local level, different meteorological parameters need to be considered and analyzed. A numerical tool has to be used for handling large data and developing a model to predict the solar and wind potential within AP and TS. However, RES is intermittent in nature and site-specific, which makes prediction problem complex. Hence, an efficient model like Artificial Neural Network (ANN) needs to be developed to predict solar and wind potential. Measured data of meteorological parameters obtained from Government agencies can be used to train and develop a model. Predicted solar and wind potential of AP and TS need to be mapped using a geographical mapping technique, such as Geographic Information System. Based on predicted potential of RES and maps, regions with higher potential can be identified. Ideal types and area of land within the regions with higher RES potential have to be investigated for installation of power generation system, such as wind farms and solar fields using land use and land cover analysis. Power generation capacity from available source of energy has to be estimated and optimized, which can meet the demand of targeted community. Therefore, actual estimation of energy demand for small population is also required, which has to be generated by microgrid. In addition, a storage system, such as battery and fuel-cell is also required into microgrid to improve its reliability. Along with storage system, diesel generator can also be used for backup.

All the RES and backup DGs along with storage device integrated into microgrid are required to be utilized efficiently to meet the power demand. This led to the introduction of Energy Management Systems (EMS) to microgrid. The EMS works on the primary function of monitoring the different energy resources and controlling energy consumption at a particular location. This way, EMS coordinates the DGs effectively, which are integrated with the microgrid, to ensure the power supply to loads with least possible operational cost. It helps the decision maker to understand the limitations and advantages of a location and thereby control the usage accordingly (Shi *et al.*, 2015). All possible DGs need to be integrated into microgrid and optimized for high productivity. Researchers worldwide have developed several methods for energy management system, yet there are some challenges to be addressed. Microgrid should deliver quality of power with high reliability. Hence, managing a microgrid is challenging due to high geographically dispersion, limited location of distributed resources and seasonal as well as intra-day variability in renewable resources.

1.4 Organization of the thesis

The research work is presented in seven chapters as follows:

Chapter – 1: This chapter presents an introduction to the thesis. It discusses the motivation and needs to model RES and to develop an energy management system for microgrid operations. It also states the study objectives and the methodology adopted, followed by organization of thesis contents.

Chapter – 2: This chapter gives a brief introduction to microgrid and energy management system. A review of the literature on different techniques of estimation and modeling of energy resources at the local level, and the difficulty and limitation associated with it, are presented. This is followed by a discussion on optimal utilization of resources, such as wind farm layout and solar field layout. Subsequently, various approaches and major issues related to energy management system and microgrid, such as sustainability and reliability are discussed in detail. Finally, research gaps are highlighted.

Chapter – 3: This chapter discusses the estimation and mapping of wind energy resources. The detailed description of measured meteorological parameters used to develop an ANN based predictive model is presented. Afterwards, training, testing and optimization of the predictive model is discussed for accurate prediction of wind speed. Predicted wind speed is then mapped over AP and TS using GIS approach. In addition, identification of regions with higher wind potential is presented using the predicted wind speed and wind potential maps. The LULC analysis is performed to estimate the available area of suitable types of land for wind farms.

Chapter – 4: In this chapter, prediction and assessment of solar radiation are discussed. Development of an ANN model is presented to predict solar energy potential in AP and TS. The ANN model is trained and optimized using geographical and meteorological parameters for predicting solar radiation. The predicted solar radiation is then analyzed and used to create monthly mean maps using GIS approach. Based on the developed maps of solar potential, regions of higher solar potential are identified. Moreover, availability of suitable type of land and its area are estimated for solar fields.

Chapter – 5: This chapter deals with the optimal use of resources and power generation with cost estimation. Wind power and solar potential are considered in the study. The WFLO is carried out for the positioning of wind turbine. Solar field layout is also optimized for maximizing the power generation, considering shading effect of panel, solar elevation angle and panel dimension. An excel based model is developed for optimal use of solar energy within AP and TS. Roof-top solar power generation is studied for a small community, which can be operated stand-alone.

Chapter – 6: In this chapter, integration and the optimal use of various energy resources in a stand-alone microgrid are discussed. To meet the demand, Integrated Renewable Energy System (IRES) approach has been developed and analyzed. Different energy generation units such as photovoltaic, wind, diesel, and biogas were used along with energy storage units, such as batteries and fuel cell. Analysis of seven possible scenarios (realistic and futuristic) with different combination of energy resources and storage systems on the basis of lowest levelized cost of energy and net present cost is presented. Various technologies were integrated to form an optimal IRES configuration for a study region and possible policy interventions are suggested based on IRES results.

Chapter – 7: This chapter presents the summary of results, conclusions and specific contributions of the study. Future scope of work is also presented.