PREFACE

In the modern era, the human dependence on technology is increasing day by day, which demands significant supply of electricity for its functioning. There are various segments of energy sources to generate electricity like fossil fuels (coal, oil, and natural gases), renewable energy (photovoltaic, solar thermal, wind turbine, biomass and geothermal) and nuclear energy. Major power generation comes from the fossil fuel based conventional thermal power plants. Limited resources and adverse environmental effect are the major reasons behind setback of the conventional power plants. For environmental concern, world identified alternative and sustainable energy sources like renewable energy for the sustainable development. Owing to the reason of being carbon-free energy source, utilization of renewable energy resources is increasing exponentially. The World is moving towards harnessing of renewable energy sources to reduce excessive carbon emission and having effective alternative energy sources. With regressive research and development work in renewable energy sector, now it is getting more economical and more feasible one. In the digital world, availability of onsite renewable energy sources improved grid supply system and evolving smart grid concept is getting this more preferable. This increased the transparency in metering system of the power supply also helps to reduce losses with better control by using the newly evolved smart grid technology. Evolution of smart grid helps to increase the role of decentralization of power generation with renewable energy sources as per consumers' preferences in low voltage distribution grids. These technological advancements have changed the nature of conventional power distribution system. The paradigm of conventional power distribution system is changing globally and more liberalization is given by the state to increase its capacity and fulfill demand. Economic development

through increasing per capita power consumption of a nation and its commitment to reduce carbon emission as per Kyoto protocol made this very complex and strategic.

The theoretical idea of installing renewable energy based distributed generation, named as renewable distributed generation, under uncertainty of load demand and power generation, is a managerial strategic decision to cope up with demand-supply variations; nevertheless, its implementation is impaired by many practical difficulties till now.

In modern Indian power distribution system, the role of renewable distributed generation is growing rapidly with the evolution of smart grid concept in the modern power sector. With effect of the new reformation in Indian power sector, India reformed its power sector and moved towards harnessing of renewable energy sources and increasing contribution of renewable distributed generation technology to reduce the demand-supply gap. Renewable distributed generation technology is helping India to electrify its rural areas with minimum transmission and distribution losses and giving more flexibility to match demand variability. Increasing renewable energy capacity in India also withstands its global commitment to help in reduction of carbon emissions and having sustainable future.

The increasing global demand of renewable energy sources increased the demand for small-scale capacity of renewable distributed generation technology in the modern power sector. In the form of small generating capacity, renewable distributed generation technology gives the flexibility to generate power in a decentralized power generation system. Integration of renewable distributed generation technology with radial power distribution system is rapidly growing. In this PhD study, author studied on the topic of optimal planning of renewable distributed generation system with some novel contributions with a case of Banaras Hindu University (BHU) campus, India. For this, government policy to boost this area, appropriate selection of a renewable distributed

generation technology for installation region with the uncertainty of power generation and load demand have been analysed in this PhD study

In the literature review, literature of the respective four problem areas reviewed and identified the research gaps. In the theoretical background, development of modern power generation system from the conventional power generation system has been discussed. About the availability, current status, economic benefits, technical advantage, and future potential of renewable distributed generation in the modern power system is discussed in this section.

Selection of appropriate renewable distributed generation technology is more strategic and decisive area. This is a complex multi-criteria decision making (MCDM) problem of having uncertain and conflicting factors. In this work, we used the recently developed MCDM technique VIKOR method to choose best appropriate renewable distributed generation technology at BHU campus. The advantage of VIKOR method is to have a solution closest to the ideal solution having an acceptable compromise of conflicting and non-commensurable criteria. For assigning weights to the different criteria, analytical hierarchy process (AHP) has been used. The importance of different criteria has been assigned by decision-makers based on their preferences. The result shows that the wind turbine option is the best choice in the case of BHU campus.

Amongst the number of available renewable energy sources, the role of wind energy source in the power sector is very important. With the use of MCDM, VIKOR method, wind turbine as the best alternative of renewable distributed generation technology at BHU campus has been identified. Knowing the wind energy potential distribution, estimation of the wind energy potential at BHU campus should be computed. Estimation of wind energy potential depends on statistical analysis of wind speed distribution, which will give us the best-fitted probability density function of the desired

location. For statistical analysis of wind speed distribution, Hourly data of wind speed at BHU area has been collected from the source of National Renewable Energy Laboratory (NREL) by giving the geographical position of BHU campus 25.16^{o}N to 25.26^{o}N and 82.89^{o}E to 82.99^{o}E. For computing the available wind speed data, statistical R programming language software has been used. Recently developed R programming language software gives free access to users for doing statistical analysis. In statistical analysis, Weibull, Gamma and Lognormal continuous probability distributions are considered for getting best-fitted distribution. For testing of the goodness-of-fit test, three methodologies are considered for better results named as Kolmogorov-Smirnov, Anderson-Darling and Cramer-Von Mises. After the analysis, best result identified for the empirical wind speed data of BHU campus, Weibull distribution to be the best-fitted one.

Optimal utilization of renewable energy sources and continuous electricity supply in any location needs statistical analysis to predict the random distribution of electricity load demand of the demand area. For the statistical analysis, hourly load demand data of BHU campus for one year period has been collected from the Electricity & Water Supply Service (EWSS) centre, BHU. In statistical analysis, Lognormal, Weibull and Gamma probability distributions are considered to estimate the randomly distributed load demand data of BHU campus. The given load demand data is computed through the R programming language software for the statistical analysis and comparative study of proposed three probability distributions. With the help of Kolmogorov-Smirnov, Anderson-Darling and Cramer-von Mises, the three goodness-of-fit tests, Lognormal distribution is identified as the best fitted one in the case of BHU campus load demand variation.

Optimal planning of renewable distributed generation under uncertainty of load demand and power generation for the BHU campus has studied in this PhD study. Net project cost minimization is the major challenging and complex work in the managerial decision-making process. A mathematical model has developed for getting the optimal solution based on evolutionary genetic algorithm methodology computed in Java programming language. The objective function of the optimization model is to minimize net cost of the renewable distributed generation project.

The study shows that power-sharing with the grid from the prosumers (consumers who are producers as well) under smart grid technology is the new future of modern power sector in India. This will help to reduce carbon emission level and will reduce power losses. In developing nations, like India, where the maximum population lives in villages and remote areas, this is a solution to reach out to an inaccessible region. Renewable distributed generation technology integrated with the smart grid will help India to achieve its goal to reach out to every citizen with 24x7 power supply and shows global commitment to reduce carbon emission.

This PhD study emphasised on the optimal planning of renewable distributed generation system in India for the sustainable development. This study discussed the government's insight to promote renewable distributed generation system in the smart grid network. This PhD study emphasised on regional importance in the selection of best renewable distributed generation technology in investment region, which are not discussed in previous literature. For getting optimal power flow and cost minimization, statistical analysis of stochastic power generation and load demand were computed, and developed a mathematical model of optimization to get the optimal results. This study was validated by taking a case of BHU campus, India.