CHAPTER-VIII

Summary and conclusions

8.1. Summary

This chapter includes the summary and conclusions of research work presented in this thesis. It summarizes the key findings, discusses the main aspects, and brings together the contributions to the body of knowledge. The limitations of the methods that have arisen throughout this thesis are also presented, which lays the foundation for some further research directions. The potential future work is recommended and outlined.

The work presented in this thesis concentrated on region-based renewable distributed generation planning, especially the study of installing capacity, which is now a substantial area of research in India and is the key to facilitate renewable distributed generation technology penetration. Eight chapters have been presented in this thesis, each of which provides a perspective on the main thesis work; the main works are summarized as follows:

Chapter-1 deals with the introduction of the thesis, which consists basic ideas about this thesis. A brief introduction to the research topic has discussed in this thesis with objectives of the thesis. It also consist hypothesis and assumptions used in this thesis with thesis outline.

Chapter-2 describes literature review part of the thesis. It discussed role of renewable distributed generation in the modern sustainable growth of power generation system. The literature review has been segmented into four major work areas, which have been presented in this thesis. The work areas are the selection of renewable distributed generation technology, estimation of wind energy potential, estimation of load demand distribution and optimal planning of renewable distributed generation. The gaps in existing knowledge are identified for respective work areas.

Chapter-3 discusses evolution of electricity and their commercialisation with the wide mode of power generation technologies. This chapter shows the paradigm shift in mode

of power generation from conventional fossil fuels to sustainable renewable energy sources. It discussed future role of smart grid integrated renewable distributed generation technologies for sustainable growth.

The chapter-4 shows multi-criteria decision making based novel VIKOR method approach is used to select the suitable renewable distributed generation technology in a case of BHU campus. Using this method, alternatives to feasible renewable distributed generation technologies identified and prioritize, which helps appropriate renewable distributed generation technology selection to justify the investment from both technical and economic aspects. The knowledge benefit of different priority settings could also form a basis of multiple criteria for selecting renewable distributed generation technology to provide economic incentives to facilitate the managerial decision-making process.

Chapter-5 is a study to predict random wind speed distribution at BHU campus for estimation of the wind energy potential. Uncertainty management of wind speed distribution has been predicted from the three continuous probability distribution functions Lognormal, Gamma and Weibull with three goodness-of-fit tests Kolmogorov-Smirnov, Anderson-Darling and Crame-von Mises. Data has been computed from the R programming language software.

Chapter-6 is a study of the issue of estimating randomly distributed hourly load demand with a case of BHU campus. Three continuous probability distribution functions Lognormal, Gamma and Weibull have proposed with three goodness-of-fit tests Kolmogorov-Smirnov, Anderson-Darling and Crame-von Mises identify best-fitted probability distribution function in for the BHU campus load demand uncertainty. R programming language software has been used for the computation.

Chapter-7 represents the optimal Planning of renewable distributed generation by exploring the objective function to minimize net project cost. Objective function consists of investment cost, operation and maintenance cost, cost of power purchased from the grid, saving with internal consumption and revenue of surplus power supplied to the grid. A mathematical model has developed with constraints to get the optimal solutions. A well known and effective evolutionary genetic algorithm methodology has been used to get optimal solutions.

Chapter-8 summarizes and gives conclusions of the work done in this thesis. This includes contributions of this thesis in development of research work in renewable distributed generation area. Limitations of the research work have been discussed. Lastly, the scope for further research has been discussed for future research work in this chapter.

8.2. Conclusions

The research work of this thesis tackled the problem of the optimal planning of renewable distributed generation. The following points summarize the work presented in this thesis:

- This work started with an overview regarding the different approaches used to model renewable distributed generation planning, accompanied by the advantages, the disadvantages, and the applications of each approach. We analysed the future development of renewable distributed generation in the modern power system. Evolution of smart grid making renewable distributed generation technologies more demandable and acceptable power source.
- Selection of the right renewable distributed generation technology to get the maximum return is a multi-criteria decision-making problem. In this research work, a novel VIKOR method has been used to identify the suitable renewable

distributed generation technology for a case of BHU campus. The best alternative has been prioritised amongst five alternatives through the eight criteria. AHP method has been used for the weight assignment of each criterion.

- Regarding the impact of renewable distributed generation on distribution system reliability, a methodology was proposed to assess the distribution system supply adequacy during stochastic modes of operation, using analytical and computational techniques. In the analytical technique, the hourly wind speed is modeled using Weibull pdf while a Lognormal pdf is used to model the random behavior of the load demand at BHU campus. The proposed technique is based on two steps utilizing one year period hourly previous year data. The first step is to draw the histogram, while in the second step statistical analysis has been done to estimate the wind speed and load demand profile. Further, to model wind speed and load demand, the pdf and CDF were determined, and then results of goodness-of-fit tests computed through the R programming language software to identify the best-fitted distribution.
- For optimal planning of renewable distributed generation, a cost minimization objective function has been developed to minimize the net project cost. The key idea in this work is to develop a system of smart grid integrated renewable distributed generation system without any storage in a stochastic demand-supply model that includes all possible operating conditions; hence, this model can be accommodated into a probabilistic optimal power flow formulation without violating any constraint. The main contributions of this model can be summarized in the following points:
  - ✓ The proposed model guarantees no violation of any of the system constraints under any operating conditions

- ✓ The model guarantees the optimal allocation of the renewable distributed generation units for all possible operating conditions
- ✓ A by-product of the proposed model is an optimal power flow solution for all possible operating conditions, which will provide a useful database for the system operator

8.3. Contributions

The main contributions of this thesis can be highlighted as follows:

- ➢ Literature review in the four respective problem areas and research gaps have identified.
- ➢ Evolution of modern smart grid integrated renewable distributed generation technologies from the conventional power system.
- ➢ A novel technique has been used to identify the region-specific suitable mode of renewable distributed generation technology for decentralized power generation.
- ➢ Uncertainty management of annual wind speed distribution to estimate energy potential using statistical analysis with goodness-of-fit tests computed in R programming language software.
- ➢ Uncertainty management of the hourly load demand variation of demand-side management in smart grid environment using statistical analysis with goodness-of-fit tests computed in R programming language software.
- ➢ Optimal planning of renewable distributed generation in the stochastic environment of the demand-supply uncertainty. An evolutionary genetic algorithm methodology has been used to get the optimal solutions. The model has the privilege of maintaining no violation of any of the system constraints under any operating condition.

8.4. Limitations

While the research gaps in the area of optimal planning of renewable distributed generation has been tackled in this thesis and this formed a valuable step forward in improving renewable distributed generation planning techniques in the transition to smart grid, there are still a number of enhancements that the author would have liked to consider but could not do contribute due to some limitations.

- Limitation of five feasible alternatives to renewable distributed generation technologies in a case of BHU campus.
- Based on previous literature and availability of data only eight criteria have been selected in this study.
- Limitation of hourly load demands data availability only for one year period.
- Hourly wind speed data was accessed from the website of NREL of BHU area of only one year period.
- To reduce the complexity of optimization model, we used unimodal distribution in the estimation of wind speed and load demand variability.
- Avoid hybrid system and considered a single generation source to reduce the complexity of the model.
- Did not consider green house gas emissions in the objective function.

8.5. Scope for Further Work

As for the whole picture in the research area of the optimal planning of renewable distributed generation, the following directions are recommended for future work.

- Selection of criteria may vary and considered with availability of data and regional factors to get the best solution. In this study, section criteria have been chosen with availability of data for the case specific. This can be extended with getting data of some other factors for the better decision making

- In this study VIKOR method has been considered as multi-criteria decision making method. It may compare with other methodologies.
- More than one year data of hourly load demand distribution may give better fitness with probability density curve.
- With large data of previous years, hourly wind speed distribution at BHU campus may give the better estimation.
- Can use bimodal distribution with other continuous probability distributions to get better result.
- Hybrid technology can be considered for optimal planning of renewable distributed generation at BHU campus.
- Environmental benefits can be analysed for the case of BHU campus with increasing penetration of integrated renewable distributed generation system.
- Power loss minimization can be analyzed as extended work with integrated renewable distributed generation system.
- Other evolutionary methodologies may lead to get the better results, and comparative analysis between them can be done.
- More work may be done with consideration of technical factors, as in this study more focus was on managerial concern.