CHAPTER 6

CONCLUSIONS AND FUTURE SCOPE

6.1 GENERAL CONCLUSIONS

The power system network in the modern time has become more complex due to interconnection of large number of generating areas sharing their power through the tie-lines. In order to achieve the desired operation of the interconnected power system network, the nominal frequency is maintained during the normal operating conditions as well as during the small perturbations in the system. The work in this thesis focuses on designing the different robust and efficient load frequency controllers for various types of interconnected power system networks of macrogrid and microgrid level. The classical and optimal controllers have been adopted for load frequency control (LFC) of various systems. The automatic generation control (AGC) can be achieved by control of the real power through the controllable sources of the system. The frequency can be maintained within permissible limits when the power generation matches with the load. The load frequency controllers can be connected in power system in centralized or decentralized mode. In the present work, the linear quadratic regulator (LQR) based optimal controller is connected in centralized mode and classical PI controller is connected in decentralized mode in different interconnected power system networks.

The computationally intelligent optimization techniques have been adopted for tuning of various controllers and the parameters of the systems like frequency bias ($B_i$), power-frequency droop ($R_i$) are also optimized during the load variation. The convergence and attainment of optimal parameters are the two important factors during the selection of optimization technique. The integral square error (ISE) criterion is used while optimizing the gains of controllers. With the increased complexities in power system and restrictions on permissible frequency band, the more efficient intelligent computational techniques can improve the performance of classical controllers. In this respect, the work depicted in this thesis presents a systematic approach of designing and
optimally tuning the parameters of LQR based optimal controller and PI controller for frequency response enhancement and parameter setting for different interconnected power system networks. The population based search techniques such as particle swarm optimization (PSO), bacterial foraging optimization (BFO), firefly algorithm (FA), Genetic Algorithm-Firefly algorithm (GA-FA) are employed to tune the controllers of various power system networks.

In this thesis, PSO-based state feedback controller and LQR-PI controller are designed for two-area thermal network. Total eleven state variables of the system are simultaneously optimized to maintain the optimum frequency response during variation in load. The number of states will increase if the state feedback control is implemented for three-area interconnected power system network. The time and accuracy of optimization for such large number of states can affect the performance of LQR optimal controller. So, PI controller tuned with computationally intelligent techniques like particle swarm optimization (PSO), bacterial foraging optimization (BFO) and classical method of gradient descent (GD) is proposed for the three-area network with thermal-wind-hydro power generation systems.

The work in this thesis also deals with frequency control and power sharing among various sources of hybrid microgrid (MG) systems. The modelling of two hybrid microgrid systems as well as the design of their controllers is carried out in the context of frequency control of these microgrids. The first type of microgrid is realized with wind energy conversion-diesel generator (WECS-DG) systems considering generating margin of doubly fed induction generator (DFIG). The second microgrid system comprises of large number of generating sources such as off shore wind turbine (WTG), photovoltaic cell (PV), fuel cell (FC), aqua electrolyzer (AE), diesel engine generator (DEG) and energy storage devices such as battery energy storage system (BESS), flywheel energy storage system (FESS), ultra capacitor (UC). The fractional order PID (FOPID) controller is proposed for the frequency response enhancement of this microgrid. The FOPID controller is tuned with firefly algorithm (FA). Extensive simulation studies are performed utilizing MATLAB/SIMULINK working platform to support the potency of the proposed techniques and thereby designing the efficient load frequency controllers for various interconnected power systems.
The Section 6.2 in this chapter highlights the contribution of this thesis through the essence of outcomes of each chapter. In section 6.3, the suggestions are given for the related future research work.

6.2 CONTRIBUTION OF THESIS

The important contributions of the research work presented in this thesis are:

- The designing of robust and efficient load frequency controllers for power system networks, under the ever-increasing regulatory restrictions and demand for quality power has always been one of the most promising research area in the field of power system operation and control. The work in this thesis gives an insight and techniques for load frequency control of both macrogrids and microgrids using various controllers tuned with different evolutionary algorithms, which satisfy the recent grid codes and power quality requirements.

- It highlights the innovative methods adopted and various computational techniques implemented to improve the frequency response of different power systems. The prime contribution of this thesis is designing the effective and robust load frequency controllers for different multi-area interconnected power system networks which satisfy the modern power quality standards.

- A new PSO based state feedback (PSO-LQR-I) controller is implemented using evolutionary optimization technique for tuning the optimal LQR and classical integral control simultaneously in Chapter 3. The optimal control is designed with total eleven state feedback variables for two-area thermal power network. The computationally intelligent optimization technique PSO is applied for optimization of state feedback gain matrix (K) for providing optimal control and parameter setting of the system. The robustness of the proposed techniques is validated through the simulation results as obtained by considering the load variation in different areas. The statistical analysis performed justifies the superiority of the proposed method as compared to that existing in literature. The hybrid control method PSO-LQR-I exploit the merits of traditional integral control and at the same time optimal control approach using LQR along with
PSO technique, it generates better result in terms of computational efficiency and simulation results.

- In Chapter 4, the new power system test case model is developed with renewable and non-renewable power generation sources and load frequency control is attained for three-area interconnected thermal-wind-hydro power system network. Three PI controllers are connected separately to each area of interconnected three-area power system network for the LFC of the system and computational methods such as BFO, PSO, GD are used to optimize the controller gains and system parameters. The classical PI controller tuned with intelligent optimization algorithms provides the desired results for frequency response enhancement of such large power systems.

- In Chapter 5, the LFC is achieved for interconnected renewable energy systems which form the microgrid. The first type of microgrid is simulated considering WECS-DG and generating margin based novel approach is realized for frequency control. The second microgrid is designed with various small generating sources such as WTG, PV, AE, FC, DEG systems and energy storage systems such as BESS, UC, FESS. It is validated through simulation results that GA-FA-FOPID controller performs better for frequency control of the microgrid than traditional PID controller, Fuzzy-FOPID and FA-FOPID controller.
6.3 SCOPE FOR FUTURE WORK

Any research work leads to more ways to carry forward the work in that area and there is always a scope for further growth in the research work. On the basis of research work performed in this thesis in the domain of load frequency control of various macrogrid and microgrid multi-area interconnected power system networks using different control techniques, the following domains are identified as future scope of research.

1. In this thesis, the generation side control of multi-area interconnected power system networks is considered for the regulation of the frequency, the demand side management for power quality can be formulated as one of the future scopes of this work.

2. The work can also be explored further by considering other advanced optimization techniques to achieve the frequency response enhancement of more complex power system networks.

3. The proposed load frequency controllers for different interconnected networks and microgrids can be implemented experimentally.

4. This thesis work was mainly focused on frequency control in various power system networks. For satisfactory operation of the power systems whether macrogrid or microgrid systems, the voltage control is also an important aspect, which can be explored.

5. The research work for microgrid operation is carried out considering the autonomous operation of the microgrid, however control strategies can also be developed for the grid connected mode of the microgrid. The concept of optimal load dispatch can also be incorporated for analysis of control of microgrid.