CHAPTER 2

LITERATURE REVIEW

2.1 CHAPTER OVERVIEW

The continuous power supply to the consumers while maintaining the power quality is the main role of power system operation. The active power demand of industries keeps fluctuating, which in turn, changes the system frequency. The investigations in the field of LFC have led to numerous research papers and fact findings which appear in the form of extensive literature available in this area over the years. In an attempt to maintain the nominal frequency in current complex power system network, numerous control methodologies and optimization techniques are applied in this domain in order to attain the load frequency control. A sincere attempt has been made in this section to discuss the most significant work related to load frequency control of multi-area interconnected power systems.

The review of research papers has been organized into three categories. In the first category, the literature related to intelligent optimal controller based on LQR designing and implementation for enhancing the frequency response of the system has been reviewed. Secondly, the literature has been reviewed for improvement of system frequency response of various multi-area interconnected power systems with intelligent PI controllers. In the third category, the research papers have been reviewed on system designing and LFC of various hybrid microgrids (MG) power system. After the extensive literature survey and identifying the research gaps, the design problem is formulated as load frequency controller of various interconnected power system networks and modern optimization techniques are employed to search for either optimal parameters, optimum gains of controllers or optimal states of LQR based controller. The highlights of the papers reviewed and research gaps are given in next section.
2.2 LQR BASED CONTROLLER FOR OPTIMUM SYSTEM RESPONSE

He et al. [6] presented a new optimal PI/PID controller tuning algorithm for low-order plus time-delay processes via LQR approach. A new criterion for selection of the weight matrices Q and R is proposed which will lead to the desired natural frequency and damping ratio of the closed-loop system. Parmar [7] work is based on optimization of integral controller for two-area thermal power system without reheat turbines. The time varying acceleration coefficients are taken in particle swarm optimization technique. The results are obtained for load variation in one area only. Further, reheat is not considered for thermal systems whereas in real environment the thermal power systems have reheat turbines. Panda et al. [8] applied the hybrid neuro-fuzzy approach for LFC of two-area interconnected power system. The comparison has been done with conventional PI controller and fuzzy controller. The system performance has been examined with and without generation rate constraint. The superiority of the method has been found over the conventional controller and fuzzy controller.

Das et al. [9] have simulated a second order sluggish and oscillatory system in which optimum selection of weighting matrices of LQR has been done through GA. The cost of control for the LQR-PID design is dependent on the process characteristics. Yu et al. [10] proposed a stochastic optimal relaxed control methodology based on reinforcement learning for solving the automatic generation control (AGC). The moving averages of ACE are adopted as the state feedback input, and the control performance standards CPS control and relaxed control objectives are formulated as multi-criteria reward function via linear weighted aggregate method. Mi et al. [11] have proposed a proportional integral controller for three-area system using matching and unmatching uncertainties. The switching surface has been developed for each area to improve the performance. Vlachos et al. [13] illustrated the LFC using decentralized PI controllers based on genetic algorithms. The performance index is chosen to obtain the specified closed loop response. The proposed method can be applied effectively to many multivariable processes. Tyagi et al. [14] designed a decentralized AGC for interconnected multi-area power system. The various types of transactions taking place in a competitive electricity market have been incorporated while designing the
controller. The functioning of the proposed decentralized controller has been tested on a 39-bus New England system and a 75-bus Indian power system. The results have been compared with a centralized control scheme. Joshi [16] proposed the effective generation control method based on programmable logic for two-area network so that the frequency remains constant at nominal value and the tie line power is between specified limits along with economic operation of the generators. Kothari et al. [17] have given a sampled data control for two-area reheat systems. The decentralized control with discrete type regulators has been developed using difference equations. The generation rate limitation has been taken into consideration while developing the discrete system. Patel et al. [19] implemented the fuzzy controller for thermal and hydro thermal interconnected systems. The artificially intelligent techniques such as GA and PSO have been applied for tuning the controller. This controller gives an improved performance for load frequency control. Nanda et al. [20] have explored the performances of hydro thermal systems with electrical governor, mechanical governor, single reheat turbine and double reheat turbine. The generation rate constraint is taken for both hydro and thermal power plants. The controller used is conventional proportional and proportional integral controller.

Kakilli et al. [21] has designed the optimal LQR controller to develop a secure system for single-area which gives the desired performance under changing power system parameters. Wei et al. [22] demonstrated the effectiveness of the PSO-based LQ regulator for rotating inverse pendulum. The parameters of LQ regulator are determined by PSO method. Hossain et al. [24] have proposed an effective control scheme for multiple microgrids in islanding mode. The time domain analysis is done and dynamic behavior of the system is investigated under the large disturbances. Kamel et al. [25] designed a microgrid with several types of diesel generators and the microgrid is connected to the primary distribution network. This work simulates the dynamic performance of the microgrid during and subsequent to islanding process. The system has a solid oxide fuel cell, a single shaft micro turbine, a flywheel, two photovoltaic panels and a wind generator system. The first inverter strategy used is PQ control, in which the inverter will inject certain active and reactive powers. The second inverter strategy used is V/f control. Two cases are studied for frequency control with the import and export of power from microgrid. L.C. Saikia et al. [27] provided classical control
based on Integral–Double Derivative (IDD) and its performance is compared with other classical controllers such as Integral (I), Proportional–Integral (PI), Integral–Derivative (ID), and Proportional–Integral–Derivative (PID) controllers for two-area and multi-area thermal systems. Abdel-Magid et al. [28] described the application of GA for optimizing the various parameters of automatic generation control (AGC) systems. An integral controller and a proportional-plus-integral controller are used for two-area reheat thermal system. The performance indices are integral of the square of the error and the integral of time-multiplied absolute value of the error performance which are minimized for finding the values of the optimal parameters. Oysal [30] investigated the controller design with dynamic neural network (DNN) for two-area power system. The lag dynamics in the proposed system are due to delayers and integrators. The input signals of the DNN models are the area control errors (ACE) and frequency deviations due to a load disturbance.

Mallesham et al. [31] investigated the AGC for the microgrid considering the generation rate constraint (GRC) and power-frequency (P-f) droop characteristics (R_i). The gradient descent based optimization is applied to tune important parameters of non-linear system for AGC. Nanda et al. [32] applied the bacterial foraging (BF) for automatic generation control (AGC) of interconnected three-area thermal systems. Various parameters like integral controller gains (K_i), speed regulation parameters (R_i) and frequency bias parameters (B_i) have been optimized. The results have been compared with GA and classical methods. It is observed that the BF algorithm is quite faster in optimization with less computational burden. Ali et al. [33] have employed BFO algorithm to search for optimal controller parameters to minimize the time domain objective function. Naik et al. [34] demonstrated the performance of FLC tuned with Adaptive Particle Swarm Optimization. The two-area power system has been used for the simulation and analysis of performance of controller. Electrical power system design/operation has become complex lately with increasing size, fluctuating structure and intricacy in interrelated power system, to change to an enhanced system dynamic performance with better stability margins with small disturbances in the system are the major concerns [36-39]. Several operating strategies are explored by Chang-Chien et al. [40] for doubly fed induction generator to support system frequency with less sacrifice in the wind energy production. The concept of small scale energy sources called a
microgrid and its importance in the current power system along with different applications in various industries are discussed by Lasseter [42]. Pepermans et al. [43] elaborated the benefits of DG technologies with which we can harness the low cost and environment friendly electricity with higher power reliability as compared to traditional power generators. Elmitwally et al. [44] proposed a control scheme for a three-phase photovoltaic (PV)-diesel microgrid without energy storage in isolated mode. The control scheme objectives are to track maximum power from the PVA, to control the load voltage, optimum power sharing between PVA and diesel generator. This is done by controlling the pulse width modulation inverter for PVA and by connecting a modified fuzzy logic controller for the diesel engine. The renewable power generation participation can be increased with proper renewable portfolio standards as proposed by Ipakchi et al. [45].

Liu et al. [46] applied the constrained generalized predictive algorithm. The linearization of the model has been done for study of LFC with this technique. The GRC has also been considered for the modelling of the two-area network. Rerkpreedapong et al. [47] proposed a decentralized controller for LFC by developing a decentralized controller model with the interface of variables having frequencies of other subsystems. Kalman filter is designed to estimate each subsystem's own and interface variables to overcome the uncertainties. The performance index is optimized with such estimates and output of each generating units is controlled. Ruey Yu et al. [48] analyzed the effectiveness of PID controller for brushless DC motor tuned with LQR approach in which the weighting functions are calculated through poles assignment. Choi et al. [49] demonstrated the inverse dynamics and its limitation for Lagrangian systems while doing the auto tuning with PID controller. In such situations, the quasi equilibrium region acts as an alternative for equilibrium point. Khodabakhshian et al. [50] present a robust PID controller for AGC of hydro turbine power systems. The method is mainly based on Nichols chart and maximum peak resonance specification. The method is efficient for controlling the overshoot and improving the stability and the dynamics of the system. Panda et al. [51] described five different tuning rules for control of second-order systems. In addition, the systems with damping coefficients and dead time to time constant ratios (D/t) have been analyzed. It is observed that the internal model control designed with the Maclaurin series expansion type PID performs well for both set point
and load changes when D/t is greater than unity. The desired closed-loop specification approach is better for systems with D/t less than unity.

Ali et al. [52] employed BFOA to search for optimal controller parameters to minimize the time domain objective function. The performance of the proposed technique has been evaluated with the performance of the conventional Ziegler Nichols (ZN) and Genetic Algorithm (GA) in order to demonstrate the superior efficiency of the proposed BFOA in tuning PID controller. Anderson et al. [54] have elaborated the use of linear quadratic Gaussian methods for the design of control systems. The basic theory of the linear regulator for time-invariant and time-varying systems has been described. Then the degree of stability, phase and gain margin, effect of nonlinearities, asymptotic properties, various sensitivity problems and state estimation have been discussed.

Hamidi [58] presented Particle Swarm Optimization (PSO) algorithm as an intelligent procedure for designing of optimal controller. Superior features of PSO method are fast tuning of the parameters, rapid convergence, less computational burden and capability to avoid local optima. Kennedy et al. [59] proposed the optimization technique for nonlinear functions using particle swarm methodology. The evolution, applications, relationships between particle swarm optimization and artificial life based several paradigms are discussed. Pingkang et al. [62] simulated two-area thermal power system model and AGC is attained with PID controller tuned with genetic algorithm. The dead band of turbine governor and generation rate constraint are considered during the modelling of the system.

Zhang et al. [63] highlighted the familiar encounters of time delays because of the custom of unprotected communication networks and also to use the delay margins as an enactment index to control the design and operation of the LFC controller. Ngo et al. [64] described the effect of frequency bias (B_i) on AGC. The more appropriate setting of B_i helps in achieving the better results of frequency response during load variation. Bangal [65] developed the frequency control using artificial neural network for two-area and three-area interconnected thermal systems. The neural network controller is trained using Lavenberg-Marquardt back propagation algorithm. Ghosh et al. [66] have solved the wide range of optimal control problems with various optimization techniques. A parameterization technique is used for representing the multi-variable control system.
into manageable number of parameters without the loss of accuracy and optimization efficiency. Long Guo et al. [67] described the linear quadratic optimal controller and observed the effect of parameter variations on the optimal control.

As it is evident from literature review of Section 2.2 that the majority of the load frequency control techniques tend to improve the frequency response of the systems with classical controllers and several optimization techniques have been proposed to tune these controllers. The main research gaps identified in this section and motivation for research work carried out in Chapter 3 are listed below:

- There is a scarce research available which provides the intelligent optimal control for interconnected power system network under load variation conditions. The proposed work in Chapter 3 of the thesis is an attempt to exploit the benefits of optimal control which is based on linear quadratic regulator (LQR).

- The number of the states taken to design the systems can further be increased so that optimal control can be applied more effectively. Here, the state space modeling of the system has been done for designing the state feedback controller for LFC of two-area network considering maximum number of states of the system.

- The optimal control can enhance the frequency response if computationally intelligent algorithms are adopted for optimizing the state feedback gain of the system. The intelligent optimal controller along with classical controller is realized for fast and accurate frequency response of the two-area system.

### 2.3 Modeling of Thermal-Wind-Hydro System and LFC with Intelligent PI Controller

Ram et al. [69] designed the AGC for an interconnected hydro-thermal system. The electrical governor for hydro system and mechanical governor for thermal system have been taken into consideration. The performance of PI controller, fuzzy logic controller and neuro-fuzzy controller has been evaluated under different loading conditions. The
genetic algorithm technique is used for optimization. The soft computing techniques are very efficient in load frequency control of non-linear systems. Khan et al. [71] simulated the finite element based phase variable model of permanent magnet synchronous motor. To optimize the parameters of low speed sensor less algorithm the gradient descent method has been used. It improves the speed and position estimation performance of the sensor less algorithm. The literature in [73-75] has elaborated the use of conventional proportional integral, optimal control, genetic algorithm, differential evolution, fuzzy logic controller, and artificial neural network control and optimization methods that have been studied for LFC.

Padhy et al. [77] present a three-layer feed-forward neural network controller trained with back-propagation algorithm (BPA) for 75-bus Indian power system network. The result of the ANN controller is compared with a conventional Proportional-Integral-Derivative (PID) controller tuned with genetic algorithm. Rerkpreedapong et al. [78] simulated the controller based on linear matrix inequalities (LMI) and genetic algorithm is used to tune the parameters of LMI. The three-area network is connected for the study of effectiveness of controller for various load variations. Abdel-Magid et al. [79] proposed the AGC for two-area non-reheat system and the parameters of AGC are tuned with genetic algorithm. Kumar [80] compared the performance of fuzzy logic, neural network and hybrid neuro-fuzzy controller for frequency control of one-area and two-area network. The non-linearities of the system have been taken into consideration. Shiroei et al. [81] have proposed a multi-variable based predictive control for frequency control of three-area system. The system uncertainties and variation in parameters are significantly reduced with the proposed linear matrix inequality approach. The optimal control input has been given while considering the generation rate constraint.

Sahu et al. [84] have concluded that degradation of the power system performance has made the control much problematic because of the unbalance between supply and load, which causes the fluctuations in the system frequency. Mohanty et al. [85] has elaborated through his work that the most vital problem in power system operation and control for supplying adequate and consistent electric power with decent quality is LFC. Pinang et al. [86] implemented the genetic algorithm for AGC of two-area power network considering non-linear elements. The method has the advantages of both PID and sliding mode control while giving the reasonable results. The dead band of turbine
governor and generation rate constraint are considered during the modelling of the system. Chatterjee et al. [87] have modelled a thermal power plant with single-stage reheat turbine. A hybrid distributed generation is configured with system consisting of wind turbine generators, aqua electrolyzer, fuel cells, diesel engine generator, flywheel energy storage system and battery energy storage system and is connected to thermal unit. The parameters of the power system are optimized by a new algorithm called craziness-based PSO with wavelet mutation. The transient response improves with the usage of capacitive energy storage and distributed generation. Saikia [88] considered three-area hydrothermal system for the LFC. The modelling of the systems has been done with reheat turbines in thermal areas and electric governor in hydro area along with suitable GRC. The integral gains ($K_i$) and speed regulation parameter ($R_i$) keeping frequency bias ($B_i$) fixed are optimized with bacterial foraging optimization (BFO) technique. The performance of a multilayer perception neural network controller using reinforcement learning is compared with BFIC for the system over various loading conditions. The results show the superior performance of MLPNN controller over BFIC.

The energy storage strategies are organized and decontrolled LFC power system model and their efficiency in enlightening the system performance has been comprehended, associated and presented by Selvaraju et al. [92] for restraining the fluctuations caused by unexpected variations in power system. The controller design was enforced to a unified two-area two-unit thermal liberalized power system with one reheat and one non-reheat unit in every part. A scheme of intelligent controller for the load frequency control of interlinked deregulated power systems with energy storage strategies with the help of cooperative search algorithm was presented in this article. McArthur et al. [93] discussed the multi-agent systems for proper utilization of resources as well as for generating proper control signals. In [94-98], load frequency control for power generation system with several units of renewable and non-renewable energy has been presented. The proportional integral controller has been tuned with different methods. Fadaeinedjad et al. [99] designed a new model of large wind power plant which comprises of many wind turbines along with electrical, mechanical and wind parts of the plant. The various effects such as wind shear, wind fluctuations, tower shadow on the power have been studied. The power system frequency regulation is the
most significant control complication in electric power system design and operation as described by Sahu et al. [100]. The power system is now extremely multifaceted because of the rapid growth of industries with many security necessities and constraints as elaborated in [101, 102].

Abd-Elazim et al. [106] proposed the optimal tuning of PI controller with BAT algorithm for two-area thermal network. The results have been obtained with different operating conditions and non-linearities. The performance of the controller is compared with simulated annealing technique which shows the more robust control with BAT algorithm. Abd-Elaziz et al. [107] proposed Cuckoo Search (CS) algorithm for optimum tuning of PI controllers for Load Frequency Control (LFC). A three-area interconnected system is investigated and this technique offer better performance over others in terms of various parameters. The mismatch among the incidences of the interrelated areas and schedule the movement of power via the tie lies that helps the interrelated power system towards overcoming the aberrations presented because of the changing load demand, generation outage etc. are balanced by the LFC techniques [110, 111]. Passino [116] presented a distributed optimization process based on the activity of social bacterial foraging. It has been applied to simple multiple extremum function minimization problem and the relationship has been observed to some existing optimization algorithms. Lin et al. [117] developed a new algorithm for Hammerstein model identification based on bacterial foraging is developed. Simulations and comparisons show its advantages over the particle swarm optimization algorithm in terms of immunity to colored noise, model accuracy and the convergence of parameters.

Tripathy et al. in [118] has optimized the unified power flow controller by using bacteria foraging technique for solving the multi-objective multivariable problem, with the UPFC location, its series injected voltage and the transformer tap positions as the variables. Mishra et al. [119] have designed an active filter using proportional integral controller. The gains of the controllers have been optimized with E. Coli bacteria based bacterial foraging optimization. The proposed method in their paper gives better results than genetic algorithm. Abd-Elazim et al. [120] developed a hybrid approach using particle swarm and bacterial foraging optimization techniques for the designing of a thyristor controlled series capacitor. The controller is designed for multi-machine power system. The direction of tumble behavior is affected as bacterium get oriented by
individual best and global best positions. Mandour et al. [121] demonstrated the use of three load frequency which are based on $H_\infty$ method, reduced model of the $H_\infty$ controller and GA based PID controller. The robustness of these controllers is investigated for two-area power system network through parameter variations and changing the magnitude of load disturbances. Haddin et al. [122] have presented the linear model of synchronous generator, AVR excitation, AGC and power system stabilizer (PSS). Minimum value of comprehensive damping index is used as fitness function of particle in PSO. The simulation results show that the dynamic stability of the system improves with the coordination of main parts of the generation system. Sagara et al. [123] applied the linear quadratic control for megawatt frequency control problem. The combined algorithm comprises of the Newton’s method and fixed point algorithm. The quadratic convergence and the reduced-order computation in the same dimension of the subsystem are both attained.

The emphasis and demand for classical PID controller in power industry has been analyzed for LFC studies. There are numerous challenges to assess the potential of existing controller for large interconnected power system networks and some of them are listed below:

- As it is evident from literature survey that the PI control is mostly adopted for LFC of multi-area networks comprising of similar types of generating systems. The work presented in Chapter 4 will explicitly bring out the versatility of intelligent PI controller which is suited best to upgrade the frequency response of power system network with multiple types of generating sources.

- There are numerous population based search algorithms which can be employed for tuning of the controller gains and system parameters. The selection of suitable optimization method with less computational burden, which can give adequate results is a challenging task.
2.4 POWER SYSTEM DESIGNING AND LFC FOR HYBRID MICROGRID POWER SYSTEMS

Ekanayake et al. [95] constructed a wound rotor asynchronous DFIG. Variable speed operation is obtained by injecting a variable voltage into the rotor at slip frequency obtained by using two AC/DC voltage source converters (VSC). The speed range is determined by converter ratings. The wind turbine control methods are presented by Loukarakis et al. [96] thus enabling the wind generation role in a system's primary frequency response. Keung et al. [97] described that the fear that there will be insufficient kinetic energy from the wind power plants to support the system frequency is groundless because the high inertias of wind turbine generators (WTGs) can be integrated to provide frequency support during generation outage.

Mallesham et al. [115] for the optimal frequency response of a microgrid with wind, solar, fuel cells, diesel generator and aqua electrolyzer and battery. The p-f droop and GRC has been taken into consideration for controllable sources. The intelligent optimization methods have been applied for calculation of variable parameters of the system. Katiraei et al. [124] have analyzed that due to natural intermittent properties of wind velocity and solar irradiation, stand-alone wind/PV renewable energy systems normally require energy storage devices or some other generation sources to have reliable electric energy supply there by forming a hybrid system. Krishnamurthy et al. [125] demonstrated the performance of controller for multiple inter connected diesel generator sets. Further the various inverter based sources are also connected to the DG sets to share the power and improve the quality of power.

Feng Lu et al. [127] have provided an incremental model of battery energy storage (BES) system. The digital computer model of two-area interconnected systems is developed with governor dead band and GRC. The simulation study show that the BES is effective in damping the oscillations due to load disturbances.

Acker et al. [128] analyzed the effects of large wind power generation on the grid system. It has been found that although the cost of wind power generation is decreasing due to evolving technologies still the grid connection requires high cost interconnection systems. Banakar et al. [129] proposed a wind power model in which wind power
variations are decomposed into slow, fast and ramp components. It has been observed that the systems with limited ramping capabilities are at risk. The proper placement of the wind farms within the interconnection has also been discussed along with wind penetration approaches and control area performance. Krpan et al. [130] have presented a novel approach to low-order system frequency response modelling of a future power system with a high share of frequency-support-capable variable-speed wind turbine generators. Suwannarat et al. [131] have discussed the model of an AGC system with wind power integration of large scale wind power systems under fluctuating wind power production due to varying wind speed. Long term stability method has been simulated under varying load conditions. An artificially intelligent controller is proposed and the dynamics of diesel generation are investigated by Zhixin et al. [132]. The interaction of the diesel generators and the inverter-based distributed energy resources using eigen value analysis and time-domain simulations have been studied. Different aspects of power quality of wind power plant are described by Muljadi et al. [133]. Reactive power compensation helps in achieving the voltage stability for wind power plant with many wind turbine. The actual system also has many wind turbines with different specifications related to impedance and control settings. A scheme for AGC of interrelated multi source power generation below comfortable environment was presented by Hota et al. [135]. The presentations of PI, integral derivative (ID) and proportional integral derivative (PID) controllers were assessed for the AGC system in the released environment. Differential evolution algorithm, hybrid gravitational search and pattern search algorithm, neural network based integral sliding mode control have been applied in optimizing the performance of the controllers and speed regulation parameters. Majumder et al. [137] described the efficient utilization of battery storage. The co-ordination of fuel cell, aqua electrolyzer with hydrogen storage tank has also been discussed. A linear active disturbance rejection control technique for the LFC of power systems in derestricted surroundings was proposed by Wen Tan et al. [138]. Golshani et al. [141] simulated the permanent magnet synchronous generator (PMSG) wind turbine system with three levels NPC back-to-back converter. The PSO algorithm is used to optimize the parameters of a conventional PI and the sliding mode controllers for PMSG, grid-side and rotor-side converters. Liu et al. [142] described a coordinated distributed model predictive control for the LFC of a power system that includes
inherently variable wind-power generations. The DMPC communicates power system measurement and prediction data, considers the information of other controllers for their local objective to realize effective coordination.

Ramtharan et al. [144] presented the frequency regulation capability of a doubly fed induction generator (DFIG) wind turbine through the aerodynamic, structural and electrical dynamic models. A frequency droop controller is also studied for different wind speeds. Syahputra et al. [145] have done the performance analysis of wind turbine as a distributed generation unit. To analyze more deeply the performance of the wind turbine system, both normal and fault conditions scenarios have been applied. Wang et al. [146] proposed an efficient method for the optimal placement of distributed generation units of small ratings and selection of proper bus for the location of generation units. The simulation study is based on the concept that the transmission losses are minimum. The radial distribution system has been analyzed with time varying and time invariant loads. The integration of the renewable resources in the existing power grid is possible through DG technology. The inertial response of wind turbines has been analyzed by Mullane et al. [147] employing field-oriented doubly fed induction generator. A comparison has been done between the inertial response of a squirrel-cage and doubly fed induction-machine-based wind-turbine generator. The rotor current controller bandwidth affects the inertial response of a DFIG.

Khooban et al. [149] proposed a combination of the general type-2 fuzzy logic set and the modified harmony search algorithm technique, as a novel heuristic algorithm, to adaptively tune the proportional-integral controller for LFC in islanded microgrids. Rubio [150] described a robust feedback linearization technique for nonlinear process control. The theory says that if a linearized controlled process is stable, then nonlinear process states are asymptotically stable. Only the main states feedbacks are utilized to obtain a satisfactory result in applications. Saif [151] presented the recursive algorithm to achieve a desired set of eigenvalues with proper selection of the state weighting matrix of a linear quadratic regulator (LQR). Mishra et al.[153] have given a biogeography based optimization (BBO) technique which optimizes Q and R matrices for microgrid system. The Kalman estimator has been applied for non-measurable states. The microgrid has been made smart by integrating with a master controller and using a suitable communication protocol.
Bevrani et al. [162] proposed a combination of fuzzy logic and PSO method tuning of PI controller. The system consists of microgrids which are varying source of energy. Shahabi et al. [164] present a control strategy for microgrid in islanding and grid connected mode. The voltage and frequency control has been done for interconnected DFIG system and gas turbine synchronous generator.

Amjady et al. [170] have studied the characteristics of the microgrid load time series and have proposed a new bilevel prediction strategy for short term load forecasting of microgrids. The proposed strategy is comprised of a feature selection technique and a forecast engine which include neural network and evolutionary algorithm. Wang et al. [174] simplified the mathematical model of unmanned helicopter. The longitudinal hovering altitude control has been realized with linear quadratic regulator. The optimal values of Q and R parameters have been calculated with parameter search algorithm. The solution contains the two or four-dimensional matrix equations regardless of the dimensions of the system. Li et al. [175] demonstrated the non-linear constraint optimization with Lyapunov approach. The effect of control weights on designing of optimal PID controller has been analyzed.

The research gaps identified through literature survey of Section 2.3, which are the motivation for the research work of Chapter 5 are as follows:

- The interconnection of wind-diesel system is extensively studied and several techniques are proposed for attaining the LFC of such system. The simultaneous usage of preserving the generating margin through wind turbines and intelligent PI controller for diesel system for frequency response enhancement has not been explored. This challenge has motivated to undertake the research on designing the LFC for wind-diesel system with both generating margin and PI controller tuned with particle swarm optimization.

- It is observed that there has been much research interest in developing the control methodologies for improving the performance of microgrids. The majority of control methodologies concern improvement of frequency response by using PI/PID controller. The potential of fractional order PID controller (FOPID) can be harnessed for LFC of complex microgrid systems
as the usage of two additional operators augment two extra degrees of freedom to the controller and creates the possibility of more effective performance of the traditional PID controller.

- The main purpose of microgrid is to make the use of renewable energy sources to deliver the power to nearby load centers. These types of sources are intermittent in nature and the usage of different energy storage devices has been limited in designing of different microgrids. The design problem in Chapter 5 is formulated by considering various energy storage devices along with renewable energy sources.

- Further, the proposed work in Chapter 5 is an attempt to exploit the benefits of FOPID controller which is designed to improve the frequency response of hybrid microgrid system. The effectiveness of FOPID controller is improved by using various modern optimization techniques.

The exhaustive literature review reveals the requirement to develop more efficient and robust load frequency control methodologies for improving the performance of modern complex interconnected power system networks which can satisfy the recent grid codes.