Load frequency control (LFC) in interconnected power systems is undergoing numerous changes due to rapidly growing amount of wind turbines, solar PV and other new type of power generation/consumption technologies. In this paper an extensive literature review on load frequency control (LFC) problem in distributed generation based power system has been highlighted. The various control techniques/strategies that concerns to LFC issues have been addressed in distribution generation-based power systems.

Key Words: Artificial Intelligence techniques, Distributed Generation, Load Frequency control, Sliding mode controller.
1 Introduction

Load frequency control, as the name signifies, regulates the power flow between different areas while holding the frequency constant. We can therefore state that the load frequency control (LFC) has the following two objectives:

- Hold the frequency constant \(( f = 0)\) against any load change. Each area must contribute to absorb any load change such that frequency does not deviate.
- Each area must maintain the tie-line power flow to its pre-specified value. The first step in the LFC is to form the area control error (ACE) that is defined as (1)

\[
P_{\text{tie}} \quad \text{and} \quad P_{\text{sch}} \quad \text{are tie-line power and scheduled power through tie-line respectively and the constant } B_f \text{ is called the frequency bias constant .}
\]

Where \(P_{\text{tie}}\) and \(P_{\text{sch}}\) are tie-line power and scheduled power through tie-line respectively and the constant \(B_f\) is called the frequency bias constant.

The change in the reference of the power setting \(P_{\text{ref}, i}\), of the area \(i\) is then obtained by the feedback of the ACE through an integral controller of the form

\[
\text{where } K_i \text{ is the integral gain. The ACE is negative if the net power flow out of an area is low or if the frequency has dropped or both. In this case the generation must be increased. This can be achieved by increasing } P_{\text{ref}, i} \text{. This negative sign accounts for this inverse relation between } P_{\text{ref}, i} \text{ and } \text{ACE. The tie-line power flow and frequency of each area are monitored in its control center. Once the ACE is computed and } P_{\text{ref}, i} \text{ is obtained from equation 1, commands are given to various turbine-generator controls to adjust their reference power settings.}
\]

In general, Distributed Generation can be defined as electric power generation within distribution networks or on the customer side of the network[1]. The electricity generation technology and grid connection of DG technologies can be significantly different from traditional centralized power generation technologies. Large power units use synchronous generators. These are capable of controlling the reactive power output, for example. Large DG units, utilizing natural gas for instance, use synchronous generators, too. Medium-sized and especially small DG technologies often use asynchronous generators (also known as induction generators), as they are significantly cheaper than synchronous generators. Asynchronous generators, however, have different operational char-
characteristics than synchronous generators. For example, a directly grid-connected asynchronous generator is not capable of providing reactive power. It actually requires reactive power from the grid during the start-up process and at operation. Different technical options exist to overcome the disadvantages of grid-connected asynchronous generators. Manufactures of DG technologies have used a large range of options, such as capacitors and power electronic converters [28]. And finally, micro systems such as photovoltaic, Wind and solar power are kind of clean and rich renewable energy has attracted more attention, but the output power of wind turbine generator (WTG) and solar output are usually variable because of weather conditions. When a large scale of wind energy is included in traditional power system, the renewable energy fluctuation and loads variation may cause large frequency deviation [2-4]. So, lot of research is going in developing controllers or techniques for Load Frequency control in the penetration of wind and solar in the power system. With rapid decline of the fossil fuel and advancement in green energy, the DG such as wind, solar comes into play to meet the scarcity of load demand. Hence the LFC problem associated with DG is discussed. PV, wind farms, diesel engine and energy storage system based hybrid DG The PV power generating systems are expected to play a key role in meeting future demands for electricity. The relatively high cost of PV generated electricity makes it attractive only for remote stand-alone loads or small applications. In isolated operation of wind/diesel/photovoltaic hybrid power system, the intermittency in wind speed, and solar radiation causes a large fluctuation in system power and frequency. The influence of PV power generation on LFC is presented in [43].

The LFC problem becomes complex by integration of wind farm grid because of the fluctuating output power due to intermittent nature of wind speed. Thus in such cases, the LFC needs to be addressed differently. In [46], the authors have presented modification in unit commitment, economic dispatch, regulation and frequency controls, when the level of wind generation capacity is significant. In [47] author presented a study to analyze the effects of small wind turbines output on the LFC. The LFC of WT based power system is discussed in [48]. In [49], a wind-turbine driven self-excited induction generator is considered as variable speed, constant voltage, and constant frequency supply with isolated resistive
load connected. The simplified model is used to develop a control strategy that aims to maintain the generator terminal voltage and frequency constant in case of variations in the load and/or wind speed. The frequency control with controlling speed of wind turbine is presented in [5064]. Next, the authors in [65] analyzed the effect of stand-alone hybrid power system consisting WTGs, DEG, FC, and AE on frequency variation. The authors [66] presented an integrated control approach for WF to control the frequency deviations of winddiesel power system. In their work, the frequency control is achieved by load estimation and short-term ahead wind speed prediction. The minimal-order observer as disturbance observer is used for load estimation, while the least squares method is used for the prediction of short-term ahead wind speed. The predicted wind speed adjusts the output power command of the WF as a multiplying factor with fuzzy logic concept.

The innovative LFC method by use of both electric vehicle and heat pump water heater as controllable loads is proposed in [67]. The aggregate LFC of a wind-hydro autonomous micro-grid system is described in [68]. The LFC by PHEVs, controllable loads, and a cogeneration unit is discussed in [70]. The authors [71] address the current AGC structure and its drawbacks, and new AGC with cyber architecture to accommodate intermittency of high penetration, non-dispatchable distributed energy resources for smart power grids. The autonomous distributed vehicle to grid control scheme providing a distributed spinning reserve for the unexpected intermittency of the renewable energy sources is proposed in [72]. The study presents a droop control based on the frequency deviation at plug-in terminal. The aggregated electric vehicle-based battery storage representing vehicle to grid system, modeled for use in long-term dynamic power system is proposed in [73].

The various techniques proposed for LFC in distributed generation and conventional power systems that includes Proportional Integral Controller (PID), Artificial Neural Network, Genetic Algorithm, Sliding Mode Controller, Fuzzy logic based Controller
2 PID controller based LFC

PID controller basically caters to the issue of decentralized LFC cases. This is a robust system and tackles ambiguities well enough through its multiple controls like disturbance accommodation and ramp following. In addition to this, it also has a predictive control scheme and an optimal tracking approach as well. The LFC of two-area hydro-hydro power system with proportional-integral-derivative (PID) controller based on maximum peak resonance specification that is graphically supported by the Nichols chart is discussed [37]. Two-Degree-of-Freedom (TDF) Internal Model Control (IMC) method to tune decentralized PID type controller for LFC in four area power systems with deregulated environments [30]. The TDF-IMC-PID method has been studied for LFC in conventional situation and the performance of the control system is only related to two tuning parameters [38] [39]. the design of multi-objective PID controller for LFC based on adaptive weighted particle swarm optimization in two-area power system is described [41] [42].

3 Sliding Mode Controller (SMC)

The output power fluctuation of integrated wind energy, load frequency control (LFC) for power system with variable sources and loads has become more complicated. The novel decentralized sliding mode (SM) LFC strategy is proposed for multi-area time-delay power system with significant wind power penetration. The appropriate switching surface gain is selected to assure the stability of power system with mismatched uncertainties. The SM controller is constructed to satisfy the hitting condition. The Sliding Mode controller is proved by using the real-time digital simulator device under different case of time delay, wind penetration, load disturbance and operating point [5]. In [10] author investigates the robust H sliding mode load frequency control (SMLFC) of multi-area power system with time delay. By taking into account stochastic disturbances induced by the integration of renewable energies, a new sliding surface function is constructed to guarantee the fast response and robust performance, then the sliding mode control law is designed to guarantee the reach ability of the sliding surface in a finite-time interval. The sufficient robust frequency stabilization
result for multi-area power system with time delay is presented in terms of linear matrix inequalities (LMIs)

4 Artificial Neural Network (ANN) Based LFC

An Artificial Neural Network (ANN) is an information processing paradigm, motivated from biological nervous systems. The key element of this paradigm is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements (neurons) working in unison to solve specific problems. An ANN is configured for a specific application, such as pattern recognition or data classification, through a learning process. The ANN has been applied to achieve better control strategies especially in a non-linear complex power system. In [6] the author outlined the application of layered neural networks in nonlinear power systems. In [6] investigated the use of neural networks to act as the control intelligence in conjunction with a standard adaptive LFC scheme that improves the control. Authors have developed an automatic load frequency controller using ANN to regulate the power output and system frequency by controlling the speed of the generator through water or steam flow control [8].

5 Fuzzy Logic Based LFC

Fuzzy logic because of simplicity, robustness and reliability is used in almost all fields of science and technology, including solving a wide range of control problems in power system control and operation. Unlike the traditional control theorems, which are essentially based on the linearized mathematical models of the controlled systems, the fuzzy control methodology tries to establish the In paper [8] addresses a new decentralized fuzzy logic-based LFC schemes for simultaneous minimization of system frequency deviation and tie-line power changes, which is required for successful operation of interconnected power systems in the presence of high-penetration wind power. In order to obtain an optimal performance, the particle swarm optimization technique is used to determine member-
ship functions parameters. A new intelligent methodology using a combination of fuzzy logic and particle swarm optimization (PSO) techniques to satisfy LFC objectives concerning the integration of wind power units. The PSO technique is used to find optimal values for membership functions parameters of the fuzzy logic controllers. The authors [44] presented a coordinated control approach for output power fluctuation leveling of PV systems using fuzzy logic concept with consideration of power system condition and insolation condition. The LFC problem of isolated utility-connected large PV-diesel hybrid power system based on simple fuzzy logic approach is also proposed in [45].

6 Genetic Algorithm based LFC:

Genetic Algorithms are based on Darwins theory of natural selection and survival of the fittest. It is a heuristic optimization technique for the most optimal solution (fittest individual) from a global perspective. GA have attractive features like robustness, simplicity etc. so it is widely applied for various power system problems such as optimal power flow, analysis of system topologies, power distribution system design, and economic dispatch. The GA is widely used for solving the complex nonlinear optimization problems in deregulated power system are presented in the following literary works [10-14]. In [18] Genetic Algorithm based control technique is a depiction of one of the best kind of computer intelligence in power systems. Different research designs have approved of the GA where it was used along with PI type controllers. Using linear matrix inequalities (GALMI), GA has been able to solve complex optimization problems. The main difference in the functionality of GA and PID is that the latter one uses a H2/H controller. The optimization of control parameters for robust decentralized frequency stabilizer by using micro GA is presented in [16]. A new design of multi-objective evolutionary algorithm based decentralized load-frequency controllers for interconnected power system with AC-DC parallel tie-lines is proposed in [17].
7 Particle Swarm Optimization (PSO) based LFC

The Particle Swarm Optimization (PSO) conducts searches using a population of particles which correspond to individuals in the GA. The PSO is a population based stochastic optimization technique, inspired by social behavior of bird flocking or fish schooling. To ease the design effort and thereby improve the performance of the controller, the design of fuzzy PI controller by hybridizing GA and PSO is presented in [19]. With the use of control scheme based on adaptive neuro-fuzzy inference and PSO with gains being updated in real time, a better dynamic and steady state response is obtained in [20]. Similarly the design of multi-objective PID controller for LFC based on adaptive weighted particle swarm optimization in two-area power system is described in [21,22].

8 Tabu search algorithms (TSA) based LFC

The Tabu search algorithms (TSA) is an iterative search that starts from some initial feasible solution and attempts to determine a better solution in the manner of a hill-climbing algorithm. The TSA has a flexible memory which maintains the information about the past step of search and uses it to create and exploit the better solutions. In [23] presented an approach for the automatic definition of fuzzy rules in fuzzy controller based on TSA and the authors explaining the improvement in learning of fuzzy rule by using heuristic symbolic meta rules. In [23] presented a new optimization technique of a fuzzy logic based PI-LFC by the multiple tabu search algorithm.

9 Bacterial Foraging Optimization Algorithm (BFOA)

Another known optimization techniques; the bacterial foraging optimization algorithm (BFOA) is motivated by the natural selection
which tends to eliminate the animals with poor foraging strategies and favor those having successful foraging strategy. The foraging strategy is governed by four processes namely chemotaxis, swarming, reproduction, elimination and dispersal. BF method is used for tuning the control parameters of fractional-order PID controller and conventional integer order controllers for LFC are explained in [34]. In [16] author used the BF technique for obtaining the optimum gain values for controllers and speed regulation parameters. BFOA method is used to optimize the integral gains (Ki) and speed regulation parameter (Ri) for a three area system is discussed in [35,36].

10 Variable structure controller (VSS)

The variable structure controllers change the system structure in accordance to some law of structure change, in order to improve the dynamic performance and thereby make the controller insensitive to the plant parameter changes. Hsu and Chan [25] proposed the LFC problem for interconnected two-area hydro-thermal power systems using the theory of variable-structure systems and linear optimal control theory.

Variable structural control application for various LFC problems in a deregulated power system is discussed in [25,26]. In paper [25] author explained a novel robust decentralized controller using Quantitative Feedback Theory (QFT) for solving the LFC problems in a restructured power system and it operates under deregulation based on bilateral policy scheme. The author in [26] presented a variable structure system (VSS) control scheme for LFC issues in a multi area deregulated power system and justified that VSS control scheme improves the transient response and maintained zero error at steady state of the system.

11 Big Bang Big Crunch (BBBC) optimization technique

BBBC is a new optimization method is derived from the theories of the evolution of the universe namely, the Big Bang and Big Crunch theory are introduced by Erol and Eksin. Optimal gain parame-
ters of Integral (I), proportional Integral (PI), Integral-Derivative (ID) controllers in a four area system are optimized by big bang big crunch (BBBC) method is explained in [29]. In [30] authors proposed an ant colony system algorithm (ACS) based integral controller for LFC issues in a two area deregulated power system.

12 Conclusion

The various existing techniques and strategies of Load Frequency Control for Distributed Generation systems are discussed. A detailed survey has been done and the various Load Frequency Control techniques adopted are explored. It is observed in this literature survey that there exists a lot of research opportunities in Distributed Generation systems on issues related to Load Frequency Control.

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