

# Load Frequency Control of Wind Integrated Power System: A Review

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**ABSTRACT:** This paper deals with a new control strategy of quenching transients of a load frequency problem. The load frequency problem is represented by a new state space model for a single area Electric power system. Global analysis of the power system markets shows that load frequency control (LFC) is one of the most profitable ancillary services of these systems. This service is related to the short-term balance of energy and frequency of the power systems and acquires a principal role to enable power exchanges and to provide better conditions for electricity trading. The state variables selected in this model are frequency, first and second derivatives of frequencies. The steady state operating points before and after the load disturbance are named as initial and final states of the system. Now the LFC problem is restructured as a state transition problem (initial to final states) using a suitable control parameter. The article is aimed to present the various control and structural schemes of LFC present in the power systems. The LFC schemes on different aspects like classical control based LFC schemes, LFC schemes based on modern control concepts are discussed. Due to the rising penetration of the renewable energy sources LFC on RESs also discussed to an extent.

**Keywords:** Load frequency control (LFC), classical control based LFC schemes, modern control concepts, Intelligent control techniques.

## I. INTRODUCTION

Power system is a dynamic system where interacts active elements connected together via power lines. Its goal is to deliver power to a variable load or ensemble of consumers which is one of its critical[1]. Changes in loads affect mainly the frequency of the power network, while the reactive power related to voltage magnitude is less sensitive to the changes of frequency, that why active and reactive powers are controlled separately. Automatic generation control (AGC) or load

frequency control (LFC) is one of the main operations for a good management of any electrical systems. The aim of LFC is to monitor the variation of active power by providing the signals for control of the frequency regulator and active power output of different generating units within the limits prescribed control area in response to the changes in system frequency and tie-line loading, and it help to maintain the scheduled system frequency and establish interchange with others areas [2]. Due to dynamic characteristics of the load add its continuous and random changes during the operation of the power system, most of the time the quality of the power supplied to the consumers is affected [3]. Therefore, in the day to day management of the electrical system the control aspect is necessary to maintain a continuous balance between power generated and power consumed or load demand.

The problem becomes more complex when dealing with an interconnected system [4]. In fact, the reliability and continuity of service of two or more isolated power grids (microgrids) can be achieved by their interconnection through tie-lines. An interconnected power system can be considered as being divided into control areas; all generating units are assumed to form a coherent system [5]. In the steady state power system demands of areas are satisfied at the nominal frequency. The change of active power in one area is sustained by the increase in generation in all areas associated with a change in the tie-lines power flow and a reduction in frequency [6]. As the power load demand varies randomly, all areas frequency and the tie-lines power interchange also vary [7]. The objectives of LFC are to minimize the deviations in frequency and tie-line power flows which are taken as the control variables and to ensure that the frequency variation is returned to zero. A basic control system strategy for the normal mode is to operate in such a way that it keeps the frequency at approximately nominal value, maintaining the tie-line power flow out of each area at the planned value. Each area

should absorb its own load changes[8]. That is why the primary purpose of operating the LFC is to keep the frequency changes during the load changes uniform.

Recently, penetration of Renewable Energy Sources (RES) has risen globally. With the rising needs and advantages of RES, it's beneficial to integrate it with conventional power generators. The issues like depletion of fuels, global warming emissions, destruction of wildlife, rising pollution level, etc. can be resolved by the integration of renewable sources. RES consisting mainly solar, wind, tidal and geothermal energy etc, among all these wind power is cleanest, reliable and sustainable source to generate electric power [9]. The major issue present in the integration of these resources is the frequency and voltage mismatch of these with the main grid.

## II. TRADITIONAL CONTROLLERS

Most of the research in the field of the control of microgrids is devoted to the use of conventional controllers such as integral (I),

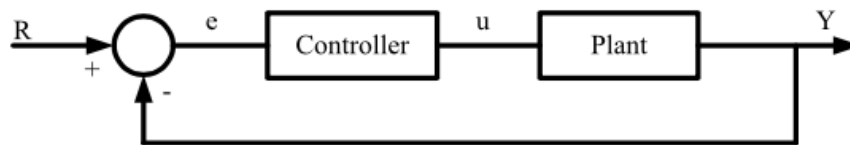


Fig. 1. Conventional Controller.

where each  $k_i$  represents the gain of the controller. A new PID load frequency controller design method in frequency domain through direct synthesis approach was proposed [12]. The method yields linear algebraic equations, solution of which gives the controller parameters.[13] have proposed a decentralised PID-LFC for perturbed multi-area power systems. The beauty of the proposed approach was that the fixed PID controller is taking care of uncertainty in the each control are. Delay distribution dependent LFC of power systems with probabilistic interval delays was proposed[14]. An algorithm was provided to obtain the gain of PI-based LFC and the allowable upper bound of the communication delay simultaneously while preserving the desired performance. The author have proposed an AGC using two degree of freedom fractional order PID controller[15]. The work also explored the effectiveness of the firefly algorithm based optimisation technique in finding the optimal parameters of the controller and selection of R parameter. Optimal tuning of 3 degree of freedom PID controller for hybrid distributed power system using dragonfly algorithm (DA) was proposed[16]. The efficacy of proposed

proportional Integral (PI) or proportional Integral-derivative (PID). The main reason is 90% or more of control loop in industry are traditional models. Fig. 1 gives the standard control model, where the variables (R), (e), (u), (Y) represent successively the difference between the desired input value, the tracking error, the input signal, and the actual output. To obtain a desired response, PID controller model is the most used when considering the conventional controllers models[10-11]. This situation is based on a trying process. The following steps are generally used:

- Obtain an open-loop response and determine what needs to be improved;
- Add a proportional control to improve the rise time;
- Add a derivative control to improve the overshoot;
- Add an integral control to eliminate the steady-state error;
- Adjust each of  $k_p$ ,  $k_i$ , and  $k_d$ , until you obtain a desired overall response.

DA over different reported algorithms was established in terms of convergence rate, minimum fitness value and dynamic performance of the system. Design of a fractional order PID controller for an AVR using particle swarm optimisation (PSO) algorithm was proposed[17]. A novel cost function was defined to facilitate the control strategy over both the time-domain and the frequency domain specifications.

## III. HYBRID MODELS

The integration of the renewable energy resources into the power system creates new issues because most of them are whether dependent. Power systems need advanced control methods for its daily management. In the control area, the new tendency is the combination of the artificial intelligence algorithms particle swarm optimisation algorithm (PSO), fuzzy logic (FL), genetic algorithm (GA), etc. with the conventional controller to solve the frequency or active power flow control issue in power system. Some models based on FL approach are available in the literature [18].

### 3.1 LFC based particle swarm optimisation algorithm

PSO algorithm is one of the best algorithm in the artificial intelligence class. Multi-stage fuzzy LFC using PSO was proposed [19]. For achieving the desired level of robust performance, exact tuning of membership functions was very important. Intelligent frequency control in an AC microgrid on-line PSO-based tuning approach was presented in Bevrani [20]. The performance of the proposed model was compared with the pure fuzzy PI and the Ziegler–Nichols PI control design methods. A novel hybrid PSO–PS optimised fuzzy PI controller for AGC in multi area interconnected power systems have proposed [21]. Additionally, the proposed approach was further extended to multi-source multi area hydro thermal power system with/without HVDC link. Using a PSO and fuzzy rules the authors presented a multi-area LFC. Heuristic procedures involving Particle Swarm Intelligence and Fuzzy based inferences have been employed to effectively obtain the optimised gains of PID controller. Any change in the load demand causes generator's shaft speed lower than the preset value and the system frequency deviates from the standard value results [22].

### 3.2 LFC based genetic algorithm

Research on LFC based on GA can be found in the available literature. The authors have proposed an AGC of multi-area power system using multi-objective non-dominated sorting genetic algorithm-II. The proposed approach was first applied to a linear two-area power system model and then extended to a non-linear system model by considering the effect of governor dead band non-linearity [23]. A modified GA based load frequency controller for interconnected power systems was proposed. Floating point representation has been used, since it was more consistent, more precise and leads to faster convergence. [24] have proposed two robust decentralised control design methodologies for LFC. The first one is based on control design using linear matrix inequalities technique in order to obtain robustness against uncertainties. The second controller had a simpler structure, which was more appealing from an implementation point of view. Design of load frequency controllers using GA for two area interconnected hydropower system was proposed. As far as the authors can discover, no work has been done for the optimisation of the gain settings of different types of controllers using the GA for LFC of an interconnected hydropower system [25].

### 3.3 LFC other models based on artificial intelligence algorithm

This section gives the controllers models based on algorithm using artificial intelligence strategies. The research in presents the design of optimal AGC regulators using an output feedback control strategy for a multi-area interconnected power system. [26] has proposed a comparative performance analysis of TLBO for automatic LFC of multi-source power systems. It was found that the dynamic performance of the proposed controller was better than that of recently published DE optimised controller and optimal output feedback controller and also the proposed system was more robust and stable to wide changes in system loading, parameters, size and locations of step load perturbation and different cost functions. [27] have proposed an observer based robust integral sliding mode LFC for wind power systems. The proposed model not only guarantees the asymptotical stability of overall power systems but also capable of improving the system robustness. Numerical examples were provided to demonstrate the effectiveness of the proposed model. The researchers in have proposed a fractional order PID controller to solve the LFC problem. Robust  $H_{\infty}$  for LFC solution was presented. [28] have presented a LFC by neural-network-based integral sliding mode for nonlinear power systems with wind turbine [29]. By this scheme, not only are the update formulas obtained, but also the control system possesses the asymptotic stability. The simulation results by an interconnected power system illustrate the feasibility and validity of the presented method.

### 3.4 LFC based FACTS and storage system

The contribution or importance of the battery in the new power system is no longer demonstrated. Most of the renewable energy sources are weather dependent and not available at any time and the battery can be used to supply the load on time of unavailability of these sources. [30] have presented a LFC of multi-source multi-area hydro thermal system using flexible alternating current transmission system (FACTS) devices. An impact of energy storage system on LFC for diverse sources of interconnected power system in deregulated power environment was presented [31]. The proposed control mechanism has been analysed in a deregulated power environment with the help of different simulation case studies to find out improved dynamic performance over integral control strategies. LFC of an interconnected reheat thermal system using type-2 fuzzy system including SMES units was proposed. The performance of the Type-2 (T2) fuzzy controller is

compared with optimal PID (Khamsum's optimal PID) controller and Fuzzy PI Controller (Type-1 Fuzzy) controller in the presence of GRC, BD and SMES. LFC in deregulated power system integrated with super SMES-Thyristors controlled phase shifters combination using adaptive neuro fuzzy system controller was proposed. The dynamics of the proposed model was analysed with unilateral, bilateral and contract violation cases for a small load perturbation[32]. The authors have

proposed a frequency stabilisation of multi-area multi-source interconnected power system using TCSC and SMES mechanism. The step load perturbation (SLP) and random SLP are used for the dynamic performance analysis. Adaptive AGC with SMES in power systems was presented. A comprehensive comparative performance evaluation of control schemes using adaptive and non-adaptive controllers in the main AGC and in the SMAES control loops was presented[33].

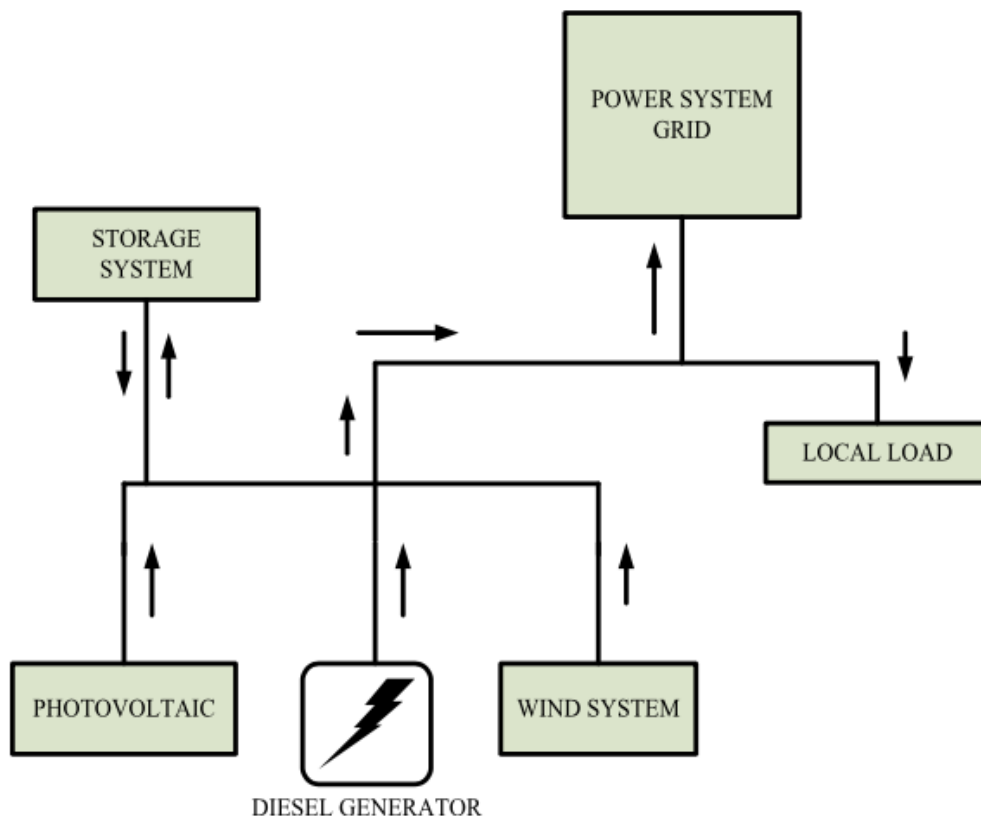


Fig. 2. New power system configuration.

### 3.5 LFC based on robust model

Some robust controllers are presented in the literature.[34] have presented a robust decentralised PI and design of power system LFC using the Kharitonov's theorem in a multi-area. This theorem was used to determine the robustness margin. A robust method of tuning the feedback gains of a variable structure LFC controller using GA optimisation was presented. The authors have compared the system performance against step load variations with the conventional trial and error method. [35] have proposed a new robust PID load frequency controller. The proposed controller was straightforward and effective. A robust adaptive LFC for microgrids was presented. The simulations results

prove the successfulness and effectiveness of the proposed method.[36] have proposed a robust LFC with dynamic demand response for deregulated power systems considering communication delays. A robust PID-LFC controller was designed through the  $H_{\infty}$  performance analysis and the PSO searching algorithm. Robust stability of networked LFC systems with time-varying delays was proposed. Using Lyapunov-Krasovskii functional approach, a less conservative stability criterion was presented to ascertain delay-dependent stability of such LFC systems. [37] have proposed a robust analysis and design of load frequency controller for power systems. The proposed method took into account the un-modelled dynamics of power systems.



#### IV. OTHER MODELS BASED LFC

In 2016, [38] has developed the impact on biogeography optimization (BBODMFOPI) application on the basis of the scheduling of dual mode gain for fractional order PI controllers in terms of LFC over a multi-source multi area interconnected power systems. This research work has applied with BBO for the effective tuning of controller parameters. BBO was considered as a new evolutionary approach that has contained the method to make the system efficiently by means of arithmetical approaches. The experimental analysis has thus revealed that the implemented biogeography optimization on the basis of dual mode gain scheduling under fractional order PI controllers has offered superior transient and also the steady state response. Further, it was proved that the implemented controller has least perceptible to the system parameter changes and was robust over the diverse operating power systems conditions. [39] has made an attempt to deploy the conventional MUGA in LFC for Pareto optimization of PI/PID controllers of power systems. The design variables has been assigned as the gains of PI and PID, where the main objectives were explained as settling times in frequency, ITAE, tie-line power deviations and minimum damping ratio of dominant eigen values. The experimental outcome has revealed the noteworthy enhancement in the system response of the proposed model. Finally, this work has taken the three unequal area hydro thermal system having GRS into consideration using the physical constraints and nonlinearities, by which the evaluation of MUGA performance was made within the complicated system.

#### V. RESEARCH GAPS AND CHALLENGES

At the time of transportation, the reactive power balance and the active power balance needs to be sustained among utilizing and generating the AC power. These active and reactive power balances are corresponding over two equilibrium points: voltage and frequency. During operation, better electric power system quality is needed for both the voltage and frequency for remaining at benchmark values. Though, the electric power users alter the loads momentarily and randomly[40]. The maintaining of balances among the active and reactive powers with no control is very crucial. Owing to the consequence of imbalance, according to the load change, the voltage and frequency levels will be varied. Therefore, in order to neglect the arbitrary load change effect and for sustaining the voltage and

frequency at benchmark values, a control system is very much important. Even though the frequency and voltage are impacted by the combined effects of the active power and reactive power, the control issue of the voltage and frequency may get decoupled[41]. The dependency of frequency is largely based on the active power whereas the dependency of voltage is largely based on the reactive power. Therefore in power systems, the control problem might be decoupled as two independent issues. The first is on the frequency control and active power whereas the second is on the voltage control and reactive power. In this, the frequency control and active power is termed as LFC. The primary target of LFC is on maintaining the constant frequency over the arbitrarily changing active power loads that as well termed as unidentified explicit disturbance. An additional target of LFC is on regulating the tie-line power exchange error. Typically, a huge-scale power scheme is comprised of various areas of producing units. These producing units are associated through TL for enhancing the fault tolerance of the whole power system[42].

#### VI. CONCLUSION

The present paper review the comprehensive literature concerning the load frequency controller models. There cent issues and challenges faced by these controllers as well as by the power system in order to maintain the frequency of the system to nominal values and to maintain the voltage and active power profile within predetermined limits are also addressed in this paper. The frequency control is a major issue in the power system operation and control and lot of advanced control strategies have been developed over the last decades in order to improve the frequency control of the power system. However, there is a growing trend to develop microgrids which may be operated in grid connected or isolated mode. The microgrids essentially have unpredictable renewable sources of energy besides storage. Therefore, further efforts are required to design frequency control strategies which can take into account the dynamics of microgrids if they are grid connected.

#### VII. FUTURE SCOPE

The integration of fluctuating energy sources like solar and wind power with energy storage devices improve the reliability of the system as well as the quality of power delivered to the consumers. The frequency control is a major issue in the power system operation and control and lot of advanced control strategies have been

developed over the last decades in order to improve the frequency control of the power system. Therefore, further efforts are required to design frequency control strategies which can take into account the dynamics of microgrids if these are grid connected.

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