

REVIEW ON LOAD FREQUENCY CONTROL TECHNIQUES

Muhammad, M.M. *, Gana, M.A., Usman, J. and Mustapha, I.

Department of Electrical and Electronics Engineering, University of Maiduguri, Borno State, Nigeria

*Corresponding email: enr.massa@gmail.com

ABSTRACT

Automatic frequency regulation or control is aimed to control the individual turbine-generator systems to control the system's frequency. In addition, maintaining power balance is another goal of power system operation and control. Sudden change in load causes mismatch between generation and load demand. This mismatch causes frequency deviation and it is one of the major problems in power system stability. This frequency deviation brings system instability which may cause system collapse. Numerous control strategies have been proposed in recent decades for load frequency control in power networks. In this work, a thorough literature review on load frequency regulation in power systems is presented. The purpose of this article is to outline the various load frequency control techniques used power systems. Review can be carried out using a numerous approach. In this review work, the method adopted for conducting the review of the load frequency control is by explaining in detail about the article published. This detail include method applied, area/amount disturbance occurred, advantages and observations are presented in the paper. The research limitations and novel research directions in the area of load frequency control were mentioned in the paper's conclusion.

Keywords: Automatic generation control; load frequency control; interconnected power systems; load deviation; frequency deviation; tie-lines power

1 INTRODUCTION

The essential need for an electrical power system to be stable is that the system frequency and voltage level be close to their steady state limitations [1]. The capacity of a power system to maintain its operating equilibrium under normal operating conditions and to return to that equilibrium following a disruption is known as power system stability [2]. Rotor angle, voltage, and frequency can be used to categorize power system stability. Disturbances can be long- or short-term, and can happen as variations in real power, which primarily affects system frequency, or in reactive power, which primarily impacts voltage magnitude [3]. Frequency change is caused by the imbalance between the total power generated and the total electrical demand. Area frequency and tie-line power interchange both fluctuate in an interconnected power system as a power load demand does [4]. Induction motors or synchronous machines experience significant magnetic current when the frequency deviates from its reference value (50Hz/60Hz), which destroys the equipment [5]. Large frequency deviations can overload/underload transmission lines, interfere with system protection protocols, and ultimately render the power system incapable of functioning [6]. The power system provides a load frequency control (LFC) to address the issue of frequency deviation in power network. The goals of LFC are to ensure steady state errors are zero and to reduce their transient variances (area frequency and tie-line power exchange). It is necessary to maintain the system frequency because (i) AC motor speed directly depends on frequency, (2) turbine speed

changes as a result of frequency change, damaging the blades, and (iii) when frequency drops below normal value, core flux of transformer increases and transformer enters saturation [7]. The main objectives of automatic generation control (AGC) are to keep the system frequency at or very close to nominal value, maintain the value of power exchange across areas, and keep each unit's generation at its most advantageous level [8]. Frequency control is categorized into primary control, secondary control and tertiary control levels. The primary frequency control is usually implemented by the governor droop which results in steady stated errors. Secondary frequency control, is also known as LFC or AGC, is responsible for controlling the frequency in power systems, it has the objectives of keeping the frequency within an acceptable range; and regulating the power exchange between the various control areas via major tie-lines. Tertiary control level is achieved by re-dispatching generating units and ancillary reserve after a sever disturbance [9].

2 METHODOLOGY

Numerous control strategies have been proposed for LFC in interconnected power systems. These strategies are divided into classical control approach, modern control approaches, intelligent control schemes, and soft computing-based approaches. A good and systematic review can be carried out using a numerous approach. In this review work, the method adopted for conducting the review of the LFC is by explaining in detail about the article published. Figure 1 depicts the review process flowchart used to perform the steps above. It shows the detail of how the papers were review and recorded. Selection criteria such as language (English language), duration of papers (published not more than 5 years) and other are considered. Using specified keywords, the most prominent and well-known databases are searched for articles published in the field of LFC, including Scopus, IEEE explore, Science Direct, and Springer. It is important to note that, this paper only focused on research that was published online, such as journal articles, book reviews, conference papers, scientific manuals, and standards. The topic name is searched and relevant papers will be considered in the next step and study the abstract, keywords and conclusion for relevancy. If is useful, record the methods, materials, merits/demerits, gaps, recommendation/observation/comment of the paper. This paper reviews highlighted the methods, merit, drawbacks, gap of studies and observation of LFC in the last decade. In this review, we highlight the advantages and challenges of each control method. At the start, 659 papers were searched, 413 remaining after deleting duplicates. After that, 253 papers were eliminated after the abstracts, contributions, and titles of the aforementioned papers were scrutinized in accordance with the paper's criteria and objectives. Final screening was carried out by carefully and attentively reading the remaining 160 papers and list of 55 papers were recorded. Figure 1 shows the flow chart.

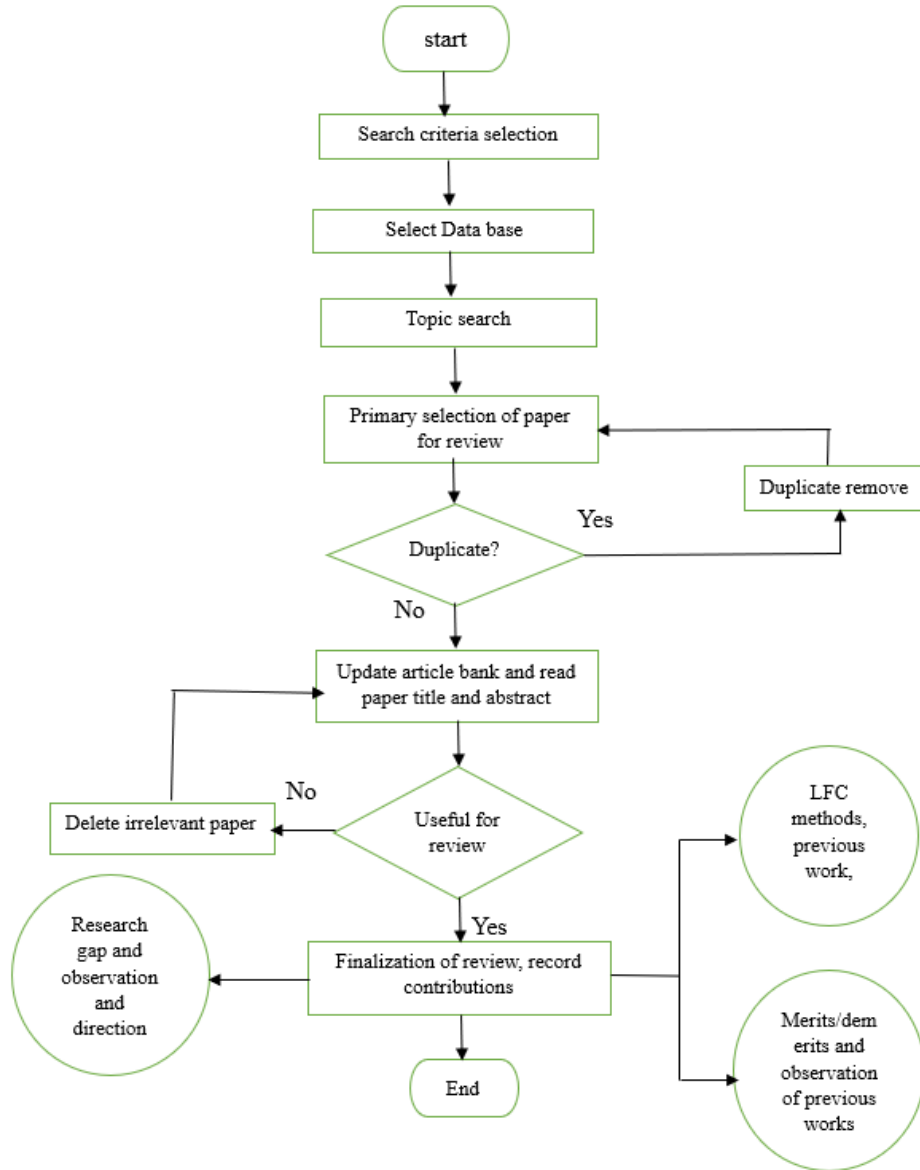


Figure 1. Flowchart [10]

For a two-area interconnected power system, the effectiveness of Proportional Integral Derivative (PID) and PI controllers for load frequency management is examined. Due to the $0.01p.u.$ load increase in region 1, the controllers assisted the system in reducing frequency deviations and tie-line power. The result shows that the PID controller outperforms the PI controller in terms of overshoot and settling time [11]. In this paper, optimal tuning of Proportional-Integral-Derivative (PID) controller for both LFC and Automatic Voltage Regulator (AVR) of two area interconnected power system is presented in [12]. A step disturbance of $0.18p.u.$ is applied in the Area 1. The use of PID controller results in relatively smaller peak overshoot and lesser settling time with zero steady state error as compared to the use of conventional Integral controller and PI controller. [13] presents a control system for improving the transient response time of speed/load-frequency of a gas turbine in a refinery in Nigeria. PID controller that will improve the transient response of a HDGT in a refinery in Nigeria. PID controller and Integral controller are applied to a single area hydro-turbine power system to improve the stability in the system. PID produced better results compared to Uncontrolled and integral controller [14]. The load frequency control for two area power system using PI and PID controllers is presented in [15]. PID controller has better dynamic performances

of overshoot, rise time and settling time than the PI controller when a load change of 0.2pu occurred in control area one. The dynamic performance of AGC of two area interconnected power system of deregulated system with the use of PID controller when load change of 0.01pu is applied to the system is presented in [16]. PID controller gives better performance than the PI controller. Load frequency control of three area power system is presented in [17]. The performance of the system was studied when load change of 100 MW is applied to area-1 and area-2. PID control system is leading to a stable power system with zero steady state error. Cuckoo Search Algorithm (CSA) is used to tune of the two-degree freedom of PID controller (2DOF-PID) for LFC of an interconnected linear/nonlinear power system in [18]. 2DOF-PID controller is proved over conventional PID controller in terms of responses like minimum undershoot, settling time and peak overshoot. particle swarm optimization (PSO) is used to optimize the PID parameters of two area power system in the presence of load disturbance in [19]. The result of the PSO is compared with that of conventional PID. The proposed PSO tuned PID controller gives better results than the conventional PID controller. PSO is used to determine the optimal values for the proportional-integral-derivative (PID) controller parameters of LFC of two area power system is presented [20]. Simulation results justify the proposed approach in terms of damping the oscillations, improved settling time, less over/under shoots when step change in load (0.2 pu) in area-1. [21] presents design of a PSO method of tuning PID controller for a load frequency control of single and two-area network. PSO-PID proven high performance such as easy implementation, stable convergence characteristic, and good computational efficiency compared with GA based PID controller. [22] Particle swarm optimization was employed to tune the parameters PID for AGC of two-area hydro-thermal power system. Proposed control method is provided better performance for dynamic responses of the power system. In [23], PSO algorithms applied in multi objective LFC of two-area power system to get the optimum value of PID parameter. ITAE and ITSE objective function were considered for the study as performance criterions. Step load change of 10% is applied in Area 1. The proposed controller gives better control performance by minimizing settling time and maximum overshoot. The PSO algorithm has proven to be effective dealing with multi objective optimization. [24] the load frequency control problem in a power system consisting of two power generation unit and the dynamic performance of LFC in three-area interconnected hydro-thermal reheat power system by the use of Artificial Intelligent. Conventional controller is proposed for three-area interconnected hydro-thermal reheat power system. [25] PID controller has been proposed to improve the frequency deviation of single area hydro power plant of power system. Load variation 0.02p.u is considered, the tuning PID controller has properly got well output system response. In [26] PSO based on Integral of Absolute Error (IAE) and Integral of Square Error (ISE) criterion to obtain the optimum controller gain for the single area power network. Load deviation of 10%, 20%, and 30% is applied to the network. [27] The PID parameters were tuned using (PSO-GSA) for two area networks. In this study, the load demand of 10 MW and 20 MW is applied to area1 and area2 respectively. The proposed algorithm is compared with Z-N, PSO, GSA and BAT controllers. [28], Stochastic Particle Swarm Optimization (SPSO) technique was used to optimize the Proportional-Integral (PI) controller for LFC of a single area reheat thermal power system. IAE, ISE and ITAE objective functions were considered with 1% of load change. The results show that IAE based PI controller response settled quickly with minimum over and undershoot compared to other objective function-based controller performance. The load frequency control of a single area thermal power plant with reheat turbine is presented in [29]. The gain of the integral controller is optimized with the help of PSO technique. Various objective functions such as IAE, ITAE, ITSE and ISE are used as benchmark criteria for optimizing the gain of the controller when 0.01 p. u. As a result of load change in the system. In [30], PSO-PID controller is used to improve the stability of four-area power system in Zambia network. Step load change of 0.063p.u, corresponding to 180MW of the 2850MW is applied to area-1. The performance of the proposed controller is compared with that of isolated AGC. [31] presents fuzzy logic and PID controller are applied to two-area power system interconnected to remove the fluctuations of the system. The performance of the PID and fuzzy controllers were compared and proved that fuzzy approach is better than PID based applications. In [32], Fuzzy logic controller was employed to LFC for two area power system to improve the stability. Load disturbance of 0.2pu was applied to area 1 only. Fuzzy logic controller gives faster response within a few milliseconds than conventional integral controller. [33] Fuzzy

logic and PI controllers are used for LFC to reduce the frequency deviation and maintaining dynamic performance for two area interconnected power system. Fuzzy logic controller was compared to the conventional PI controller. [34] Fuzzy controller is composed for solving frequency deviation problem in a single area non-reheated thermal power system. A load change of 1% is applied to the system. The performances of the power system using fuzzy controller are compared with that of PID controller. In [35] the performance of Fuzzy controller is compared with PI controller on LFC of two area interconnected power system to achieve stability when a sudden change in load in the system. Fuzzy controller is proposed for the two area power system in [37]. The performance of the proposed Fuzzy is compared with PI when load change at both areas. [36] design a fuzzy logic load frequency control for interconnected power system. Fuzzy logic intelligent controller exhibited the best frequency settling time of 3.5s. Comparison controller, the load disturbance and the area applied were not disclosed. [38] Adaptive neuro-fuzzy technique is used to address the AGC problem. The proposed method is compared with RCGA, HCPSO, and ANN controllers. [39] presents the use of Artificial Neural Network and conventional PID to control load frequency of Two area interconnected power system in Nigeria. The step load change in the system is not specified and the system responses base on increase or decrease also is not detailed. [40] Grey wolf optimization (GWO) is proposed to solve LFC problem of a two-area thermal power system and two-area multi-units hydro-thermal power plant. 1% load perturbation in area-1 is applied to the power system. The superiority of proposed method is established by comparing the results with original GWO, CRPSO, DE, FA, and hFA-PS algorithms. [41] PI controller parameters are tuned by GWO technique for load frequency enhancement problem. The two-area power system is subjected to 2% load perturbations in each area. GWO has improved the stability in the system. [42] Multi degree of freedom PID controllers (MDFPID) is selected for frequency control in two-area hydro-thermal interconnected system. GWO Technique is used to tune the parameters of the MDFPID parameters. Load disturbance of 1.5 and 10% were applied for case-1 and case-2 respectively. The performance of MDFPID is compared with that of PID controllers. GWO is introduced to optimize the PI and PID parameters for automatic load frequency control of two area network system. The disturbance of the 2 and 3% are introduced to the 2 areas in relative manner [43]. [44] Made an attempt to solve LFC problem in two-area interconnected power system network equipped with classical PI/PID controller using GWO technique. The performance of the proposed GWO algorithm is compared with CLPSO considering ITAE based fitness function. The proposed GWO tuned PID-controller can effectively. In [45] GA, PSO, and GWO for single-area and two-area system power system for LFC. Performance indices IAE, ISE, ITAE and ITSE were taken as an objective function for designing the PID controller parameters. The GWO algorithm provides better performance, with fast response when the system is subjected to load change of 10%. [46] Bacteria Foraging Optimization Algorithm (BFOA), Differential Evolution (DE) based PI controllers were employed to tune the optimum gain of the PID1 controller for two area interconnected power system. Load disturbance of 10% was applied to area-1 and area-2 separately and the performance of the two algorithms were recorded. This concludes that DE PID1 outperform BFOA PI and DE PI. A combined LFC and AVR of a two-area hydro-thermal interconnected power system has been presented in [47]. The system is subjected to a 1% SLP in area-1. Firefly algorithm based-PID controller has been used for the system. Comparison of proposed control scheme with PSO techniques shows its superiority. [48] optimum load LFC of a multi-area thermal power plant-based power system using PID controller parameter regulation based on a heuristic optimization technique called seeker optimization algorithm to eliminate the power system oscillations. The result of controller of provides better damping in comparison GA and POS based PID controllers. In [49], Seeker Optimization Algorithm (SOA) based optimal PI controller is designed for LFC of two-area interconnected thermal power systems is presented. The system is simulated with 0.01p.u step load change in area-1. [50] presents Ant Colony Optimization (ACO) is used for optimal tuning of PID controller for LFC of single area with reheat thermal system. The proposed algorithm is compared with Ziegler-Nichols (ZN) tuned. Load frequency control strategy for Nigerian power system using artificial bee colony optimized PI controller is presented in [51]. A 1% load variation in area-1 is used to obtain the dynamic responses. The simulation results demonstrate that the proposed controller performs better than a conventional PI controller. Tilt integral derivative is presented as the added controller for Load Frequency Control for two area interconnected network in [52].

The change in Frequency deviation is studied when there is increase and decrease of 25 and 50% in area 1 and area 2. [38] implement a modified PID-based on Differential Evolution (DE) to control the load frequency of a two-area interconnected power system with step load increases of 10% in area 1, 10% in area 2, and simultaneously step load increases of 10% in area 1 and 20% in area 2. DE PID1 performs better than BFOA PI and DE PI. [53] presents a dynamic model of a standard mixed cycle gas turbine with two connected blades of equal area. To enhance the dynamic performance of the Combine Cycle Gas Turbine, a fuzzy rule-based control is used to create an effective controller for both sections of the interconnect system. To choose the best form of the membership function, the proposed fuzzy logic is applied to the model for both triangular membership and trapezoidal membership functions. The findings showed that the triangular membership function outperforms the trapezoidal membership function in terms of dynamic performance. The outcomes show that, especially in load perturbation conditions, the proposed ANFIS controller is significantly more efficient than the traditional and proposed fuzzy logic controller. [41, 54] An integrated multi-area system's PD-PID cascaded for AGC parameters are optimized using the BAT optimization technique. With a step load perturbation of 1%, the system dynamics are examined in Area1. When PI, PID, and PD-PID Cascade controllers are compared, the outcomes show that BA performs significantly better than GA and BF. [55], Optics Inspired Optimization (OIO) algorithm is designed to improve the stability of two-area interconnected thermal reheat power systems and two-area interconnected multi-unit hydro-thermal power systems, The outcomes of the OIO is compared with that of PSO and Bee Colony algorithms. [56] presents Firefly Algorithm (FA) optimized hybrid fuzzy PID controller with derivative Filter (PIDF) for LFC of multi area multi source system. the superiority of the FA is demonstrated by comparing the results with tuned Genetic Algorithm (GA) when load change of 0.005p.u is applied to all four-areas. [57] FA is employed to for LFC of three-area nonlinear power system. ITAE objective function was used in the system. It is observed that FA outperforms GA when the system experienced load change of 5% and 2% at area-1 and area-2 respectively. [47] presents a combined LFC and AVR of a two-area interconnected power system. Firefly Algorithm (FA) was used to optimize the PID controller which is used as the secondary controller for the system. The superiority of FA is proven compared to PSO when the system is subjected to a 1% SLP in area-1. [45] Automatic Load Frequency control of two area power systems using PID tuning through internal model control (IMC) technique is presented by [58]. The performance IMC is compared with that of conventional integral Load Frequency controllers for a two-area power system. Step load change of 0.01pu is applied to area 1. [59] Fitness Dependent Optimizer (FDO) algorithm is employed for the optimization of I-PD controller for AGC of the two-area multi-source Interconnected Power System (IPS) problem. PID (DE-PID) controller and TLBO and LUS-PID controllers were used to verify the effectiveness of the proposed FDO based PID and I-PD controllers at 1% step load perturbation in the system. [60] Enhanced Gradient-Based Optimizer (EGBO) is proposed for Load LFC problem in a two-area interconnected power system. EGBO algorithm is compared Gradient-Based Optimizer (GBO), Chimp Optimization Algorithm (ChOA), Sine Cosine Algorithm (SCA), GWO, and PSO for ITAE based objective function. [45] GA, PSO, and GWO were used to solve LFC for single-area system as well two-area system. IAE, ISE, ITAE, and ITSE performance indices were considered. GWO technique shows better performance in compared with other GA and PSO when load change of 10% is applied to the system. [61] grasshopper optimization algorithm (GOA) is used to optimize the proportional derivative filter type (PDF) with 0.85 plus Proportional Integral (0.85+PI) controller parameters for LFC in a two-area power system. ITAE was proven to perform better IAE and ISE performance indices. The proposed controller was compared with Salp swarm algorithm with PID (SSA-PID) controller and GA-PID at 1% step load perturbation. [62] GWO algorithm based fuzzy PID controller with derivative Filter (Fuzzy-PIDF) is chosen to solve the load frequency control (LFC) problem of a two-area multi-source power system with each area consisting of a reheat thermal and a hydro unit. I/PI/PIDF/Fuzzy-PIDF controllers, optimized by GWO algorithm when a step load change of 1.5% occur in area 1. GWO produced better results in terms of frequency and tie-line power deviations than PSO, BF, hBFPSO and DE. [63] Harmony search algorithm (HSA) is use to optimize the parameters of fractional order PID (FOPID) controller solve the non-convex non-linear problem of AGC for two-area power system. Cost function of Integral of Time Multiplied Square Error (ITSE) is used for the system. Load disturbance of 0.01p.u is applied to both areas.

the proposed method shows a better performance comparing with GA-PID and HAS-PID methods. Automatic Load Frequency control of two area power systems using PID tuning through internal model control (IMC) technique is presented by [64]. The controller is used to improve the dynamic response as well as to reduce or eliminate the steady-state error. It is much faster, applicable under different nonlinearities and gives better stability response as compared to the conventional integral Load Frequency controllers for a two-area power system. Step load change of 0.01pu is applied to area 1.

3 RESEARCH GAPS AND DIRECTIONS

Electrical power demand/load always varies, which may cause mismatch between power generation and the power demand. This will cause frequency deviation. From the literatures above, drawbacks of conventional controllers, intelligent controllers, soft computing-based approaches, were putting out novel LFC objective functions that can enhance power system performance, needs for new fault diagnosis techniques that work with LFC. Slow performance, poor accuracy, difficulties in implementation, Training complexity, trial and error, weak/uncertainty of convergence, Sequences of random decisions. local optimum problem, bad searching ability, complexity, areas of where disturbance occurred, values/amount of the disturbance applied are some of research gaps to be considered.

4 CONCLUSIONS

Due to the importance of frequency stability in power system, this paper presents the review of papers on load frequency control. Various system modeling techniques, both traditional and contemporary, are distinguished. Additionally, surveys of traditional control strategies and adaptive control techniques were conducted. Also discussed are contemporary control techniques based on soft computing, robust control, and optimum control theory. The paper outlines the various LFC techniques used power systems. The detail of the paper, method adopted, advantages, draw back and observations were also presented in the paper. Finally, research gaps were also presented for further research. Further research is recommended in the area of LFC of power system with multisource, microgrid, renewable sources of energy.

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