Comprehensive Analysis of Load Frequency Control in Multi-Area of Power System Networks

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Abstract -- **The most complicated control system ever devised by the humans is electric grid at present time. For Automatic Generation Control (AGC), it becomes very critical under normal condition to keep the frequency within tolerable range & respond appropriately in power system during load variation. Load frequency control (LFC) becomes very essential when there is disturbance or variation in the load to achieve better control on the load and it do not affect more on the tie-line power as well as in system frequency variation. Several control techniques or methods based upon classical, resilient and self-tuning as well as soft computing controller are analyzed.**

Keywords: Load frequency control, Classical control technique, Multi-Area, Automatic Generation Control

I. INTRODUCTION

LOAD Frequency Control (LFC) is challenging in the functioning of the power system, as it restores the variations between generation and load of the whole power system or area which are linked by a tie-line. Power of tie-line of interconnected area is to be kept at fixed level and keep the frequency of interconnected area of power system within a fixed range [1–3]. In a traditional power system, it is "vertically integrated", which includes power generation, transmission, as well as distribution and delivery of electricity directly to the consumer. To supply power to their customer, vertically integrated utility (VIU) has set a fixed rate for this. With different market companies, for generating, transmission, distribution companies, and independent system operators, started controlling the generation as well as demand of load side by maintaining the stability of the whole power system in an extremely competitive and distributed control environment. However, in an unregulated electricity system, the crucial function of LFC faces a lot of challenges. Spreading of instabilities to other control areas in a deregulated power system could result in a severe system blackout, or electrical fault because of lack of appropriate design of the controller.

The importance of LFC in the designing as well as operation of entire electric power systems. Predetermined value deviates from its nominal operating point of the power system when there is some disturbance occur in the power system. Due to this disturbance, there is variation near the operating point like, scheduled power exchange to other areas and nominal system frequency, which is unfavorable in [4]. Now it can be seen that the problem of LFC can be solved by using some of the advanced control methodologies such as Variable Structure Control (VSC) techniques, Optimum Control Method (OCM), Self-tuning Control Method (SCM) adaptive control, resilience,

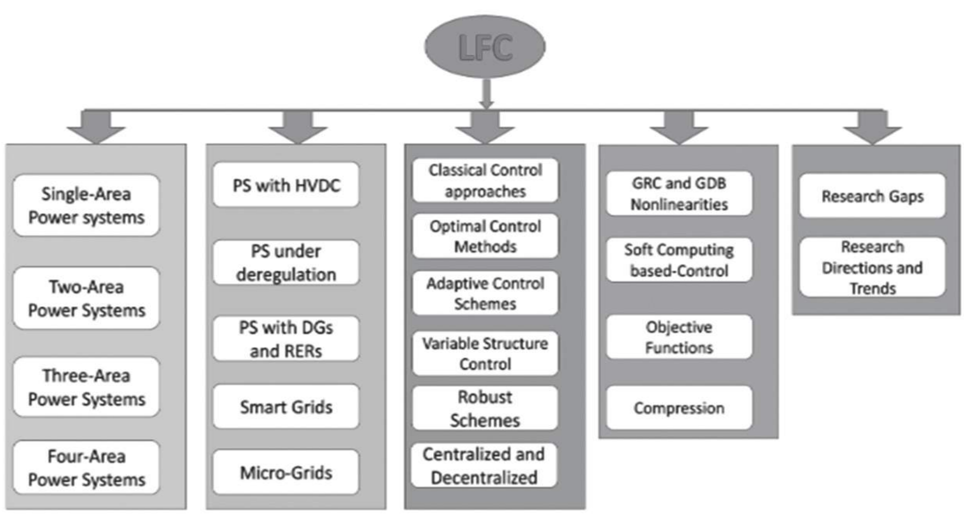

Figure 1. Pictorioal diagram of various schemes of LFC.

as well as intelligent controller technique. The difficulties faced by LFC in the traditional power system is discussed/highlighted in this paper.

Load frequency control (LFC) manages flow of power of the tie-line of different-different locations while keeping the frequency constant. By dg technology manufacturers, capacitors as well as power electronic converters have been used [5]. Due to weather condition the output of both (solar & wind turbine) vary. The renewable energy variation and demand changes can cause remarkable frequency deviation when a big volume of wind energy is implemented into a conventional power system [6-8]. As a result, a lot of work has been gone through in developing load frequency control controllers or techniques to improve the insight of solar power plant and wind power plant.

II. CLASSICAL CONTROL TECHNIQUES

Classical controller is designed to get over from the drawback of open loop control system, these controllers are in the first generation in the closed-loop system. From past years, there were many classical control mechanisms were present for LFC in power system in which gain & phase margin analysis is employed which used Nyquist & bode plot method [9-11]. The system uses a similar area control center to control frequency deviation due to load changes, but ignores the interaction between frequency and power of tie-line [12]. Decentralized PI control [13], dual-mode proportional-integral controller [14], and PI control for hydropower systems [15] they all are proposed to maintain the system frequency and power of tie-line which utilizes communication link. For correcting time inaccuracy and unintentional exchange in AGC, system-based coordinated method was described in [16-19].

To create a PI controller, for a hybrid system uses tiny signal analysis [18]. For micro source systems pi controller is described in [19]. Model predictive control techniques and PI are used [20] to gain the best closed loop performance. Author uses an integral derivative (ID) controller for LFC is discussed in [21,22]. The best multiple input–multiple output control and a unified PID tuning technique are used [23]. For LFC, a chaotic optimization strategy is utilized to calculate the settings of PID controller in a multi-area LFC [24-25].

There are some benefits as well as drawbacks such as: classical control techniques have been substantially explored, and they are currently used in various electric power systems. However, there are a many drawbacks and concerns with future power systems that must be solved.

Some of the main issues & drawbacks:

i. The challenge of optimally setting the load frequency controllers parameters requires more realistic solutions.
ii. Robustness in the face of parametric and nonparametric uncertainties must be defined properly.
iii. To tolerate sensor and actuator faults these control approaches should be developed.

So, further work is required to determine their resilience to potential cyber-attack issues.

III. DIFFERENT CONTROLLING SCHEMES FOR LFC

By detecting the changes in the frequency, the setting of speed changer modified automatically, the system transforms into a proportional along with integral controller, resulting in a steady state error of 0.

Proportional Integral Controlling Technique: By sending previous errors forward to the plant, the main advantage of PI control technique is that it makes the steady state error 0. In the case of communication delays. Developed a decentralized proportional-integral control as well as dual-mode PI controller scheme using PI control in hydropower systems. It is very popular load frequency controllers.

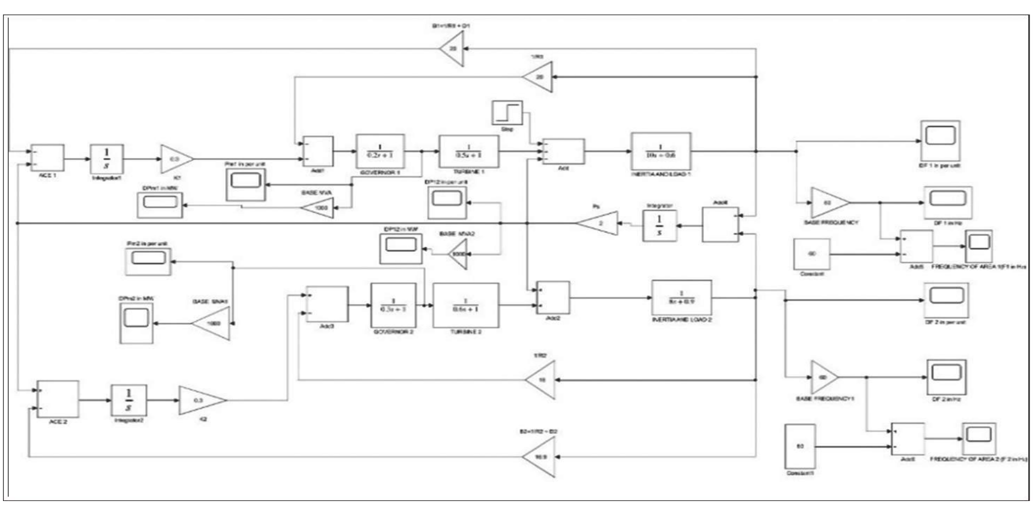

Figure 2. Two-area system model (Integrator).

Figure 2 displays LFC model of two-area system using PID controller with 195 MW change in load in AREA 1 only, hence generator of area 1 supplies the whole load demand without interfering in AREA 2. Therefore, tie line power is zero.

Figure 3 shows LFC model of two-area Simulink model system using PI controller with 195 MW change in load in area 1 only, hence generator of area 1 supplies the whole load demand without interfering in area 2. Therefore, tie line power is zero.

The goal of this study is to employ the PI controller technique to implement Automatic Generation Control (AGC). A hybrid system with a small signal analysis of using a PI controller is shown in article [32]. [33] Also addressed is a PI-based LFC for a micro source system. The use of PI control in conjunction with model predictive control to obtain the best performance of closed-loop, as well as optimization methodologies based on LFC in conjunction with PI control, are discussed in detail. In a study, researchers looked into hybrid PI control (proportional integral with fuzzy logic) and PI with artificial intelligence [34].

Proportional integral derivative method: By performing calculations and then executing a corrective action that can quickly and efficiently alter the process, a PID controller seeks to minimize the gap between the desired set point and a measured value. There are three parameters which are used in PID controller computation: proportional, integral, as well as derivative. The value of the proportional defines the response of present error, where integrated value determines the summation of recent errors, while value of derivative decides the error's rate of evolution [35].

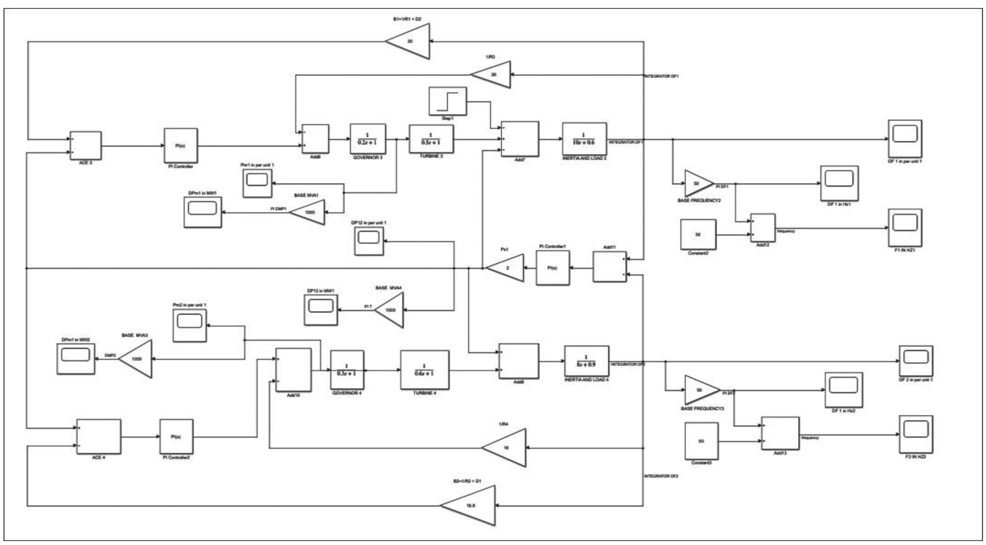

Figure 3. Two-area system model (PI controller).

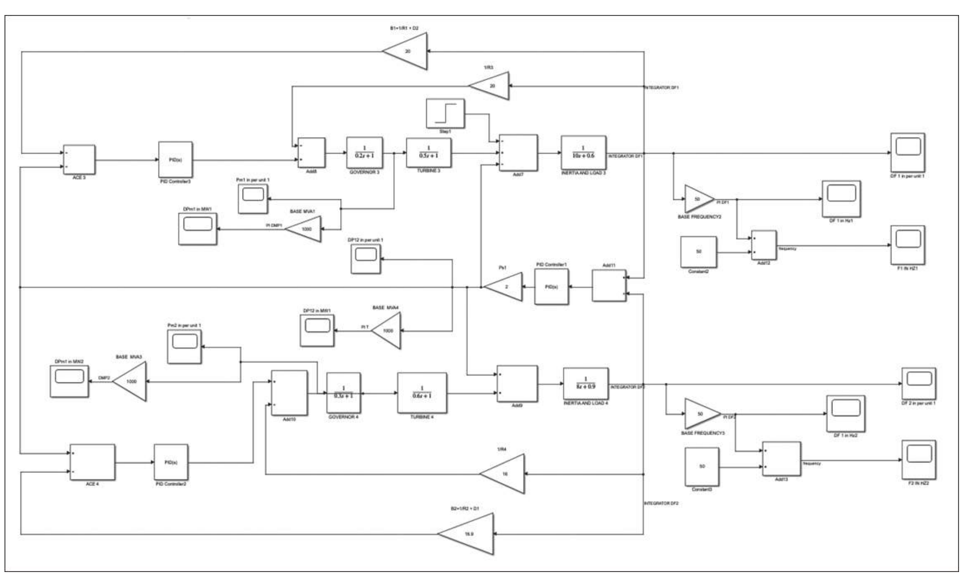

Figure 4. Two-area system model (PID controller).

Figure 4 shows LFC two-area system by inserting PID controller with 195 MW load change in area 1 only, hence generator of area 1 supplies the whole load demand without interfering in area 2. Therefore, tie line power is zero.

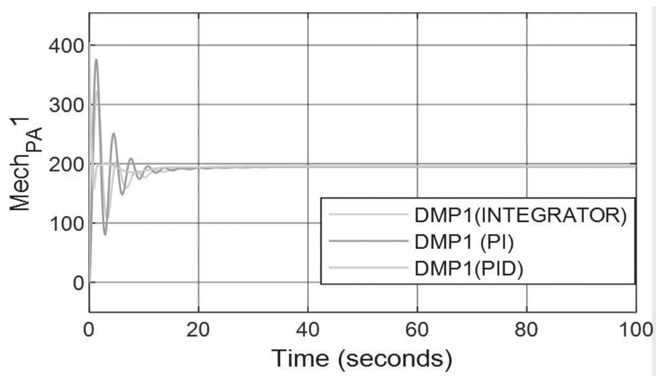

Figure 5. Supply of A_1 using different controllers.

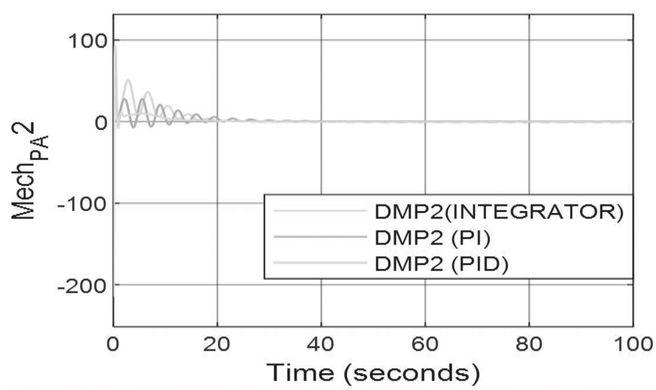

Figure 6. Supply of A_2 using different controllers.

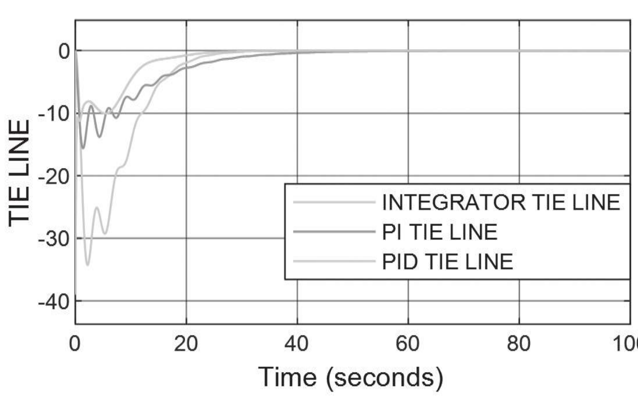

Figure 7. Power changes effects in tie-line.

Based on maximum peak resonance criteria, in LFC of two-area where both the areas are hydro systems with PID controller in it [36]. An IMC called as internal model control technique which is based on (TDF) stands for two degrees of freedom was used to improve a decentralized PID controller of load frequency control (LFC) in four region systems along with unregulated settings [37]. In a normal case, the control system action depends only on the two tuning variables when using the TDFIMC- PID approach for LFC [38] [39].

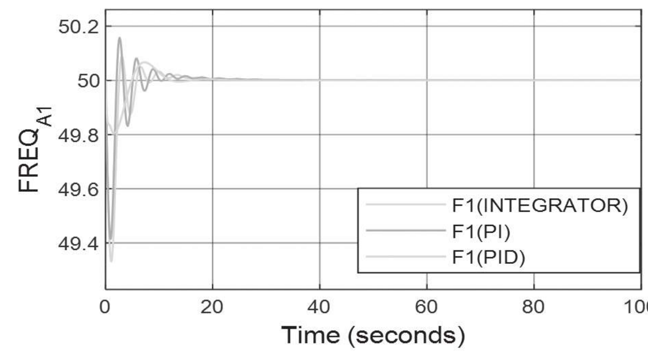

Figure 8. Frequency of A_1 using different controllers.

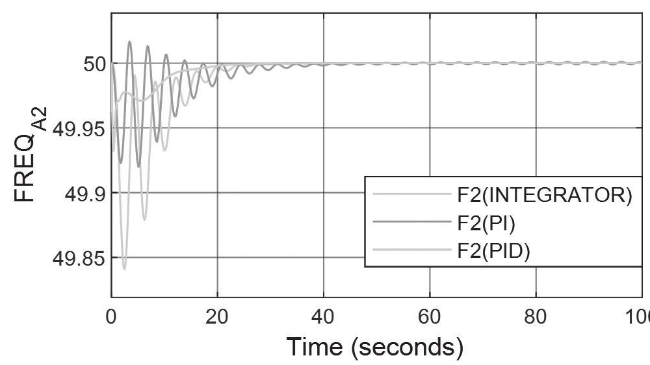

Figure 9. Frequency of A_2 using different controllers.

For the LFC in two-area system explain the importance and use of adaptive weighting particle swarm optimization method to construct a multi-objective PID controller [40]. By Using LFC along with a PID controller, for a two-area thermal power system where AGC is used which is based upon a genetic-fuzzy controller is presented. Decentralized LFC is conducted using ideal Multiple Input- Multiple Output control and LFC is investigated using a single PID tuning technique.

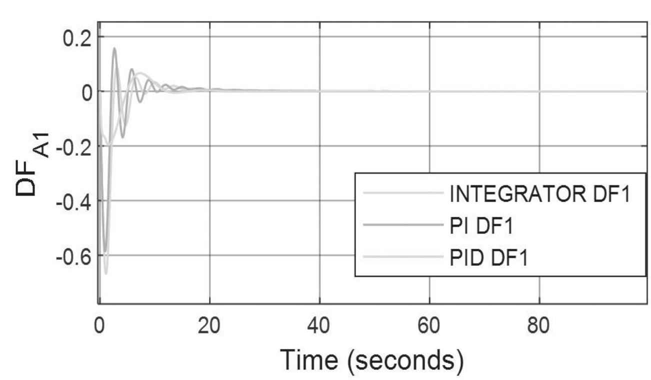

Figure 10. Freq. Dev. of A_1 using different controllers.

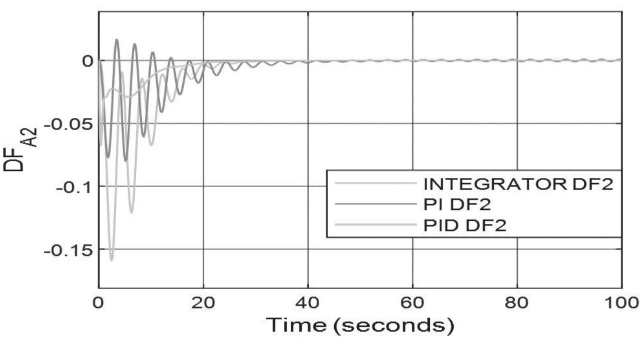

Figure. 11. Freq. dev. of A_2 using different controllers

These graphs show the different settling time and stability using different controllers. It shows PID controller is more stable than other two controllers.

Double Integral and Double Derivative Controller: Reheat power system in two areas with synchronized control action using Redox Flow Battery as well as Unified Power Flow Controller (UPFC), and a novel Proportional–Double Integral also called PI2 controller was designed & constructed using the AGC concept. The results of several classic controllers, such as Integral, Proportional plus Integral plus Derivative, Integral plus Double Derivative, and Proportional Plus Integral, are compared to Proportional Plus Integral with Double Derivative, a newly added Classical Controller in automatic generation control.

IV. VARIABLE STRUCTURE CONTROL METHOD

To improve dynamic performance, there are a few things that can be done. Variable structure controlling method is an important technique for challenge of deterministic control of uncertain systems. When parameters meet certain matching criteria, they become completely immune to system fluctuations. The controller's capacity to alter power system parameters is rendered ineffective as a result.

Hsu and Chan found the load Frequency Control issue for integrating two-areas which is based upon hydropower system along with thermal power systems by using linear optimal control theory and variable-structural control systems theory. Look at how variable structural control can be used to solve various LFC challenges in no introverted power system.

V. OPTIMAL CONTROLLING SCHEME

By using modern optimum control theory to create a load frequency controller, electrical power professionals can model an ideal load frequency controller with a defined performance. When this need to keep is applied, multivariable control issues become easier to solve. The LFC is a linear regulator that operates using optimum control theory. The author examined and designed plant reaction time using closed-loop poles.

Optimal control methods have a number of advantages, including the ability to control and regulate all of the dynamic states of the controlled systems.

VI. SOFT-COMPUTING TECHNIQUES

The soft computing technologies (SFC) offer a number of remarkable advantages such as lower solution costs, greater solution assurance, and greater practicability. They can deal with technical difficulties like as uncertainty, nonlinearity, and complexity. Soft computing-based control systems have been shown to be feasible in numerous studies, unlike previous methods. To obtain good control and dynamic performance of the system, SFC were applied to adjust the parameters of the load frequency controllers.

Control Strategies Based Upon Fuzzy Logic: Fuzzy control tries to figure out how variables are connected just like classic control theorems, which are based upon linearized mathematical models of managed systems. Author presents a newly decentralized fuzzy logic which is form of Load frequency control method of simultaneously minimizing frequency deviation of the power system and power changes of tie-line that is crucial for linked power systems to function effectively in the context of high-penetration wind power.

A new intelligent solution for wind power unit integration has been devised that combines fuzzy logic with particle swarm optimization (PSO) method to meet LFC requirements. For fuzzy logic controllers, the PSO approach is used to determine the optimal membership function variable selections. Authors proposed a fuzzy logic-based coordinated control method for levelling power variations of output in PV systems while taking power system and insolation circumstances into account. Fuzzy logic those are simple, they handle the problems of LFC of a large PV-diesel hybrid power plant that is separated from the utility grid.

Artificial Neural Network: A PID controller having fixed values for the Proportional, Integral, and Derivative terms. By adjusting the constants, the effect of the controller of transient state can be improved. This is dealt with by the ANN controller. By training an ANN controller with the set of data, the PID controller parameters may be calculated.

Artificial neural networks (ANN) are computer programs that mimic the functions of biological brains. A new design strategy is proposed that combines the benefits of ANN with synthesis controlling methods for LFC to achieve the required level of reliability. The ANN was employed to provide superior control approaches in an uncertain demanding power system. How multilayer neural networks might help nonlinear power systems explained in [25]. Researchers explored on combining control knowledge from neural networks with a traditional adaptive LFC technique to boost control [26]. The authors have developed a load frequency controller which is automatic that employs ANN to control the generator's speed while managing the output of energy frequency of the power system by utilizing water or steam flow control in [28].

Partial Swarm Optimization: It begins with a population of irregular solutions and assigns each possible solution at a random swiftness. Then "particles," or potential solutions, are "flown" into the problem area. Every bit keeps tracking of its correlated ones in the issue space, that correspond to the well-defined solution or efficiency found thus far.

Genetic Algorithm: In a survival-of-the-fittest environment with randomly ordered exchange of information, the GA is a global search optimization approach derived from natural genetics and Draw. In a range of engineering areas, including power system AGC, to solve complicated uncertain optimization issues GA have been utilized [52].

In deregulated power systems, the GA is often used to solve complex uncertain optimization issues [53-57]. One of the most important types of computer intelligence in entire power systems is the Genetic Algorithm Based Control Technique, which is described in [58]. The GA has been approved for use with PI-type controllers in a number of research scenarios. Using linear matrix inequalities, GA has been able to solve complex optimization issues (GALMI). The main difference between PID and GA is that GA uses an H2/H controller.

The use of micro-GA to optimize control parameters for a robust decentralized frequency stabilizer is described in [59]. A new architecture of decentralized load frequency controllers which linked with power systems having AC to DC parallel tie-lines which is based upon multi-objective evolutionary algorithms in [60].

Tabu Search Algorithms Based LFC: Tabu search algorithms, also known as TSA, is a repetitive search that, like a hill-climbing algorithm, begins with a reasonable initial answer and seeks to improve it. The TSA has a flexible memory that stores data from earlier search stages and uses it to build and exploit better solutions. [60] Demonstrated how heuristic symbolic Meta rules improve fuzzy rule learning by using a TSA-based technique for automatically constructing fuzzy rules in fuzzy controllers. Author proposes a new optimization methodology for a PI LFC based upon fuzzy logic using the multiple tabu search method in [60].

Bacterial Foraging Optimization Algorithm: There is another optimization approach, is Bacterial foraging optimization algorithm, is driven by ordinary or common selection, which tries to exclude organisms with terrible seeking tactics and favors those with great searching methods (BFOA). Reproduction, elimination, Chemotaxis, swarming, and dispersal are the four mechanisms that determine foraging strategy. The BF approach is used to optimize the control variables of fractional-order PID controllers, while traditional integer order-based controllers are specified for LFC in [60]. The author has used the bacterial foraging technique, to find the best controller gain settings and speed changing variables [60].

Big Bang Big Crunch Optimization Method: BBBC is a newly optimized approach proposed by Erol and Eksin based on assumptions about the appraisal of the world, particularly the Big Bang and Big Crunch theories. For Integral, Proportional Integral, & Integral-Derivative controllers *i.e.* I, PI & ID in quaternary region system, the BBBC technique is used to obtain the appropriate gain parameter. For dealing with LFC difficulties in a no interrupted power system of two-area, authors present an integrated controller which is based upon the ant colony system algorithm (ACS) [18].

VII. LINEAR MATRIX INEQUALITIES (LMI) CONTROL

In the disciplines of control engineering, linear matrix inequalities (LMIs) and its method have become important design tools for identification of the system as well as designing of structure. LMI approaches are appealing because they can be used to express a wide range of design specifications and constraints, and once the problem has been stated, precise efficient convex optimization methods may be utilized to solve it. Xiao Feng demonstrates the application of LMI in a linked power system with LFC network latency.

VIII. OTHER CONTROL TECHNIQUES

To make the LFC more durable, a new model was required to maintain the relationship between generation and dynamics of the load. Author created a PI controller which is also powerful that finds the stable zone and achieves resilient stability using the interval plant concept and Kharitonov's theorem in [64]. It produces controllers that provide stabilization and reliable performance using control theory's H-infinity techniques.

IX. RESEARCH GAPS & DIRECTIONS

Environmental issues, fossil fuel restrictions, energy system securities, and economic and operational price factors are all influencing the power system's evolution. There were many countries who had decided to enhance the proportion of non-conventional energy resources in their energy systems which include wind energy as well as solar energy.

Frequency control challenges are inherent in today's and tomorrow's power systems. In these systems, there would be an inactiveness of system as well as lack of damping. As a result, adequate control mechanisms and ancillary services such as main and secondary reserves are necessary so that such frequencies issues to be in control through online. According to literature study, the following are significant flaws in this research on the topic of LFC that need to be examined further:

Several studies are underway to determine whether demand-side involvement can supply ISO with additional services as main as well as secondary reserve, and also LFC services. As a result, practical oscillation frequency-increasing approaches are necessary. For LFC at modern power systems, researchers should strive for optimal coordination between demand-side and generation-side engagement.

X. CONCLUSION

In this paper, various methodologies and strategies for LFC for Distributed Generation systems are investigated. The various Load Frequency Control techniques were studied after a thorough literature survey. According to the findings of this literature study, problems which are related to load frequency control, there are various research opportunities in distributed generation systems. In this study, we have covered different types of methodologies that have been used by researchers in designing. Some of the methodologies employed are classical control, robust control and soft computing techniques. According to the study, it seems that soft computing technologies can better control frequency of the load. This research investigates the current state of load frequency variations in the power systems. Due to the relevance of frequency response mathematical models for various power system types, like a conventional and smart systems that are extensively explored.

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