

A Review on Load Frequency Control of Interconnected Power Systems

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ABSTRACT: Power systems are the most complex systems that have been created by men in history. To operate such systems in a stable mode, several control loops are needed. Voltage frequency plays a vital role in power systems which need to be properly controlled. In this paper, an extensive literature survey has been performed on different control strategies of Load Frequency Control (LFC). The various configurations of power system models and control techniques/ strategies that concerns to LFC issues have been addressed in conventional as well as distribution generation-based power systems. The objective of the control strategy is to generate and deliver power in an interconnected system as economically and reliably as possible while maintaining the voltage and frequency within permissible limits. This paper presents a comprehensive literature survey on the topic of LFC. In this survey, the used LFC models for diverse configurations of power systems are firstly investigated and classified for both conventional and future smart power systems. Furthermore, the proposed control strategies for LFC are studied and categorized into different control groups. The survey includes the detail discussion of single area and double area power system and different control strategy that is the control techniques of conventional power system and soft computing techniques which can be used in load frequency control system.

KEYWORDS: Interconnected system, Load frequency control (LFC), frequency deviation, controller, Techniques.

I.INTRODUCTION

Modern Power Systems, with increasing electrical power demand are becoming more and more complicated. Large interconnected power systems consists of interconnected control areas which are connected through tie lines. Maintaining power system frequency at constant value is very important for the health of the power generating equipment and the utilization equipment at the customer end. The complexity of power systems is growing due to: (i) increasing the penetration of renewable energy resources; (ii) adopting new concepts such as smart grid; and (iii) digitalization of the power systems control based on unsafe communication systems. The aforementioned reasons directly affect the power systems operation, stability, and security. One of the most important indexes of power systems is the voltage frequency. Recently, frequency control in power systems has gained a considerable attention due to its importance. Subjected to any disturbance, the nominal operating point of a

Power system changes from its pre-specified value. As a result the deviation occurs about the operating point such as nominal System frequency, scheduled power exchange to the other areas which is undesirable. Need of maintaining the system frequency become necessary

because (a) speed of AC motors directly depends on frequency, (b) turbine speed changes due to change in the frequency which causes damage to the blades, (c) when frequency becomes less than normal value (>50hz), the core flux of transformer increases and transformer goes into saturation. Load frequency control (LFC) is of importance in electric power system design and operation. The job of automatic frequency regulation is achieved by governing systems of individual turbine generators and Automatic Generation Control (AGC) or Load frequency control (LFC) system of the power system. The objective of the LFC in an interconnected power system is to maintain the frequency of each area within limits and to keep tie line power flows within some pre-specified tolerances by adjusting the MW output so f the generators so as to accommodate fluctuating load demands. A well designed and operated power system must cope with changes in the load and with system disturbances, and it should provide acceptable high level of power quality while maintaining both voltage and frequency with in tolerance limits. With increasing the penetration level of renewable resources such as wind farms and photovoltaic plants in power systems, the uncertainties of active power production is highly increased, thus determining frequency variations. Such increase in active power fluctuation, beside the demand stochasticity, the frequency of power system would be highly oscillated. Therefore, future power systems need more robust and optimal LFC approaches that can handle such problems. Many control approaches have been suggested for LFC in interconnected power systems. These approaches can be categorized into four groups: (i) classical control approaches focus on designing proportional-integral-derivative (PID) controllers for controlling the frequency

and tie-lines power flows; (ii) modern control approaches including optimal control method, sliding mode control schemes, and adaptive control systems; (iii) intelligent control schemes, such as fuzzy control systems; And (IV) soft computing-based approaches for controllers' parameter tuning which had a considerable attention from researchers in the last decade

II. LOAD FREQUENCY CONTROL

For large scale interconnected power system, load frequency control (LFC) is important to keep the system frequency and the inter-area tie-line power as close as possible to the schedule values. The frequency of a system is dependent on active power balance. In an interconnected system, with two or more independently controlled areas, the generation within each area has to be controlled so as to maintain scheduled power interchange. The control of tie-line power and frequency is commonly known as load frequency control (LFC). The objectives of the LFC are to maintain reasonably uniform frequency, to divide the load between generators, and to control the tie-line interchange schedules. main objective of Load Frequency Control (LFC) are:-

1. To maintain the real frequency and the desired power output (megawatt) in the interconnected power system.
2. To control the change in tie line power between control areas.

If there is a small change in load power in a single area power system operating at set value of frequency then it creates mismatch in power both for generation and demand. This mismatch problem is initially solved by kinetic energy extraction from the system, as a result

Declining of system frequency occurs. As the frequency gradually decreases, power consumed by the old load also decreases. In case of large power systems the equilibrium can

Be obtained by them at a single point when the newly added load is distracted by reducing the Power consumed by the old load and power related to kinetic energy removed from the system. Definitely at a cost of frequency reduction we are getting this equilibrium .The system creates some control action to maintain this equilibrium and no governor action is

Required for this. The reduction in frequency under such condition is very large.

III. SURVEY ON DIFFERENT LOAD FREQUENCY CONTROL (LFC) TOPOLOGIES AND STRUCTURES

An electric power system is a network of electrical components used to supply, transfer and use electric power. An example of an electric power system is the network that supplies a region's homes and industry with power—for sizable regions, this power system is known as the grid and can be broadly divided into the generators that supply the power, the transmission system that carries the power from the generating centres to the load centres and the distribution system that feeds the power to nearby homes and industries. Smaller power systems are also found in industry, hospitals, commercial buildings and homes. The conventional power system that has been in use since centuries from the generation and transmission level to the distribution was mainly dominated by hydro, thermal and nuclear. Any power system that has the fundamental control problem of matching real power generation to load including losses is called load–frequency control. Most of the works reported so far has been carried out by considering various linearized model of thermal/ hydro of single area or multi-area power systems. The frequency is dependent upon the active power which comes from the load generation mismatch. Our survey paper is comprises of different several structure of the conventional power system such as single area and multi-area, the structure with HVDC link. And the deregulation environment is discussed separately for easier understanding in the LFC issues.

(A) *Single-Area Power Systems*

Several single-area power system models incorporating LFC control schemes are investigated in the literature .single-area power systems consisting of thermal power plants are marked out. A mathematical dynamic model of frequency response for single-area power systems is discussed in [8]. Single-area frequency response models for power Systems with multi energy sources such as hydro, gas and thermal sources are presented in [2]. In [4], a frequency response model of electric power systems consisting of hydro power plants is well-described. The LFC problem for single area hydropower system is presented in [7–9]. The transient speed response of a single, isolated, governed hydro-generator operating at ,or near full load is discussed in [7]. The automatic generation control of hydro- plant is presented in [8]. The LFC of an isolated small-hydropower system with reduced dump load is described in [9].

(B) Two area power systems

The LFC problem for two area power systems is presented in [1]. Due to non-linearity in the connected load and governor dead bands, the actual system response characteristic is non-linear. Therefore, a linearity-line bias characteristic does not match the actual system response characteristic. Overview of LFC and AGC systems in two-area power systems is presented in [4]. Tie-lines models and their effects on LFC of two-area power systems are studied in [2]. The LFC models for two-area power systems considering the effects of voltage control loops in the frequency response are developed in [3]. In [2], frequency response models for two-area power systems considering governor dead-band (GDB) and the generation rate constraints (GRC) nonlinearities are suggested. Discussion on the reduction of the frequency response model order to reduce its complexity is presented in [1]. The LFC models of multi-source two-area power system considering nonlinearities are marked out in [3]. LFC models for two-area power systems considering

Super conducting magnetic energy storage (SMES) system are proposed in [7]. In [8], a frequency control model for two-area power systems considering the contribution of batteries and SMES is described.

(C) Three-Area Power Systems

The LFC challenges in three area power systems are presented in [2]. The three area interconnected [4] consists one steam plus one hydro unit, which forms area1, while one steam plus one hydro unit of area 2 and area 3 with one steam. Studies on LFC modelling for three-area interconnected power systems are presented in [6]. A LFC model for three-area interconnected power system in which steam-hydro power plants are considered in the first and second areas while the third area has a steam power plant only is given in [5]. The LFC for three-area hydro power systems is marked out in [9]. Load frequency controllers are designed for a hydro-thermal power system divided into three-areas [7]. The LFC for multi-source power systems in which thermal, gas, and hydro energy sources are considered is proposed in [6].

(D) Four area power systems

The LFC problem for four area power systems is presented in [1]. Two types of interconnected longitudinal 4-area systems are considered in [3]. In the first model, all the areas consist of non-reheated system plant while in second type of model; each area has the different types of plants, i.e. steam with GRC and hydro plants without GRC. The different kinds of generating units (non-reheat, reheat and hydro-turbine type), linked together in an interconnection and also considering GRC and governor dead-band non-linearity's is presented in [4]. Four thermal power-areas are connected together by different connection structures, such as longitudinal and ring connections are considered in [7], in which each area consisting of three thermal units and one hydro unit, is proposed in [8]. LFC for three-area consisting of reheat thermal units connected by a tie-line to another hydro control area is presented in [5].

IV. CONTROL TECHNIQUES FOR LOAD FREQUENCY CONTROL

A lot of control techniques are proposed by the researches in their pioneer work to design LFC controllers. The controllers are based on:

A) Classical Control Strategies

In this context, the supplementary control is introduced to the governor via signal directly proportional to the frequency deviation plus its integral action. Conventional control approaches are based on classical controllers usually applied to the governor to minimize the area control error (ACE) in power systems to enhance the frequency response. In the past, several classical control methods have been proposed for LFC in power systems [6]. Gain and phase margin analysis are used in classical control procedure using Nyquist and Bode techniques [5]. Adaptive control is a control methodology of controller to adapt with parameter variations. Adaptive control strategy is found to be very effective in improving the stability and transient response of the system. There is a difference between robust control and adaptive control technique. Robust control technique guarantees that control laws for parameter variations can't change for a given boundary. While adaptive control law will be change with changing conditions. Ross proposed an error adaptive computer control (EACC) technique which gave new and different degrees of freedom for automatic control. A number of classical control techniques namely, Nyquist, Bode reveal that closed loop transient response will result into relatively large overshoots and transient frequency deviation.

Advantages and Drawbacks:

The classical control approaches are well-investigated for LFC in power systems and in reality, there are several electric power systems using these approaches for LFC. However, there are several drawbacks and problems that need to be handled for future power systems. The main problems and drawbacks are as follows:

- The problem of optimally tuning the parameters of load frequency controllers needs more realistic methods.
- The robustness against parametric and nonparametric uncertainties need to be clearly-solved.
- These control approach should be developed to have tolerance against sensor and actuator faults.
- They need more investigation for their robustness against possible cyber-attack issues.

B) Optimal Control Strategies

The LFC regulator design techniques using modern optimal control theory enable the power engineers to design an optimal control system with respect to given performance criterion. The optimal control theory has made a new direction to solve the large multi variable control problems in a simplified form. The control scheme considers the state variable representation of the model and an objective function to be minimized. The optimal control methods have provided solutions for multi-variable control systems. These kind of methods consider state variable model and the minimization of an objective function. Hence, optimal control methods are feasible if all state variables are available to design the feedback control signals. If the system state vector is observable with some measurements of the control-area, this requirement can be met. These requirements make optimal control method complicated and undesirable for large-scale power system.

Advantages and Drawbacks: Optimal control methods have several advantages such as Optimally controlling the systems and regulating all the dynamic states of the controlled systems. These methods can play an important role in the future power systems if some drawbacks, given below, are well-addressed.

- The dynamic states of the power system need to be observed in real time.
- Cyber-attacks issues need to be considered in the designed dynamic estimators.
- The parametric uncertainties in the designed observers need to be considered
- Dynamic observers that can eliminate the unknown input effects need to be developed.

C) Adaptive and Self-Tuning Approaches

As the operating point of the system gets changed, the controller performance in the system may not be optimal. As a matter of fact to keep the system performance near the optimal value, it is desirable to track the operating point of the system and accordingly update its parameter to achieve a better control scheme. The self-tuning control (STC) approach also includes an integral part of the adaptive control scheme. The self-tuning regulator strategy implemented for adaptive LFC seems a viable solution. The performance of frequency controller may not be optimal if the operation point of the system changes. Hence, it would be preferable to update the parameters based on the operating point for achieving a better control performance. Generally, adaptive control schemes can be classified into self-tuning control (STC) schemes and model reference control schemes. A self-tuning approach is presented in [4] to improve the performance of AGC as a stabilizer for main AGC loop and SMES. A self-tuning controller to minimize a multi variable optimization function including cost function and constraints on control effort is discussed in [3]. A new adaptive LFC considering uncertainties of parameters is proposed in [1] with a combination of robust control, the Riccati equation and adaptive control. Investigation of load frequency control for a two-area hydro-thermal system by using Adaptive Neuro-Fuzzy Interference System (ANFIS) is presented in [2]. An adaptive fuzzy gain scheduling scheme for proportional integral and optimal LFC is described in [9].

Advantages and Drawbacks: Despite the remarkable advantages of these control schemes, adaptive controllers are complicated, need a perfect model following condition, and on-line model or explicit parameters identification. Therefore, these methods are sometimes unrealistic and difficult for implementation.

D) Proportional, Derivative, Integral Controlling Techniques:

Among various types of load frequency controller, the PI controller is most widely used to speed-governing system for LFC scheme. An advantage of the PI control technique is to reduce the steady-state error to zero by feeding the errors in the past forward to the plant. The most of proposed techniques were based on the classical proportional and integral

(PI) or proportional, integral and derivative (PID) controllers. Its use is not only for their simplicities, but also due to its success in a large number of industrial applications. For PID controller design, overshoot/undershoot and settling time are used as objective function for multi-objective optimization in LFC problem. One of the developments in the field of modern control theory is in the direction of its application in optimal control allows the power engineers to cope with the problems arising out of due to the complex structure of power systems. The development of design techniques for load frequency control of a power system in the last few years is very significant. AGC regulator designs are based on adaptive control schemes. The AGC regulator design techniques using modern control system theory enable the power engineers to design the optimal control system with respect to given performance criteria. Most of the researchers have taken the dynamic system equations for the development of adaptive controller, to cope up the change in process parameters and modelled process dynamics. Many researchers have carried out research work on adaptive automatic generation control scheme which has been reported in the literature. The main 15 contribution of the proposed controller is to enhance the controlled performance of the conventional PID controller by adding a self-tuning on the existing conventional PID controller. The conventional PID controller with online self-tuning pre compensation shows Superior performance than conventional PID controller.

E) Soft Computing Techniques In LFC

In last decade, evolutionary computing based-control system design has gained considerable attention from researchers around the world due to its advantages. Low solution costs, guarantee of a solution, and its practicability are the well-known advantages of soft computing methods. They can handle technical issues such as uncertainties, nonlinearities, and complexity. To this problem, the intelligent control scheme with use of soft computing techniques such as artificial neural network (ANN), fuzzy logic, genetic algorithm (GA), and particle swarm optimization (PSO) algorithms, etc. has been explored. Among the various AI based techniques, fuzzy logic approach is observed to be applicable and attractive for dealing with complex and ill-defined problems which may be impossible or too expensive with conventional methods.

V. CONCLUSION

The techniques and strategies of LFC for conventional and DG systems attracted much discussion in the recent past. An effort has been made to present critical and comprehensive review on this subject. In this paper, a state of the art on load frequency control in power systems is presented. Due to their importance, frequency response mathematical models of different power system types such as conventional and smart systems are completely reviewed. In addition, different types of smart system models such as modern power systems with high penetration of renewable energy resources distributed generation, micro-grids, and smart grids are marked out. Furthermore, classical control approaches and adaptive control methods are fully surveyed. From survey of literature regarding Automatic Generation Control and Load Frequency Control, it has been observed that appreciable efforts have been made in the area of smart load frequency control of multi area system to optimize the controller gain. Several classical as well as modern optimization techniques viz. Genetic Algorithm (GA), Fuzzy Logic, Artificial Neural Network (ANN), Particle Swarm Optimizations had been used for the designing of supplementary controller.

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