International Journal of Trend in Scientific Research and Development (IJTSRD)
International Open Access Journal
ISSN No: 2456 - 6470 | www.ijtsrd.com | Volume - 2 | Issue – 3

Load frequency control issues in multiarea power system: A Review

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ABSTRACT

The modern electric grid is one the most complex man-made control systems. Automatic generation control plays an important role in power system operation to maintain the frequency within an acceptable range and to properly respond to load changes under normal conditions. Many publications have been made in the area of Load frequency control (LFC) of interconnected power systems. Load frequency control is necessary to develop better control in order to achieve less effect on the frequency and tie line power deviations after a load perturbation. However, number of control strategies has been employed in the design of load frequency controllers in order to achieve a better dynamic response and the exact choice of the LFC controller in a particular case requires sufficient expertise because each controller has its own merits and demerits. Due to this, an appropriate review of load frequency control (LFC) mechanism is essential and a few attempts have been made in this concern. This paper presents a detailed survey on load frequency control (LFC) mechanism. In this paper detailed analysis of various control methodologies based on classical control, robust and self-tuning control and various soft computing control techniques are discussed. Finally, the investigations on incorporating fast acting energy storage devices such as Battery energy storage system (BESS), superconducting magnetic energy storage (SMES), Redox flow batteries (RFB) and Flexible AC transmission systems (FACTS) devices for mitigating the LFC problems in a deregulated power system are also addressed.

Keywords: *Load frequency control, Classical control, Optimal Control, Adaptive control, Energy storage systems*

I. INTRODUCTION

The load frequency control is one of the major control problems in an interconnected power system operation [1,2]. In an interconnected power system, LFC has two important objectives; maintain the frequency of each area within specified limit and controlling the inter area tie-lines power exchanges within the scheduled values [1–3]. LFC is becoming more significant in recent times due to the size and complexity of entire power system network.

In a conventional power system, the power generation, transmission, distributions are owned by a single entity called vertically integrated utility (VIU). VIU supplies power to their consumers at a specified rate. After restructuring, the role of VIU is carried out by different market players like generating companies (GENCOs), transmission companies (TRANSCOs), and distribution companies (DISCOs) and independent system operators (ISO). These market players control the generation and load demand by keeping the entire power system stable under highly competitive and distributed control environment. However, the critical function of LFC is still an ongoing challenge in the deregulated power system. Due to lack of proper controller design in a deregulated power system, the instability may spread to other control areas and may lead to a severe system black out. To overcome these situations, a lot of studies are conducted about various LFC issues in a deregulated power system. Major research works on advanced control methodologies like optimal control, suboptimal control, adaptive control, self-tuning control, robust control, variable structure control and intelligent control techniques for mitigating the LFC issues in a deregulated power system are focused. In addition with this, various soft computing techniques like artificial neural network (ANN), fuzzy logic, genetic algorithm (GA), ANFIS controller, bacterial foraging algorithm (BFA), firefly algorithm etc is being focused. Thus, the objective of this paper is to present an overall state of the art comprehensive survey, recent up to date technical core issues on load frequency controller and its different control aspects methodologies for the interconnected power system. The flow chart of the survey carried out for LFC depending on area and controller is shown in Fig. 1.

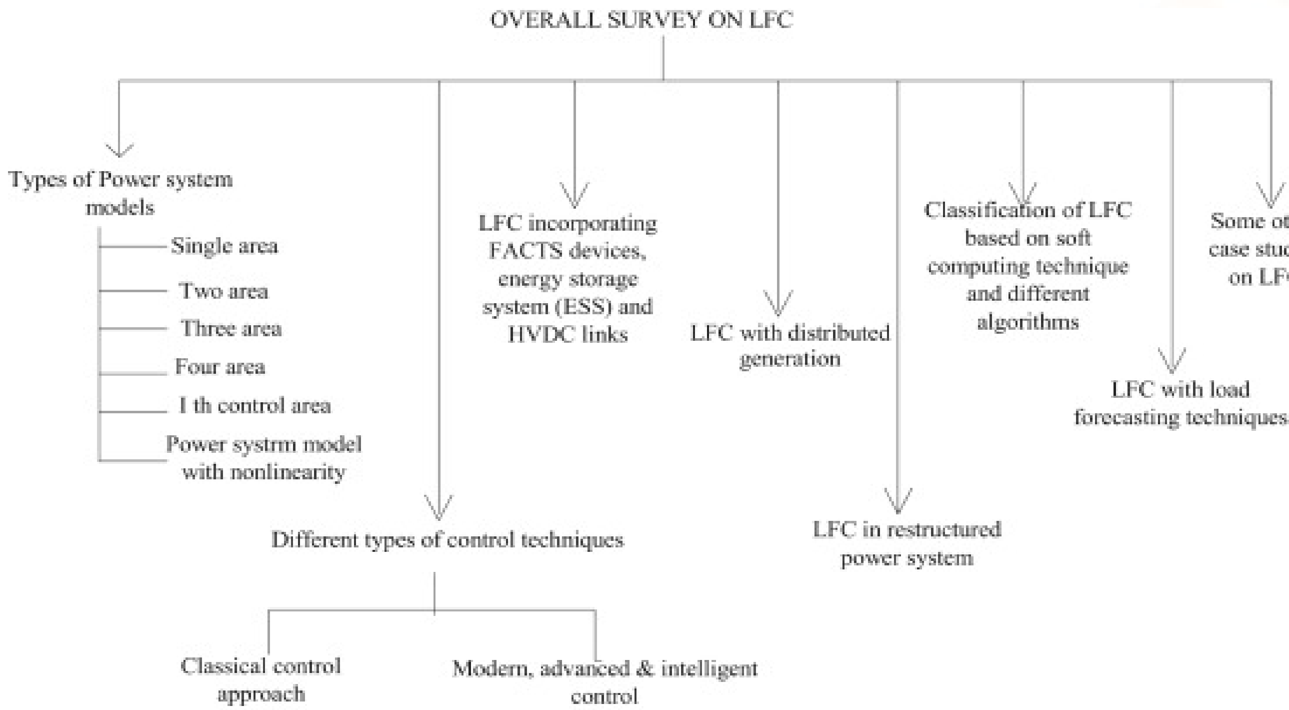

Fig. 1. : Flow Chart of Survey on LFC Review.

According to this above mentioned chart we find that the first section provides the elementary sketch of different types of power system models according to the suitability of the control area as well as nonlinearities for single area, two-area, three-area etc., of the interconnected power system. In the next section, the classification of LFC based on various control techniques are discussed which cover conventional and modern control mechanism for the power system. Ahead of this section, it deals with the classification of LFC methodology according to the application of different FACTS devices, Energy Storage Systems (ESS) and HVDC links.

II. DIFFERENT TYPES OF POWER SYSTEM MODEL

As we earlier discussed in the introduction that 1st classification as per the Fig. 1 provides different types of power system. In the current scenario power system is classified as conventional power system. Conventional power systems are that which has been in operation since many centuries and basically comprise of thermal, hydro, and nuclear generating units. However, gradually reduction in fossil fuel and significant environmental issues the non-conventional sources of energy give its active participation to the conventional system as the form of distributed generation based power system. Herewith we explore major models of power system as follows:

1. Deregulated Power With Conventional Energy Sources In a conventional type power system, the major power producers are conventional sources like hydro, thermal, diesel, natural gas, nuclear power etc. The primary function of an electric-power system is to match the real and reactive power generation to the load including losses. The problem of controlling the real power output of each generating units with respect to the system frequency deviation and tie-line power exchange within prescribed limits, is termed as Automatic Generation Control (AGC) or Load Frequency Control (LFC). The problem of controlling the reactive power balance in the system is often referred to as Excitation Control. The first attempt to control the frequency was via the flywheel governor of the synchronous machine and was found to be insufficient. Then a supplementary control was added to the governor by means of a signal directly proportional to the frequency deviation plus it's integral. This proportional plus

integral control scheme constitutes the classical approach to the automatic generation control of power systems. In order to bring back the frequency and tie-power to their respective scheduled values, most of the utilities prefer to use integral, proportional-integral, proportional-integral-derivative (PID) controllers in their system.

2. Two area power system

Several studies are reported about the various LFC issues of a two area power system in [2–17]. Kothari et al. [2] explained the realistic automatic generation control (AGC) model for a two area reheat thermal system under open market environment. LFC of a two area deregulated multi-unit power system with each area having non-reheat thermal units and reheat thermal units. LFC for a deregulated power system with hydro, reheat thermal and gas generating units type GENCO are explained in [11]. LFC for a two area deregulated power system having thermal reheaters and hydro units with GRC and without GRC are explained in [14]. LFC scheme for a two area hydro-thermal system consists of mechanical and electric governor with GRC are explained in [14]. Two area deregulated system with thermal reheat turbine and gas turbine coming under LFC applications is described in [17]. Short time energy storage devices coming under two area deregulated power system is described in [16]. Two area reheated steam turbine with GRC and governor dead band (GDB) nonlinearity are considered for realistic LFC response is described in [14]. A control scheme for generators taking part in load-following in a two area system to share the uncontracted power demanded is explained in [15]. LFC for a two area deregulated power system with the nuclear power source is explained in [15].

3. Three area and four area deregulated power system

The LFC problems for a three area deregulated power system is explained in [16]. LFC of a three area power system having thermal reheat type GENCOs is explained in [16]. LFC for a three area hydro-thermal deregulated power system with HVDC link are explained in [19,34]. LFC for a three area deregulated power system with hybrid turbines are explained in [18]. In this, a combination of Thermal-Thermal-Diesel, Thermal-Diesel-Hydro, Thermal-Thermal-Hydro with thermal units having reheat facility is analyzed. A conventional and sliding mode control (SMC) method for mitigating the LFC issues in a three area system is explained in [21]. LFC for a three area hydro-thermal power system with and without Generator rate constraint (GRC) under three different contract scenarios are described in [19,21]. LFC challenges in a deregulated power system having three unequal areas consist of reheat turbines in thermal areas and electric governor in the hydro area are explained in [17]. A combination of conventional and renewable GENCOs in a three area system is presented in [17].

4. Deregulated power system incorporate with HVDC link

To transfer bulk amount of power for a very long distance, the DC link connected in parallel with HV AC link are widely used because of its performance, economic and environmental advantages over other alternatives. The two and three area power systems with AC and DC tie-lines between power sectors are described in [32]. LFC for three area deregulated power system having AC tie-line parallel with HVDC link is used as a system interconnection between all the control areas are explained in [19]. Chandrashekar et al. [32] explained the dynamic LFC analysis for a two area deregulated power systems with HVDC link in parallel with AC tie line. The two area power systems interconnected via parallel AC/DC transmission links are described in [30]. Kumar et al. [32] present the design of sliding mode observer based controller (Local Load Frequency Controller) in a multi-area power system in coordination with HVDC link. The load frequency control of three area power system contains one hydro and one thermal system in each area and all these three areas are interconnected with of HVDC link is described in [34]. LFC for a multi-area multi-source hydro-thermal power system interconnected via AC/DC parallel links under deregulated environment is discussed in [31]. Ramp following controller (RFC) applications in a deregulated power system containing HVDC interconnections are explained in [26]. Two area power system having renewable energy sources, incorporating with HVDC link are presented for LFC in [30].

III. CLASSIFICATION OF LFC BASED ON DIFFERENT CONTROL TECHNIQUES

As per the frication in flow chart this section deals with classification of LFC based on different control technique. From the commencement of LFC many controllers are designed and implemented successfully and with the passage of time the control techniques are improved and some new hybrid methods are reflected. A complete study on the research works those have already done on LFC till date are categorised and highlighted below.

Classical control techniques

Classical controllers are the first stage closed loop controllers designed for overcome the limitations of open loop control system. In this survey some common used controller are discussed below which are used in LFC and LFC with integral controller is presented and discussed that automatic generation control of a hydrothermal system in continuous-discrete mode using integral (I) and PID controller is investigated [169].

1. Proportional integral (PI) control and dual mode PI controller

A dual mode PI controller and decentralized proportional-integral (PI) control design for load frequency regulation with communication delays is presented by Vrdoljak et al. who discussed PI control in hydropower system. It is one of the most widely used controllers in LFC. This paper presents LFC based on PI control technique and the Automatic Generation Control (AGC) with PI controller and dual mode PI control technique is discussed. In paper [13] PI controller based small signal analysis of a hybrid system is given. LFC of a PI based micro source system is also described [14]. Optimization technique based LFC in accordance with PI control technique is discussed and PI control with a model predictive control is used in order to achieve best-closed loop performance. In paper [18] hybrid PI control (PI with fuzzy) is discussed and PI with artificial intelligent technique is presented.

2. Integral derivative (ID) control

A five-area system for LFC with ID control, other classical control and a comparison with integral-double derivative control is given. A Modified Integral Derivative (MID) controller is proposed for LFC in deregulated environment.

3. Proportional integral derivative (PID) control

LFC with PID controller is presents a genetic-fuzzy controller for AGC of a two area thermal system. LFC with a unified PID tuning method is discussed and decentralize LFC using optimal Multiple Input-Multiple Output (MISO PID) control is implemented.

4. Double Integral and Double derivative control

The concept of AGC in two-area reheat power system having coordinated control action with Redox Flow Battery (RFB) and Unified Power Flow Controller (UPFC) and in addition to that, a new Proportional–Double Integral (PI2) controller is designed and implemented. This Paper presents Performances of several Classical controllers like Integral (I), Proportional plus Integral (PI), Proportional plus Integral plus Derivative (PID), Integral plus Double Derivative (IDD) are compared with newly introduced Classical Controller in AGC named as Proportional plus Integral plus Double Derivative (PIDD) controller.

5. Variable structure control technique

In order to improve the dynamic performance Variable structure control (VSC) is a well-known solution to the problem for the deterministic control of uncertain systems. Since, it is with the completely insensitive to the system variations, when parameters satisfy certain matching conditions. This makes the controller senseless to power system parameter change.

6. Artificial neural network (ANN) control

Artificial neural networks are computational tools based on the properties of biological neural systems. Artificial neural network (ANN) applied to LFC presents in [20]. In a hybrid power system ANN is used as one of the two-loop controller for maximum power point tracking. A robust and adaptive Temporal Difference learning based MLP (TDMLP) neural network for power system LFC is presented. A newly developed design strategy, which combines advantage of the ANN and μ-synthesis control techniques for LFC, is discussed to achieve the desired level of robust performance.

7. Fuzzy control

A fuzzy control mechanism, which is a mathematical system that decomposes the analog input values in terms of logical variables. It takes uninterrupted values ranging from 0 to 1, in contradiction to classical or digital logic, which works on distinct values of either 1 or 0 i.e. true or false. Automatic generation control with fuzzy control presented. The fuzzy controller performances such as design, implementation and operation as part of the Automatic Generation Control (AGC) system are discussed.

3.3.1. Fuzzy with PI and PID control approach
This section carries research papers regarding fuzzy logic based controllers are surveyed and coordination of PI, PID, and artificial neural techniques with fuzzy related papers are discussed below [24]. A synthetic PI fuzzy with sliding mode technique for multi area interconnected power system is proposed [28].

8. Optimal control
This control scheme contemplate the model represented in state variable form and minimization of the objective of function. Fosha and Elgerd developed a new feedback control law including the idea of state variable model and regulator problem of optimal control theory for two-area interconnected power system . The Use of modern optimal control theory in design of load frequency controller empower the electrical power researchers to model an optimal controller with prescribed performance. This performance criterion helps in solving multivariable control problems with a simplified manner LFC based on optimal control theory, which is linear regulator designed. The author, has investigated and designed plant response time due to closed loop poles.

IV. CENTRALIZE AND DECENTRALIZE CONTROL APPROACH
The power systems in the beginning used centralize control strategy to deal with LFC issues. In centralize control scheme is a global controller operators on the whole system which needs the knowledge about all the states of the power system. Centralize control technique is a control strategy which based on classes of disturbances of the system design of centralized and decentralized robust output feedback controllers, which works on mixed H∞/H2 control theory with pole-placement technique, is investigated.

In case of large wide area power system decentralize control scheme is preferable over centralize control, as it make the control more feasible and simple by reducing the computational burden and communication complexity between different systems. The basic aim of decentralize controller is to frame the complex system in to a number of sub systems, and every sub system has its own controller.. Geromel and Peres proposed a numerical procedure to obtain the load-frequency control of an interrelated power system. To minimize the corresponding implementation cost, the control law is confined to have two separate special structures: decentralized feedback and output feedback control. The process is based on a new property of the classical Riccati equation, which is analyzed in two different aspects: closed-loop asymptotic stability and sub optimality degree. In a PI based decentralize control is presented for multi area interconnected power system.

1. Sliding mode control
Sliding mode control (SMC) is another nonlinear control technique that alters the dynamics of a system by employing a discontinuous control signal that pressurizes the system to slide along a cross-section of the system's regular behavior. Use of SMC with different control approaches makes the system robust.

2. Linear matrix inequalities (LMI) control
For system identification and structural design, Linear Matrix Inequalities (LMIs) and LMI techniques have emerged as a powerful design tools in the control engineering areas. Some important factors, which make LMI techniques attractive i.e. a variety of design specifications and limitations, can be expressed as LMIs, once the problem is formulated then precisely efficient convex optimization algorithms can solve it. Xiaofeng presents an application of LMI in the area of LFC of interconnected power system with communication time delays. An iterative LMI technique based on decentralize control approach is described along with some other robust control based on LMI is discussed and a robust LFC with LMI and genetic algorithm.

3. Other control techniques
The earlier stage load frequency controllers are particularly relied on simple classical tuned controllers, which having uncoordinated parameter settings. Therefore, these are not able to provide better dynamic performances over a large range of operating conditions and various load perturbation. Due to this a novel model required to maintain between generation and load dynamics to make the LFC robust. To Design a powerful PI controller, which is based on the concept of interval plants and Kharitonov's theorem to determine the stability region to get robust stability, is presented in [33]. It develops H-infinity methods in control theory to synthesize controllers obtaining stabilization with assured performance. For using H∞ control methods, first a designer have to make a mathematical optimization form of the control problem and only then gets the controller, which solves this optimization problem.

CONCLUSIONS

hus, this paper explores the different aspects of LFC, its methodologies as well as its interconnected implementation in power system. Various control aspects and strategies have been elaborated and highlighted in a very precise manner. This survey find out the different ideas and recent up to date of control technology for LFC of the interconnected power system and talks about the contemporary status of LFC in related areas. This paper also discussed the recent development of LFC methodology for distributed generation, hybrid generation scheme, use of FACTS and energy storing device, optimization technique, load forecasting scheme, micro grid, smart grid, deregulation power system and some practical implementation. It does not deal only with methodology but also with control aspects, which are explored in a chronological order. Therefore, through the tables with the use of comparisons the superiority of the different proposed load frequency controller of the relevant research work is investigated.

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