Application of Soft Computing Techniques to Automatic Load Frequency Control Problem: A Literature Review

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***Abstract*:**

This paper attempts to show the review on soft computing techniques to the problem of Automatic Load Frequency Control (ALFC) in conventional power systems. The review emphasises the basic meaning of Automatic Load Frequency Control, it's working mechanism and the type of research being done in this area. The review also focuses on the opportunities and gaps in Automatic Load Frequency Control problem. To understand the entire review it has been characterized into three parts. The survey in the first part has done based on the type of controllers used in the literature, in the second part it as done on the need of computational intelligence and the types of optimization techniques and in the last part it has made on nature of power system. The system models considered are single area, two area and multi area systems, and also explains application of external devices such as Flexible Alternating Current Transmission (FACT) devices and Energy Storage Devices consists of Redox Flow Battery (RFB) and Superconducting Magnetic Energy Storage (SMES). Addition to this present paper also reviews the different physical constraints like Governor Dead Band (GDB), Time Delay (TD), Boiler Dynamics and Generation Rate Constraint (GRC) present in the power system.

***Keywords*:** Automatic Load Frequency Control (ALFC); Boiler dynamics; Differential Evolution (DE); Pattern Search (PS); Governor Dead Band (GDB); Generation Rate Constraint (GRC); Flexible Alternating Current Transmission (FACT); Redox Flow Battery (RFB).

1. Introduction

Radial expansion in dimension and complication in modern electric power system network besides hundreds of small and large interconnected generating units supply to the different loads which are connected to each other. The power is switched to the utilities over tie-line. It increases the power demand across the huge graphical area through highly meshed transmission lines and distribution networks. This obligates the application of intelligent systems which join the acquaintance methods from different sources power system real time control. A typical power system has found its normal state (i.e. the state frequency and bus voltages are maintained at prescribed values and these constant frequency and voltage consequences continue the balance between the real and reactive power sources supply to their respective demands by the connected loads) for more than 99 percent of its commissioning time.

Major problematic areas which are concerned to preserve the power system in its normal operating condition are:

i) Mega Watt – Frequency interaction
ii) Mega VAR - Voltage interaction
iii) Power Flow Problem
iv) Optimum Dispatch Problem and
v) The Control Problem

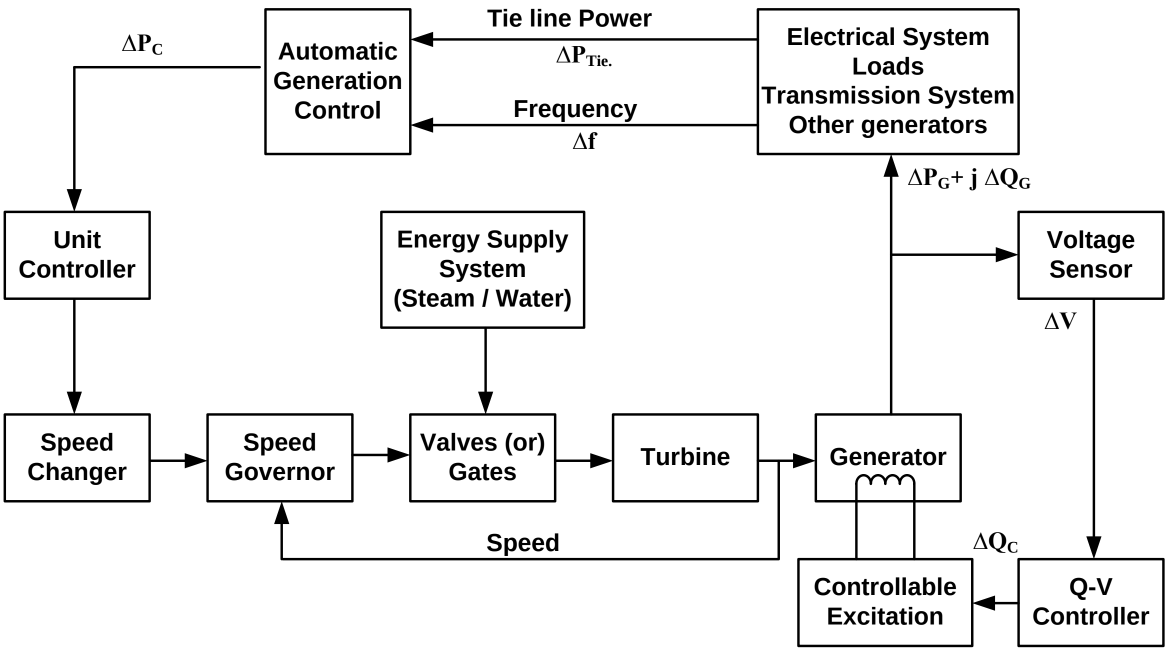

Fig. 1 The basic block diagram of power system control

Block diagram shown in figure 1 presents an overview of the power system control. In addition, it illustrates control of the active and the reactive powers technically called Automatic Load Frequency Control and Automatic Voltage Control respectively. In general the complete system normally operates at a constant frequency. Due to the following reasons the power system frequency should be maintained within the permissible limits:

2. Load Frequency Mechanism and Literature Review

System frequency in a comprehensive power system network is strictly associated with the real power balance. All the power generating units run synchronously and generate the power together under normal operating condition that each instant is being pinched by all the connected loads plus the real power loss in transmission. As the electrical energy being transmitted at almost the velocity of light and it cannot be stored in the system in the electric form, therefore, it has to be remembered that the electrical energy production rate must be equal to the consumption rate at each and every moment.

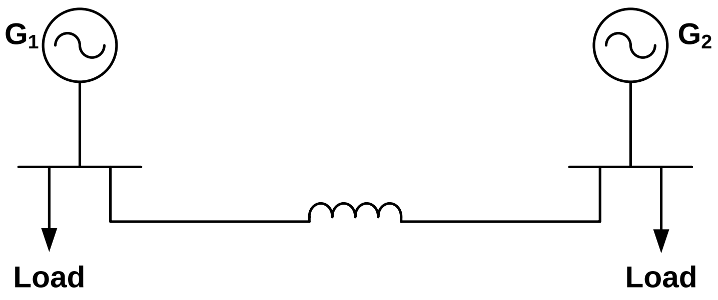

Fig. 2. Single line diagram of an interconnected power system

In a power system, ALFC as an ancillary service has procured a significant aspect to maintain the electrical system reliability at an acceptable level. Further ALFC becomes more significant with the change in the structure of power system and the growth of size and complexity of interconnected power systems. This is the motivation for an extensive literature on ALFC problem. A concise survey on the problem of ALFC is done and some reported works are referred in the present manuscript. Over the past three decades, huge number of research articles are materialized in the area of ALFC. Various control strategies and optimization techniques have found their applications in this area. Different ranges of system models are proposed for the ALFC studies. It preserves an interest in designing ALFC problem with better performance. It is to maintain the frequency and the tie-line power flows within pre defined values using different control methodologies.

3. Control Techniques

It is evident from the literature that the primary controller is not sufficient to maintain the system frequency in the pre defined limits as well as to control the power system for the variations in the power load demand. So, secondary controller should be included which minimizes frequency changes in the power system and change in tie -line power in an interconnected power system. These controllers can be classified as follows:

i. Adoptive Control:

Adoptive control is an approach of controller to adopt with parameter variation [74]. To improve the system stability and transient response the usage of adaptive control is very effective but the changes in the system dynamics and process parameters is less responsive [75, 76].

ii. Robust Controller:

The simple classical controllers having parameter adjustments are incompetent of providing good dynamic performance due to various disturbances and contingencies in the load characteristics. The system parameters as well as errors in linearizing and modeling of the system will depends upon the environmental conditions of the system [77]. In consequence, a robust approach is essential to attain an advanced trade off / (substitutions) bounded by the outcome of the market and its dynamics [78].

iii. Self Tuning Control:

Self tuning control (STC) technique is a fundamental component in adaptive control technique. The objective function should be minimized or maximized in the self tuning controllers (STC) in order to optimize the running parameters of the system [12, 78]. In general the error in ALFC problem should be minimized where as the system efficiency should be maximized. In ALFC problem the objective function or the error is always minimized.

iv. Optimal and Suboptimal Control Approach:

The revolutionized change in modern optimal control theory directs to consider the performance conditions of the optimal control system. Indeed, a large multi variable control problem has been solved in a simplified manner. This control approach reflects on the representation of model state variables and minimization of system object function [78]. As a consequence, the practical and computational complexities of

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a multi area power system shows the way to suboptimal control approach. These are considered to confiscate the constructive restrictions in accomplishment of controllers depends upon the full order state feedback [79-82].

v. Error Adoptive Computer Control: (EACC)

Error Adoptive Computer Control (EACC) technique was proposed by Ross [83]. This technique gives a solution for the problem of Automatic Load Frequency Control with novel and various degrees of freedom. This is one type of logical computer technique to formulate logical decisions, observes characteristics of error signal and control action will be taken on the Area Control Error signal. This approach can be reviewed to any sensibly adjusted EACC to distinguish against certain disturbances like statistical deterministic and periodic disturbances [84].

vi. LQR based controlling approach:

Linear Quadratic Regulator (LQR) is ascertained to design the optimal controller with quadratic performance in linear systems [85-88]. The intention of designing the optimal controller is to establish the rule for optimal control. To measure the system stability and robustness numerous computing objectives which are surrounded by the system Eigen values. It is desirable to simultaneously fulfill the step response of the system consisting rise time, over shoot, integral absolute error or disturbance rejection [89].

vii. P, D, I Controlling Approach:

The classical Proportional, Integral and Derivative controllers have been extensively applied on the problem of ALFC by majority of researchers [90-92] on the speed governing system. In ALFC problems, the objective functions that are used in designing of PID controllers are undershoot / overshoot. And the settling times are used in multi objective optimization. Saikia LC et al. [44] has made an attempt of comparing the results of I, PI, ID, PID and Integral Double Derivative (IDD) controllers.

viii. 2-DOF controllers:

2-DOF (Degree of Freedom) controllers have performed better results in existence of disturbed inputs for regulation and set point tracking. The output signal in the 2-DOF Controllers has been produced by the difference between the reference output and a measured signal output. R.K.Sahu *et. al.* [93] made an attempt in the LFC problem to apply 2-DOF Controllers for an interconnected power system.

4. Soft Computing/ Intelligent Control Techniques:

Various non linear systems are estimated by model order reduction. Probably the linear models are evidently associated to the fundamental process characteristics in practice. These representations may be legitimate under distinct operating circumstances or they should take up with new constraints of the system model. The initiation of Soft Computing or Intelligent Control techniques have resolved this problem to a great extent [38]. In this context these soft computing / Artificial Intelligence approaches are appropriate alternatives for traditional control approaches in the problem of ALFC to deal with the non-linearities and system uncertainties [78].

i) Bacterial Foraging Optimization Algorithm (BFOA):

BFOA has been introduced by Passion [135]. It is provoked by a natural selection. The performance of Escherichia coli bacteria present in the intestine is imitated. The foraging strategy is sub divided into different process. They are chemotaxis, swarming, reproduction and elimination and dispersal. L.C. Saikia et al. [136] have attempted to apply BFOA to AGC problems.

ii) Fuzzy Logic Control (FL):

Fuzzy logic controllers has been deliberated for the problem of ALFC in order to respond for the sudden load changes. The power system must be in stable state and it should not go under oscillatory state and it must be in smooth operating state [94-99]. Most of the traditional controllers are linearized mathematical models on the converse in the spirit to human intelligence. The Fuzzy logic controllers are substantially closer to solve the problems which are subjected to knowledge and experience about the working system. The robustness, accuracy and acceptability of the Fuzzy logic controllers make them useful to solve an extensive range of ALFC problems [94-107]. Indulkar et. al. [98] was probably the first to design a Fuzzy logic controller for the problem of ALFC and compared the response with classical integral controller.

iii) Genetic Algorithms (GA):

The Genetic Algorithm (GA) is very trendy and extensively used optimization algorithm in global search optimization techniques based on the operations observed in natural selection of Genetics and Darwinian survival of fittest. It exchanges the arbitrary structured information and operates on the contemporary approximations of population [116].

Genetic Algorithm was developed by John Holland. To solve the complex non-liner optimization problems GA has been extensively adapted in the area of ALFC [26, 36, 117-120].

iv) Differential Evolution (DE):

Storn and Price [137] have investigated an evolutionary algorithm called vi) Differential Evolution(DE). DE is trouble free trustworthy and efficient algorithm with simple coding. DE depends on mutation operators where as GA uses cross over operator. The mutation operator in DE is based on the difference of arbitrary sampled couple of solutions in the population. It uses old generation and new generation of the identical population size. Individuals of existing population become target vectors of the next generation. It has also been widely used for the problem of ALFC in power systems [69, 93, 138, 139].

v) Firefly Algorithm (FA):

Yang X.S. [223] has proposed an algorithm called Firefly Algorithm (FA) that has been working on population-based. Bioluminescence is a biochemical process which has been used by the Fireflies, where the flies use the flash light as a signal to distinguish and for mating. In the area of ALFC, FA has mostly used [183, 204, 210, 224].

vi) Teaching Learning Based Optimization (TLBO):

TLBO has become very trendy and powerful optimization algorithm proposed by Rao et al. [140] that has applied in many engineering fields. As TLBO is a parameter free algorithm, it does not necessitate any controlling parameter. TLBO inspires lots of researchers to use in view of the fact that it is simple, efficient and faster. The TLBO operational procedure consists of i) Teacher Phase ii) Learner Phase. In teachers phase - learners will learn from teacher where as in learner phase - learner will learn through interaction between learners [141].

vii) Digital Approaches:

Digital Control inspires lots of researches to use in AGC problems in view of the fact that they are more precise, trustworthy, more flexible, concise and less sensible to noise and drift [142-148].

An extensive direct digital automatic load frequency controller has been initially developed by Ross and Green [142] in the area of power systems. Later, that designing of digital LFC has been approached by integrating the dynamic control standards for routine evolution of digital control system and it was summarized related to the results of the field test.

viii) Hybrid Techniques:

The power system stability and performance can be improved by using very trendy and powerful hybridization approach. An innovative and intelligent control technique which was designed by Fuzzy system in combination of evolutionary algorithms has been proposed in [149, 150]. In this combinations Genetic – Fuzzy system is identified as the best. DU – et al. has proposed an online process for the combination of controlling Fuzzy with GA [151].

5. Types of Power System Models:

In fact in 1980s and earlier, the structure of the power system was confined and so simple. Now a days the substantial growth of electric power systems is large in size and becomes complex with non-linear dynamics [78]. In the beginning the power system frequency has been controlled by the fly wheel mechanism. But it has been encountered that this fly wheel mechanism is inadequate. Hence an auxiliary control has been integrated to the speed governor system with the help of a controller which is corresponding to its deviation in frequency plus its integral [38]. In [160] Cohn illustrated that the ACEs have been reconciled to zero adequately based on the tie-line bias control approach to design the supplementary controller. The power system models can be broadly classified as:

i) Single Area Power Systems

Ascertainable consideration has been accomplished for ALFC problems in Single Area Power Systems. In single area thermal power systems the ALFC problems were materialized in [50, 161 - 165] and significant publications have appeared related to single area hydro power systems in [166 – 168]. Effect of GRC on single area thermal power system was comprised in [162-167]. In [50] K. P. S. Parmar et al. have considered a single area power system for the problem of ALFC with multi source (Thermal - Hydro – Gas). The transient step response of an isolated single area with a hydro generator operating at or nearer to its full load has been witnessed in [166].

ii) Two Area Power Systems:

An extensive consideration has been performed on two area power systems by the researches so far on the linearized models [169-174]. Many significant contributions have been witnessed so far by the researchers to consider the system non-linearities [175-178] due to the non-linear system response characteristics in governor dead bands and the connected load. In [93] the authors have materialized the effect of governor dead band non-linearities in a two area thermal power system. Consequences of dead-band and GRC in two area thermal power systems have been recognized in [179, 180] where the two area system includes different energy storage systems. Power transfer can be done only through the tie-line between two control areas which are presented in an interconnected power system with two areas. Many researchers in world have suggested that multi area power system can reduce the reserve capacity of a power system.

6. Conclusion

The advanced approaches in the problem of ALFC for deregulated and conventional power systems are extensively reviewed and the approaches used for DG power system are also presented. A detailed survey has been done and presented here in this manuscript based on the types of control techniques and types of power system. The reader can easily understand the problem of ALFC. It also focused on the need of computational intelligence. The different controller techniques, optimization techniques and type of power system are categorized and studied extensively. In addition, the review on FACT devices and energy storage devices such as RFBs and SMES is also presented.

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