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AUTOMATIC GENERATION CONTROL SCHEMES IN INTERCONNECTED POWER SYSTEM - A CRITICAL SURVEY

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Abstract- The main objective of this paper is to present a critical literature review and aimed to highlight the various control and structural aspects of AGC used in multi area interconnected power system. The Artificial Intelligence technology offers many more benefits in the area of nonlinear control problems, particularly when the system is operating over the nonlinear operating range. In addition, this paper work reported in the Automatic Generation Control schemes based on power system models and control strategies are reviewed.

Keywords: Automatic Generation Control, Load Frequency Control, Control Schemes, Interconnected Power System.

I. INTRODUCTION

The main objective of the control strategy is to generate and deliver the power as economical and reliable as possible while maintaining the frequency and voltage within the permissible limits. The control of power and frequency with secondary loop, which is known as Automatic Generation Control (AGC) is a very important concept in power system, as its main role is to maintain the system frequency very close to its scheduled value during normal period and when the system is subjected to small step load variations (Kothari'2003, Kundur'94).

Automatic Generation Control or Load Frequency Control is a very important issue in power system operation and control of supplying sufficient and reliable electric power with better quality. An interconnected power system can be considered as being divided into the control area, all generators are assumed to form a coherent group (George et al, 2001). Load Frequency Control (LFC) is being used for several years as part of the Automatic Generation Control (AGC) scheme in electric power systems.

One of the objectives of the AGC is to maintain the system frequency at nominal value. In the steady state operation of power system, the load demand is increased or decreased in the form of kinetic energy stored in a generator prime mover set, which results the variation of speed and frequency accordingly. Therefore, the control of load frequency is essential to have safe operation of the power system (Kothari'2003) [82].

Automatic generation control is defined as, the regulation of power output of controllable generators within a prescribed area in response to changes in system frequency, tie-line loading, or a relation of these to each other, so as to maintain the schedule system frequency and/or the established interchange with other areas within predetermined limits (Elgerd). Therefore, a control strategy is needed that not only maintains constancy of frequency and desired tie-power flow but also achieves zero steady state error and inadvertent interchange. Among the various types of Load Frequency Controllers, the most widely employed is the conventional proportional integral (PI) controller.

The PI controller is very simple for implementation and gives a better dynamic response, but their performances deteriorate when the complexity in the system increases due to disturbances like load variation boiler dynamics [60]. Therefore, there is need of a controller, which can overcome this problem. The Artificial Intelligent controller like Fuzzy and Neural Control approach is more suitable in this respect. Fuzzy system has been applied to the LFC problems with rather promising results (Nanda et al, 2003).

The salient feature of these techniques is that they provide a model-free description of control systems and do not require model identification. The fuzzy controller offers better performance over the conventional controllers in complex and nonlinearities associated. However, it is demonstrated good dynamics only when selecting the specific number of membership functions, so that the method had limitation. To overcome this, ANN controller which is an advance adaptive control configuration, is used because controller provides faster control than the others.

II. SURVEY ON POWER SYSTEM MODELS

The AGC problem has been dealt with extensively for more than three and half decades. The major part of the work reported so far has been performed by considering linearized models of two/multi-area power systems.

A. Types of Power System Models

In Feb'84, the UEA began implementation of a test to identify the improvement to electric system automatic generation and tie line control that could be achieved by the application of variable, nonlinear tie-line frequency bias. The test showed that when tie line frequency bias is better matched to system response, the result would be that, the area control error performance would be improved and generating unit regulation would be reduced.

In addition, the interconnection reliability was enhanced. This work has been discussed by T. Kennedy et al [7]. K.C. Divya [4] have discussed the simulation model of two area hydro-hydro interconnected system and they showed that the difficulty in extending the traditional approach. They prepared the model by ignoring the frequency deviations between the control areas. E. Yesil, A. Demiroren, E. Yesil [5] have presented a three area power with two reheat turbine type thermal units and a hydro unit. Here the nonlinear (dead-band effects) state space equations of the power system are used directly during the control of the system by the FLC and by conventional proportional integral controller.

E.C. Tacker [11] has presented the formulation of AGC of interconnected systems and investigations via linear control theory. They compared three relative to their ability to influence the transient response of important system variables. Later on, the effect of generation rate constraint was included in these types of studies, considering both continuous and discrete power system models. D. Rerkpreedapong, A. Hasanovic and A. Feliachi [8] presented a three area interconnected power system (reheat turbine type).

The effect of governor dead band nonlinearity was considered by using the describing function approach and including the linearized equations. G. Panda, S. Panda, and C. Ardil [9] stated that since the system under consideration is exposed to small change in load during its normal operation, so a linear model is sufficient for its dynamic representation. Here the proposed algorithm is applied to both four-area interconnected reheat thermal system without and with governor dead band nonlinearity. They prepared model by using decomposition technique.

B. Types of Inter-Tie Lines

Because of so many technical and economic advantages, for transmission of large amount of power over long distances, the HVDC transmission has emerged on a power scenario. The [89-92] research papers gives a considerable research work on the LFC of interconnected power systems incorporating AC-links and DC-links. Investigations on decentralized robust LFC of a multi-area interconnected power system with AC as well as frequency controllable HVDC links are reported in [89]. Kumar and Ibraheem [90-92] have been proposed optimal AGC regulators for two-area power systems with parallel AC/DC-links.

The interconnected power systems were investigated with the implementation of designing optimal regulators by considering the incremental DC-link power flow as an additional state as well as the control variable. It is required to pay a considerable attention to consider damping effect of DC system as an area interconnection between AC systems. With consideration of frequency control of power systems interconnected via a DC-link, a title research work [94-96] is available on this topic.

Yoshida et al. [94] has been developed an Automatic Frequency Ratio Control (AFRC) system of an HVDC transmission utilizing the high-speed control features of a DC system with automatic frequency control on interconnected AC systems. Later, the effects of an AFRC system for HVDC transmission to the Automatic Frequency Control on AC systems when AFRC is applied to a random load perturbations in a steady state.

With the help of digital computer, the frequency improving and reduction effects of the output power of regulating power stations by AFRC are analyzed [95]. A new DC Automatic Frequency Control system, which applies a multivariable control to DC system-based frequency control and capable of controlling frequencies of the two AC systems optimally while maintaining their stability, is developed by Sanpei et al [96].

III. REVIEW ON AGC CONTROL SCHEMES

The first attempt in the area of AGC has been to control the frequency of a power system via the flywheel governor of the synchronous machine, but this technique was subsequently found to be insufficient, and a supplementary control is required to the governor with the help of a signal directly proportional to the frequency deviation plus its integral [21]. Before 1952, the controllers are designed with so many classical control methods such methods as Root Locus, Bode, Nyquist and Routh-Harwitz. These methods have in common the use of transfer functions in the complex frequency domain, emphasizes on the graphical techniques, the use of feedback, and the use of simplifying assumptions to approximate the time response.

A major limitation of classical control methods was the use of transfer functions and frequency domain limited to linear time-invariant systems. In between 1950s-1960s, the modern control, which refers to state-space model methods, is developed. In modern control, the system models, analysis, and design are directly written in terms of the time domain. With the State space model based methods, the limitations of classical control are removed. During the years of the 1970s and 1980s, a number of methods are developed that were considered to provide solutions to uncertainty of the system.

These techniques are known as Robust Control Schemes and are a combination of both modern state space and classical frequency domain techniques. More recent trends in the science have been moved towards intelligent control systems, which combine the ideas of conventional control as well as methods such as such as Fuzzy Logic, Search and Genetic Algorithms (GA) and Artificial Neural Networks (ANN).

A. Classical Control Schemes

The idea behind classical control schemes is the representation of closed-loop properties in terms of open-loop concept. Root Locus, Bode, and Nyquist plots are the examples of the classical control concept. These classical plots are drown based on open loop transfer function. In literature, a limited work has been reported regarding AGC of interconnected power systems using classical control theory [10-21]. In addition, J.E. Van Ness [11] and W.R. Barcelo [12] investigate the Load Frequency Control System using Root Locus techniques. For ACEs, to determine the optimum integrator gains, O.I. Elgerd and C.E. Fosha [14] had presented a work on AGC with the classical approach [21]. In [1] M. Shahriari Kahkeshi and F. Sheikholeslam has been proposed a classical method, which is based on the Characteristic Loci (CL) to Load Frequency Control (LFC) of the power systems. The proposed method is tested on two-area power system under various operating conditions.

Willems [16] has proposed the classical approach to determine optimum parameter values of conventional Load Frequency Regulation of interconnected power systems. T. Hiyama [18] has proposed a method for designing a discrete-time load frequency controller based on conventional tie-line bias control strategy of a two area reheat thermal system considering generation rate constraint. In [17], Wen Tan has proposed a new method for designing load frequency controller based on the Two Degree of Freedom (TDF) Internal Model Control (IMC) design method and a PID approximation procedure. This method is well applicable for power systems with non-reheated, reheated, and hydro turbines.

B. Modern Control Schemes

The classical control theory has the capability to handle single-input and single-output systems, in general modern power systems are multi-input and multi-output type systems. One of developments in field of modern control theory is in direction of its application in optimal control. The AGC regulator design techniques using modern control theory enable the power engineers to design optimal AGC with respect to a given performance criteria.

B.1. Optimal and Sub-Optimal Control Schemes

The AGC regulator design techniques using modern optimal control theory enable the power engineers to design an optimal control system with respect to given performance criterion. Fosha and Elgerd [14] were the first to present their pioneering work on optimal AGC regulator design using this concept. A two-area interconnected power system consisting of two identical power plants of non-reheat thermal turbines were considered for investigations. Since then, a wide variety of research articles on the optimal AGC of power systems has been witnessed [13, 16, 22-33].

Glover and Schweppe have developed an advanced version of load frequency control law based on optimal control strategy in 1972. A new design procedure for LFC, which satisfies all classical requirements, as well as some additional requirements on the feedback control structure, is given by Geromel, et al [34]. There are some practical limitations in the implementation of regulators based on feedback of all state variables, to overcome these practical limitations suboptimal AGC regulator designs were considered [32-34].

Moorthy and Aggarwal provided excellent information about a suboptimal and near-optimal LFC concept using modern control theory [35]. O.P. Malik et al. [40] presented a Sub-Optimal Load-Frequency Control of Hydrothermal power system. The authors have shown that the sub-optimal control with feedback of some, but not all, of the remote area state variables is a feasible alternative to the optimal control. In [38], the authors have proposed a suboptimal controller design technique such that the proportional part of the regulator is a linear function of a smaller number of states of the system plus an integral function of the area control error (ACE).

Apart from optimal/sub-optimal control concepts, modal control Theory has also been used to design AGC regulators for power systems. The design method employing modal and singular perturbation techniques to affect decoupling of the interconnection into its subsystem components has appeared in [38]. In the method, after achieving the decoupling, local controllers for each subsystem are designed individually to place closed-loop poles of each subsystem in some pre-specified locations in the complex plane, and then, the resulting controllers are used to generate local control inputs, using local information only.

The AGC regulator design using the Lyapunov's second method and utilizing minimum settling time theory has been proposed by Shirai [42]. The importance of the dominant time constant of the closed-loop systems in designing the regulators has been emphasized. The author has reported a bang-bang AGC policy based on this method.

B.2. Adaptive and Self-Tuning Control Schemes

Generally, the adaptive control schemes are broadly classified into two categories, these are self-tuning regulators and the model reference control systems. The main aim of adaptive control is to make the process under control and to un-modeled process dynamics. A number of articles have been reported on adaptive AGC schemes [42-45] and Self Tuned Control schemes [47-51] for AGC of power systems. In [42], Ross described control criteria in LFC and the related practical difficulties encountered in trying to achieve these criteria.

Pan and Liaw have presented an adaptive controller using PI adaptation to meet the hyper-stability condition requirements to take care of the parameter changes on the system [44]. A multi-area adaptive LFC scheme for AGC of power systems [45] and a reduced-order adaptive LFC for interconnected hydrothermal power system [46] are reported in the literature. A multivariable self-tuning controller has been derived by defining a cost function with a term representing the constraints on control effort and then minimizing that with respect to the control vector.

Later on, Lee has presented a self-tuning algorithm for AGC of interconnected power systems [47]. A unified PID tuning method for Load Frequency Control (LFC) of power systems is discussed in [17]. Here the tuning method is based on the Two Degree of Freedom (TDF) Internal Model Control (IMC) design method and a PID approximation procedure. The time-domain performance and robustness of the resulting PID controller is related to two tuning parameters, and robust tuning of the two parameters is discussed. The method is applicable to power systems with non-reheated, reheated, and hydro turbines.

B.3. Centralized and De-Centralized Control Schemes

Automatic Generation Control of power systems was dealt with control strategies based on centralized control strategy in the early days. The main limitation of the centralized control strategy with the consideration of AGC is the need to exchange information among control areas. [47, 76, 80-82]. A wide range of research papers on decentralized AGC control strategy for large-scale power systems with continuous and discrete time system models have appeared in literature [48, 51, 53, 56, 73, 74, 83-97].

A decentralized AGC regulator has been proposed by Elemetwally and Rao [48] assuming a constrained structure with a minimum error excitation concept. A decentralized Sub-Optimal Load Frequency Controller considering the minimum error excitation principle of a two-area hydrothermal power system is proposed in [91] by Malik et al.

C. Intelligence Control Schemes

The advent of Artificial Intelligence techniques, such as Fuzzy Logic, Artificial Neural Networks (ANN), Optimization techniques, Genetic Algorithms (GAs) etc., has solved this problem largely. The Fuzzy Logic technology offers many more benefits in the area of nonlinear control problems, particularly when the system is operating over the nonlinear operating range [2, 3]. The Fuzzy Logic Control (FLC) concept departs significantly from traditional control theory, which is essentially based on mathematical models of the controlled process. Instead of deriving a controller via modelling the controlled process quantitatively and mathematically, the fuzzy control methodology tries to establish the controller directly from domain experts or operators who are controlling the process manually and successfully [55].

In [56] they compared results of PI and PID controller with fuzzy PI controller for two-area power system in presence of parameters variation and non-linearity. E. Bashier and M. Tayeb proposed a fuzzy logic controller for Load Frequency Control Problem of the interconnected power system. The study has been designed for a two area interconnected power system. Recently, many studies exploiting the fuzzy logic concept in AGC regulator design dealing with various system aspects have appeared in the literature [61-64].

In [60] a four-area interconnected power system model with the reheat nonlinearity effect of the steam turbine and upper and lower constraints for generation rate nonlinearity of hydro turbine was considered in the investigation. In [98] a new Fuzzy type controller is considered for Load Frequency Control problem. In this new Fuzzy technique, upper and lower bounds of Fuzzy membership functions are obtained using genetic algorithm optimization method. A multi-area electric power system with a wide range of parametric uncertainties is given, to illustrate proposed method. To show the effectiveness of the proposed method, a classical PI type controller optimized by Genetic Algorithms (GA) was designed in order to make comparison with the proposed scaled Fuzzy method. E. Ozkop, I.H. Altas, A.M. Sharaf has been proposed fuzzy gain scheduling of PI controller for four area power system in [102].

The neural technology offers many more benefits in the area of nonlinear control problems, particularly when the system is operating over the nonlinear operating range. The applications of neural networks in power system control are witnessed in [54-59]. Researchers through articles [65-71] have also mooted the development of AGC schemes using ANN and Fuzzy Set theory to utilize the novel aspects of both in single hybrid AGC system design for power systems.

The drawback of implementation of conventional controller is to solve complex non-linear optimization problems, a new intelligent technique was introduced called Genetic Algorithms (GAs). GAs is the most popular and widely used to solve complex non-linear optimization problems like other computational intelligent systems such as neural networks and fuzzy systems. In [72-77] the applications of GAs for AGC of two-area interconnected power systems are reported.

D. Other Control Schemes

The LFC performance of a power system area has been assessed by the widely adopted criteria A_1 and A_2 , over the decades. These criteria are based on engineering judgment and had no analytical basis. In [87] the estimation of the area's frequency response characteristic has been incorporated for adaptive frequency bias setting in LFC to ensure the reliability and the responsibility of frequency support. The field tests were carried out with an AGC scheme to improve accuracy and its use in decomposing the one-min average of ACE of a control area to identify regulatory burden for certain widely varying loads [88].

Apart from proposing effective and efficient AGC strategies, real-time pricing of electricity has been used as an effective means to achieve improved system dynamic operation. Berger and Schweppe [78] have demonstrated that real-time pricing in presence of system dynamics can aid in LFC. It was demonstrated, for a single-area power system, that prices determined by a PI feedback control law of frequency deviations could assist in LFC. A report dealing with various cost aspects associated with AGC, inadvertent energy, and time error is presented in [79].

A real-time adaptive pricing for LFC in an interconnected power system, taking into account the system dynamics and giving the importing area a signal in terms of increased prices for any increment in the drawl from its scheduled value, was suggested in this study. In [101], the authors have been proposed new approach i.e. a dual mode and a fuzzy controller is designed to adaptively decide the Proportional-Integral (PI) like controller gains according to the area control errors and their changes.

The proposed controller is tested for a two-area single reheat system with considering the practical aspect of the problem such as Generation Rate Constraint (GRC) and the performance of the developed FLC is compared with the Dual Mode PI controller. The uncovered subject material on AGC is available in books [81-82], reviews [83-86, 105] and journals [96-99].

IV. CONCLUSIONS

The paper presents a critical review of the recent philosophies in the area of AGC. The main drawback of conventional controllers is they may be valid only within certain specific operating ranges due to nonlinear properties of the system. With the advent of Artificial Intelligence techniques, such as Fuzzy Logic, Neural Networks and Optimization Techniques have solved this problem largely. The Artificial Intelligence technology offers many more benefits in the area of nonlinear control problems, particularly when the system is operating over the nonlinear operating range.

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