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AGC STRATEGIES-A REVIEW

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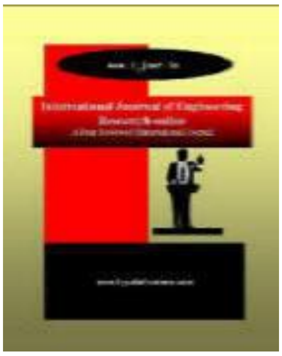

ABSTRACT
Thispaper presents a comprehensive literature review of control schemes of automatic generation control (AGC) of power systems. The various configuration of power system models and control techniques/ strategies that concerns to LFC issues. Finally, AGC strategies based on variable structure, robust, adaptive, self-tuning, and intelligent control have also been incorporated. Also in this paper work reported in the literature in the area of automatic generation control has been reviewed critically.
Keywords — Automatic Generation Control (AGC), Adaptive Control, Interconnected Power Systems, Optimal Control, And Suboptimal Control.

INTRODUCTION

Owing to the importance of the distribution of the electrical power, the organizations are responsible for providing it with great reliability, availability and efficiency. A power system consists of a number of interconnected subsystems. For each subsystem it becomes compulsory to fulfill the requirements usually include matching system generation to system load and the associated system losses and then regulating system frequency and tie line power exchanges. This is usually known as load frequency control, also called Automatic Generation Control (AGC) problem and is very important in the operation of power systems [1,2].

A well designed and operated power system must cope with changes in the load, with system disturbances, provide acceptable high level of power quality and maintaining both voltage and frequency with intolerance limits. 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.

The problems have been tackled by the various researchers in different time through AGC regulator, excitation controllerdesign and controlperformance with respect to parameter variation/uncertainties and different load characteristics .As the configurationofthemodernpowersystemiscomplex.With the recent technological innovations, intelligent controllers have been replacing conventional controllers in order to have fast and good dynamic response for load frequency control problem. Many intelligent techniques such as fuzzy logic, artificial neural network (ANN), genetic algorithm, bacterial foraging, etc. are being used extensively in isolated as well as interconnected powersystems

TYPE OF POWER SYSTEM MODEL

Mainly hydro, thermal and nuclear power stations have been used a conventional power system for centuries for generation, transmission and distribution. But in twenty first century due to depletion of fossil fuels and threats to environmental non-conventional energy sources plays a vital role.

A. Conventional power systems

The main control problem for any power system is to match real power generation to load including stresses. The frequency depends on active power which comes from load generation mismatch. It is the secondary control in LFC, which re-establishes the frequency to its nominal value (50 Hz) and sustains the interchange of power between areas (in case of more than one control area). For this the load demand in the generator prime mover set is increased or decreased in the form of kinetic energy, resulting in change of frequency. The primary and tertiary control is performed by speed governors and economic dispatch respectively. The transient in primary, secondary and tertiary control is of the order of seconds and minutes respectively.

Conventionally hydro, thermal or both were used as primary source of electricity generation to meet the demand of electrical energy. However, due to increase in demand and load fluctuations it leads to restructuring it. Thus the incorporation of flexible transmission system and other auxiliary devices came into existence.

B. Distributed generation power systems

The DG system is considered economical for electrical power supply to remote and isolated areas where the electric power is not easily available from the grid. DG technologies become popular due to various environmental and economic issues. Distributed generation can be defined as on site generation i.e. generation near the load. The prime movers of DGs technologies use both renewable and non-renewable sources of energy. Most of DGs technologies are based on renewable sources of energy. The rapid development of DG technologies is gradually reshaping the conventional power system. The Wind power, solar power, micro turbines and small hydropower plants are among the most actively developing distributed generation. The integration of DG to existing power system brings both negative and positive consequences.

OVERVIEW OF AGC SCHEMES

Flywheel governor of synchronous machine may be the initial idea implemented for AGC of a power system. But this approach was found inadequate. Therefore, a secondary was incorporated to the governor with the help of a signal directly proportional to the frequency deviation with its integral. This technique composes the classical approach to the AGC of power systems. Secondary AGC schemes are developed to control the area control error (ACE), which is defined as a linear combination of power net-interchange and frequency deviations, is generally taken as the controlled output of AGC. As the ACE is driven to zero by the AGC, both frequency and tie-line power errors will be forced to zeros .

Perhaps, Cohn [5-10] was the first to introduce the scheme for the control of bulk power transfer in interconnected power systems based on tie-line bias control strategy, particularly deciding the frequency bias setting and techniques timing error and inadvertent interchange correction[92] for large multi area power system.In [11], he has presented a comprehensive study on extensive growth and expansion of interconnected electric power systems. Concordia and Kirchmayer [12, 13] have analyzed the AGC problem of two area hydrothermal power systems. They have also studied the effect of governor dead band [14] and the effect of variation of several parameters on dynamic performance of the system.

D. M. Patel et al. [15] dealt with AGC in power system operation with reference to the tie-line control and the requirement of reactive power and voltage regulation under normal operating conditions in the model. A model was proposed to show the interaction between the Load frequency control (LFC) and the Automatic voltage regulator (AVR) loops. The coupling effects of the AVR and LFC loops were studied by including the excitation system in system dynamic model [16]. T. W. Reddoch et al. [17] have presented a state variable model for AGC of a linear interconnected power system.

Other advanced techniques in control, such as optimal and adaptive control, are also formulated instate space. More recent trends in the science have beentowards intelligent control systems that tend to use both the ideas of conventional control as well as methods such as fuzzy logic, Petri nets, search and genetic algorithms and neural networks. Following these developments in control systems, many AGC schemes have been proposed in the literature as their applications to power systems.Bhatt et al. [18] proposed a traditional AGC loop with modifications incorporated for simulating AGC in restructured power system model and the concept of distribution participation matrix for power system model. This model is used to simulate the bilateral transactions contract in the multi-area models.

CLASSICALCONTROL BASEDAGC SCHEMES

In classical control a basic concept is to describe close loop properties in terms of easily measurable open loop properties. A few examples of classical control scheme include Nyquist, Bode, and Root Locus plots which are drawn based on open loop transfer function. These methods reveal that closed loop transient response will result into relatively large overshootsandtransientfrequencydeviation [19-21]. A major limitation of classical control methods was the use of single-input, single-output (SISO) methods. Also the use of transfer functions and frequency domain limited to linear time invariant systems. In literature, a limited work has been reported concerning AGC of interconnected power systems using classical control theory [22-34]. Also the load frequency control system is investigated using root locus techniques by J. E. Van Ness [22] and W. R. Barcelo [23]. O. I. Elgerd and C. E. Fosha had presented a work on AGC concerned with the classical approach to determine the optimum integrator gains for ACEs 18[33]. Willems[28] has proposed the classical approach to determine optimum parameter values of conventional load-frequency regulation of interconnected power systems. T. Hiyama [30] 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. Based on classical control scheme M. L. Kothari et. al. have discussed some aspects of sampled AGC in [31]. Later, in [32] they have studied the AGC problem of an interconnected power system in continuous and discrete-mode using classical control theory.

Modern control concept based AGC schemes

In present times the demand for electrical energy and load fluctuations is increasing so modern power systems are multi input and multi output (MIMO). The classical control schemes used for single input, single output (SISO) systems are incapable of handling modern power systems. The AGC regulator design techniques using modern control theory enable the power engineers to design optimal control schemes with respect to a given performance criteria. In literature, volumes of research articles are reported using various aspects of modern control concepts for modern power systems.

A. Optimal Control AGC schemes

The optimal control theory has provided new schemes to solve the problems of multivariable control problem of modern power systems in a simplified form. In this control scheme the state space representation of the model is considered andan objective function to be minimized. In a two area interconnected power system consisting of two identical power plants of non-reheat thermal turbines Elgerd and Fosha have exhibited their pioneering work on optimal AGC regulator design using modern control conceptin [35]. Also, two area interconnected power system investigated by Tacker et al. [36] have investigated with optimal AGC regulators. K. Yamashita and T. Taniguchi [37] have analyzed the AGC problem for interconnecting systems considered from the point of view of optimal control theory. M. L. Kothari and J. Nanda [38] introduce other algorithm for AGC regulators of an interconnected hydro-thermal power system using a performance index that circumvents the need for a load demand estimator. K. P. S. Parmar et al. [39] have developed dynamical response of the AGC problem in an interconnected reheat type power system under consideration with a practical viewpoint by designing the optimal full state feedback controller. Ibraheem and P. Kumar [40] have dealt a computational approach for the solution of the Matrix Riccati (MR) equation. A control strategy was proposed by Mariano et al. [41]. Later, in [42] they considered the stabilization and performance of the AGC regulator by using the theory of the optimal control.Bohn and Miniesy[43] have studied the optimum LFC of a two-area interconnected power system by making the use of (i) differential approximation and (ii) a Luenberger observer and by introducing an adaptive observer for identification of unmeasured states and unknown deterministic demands, respectively.

B.Sub Optimal Control AGC schemes

The optimal controller design requires the measurement of all the state variables for their feedback which is a serious limitation because measurement and access of all the state variables is not possible all the times. Therefore, the idea of sub-optimal AGC regulator design was introduced to overcome the limitations of former scheme. A remarkable work was presented by V. R. Moorthiand R. P. Aggarawal [44] on sub-optimal and near optimal control of AGC system. Many aspects of sub-optimal AGC regulator designs for power systems havebeen considered in the publications [45-49]. In [50], 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 integral function of the area control error (ACE). The AGC schemes based on an optimal observer, which a state estimator with decaying error at a desired speed, using a nonlinear transformation [51] and reduced-order models with a local observer [52] is discussed. Hain et al. [53] reported a simplified generating unit model oriented towards LFC and the method for its transfer function identification based on atwo-stage procedure indirectly reducingbothnoise effectsandtransferfunctionorder.The proposed suboptimal control law was obtained by eigenvalues grouping technique and has shown the feasibility of the design technique of the sub-optimal regulator for load frequency control of power systemconsisting of non-reheat thermal turbines. S.S. Choi [54] discussed a design of an LFC using the feedbackof only the directly measurable system state variables. P. Kumar et. al. [55] designedAGC regulators for hydrothermal power system based ondecentralized control strategies. O. P. Malik et. al. [56]presented a sub-optimal load-frequency control forhydrothermal power systems. The authors have shown thatthe sub-optimal control with feedback of some, but not all,of the remote area state variables is a feasible alternative tothe optimal control, whereas local control without feedbackof any remote state variable is inadequate for stabilizing thesystem. A sub-optimal control method using the areadecompositiontechnique to the multi-area power systemLFC is presented by Yoshibumi in [57].Sub-optimal AGC schemes have also been reportedusing the concept reduced order modeling of the system.Elangovan et al. [58] proposed a method by which asuboptimal control policy of a given linear system isderived using its simplified model whose order is less thanthat of the original system. 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.

C. Centralized AGC scheme

The implementation of global controller requires information about all the states of the power system. In the beginning, the LFC problem was based on centralized control strategy [59].On the basis of classes of disturbances the control strategy has been proposedin [59]. ElgerdandFosha [19] suggested a feedback and loop gain to eliminate the disturbance, and new feed backcontrol law is developed by using a state variable model and the state regulator problem of optimal control theory [60].

D. Decentralized AGC scheme

The main limitation of the works presented on AGC considering centralized control strategy is the need to exchange information among control areas spread over distantly connected geographical territories along with their increased computational and storage complexities [61-62]. 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 the literature [63].Shirai [64], reported the decentralized LFCfortwo-areathermalpowersystemthrough agovernor and voltage controls by a new approach based on Siljak's theory. Velusami and Chidambaram [65] proposed a decentralized (PI) biased dual mode controllers for two areas interconnected thermal power system. Aldeen and Marah [66] introduced a simple and computationally efficient decentralized control design method for the LFC problem in interconnected power systems based on the use of a reduced-order observer and a PI controller in each area of the power system. A decentralized AGC regulator has been proposed by Elemetwally and Rao 40 [67] assuming a constrained structure with a minimum error excitation concept. A decentralized sub-optimal load frequency controller considering minimum error excitation principle for a two area hydrothermal power system is proposed in [50] by O.P. Malik et al.Zribi et al. [3] designed an adaptive decentralized load frequency control scheme for multi-area power systems. Lim et al. [4] introduced a new robust decentralized load-frequency controller based on the Riccati equation approach for an N-area power system; the design and operation of each local controller requires only its local states while the robustness of the controller is achieved by imbedding the local-system parametric bounds into the Riccati equation. Trinh and Aldeen [67] proposed a decentralized design of load frequency controllers of multi-area interconnected power systems where model reduction techniques were incorporated into the design method. Wang et al. [68] proposed a new robust decentralized controller to improve a multi-machine power system transient stability; the proposed controller is a linear controller which can guarantee the system stability over the whole operating region.Yang and Cimen [69] considered the design of a decentralized robust LFC for interconnecting power systems. It is shown that, subject to some conditions, each local area-load frequency controllercan be designed independently.

E. Adaptive and Self-tuning AGC scheme

The operating point of modern systems may not remain same so the performance of the controller may not be optimal. To keep the performance optimal it is desirable to track the operating point of the system and change the value of parameters accordingly to achieve a better control scheme. Theself-tuningcontrol(STC)approachincludesan integralpartoftheadaptivecontrolscheme.Pan and Liaw [2] presented an adaptive controller for the LFC problem of power systems where the controller uses a PI adaptation. Rao and Ahson [70] examined the use of a two-level control scheme for a two-area power system with nonlinear interactions between the areas. Rubaai and Udo [71] proposed a multilevel adaptive load frequency controller which is based on the self-tuning regulator.Yamashita and Miyagi [72] devised a method for designing a multi variable self-tuning regulator for an LFC system with the inclusion of the interaction of voltage on load demand. A multilevel adaptive algorithm based on a relatively fast implicit self-tuning regulator for multi-area power systems is investigated. Jovanovic et al. [73] presented an application of knowledge-based adaptive turbine governor control. A self-tuning steam turbine control scheme designed to improve the quality of control of power system frequency is discussed.

F.Intelligent AGC Schemes

The structural complexity and reshaping of the plant may be required in robust systems. To solve this problem,the intelligent control scheme with use of soft computing techniques such as artificial neural network (ANN), fuzzy logic, genetic algorithm (GA), particle swarm optimization (PSO) algorithms, etc. has been explored. In this context to address the non-linarites, system uncertainties, the intelligent LFC scheme may be the suitable alternative, than the traditional controls. Abdel-Magid and Dawoud [74] used genetic algorithms to handle the LFC problem. Rerkpreedapong et al. [75] proposed a robust load frequency controller using genetic algorithms and linear matrix inequalities. Birch et al. [76] applied a robust control technique to a nonlinear LFC problem. Demiroren et al. [77] used an artificial neural network (ANN) controller for the LFC problem. Talaq and Al-Basri [78] used an adaptive fuzzy gain scheduling technique to deal with the LFC problem. Other works on the application of intelligent control techniques to the load frequency control problem were reported in the literature. J. Talaq et. al. have proposed an adaptive fuzzy gain scheduling scheme for conventional PI and optimal AGC regulators.The generation of optimal fuzzy rule based on fuzzy C-means clustering for decentralized LFC in two-areas reheat thermal power system with GRC is proposed in [79].The authors in [80] proposed GA for parameter optimization of PID sliding mode LFC for AGC in multi-area power systems with nonlinear element. The multi-objective optimization based GA used to optimize the gains of PI/PID-controllers for LFC of three-area thermal power systems is presented in [81]. The fractional-order-PID controller tuned by bacterial foraging technique is used for LFC in three-area power systems with deregulated environment in [82]. To ease the design effort and thereby improve the performance of the controller, the design of fuzzy PI controller by hybridizing GA and PSO is presented in [83].

Other controllers for AGC

Most of the AGC schemes presented so far have been formulated considering linear power system models. However, like other physical systems, power systems are also highly non-linear in nature. An overview of applications of robust control techniques in power systems is illustrated by L. Fan . This review has considered a variety of robust control techniques such as non-linearity H∞, linear matrix inequalities, MR equation approaches, Kharitonov's theorem, structured singular value theory, linear quadratic Gaussian, quantitative feedback theory and pole placement technique have been used, and an investigation is carried out for power system reliability against the uncertainties. A combination of matching conditions and Lyapunov stability theory has been adopted to implement a robust stabilizing controller of interconnected power systems with uncertain parameters [84]. In [85] the Q-parameterization method is used to design robust AGC regulators while the set of all robust controllers of the power system was characterized by a parameter free 'Q' matrix. Hsu and Chan [86] proposed the LFC problem for interconnected two-area hydro-thermal power systems using the theory of variable-structure systems and linear optimal control theory. Investigations carried by Tripathi et al revealed that improved dynamic performance of the system could be achieved by simultaneous control of steam turbine and energy storage device.Ngamroo et al. [87] proposed robust decentralized frequency stabilizer design of static synchronous series compensators by taking system uncertainties into consideration for three area interconnected power system.Aditya and Das [88] have revealed that use of BESS is helpful in meeting sudden requirements of real power and is effective in reducing the peak deviations of frequency and tie-line power. Thus it reduces the steady-state values of time error and inadvertent interchange accumulations. Banerjee et al. [89] presented the effectiveness of small sized magnetic energy storage units (both superconducting and normal loss types) to improve the load-frequency dynamics of two-area thermal power system.Chaudhuri et al. [90] demonstrated the enhancement of inter-area mode damping by multiple flexible AC transmission systems (FACTS) devices. Kong et al. [91] proposed a new model predictive control scheme based load frequency controller; the proposed controller guarantees the stability via the introduction of a state contractive constraint.

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