A New Literature Review Of Automatic Generation Control In Deregulated Environment

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Abstract : One in all the foremost vital issue is Automatic Generation Control (AGC) in electrical power system design and operation. The main objective of AGC in a power system is to take care of the frequency of the particular power area. If interconnected facility is taken into account then the tie-line power is to be unbroken near to regular values by adjusting the MW outputs the AGC generators therefore on accommodate unstable load demands. This paper reviews numerous control strategies for elegance of Automatic Generation Control (AGC) within the deregulated power system environment. Models and control procedures / structures of power structure that concern the AGC prevention program and application issues tend to be and are fragmented. Further, discussion on challenges and benedictions related to the reviewed Control techniques/ structures have been conferred.

1.INTRODUCTION

Time efficiency is the most efficient method of power generation, transmission and distribution, where the availability and reliability of the entire system is high enough to meet the unpredictable power demand every minute [1]. Several electrical utilities and power firms in worldwide, modified the method they want to operate from Vertically Integrated Utility (VIU) to deregulated setting. The aim of deregulating in power systems is to encourage competition, permit open transmission access and scale back electricity value to buyers [2]. The previous VIUs that are wont to regulate all the activities associated with electricity within the generation, transmission, and distribution subsystems now's decayed into separate organizations [3] [15] [9]. Generation companies (GENCOs), Distribution companies (DISCOs), Transmission companies (TRANCOs), And an Independent System Operator (ISO) all has committed to its individual tasks. For reliable operation of the power system, the ISO controls the operation of the many auxiliary services, one in all them is frequency regulation supported the idea of Automatic Generation Control (AGC).The automatic generation Control during this new deregulated structure is meant to produce the most energy transactions like polo-based, bilateral likewise the mix of those 2 transactions [3] [11] [20]. Additionally, it should conjointly fulfill the well-known objectives of AGC in a very VIU. These embrace the regulation of the system frequency at nominal par value, maintaining the tie-line power interchange among Control areas and keeping every generating unit to its most economical wealth [14][25][26]. Because it is understood, any pair between the overall generation and therefore the total load demand might lead the nominal system frequency and regular power exchanges to different areas to be deviated from their nominal values, which might cause unwanted effects [10].

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Many studies are conducted regarding AGC in a very deregulated environment over last twenty years. The early studies may be found within the work conducted by Christie. D and Bose. A. [15]; Kumar et. al., (1997) [11]; Bakken and Grande (1998) [17]; and Meliopoulos et al (1999) [28]. Further, Bevrani et. al., (2005) [14] changed the standard AGC system [32] to require into consideration the impact of bilateral contracts on the dynamics. The state space model of multiple power system to Composition regionalized state feedback controller Using eigen structure assignment by Tyagi and Srivastava (2006) [20]. The foremost of mentioned studies are done on thermal plants [30] that don't represent the plot of AGC drawback in deregulated environment. As result, some recent studies have examined the mixture of multiple supply generators like thermal, hydro, nuclear, gas and renewable power plants at intervals one Control space. For examples, Ram and Jha (2010) [23] and Rahman et al (2015) [16] explored 2 Control areas with thermal station in area one and hydro-thermal plants in area 2. In another study, the dynamic of the 2 Control areas consisting of thermal and gas power plants are according in Hota and Mohanty (2016) [8]. Further, Shree and Kamaraj (2016) [24] investigated the performance of AGC in 3 Control areas consisting of thermal and hydro plants taking in thought the Generation Rate Constraint (GRC) during this respect, advanced Modern Control theory like robust Control, variable structure Control, soft computing control techniques, model prognosticative control and active disturbance rejection Control were investigated in deregulated environment. This survey shortly highlights the AGC drawback in deregulated power system environment. In a section 2 the final model of deregulated multi-area power system is conferred. Section 3 narrate the AGC Control techniques that are principally investigated within the literature. Section 4 explain the AGC Control structures. A comparison between numerous Control techniques and approaches is mentioned in 5th section, and a few final remarks are conferred in Section 6

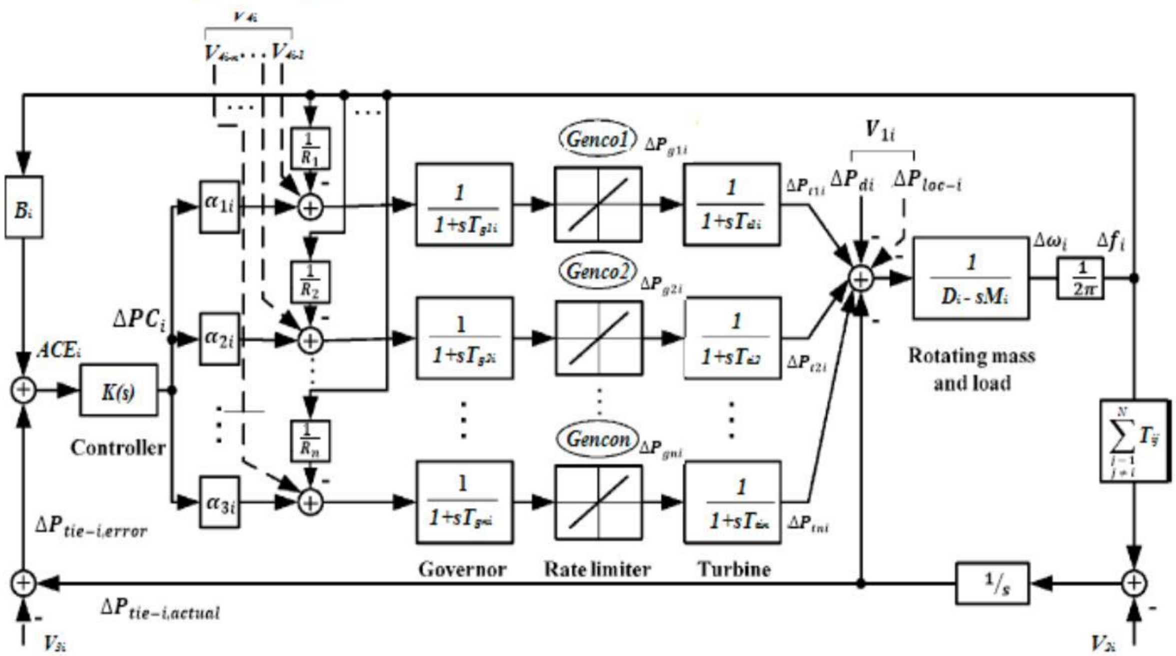
2. MODELLING OF DEREGULATED POWER SYSTEM

To consider the consequences of bilateral contracts between GENCOs and DISCOs all stated Control areas, the thought of DISCO participation matrix (DPM) is imported. It is an n × m matrix (n is the number of GENCOs & m is the number of DISCOs) [33] . The diagonal elements of DMP correspond to local demands; whereas off diagonal parts of DMP correspond to the demands of the DISCOs in one area to the GENCOs in another area. The integration of this idea within the dynamic response of AGC is well explained within the literature [7] [23] [24] [24]. the overall structure of DPM for large power system with m DISCOs and n GENCOs is expressed as:

$$DPM = \begin{bmatrix} cpf11 & cpf12 & \dots & cpf1(m-1) & cpf1m \\ cpf21 & cpf22 & \dots & cpf2(m-1) & cpf2m \\ : & : & : & : & : \\ cpf(n-1)1 & cpf(n-1)2 & \dots & cpf(n-1)(m-1) & cpf(n-1)m \\ cpfn1 & cpfn2 & \dots & cpfn(m-1) & cpfnm \end{bmatrix} \quad (1)$$

where, Cpfij (i =1,2,..,n, j = 1, 2, …m) are contract participation factors corresponds to the fraction of the entire load power narrowed by DISCO j from GENCO i. The sum of all the elements in a column in this matrix is unity. The overall AGC diagram for the Control area-i is shown in Figure1, [14], where the dashed line inputs represent the new info signals and due to probable contracts between DISCO i and also the alternative DISCOs and GENCO j. V4i is bilateral signals vector, V3i and V2i were the new tie line power flows and conflicts signals respectively. The distribution of area Control Error among generators in every area is named ACE participation factors (APFS) [3] (Donde.et al, 2001). The new regular steady state power flow on tie-line is given as [7] (Hosseini and Etemadi, 2008):

$$P_{t-i-new} = V_{3i} = P_{tie-i} + \sum_{\substack{j=1 \\ j\neq i}}^{m} D_{ij} - \sum_{\substack{j=1 \\ j\neq i}}^{m} D_{ij} \qquad (2)$$



where Pt-i-new is that the new regular power flow on tie line, Dji is that the demand of DISCOs within the area j from GENCOs within the area i , and Dij is that the demand of DISCOs within the area i from GENCOs within the area j. Ptie-i is that the net tie line power flow from the world i. Hence, throughout transient period the tie-line power error is :

$$\Delta P_{tie-i-error} = \Delta P_{tie1-2actual} - \Delta P_{tie-i-new} \qquad (3)$$

The ΔPtie-i-error is employed to see the ACE for area i as:

$$ACE_i = B_i \Delta f_i + \alpha_{ni} \Delta p_{tie-i-error} \qquad (4)$$

where, α_{ni} is a Area Control Error (ACE) participation issue. within the release environment-based automatic generation Control, each DPM and APFS thoughts are strictly used. The DPM matrix is chosen on the basis of market economic, however no approach is known for selecting APFS [23], which can make as results wrong result.

3. CONTROL TECHNIQUES

In deregulated power system (DPS), several advanced Control strategies are applied to attain power to trace the contracted/uncontracted demands, take into consideration under competitive conditions the result of bilateral contracts on the dynamics and improve the dynamic transient response of the system. Here is that the review of some Control strategies that were wide investigated within the literature.

3.1. Soft Computing Techniques in AGC

Initially in 1971 the load-frequency control problem for interconnected systems is considered from the viewpoint of optimal stochastic system theory [39]. Then the control of deregulated power system using soft computing/intelligent techniques such as Newton-Raphson algorithm, Bacterial Foraging Optimization Algorithms (BFOA), and Genetic Algorithms (GA), as well as artificial intelligent control techniques have investigated by number of researchers.[3] Dande et al., (2001) was one of the first researchers who obtain optimal parameters of the integral control using gradient type Newton-Raphson algorithm by trajectory insensitivities. The Linear Quadratic Regulator (LQR) with Integral action (LQRI) is designed and implemented to solve the Automatic generation control problem in a restructured power system that operates under deregulation based on bilateral policy [34]. Rerkpreedapong et al., (2003) [22] used Genetic Algorithms (GA) and Linear Matrix Inequalities (LMI) to develop durable Proportional Integral (PI) Automatic Generation Control (AGC) against load disturbances. Demiroren and Zeynelgil (2007) has been used GA for optimizing the integral Control gains and frequency bias factors during a 3 - area power system [5]. Hosseini and Etemadi (2008) AGC Control was based on Adaptive Artificial Neural Fuzzy Inference System (ANFIS) and Particle Swarm Optimization (PSO) has been projected for optimum gain scheduling in deregulated facility [7]. During this study, generation rate constraint is taken into account in 2 Control areas composed of steam turbines and also the ANFIS is employed to estimate the dead band. The simulation results establish that the control system provides sensible dynamic response for each Control areas frequency deviations and tie-line power error. Additionally, accommodative Control gains is updated in real - time in line with the variations within the power demands. Despite, sensible performance was obtained; PSO took very long time to work out the optimum gains, that is impractical for real time applications. Debbarma et al (2013) is applied Bacterial foraging technique to optimize simultaneously the gains of non-integer controller and speed regulation parameter R in multiple–area thermal power systems [4]. It is significant to note that all the authors considered AGC problem without considering the combination of various power sources such as thermal, hydro, nuclear and renewable power sources in one control area which did not reflect the real scenario case [8]. In last decade, several efforts were created to combine multiple power sources in one Control area. Ram and Jha (2010) [23] examined typical and artificial intelligent Control techniques like neural network, fuzzy logic and neuro-fuzzy using genetic algorithms against load disturbances in hydro-thermal power system [37]. Work by Shree and Kamaraj (2016) [24] has projected Hybrid Neuro Fuzzy approach for automatic Control supported bilateral policy. The contracts were taken as set of latest input signals into the new power system. The analysis has indicated on the strength of ANFIS Control against huge load changes and disturbances in presence of model uncertainties and also the system nonlinearities. In this approach, 3 area hydro–thermal power systems with Generation Rate Constraint (GRC) under varied operational conditions and totally different narrowed eventualities are tested for the controller analysis. Advantage of ANFIS approach over Real Coded Genetic algorithmic rule (RCGA), Hybrid Particle Swarm Optimization (HCPSO) and Artificial Neural Network (ANN) techniques lies on its simple structure, humble implementation and high stabilities capabilities. This methodology needs estimation power and isn't economical in industries. It desires a much bigger coaching set to reinforce the efficiency of the controller. This successively will increase the calculation time. Since within the real time the calculation is carried over the sampling amount. Thus, this Control technique isn't helpful for real time power systems. In another study, Biogeography-Based optimization (BBO) technique to enhance simultaneously the 3DOF-PID controller gains as well as the electrical governor parameters for two-area power system (thermal-hydro) have used by Rahman et al., (2015) [16] [33]. In this investigation, Integral of squared Error (ISE) is taken as a cost function. The physical constraints, GRC and dead band are assumed in the study and also the system dynamics was evaluated considering 1% step load perturbation. The results reveal that the 3 Degree of Freedom Integral Derivative (3DOF-ID) controller has higher performance than I, ID, and 2DOF-ID controllers in terms of peak deviation, settling time, and magnitude of oscillation. Additionally, the 3DOF-ID's parameters optimized by BBO are found to be strong against load changes and inertia constant. The weakness of this approach is that the governor speed regulation parameter (R) and frequency bias Coefficient (B) are selected based on trial and error commands. In 2019 the parameters of the controllers are optimized using gray wolf optimization algorithm to improve time response of the system and reduce generation costs for optimal load frequency control of a power system with wind generation units [40]. Later, Shiva and Mukherje (2016) [25] applied Quasi Oppositional Harmony Search algorithm (QOHS-PID) and analyzed to a 5-area power system under deregulated environment. During this inspection every area consists of multiple combos of generation units, like reheat thermal, hydro and gas generating units. The physical constraints nonlinearities like GRC and government dead band time delay are imposed, treated and tested on 3 totally different cases, namely, unilateral transactions, bilateral transactions, and contract violation. Additionally, Cost function of Integral of Squares Error (ISE) was employed by QOHS algorithm to improve the PID controller parameters. The simulation results expose that QOHS-PID Control stabilized the schedule tie line power flow deviation profiles, frequency deviations and controlled GENCO's power to their nominal values in presence of the physical constraints. Although acceptable performance was determined, the communications delays don't seem to be thought of and QOHS-PID practical implementation isn't yet verified.

3.2. Robust control Techniques in DPS

A generalized approach to load frequency control in deregulated environment that combines discontinuous control and dual-mode control and uses variable-structure-systems concepts is developed [35]. Robust primarily based automatic generation Control approaches even have received attention by investigators for their establishment and robustness characteristics against plant uncertainties, parameters variation, and load disturbances in deregulated power system environment. Since then, there have been variety of purpose and work explored within the literature. The main two objective of these approaches, the frequency regulation, pursuit the load variations, and maintaining tie-line power exchanges with such that values in presence of physical constraints and plant uncertainties. The Control design issues on mentioned above approaches may be classified into 2 main Control problems: The primary one is that the robust Control problem as well as H_∞ Control and multi-objective Control problem via mixed H_2/H_∞ Control technique. The second is that the μ synthesis and analysis theory. the subsequent section provides a short review of those approaches.

The early robust load frequency Control issue was addressed by Feliachi (1996) wherever AGC issue was formulated as H∞ Control problem to ensure the frequency regulation pursuit in presence of step perturbations [6]. However, applying this procedure yields a controller that encompasses a higher order which can ought to be decreased for real time and complex systems. additionally, Bevrani et al., (2003] [13] used µ synthesis and analysis theory to form a robust AGC and ensure stability in presence of increasing uncertainty and load disturbances for four Control areas. The µ synthesis approach has verified to be a helpful technique for minimizing the impact of disturbances and achieving acceptable frequency regulation in presence of uncertainties and load variation. Later on, Bevrani et al (2005) projected mixed H2/H∞ technique to construct decentralized robust AGC in deregulated environment beneath bilateral policy theme. The AGC issue is developed as multi-objective optimum control problem wherever many completely different performance and robustness objectives may be met. In this technique, H2 control minimizes the linear quadratic value of tracking error and therefore the Control input whereas H∞ Control ensures the steadiness of the control system within the existence of Control constraints and uncertainties. Iterative linear matrix inequality method is employed to resolve this bell-shaped optimization issue, however, the planning issue for optimum robust controllers supported H infinity techniques leads to a non-convex optimization issue, that suffers from computational intractability and Conversation [18].

3.3. Other control Techniques in DPS

AGC modeled using PI controller and then the steady state error elimination is done by using PID controller, which eliminates the error up to a great extent [33]. Sekhar and Vaisakh (2013) given VSC/SMC Controllers (variable structure control based on sliding mode control (VSC/SMC)) for AGC in deregulated environment to attain high-performance and robustness of AGC [27]. This approach combines the options of each variable structure Control and slippery mode Control. The results reveal that the projected controllers remain quite insensitive to parameter variations and speed governor dead band with or without generation rate constraints.

Decentralized Active Disturbance Rejection Control (DADRC) has been designed to enhancement AGC Control performance in multi-area power systems under deregulated environment (Hao et al, 2014) [9]. This Control the Decentralized Control performance is commonly improved by taking the quantity of interactions dynamic in consideration.

In another study, distributed Control systems structure has been projected for deregulated large-size power systems [29]. during this framework, the big system is rotten to many subsystems, wherever every controller regionally controls its own system. additionally, the controllers exchange info between them via communication bus. Distributed Control systems were found to be appropriate for large-size systems if the correct nonlinear Control has been chosen. This approach doesn’t want the entire model of the power system and disturbances. Thus, an Extended State Observer (ESO) is employed for estimating unidentified generalized disturbances. The approach achieves a decent disturbance rejection performance and its easy structure may be simply enforced in apply. However, DADRC is related to worse performance once anti- GRC isn't optimized.

To overcome the constraints on deregulated large-scale system the above Control methodology, in 2016, Ma et al., (2016) projected a brand-new Distributed Model prophetic Control (DMPC). The AGC issue with contracted and uncontracted load demands was developed as a pursuit Control issue of large-scale system in presence of external disturbances and constraints. DMPC won't be sensible for real time applications for the accurate information, the closed loop stability performance the optimization step size and online optimization time.

4. CONTROL DESIGN STRCTURES

In terms of Control structure, centralized load frequency Control is rare usually to be thought-about for deregulated grid. For large-size systems, it's too complicated and troublesome to implement and tune the controllers (Tyagi and Srivastava, 2006) [20], due to the robustness and specified stability, communication Bandwidth limitations and inherent computational complexness [12]. Decentralized Control Structure has been projected to several massive multivariable systems, as well as deregulated grid. The decentralized theme is simple to be enforced in apply and conjointly reduces the complexness that's related to the centralized Control theme [19][31]. However, the changing performance is also degraded just in case the interactions effects don't seem to be thought-about between adjacent subsystems, that assumes there, are not any tie-line power flow exchanges, and will lead to poor system performance [9]. The decentralized Control performance is commonly improved by taking the quantity of interactions dynamics in thought. Recently, distributed Control systems framework has been projected for deregulated large-size power systems [29]. During this framework, the big system is rotten to many subsystems, wherever every controller regionally controls its own system. Additionally, the controllers exchange info between them via communication bus. Distributed Control systems were found to be appropriate for large-size systems if the correct nonlinear Control has been chosen.

***Table 1**: Summary of various control methods’ capabilities and drawbacks in deregulated Power system.*

S.No	Control Method	Capabilities of the method	Drawbacks of the method
1	Conventional linear control (P,PI,PD and PID)	Simple design and implementation.	-takes more time and gives large frequency deviation. -fail to provide best control performance over a wide range of operating conditions.
2	Newton-Raphson	Bilateral contracts simulation, achieves optimum integral control gains and frequency bias.	Simulation study only and not tested on real time power system
3	GA+ LMI	Robust against load disturbances, low control order.	Simulation study not tested on real time power system.
4	ANFIS based on PSO	-Provides good dynamic response for the both control areas frequency deviations and tie-line power error. -Adaptive control	PSO took long time to compute the optimal gains, which is impractical for real time applications.

S.No	Control Method	Capabilities of the method	Drawbacks of the method
		gains can be updated in real – time.	
5	ANFIS based on ANN	Simple structure, easy implementation and high robustness capabilities.	Bigger training set is needed in order to enhance the efficiency of the controller which in turn increases the calculation time which impractical in real time.
6	BBO	-Robust against load changes and inertia constant - Very good dynamic responses terms of settling time, peak deviation and magnitude of oscillation.	The parameters B and R were selected based on trial and error guidelines.
7	QOHS-PID	Promising optimization method for complex multi unit's power systems in presence of various nonlinearities and physical constraints.	Simulation study only, communications delays were not considered in the study.
8	H_∞ control	Robust against disturbances for large scale power Systems	yields a higher order control
9	μ synthesis control	Effective for disturbances rejection.	Has Low frequency regulation in presence of uncertainties and load variation.
10	H_2/H_∞	Has good tracking error and stability performances and robust for bilateral contracts.	Requires static feedback synthesis and LMI for robust control design.
11	VSC/SMC	Insensitive to parameter variations, nonlinearities and physical constraints as well it requires low computational cost.	Chattering effects was not considered which makes its implementation impractical.
12	DMPC	Formulates the AGC problem as a tracking control Problem of large-scale system in presence of both external disturbances and constraints, bounds. -Improves the closed performance.	Model based approach; the closed loop stability performance is dependent of constraints and the on-line optimization needs expensive computational power.

5. DISCUSSION

Conventional Control design was easy however takes longer and offers huge frequency deviation [23]. Fixed gain Controllers are designed at nominal operative conditions and fail to produce best control performance over a large vary of operative conditions [21]. Individually intelligent Control strategies and optimization algorithms are known as soft computing strategies [30]. Artificial intelligent Control strategies like symbolic logic Control, artificial neural network, reinforcement learning and ANFIS ar model freelance strategies, however they're time intense, rough to design and not economical within the business [24]. On the opposite hand, the optimization algorithmic programs like genetic algorithm (GA) [5], Hybrid Particle Swarm optimization (PSO)[18], microorganism hunting (BF) algorithmic program [4], and Differential Evolution (DE) algorithmic program [8] have shown changing improvement, however don't seem to be tested to a additional realistic grid model, considering time-delay, governor dead band and GRC, all-together, as obligatory in time period grid beneath deregulated regime. These limitations of the mentioned optimization algorithmic programs are addressed by Shiva and Mukherje (2016) [25] mistreatment quasi-oppositional harmony search algorithm. However, the communication delays were not still solved. Robust Control design like H∞, μ synthesis and mixed H2/H∞ schemes secure control system robust stability from disturbances and achieved acceptable frequency regulation in presence of uncertainties and load variation. However, they were restricted to constraints uncertainties and within the most cases provided conservative answer with higher order Control. On the opposite hand, the advanced Control designs such variable structure with slippery mode Control and distributed model prophetic Control are model primarily based schemes which require correct info of the plant, so that they don't seem to be sensible for big size power systems. For latest approach a nonlinear multi-agent feedback linearization method is adopted for optimal load frequency control of a power system with wind generation units. In this Multiagent controllers with both distributed and decentralized structures are proposed and executed and centralized feedback controller is also applied for comparison purposes [40].

6. CONCLUSION

A detailed survey of Automatic Generation Control in the deregulated environment has been recorded in the literature. The system performance characteristics explain that the performances of various types of controllers try to bring the system back to steady state. The increasing in size and complexness within the interconnected Power system makes it difficult to Design a controller and analyses the performance for the whole system. a number of the higher than mentioned Control strategies couldn't deliver the goods satisfactory performance since the results of physical constraints like GRC and Load reference set-point limitation and dead band not expressly thought-about within the controller style and completely unavoidable on the systems throughout simulation. Therefore, to attain higher Control performance, some level of communication should be established between the various subsystems and AGC issue methodology, must turn out distributed control of the interconnected power system.

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