Automatic Generation Control of Three-Area Hydro Thermal Power System with Generation Rate Constraints

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Abstract—Invasive Weed Optimization (IWO) algorithm is a novel population based stochastic, derivative free optimization algorithm inspired by biological growth of weed plants. In this paper, the effectiveness of IWO has been tested to design Fuzzy Proportional Integral Derivative (FPID) controllers for Automatic Generation Control of three area power system. The proposed approach is applied to a three area hydro thermal power system with appropriate Generation Rate Constraints. The superiority of the proposed approach is demonstrated by comparing the results with Adaptive Neuro Fuzzy Inference System (ANFIS) and hybrid Bacteria Foraging Optimization Algorithm and Particle Swarm Optimization (hBFOA–PSO) based controllers for the similar power system. Finally, the efficiency of the proposed controller design is verified with pulse type of loading pattern.

I. INTRODUCTION

The automatic Load Frequency Control (LFC) is basically a part of Automatic Generation Control AGC) plays an important role in power pool by maintaining scheduled system frequency and scheduled tie-line power in normal operation and during small perturbations. The purpose of LFC is to maintain frequency of each area and to keep tie line power flows at their pre-specified values by adjusting the real power outputs of the participating generators so as to accommodate the fluctuating load demands. The Area Control Error (ACE) which is a linear combination of net interchange and frequency errors as the controlled output of AGC is driven to zero in order to make the frequency and tie line power deviations of control area to zeros[1]. Over the years several strategies have been proposed for LFC of power systems in order to maintain the system frequency and tie line power flow at their scheduled values during normal operation and also during small perturbations. In this regard intelligent controllers are gaining importance for reliably control of power system. While considerable progress has been made in the development of intelligent controllers and their applications to AGC still remain a challenging task. Early work on AGC was started by Cohn [2] but the design of modern optimal controller concept for interconnected power system was initiated by Elgerd and Fosha [3]. Talaq and Al-Basri [4] have suggested an adaptive fuzzy gain scheduling method for conventional PI controller which gives better performance than the conventional controllers. It is observed from literature survey that a linear model around nominal operating point with fixed controller has been considered in most of the work for AGC studies. However, because of the inherent characteristics of changing loads, the operating point of a power system may change often during a daily cycle. Therefore, a fixed controller may not work satisfactorily under varying operating point. In order to solve this problem variable structure control have been reported [5] pertaining the controller insensitive to system parameter changes under study. However, this method requires a lot of information of the system states which are completely unknown. Fuzzy logic controllers were introduced by many researchers to overcome these above problems. The advantage of fuzzy gain scheduling approach is that the controllers can be changed very quickly in response to changes in the system dynamics because no parameter estimation is required. However, the main drawback of conventional gain scheduling is that the system parameter may change abruptly across the regional boundaries which may lead unsatisfactory or even unstable performance across the transition regions. To overcome the problems of conventional gain scheduling, Chang et al. have proposed a fuzzy rule based scheme for gain scheduling of PI controllers [6]. The various fuzzy logic controllers tuned by intelligent algorithms such as self tuning fuzzy type PID controller [7], Particle Swarm Optimization (PSO) optimized fuzzy

PID controller [8], PSO based adaptive fuzzy PID controller [9], Artificial Bee Colony (ABC) algorithm [10], Lozi map based Chaotic Optimization Algorithm (LCOA) PID controller [11], Teaching Learning Based Optimization (TLBO) PID controller [12], TLBO algorithm based fuzzy PID controller [13], conventional integral controllers in multi area hydrothermal system considering generation rate constraints (GRC) [14], Adaptive Neuro Fuzzy Inference System (ANFIS) based control [15], Hybrid Bacteria Foraging Optimization Algorithm with PSO (hBFOA-PSO) optimized PI controllers [16] of multi area power system have successfully been employed in AGC studies.

II. SYSTEM UNDER STUDY

A. Three-area hydro thermal power system with generation rate constraints

To demonstrate the capability of the proposed algorithm to deal with nonlinearity and multiple tie-lines, the study is subjected to a three area system [14-16] considering both thermal and hydro units with different controllers for each area. The transfer function model of three area system is adopted from reference [16] and also shown in Fig, 1. For thermal units a generation rate constraints (GRC) of 3%/min is considered. For hydro unit, GRC's of 270%/min for raising generation and 360%/min for lowering generation are considered. The relevant parameters are given in Appendix.

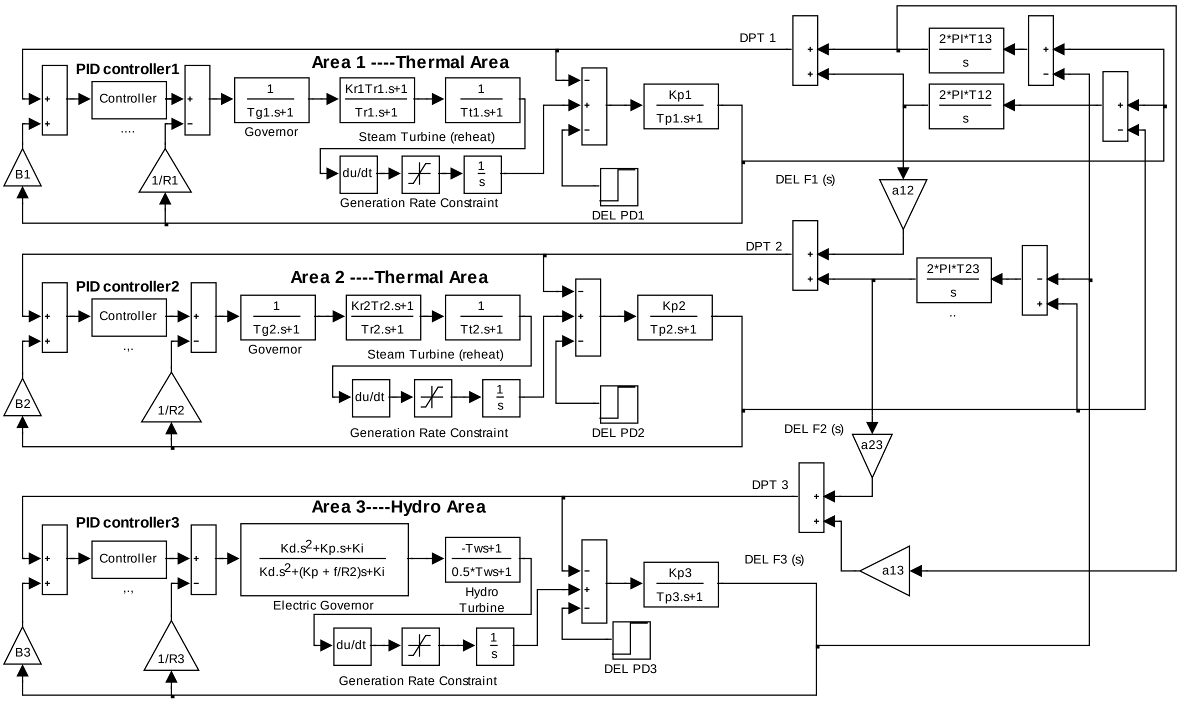

Fig. 1. Transfer function model of model of three-area hydro-thermal system with generation rate constraint

The objective function for three area hydro system is given in equation (1).

$$J_1 = \int_0^{t_{sim}} \left(|\Delta\omega_1| + |\Delta\omega_2| + |\Delta\omega_3| + |\Delta Pt_{13}| + |\Delta Pt_{12}| + |\Delta Pt_{23}| \right).dt \qquad (1)$$

Where, ΔPt_{13}, ΔPt_{12} and ΔPt_{23} are the tie-line power deviations between respective areas.

III. FUZZY PID CONTROLLER

The overall structure of fuzzy PID controllers of all area like area1, area2 and area3. It is basically a combination of fuzzy PI and fuzzy PD controller. The performance of fuzzy PID controller depends on the input scaling factors K_1 and K_2 and K_3 and K_4 output scaling factors. An identical fuzzy PID controller is also equipped in area2 and in area 3 having similar input scaling factors andoutput scaling factors. The Fuzzy Logic Controller (FLC) have two inputs as ACE and rate of change of ACE and output u1 which are transformed in to linguistic variables. There are five linguistic variables such as NB (Negative Big), NS (Negative Small), Z (Zero), PS (Positive Small) and PB (Positive Big). The two-dimensional rule base for error, error derivative and FLC output. In the present study, fixed membership functions and rule base are assumed for the FLC structure. The input scaling factors and output scaling factors are optimized employing IWO algorithm to minimize the objective function.

IV. RESULTS AND DISCUSSION

To tune the PID controller parameters, the IWO based computational procedure is followed. The final controller parameters obtained for each area using proposed IWO algorithm employing objective function given in Eq. (1) are:

Area-1: K_1 = 0.7717, K_2 =0.6890, K_3 =0.6890, K_4 =0.3642;
Area-2: K_5 = 0.0723, K_6 =0.9178, K_7 = 0.1019, K_8 =0.7482;
Area-3:K_9=0.7841, K_{10} =0.3525, K_{11} =0.0202, K_{12} =0.0154;

A 1% step load disturbance is applied simultaneously in all the three areas at t=0 sec and the system responses are shown in Figs. 2-4. For comparison the simulation results with conventional integral controller [14], ANFIS based controller [15] and hBFOA-PSO [16] based controller are also shown in Figs. 2-4. Critical analysis of the system dynamic responses clearly shows that performance of the system is significantly improved with proposed approach compared to some recently reported approaches.

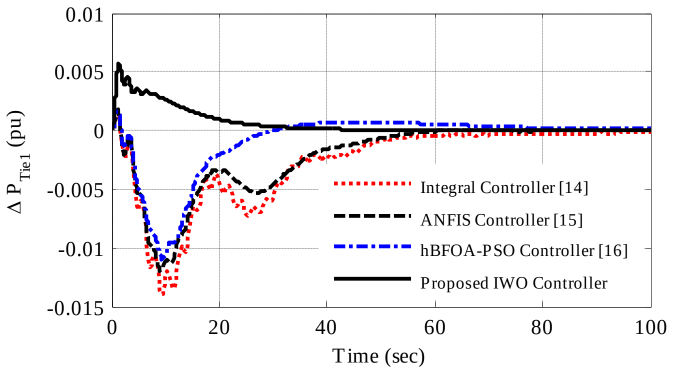

Fig. 2 Tie-line power deviation in area 1 for 1% SLPs in all areas

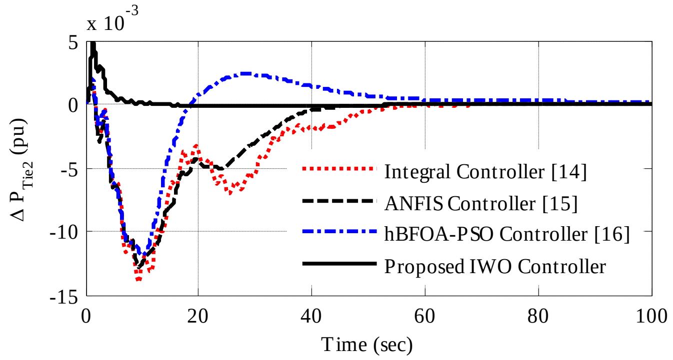

Fig. 3 Tie-line power deviation in area 2 for 1% SLPs in all areas

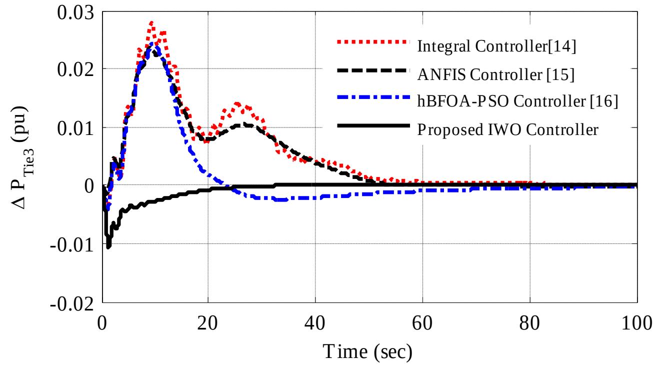

Fig. 4 Tie-line power deviation in area 3 for 1% SLPs in all areas

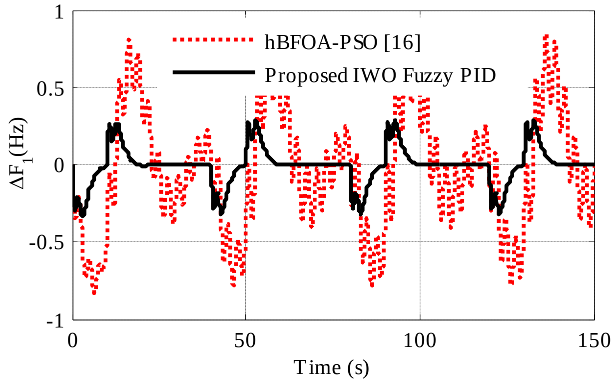

Fig.5Frequency deviation of area-1with pulse load pattern

V. PULSE LOAD PATTERN

To investigate the effectiveness of the proposed Fuzzy PID controller, pulse type of random load disturbance is applied to area-1 of three area hydrothermal system. The nature of a random pulse load disturbance [17] is considered. The frequency response for pulse load disturbance is shown in Fig. 5. From Fig. 5, it is ensured that the system performs well with proposed approach.

V. CONCLUSION

The proposed approach is applied to a three area hydro thermal system with Generation Rate Constraints (GRC). It is observed that the proposed approach gives superior performance compared some recently proposed controllers such as conventional integral controller, ANFIS based controller and hBFOA-PSO optimized controller for the same interconnected power system. Finally, one type of random load patternis applied in area-1 to validate the superiority of the proposed approach. One can see from simulation results that proposed controller performs better against pulse load pattern in comparison to hybrid BFOA-PSO optimized controller.

APPENDIX

Nominal parameter of the three area hydro thermal power system [14, 15, 16]:
f = 60 Hz; $B_1 = B_2 = B_3$ = 0.425 p.u. MW/Hz; $R_1 = R_2 = R_3$ = 2.4 Hz/p.u. MW; $T_{G1} = T_{G2}$ =0.08 s; $T_{r1} = T_{r2}$ =10.0 s; $T_{T1} = T_{T2}$ = 0.3 s; T_W = 1.0 s; T_R = 5 s; $K_p = 1$; $K_d = 4$; $K_i = 5$; Nominal power system parameters: $K_{PS1} = K_{PS2} = K_{PS3}$ = 120 Hz/p.u. MW; $T_{PS1} = T_{PS2} = T_{PS3}$ =20 s; $T_{12} = T_{23} = T_{31}$ = 0.086 pu; $a_{12} = a_{23} = a_{31}$ = -1. $\Delta P_{D1} = \Delta P_{D2} = \Delta P_{D3}$ =0.01 p.u. MW.

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