

Design of GA Tuned Two-degree Freedom of PID Controller for an Interconnected Three Area Automatic Generation Control System

A. Ruby Meena* and S. Senthil Kumar

Electrical and Electronics Engineering Department, Government College of Engineering,
Salem, India; rubymeena77@gmail.com

Abstract

In this paper an innovative controller named parallel two-degree freedom of PID controller has deliberated and employed in an interconnected three area reheat thermal power system. The optimal controller gains obtained by using Genetic algorithm and the Integral Time Squared Error (ITSE) employed as an objective function. To realize the system practically, physical constraints like generator rate constraints and governor dead band nonlinearities have considered. To compensate the loss of kinetic energy during sudden load increase Superconducting Magnetic Energy Storage used in each area. The results gained by using GA tuned parallel two-degree freedom PID controller has compared with the conventional Ziegler's Nichols tuned PID controller and genetically tuned PID controller. The GA tuned parallel two-degree freedom of PID controller produces better transient response characteristics for frequency and tie line power deviations under step load perturbations. The system simulation have realized by means of MATLAB/SIMULINK software.

Keywords: Area Control Error, Automatic Generation Control, Frequency Deviation, Genetic Algorithm, Proportional Integral Derivative Controller

1. Introduction

Automatic Generation Control (AGC) is a significant topic in power system design and operation to regulate the system frequency and Tie-line power within the tolerable values and to supply consistent electric power with excellence. The demand of control area rapidly varies for an interconnected power system leads to frequency and tie line power deviations. But normal operating conditions of the power system depends on constant frequency¹⁻⁴. The deviations should be driven back quickly to zero for a good automatic generation control design. Various Automatic Generation Control techniques have introduced to get better transient response characteristics. The normal PID controller is always superior to the PI and PD controller due its actions like proportional, integral

and derivative of an error signal^{5,6}. While optimizing the gains using intelligent techniques the transient response has further improved. To get optimal gains and better response various methods like state feedback, soft computing techniques such as Neural Network, fuzzy logic, and evolutionary algorithm based controllers implemented in single and multi area power system⁷⁻¹². Type 2 fuzzy controllers have considered and imposed in a multi area power system excluding nonlinearities¹³. Although the various intelligent controllers used in many research articles, they consider mostly two area power system excluding nonlinearities. This paper deals with three interconnected control areas including Generator Rate Constraints (GRC) and dead band nonlinearity. GRC with the rise and lower of 10 per minute (0.0017pu/s) has considered in this study for thermal turbine¹⁴. The

*Author for correspondence

transfer function of the governor considers dead band shown in equation 1.

$$G_g(s) = \frac{0.8 - \frac{0.2}{\pi}s}{1 + T_{gs}s} \quad (1)$$

Due to the complexity of this system SMES has included in each area to compensate the loss of kinetic energy during sudden load increase¹⁵⁻¹⁸. The governor should correct the frequency variations quickly whenever load change occurs. The energy storage device provides stored energy for the sudden load change within the power system. Thus, the imbalances between the generation and demand have reduced by energy storage devices like Battery energy storage units and Superconducting magnetic energy storage units. SMES can control active and reactive power all together, and acts as one of the efficient and significant stabilizers for power system disturbances. During load disturbances, occurrence of frequency oscillations has efficiently controlled with SMES unit.

2. Controller Design

PID control becomes an essential control tool because of its past history of achievement, extensive accessibility and its use of intelligibility. This emphasizes one another for the process control and demands for a well refined controller to control a difficult process. PID controller controls the process successfully even with the increased complexity. Three different PID controllers have been applied in an interconnected three area reheated thermal power system for the automatic generation control purpose. Performance indices have been calculated to estimate a system's performance with optimum control. To get an optimum control system the system parameters regulated for a minimum value of performance index. The Integral Time Squared Error (ITSE) method, which has employed to optimize the gain values of PID controller.

2.1 Ziegler Nichol's Method

Commonly used techniques for choosing the controller gains in PID controller, is Ziegler Nichol's method which compromises between the disturbance rejection and tracking behavior. In this technique, the integral and derivative gains were moved to zero and the proportional gain has adjusted in steps and the response of the controlled variable has observed. The controlled variable

should start oscillating on the gain increased. When the amplitude of oscillations remains approximately constant the ultimate controller gain (K_{ug}) has been reached. The period of oscillations is called as ultimate period (T_{ug}). This ultimate gain and ultimate period have been applied for calculating the gain parameters of ZN tuned PID controller. The optimal gain formula using K_{ug} and T_{ug} is shown in Table 1.

2.2 GA Tuned Conventional PID Controller

Genetic Algorithm begins with a population of chromosomes which are the combinations of proportional, integral and derivative gains of PID controller. By finding several crests concurrently, GA finds the global optimum by evaluating the performance objectives and decreases the chances of catch into a local optimum¹⁰⁻²¹. The controller gains are coded as binary bits of string called chromosomes and its length is based on accurateness. Objective function value of each chromosome is calculated in order to find the optimum. The fitness value of all the chromosomes in each generation will be evaluated using the performance objectives. According to the Objective function value, parent chromosomes have chosen for the next generation. Then crossover and mutation carried out among the selected parent chromosomes. The gain has arrived at the global minima, when all the strings in the population have the same Objective function value. ITSE method employed to find the fitness function or performance objective and the controller gains have optimized using GA. The optimized gains are substituted as controller gains and the power system has simulated and analyzed for the new gains. The flow graph for the genetic algorithm is illustrated in Figure 1.

The performance index J for the optimization of controller gains is given by the following equation (2).

$$J_{opt} = \int (\Delta f_1^2 + \Delta f_2^2 + \Delta f_3^2) dt \quad (2)$$

The optimization problem for GA tuned PID controller defined as

Minimize J_{opt}

Table 1. Optimal gains

ZN tuned PID controller		
K_p	K_i	K_d
$0.75 K_{ug}$	$1.6 K_p / T_{ug}$	$K_p T_{ug} / 10$

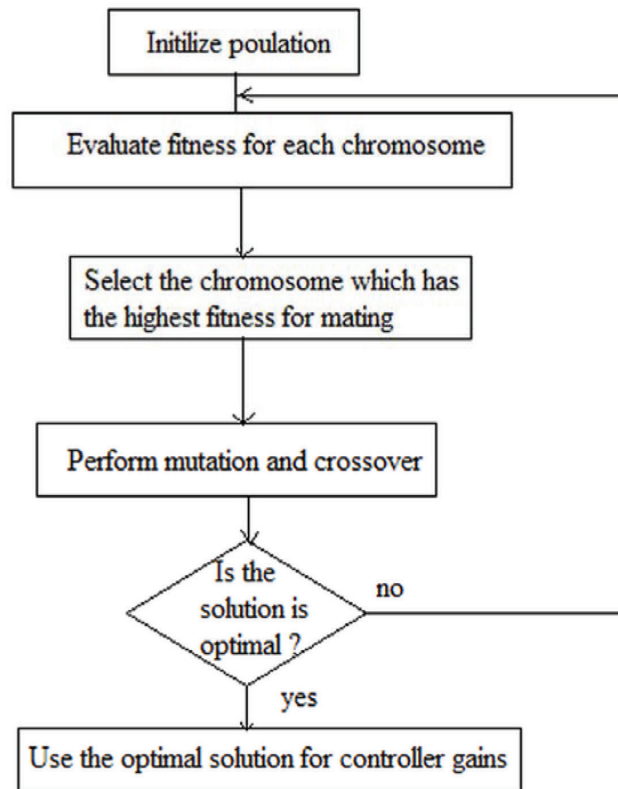


Figure 1. Flow chart for the genetic algorithm.

Subject to the constraints

$$K_p^{mn} < K_{p_i} < K_p^{mx}$$

$$K_i^{mn} < K_i < K_i^{mx}$$

$$K_d^{mn} < K_d < K_d^{mx}$$

where K_p , K_i and K_d are the proportional, integral, derivative gains of the PID controller.

2.3 GA Tuned Parallel Two-degree Freedom of PID Controller

Degrees-of-freedom plays an essential role in the configuration of the control loop. Mostly the classical control systems established in the research articles utilizes the single degree of freedom structure^{22,23}. The two degrees of freedom structure has two control components, one deals with plant uncertainties and the other deals the disturbance rejections by reference tracking^{24,25}. Using this two-degree freedom structure, the zeros can be shifted by tuning the controller gains to achieve the improved tracking behavior without affecting the disturbance rejection. The two-degree freedom controller gives output signal by comparing a reference signal and a feedback signal.

Therefore, the controller generates the output which is the weighted sum of difference signals. The gains and the proportional and derivative set points can be tuned by genetic algorithm. Due to these advantages of the two-degree structure is attempted in this paper. The structure of GA tuned Parallel Two-Degree Freedom (GAPTDF) of PID controller is depicted in Figure 2. Where $R(s)$ corresponds to reference signal, $Y(s)$ corresponds to the feedback signal and $C(s)$ is the controlled signal from the controller which can be used to control the plant.

The optimization problem for GAPTDF PID controller is defined as

$$\text{Minimize } J_{opt}$$

Subject to the constraints

$$K_p^{mn} < K_{p_i} < K_p^{mx}$$

$$K_i^{mn} < K_i < K_i^{mx}$$

$$K_d^{mn} < K_d < K_d^{mx}$$

$$K_{psp}^{mn} < K_{psp} < K_{psp}^{mx}$$

$$K_{dsp}^{mn} < K_{dsp} < K_{dsp}^{mx}$$

where K_p , K_i , and K_d are the proportional, integral, derivative gains and K_{psp} , K_{dsp} are the proportional

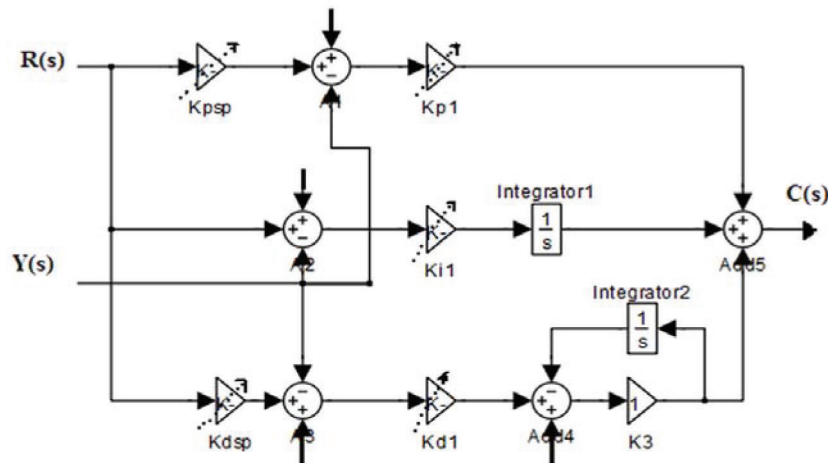


Figure 2. Structure of GA tuned parallel two-degree freedom of PID controller.

and derivative set point weights of GAPTDF PID controller.

3. Power System Model for Investigation

The power system with three control areas interconnected by tie line is considered. Each area delivers power to its own area and the exchange of power between areas done with the tie line. Therefore, the load distribution in any area has an effect on the frequencies of other areas, and also the power exchange through tie line. Therefore, a control loop is needed in order to bring the system frequency to its scheduled value.

The area control error of i^{th} area of a multi area system power system expressed as

$$ACE_i = \sum_{j=1}^n \Delta P_{ij} + \beta_i \Delta f \quad (3)$$

The Simulink diagram of three area power system for automatic generation control designed is depicted in Figure 3. Each Area is equipped with reheat thermal turbine with the consideration of GRC's and GDB's. SMES has incorporated in each area to compensate the loss of kinetic energy during sudden load change. The structure of the SMES unit is depicted in Figure 4. All the three areas are interconnected and 1% step load perturbations has given in all the three areas and the performance of Ziegler Nichol's tuned PID controller, GA tuned PID controller and GA tuned parallel two-degree freedom of PID controller was studied.

4. Results and Discussion

The three area reheat thermal power system realized using the Zieglers Nichols tuned PID controller, GA tuned PID controller and GA tuned parallel two-degree freedom PID controller. Table 2 shows the optimal gains for each controller. The following three different cases are carried out to examine the performance of the above three types of controllers.

Case 1: 1% step load perturbations given at area 1, 2 and 3 without considering GRC and Governor dead band.

Case 2: 1% step load perturbations given at area 1, 2 and 3 without GRC but considering governor dead band.

Case 3: 1% step load perturbations given at area 1, 2 and 3 considering both GRC and governor dead band.

Table 2. Optimum Gains

	Gains	ZN PID controller	GA PID controller	GAPTDF PID controller
Case 1	Kp	0.0308	0.5	0.05
	Ki	0.7880	0.5	0.0688
	Kd	0.1261	0.5	.05
Case 2	Kp	0.0308	0.5	0.5
	Ki	0.7880	0.5	0.3
	Kd	0.1261	0.1	0.1
Case 3	Kp	0.0270	0.5	1
	Ki	0.6075	0.5	0.26
	Kd	0.0972	0.1	0.01

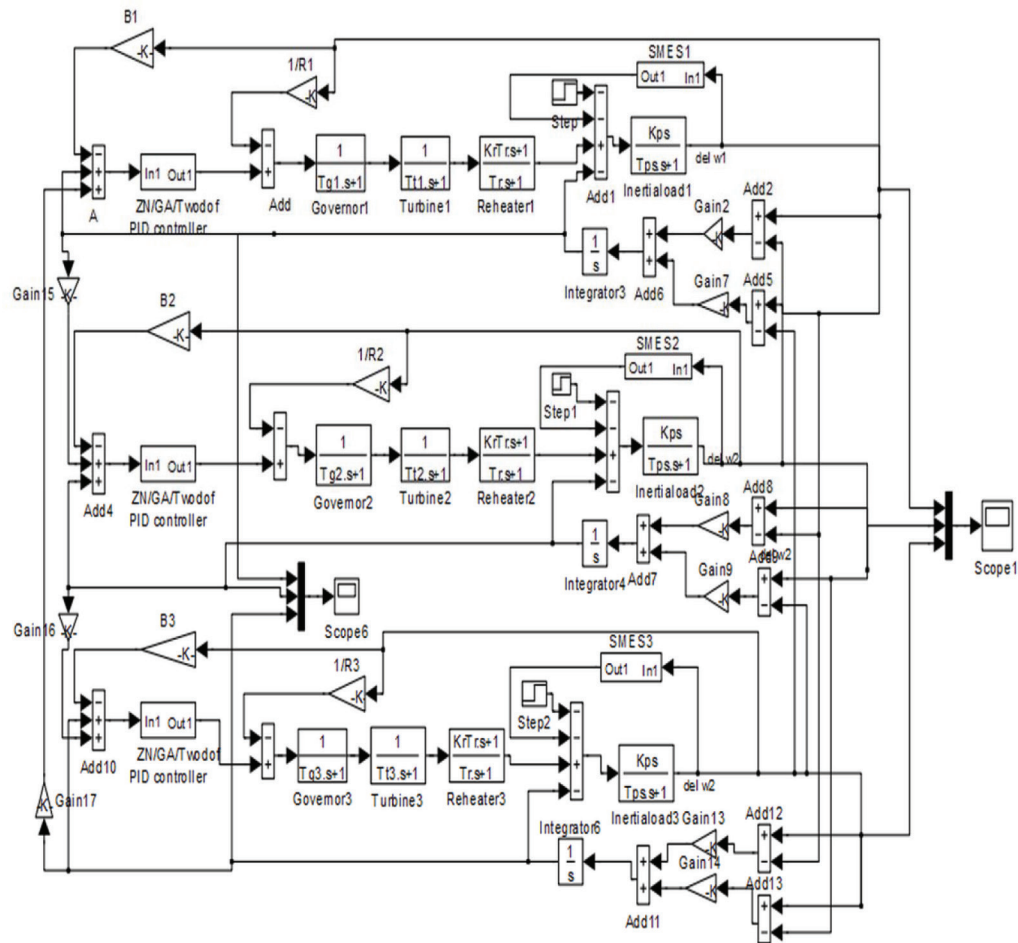


Figure 3. Simulink diagram of three area power system with GRC and GDB.

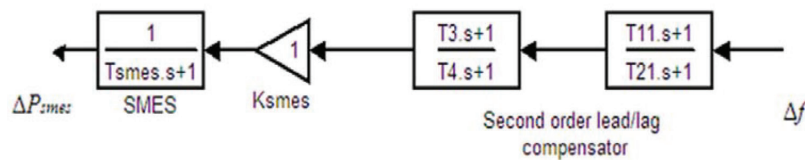


Figure 4. Structure of Super Conducting Magnetic Energy Storage unit.

In case 1 it is clear that the frequency and tie line power deviations have smaller overshoots in transient state and then becomes zero in the steady state. The frequency deviation curve of the area 1, area 2 and area 3 shown in Figure 5. It could be seen that the GAPID controller has improved response than the conventional ZNPID controller, but noticeably with increased settling time values. The response with GA tuned two-degree freedom PID controller get back speedily to zero with less peak overshoot and undershoot. The Tie line power deviation curve of the area 12, area 23 and area 31 depicted in Figure 6. Tie

line power deviation curve for case 1 has enhanced performance while using GA tuned two-degree freedom PID controller compare to the performance using other two types of controllers.

Case 2 considers only the governor dead band not including GRC, and the simulation results shown in Figure 7 and Figure 8 respectively. The parallel two-degree freedom PID controller performed well even in the existence of governor dead band.

Case 3 considers both GRC and GDB, and the frequency deviation curves shown in Figure 9 and the tie

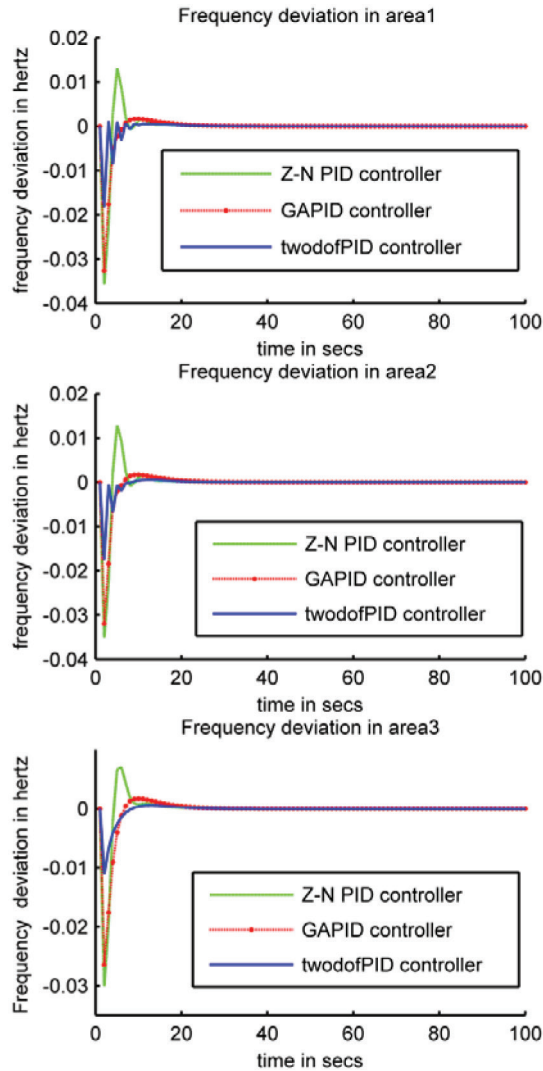


Figure 5. Frequency deviation of area1, area2, and area3 without considering GRC and GDB nonlinearity.

line power deviation curves for each tie line is shown in Figure 10 respectively. The parallel two-degree freedom PID controller performed well even with the existence of both generator rate constraint and governor dead band. The transient response specifications for frequency deviation curves in terms of peak overshoot, peak undershoot and settling time for all the three different scenarios shown in Table 3 and for tie line power deviations are shown in Table 4.

5. Conclusion

In this study, Automatic generation Control of three area reheat thermal system with GRC and GDB nonlinearity

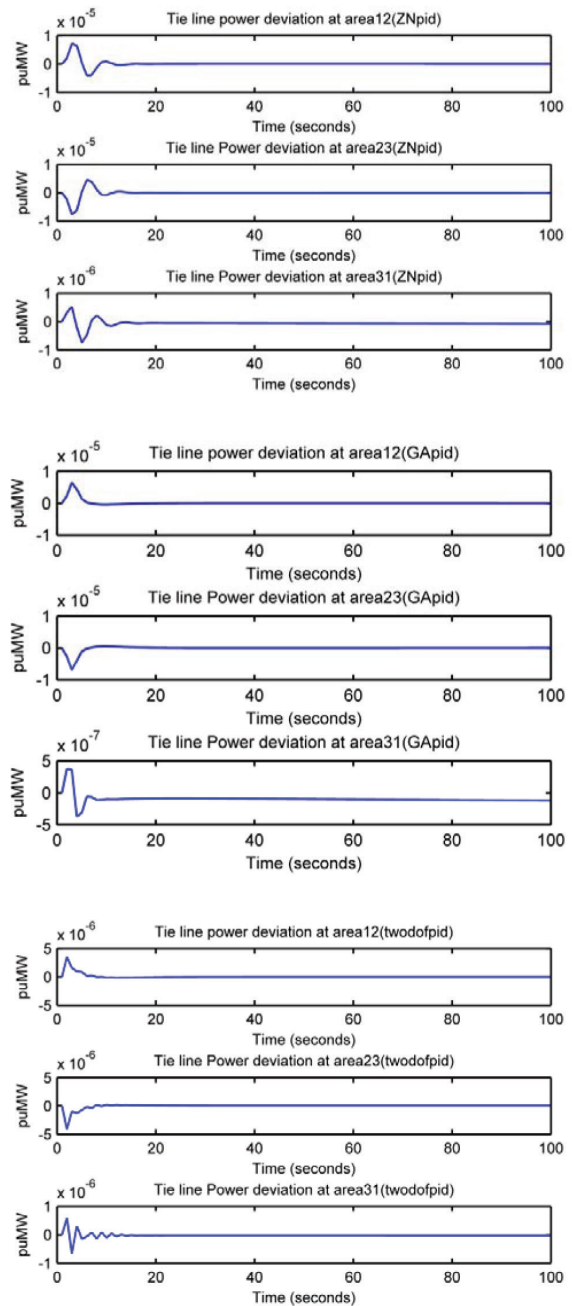


Figure 6. Tie line power deviation of area 12, area 23, and area 31 without considering GRC and GDB nonlinearity.

is employed. Due to the system complexity an SMES unit has included in each area in order to compensate the sudden rise in load. The performance of ZN tuned PID controller, GA tuned PID controller, and GA tuned parallel two-degree freedom of PID Controller is shown in the simulation results. From the results, it is observed that the GA tuned parallel two degree freedom of PID

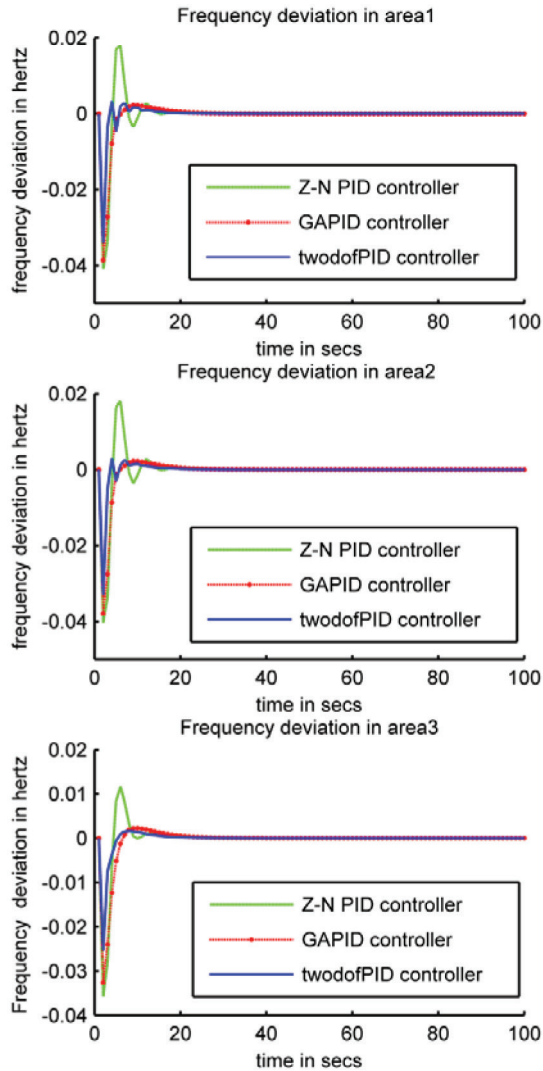


Figure 7. Frequency deviation of area 1, area 2, and area 3 including GDB nonlinearity only.

Controller has less settling time and less peak overshoot and undershoot for frequency deviation as compared to conventional ZN tuned PID controller and GA tuned single degree freedom of PID controller.

6. Appendix (A)

Nomenclature

T_g	Governor Time constant
T_t	Turbine time constant
K_r	Reheat coefficient of steam turbine
T_r	Reheat time constant
R	Speed Regulation parameter
T_{12}	Synchronizing coefficient

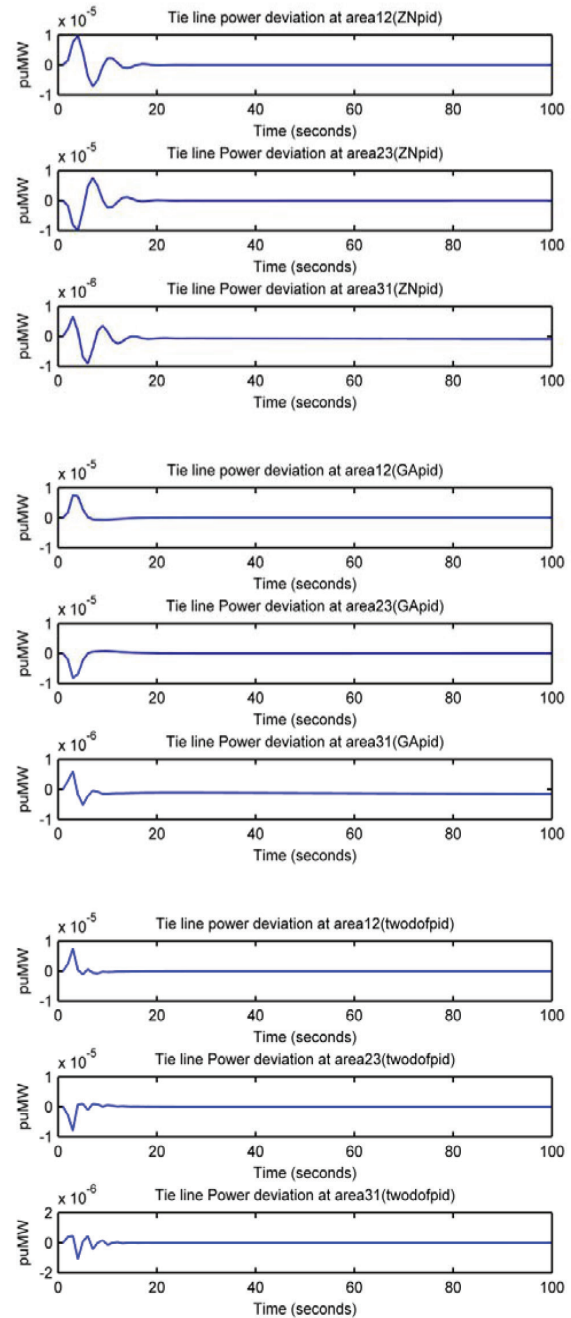


Figure 8. Tie line power deviation of area 12, area 23, and area 31 including GDB nonlinearity only.

D	Frequency sensitive load coefficient
B	Frequency bias factor
K_p	Power system gain constant
T_p	Power system time constant
K_{smes}	SMES gain constant
T_{smes}	SMES time constant

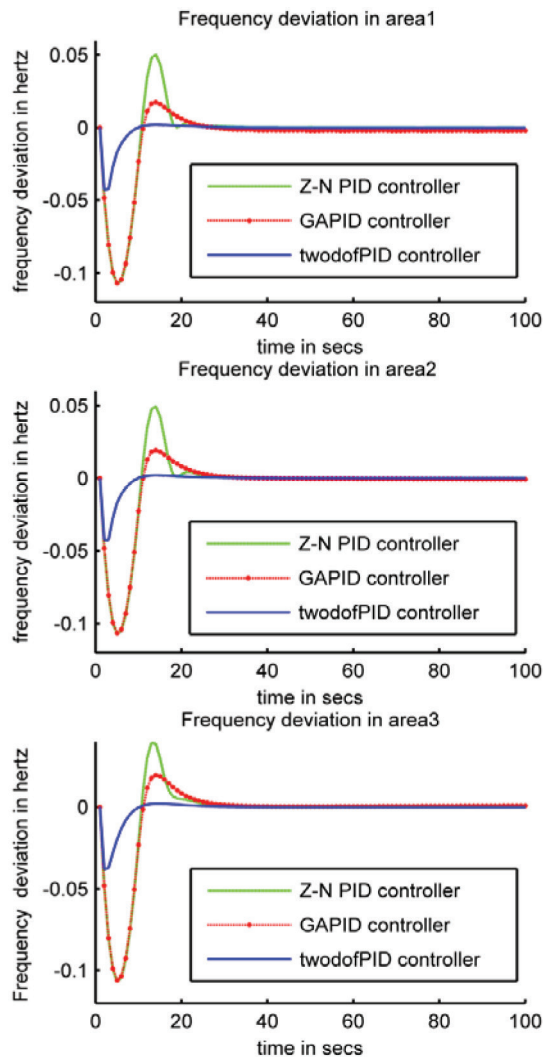


Figure 9. Frequency deviation of area 1, area 2, and area 3 considering both GRC and GDB nonlinearity.

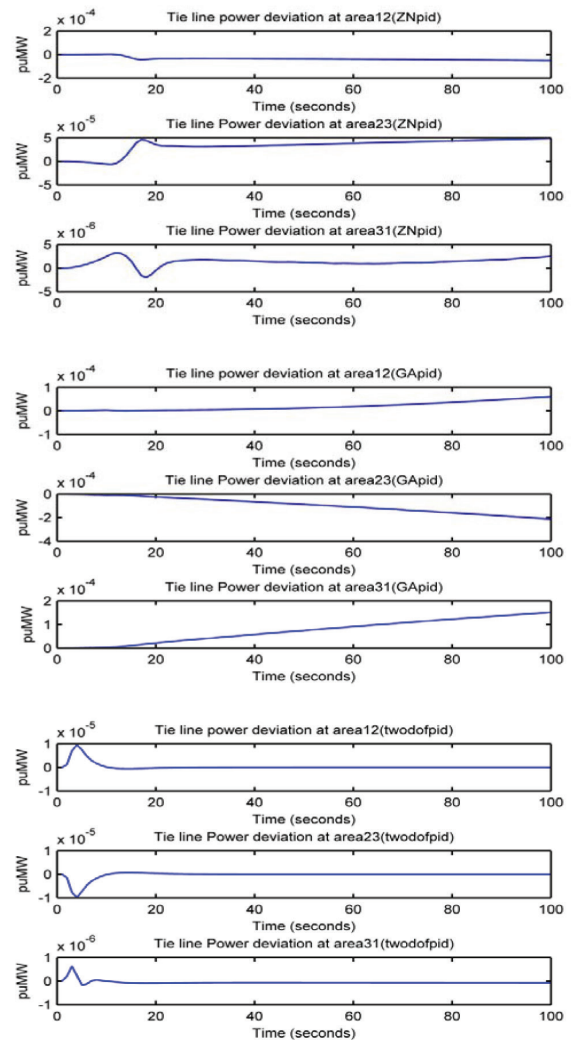


Figure 10. Tie line power deviation of area 12, area 23 and area 31 considering both GRC and GDB nonlinearity.

Table 3. Transient response specifications for frequency deviations

Time domain specifications		ZNPID controller			GAPID controller			GAPTDF PID controller		
		Δf_1	Δf_2	Δf_3	Δf_1	Δf_2	Δf_3	Δf_1	Δf_2	Δf_3
Case1	Peak Overshoot (HZ)	0.013	0.013	0.007	0.002	0.002	0.002	0.001	0.001	0.001
	Peak Undershoot (-ve)(HZ)	0.035	0.035	0.030	0.032	0.032	0.026	0.018	0.017	0.011
	Settling Time (sec)	16	16	12	18	18	18	10	10	10
Case2	Peak Overshoot (HZ)	0.017	0.018	0.011	0.002	0.002	0.002	0.003	0.003	0.001
	Peak Undershoot (-ve) (HZ)	0.041	0.040	0.036	0.039	0.038	0.034	0.034	0.033	0.025
	Settling Time (sec)	25	21	21	25	20	21	20	20	17
Case3	Peak Overshoot (HZ)	0.050	0.049	0.039	0.017	0.019	0.019	0.002	0.002	0.002
	Peak Undershoot (-ve) (HZ)	0.107	0.107	0.161	0.107	0.106	0.106	0.043	0.042	0.038
	Settling Time (sec)	28	28	28	28	30	31	17	16	15

Table 4. Transient response specifications for tie line power deviations

Time domain specifications		ZNPID controller			GAPID controller			GAPTDF PID controller		
		ΔP_{tie12}	ΔP_{tie23}	ΔP_{tie31}	ΔP_{tie12}	ΔP_{tie23}	ΔP_{tie31}	ΔP_{tie12}	ΔP_{tie23}	ΔP_{tie31}
Case 1	Peak Overshoot (HZ) $\times 10^{-4}$	0.10	0.08	0.01	0.08	0.01	0.01	0.08	0.01	0.00
	Peak Undershoot (HZ) $\times 10^{-4}$	0.07	0.10	0.01	0.01	0.08	0.01	0.01	0.08	0.01
	Settling Time (sec)	20	22	21	10	10	12	12	10	12
Case 2	Peak Overshoot (HZ) $\times 10^{-4}$	0.07	0.05	0.01	0.06	0.00	0.00	0.05	0.02	0.01
	Peak Undershoot (HZ) $\times 10^{-4}$	0.04	0.08	0.01	0.00	0.07	0.00	0.01	0.04	0.01
	Settling Time (sec)	20	13	13	6	7	10	13	16	20
Case 3	Peak Overshoot (HZ) $\times 10^{-4}$	0.03	0.495	0.03	0.61	0.00	1.51	0.10	0.01	0.01
	Peak Undershoot (HZ) $\times 10^{-4}$	0.51	0.07	0.02	0.00	2.12	0.00	0.01	0.10	0.00
	Settling Time (sec)	100	100	100	100	100	100	100	100	100

T_{11}, T_{21}, T_3 & T_4 Second order frequency stabilizer constants

6.1 Appendix (B)

Numerical Data

$T_{g1}=0.2s, T_{t1}=0.3s, K_{r1}=0.5, T_{r1}=10s, T_{g2}=0.1s, T_{t2}=0.4s, K_{r2}=0.5, T_{r2}=10s, T_{g3}=0.08s, T_{t3}=0.2s, K_{r3}=0.5, T_{r3}=10s, P_r=2000MW, f_r=60Hz, K_{ps}=120Hz/puMW, T_{ps}=20s, R_1=R_2=R_3=2.4Hz/puMW, B_1=B_2=B_3=0.425 pu MW/HZ.$

7. References

- Jaleeli N, VanSlyck LS, Ewart DN, Fink LH, Hoffmann AG. Understanding automatic generation control. IEEE Transactions on Power Systems. 1992; 7(3):1106–22.
- Ibraheem, PK, Kothari DP. Recent philosophies of automatic generation control strategies in power systems. IEEE Transactions on Power Systems. 2005; 20(1):346–57.
- Shayeghi H, Shayanfar HA, Jalili A. Load frequency control strategies: a state of-the-art survey for the researcher. Energy Conversion and Management. 2009; 50(2):344–53.
- Malik OP, Kumar A, Hope GS. Automatic generation control algorithm based on a generalized approach. IEEE Transactions on Power Systems 1988; 3(2):378–82.
- Franze G, Tedesco F. Constrained load/frequency control problems in networked multi-area power systems. Journal of Franklin Institute. 2011; 348(5):832–52.
- Nanda J, Mangala A, Suri S. Some new findings on Automatic generation control of an interconnected hydro thermal system with conventional controllers. IEEE Transactions on Energy Conversion. 2006; 21(1):187–94.
- Shayeghi H, Shayanfar HA, Malik OP. Robust decentralized neural networks based LFC in a deregulated power system. Electric Power System Research. 2007; 77(3-4):241–51.
- Al-Hamouz Z, Al-Musabi N, Al-Duwaish HA. Tabu search approach for the design of variable structure Load Frequency Controller incorporating model nonlinearities. Journal of Electrical Engineering. 2007; 58(5):264–70.
- Chang CS, Weihui Fu. Area load frequency control using fuzzy gain scheduling of PI controllers. Electric Power System Research. 1997; 42(2):145–52.
- Cam E, Kocaarslan I. Load frequency control in two area power systems using Fuzzy logic controller. Energy Conversion and Management 2005; 46(2):233–43.
- Soundarrajan A, Sumathi S. Effect of Non-linearities in fuzzy based load frequency control. International Journal of Electronic Engineering Research. 2009; 1(1):37–51.
- Shayeghi H, Jalili A, Shayanfar HA. Robust modified GA based multi-stage fuzzy LFC. Energy Conversion and Management 2007; 48(5):1656–70.
- Sudha KR, Vijaya SR. Robust decentralized load frequency control of interconnected power system with Generation Rate Constraint using Type-2 fuzzy approach. Electric Power and Energy Systems 2011; 33(3):699–707.
- Shiroei M, Toulabi MR, Ranjbar AM. Robust multivariable predictive based load frequency control considering

- generation rate constraint. *Electrical Power and Energy Systems*. 2013; 46:405–13.
15. Ise T, Mitani Y, Tsuji K. Simultaneous active and reactive power control of superconducting magnetic energy storage to improve power system dynamic performance. *IEEE Transactions on Power Delivery*. 1986; 1(1):143–50.
16. Bhatt P, Ghoshal SP, Roy R. Load frequency stabilization by coordinated control of Thyristor Controlled Phase Shifters and superconducting magnetic energy storage for three types of interconnected two-area power systems. *Electrical Power and Energy Systems*. 2010; 32(10):1111–24.
17. Ngamroo I, Taeratanachai C, Dechanupaprittha S, Mitani Y. Enhancement of load frequency stabilization effect of superconducting magnetic energy storage by static synchronous series compensator based on H_{∞} control. *Energy Conversion and Management* 2007; 48(4):1302–12.
18. Pothiya S, Ngamroo I. Optimal fuzzy logic-based PID controller for load–frequency control including superconducting magnetic energy storage units. *Energy Conversion and Management*. 2008; 49(10):2833–38.
19. Golpira H, Bevrani H, Golpira H. Application of GA optimization for automatic generation control design in an interconnected power system. *Energy Conversion and Management*. 2011; 52(5):2247–55.
20. Singh R, Kuchhal P, Choudhury S, Gehlot A. Implementation and evaluation of heating system using PID with genetic algorithm. *Indian Journal of Science and Technology*. 2015; 8(5):413–8.
21. Ghosal SP. Application of GA/GA-SA based fuzzy automatic generation control of a multi area thermal generating system. *Electric Power System Research*. 2004; 70(2):115–27.
22. Shahri ME, Balochian S, Balochian H, Zhang Y. Design of fractional–order PID controllers for time delay systems using differential evolution algorithm. *Indian Journal of Science and Technology*. 2014; 7(9):1307–15.
23. Kasilingam G, Pasupuleti J. Coordination of PSS and PID controller for power system stability enhancement – overview. *Indian Journal of Science and Technology*. 2015; 8(2):142–51.
24. Sahu RK, Panda S, Rout UK. DE optimized parallel 2-DOF PID controller for load frequency control of power system with governor dead-band nonlinearity. *Electrical Power and Energy Systems*. 2013; 49:19–33.
25. Sancheza J, Visioli A, Dormido S. A two-degree-of-freedom PI controller based on events. *Journal of Process Control*. 2011; 21(4):639–51.