Design of Proportional - Integral - Derivative controller using Ant Colony Optimization technique in multi-area Automatic Generation Control

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Abstract: This work investigates Automatic Generation Control and optimal gain setting of conventional controller for multi area interconnected reheat thermal power systems. Conventional Proportional – integral – Derivative (PID) controller is used for this investigation. Optimization of controller gain values are tuned by Integral Time Absolute Error (ITAE) traditional approach. The proposed work presents new Artificial Intelligence for tuning of controller gain values. The effectiveness and robustness of proposed technique is investigated with one percent step load perturbation in either area of the system with and without considering appropriate Generate Rate Constraint (GRC). Time domain analysis is used for the performance comparison and analysis for this work. Finally, simulation result reveals that new proposed AI based controller provide more superior response, when compared to conventional controller with and without considering the effect of non-linearity.

Keywords: Automatic Generation Control (AGC), Ant Colony Optimization, Interconnected power systems, Performance indices, Proportional –Integral-Derivative (PID) controller.

1. Introduction

The size and complexity of power systems are increases due to large power surplus. Which leads interconnection between power generation units. Power surplus is varied every instant of time and it will affect the real and reactive power of the system. Changes in real power causes effects in system frequency and tie power flow between interconnected units [12-14]. But changes in reactive power mainly affect the magnitude of voltage across the generator terminals. In order to conquer above said problem, LFC control scheme is introduce to control and regulate the real power of system. LFC plays major role, to keep the frequency and tie line power flow fluctuation within the nominal or specified limit during normal operation and small load perturbation in either area of the system.

From the fast several years many research control schemes are proposed and investigations are made to regulate the operation of power system [1-11]. The proposed schemes and investigations are incorporating various types of controller with different optimization techniques. Different types of controllers are used in the LFC, such as classical, optimal, artificial neural network [10,11], fuzzy logic[7], genetic algorithm [8], etc. Different optimization techniques are used to select the optimal gain values. Such as traditional approach, particle swarm optimization, Bee colony, ant colony optimization, bacterial foraging optimization, etc. In this investigation most commonly used industrial PI controller is used and gain values are optimized using traditional approach optimization technique. Traditional optimization techniques are Integral Time Square Error (ITSE), Integral Square Error (ISE), Integral Time Absolute Error (ITAE) and Integral Absolute Error (IAE) [6]. Here ITAE optimization technique is used for the selection of controller gain. During optimization process

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one parameter is optimized at a time, by keeping other parameters at fixed value. Similarly all the parameters are optimized by repeating this procedure. But it will take more time to optimize and result is differing from evolutionary optimization techniques. In order to overcome these problems and keep the operation of system in steady condition is most essential with implementing new efficient optimization technique.

Artificial Bee Colony (ABC) algorithm is implemented in two area interconnected reheat thermal power for the purpose tuning PI and PID controller with different cost functions and performance is compared with PSO techniques [2]. In [3] author used Bacterial Foraging Optimization (BFO) for tuning on integral controller for LFC in a two area power system. The three area AGC hydro thermal power systems with IDD controller is implemented in [3] and parameters of I, PI, PID , IDD and fuzzy IDD controllers are optimized with Bacterial Foraging for finding suitable controller. In [4]BFO algorithm is implemented in two area LFC of thermal power system for tuning of PI controller and response is compared with GA based PI controller. Stochastic Particle Swarm Optimization technique is introduced two area thermal power system for the purpose of tuning PID controller parameter and it is compared with conventional PID controller [5]. Another AI technique, Ant Colony Optimization (ACO) is used in two area hydro thermal power system for optimizing PID controller with and without considering the effect of non-linearity and response is compared with different cost functions [1, 9]. Recently many bio-inspired algorithms are developed and successfully implemented in LFC/AGC of single/Multi-area inter connected power system [17-23]. The algorithms are Cuckoo Search Algorithm (CSA), Firefly Algorithm (FA), Teacher learning Based Optimization (TLBO), Beta Wavelet Neural Network (BWNN) approach, hybrid Particle Swarm Optimization-Pattern Search (hPSO-PS) approach. Cuckoo Search Algorithm (CSA) was presented by Chaine and Tripathy [19], for tuning of integral controller gain values and Super conducting Magnetic Energy Storage (SMES) unit parameters. Sahu et al [20] presents

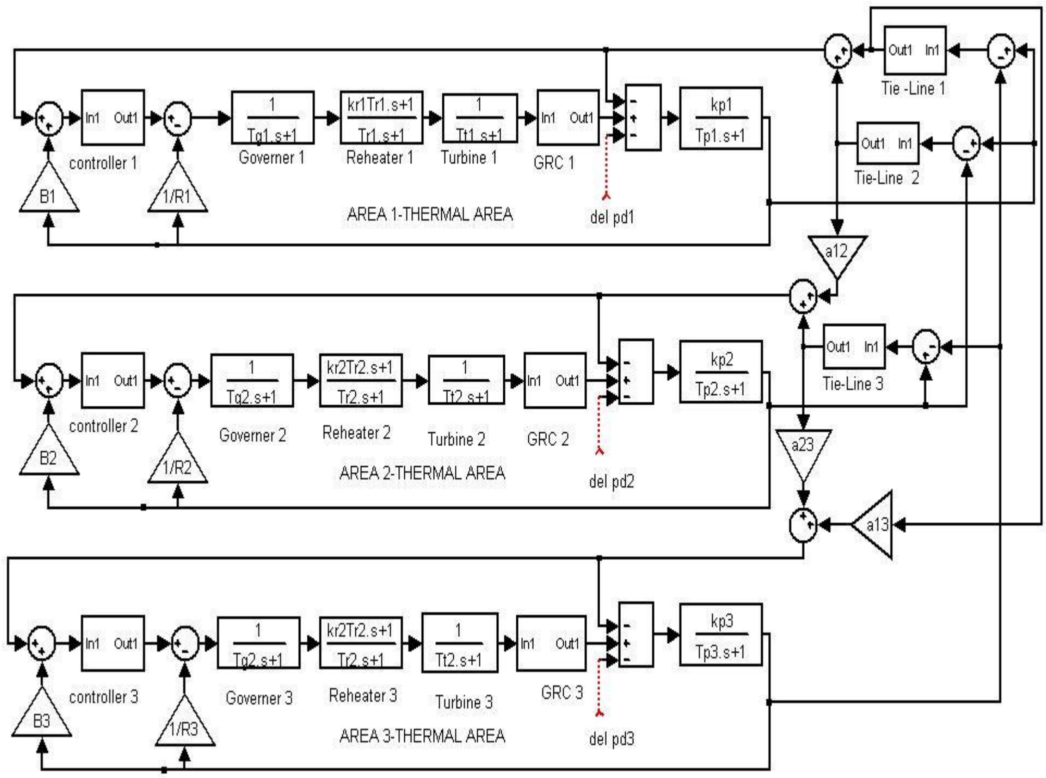

Figure 1. Transfer function model of three area interconnected thermal power systems with GRC Non-linearity

hybrid Firefly Algorithm-Pattern Search (hFA-PS) for tuning PI/PID controller gain values in automatic generation control of multi-area non-reheat thermal power system. Fuzzy PID controller gain values in multi-area non reheat thermal power system was designed and presented by Sahu et al [21] and performance was compared with Genetic Algorithm (GA), Pattern Search (PS). Proportional Integral Plus (PI+) controller was designed by Francis and Chidambaram [22], using BWNN technique for load frequency control of interconnected power system with Redox Flow Battery and hydrogen electrolyser energy storage units. Load frequency control (LFC) of two area non reheat thermal power system was presented by Sahu et al [23] with fuzzy Proportional Integral (PI) controller and the controller gain values are optimized by using hPSO-PS optimization technique. The performance of proposed technique was compared with GA-PI controller, Bacterial Foraging Optimization Algorithm, Ziegler Nichols (ZN) and Differential Evolution (DE) algorithm based controller performance.

In this work, an efficient AI based soft computing ACO is used for tuning the parameters of Proportional-Integral-Derivative (PID) controller. In the view of above discussion, the following are the main objectives of the proposed work:

- 0ptimization of conventional PID controller in three area thermal power system is obtained using traditional approach with Integra Time Absolute Error (ITAE) cost function, with and without considering non-linearity effects in all three areas.
- The efficient Artificial Intelligence based ACO technique is designed and implemented in the three area interconnected reheat thermal power systems for tuning of PID controller gain values.
- Dynamic performance of conventional PID controller is compared with proposed Artificial Intelligence technique.
- The robustness and effectiveness of proposed technique is tested by the use of one percent step load perturbation in area 1 and considering the appropriate GRC non-linearity in all areas.

2. Power system modeling

A MATLAB simulink model for AGC of a three area thermal power system with equal size of area 1: 2000MW, area 2:2000MW and area 3: 2000MW is designed for this work as shown in figure 1 [6,7]. All three areas are provided with single reheat turbine and interconnected through AC tie line. Generation Rate Constraint (GRC) non-linearity is considered in all the three areas. MATLAB 7.5(R2007b) has been used to obtain dynamic response for frequency deviations, tie line power flow out deviations and area control error in all areas. The optimal values of Proportional-Integral - Derivative controllers are tuned by using both conventional and artificial intelligence technique, Integral Time Absolute time error cost function is used for controller tuning purpose. The system dynamic performance is evaluated by considering one percent step load perturbation in area1, with and without considering the effect in all areas.

A. Generation Rate Constraint

In power plants having steam turbines [7], power generation can change within the specified maximum rate only. The generation rate for reheat unit quit low. The generation rate for most reheat unit is around 3%/min, some having the value between 5 to 10%/min. If Generation Rate Constraints (GRC) is not included means, the system is ready to compensate the large momentary disturbance. This results in wear and tear of the controller. When GRC is considered in the system, it becomes non linear and linear control techniques are not suitable for optimizing the controller gain. The GRC is considered in both areas of the systems, is to add limiters to the governors [3],[5]. The maximum rate of valve opening or closing speed is controlled by the limiter. $T_{sg}\, g_{max}$ is the power rate limit imposed by valve or gate control.

$$|\Delta \dot{Y}_E| < g_{\max} \quad (1)$$

3. Design of Proportional- Integral-Derivative Controller

The intention of implementing controller in power system is, to keep the system operation in stable and delivery of good quality power to the consumers. Proportional controller reduce the peak overshoot in the system responses and integral controller reduce steady state error into zero and the stability of the system is increased by using derivative controller. Simulink model of conventional PID controller is shown in Figure 2. The main aspire of load frequency control is to generate proper control signal, which is having the capability to keep the system parameter within the specified or nominal value [15]. The value of control signal generated by the controller can be written as follows:

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_d e(t) \quad (2)$$

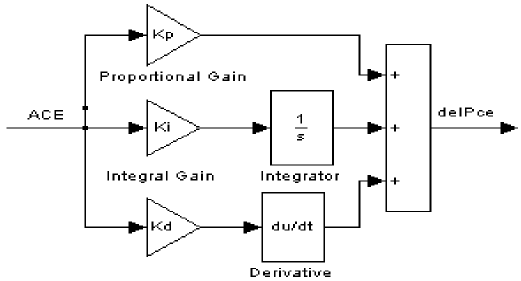

Figure 2. Structure of PID controller

Hence integral time absolute error performance cost function is used for optimal conventional controllers gain settings design[6]. A cost function

$$J = \int_0^\infty t\,|\{\Delta f_i \;\; + \Delta P_{tiei-j}\}|\,dt \quad (3)$$

is used to obtain optimum gain settings of controller gain Kp , Ki. and Kd

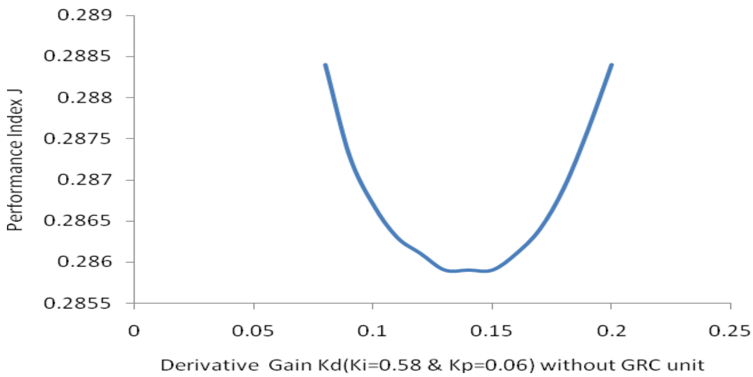

Figure 3. Cost function vs K_d without GRC

Figures 3 and 4 shows variations of cost function with various values of derivative controller gain. The values of cost functions are first decreases with increasing values of derivative gain and cost function value is decreases further increasing value of controller gain. It is seen that derivative gain Kd= 0.03 and Kd =0.15 are the optimal values of controller gain with and without considering non-linearity effect respectively.

Table 1. gain values of conventional PID controller with and without non-linearity

	Conventional PID controller gain values		
	Integral Gain Ki	Proportional Gain Kp	Derivative gain Kd
Without Non-linearity	0.58	0.06	0.15
With Non- linearity	0.37	0.006	0.3

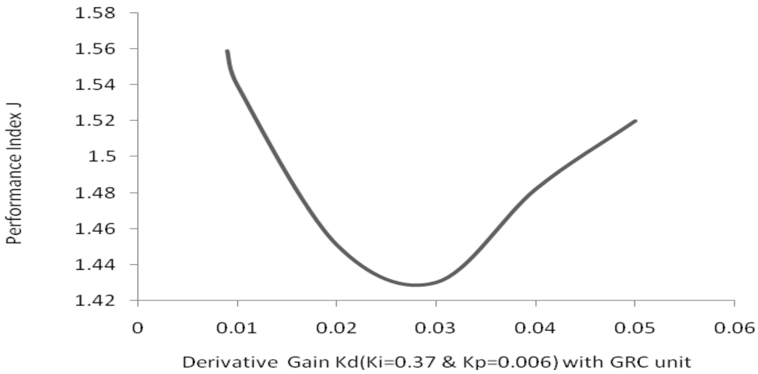

Figure 4. Cost function vs K_d considering GRC

4. Ant colony optimization

In this work new general purpose natural metaphor Ant Colony Optimization technique is used for tackling different combinatorial optimization problems. Based on the pheromone information, real ants having the capability to find the path between food source and their nest, via pheromones (aromatic substances). When ant start searching the food initially all ants explore the surroundings of their nest, in a random manner. Ant finds the food source very quickly and it evaluate the quantity and quality of the food source. During return trip , it carries some amount of food to the nest and it deposit pheromone chemical on their path. The quantity deposited chemical in the path is based on the quality of the food and it will guide for other ants to find the food source. The shortest path between their nest and food source can be identified through indirect communication of pheromone chemicals. Based on this types of real ant characteristics , it is useful for developing new artificial Ant Colony techniques for solving many discrete optimization problem. Ant Colony Optimization (ACO) initially proposed by Marco Dorigo in 1992 in his Ph.D thesis.

The transition probability from town i and j for the k_{th} ant as follows

$$p_{ij}(t) = \frac{\tau_{ij}(t)^{\alpha}(\eta_{ij})^{\beta}}{\sum_{j \in nodes} \tau_{ij}(t)^{\alpha}(\eta_{ij})^{\beta}} \tag{4}$$

The value of pheromone versus heuristic information η_{ij} is given by

$$\eta_{ij} = \frac{1}{d_{ij}} \tag{5}$$

The global updating rule is implemented in ant system as follows, where all ants starts their tours, pheromone is deposited and updated on all edges based on

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \sum_{\substack{k \in colony\, that \\ used\ edge\,(i,j)}} \frac{Q}{L_k} \tag{6}$$

Where P_{ij} – Probability between the town i and j

τ_{ij} - pheromone associated with the edge joining cities i and j
d_{ij} – distance between cities i and j
Q – constant
L_k – length of the tour performed by Kth ant
α, β – constant that find the relative time between pheromone and heuristic values on the decision of the ant
ρ – Evaporation rate

The flow chart of Ant Colony Optimization (ACO) technique is shown in figure 5. The ACO optimization technique has three main phases in the PID controller tuning process. The first phase is initialization of algorithm parameters (Number of ants, Pheromone, evaporation parameter and number of iterations), second phase is building ant solution and final phase is updating pheromone concentration. In the PID controller the optimized parameters are, Proportional gain (K_p), Integral time constant (T_i), Derivative time constant (T_d). The transition probability between I and j noe is obtained by yhe eqn.(4) and pheromone updation during ant tour is obtained by using the formula Eqn. (6).

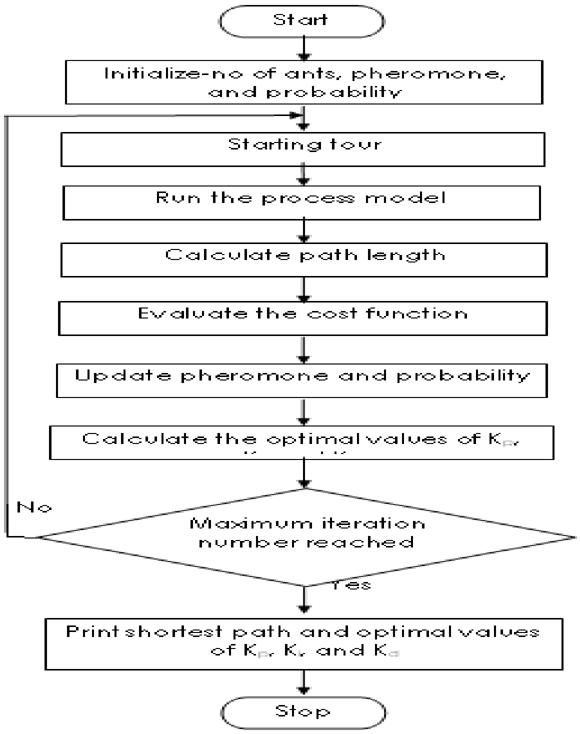

Figure 5. Flow chart of ACO technique

Table 2. Gain values of ACO PID controller with and without non-linearity

	Conventional controller gain values								
	Integral Gain Ki			*Proportional Gain Kp*			*Derivative gain Kd*		
	K_{i1}	K_{i2}	K_{i3}	K_{p1}	K_{p2}	K_{p3}	K_{d1}	K_{d2}	K_{d3}
Without Non-linearity	8.8	8.1	8.8	7.6	9	9.3	1.9	0.9	2
Without linearity	5.8	8.7	3.2	9.8	8.7	7	1.1	3.2	4

The optimal gain values of PID controller using Ant Colony Optimization technique with Integral Time Absolute Error (ITAE) cost function is given in Table 2.

5. *Tests and Simulation Results*

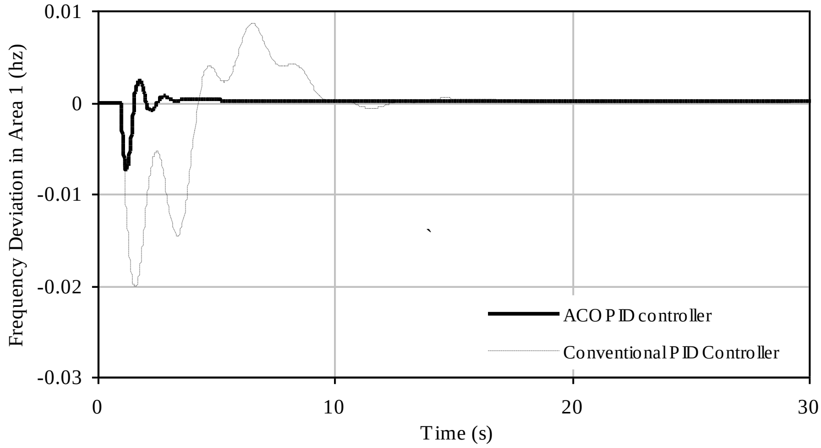

Figure 6. Controlled response without GRC non-linearity unit (delF1)

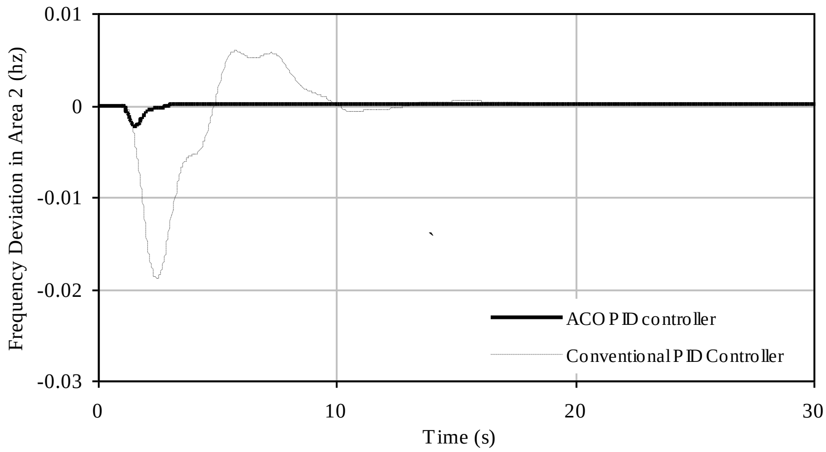

Figure 7. Controlled response without GRC non-linearity unit (delF2)

Matlab software is used for the simulation purpose. The design of investigated power system model is discussed in section II, suitable controller is designed and proposed technique is discussed in section III and IV respectively. In order to check the quality and effectiveness of the proposed controller is tested with 1% of step load perturbation in thermal area 1, it is compared with conventional PID controller. The existing and proposed technique based controller gain values are given in the table I and II. Figures 6-14 illustrates the simulation comparison of conventional PID and ACO based PID controller response of AGC system without GRC non-linearity and Figures 15-23 illustrates the simulation comparison of conventional PID and ACO based PID controller with the presence of GRC non-linearity in all the areas. It is clearly shows that the proposed optimization (ACO) technique reduces the system parameters (settling time, overshoot and damping oscillations) very well compared to conventional technique.

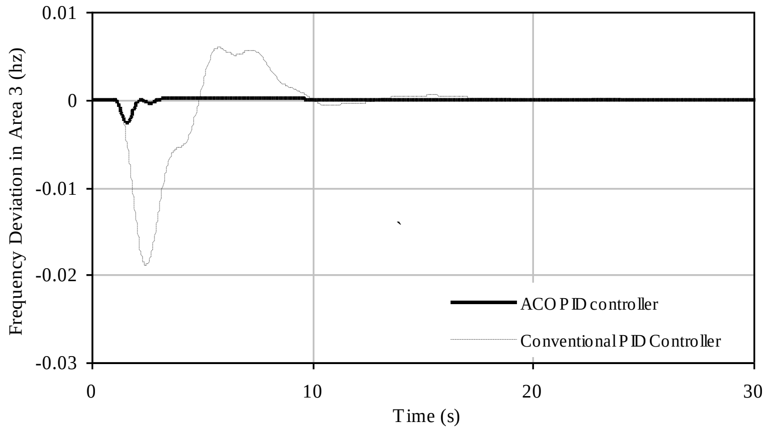

Figure 8. Controlled response without GRC non-linearity unit (delF3)

The frequency deviation comparisons of dynamic response of proposed and existing controllers are shown in figures 6-8. The domain parameters overshoots and settling times are noted and values are shown in table 3. The settling time, overshoot and damping oscillations of the proposed techniques based controller is less than existing controller without considering the GRC non-linearity in all the areas.

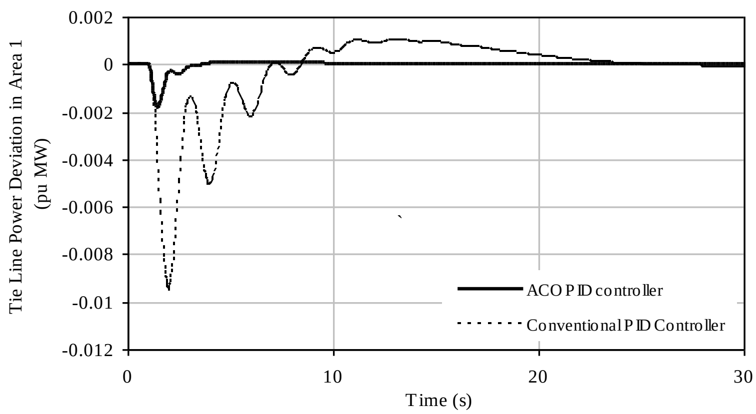

Figure 9. Controlled response without GRC non-linearity unit (delPtie1)

Table 3. Maximum overshoots and settling times of the frequency deviations by using conventional PID and ACO PID controller without non-linearity effect

		PID controller with			
		Conventional technique		ACO technique	
Fig, No	Response	Peak overshoot	Settling time (Sec)	Peak overshoot	Settling time (Sec)
6	delF1	-0.02018	20	-0.00736	11.47
7	delF2	-0.01888	18.61	-0.00237	13
8	delf3	-0.01888	18.77	-0.00269	10.8

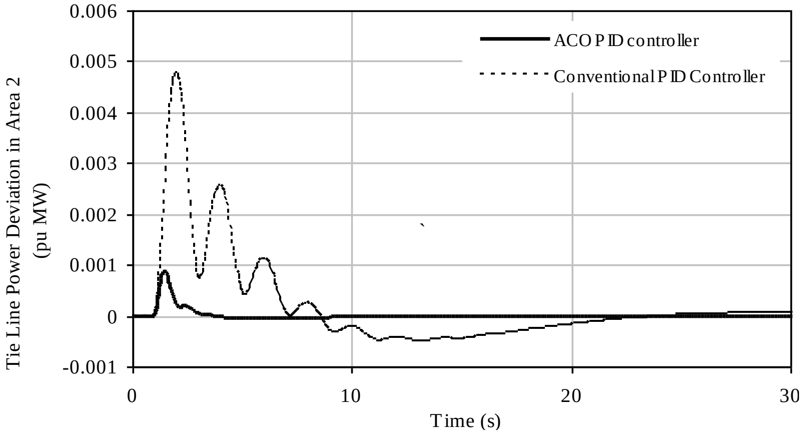

Figure 10. Controlled response without GRC non-linearity unit (delPtie2)

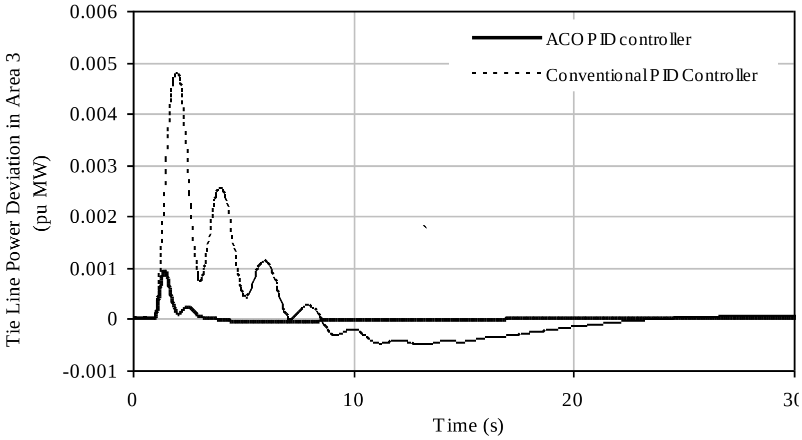

Figure 11. Controlled response without GRC non-linearity unit (delPtie3)

The tie line power deviation comparisons of dynamic response of proposed and existing controllers are shown in figures 9-11. The domain parameters overshoots and settling times are noted and values are shown in the table 4. The settling time, overshoot and damping oscillations of the proposed techniques based controller is less than existing controller without considering the GRC non-linearity in all the areas.

Table 4. Maximum overshoots and settling times of the tie line power deviations by using conventional PID and ACO PID controller without non-linearity effect.

		PID controller with			
		Conventional technique		ACO technique	
Fig, No	Response	Peak overshoot	Settling time (Sec)	Peak overshoot	Settling time (Sec)
9	delPtie 1	-0.00952	27	-0.00181	17.75
10	delPtie 2	0.00476	28	0.00088	16.4
11	delPtie 3	0.004758	26	0.000927	14.76

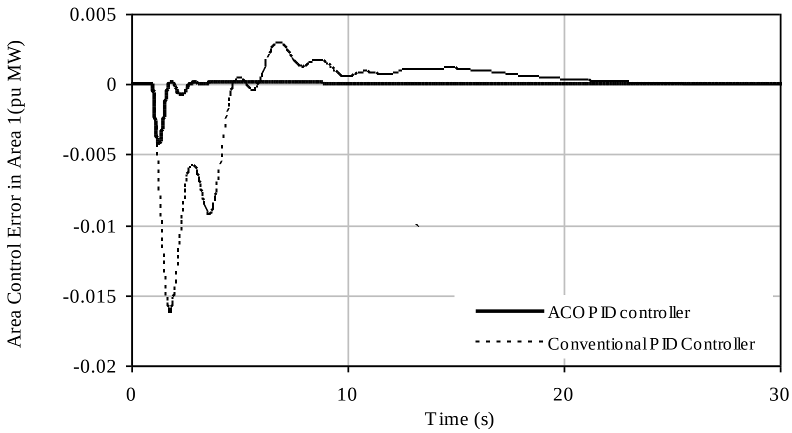

Figure 12. Controlled response without GRC non-linearity unit (ACE1)

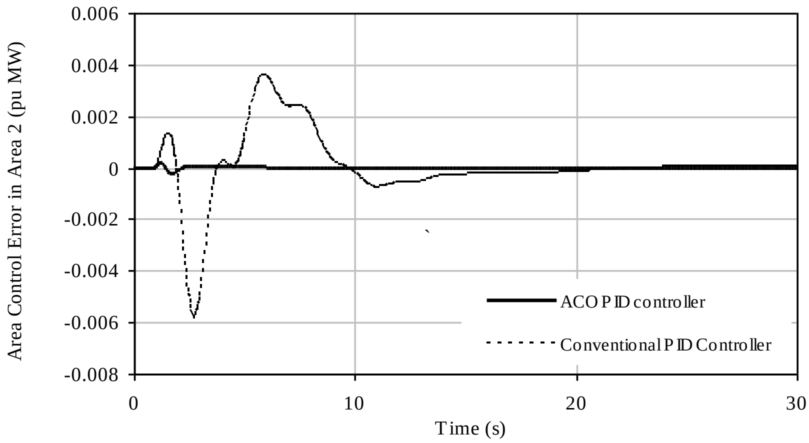

Figure 13. Controlled response without GRC non-linearity unit (ACE2)

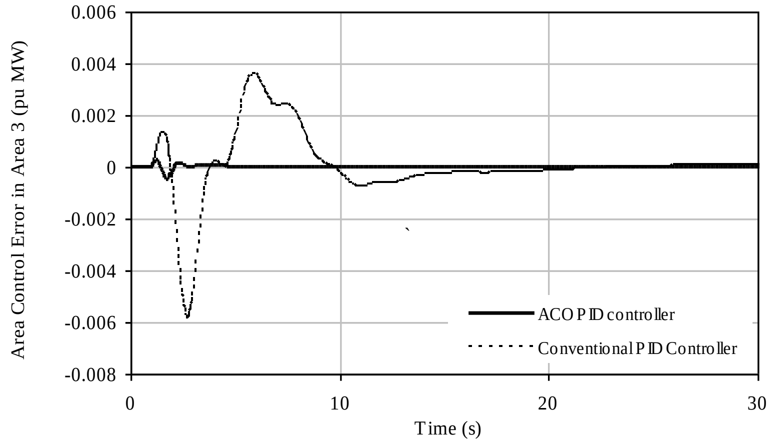

Figure 14. Controlled response without GRC non-linearity unit (ACE3)

The Area Control Error deviation comparisons of dynamic response of proposed and existing controllers are shown in figures 12-14. The time domain parameters overshoots and settling times are noted and values are shown in the table 5. The settling time, overshoot and damping oscillations of the proposed techniques based controller is less than existing. Controller without considering the GRC non-linearity in all the areas.

Table 5. Maximum overshoots and settling times of the area control error deviations by using conventional PID and ACO PID controller without non-linearity effect

		PID controller with			
		Conventional technique		ACO technique	
Fig, No	Response	Peak overshoot	Settling time (Sec)	Peak overshoot	Settling time (Sec)
12	ACE1	-0.0163	25	-0.00423	15
13	ACE2	-0.00585	24	-0.00024	16
14	ACE3	-0.00585	24	-0.00024	14

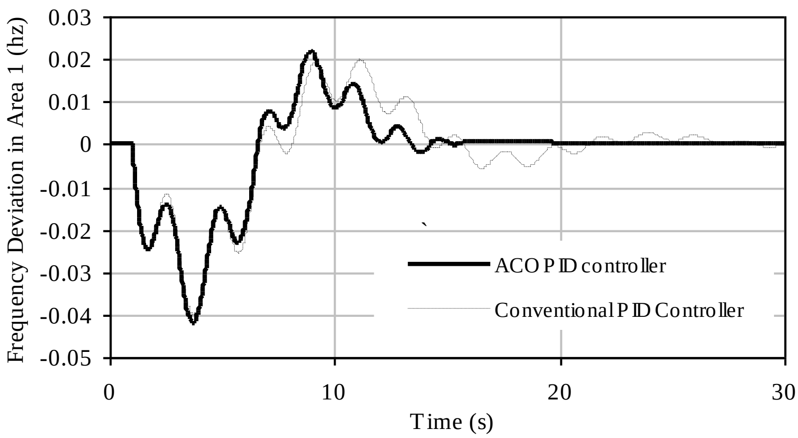

Figure 15. Controlled response with GRC non-linearity unit (delF1)

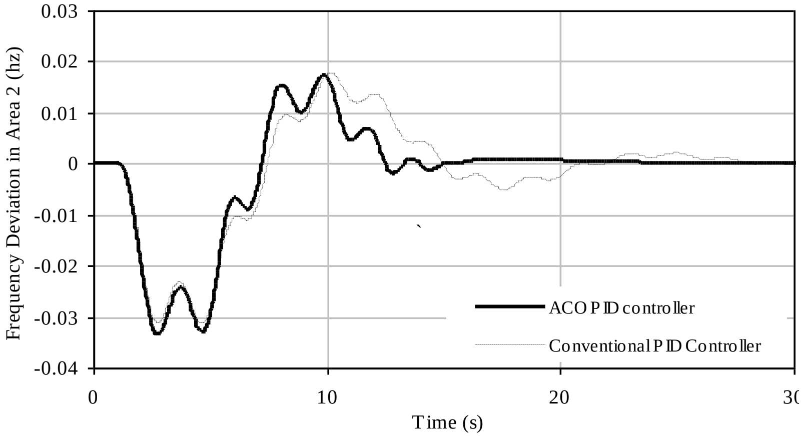

Figure 16. Controlled response with GRC non-linearity unit (delF2)

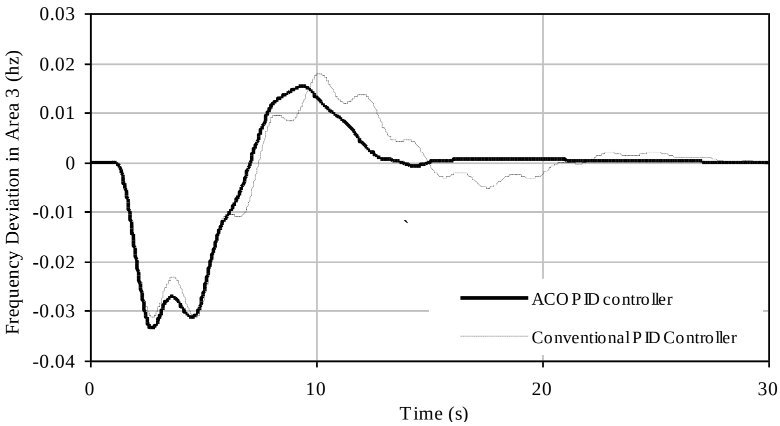

Figure 17. Controlled response with GRC non-linearity unit (delF3)

The frequency deviation comparisons of dynamic response of proposed and existing controllers are shown in figures. 15-17. The domain parameters overshoots and settling times are noted and values are shown in the table 6. The settling time and damping oscillations of the proposed techniques based controller is less than existing controller with considering proper GRC non-linearity in all the areas. But the overshoot value is reduced only considerable amount, when non-linearity effect is taken into the account.

Table 6. Maximum overshoots and settling times of the frequency deviations by using conventional PID and ACO PID controller with non-linearity effect

		PID controller with			
		Conventional technique		ACO technique	
Fig, No	Response	Peak overshoot	Settling time (Sec)	Peak overshoot	Settling time (Sec)
15	delF1	-0.02479	36.5	-0.02349	19.42
16	delF2	-0.03336	33	-0.03117	21
17	delf3	-0.03336	33	-0.03117	22

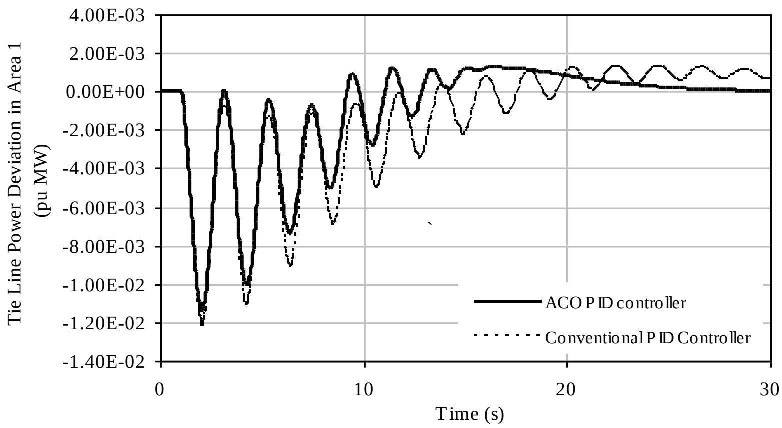

Figure 18. Controlled response with GRC non-linearity unit (delPtie1)

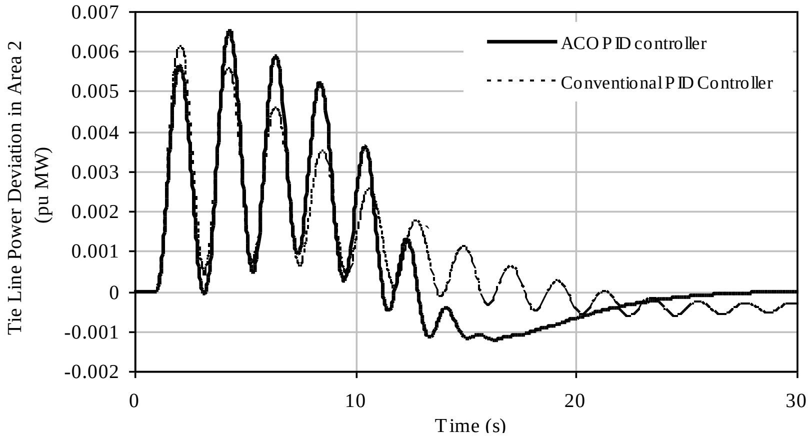

Figure 19. Controlled response with GRC non-linearity unit (delPtie2)

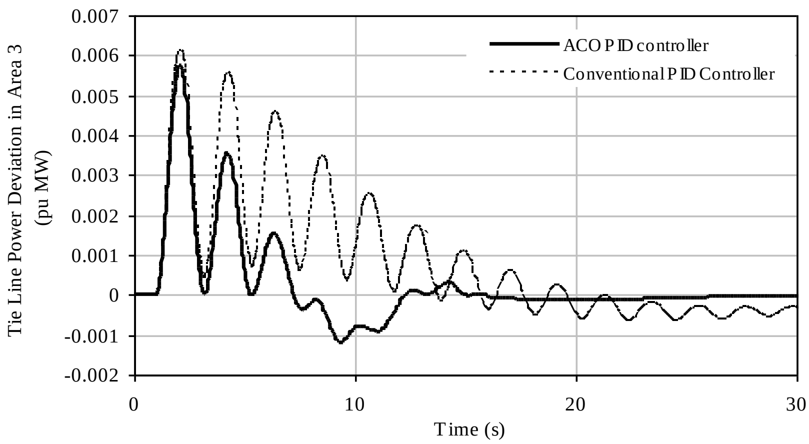

Figure 20. Controlled response with GRC non-linearity unit (delPtie3)

The tie line power deviation comparisons of dynamic response of proposed and existing controllers are shown in figures 18-20. The domain parameters overshoots and settling times are noted and values are shown in the table 7. The settling time and damping oscillations of the proposed techniques based controller is less than existing controller with considering proper GRC non-linearity in all the areas. But the overshoot value is reduced only considerable amount, when non-linearity effect is taken into the account.

Table 7. Maximum overshoots and settling times of the tie line power deviations by using conventional and ACO PID controller with non-linearity effect

		PID controller with			
		Conventional technique		ACO technique	
Fig, No	Response	Peak overshoot	Settling time (Sec)	Peak overshoot	Settling time (Sec)
18	delPtie 1	-0.01223	44	-0.01138	30
19	delPtie 2	0.006116	44	0.01138	27
20	delPtie 3	0.005746	44	0.007746	18

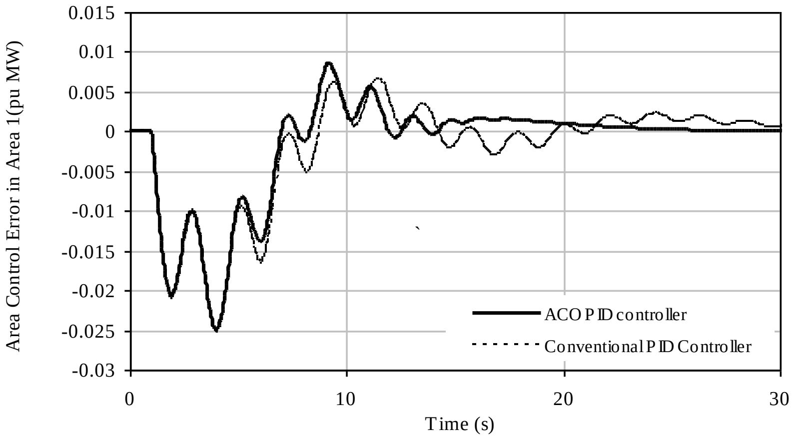

Figure 21. Controlled response with GRC non-linearity unit (ACE1)

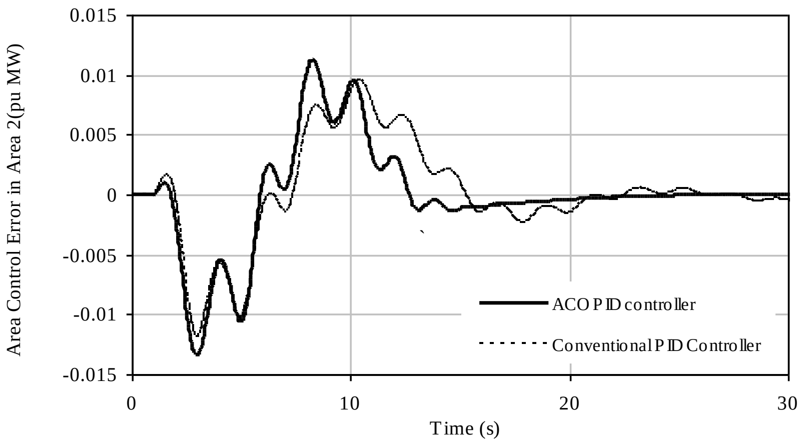

Figure 22. Controlled response with GRC non-linearity unit (ACE2)

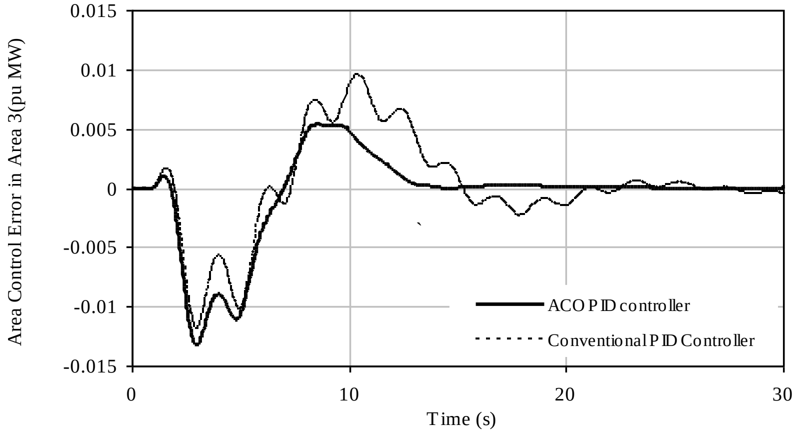

Figure 23. Controlled response with GRC non-linearity unit (ACE3)

The Area Control Error deviation comparisons of dynamic response of proposed and existing controllers are shown in figures 21-23. The domain parameters overshoots and settling times are noted and values are shown in the table 8. The settling time and damping oscillations of the proposed techniques based controller is less than existing controller with considering proper GRC non-linearity in all the areas. But the overshoot value is reduced only considerable amount, when non-linearity effect is taken into the account.

Table 8. Maximum overshoots and settling times of the area control error deviations by using conventional PID and ACO PID controller with non-linearity effect

		PID controller with			
		Conventional technique		*ACO technique*	
Fig, No	*Response*	*Peak overshoot*	*Settling time (Sec)*	*Peak overshoot*	*Settling time (Sec)*
21	ACE_1	-0.02101	40	-0.02067	24
22	ACE_2	-0.01194	36	-0.01337	25
23	ACE_3	-0.01164	36	-0.01303	15

6. Conclusion

The Proportional-Integral-Derivative (PID) controller has been applied to the AGC equal three area interconnected power systems and optimal gain values are obtained by using conventional method with and without considering the effect of GRC non-linearities. The attempt has been successfully made to use Ant Colony Optimization technique, for the optimization of PID controller gain values with different conditions. The ACO based PID controller in AGC which provide better performance (settling time, overshoots and damping oscillations) than conventional controller in equal three area reheat thermal interconnected power systems, when GRC non-linearity not taken into the account. Non-linearity in the system yield more damping oscillations with maximum overshoot and high settling time. The ACO based controller reduces the damping oscillations and settling lime compared to conventional controller. But it reduce effectively settling time, maximum overshoot, when GRC non-linearity effect is considered to an account and maximum overshoot is reduced only considerable amount.. Finally, this work concluded that, the proposed optimization technique having ability to keep the system response with minimum damping oscillations and less settling time, if non-linearity effect consider to an account or not.

7. References

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