Optimal Tuning of PID Controllers for Hydrothermal Load Frequency Control Using Ant Colony Optimization

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Abstract: This paper proposes a novel Artificial Intelligence technique known as Ant Colony Optimization (ACO) for optimal tuning of PID controllers for load frequency control. The design algorithm is applied to a hydrothermal power system consisting of two control areas one hydro and the other is thermal with reheat stage. To make the system in realistic form, the system nonlinearities represented by Generation Rate Constraint (GRC), Dead Band, wide range of parameters are introduced. Three different cost functions have been suggested for tuning the PID controllers. The system has been tested for various load changes to reveal the effectiveness and robustness of the proposed technique.

Keywords: Load Frequency Control (LFC), PID, Cost Function.

1. Introduction

In the large scale electric power systems with interconnected areas, Load Frequency Control (LFC) plays an important role. The LFC is aimed to maintain the system frequency of each area and the inter-area tie line power within tolerable limits to deal with the fluctuation of load demands and system disturbances. These important functions are delegated to LFC due to the fact that a well-designed power system should keep voltage and frequency in scheduled range while providing an acceptable level of power quality. A wide variety of different advanced control methods have already been proposed in the literature for LFC [1]. Usually LFC is organized in three levels:

Primary control is done by governors of the generators, which provide immediate action to sudden change of load.

Secondary control keeps frequency at its nominal value by adjusting the output of selected generators (controller is needed).

Tertiary control is an economic dispatch that is used to operate the system as economically as possible [2]. During the last years several researches and techniques had been applied to the field of LFC. A robust LFC via H∞ and H2 control theories has been designed in [3] with different cases for the norm between load disturbance and frequency deviation output. The main disadvantage of these two methods is that these introduce a controller with the same plant order, which in turn doubles the order of the open loop system, and makes the process very complex specially for large scale interconnected power systems. In [4] another technique had been suggested for tuning the parameters of a PID controller for LFC in a single area power system by using particle swarm optimization (PSO). Genetic Algorithm (GA) [5] also used inthis field for the purpose of selection of PID parameters. In [6] LFC with fuzzy logic controller (FLC) considering nonlinearities and boiler dynamics is introduced which has greatly improved the performance of the controller. In [1] new approach using Imperialist Competitive Algorithm (ICA) for multi area LFC has been introduced. Another method for tuning PID controller using Bacteria Foraging Optimization (BFO) for two area system with different step load changes has been applied in [7].

This paper introduces a new Artificial Intelligence (AI) technique (ACO) for optimal tuning of PID controllers. The motivation behind this research is to prove and demonstrate the

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robustness of ACO based PID, and to improve the transient response of both frequency deviation and tie line power under various loading conditions in presence of system nonlinearities. The paper is organized as follows: Section I, introduction. Section II, focuses on the modeling of two area power system. A brief description for ACO technique is illustrated in Section III. In Section IV, simulation and results obtained from the application of ACO tuned PID to the system. Sections V, conclusion.

2. Two area power system

A. System Model

A two area model of a hydrothermal power station including nonlinearities is shown in figure (1). Complete description for symbols used in the block diagram is given in table (I).

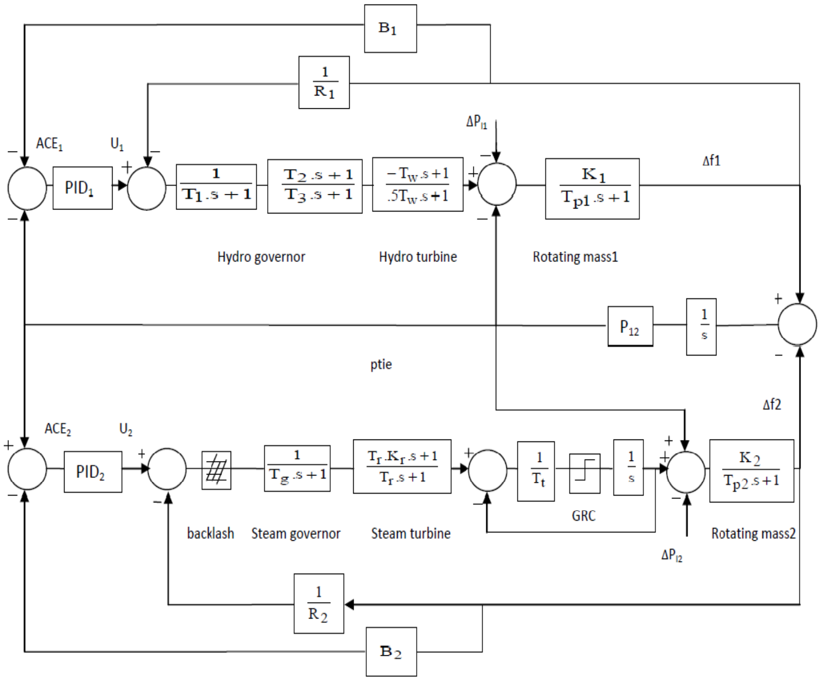

Figure 1. Block diagram of two area model.

Table 2. Symbols identification

Symbol	Quantity	Value
T_1,T_2,T_3	Governor Time constants of hydro area	0.6, 5, 32 s respectively
T_w	Hydro turbine time constant	1 s
K_1,Tp_1	Hydro plant gain and time constant	20 HZ/Pu MW, 3.76 s respectively
R_1	Regulation of hydro area	3 Hz/Pu MW
B_1	Biasing factor of hydro area	0.383 Pu MW/ Hz
T_g	Governor Time constant of thermal area	0.08 s
T_r	Reheat time constant	10 s
K_r	P.u megawatt rating of high pressure stage	0.5
T_t	thermal turbine time constant	0.3 s
K_2, T_{p2}	thermal plant gain and time constant	120 HZ/PuMW, 20 s respectively
R_2	Regulation of hydro area	2.4 Hz/PuMW
B_2	Biasing factor of hydro area	0.425 PuMW/ Hz
P_{12}	Synchronization coefficient	0.545PuMW

The steam chest time constant which is related to the non-reheat stage ranges from 0.1 to 0.5 s whereas the time constant for the reheat stage (which is series cascaded with the non-reheat stage) ranges from 4 to10 s. Nonlinearities incorporated in this model represent in GRC and governor dead band (backlash). The first one as its name implies (GRC) respects for the turbine illustrates the limitation on the generation rate of change in the output generated power due to the limitation of thermal and mechanical movements [8], for thermal stations it is taken to be 0.1 Pu Mw per minute [9]. The second nonlinearity is defined as the total magnitude of a sustained speed change; within which there is no resulting change in valve position. All types of governors have a dead band in response, which is important for power system frequency control in the presence of disturbances, here it is taken to be .0005 [9].

B. Control Technique

The controller type used here is a PID controller with the transfer function given in (1):

$$k(s)=k_p+k_i/s+k_d s \tag{1}$$

Where k_p, k_i, k_d are proportional, integral and differential gains respectively. The input to the controller is the area control error (ACE), and the output is u(s) as shown in (2).

$$u(s)=-k(s)*ACE \tag{2}$$

The function of each part of a PID controller can be described as follows, the proportional part reduces the error responses of the system to disturbances, the integral part eliminates the steady-state error, and finally the derivative part dampens the dynamic response and improves the system stability [10].

C. Cost Function

Three different cost functions had been suggested for ACO technique for tuning the parameters of the PID controller.

First cost function:

This cost function as shown in (3) minimizes the integrated square error e(t).

$$f_1=\int_0^{\infty}(e(t))^2\,dt \tag{3}$$

Second cost function:

In this method [11], the actual closed-loop specification of the system with controller, rise time (t_r), maximum overshoot (M_p), settling time (t_s), and steady state error (e_{ss}) are used to evaluate the cost function. This is done by summing the errors between actual and specified specification as given by (4).

$$f_2=\frac{1}{[c_1(t_r-t_{rd})+c_2(M_p-M_{pd})+c_3(t_s-t_{sd})+c_4(e_{ss}-e_{ssd})]} \tag{4}$$

Where, c_1: c_4 are positive constants (weighting factors), their values are chosen according to prioritizing their importance, (t_{rd}) is the desired rise time, (M_{pd}) is the desired maximum overshoot, (t_{sd}) is the desired settling time, and (e_{ssd}) is the desired steady state error.

Third cost function:
A performance criterion in the time domain is proposed as given in (5).

$$f_3 = \frac{1}{(1-e^{-\beta})(M_p + e_{ss}) + e^{-\beta}(t_s - t_r)} \tag{5}$$

This cost function can satisfy the designer requirements using the weighting factor value (β). The factor is set larger than 0.7 to reduce the overshoot and steady-state error. On the other hand is set smaller than 0.7 to reduce the rise time and settling time [11]. All of these cost functions have been minimized subjected to:

$$k_p^{\min} \le k_p \le k_p^{\max}$$
$$k_i^{\min} \le k_i \le k_i^{\max}$$
$$k_d^{\min} \le k_d \le k_d^{\max}$$

3. Ant Colony Optimization: Overview

The ant colony optimization algorithm (ACO) is a probabilistic technique for solving computational problems which can be reduced for finding good paths through graphs. This algorithm is a member of the ant colony algorithms family, in swarm intelligence methods, and it constitutes some metaheuristic optimizations.

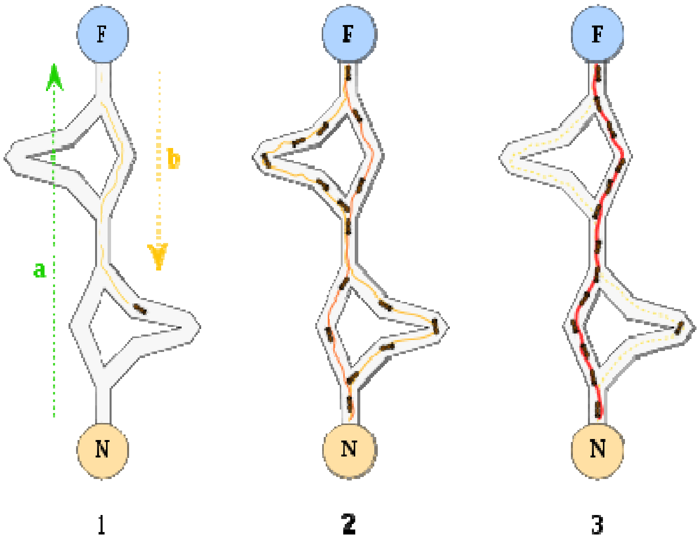

Figure 2. Ants from nest to the source of food.

Initially proposed by Marco Dorigo in 1992 in his PhD thesis [8]. The first algorithm was aiming to search for an optimal path in a graph, based on the behavior of ants seeking a path between their colony and a source of food. In the natural world, ants (initially) wander randomly, and upon finding food return to their colony while laying down pheromone trails. If other ants find such a path, they are likely not to keep travelling at random, but to instead follow the trail, returning and reinforcing it if they eventually find food. Over time, however, the pheromone trail starts to evaporate, thus reducing its attractive strength. The more time it takes for an ant to travel down the path and back again, the more time the pheromones have to evaporate. A short path, by comparison, gets marched over more frequently, and thus the pheromone density becomes higher on shorter paths than longer ones [9]. Figure (1) [10] illustrates the behavior of real ants in searching the source of food.

A flowchart for this optimization process is shown in figure 2.

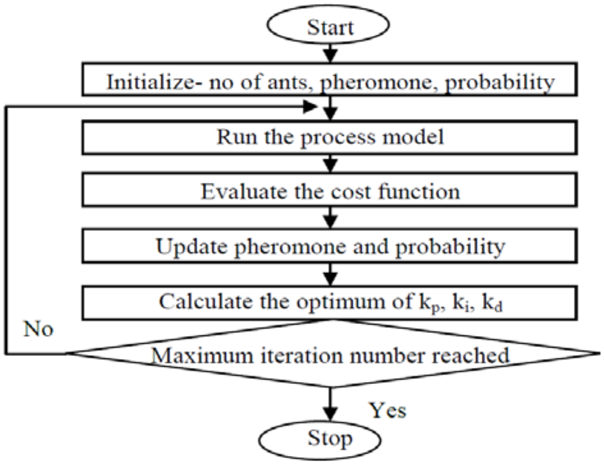

Figure 3. Flowchart of ACO based PID control system.

The algorithm of ACO is shown in (6) and (7),
where: P is the probability, α, β, τ are parameters related to ACO algorithm, d is the distance, Q being a constant parameter, L_k is the k^{th} ant solution, ρ is a parameter used to avoid unlimited accumulation of the pheromone trails and m is the number of ants.

The first equation describes the probability of the ant to move between the two nodes i and j, while the second one describes the local updating of pheromone after travelling from a node to another one.

$$p_{ij}(t) = \frac{\tau_{ij}(t)^{\alpha}\left(\frac{1}{dij}\right)^{\beta}}{\sum\limits_{j\in nodes}\tau_{ij}(t)^{\alpha}\left(\frac{1}{dij}\right)^{\beta}} \tag{6}$$

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \sum_{\substack{k\in colonythat\\ usededge\\ (i,j)}} \frac{Q}{L_m} \tag{7}$$

Advantages of ACO technique represent in:

- Positive Feedback accounts for rapid discovery of good solutions
- Distributed computation avoids premature convergence.
- The greedy heuristic helps finding acceptable solution in the early solution in the early stages of the search process.

Disadvantages of ACO on the other hand represent in:

- Lower convergence than other Heuristics.
- Performs poorly for problems have larger than 75 nodes.
- No centralized processor to guide the ACO towards good solutions [11].

In this paper ACO algorithm is used for optimal tuning of PID parameters for both the two areas at the same time by minimizing the required cost function.

4. Simulation and results

In this section the different values of PID parameters tuned using ACO technique for the early mentioned three cost functions are shown in table (II), where area 1 is the hydro power station, and the steam power station is the second one.

Table 2. Values of PID gains

	Hydro plant			Steam plant		
	K_p	K_i	K_d	K_p	K_i	K_d
1st cost function	.84	.86	.66	.9	.98	.98
2nd cost function	.02	.4	.42	.4	.15	.88
3rd cost function	.81	.42	.33	.56	.21	.27

Different cases of load disturbances are applied to the model to demonstrate effectiveness and robustness of the proposed technique.

Case 1: steploadchange of 2%in both areashas been applied to the system. The responses of frequency deviation in area 1, tie line power, and control signals for the two areas in this case are shown in figure (4, 5, 6, and 7). From these responses it is clear that ACO tuned PID for the three cost functions succeeded in damping all oscillations, minimizing settling time and reducing overshoot. It is clear that the control signals in the two areas are in acceptable values. Also it is clear that the 3rd cost function based PID has the best performance.

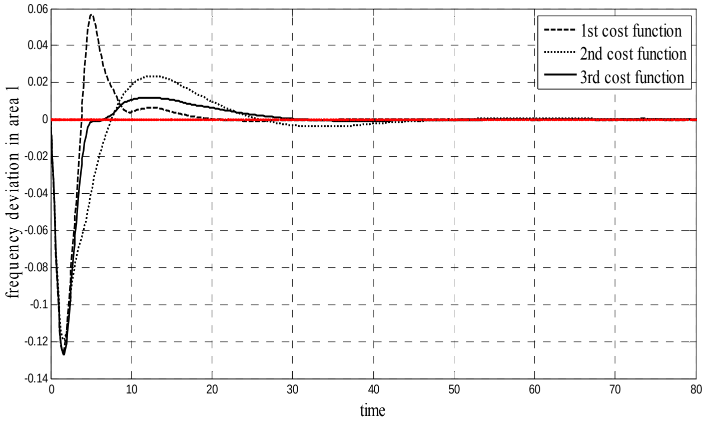

Figure 4. Frequency deviation response in area 1 for case 1.

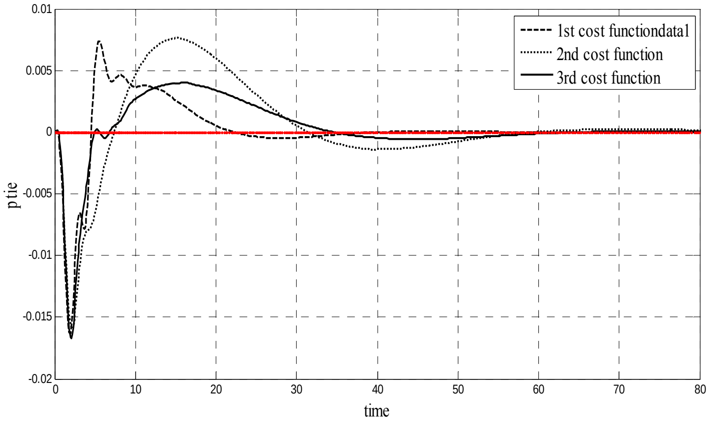

Figure 5. Tie line power deviation response for case 1.

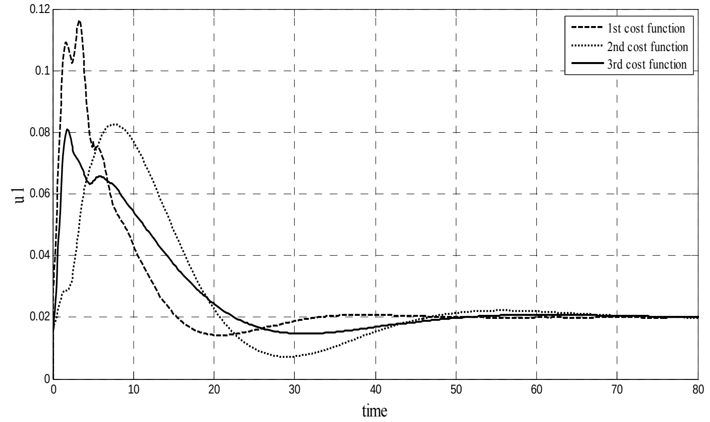

Figure 6. Control signal in area 1 for case 1.

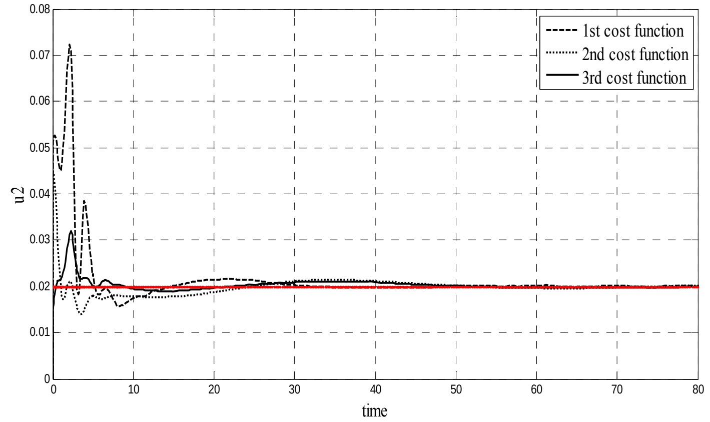

Figure 7. Control signal in area 2 for case 1.

Case 2: another violent test by changing the load disturbance nature from step to ramp shape is discussed in this case. This case is considered a simulation for realistic load change case where the load disturbances as shown in figure (8,9) simulate what happens in fact. For realistic power system load disturbance takes place in ramp shape within certain time not in no time as in step case. The responses of frequency deviation in area 1, tie line power, and control signals for the two areas in this case are shown in figure (10, 11, 12, and 13). The results proved the robustness of the propoed algorithm.

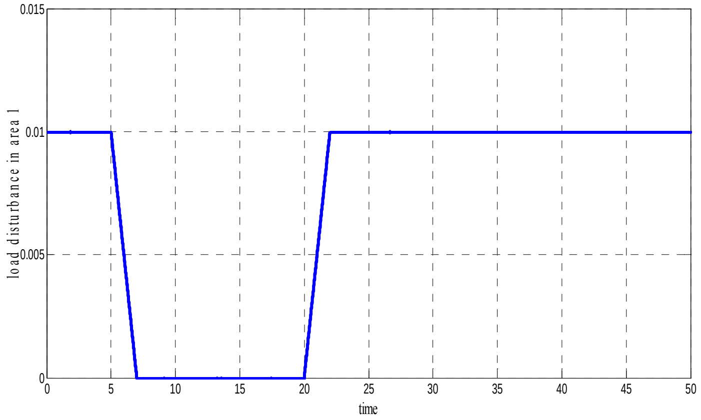

Figure 8. Load disturbance in area 1 for case 2.

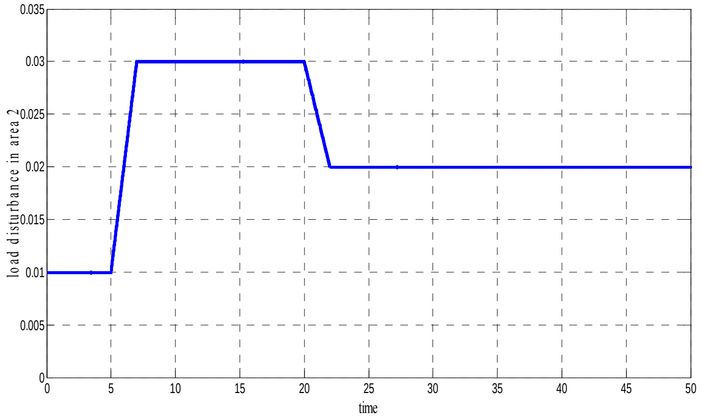

Figure 9. Load disturbance in area 2 for case 2.

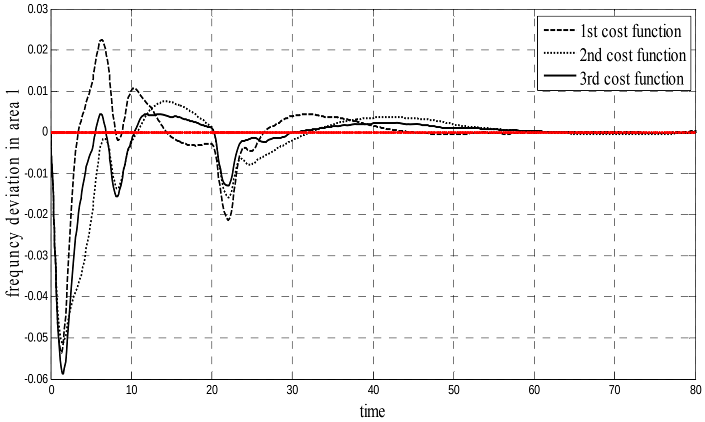

Figure 10. Frequency deviation response in area 1 for case 2.

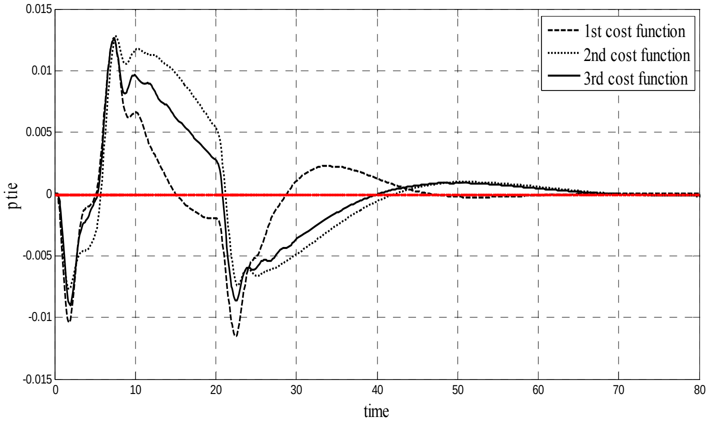

Figure 11. Tie line power deviation response for case no 2.

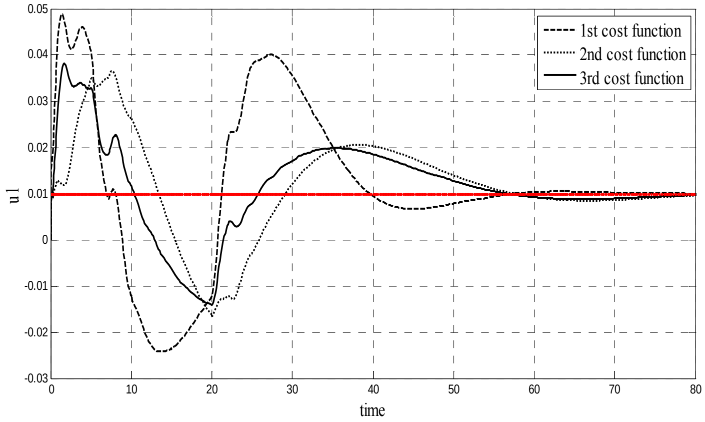

Figure 12. Control signal in area 1 for case 2.

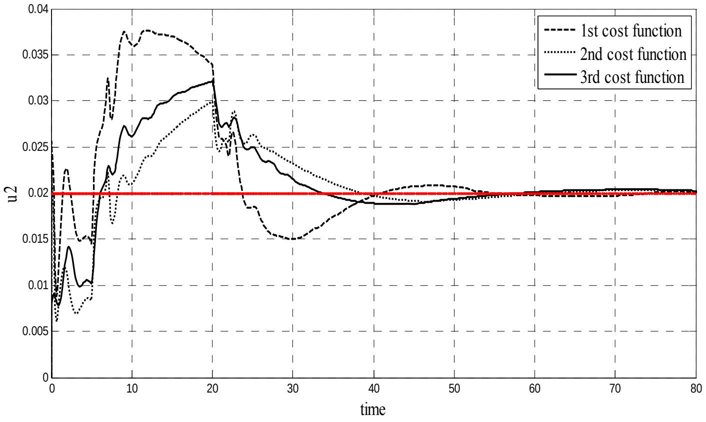

Figure 13. Control signal in area 2 for case 1.

Case 3: the load disturbances are -2% in both areas with 50% increasing in K_2, Tp_2, R_2, K_1, Tp_1, and R1. The responses of frequency deviation in area 1, tie line power, and control signals for the two areas in this case are shown in figure (14, 15, 16, and 17). It is clear that ACO based PID still robust to variation in system parameters.

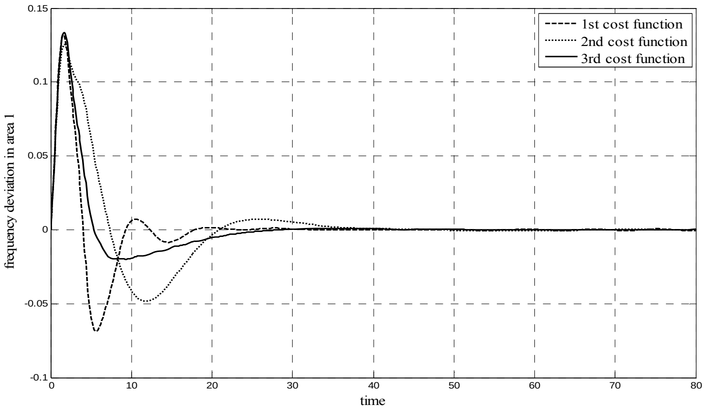

Figure 14. Frequency deviation response in area 1 for case 3.

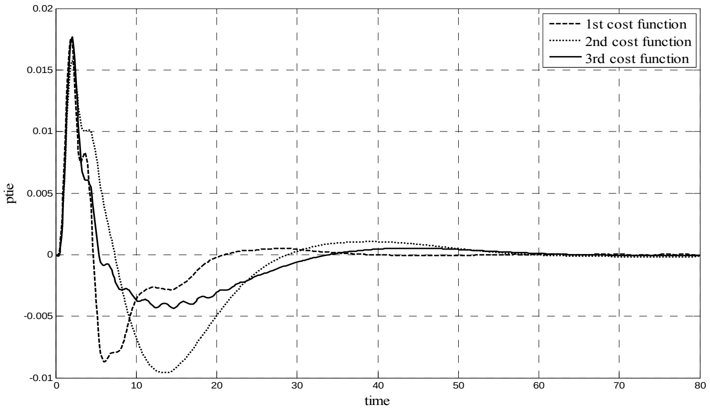

Figure 15. Tie line power deviation response for case 3.

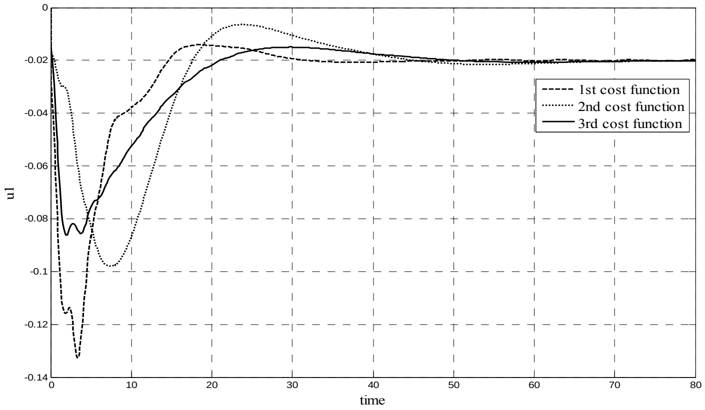

Figure 16. Control signal in area 1 for case 3.

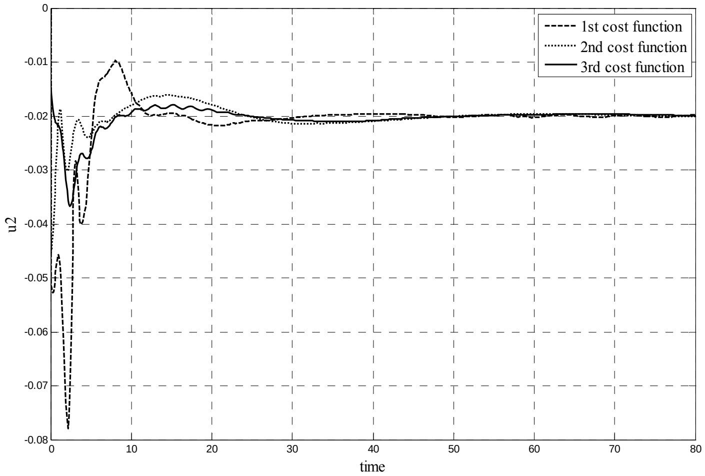

Figure 17. Control signal in area 2 for case 3.

The settling time (ts) and percentage overshoot (%o.s) for Δf1 and ptie for the above cases are given in table (III).

Table 3.

	Case 1				Case 2				Case 3			
	Δf_1		ptie		Δf_1		ptie		Δf_1		ptie	
	t_s	%o.s	t_s	%o.s	t_s	%o.s	t_s	%o.s	t_s	%o.s	t_s	%o.s
1st cost function	20	12.6	40	1.6	46	5.35	60	1.15	30	13.2	40	1.75
2nd cost function	50	11.9	60	1.6	60	5.14	70	.07	47	12.5	60	1.58
3rd cost function	32	12.7	64	1.67	64	5.87	70	.09	42	13.3	63	1.7

Conclusion

In this paper a PID controller which is tuned via ACO has been strongly proposed for the multi area LFC problem. The results declared that ACO based PID is capable to guarantee robust stability and robust performance under various load conditions and changes in system parameters for three different cost functions. The proposed controllers succeeded in damping all oscillations, minimizing settling time and reducing overshoot, this reduces wear in control valves and gates. In the future work we intend to apply the ACO algorithm to the renewable energy power stations as wind turbine for example; also we intend to specify the upper limit of load disturbances which may cause the instability problem of the power system.

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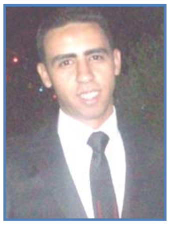

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