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Hybrid PSO-GA Algorithm for Automatic Generation Control of Multi-Area Power System

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Abstract: *Automatic Generation Control (AGC) plays very important role in power system automation, design, operation and stability. In this paper, we propose the hybrid Particle Swarm Optimization and Genetic Algorithm (hPSO-GA) method to obtain the Proportional-Integral-Derivate (PID) controller parameters for AGC of four-area interconnected hydro thermal power system. The hydro and thermal areas are comprised with an electric governor and reheat turbine, respectively. Also, 1% step load perturbation has been considered occurring in any individual area. This power system with the proposed approach is simulated in MATLAB/SIMULINK and the responses of frequency and tie-line power deviation for each area compared with PSO and GA. The simulation results show that proposed hPSO-GA based PID controller achieves better responses than PSO and GA based PID controllers.*

Keywords: *Automatic Generation Control (AGC), Genetic Algorithm (GA), hPSO-GA, Multi-area power system, Particle Swarm Optimization (PSO)*

I. Introduction

In the power system, number of generating areas are interconnected together through tie-lines by which power is exchanged between them. The main objective of a power system is to maintain balance between the demand and generation. In this situation the system will be in equilibrium but any sudden load perturbation in power system can disturb this equilibrium and cause variation in tie-line power interchange and frequency. So, the control strategy is required. There are two basic control mechanisms used to achieve power balance; reactive power balance and real power balance. The former is called Automatic Voltage Regulator (AVR) and the latter is called Load Frequency Control (LFC) or Automatic Generation Control (AGC) [1, 2]. Generally the main objectives of AGC are as follows:

- Maintaining system frequency in its nominal value or within predetermined limits.
- Maintaining the transferred power between the areas at prescribed levels.
- Maintaining each unit generation in the best possible economic value.
- Obtaining acceptable overshoot, undershoot and settling time on the frequency and tie line power deviations [2-4].

The researchers all over the world are trying to introduce several control strategies for AGC of power systems in order to restore the system frequency and tie line power to their scheduled values or close to them in the fastest possible time during load perturbations. A state-of-the-art survey and a review on the AGC of power systems has been presented in [4] and [5] respectively where various control strategies concerning AGC problem have been studied. Moreover, there are many research articles attempting to propose better control methods for AGC systems based on Artificial Neural Network (ANN) [7-11], fuzzy logic theory [11-14], reinforcement learning [15-16] and ANFIS approach [17]. Various Artificial Intelligence (AI) techniques have been proposed for AGC problem to improve the performance of a power system. Some of these approaches include Imperialist Competitive Algorithm (ICA) [2], particle swarm optimization [18, 19], Firefly Algorithm (FA) [20], Differential Evolution (DE) [21, 22], genetic algorithm [23, 24] and Artificial Bee Colony (ABC) [25] etc.

In addition to the above examples, there are also hybrid algorithms used to AGC problems such as [6], in which hybrid Bacteria Foraging Optimization Algorithm-Particle Swarm Optimization (hBFOA–PSO) method is applied to optimize the PI controller parameters of a two-area interconnected power system and the results show the superiority of mentioned methods over PSO, GA and BFOA. In [26], hybrid Firefly Algorithm and Pattern Search (hFA-PS) technique is used to optimize PID controller parameters for AGC of multi-area interconnected power systems and the results prove that the proposed hFA–PS based PID controllers provide superior performance compared to some techniques such as BFOA and GA for the same interconnected power system.

In spite of many complicated control theories and techniques, more than 90% of control strategies still use PID controllers. This is mainly because of structural simplicity, high reliability, good stability and the convenient ratio between performances and cost of PID controller. Additionally, not only it has simplified dynamic modeling, lower user-skill requirements, and minimal development effort but also it improves the transient and steady state responses, which are major issues for engineering practice. A typical structure of a PID controller includes three separate elements: the proportional, integral and derivative values in which the proportional value determines the reaction to the current error, the integral value determines the reaction based on the sum of recent errors, and the derivative value determines the reaction based on the rate at which the error has been changing [26, 27].

As mentioned, there are many articles in the area of AGC problems using GA and PSO specially tuning of PID controller parameters but GA and PSO are less susceptible to getting trapped on local optimum [28]. So, to overcome the difficulties of these two methods, the hybrid PSO-GA algorithm is used to optimize the PID controller parameters of four-area interconnected power system in this paper. This hybrid method results are consequently compared with those of PSO and GA in the same power system to indicate the superiority of mentioned method.

II. System Modelling

A. Four-Area AGC Model

Generally, power system consists of number of subsystems interconnected through tie lines. The investigated AGC system, in this paper, consists of four hydro-thermal areas. Area 1 and 2 are reheat thermal system and area 3 and 4 are hydro system. The hydro areas are comprised with an electric governor and thermal areas are comprised with reheat turbine. The simplified and generalized models of four-area interconnected power system are shown in figures 1 and 2, respectively. Directions of power transferred between areas are:

- Area 1 to area 2.
- Area 2 to area 3.
- Area 3 to area 4.
- Area 4 to area 1.

Also, nomenclature for various symbols is given in Appendix.

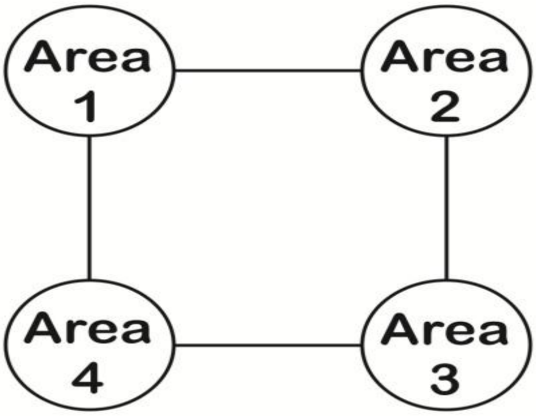

Figure 1. Simplified four-area interconnected power system.

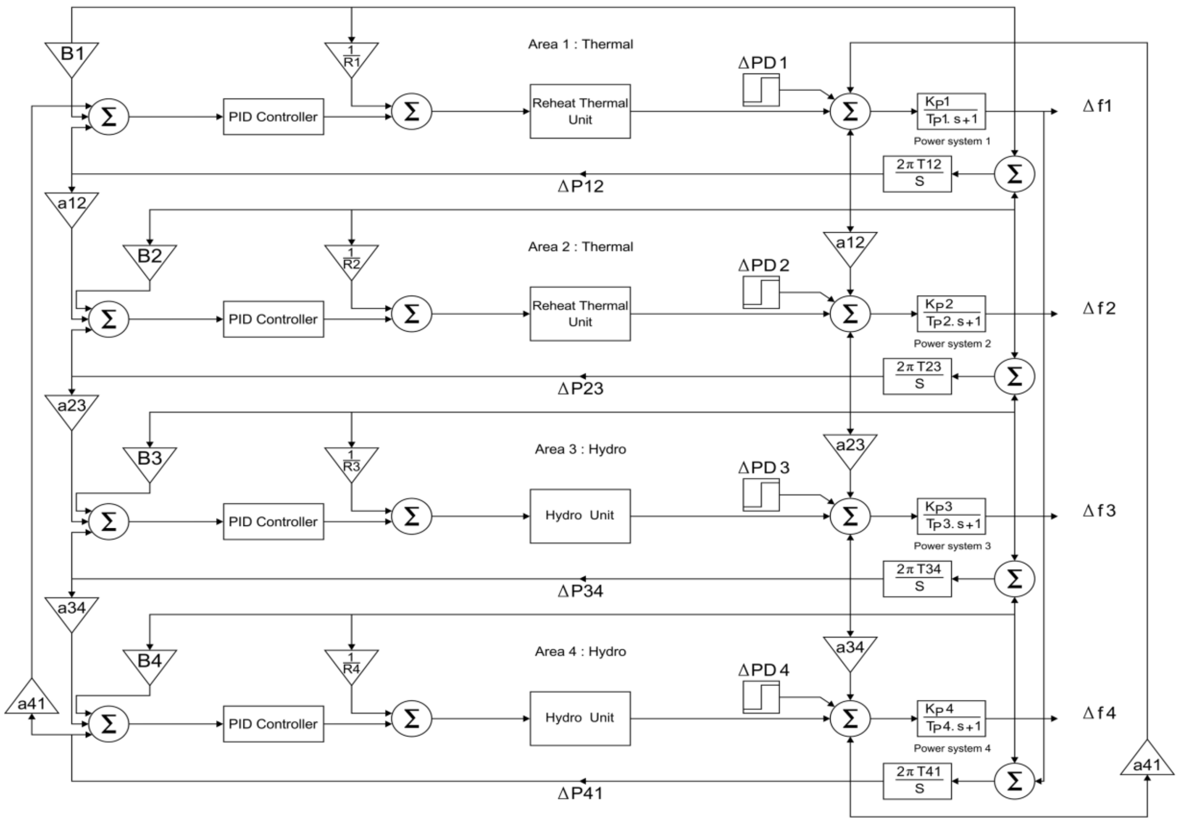

Figure 2. Investigated four-area interconnected power system.

B. Thermal Unit

Two thermal areas of investigated four-area power system are equal which consist of governor and steam turbine with reheater. Dynamic model of these two thermal areas is shown in figure 3.

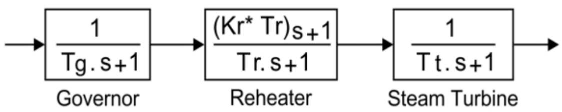

Figure 3. Dynamic model of thermal area.

C. Hydro Unit

Two hydro areas of investigated power system are equal which include electric governor and hydro turbine. Dynamic model of these two hydro areas is shown in figure 4.

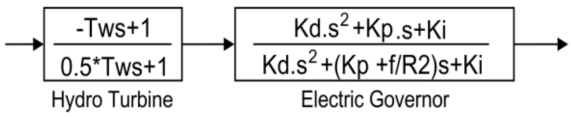

Figure 4. Dynamic model of hydro area.

III. Optimization of the PID controller

Two optimization algorithms, including PSO and GA, and a hybrid method, hPSO-GA, are used to optimize the parameters of PID controllers in this paper.

A. Particle Swarm Optimization (PSO)

PSO is a population based optimization technique based on intelligent scheme proposed and developed by Kennedy and Eberhart in 1995, inspired by the social behavior of bird flocking or fish schooling. In this algorithm, there are a number of birds called particles. PSO is initialized with a group of random particles and then searches for optimal value by updating each generation. All particles have not only fitness values which are evaluated by the fitness function to be optimized, but also velocities which direct the flying of the particles. The particles fly through the search space by following the particles with the best solutions ever found. It is also shown that, the PSO is appropriate to solve the complicated problems which have several local optimal solutions [29]. In this paper, PSO algorithm parameters are set according to table 1.

Table 1. PSO parameters.

Parameters	**Value**
Population size	100
number of iteration	100
PSO parameter C1	1.5
PSO parameter C2	1.5
PSO momentum or inertia	0.73

B. Genetic Algorithm (GA)

GA is a computational abstraction of natural evolution that can be used to solve some optimization problems proposed by Holland in 1975. It is a repetitive search procedure that operates on a set of strings called chromosomes. The implementation of this algorithm is briefly listed in the following process [30, 31]:

- Initialize the chromosome strings of population.
- Decode the strings and assess them.
- Choose the best strings.
- Copy the best strings and paste them on the non-selected strings.
- Combine and develop it to generate off strings.
- Update the genetic cycle and stop the process.

The values of GA parameters are set according to table 2.

Table 2. GA parameters.

Parameters	**Value**
Population size	100
Number of Iteration	100
Parents (off springs) Ratio	0.7
Mutants Population size Ratio	0.2

C. hPSO-GA

Generally, the random nature of the GA operators makes this algorithm sensitive to initial population. This dependence to initial population is the reason that GA may not converge properly if the initial population is not well chosen. On the other hand, PSO is not as sensitive as GA to initial population and it has been indicated that PSO converge rapidly during the initial stages of a global search, but around global optimum, the search process will become very slow. One of the features of PSO is its fast convergence towards global optima in the early stage of the search and its slow convergence near the global optima. In this paper the idea is the combination of the PSO and GA, to overcome the both algorithms problems, in such a way that the performance of the hybrid algorithm is better than either PSO or GA. This hybrid algorithm could be used for many optimization problems [32, 33].

In the first step of solving the optimization problem, the PSO algorithm will create an initial. After that the GA starts to work and takes this initial population and continues to solve the optimization problem. In this hybrid algorithm, in addition to number of iteration for hPSO-GA, we define sub-iteration for each algorithm. It means, in each hPSO-GA's iteration, PSO first runs until its sub-iteration ends then GA starts and continues till its sub-iteration finishes and this work continues until the hPSO-GA iteration finishes. The proposed hPSO-GA flowchart is shown in figure 5. Also, the values of hPSO-GA parameters are set according to table 3.

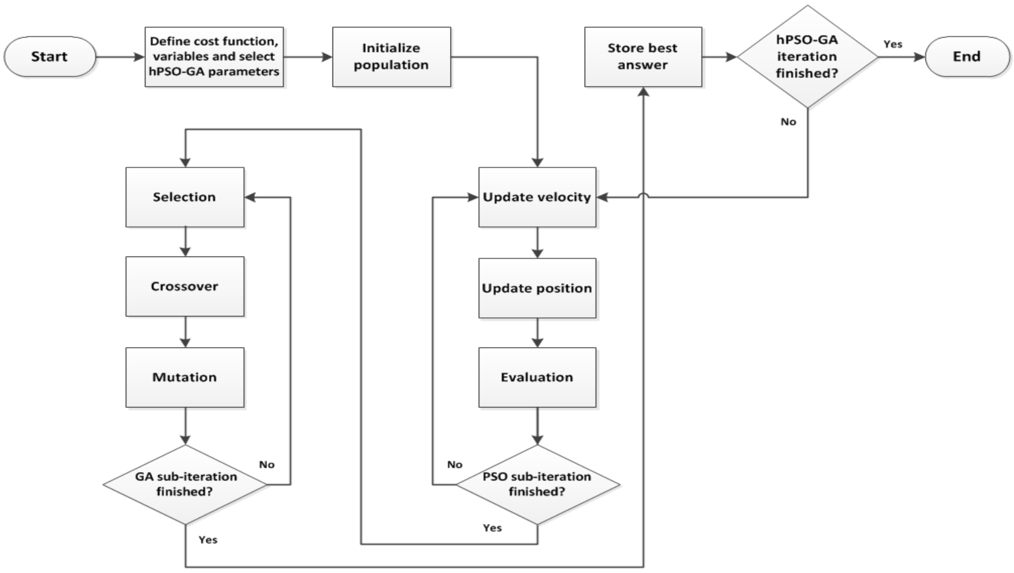

Figure 5. The hPSO-GA flowchart.

Table 3. hPSO-GA parameters.

Parameters	Value
Population size	100
Number of Iteration for hPSO-GA	100
Number of sub-iteration for GA	10
Number of sub-iteration for PSO	10
Parents (off springs) Ratio	0.7
Mutants Population size Ratio	0.2
PSO parameter (C1)	1.5
PSO parameter (C2)	1.5
PSO momentum or inertia	0.73

D. Objective Function

For the system mentioned in Figure 2, the goal is to find the best control strategy. Therefore, in this paper, the above algorithms are used to optimize the PID controller parameters. And the objective function is as follows:

$$J=\int(\Sigma\Delta f_i^{\,2}+\Sigma\Delta Ptie^2) \qquad (1)$$

ΔPtie and Δf are tie-line power among four areas and frequency of four areas, respectively.

IV. Results and analysis

In this paper, the values of PID parameters in four areas are optimized by two optimization algorithms and a hybrid one. 1% step load perturbation is considered in both thermal and hydro area. PID parameters obtained by these methods are shown in table 4. Also, the dynamic responses of frequency and tie-line power deviation by these algorithms are shown in figures 6, 7, 8, 9, 10, 11, 12, 13 and they are compared with each other. It should be noted that the black, blue and red diagrams are related to GA, PSO and hPSO-GA respectively. The insets show the more detailed responses.

Table 4. PID controllers' parameters.

Parameters	hPSOGA	PSO	GA
kp1	1.000000	0.816908	0.488340
ki1	1.000000	0.865705	0.896831
kd1	0.800001	0.794478	0.625696
kp2	0.999992	0.906048	0.873052
ki2	1.000000	0.927033	0.955886
kd2	0.999980	0.179719	0.132073
kp3	0.000100	0.002340	0.151887
ki3	0.080002	0.096163	0.060282
kd3	0.100000	0.136667	0.134642
kp4	0.000900	0.078394	0.050373
ki4	0.107835	0.130007	0.486489
kd4	0.099009	0.032166	0.033094

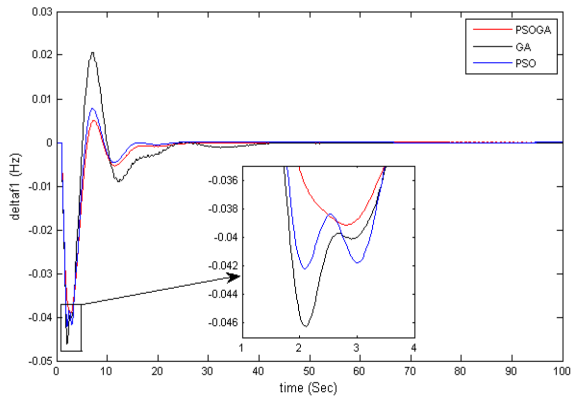

Figure 6. Frequency deviation in area 1.

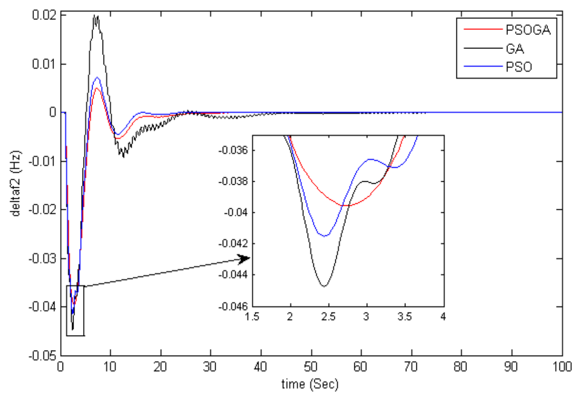

Figure 7. Frequency deviation in area 2.

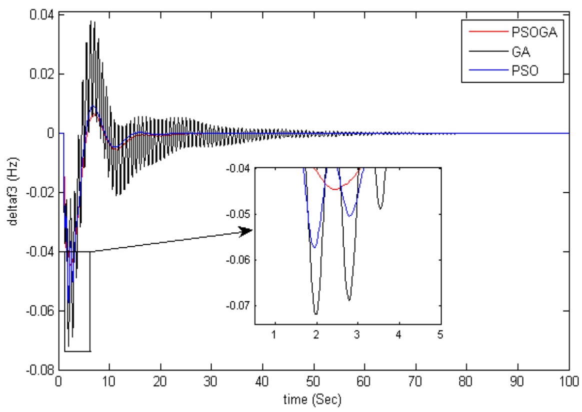

Figure 8. Frequency deviation in area 3.

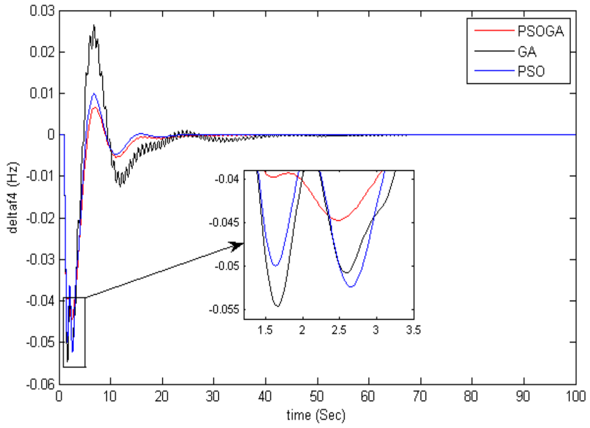

Figure 9. Frequency deviation in area 4.

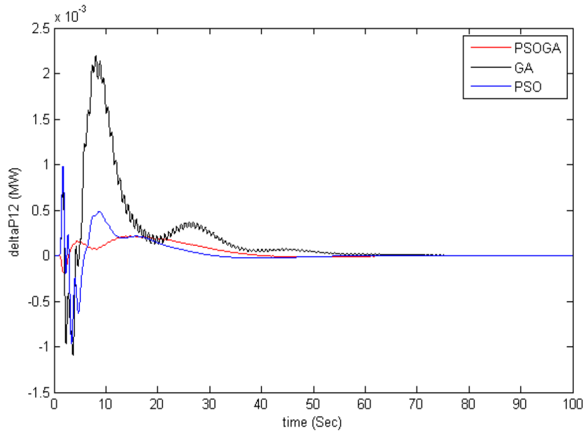

Figure 10. Tie-line power deviation between area 1 and 2.

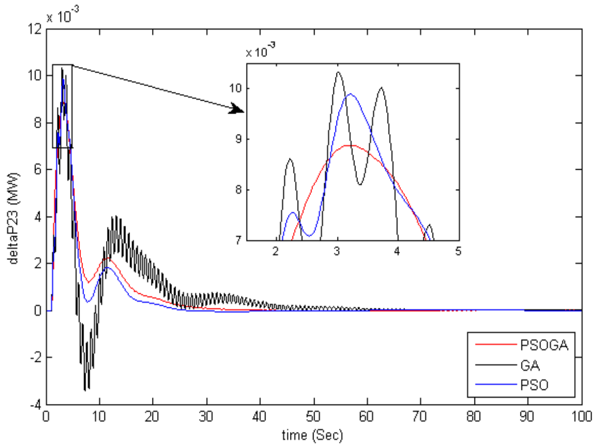

Figure 11. Tie-line power deviation between area 2 and 3.

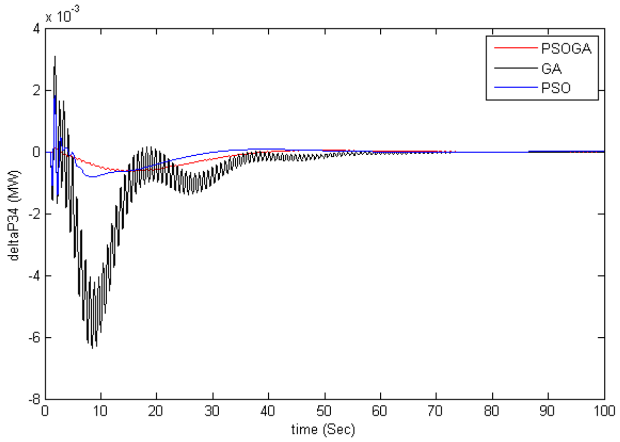

Figure 12. Tie-line power deviation between area 3 and 4.

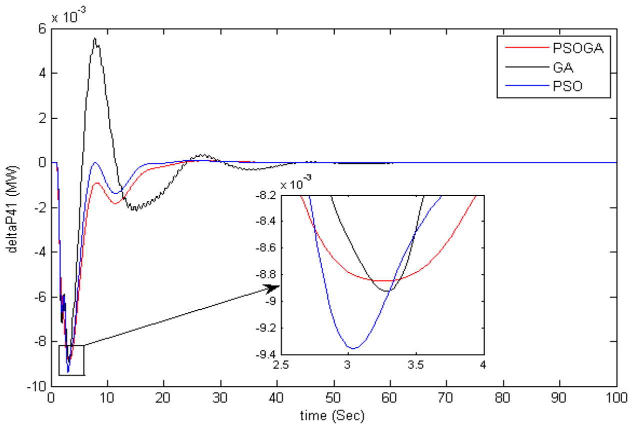

Figure 13. Tie-line power deviation between area 4 and 1.

The detailed information for frequency deviation of area 1 to 4 is shown in table 5 for three mentioned algorithms.

Table 5. Detailed information for frequency deviation.

		hPSO-GA	**PSO**	**GA**
Δf1	Settling Time	21.2973	14.6319	35.8450
	Overshoot	0.0050	0.0078	0.0208
	Undershoot	-0.0391	-0.0422	-0.0462
Δf2	Settling Time	20.9863	14.6670	36.9002
	Overshoot	0.0051	0.0073	0.0200
	Undershoot	-0.0395	-0.0415	-0.0447
Δf3	Settling Time	20.2219	13.8139	44.9990
	Overshoot	0.0067	0.0093	0.0379
	Undershoot	-0.0446	-0.0574	-0.0719
Δf4	Settling Time	19.9379	13.9030	36.1827
	Overshoot	0.0066	0.0099	0.0266
	Undershoot	-0.0448	-0.0523	-0.0545

Also, the detailed information for tie-line power deviation of area 1, 2, 3 and 4 is shown in table 6 for three mentioned methods.

Table 6. Detailed information for tie-line power deviation.

		hPSO-GA	PSO	GA
Δp12	Settling Time	64.4093	45.4197	51.0928
	Overshoot	2.1643e-04	9.7777e-04	0.0022
	Undershoot	-1.8594e-04	-9.6179e-04	-0.0011
Δp23	Settling Time	25.8396	21.7192	45.2008
	Overshoot	0.0089	0.0099	0.0103
	Undershoot	-1.4049e-05	-5.1769e-05	-0.0034
Δp34	Settling Time	51.0694	49.3174	53.0719
	Overshoot	1.3187e-04	0.0018	0.0031
	Undershoot	-6.4132e-04	-0.0014	-0.0064
Δp41	Settling Time	20.0790	15.9253	39.5948
	Overshoot	8.4743e-05	9.2681e-05	0.0056
	Undershoot	-0.0088	-0.0094	-0.0089

By observing the above tables, we can conclude the proposed hybrid method is better than GA. Also, hPSO-GA is better than PSO except in settling time factor. For example, in frequency deviation of area 1, the overshoot response of hPSO-GA has about 55% and 315% improvement in comparison with PSO and GA and there are almost 8 and 9 percent improvement for undershoot of it, too. For tie-line power deviation between area 3 and 4 (Δp34), the overshoot and undershoot results of hPSO-GA are about 1265, 118, 2250 and 898 percent better than PSO and GA, respectively.

Cost functions of hPSO-GA, PSO and GA are shown in figures 14, 15 and 16.

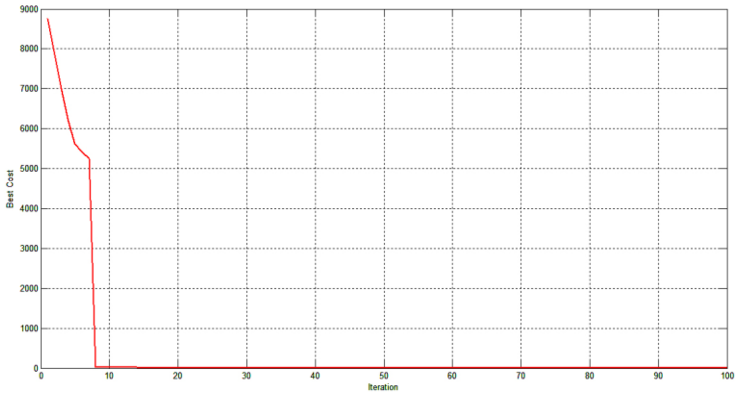

Figure 14. hPSO-GA cost function.

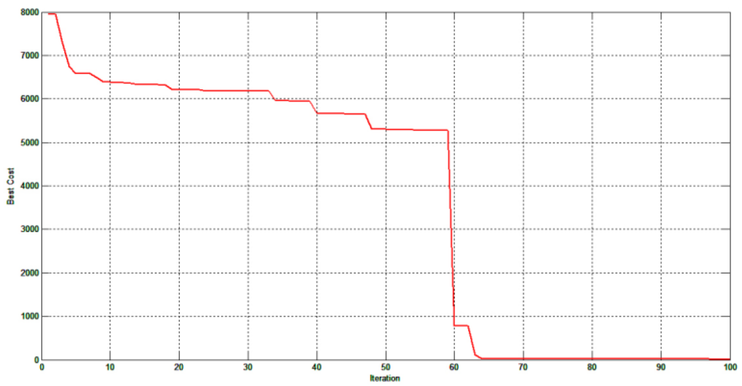

Figure 15. PSO cost function.

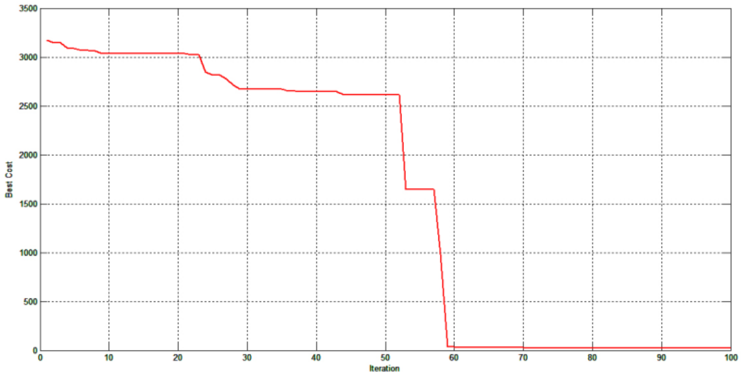

Figure 16. GA cost function.

V. Conclusion

In this paper, the PID controller has employed for AGC of four-area interconnected hydro-thermal power system and its parameters have determined by three metaheuristic methods; GA, PSO and hPSO-GA. Then, AGC model has simulated in MATLAB/SIMULINK and their results have compared with each other. It has shown in results and analysis section that hybrid PSO-GA method has superiority in comparison with PSO and GA. So, it is suggested to use this hybrid PSO-GA algorithm instead of PSO or GA because this proposed method overcomes both PSO and GA problems by using characteristics of both of them.

APPENDIX

Symbol	Explanation	Value
f	Nominal system frequency	60 Hz
i	Subscript referred to area i	1, 2, 3, 4
Pri	Area rated Power	2000MW
Hi	Inertia constant	5sec
ΔPDi	load perturbation in area i	1%
ΔPtie	Tie-lines power (Δp12, Δp23, Δp34, Δp41)	-
Di	ΔPDi/ Δfi	8.33*10-3 Pu MW/ Hz
T12	Synchronizing coefficient	0.086 Pu MW/radians
Ri	Governor speed regulation parameter	2.4 Hz/Pu MW
Tg	Steam governor time constant	0.08 sec
Kr	Steam turbine reheat constant	0.5
Tr	Steam turbine reheat time constant	10 sec
Tt	Steam turbine time constant	0.3 sec
Bi	Frequency bias constant	0.424
Tpi	2Hi/f*Di	20 sec
Kpi	1/Di	120 Hz/Pu MW
ki	Integral gain	-
kp	Proportional gain	-
kd	Derivative gain	-
Kd	Electric governor derivative gain	4
Kp	Electric governor proportional gain	1
Ki	Electric governor integral gain	5
Tw	Water starting time	1 sec
ACEi	Area control error of area i	BiΔfi+ΔPitie
a12	−Pr1/Pr2	-1
Δfi	Frequency deviation in Area i	-

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