Load Frequency Control Based on Evolutionary Techniques in Electrical Power Systems

Naglaa K. Bahgaat, M.I. El-Sayed, M.A. Moustafa Hassan and F. Bendary

Abstract Load Frequency Control (LFC) used to regulate the power output of the electric generator within an area as the response of changes in system frequency and tie-line loading. Thus the LFC helps in maintaining the scheduled system frequency and tie-line power interchange with the other areas within the prescribed limits. Most LFCs are primarily composed of an integral controller. The integrator gain is set to a level that compromises between fast transient recovery and low overshoot in the dynamic response of the overall system. The disadvantage of this type of controllers that there are slow and does not allow the controller designer to take into account possible changes in operating conditions and non- linearities in the generator unit. Moreover, it lacks robustness. So there are many modern techniques used to tune the controller. This chapter discusses the application of evolutionary techniques in Load Frequency Control (LFC) in power systems. It gives introduction to evolutionary techniques. Then it presents the problem formulation for load frequency control with Evolutionary Particle Swarm Optimization (MAACPSO). It gives the application of Particle Swarm Optimization (PSO) in load frequency control, also it illustrates the use of a Adaptive Weight Particle Swarm Optimization (AWPSO), Adaptive Accelerated Coefficients based PSO, (AACPSO) Adaptive Accelerated Coefficients

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N.K. Bahgaat (✉)
Electrical Communication Department, Faculty of Engineering,
Canadian International College (CIC), 6 October City, Giza, Egypt
e-mail: nkahgaat@hotmail.com; n_mohamed2004@yahoo.com

M.I. El-Sayed
Electrical Power Engineering Department Faculty of Engineering,
Al-Azhar University, Cairo, Egypt
e-mail: d_eng2009@yahoo.com

M.A. Moustafa Hassan
Electrical Power Engineering Department Faculty of Engineering,
Cairo University, Giza, Egypt
e-mail: mmustafa@eng.cu.edu.eg

F. Bendary
Electrical Power Engineering Department Faculty of Engineering,
Banha University, Cairo, Egypt
e-mail: fahmybendary10@gmail.com

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based PSO (AACPSO). Furthermore, it introduces a new modification for AACPSO technique (MAACPSO). The new technique will be explained inside the chapter, it is abbreviated to Modified Adaptive Accelerated Coefficients based PSO (MAACPSO). A well done comparison will be given in this chapter for these above mentioned techniques. A reasonable discussion on the obtained results will be displayed. The obtained results are promising.

Keywords Modified Adaptive Accelerated Coefficients based PSO · Adaptive Accelerated Coefficients based Particle Swarm Optimization · Adaptive weight particle swarm optimization · Load Frequency Control · and Particle Swarm Optimization Technique

1 Introduction

Frequency is an important factor to describe the stability criterion in power systems [15, 23, 29]. To provide the stability of power system, active power balance and steady frequency are required. If any change occurs in active power demand or the generation in power systems, oscillations increase in both power and frequency. Frequency cannot be hold in its rated value because it depends on active power balance. Thus, system subjects to a serious instability problem. In electric power generation, system disturbances caused by load fluctuations result in changes to the desired frequency value. Automatic Generation Control (AGC) or Load Frequency Control (LFC) is an important issue in power system operation and control for supplying stable and reliable electric power with good quality [24, 27]. The principle aspect of Automatic Load Frequency Control is to maintain the generator power output and frequency within the prescribed limits [7].

There are many controllers used in practice in order to keep the power system in normal operating state [13, 30], one of the famous controllers used in power system are Proportional Integral (PI), Proportional Derivative (PD) and Proportional Integral Derivative (PID) controllers, PID will be used for the stabilization of the frequency in the load frequency control problems [4, 15, 23, 24, 29]. When changes of the loads occur each control area is responsible for individual load changes and scheduled interchanges with neighboring areas [25]. The changes of the loads and abnormal conditions leads to mismatches in frequency and tie line power interchanges which are to be kept in the allowable limits, for the strong operation of the power system. For simplicity, the effects of governor dead band are neglected in the LoadFrequency Control studies. To study the realistic analysis of the system performance, the governor dead band effect is to be incorporated. To improve the stability of the power networks, it is necessary to design LFC system that controls the power generation and active power at tie lines [7, 8].

There are many studies done in the past on this important issue in power systems, which is the load frequency control. As stated in some literature [9, 14, 20], its objective is to minimize the transient deviations in area frequency and tie-line power interchange and to ensure their steady state errors to be zeros. This chapter discusses the application of evolutionary techniques in Load Frequency Control (LFC) in power systems, such that Particle Swarm Optimization (PSO), Adaptive Weighted Particle Swarm Optimization techniques (AWPSO), Adaptive Accelerated Coefficients based on PSO (AACPSO) and Evolutionary Particle Swarm Optimization (MAACPSO). Will be used to determine the parameters of a PID controller according to the system dynamics. Using the same parameters of PID controller for the two different areas because it gives a better performance for the system frequency response than in case of using two different PID parameters for each different area [8, 19]. The main objectives of LFC in case of changes in system frequency, is to regulate the power output of the electric generator within an arranged area in response to, tie line loading so as to maintain the planned system frequency and interchange with the other areas within the prescribed limits.

In this chapter, the power systems contents of two area and load frequency control of this system is made based on PID controller. To choose best parameters of PID Controller many techniques are used, Particle Swarm Optimization and Adaptive Weight Particle Swarm Optimization Techniques (PSO) and (AWPSO) [11, 18, 21] and Also using Adaptive Accelerated Coefficients based PSO, (AACPSO), then a new modification for AACPSO technique will be discuss called evolutionary techniques based on Particle Swarm Optimization (MAACPSO).

This chapter is organized as follow: Sect. 1 introduces the chapter. The Sect. 2 presents literature review of the study. Section 3 introduces Particle Swarm (PSO), AWPSO, the Adaptive Accelerated Coefficients based PSO (AACPSO) and Modified Adaptive Accelerated Coefficients based PSO (MAACPSO). Section 4 displays the case study and a comparative study between these methods, while Sect. 5 concludes the chapter. Finally a list of references and Appendix of this chapter are given at the end of the chapter.

2 Literature Review

The PID controller was first described by Minorsky [2]. It has been confirmed that in control applications more than 95 % of the controllers are PID type. Also, they state that 30 % of the PID loops operate in the manual mode and 25 % of PID loops actually operate under default factory settings. The choice of appropriate PID parameters can be achieved manually by trial and error, using as guidelines the transient and steady response characteristic of each of the three terms. However, this procedure is very time consuming and requires certain skills [3, 8].

PID control is a linear control methodology. The structure of PID controllers as shown in Fig. 1 is very simple. They operate on the error signal, which is the difference between the desired output and the actual output, and generate the actuating signal that drives the plant. They have three basic terms: proportional action, in which the actuating signal is proportional to the error signal, integral action, where the actuating

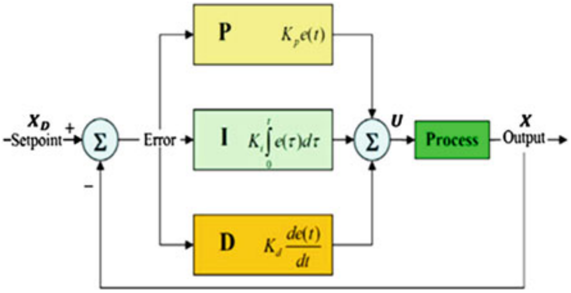


Fig. 1 Structure of PID controller

signal is proportional to the time integral of the error signal; and derivative action, where the actuating signal is proportional to the time derivative of the error signal as illustrated in [10, 22, 27].

With caution because it amplifies any existent noise in the signal. The PID standard form is given by:

$$u = K_P.e + K_i \int e.dt + K_d.\frac{de}{dt} \tag{1}$$

where:

e	Is the error signal
u	Is the control action
Kp	Is the proportional gain
Ki	Is the integral gain
Kd	Is the derivative gain

In power system which consists of many neighboring areas there are mismatches in frequency and power transfer. The controller used in power systems should provide some degree of strength under different operating conditions. Using conventional PD, PI, PID controllers does not provide sufficient control performance with the effect of governor dead band [15, 23, 24, 29]. So many methods used since 1890s till now to tune the controller. First method is the manual tuning, this method.

To design a particular control loop, the three constants (KP, Ki, and Kd) have to be adjusted to arrive at acceptable performance; If the system must remain online, then first set Ki and Kd values to zero. Increase Kp until the output of the loop oscillates; then KP should be set to approximately half of that value for a “quarter amplitude decay” type response. Then increase Ki until any offset is correct in sufficient time for the process. However, increasing Ki will cause instability. Finally, increase Kd, if required, until the loop is acceptably quick to reach its reference after a load disturbance. However, too much Kd will cause excessive response and overshoot. A fast PID loop tuning usually overshoots slightly to reach the set point more quickly; however, some systems cannot accept overshoot, in which case an over damped closed-loop system is required, which will require a KP setting significantly less than half that of the KP setting causing oscillation. The effect of increasing each of the controller parameters KP, Ki and Kd can be summarized as illustrated in

[27]. Second method is an automatic method called Ziegler–Nichols method which introduced by John G. Ziegler and Nathaniel B. Nichols in the 1940s [24, 29]. It is recognized that the step response of most process control systems has an S-shaped curve called the process reaction curve and can be generated experimentally or from dynamic simulation of the plant. [8], the shape of the curve is characteristic of high order systems, and the plant behavior may be approximated by the following transfer function [27]:

$$\frac{\mathrm{Y(S)}}{\mathrm{U(S)}} = \frac{\mathrm{K.e}^{-\mathrm{t_d.S}}}{\tau.\mathrm{S} + 1} \tag{2}$$

which is simply; a first order system plus a transportation lag. The constants in the above equation can be determined from the unit step response of the process. Ziegler and Nichols applied the PID controller to plants without integrator or dominant complex-conjugate poles, whose unit-step response resemble an S shaped curve with no overshoot. This S-shaped curve is called the reaction curve as shown in Fig. 1:

The following PID controller parameters were suggested:

$$\mathrm{K_P} = 1.2\mathrm{T/L} \tag{3}$$

$$K_i = K_P/2L \tag{4}$$

$$\mathrm{K_d} = 0.5.\mathrm{L.\,K_P} \tag{5}$$

Although the method provides a first approximation the response produced is under damped and needs further manual retuning. Some disadvantages of these control techniques for tuning PID controllers are:

(a) Excessive number of rules to set the gains.
(b) Inadequate dynamics of closed loop responses.
(c) Difficulty to deal with nonlinear processes.
(d) Mathematical complexity of the control design.

Therefore, it is interesting for academic and industrial communities the aspect of tuning for PID controllers, especially with a reduced number of parameters to be selected and a good performance to be achieved when dealing with complex processes.

The manual calculation methods no longer are used to tune loops inmost modern industrial facilities. Instead, PID tuning and loop optimization software are used to guarantee dependable results [14, 17, 25]. These software packages will gather the data, develop process models, and suggest optimal tuning.

Some software packages can even develop tuning by gathering data from reference changes, such as PSO, AWPSO [18, 19, 21], AACPSO [1, 8]. And this chapter will discuss the design of the PID controller by using modern method PSO, AWPSO, AACPSO and MAACPSO. These methods are simulated on MATLAB software program. This computer program which written on MATLAB had loops and run many times until reaching to a solution of the transfer function to have a value of PID parameters. These parameters lead to have the smallest value of settling time and over shoot. Therefore, these values of PID parameters (with these used methods) are the best values to reach to the best controller parameters. Moreover, a good comparison between the results of each used method will be done to choose the best one of them which will be suitable to use in the power system model used.

3 Overview on Practical Swarm Optimization Techniques

A Particle Swarm Optimization (PSO) is one of Artificial Intelligence (AI) Techniques. It's an optimization algorithm modeled. From the fields of AI with those of control engineering to design independent systems that can sense, reason, learn and act in an intelligent method. PSO depends on the simulation of the social behavior of bird and fish school [8, 21]. PSO is developed through the simulation of a bird flocking in two-dimension space by X-Y axis position where Vx and Vy express the velocity in X direction and Y direction. The flow chart described in Fig. 2, presented the steps of PSO. Modification of the agent position is realized by the position and velocity information [11, 18, 19, 21]. This information is analogy of personal experiences of each agent. Each agent knows its best value so far (Pbest) and its XY position; each agent knows the best value so far in the group (gbest) among Pbest s. This information is analogy of knowledge of how the other agents around them have performed. Namely, each agent tries to modify its position using the following information:

Let the particle of the swarm is represented by the N dimensional vector ith

$$\mathrm{X_i} = (\mathrm{X_1}, \mathrm{X_2}, \mathrm{X_3}, \ldots \mathrm{X_N}) \tag{6}$$

The previous best position of the Nth particles is recorded and represented as follows:

$$\mathrm{Pbesti} = (\mathrm{Pbest1}, \mathrm{Pbest2}, \ldots, \mathrm{PbestN}) \tag{7}$$

where Pbest is Particle best position (m), N is the total number of iterations.

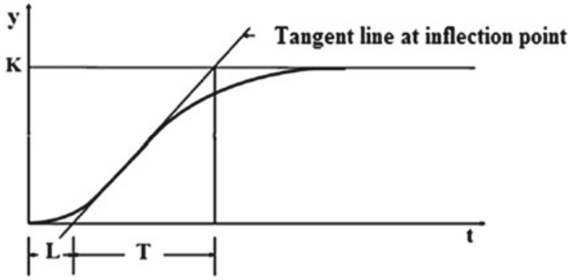


Fig. 2 Reaction curve used by Ziegler and Nichols

The best position of the particle among all particles in the swarm is represented by gbest the velocity of the particle is represented as follows:

$$\mathrm{Vi} = (\mathrm{V1}, \mathrm{V2}, \ldots \mathrm{VN}) \tag{8}$$

where V_i is the velocity of each i particle.

The modified velocity and position of each particle can be calculated from the current velocity and the distance from particle current position to particle best position P_{best} and to global best position g_{best} as shown in the following Equations [8]:

$$V_i(t) = W.V_i(t-1) + C_1.\mathrm{rand}(0, 1).(P_{best} - X_i(t-1)) + C_2.\mathrm{rand}(0, 1).(g_{best} - X_i(t-1)) \tag{9}$$

$$X_i(t) = X_i(t-1) + V_i(t) \tag{10}$$

$$i = 1, 2, 3.\ldots\ldots.N \tag{11}$$

$$j = 1, 2, 3.\ldots\ldots.D \tag{12}$$

where:

Vi(t)	Velocity of the particle i at iteration t (m/s)
Xi(t)	The Current position of particle i at iteration t (m)
D	The Dimension
C1	The cognitive acceleration coefficient and it is a positive number
C2	Social acceleration coefficient and it is a positive number
rand [0, 1]	A random number obtained from a uniform random distribution function in the interval [0, 1]
gbest	The Global best position (m)
W	The Inertia weight

3.1 Adaptive Weighted Particle Swarm Optimization

Adaptive Weighted Particle Swarm Optimization (AWPSO) technique has been anticipated for improving the performance of PSO in multi-objective optimization problems [18, 19]. AWPSO is consists of two terms which are: inertia weight (W) and Acceleration factor (A) [21]. The inertia weight (W) function is to balance global exploration and local exploration. It controls previous velocities effect on the new velocity. Larger the inertia weight, larger exploration of search space while smaller the inertia weights, the search will be limited and focused on a small region in the search space. The inertia weight formula is as follows which makes W value changes randomly from W_o to 1 [5, 6, 8].

$$\mathrm{W} = \mathrm{W_o} + \mathrm{rand}(0, 1)(1 - \mathrm{W_o}) \tag{13}$$

where:

Wo The initial positive constant in the interval chosen from [0, 1]

Particle velocity at its iteration as follows:

$$\mathrm{V_i(t) = W.V_i(t-1) + AC_1.rand(0, 1).(P_{best} - X_i(t-1)) + AC_2.rand(0, 1).(g_{best} - X_i(t-1))} \tag{14}$$

Additional term denoted by A called acceleration factor is added in the original velocity equation to improve the swarm search.

The iteration of the particle velocity described in [21] as the following:

$$A = A_o + \frac{i}{n} \tag{15}$$

where:

$\mathrm{A_o}$: Is the initial positive constant in the interval [0.5, 1].
n: is the number of iteration.
$\mathrm{C_1}$ and $\mathrm{C_2}$: Are the constant representing the weighing of the stochastic acceleration terms that pull each particle towards $\mathrm{P_{best}}$ and $\mathrm{g_{best}}$ positions.

As shown in acceleration factor formula, that the acceleration term will increase as the number of iterations increases. This will increase the global search ability at the end of the run and help the algorithm to get far from the local optimum region. In this chapter, the term $\mathrm{A_O}$ is set at 0.5. Low values of $\mathrm{C_1}$ and $\mathrm{C_2}$ allow particles to roam far from the target region before being tugged back. However, high values result in abrupt movement toward, or past, target regions.

3.2 Adaptive Accelerated Coefficients Based PSO

In Sect. 3.1 the value of W can be located a good solution at a considerably faster rate but its ability to fine tune the optimum solution is weak, due to the lack of diversity at the end of the search. It has been observed by most researchers that in PSO, problem based tuning of parameters is a key factor to find the optimum solution accurately and efficiently [28]. New researches have emerged to improve PSO Algorithms, as Time-Varying Acceleration Coefficients (TVAC), where $\mathrm{C_1}$ and $\mathrm{C_2}$ in [12] change linearly with time, in the way that the cognitive component is reduced while the social component is increased as the search proceeds [1]. This method studies how to deal with inertia weight and acceleration factors and how to change acceleration coefficients exponentially (with inertia weight) in the time, with respect to their minimal and maximal values. The choice of the exponential function is justified by the increasing or decreasing speed of such a function to accelerate the convergence process of the algorithm and to get better search in the exploration s pace. Furthermore, C_1 and C_2 vary adaptively according to the fitness value of G_{best} and P_{best}, [8, 12] becomes:

$$V_i^{(t+1)} = w^{(t)} V_i^{(t)} + C_1^{(t)} r_1 * \left(Pbest_i^{(t)} - X_i^{(t)} \right) + C_2^{(t)} r_2 * \left(Gbest^{(t)} - X_i^{(t)} \right) \quad (16)$$

$$w^{(t)} = w_o * exp\,(- \propto_w * t) \quad (17)$$

$$C_1^{(t)} = C_{1o} * \exp\left(- \propto_c * t * k_c^{(t)}\right) \quad (18)$$

$$C_2^{(t)} = C_{2o} * \exp\left(\propto_c * t * k_c^{(t)}\right) \quad (19)$$

$$\propto_c = \frac{-1}{\mathrm{t_{max}}} \ln\left(\frac{\mathrm{C_{2o}}}{\mathrm{C_{1o}}}\right) \quad (20)$$

$$k_c^{(t)} = \frac{\left(F_m^{(t)} - Gbest^{(t)}\right)}{F_m^{(t)}} \quad (21)$$

where:

$\mathrm{w}^{(t)}$	The inertia weight factor
$\mathrm{C}_1^{(t)}$	Acceleration coefficient at iteration t
i	Equal 1 or 2
t	The iteration number
ln	The neperian logarithm
α_{w}	Is determined with respect to initial and final values of ω with the same manner as αc described in [2].
$\mathrm{k}_{\mathrm{c}}^{(t)}$	Determined based on the fitness value of Gbest and Pbest at iteration t
ω_{o}, c_{io}	c_{io} initial values of inertia weight factor and acceleration coefficients respectively with i = 1 or 2.
$\mathrm{F}_{\mathrm{m}}^{(t)}$	The mean value of the best positions related to all particles at iterationt

3.3 Modified Adaptive Accelerated Coefficients PSO

In this section, a new approach called Modified Adaptive Accelerated Coefficients PSO will be described as illustrated in [16]. A suggestion will be show how to choose the acceleration factors. The new approach will be make modification on the values of C1 and C2 which described in the last Sect. 3.2. The first coefficient changes exponentially (with inertia weight) in the time, with respect to their minimal and maximal values.While, the other one changes as a factor of the first coefficient. The choice of the exponential function is justified by the increasing or decreasing speed of such a function to accelerate the convergence process of the algorithm and to get better search in the exploration space.

Instead of the Eq. (18) the parameter C_2(t) is suggested to be equal [16]:

$$C_2(t) = 4 - C_1(t) \tag{22}$$

The results of the program are shown in Tables 1, 2 and 3.

Table 1 Parameter description

Parameter	Description
Tg1, Tg2	Time constant for area 1 governor and area 2 governor in (seconds)
Tt1, Tt2	Turbine time delay between switching the valve and output turbine torque (seconds)
Tl1, Tl2	Generator 1 and generator 2 inertia constant
Kl1, Kl2	Power system gain constant (HZ/MW p.u)
R1, R2	Speed regulation constant of the governor (HZ/MW p.u)
B1, B2	Frequency bias p.u. MW/HZ
T12	Tie line synchronizing coefficient with area 2 MW p.u /HZ
a12	Gain
$\Delta f_1 or df_1$	Area 1 frequency deviation
$\Delta f_2 or df_2$	Area 2 frequency deviation
dPL1, dPL2	Frequency sensitive load change for area 1 and area 2
ΔPtie or dPtie	Net Tie line power flow
Vi	Area interface
ACE1	Area 1 control error
ACE2	Area 2 control error

Table 2 Parameters values

System parameters	Value
Tg1, Tg2	0.08 s
Tt1, Tt2	0.3 s
Tl1, Tl2	20 s
Kl1, Kl2	100 HZ/MW p.u
R1, R2	2.4 HZ/MW p.u
B1, B2	0.425 MW p.u/HZ
T12	0.05 MW p.u/HZ
a12	1

Table 3 The results of the program using PSO, AWPSO, AACPSO and MAACPSO

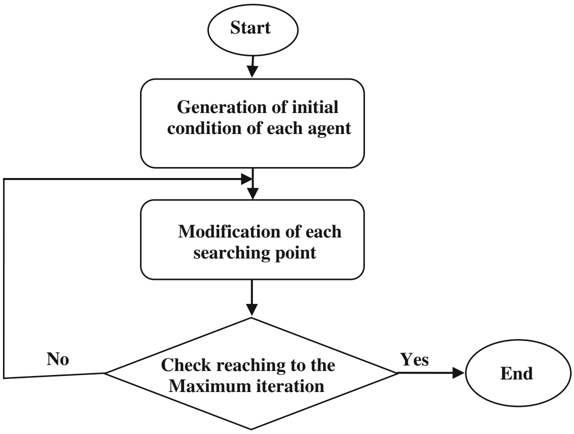
Items of comparison	PSO	AWPSO	AACPSO	MAACPSO
Number of iterations	500	500	500	500
Error IAE (Integrated error)	0.0611	0.0252	0.0149	0.0267
Settling time _Area 1 (sec)	5.4281	1.9323	1.6514	1.7267
Settling time _Area 2 (sec)	7.6946	4.1854	3.569	2.5288
Settling time _Tie line (sec)	7.7624	4.2082	3.6553	2.5696
Kp1	2.4283	8.1472	9.1995	3.7517
Ki1	1.5555	7.5774	9.4936	6.0754
Kd1	1.3753	2.7603	3.2393	0.8947
Kp2	2.9522	3.4998	4.7149	4.9802
Ki2	9.2078	1.6218	0.876	1.2982
Kd2	5.7955	8.6869	2.1397	8.4839

4 Cases Study

The model used as a case study is consists of two power system areas connected with each other's by tie transmission line as shown in Figs. 3 and 4 [8, 26]. Simulations are done by using MATLAB/SIMULINK for the case of the parameters of area 1 and area 2 are shown in the Appendix. Electric power system components are non-linear; therefore a linearization around a nominal operating point is usually performed to get a linearized system model which is used in the controller design process.

The operating conditions of power systems are continuously changing. Accordingly, the real plant usually differs from the assumed one. Therefore, classical algorithms to design an automatic generation controller using an assumed plant may not ensure the stability of the overall real system [8, 27]. The load frequency controller

Fig. 3 General flow chart of PSO



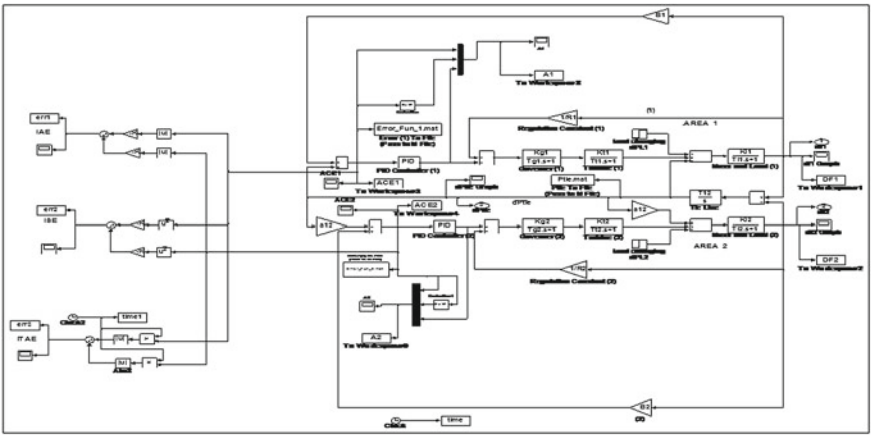


Fig. 4 Two-Area power system SIMULINK model using PID controller

function is to minimize the transient deviation of the frequency and maintains their values to steady state values and to restore the scheduled interchanges between different areas.

MATLAB programs are used for PSO, AWPSO, AACPSO and MAACPSO to make tuning of the PID controller's parameters. These parameters adjusted to have minimum integrated error value with shorted settling time. The objective function is defined as follows [8, 25]:

For Integral of Absolute Error (IAE):

$$\mathrm{IAE} = \int_{0}^{\infty} |\mathrm{e}\,(\mathrm{t})|\,\mathrm{dt} \tag{23}$$

$$\mathrm{f} = \mathrm{IAE}_1 + \mathrm{IAE}_2 + \mathrm{IAE}_{\mathrm{Ptie}} \tag{24}$$

Integral of Squared Error (ISE)

$$\mathrm{ISE} = \int_{0}^{\infty} \mathrm{e}^2\,(\mathrm{t})\,\mathrm{dt} \tag{25}$$

$$\mathrm{f} = \mathrm{ISE}_1 + \mathrm{ISE}_2 + \mathrm{ISE}_{\mathrm{Ptie}} \tag{26}$$

Integral of Time Weighted Absolute Error (ITAE)

$$\mathrm{ITAE} = \int_{0}^{\infty} \mathrm{t}\,|\mathrm{e}\,(\mathrm{t})|\,\mathrm{dt} \tag{27}$$

$$\mathrm{f} = \mathrm{ITAE}_1 + \mathrm{ITAE}_2 + \mathrm{ITAE}_{\mathrm{Ptie}} \tag{28}$$

where:

e Is the error

f Is the objective function

$IAE_1, IAE_2, IAE_{Ptie_1}$ The Integral of Absolute Error of area 1, area 2 and the tie line of the System

$ISE_1, ISE_2, ISE_{Ptie_1}$ The Integral of Squared Error of area 1, area 2 and the tie line of the System

$ITAE_1, ITAE_2, ITAE_{Ptie_1}$ Integral of Time Weighted Absolute Error of area 1, area 2 and the tie line of the System

For the two power system areas, step loading disturbance has been applied for each area, 0.07 p.u load throw has been withdrawn from the first area and 0.05 p.u loading added for the second area. The control objective is to control the frequency deviation for each area.

4.1 Steps of the Study

Using MATLAB/SIMULINK the steps of the study by using many intelligent techniques (PSO, AWPSO, AACPSO and finally using MAACPSO) areas the following:

(1) Using MATLAB/SIMULINK model of the system with its parameters.
(2) Choose the type of error used in the equations in the beginning of the MATLAB program (IAE, ISE, or ITAE).
(3) Using PSO program with the equations of the chosen type of error.
(4) Repeat using AWPSO program for the same type of error used.
(5) Repeat using AACPSO program for the same type of error used.
(6) Repeat using MAACPSO program for the same type of error used.
(7) Compare the results of the four methods used and determine the best which has a less value of settling time and frequency deviation.
(8) Assign the value of the PID controller for the best method results.
(9) Conclude the results.

The performance index selected by the user in the beginning of the program. Based on this performance index (f) optimization problem can be stated as: Minimize f the nominal system description and parameters are describing in the following:

4.2 Model Description and Parameters

The block diagram of the two areas power system model using PID controller presented at Fig. 3 as presented in [8, 27]. The description for the system parameters is displayed in Table 1 and the parameters values of the system is presented in Table 2.

So the transfer function of governors, turbine, mass and load becomes as given in [27]:

$$G_{h1}(S) = G_{h2}(S) = \frac{1}{0.08s + 1} \tag{29}$$

$$G_{t1}(S) = G_{t2}(S) = \frac{1}{0.3s + 1} \tag{30}$$

$$G_{y1}(S) = G_{y2}(S) = \frac{120}{20s + 1} \tag{31}$$

To optimize the performance of a PID controlled system, the PID gains K_P, K_i, and K_d of the two-area electric power system shown in Fig. 3 are adjusted to minimize a certain performance index. The performance index is calculated over a time interval; T, normally in the region of $0 < T <$ts where t_s is the settling time of the system. By using different techniques in conjunction with Eqs. 22–29 the optimal controller parameters under various performance indices were obtained as shown in Tables 1, 2 and 3 show the results of the different methods used based PID controller.

4.3 Results in Case of IAE Error

A MATLAB code was written to carry out the PSO, AWPSO, AACPSO and MAACPSO algorithms. The Integral of Absolute Error (IAE) is considered as a choice in the run of the program. Table 3 illustrates The Results of the Program Using PSO, AWPSO, AACPSO and MAACPSO.

Figures 5 and 6 present the frequency deviation of area 1 and area 2 without using PID controller.

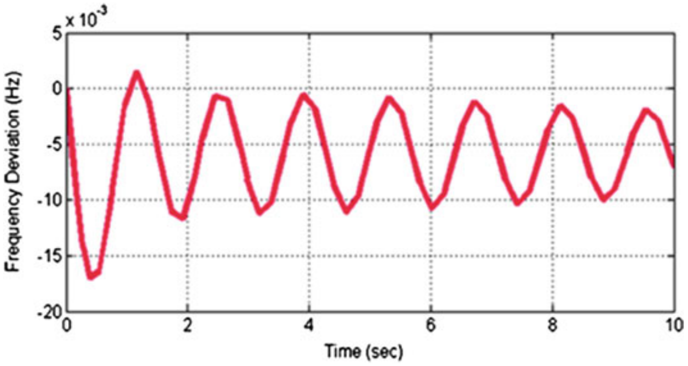


Fig. 5 The frequency deviation of area 1 without controller

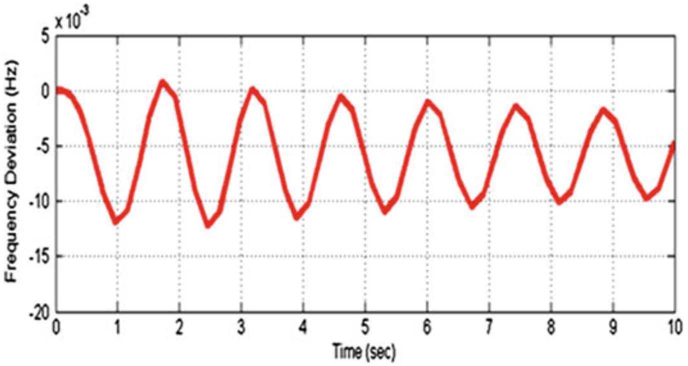


Fig. 6 The frequency deviation of area 2 without controller

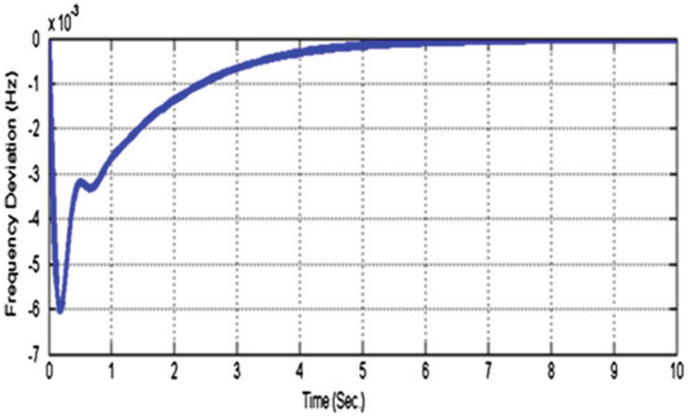


Fig. 7 The frequency deviation of area 1 with PSO based PID controller using IAE performance indices

Furthermore, there are the Figures describe the output of the system after controlling the error on area 1 and area 2. Figure 7 presents the frequency deviation of area 1 with PSO based PID Controller, Fig. 8 presents the frequency deviation of area 1 with AWPSO based PID controller and Fig. 9 illustrates the frequency deviation of area 1 with AACPSO based PID controller and finally Fig. 10 presented the frequency deviation of area 1using MAACPSO based PID controller.

The next Figures present the behavior of area 2 in different cases of Artificial Intelligence techniques.

Figure 11 presents the frequency deviation of area 2 with PSO based PID controller using IAE performance indices; Fig. 12 shows the behavior of the frequency deviation of area 2 in case of using AWPSO, while; Fig. 13 displays The frequency deviation of area 2 with AACPSO based PID controller, finally Fig. 14 presents the frequency deviation of area 2 with MAACPSO based PID controller using IAE performance indices.

From the results shown in Table 3 and also the above Figures from Figs. 7, 8, 9, 10, 11, 12, 13 and 14 all these show that:

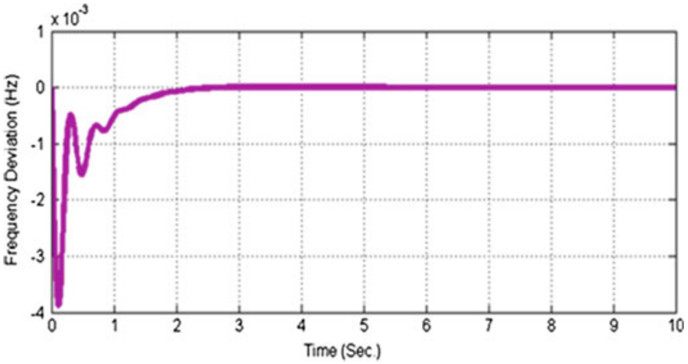


Fig. 8 The frequency deviation of area 1 with AWPSO based PID controller using IAE performance indices

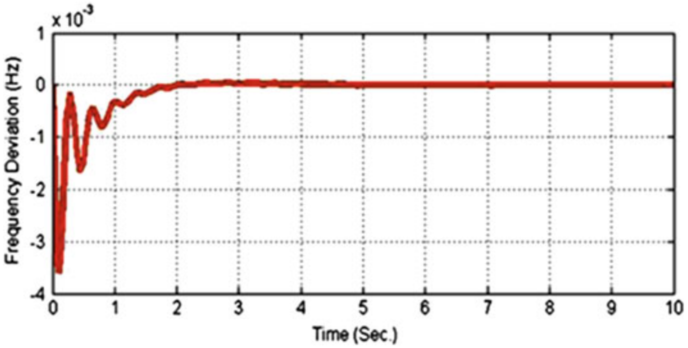


Fig. 9 The frequency deviation of area 1 with AACPSO based PID controller using IAE performance indices

Table 4 Tie line behavior at different types of control

Items of comparison	PSO	AWPSO	AACPSO	MAACPSO
Settling time_Tie line (s)	7.7624	4.2082	3.6553	2.5696
Maximum frequency of tie line power (Hz)	3.00E-07	4.24E-07	1.06E-06	4.98E-07
Time at maximum frequency of tie line power (s)	20.502	22.2727	4.8003	4.0135
Minimum frequency of tie line power (Hz)	−0.0011	−3.66E-04	−3.20E-04	−9.13E-04
Time at minimum frequency of tie line power (s)	1.0319	0.612	0.5743	0.442

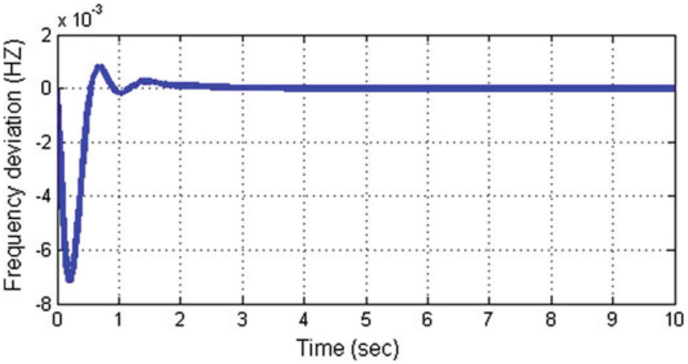


Fig. 10 The frequency deviation of area 1 with MAACPSO based PID controller using IAE performance indices

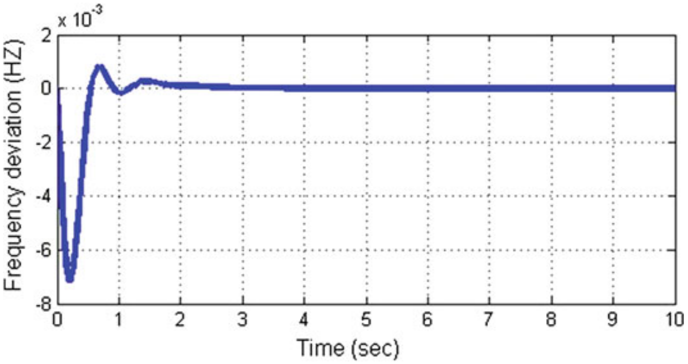


Fig. 11 The frequency deviation of area 2 with PSO based PID controller using IAE performance indices

(a) The settling time by using AACPSO is the smallest value of all the techniques used in the comparison. While, the settling time using MAACPSO comes next.
(b) The difference value between the settling time values using two methods “AACPSO, MAACPSO” is very small and equal approximately 0.08 s.
(c) All these results present that: the best method used to reach the minimum value of settling time in area 1 is AACPSO.
(d) The value of settling time of area 2 by using MAACPSO is less than all values using other methods.
(e) The difference between the value of settling time using MAACPSO and the nearest value using AACPSO is equal approximately 1.04 s.
(f) The value of settling time of the tie line using MAACPSO technique is the smallest compared to all methods used.

Table 5 Comparison between (MAACPSO) and (AACPSO)

Controller	Overshoot (Hz)	Settling time (s)
MAACPSO with IAE on area 1	5.5E-05	1.7267
AACPSO with IAE on area 1	4.10E-05	1.6514
MAACPSO with IAE on area 2	2.2E-03	2.5288
AACPSO with IAE on area 2	4.14E-06	3.6553
MAACPSO with IAE on tie line	4.98E-07	2.5696
AACPSO with IAE on tie line	1.06E-06	3.6553

(g) The difference between the values of settling time of the tie line using MAACPSO technique is less than the nearest value of settling time using AAPSO by approximately 1.08 s.

In the following sections there is Table 4 and Fig. 14 of Tie Line which describes the effects of using different techniques.

Figure 15 displays the Frequency Change Of The Tie Line Power With Using PSO, AWPSO And AAPSO Based PID Controller.

Table 5 shows Comparison of the value of Overshoot (Hz) and settling time (sec.) of the best two methods used MAACPSO and AACPSO.

The illustrated results in Table 5, Fig. 15 show that:

(a) Tables 4 and 5 indicate that on the Tie line power, the value of settling time in case of using MAACPSOis the best results and has a smaller value comparing with the other methods used (PSO, AWPSO and AACPSO).
(b) The settling time of Tie line in case of using MAACPSO is less than its value in case of using AACPSO by about 1.5 s, and less than its value when using AWPSO by about 1.6 s.
(c) Settling time by AWPSO is smaller than using PSO by 0.0359 s.

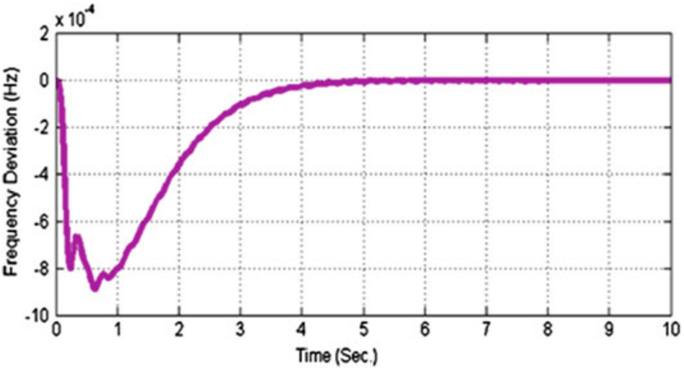


Fig. 12 The frequency deviation of area 2 with AWPSO based PID controller using IAE performance indices

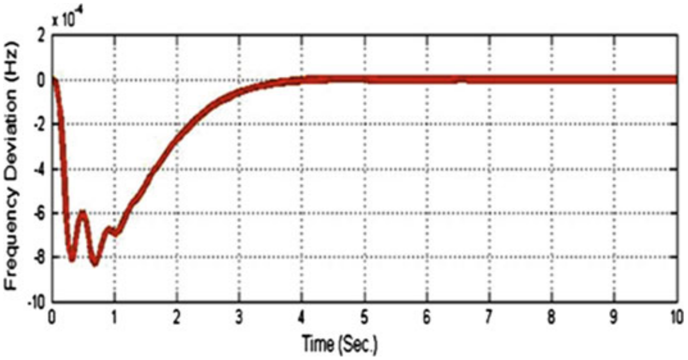


Fig. 13 The frequency deviation of area 2 with AACPSO based PID controller using IAE performance indices

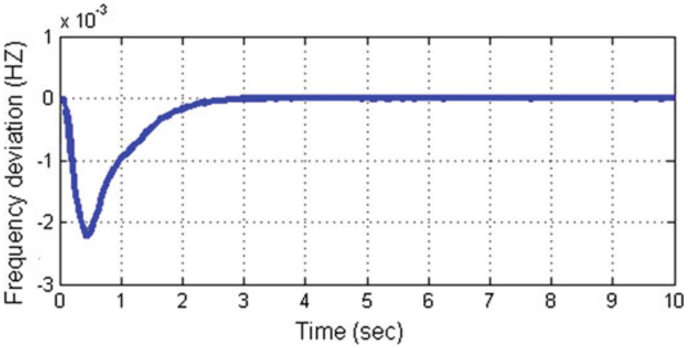


Fig. 14 The frequency deviation of area 2 with MAACPSO based PID controller using IAE performance indices

(d) The maximum frequency of Tie line power in case of using MAACPSO is less than its value of the other methods of controller used by a very small value.

(e) In general the maximum frequency of Tie line power is construed to be zero.

(f) Time at maximum power in case of using MAACPSO is less than the its value by using AACPSO by about 8 %, and the value of that time by using AACPSO is less than the other values of PSO and AWPSO. This value is less than the time of maximum power in case of using PSO by about 23.4 % and less than its value in case of using AWPSO by about 21.5 %.

(g) The minimum Tie line power in case of using MAACPSO is very small comparing with another methods, and its value in case of using AWPSO and AACPSO are almost equal and less than its value in case of using PSO.

(h) Time at minimum power in case of using MAACPSO is less than the other values of PSO, AWPSO and AACPSO.

(i) The Overshoot and settling time of area 1 by using MAACPSO is greater than that values by using AACPSO by a very small value.

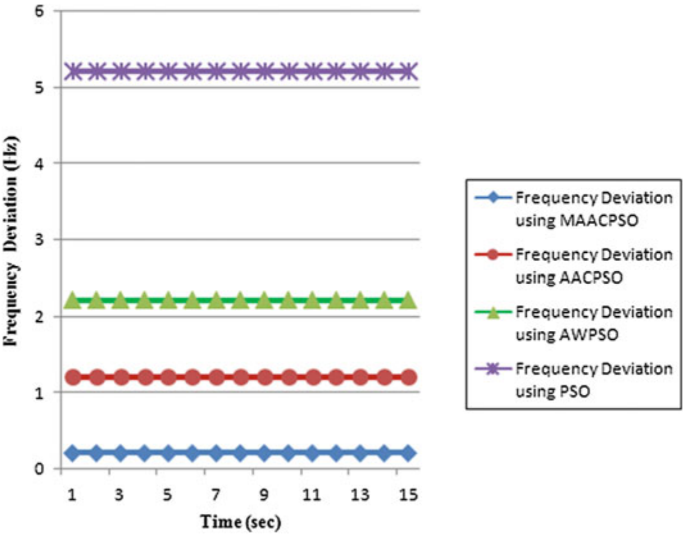


Fig. 15 Tie line power changes using PSO, AWPSO, AACPSO and MAACPSO based PID controller in case of using IAE error

(j) The Overshoot and settling time of area 2 by using MAACPSO is smaller than that values by using AACPSO.
(k) The Overshoot and settling time of tie line by using MAACPSO is very small than that values by using AACPSO.

All these results present that: the best method used to reach the minimum value of settling time is MAACPSO and AACPSO comes next.

5 Conclusions

The simulation of the proposed controllers explained in this chapter, indicate that:

Modified Adaptive Accelerated Coefficients based on PSO (MAACPSO) is the best method comparing with all methods used in this study. Then AACPSO comes next. As shown the settling time in area 1 using MAACPSO gives value near the value of settling time using AACPSO, the difference between the two methods was 0.07 s,and it's very small value.The settling time in area 2 using MAACPSO gives smaller than the value using AACPSO, the difference about 1.13 s, this is a very good result of MAACPSO. The settling time in tie line using MAACPSO gives very good value comparing with AACPSO, the difference was about 1.08 s., as presented in Tables 4 and 5 the frequency deviation values of area 1 of the best two methods MAACPSO and AACPSO was nearly equal, and the value using MAACPSO of tie tine is smaller than its value using AACPSO by about 5.6E-7 Hz.

6 Future Work

Studding the load frequency control using two different power system as a model and using MAACPSO technique will be a good study to examine the new technique, and make a comparison between the results of settling time and overshoot frequency using MAACPSO and some techniques like Fuzzy.

Appendix

Transmission line 1 parameters
Kg1 = 1
Kt1 = 1
Tg1 = 0.08
Tt1 = 20
R1 = 2.4
T11 = 20
Kl1 = 120
a12 = 1
Transmission line 2 parameters
Kg2 = 1
Kt2 = 1
Tg2 = 0.08
Tt2 = 0.33
R2 = 2.4
T12 = 20
Kl2 = 120

N = 25	Number of swarm beings
d = 6	Two dimensional problem
n = 500	Number of iterations
W0 = 0.15	Percentage of old velocity
A0 = 0.5	Acceleration factor constant between [0 1]
C1 = 2.05	Percentage towards personal optimum
C2 = 2.05	Percentage towards
x0range = [0 10]	Range of uniform initial distribution of positions
vstddev = 1	Std. deviation of initial velocities
C11 = 2	Percentage towards personal optimum used in ACC
C22 = 2.05	Percentage towards used in ACC

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