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Optimization of PID controller parameters using PSO for two area load frequency control

Brijesh Kumar Dubey[1], N. K. Singh[2], Sameer Bhambri[1]
[1]Electrical and Electronics Engineering, PSIT Kanpur, India
[2]Electrical Engineering, RVIT Bijnor, India

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ABSTRACT

In this paper, an evolutionary computing approach for determining the optimal values for the proportional-integral-derivative (PID) controller parameters of load frequency control (LFC) of two area power system is presented. The proposed approach employs a particle swarm optimization technique to find optimum parameters. The state space model of two area power system and an Eigen value based objective function is considered. The effectiveness of the proposed approach is compared with integral control. Simulation results justify the proposed approach in terms of damping the oscillations, improved settling time, less over/under shoots.

Corresponding Author:

Brijesh Kumar Dubey,
Electrical and Electronics Engineering,
Pranveer Singh Institute of Technology (PIST) Kanpur, India.
Email: brijesh80d@rediffmail.com

1. INTRODUCTION

In power systems, both active and reactive power demands are never steady and continuously change with rising or falling trend. Steam input to turbo generators (or water input to hydro generators) must therefore, be continuously regulated to match the active power demand, failing which the machine speed will vary with consequent change in frequency, which may be highly undesirable. In brief, the changes in real power affect the system frequency, while reactive power is less sensitive to changes in frequency and is mainly dependent on changes in voltage magnitude. The quality of power supply must meet certain minimum standards with regard to constancy of voltage and frequency [1].

The operational objective of LFC is to maintain reasonably uniform frequency, to divide load between generators and to control the tie-line interchange schedules. The change in the frequency and tie-line power are sensed, which is a measure of the change in rotor angle, i.e., the error to be corrected. The error signal, i.e., Δf and ΔP_{tie}, are amplified, mixed, and transformed into a real power command signal ΔP_v, which is sent to the prime mover to call for an increment in the torque. The prime mover, therefore, brings change in the generator output by an amount ΔP_g which will change the values of Δf and ΔP_{tie} within the specified tolerance.

In this paper mathematical model for the two area system is developed in order to analyses and design the control system. A state space model is developed by linearizing the mathematical equations of different components and thus the state matrix is formed. An Eigen value based objective function to place the modes in better region on the complex plane is considered and optimum controller parameters are found.

2. SYSTEM INVESTIGATED

During normal operation, the real power transferred over the tie-line is given by (as shown in Figure 1 and 2),

$$P_{12} = \frac{|E_1||E_2|}{X_T} \sin \delta_{12} \tag{1}$$

Where, $\delta_{12} = \delta_1 - \delta_2$.

For a small deviation in the tie-line flow from the nominal value:

$$\left.\begin{aligned} \Delta P_{12} &= \left(\frac{dP_{12}}{d\delta_{12}}\right)\Delta\delta_{12} \\ &= P_s \Delta\delta_{12} \end{aligned}\right\} \tag{2}$$

Where Ps is the slope of power angle curve at initial operating angle called synchronizing power coefficient.

$$P_{12} = \frac{|E_1||E_2|}{X_T} \cos \Delta\delta_{120} \tag{3}$$

$$\Delta P_{12} = P_s\left(\delta_1 - \delta_2\right) \tag{4}$$

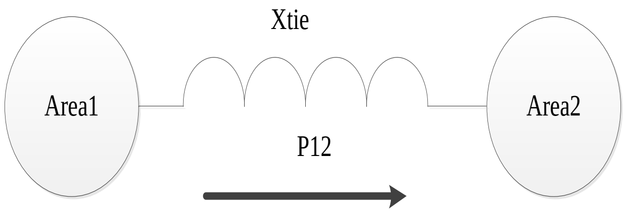

Figure 1. Two area system

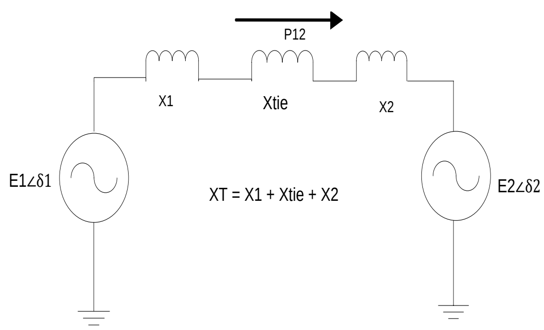

Figure 2. Electrical equivalent for a two area system

A block diagram representation of two area system with LFC containing only primary loop is shown in Figure 3 with each area represented by an equivalent inertia M, load damping constant D, turbine and governing system with an effective speed droop R. Tie-line is represented by synchronizing torque coefficient. A positive represents an increase in power transfer from area 1 to area 2 and it is equivalent to increasing load in area 1 and decreasing load in area 2.

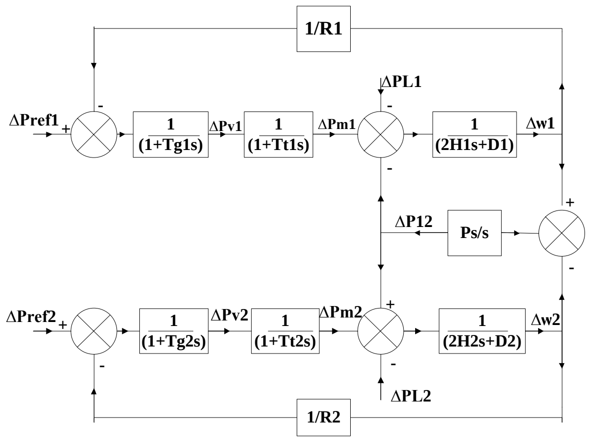

Figure 3. Two area system with primary LFC loop

Both areas will have a same steady state frequency deviation for a load change of in area 1.

$$\Delta\omega = \Delta\omega_1 - \Delta\omega_2 \text{ and } \Delta P_{m1} - \Delta P_{12} - \Delta P_{L1} = \Delta\omega D_1 \tag{5}$$

$$\Delta P_{m2} + \Delta P_{12} = \Delta\omega D_2 \tag{6}$$

From the governor speed characteristics the change in mechanical power is:

$$\left.\begin{aligned} \Delta P_{m1} &= \Delta\omega / R_1 \\ \Delta P_{m2} &= \Delta\omega / R_2 \end{aligned}\right\} \tag{7}$$

$$\Delta\omega = -\frac{\Delta P_{L1}}{\left(\frac{1}{R_1} + D_1\right) + \left(\frac{1}{R_2} + D_2\right)} \tag{8}$$

Where,

$$\left.\begin{aligned} B_1 &= \left(\frac{1}{R_1} + D_1\right) \\ B_2 &= \left(\frac{1}{R_2} + D_2\right) \end{aligned}\right\} \tag{9}$$

$$\Delta P_{12} = -\frac{\left(\frac{1}{R_2} + D_2\right)\Delta P_{L1}}{\left(\frac{1}{R_1} + D_1\right) + \left(\frac{1}{R_2} + D_2\right)} \tag{10}$$

In normal operating condition power system is operated so that demand of areas is satisfied at nominal frequency. A simple control strategy should include the following functions:
- Frequency approximately at nominal value.
- Maintaining the tie-line flow at about schedule.
- Each area should absorb its own load changes.

2.1. Tie-line bias control

Conventional LFCs are based on tie-line bias control where each area tends to control its area control error (ACE) to zero. The control error consists of linear combination of frequency and tie-line error [2].

$$ACE_i = \sum_{j=1}^{n} \Delta P_{ij} + K_i \Delta\omega \tag{11}$$

The area bias factor K_i determines the amount of interaction during the disturbances in the neighboring area. In order to get satisfactory performance area bias factor is selected as:

$$K_i = (\frac{1}{R_i} + D_i) \tag{12}$$

$$\left.\begin{aligned} ACE_1 &= \Delta P_{12} + B_1 \Delta\omega_1 \\ ACE_2 &= \Delta P_{21} + B_2 \Delta\omega_2 \end{aligned}\right\} \tag{13}$$

ΔP_{12} and ΔP_{21} are the deviations from the scheduled interchanges. ACEs are the actuating signals that are used to change the reference set points, and when the steady state is reached and will be zero. The block diagram of two area system LFC with integral control is shown in Figure 4.

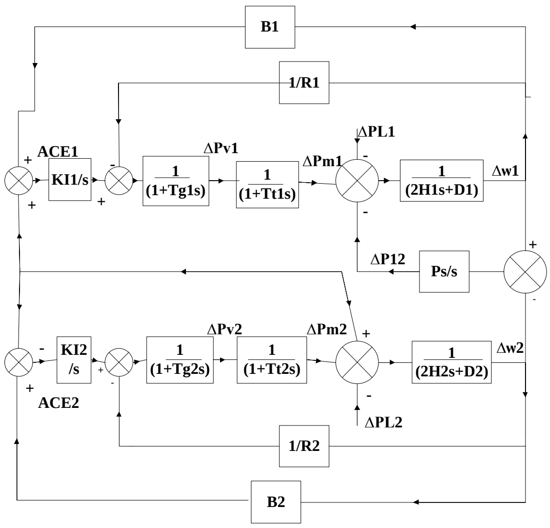

Figure 4. Block diagram of two area system LFC with integral control action

In this paper the integral control block is replaced by PID controller and state space model of the system $\dot{X}$=AX is obtained. State matrix of order 11×11 is formed with state variables ΔP_{g1}, ΔP_{v1}, ΔP_{m1}, $\Delta\omega_1$, ACE_1, ΔP_{12}, ΔP_{g2}, ΔP_{v2}, ΔP_{m2}, $\Delta\omega_2$, ACE_2 respectively. The parameters of the system which are to be optimized using PSO are K_{p1}, K_{I1}, K_{D1}, R_1, B_1, K_{p2}, K_{12}, K_{D2}, R_2, B_2 respectively [3]. Block diagram of two area system with PID controller is shown in Figure 5.

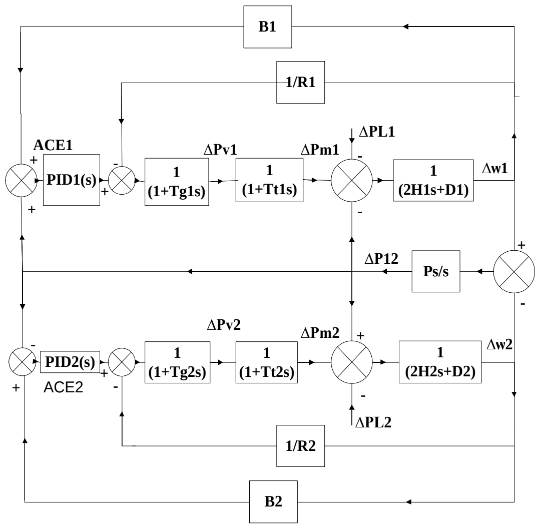

Figure 5. Block diagram of two area system LFC with PID control action

$$\text{PID1(s)} = K_{p1} + \frac{K_{I1}}{s} + K_{D1}s \tag{14}$$

$$\text{PID2(s)} = K_{p2} + \frac{K_{I2}}{s} + K_{D2}s \tag{15}$$

3. PARTICLE SWARM OPTIMIZATION

The PSO algorithm was first introduced by Dr. Russel C. Eberhart and Dr. James Kennedy (1995), inspired by social behavior of bird flocking or fish schooling. The system is initialized with a population of random solutions and searches for optima by updating generations [4]. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles. Each particle keeps track of its coordinates in the problem space which are associated with the best solution (fitness) it has achieved so far. (The fitness value is also stored) this value is called pbest. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the neighbors of the particle. This location is called lbest. When a particle takes all the population as its topological neighbors, the best value is a global best and is called gbest.

In the numerical implementation of this simplified social model, each particle has three attributes; the position vector in the search space, the current direction vector, the best position in its track and the best position of the swarm. The process can be outlined as follows [5]:

Step 1. Generate the initial swarm involving N particles at random.
Step 2. Calculate the new direction vector for each particle based on its attributes.
Step 3. Calculate the new search position of each particle from the current search position and its new direction vector.
Step 4. If termination condition is satisfied, stop. Otherwise, go to step 2.

As the particle can fly in D-dimension search space, the position and velocity of i-th particle can be represented as:

$$Xi=[x_{i1},x_{i2},x_{i3},x_{i4},\ldots\ldots.xiD] \tag{16}$$

$$Vi=[vi1,vi2,vi3,vi4,\ldots\ldots viD] \tag{17}$$

With increased iteration, the swarm will move towards its global best position by keeping track of their personal best. In D- dimensional search space the pbest of i-th particle can be represented as:

$$Pbest=[p_{i1},p_{i2},p_{i3},p_{i4},\ldots\ldots..p_{iD}] \tag{18}$$

and gbest of the whole swarm is presented as:

$$gbest=[g_1,g_2,g_3,g_4,\ldots\ldots\ldots.g_D] \tag{19}$$

The new direction vector of the i-th particle at time t, is calculated by the following scheme introduced by Shi and Eberhart.

$$\left.\begin{aligned} V_{id}^{t+1} &= \omega^t v_{id}^t + c1R_1^t(pbest_{id}^t - x_{id}^t) \\ &+ c2R_2^t(gbest_d^t - x_{id}^t) \end{aligned}\right\} \tag{20}$$

R_1^t and R_2^t are random numbers between 0 and 1. v_{id}^t and x_{id}^t is the velocity and position of the i-th particle in d-th dimension at its time track t. $pbest_{id}^t$ is the best position of the i-th particle (personal best) in d-th dimension in its track at time t and $gbest_d^t$ is the best position of the swarm in d-th dimension at time t. There are three parameters such as the inertia of the particle ω^t , and two parameters c1 and c2. c1 and c2 are the learning factors which determines the relative influence of the cognitive and social components to update the position and velocity component.

Then, new position of the i-th particle at time t, X_{id}^{t+1} , is calculated from:

$$X_{id}^{t+1} = X_{id}^t + V_{id}^{t+1} \tag{21}$$

Where X_{id}^t is the current position of the i-th particle at time t. After the i-th particle calculates the next search direction vector V_i^{t+1} in consideration of the current search direction vector v_{id}^t ,the direction vector going from the current search position X_{id}^t to the best search position in its track $pbest_{id}^t$ and the direction vector going from the current search position X_{id}^t to the best search position of the swarm $gbest_d^t$, it moves from the current position X_{id}^t to the next search position X_{id}^{t+1} calculated by Equation (21). In general the parameter ω^t is set to large values in the early stage for global search, while it is set to a small value in the last stage for local search.

The inertia weight is used to control the impact of the previous velocities on the current velocity, influencing the trade-off between the global and local experience. Although Zheng claimed that PSO with increasing inertia weight performs better, linear decreasing of the inertia weight is recommended by Shi and Eberhart.

$$w = w_{\max} - \left(\frac{w_{\max} - w_{\min}}{iter_{\max}}\right) * iter \tag{22}$$

Where $w_{\max}$ and $w_{\min}$ are maximum and minimum of inertia weight value respectively, $iter_{\max}$ is maximum iteration number and iter is the current iteration. A so-called constriction factor K, is factor that increases the algorithm's ability to converge to a good solution and can generate higher quality solution than the conventional PSO approach. In this case, the expression used to update the particle's velocity becomes

$$\left.\begin{aligned} V_{id}^{t+1} &= K*[\omega^t v_{id}^t + c1R_1^t(pbest_{id}^t - x_{id}^t) \\ &+ c2R_2^t(gbest_d^t - x_{id}^t)] \end{aligned}\right\} \tag{23}$$

Where

$$K = \frac{2}{\left|2 - \phi - \left(\phi^2 - 4\phi\right)^{\frac{1}{2}}\right|}$$

$$\phi = c1 + c2\,,\ \ \phi > 4 \tag{24}$$

4. PROBLEM FORMULATION

Provide a statement that what is expected, as stated in the "Introduction" chapter can ultimately result in "Results and Discussion" chapter, so there is compatibility. Moreover, it can also be added the prospect of the development of research results and application prospects of further studies into the next (based on result and discussion).

4.1. Objective function

According to appendix B the equation of D-contour is given by

$$F(z) = Re(z) - \min[-\zeta \,|Img(z)|, a] = 0 \quad (25)$$

Where z ϵ A is a point on the D-contour and A represents the complex plane.

Defining J as:

$$J=\max[Re(\lambda_i) - \min(-\zeta|Im\,\lambda_i|, a)] \quad (26)$$

i = 1,2,3......n

Where n is the number of Eigen values. λ_i is the i-th Eigen value of the system at an operating point. A negative value of J implies that all the Eigen values lie on the left of the D-contour. If J is positive that implies Eigen value is lying on the right of contour.

On these facts objective function F can be defined as:

$$F=\begin{cases} J & if \quad J \le 0 \\ \alpha & if \quad J > 0 \end{cases} \quad (27)$$

Where α is a large positive number.

The optimization problem can now be stated as:

Minimize F Subject to,

$$\left.\begin{array}{l} K_{pi}^{\min} \le K_{pi} \le K_{pi}^{\max} \\ K_{li}^{\min} \le K_{li} \le K_{li}^{\max} \\ K_{Di}^{\min} \le K_{Di} \le K_{Di}^{\max} \\ R_i^{\min} \le R_i \le R_i^{\max} \end{array}\right\} \quad (28)$$

$$B_i = \frac{1}{R_i} + D_i \quad (29)$$

Where K_{pi}, K_{li}, K_{Di} are PID controller parameters R_i and B_i are speed characteristics and area bias factor respectively. i=1, 2 for control area first and second respectively.

4.2. Algorithm

Step1. Initialize the set of particles with position value (population), its upper limit and lower limit, random velocities, inertia weight, acceleration constants, itermax, etc.

Step2. Linearize system and calculate the eigen values for each particle from the system modelling.

Step3. Calculate the objective function J.

Step4. Set all position values as local best values and fitness values of objective function as local fitness. Find global fitness and its corresponding position value.

Step5. Set iter=1 and compute inertia weight by

$$w = w_{\max} - \left(\frac{w_{\max} - w_{\min}}{iter_{\max}}\right) * iter \quad (30)$$

Update velocity using velocity update equation for all particles by

$$\left.\begin{aligned} V_{id}^{t+1} &= \omega^t v_{id}^t + c1R_1^t(pbest_{id}^t - x_{id}^t) \\ &+ c2R_2^t(gbest_d^t - x_{id}^t) \end{aligned}\right\} \quad (31)$$

Also check its upper and lower limits.

Step6. Update position value of particles by

$$X_{id}^{t+1} = X_{id}^t + V_{id}^{t+1} \quad (32)$$

Also check its upper and lower limits.

Step7. Linearize system and calculate Eigen values for each particle and corresponding fitness values of objective function.

Step8. Now compare these fitness values to the previous fitness values. Minimum fitness values will be selected as local fitness values and its corresponding position values as local best values. Find minimum of all fitnesses, e.g. global fitness value and its corresponding position value.

Step9. If number of iteration reaches itermax go to step 10, otherwise go to step 5.

Step10. Particle with minimum fitness value is the optimum particle.

4.3. Result

PID parameters and speed characteristics of both areas are allowed to vary within following ranges:

$$\left.\begin{aligned} -5.00 \le K_p \le 5.00 \\ -5.00 \le K_I \le 5.00 \\ -5.00 \le K_D \le 5.00 \\ 0.02 \le R \le 0.08 \end{aligned}\right\} \quad (33)$$

Time constants of different model components associated with both areas are given in appendix A.

The desired PSO parameters are given in Table 1. with the desired setting of damping ratio ‘ζ’ (0.5) and reference line value ‘a’ (-1.5) algorithm is run several times. Among all the runs most optimum run and its corresponding parameters are selected. Optimized parameters and corresponding Eigen values as shown in Table 1-3.

Table 1. Optimized parameters

K_{p1}	-1.8787
K_{I1}	-2.3640
K_{D1}	-0.9364
R_1	0.0652
B_1	15.9301
K_{p2}	-0.1353
K_{I2}	-0.5873
K_{d2}	-0.5212
R_2	0.0653
B_2	16.2087

Table 2. Optimized Eigen values (oscillatory mode)

Eigenvalues	Damping
-1.4953 + 2.4192i, -1.4953 - 2.4192i	0.5258
-1.4934 + 1.3570i, -1.4934 - 1.3570i	0.7401
-1.4762 + 0.8555i, -1.4762 - 0.8555i	0.8652
-1.4887 + 0.5015i, -1.4887 - 0.5015i	0.9477
-0.2653, -0.0600, -0.1125	1

Table 3. PSO parmeters

C1	2
C2	2
Wmax	0.90
Wmin	0.10
Vmax	*100% of Pmax*
Vmin	*100% of pmin*
Population	500
Iterations	1000
C1	2

5. SIMULATION STUDY

The system is simulated in MATLAB environment for step change in load (0.2 pu) in area first, given at one second and is checked out for 50 seconds. Comparison of responses of Δw_1, ΔP_{12}, ACE1, ΔP_{m1}, Δw_2, ACE2, ΔP_{m2} between conventional integral control and PIDPSO is carried out as shown in Figure 6-12.

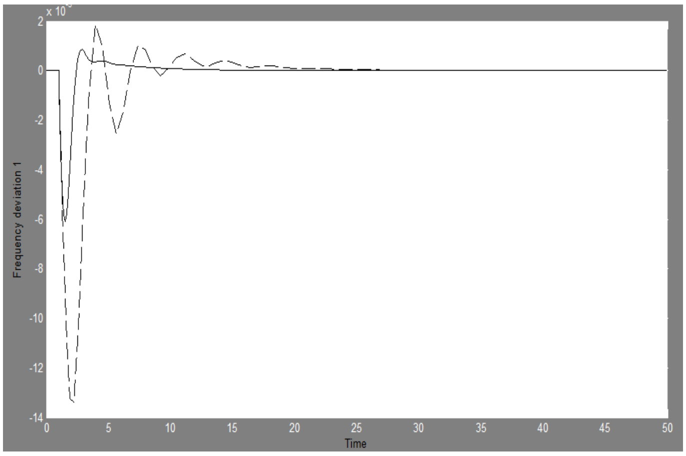

Figure 6. Frequency deviation response of area first with integral control (dashed line) and PID control (solid line)

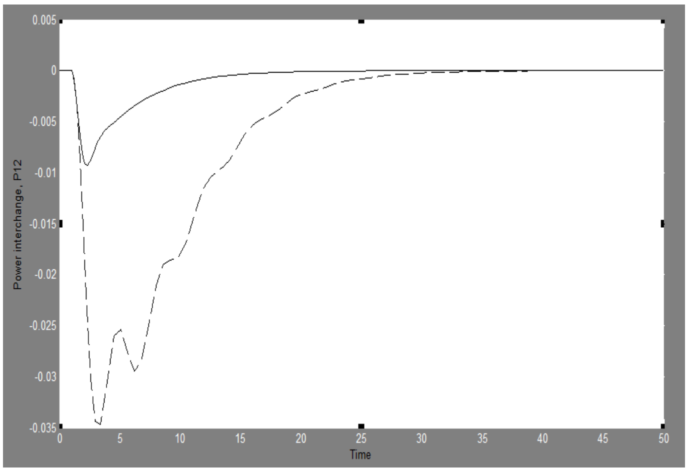

Figure 7. Power interchange response of area first with integral control (dashed line) and PID control (solid line)

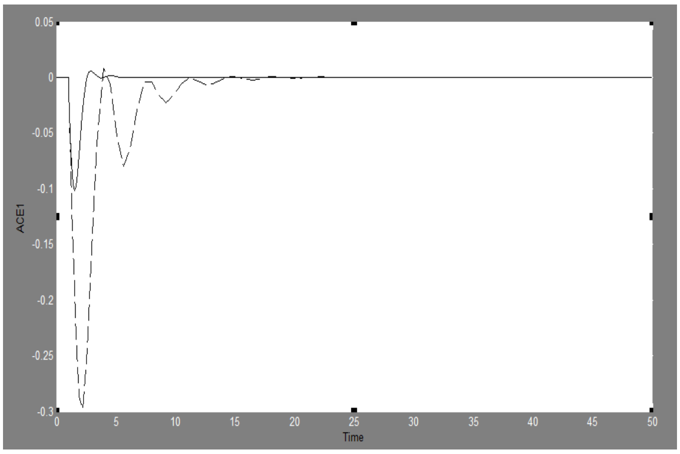

Figure 8. Area control error (ACE) response of area first with integral control (dashed line) and PID control (solid line)

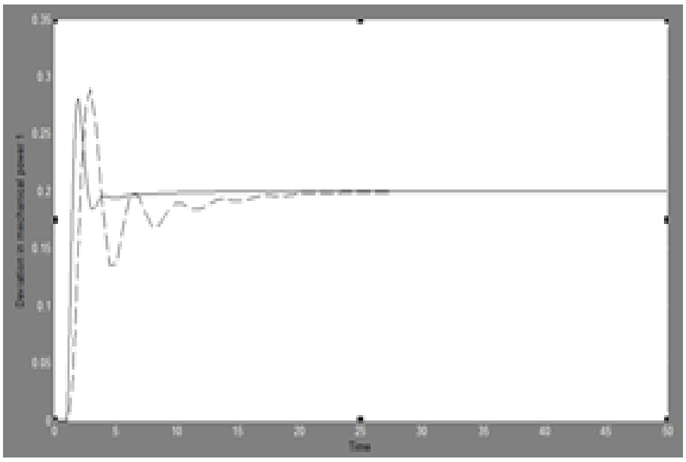

Figure 9. Deviation in mechanical power response of area first with integral control (dashed line) and PID control (solid line)

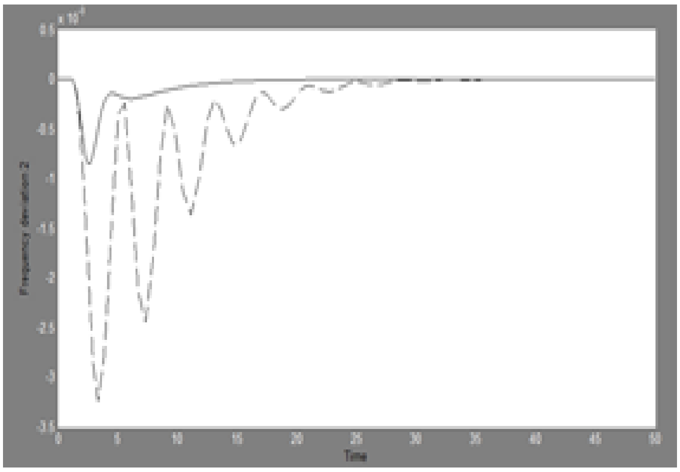

Figure 10. Frequency deviation response of area second with integral control (dashed line) and PID control (solid line)

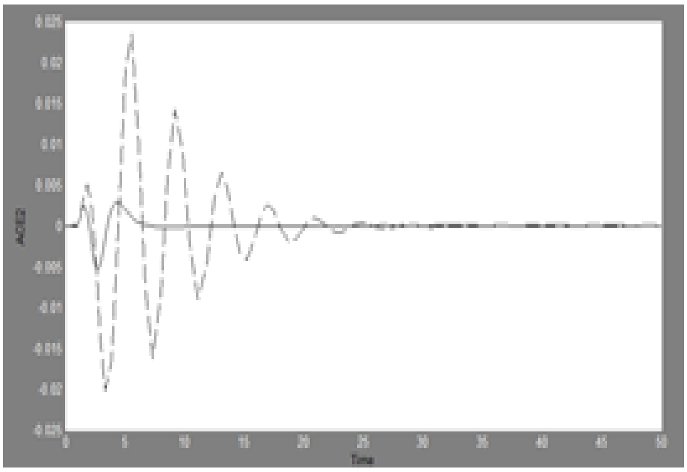

Figure 11. Area control error (ACE) response of area second with integral control (dashed line) and PID control (solid line)

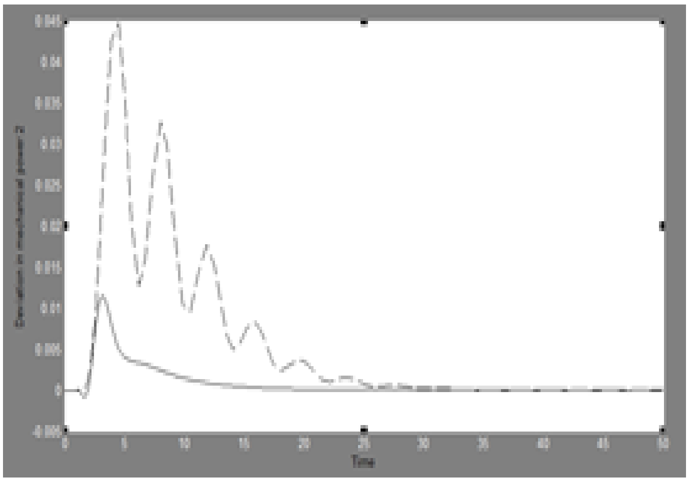

Figure 12. Deviation in mechanical power response of area second with integral control (dashed line) and PID control (solid line)

6. CONCLUSION AND FUTURE WORK

The target of the developed work is to improve the control performance of two area power system using a controller based on evolutionary algorithm. PIDPSO shows the better control performance than conventional integral control in terms of settling time, over/under shoots. The discussed formulation can be extended to multiarea power systems.

APPENDIX A

From the block diagram shown in Figure 5. the state space equations can be written as:

$$\Delta P_g(s) = \frac{1}{1+T_g(s)} \Delta P_v(s) \tag{34}$$

$$\Delta P_v(s) = \frac{1}{1+T_t(s)} \Delta P_m(s) \tag{35}$$

$$(\Delta P_m(s) - \Delta P_{12}(s))\frac{1}{(2H + D)} = \Delta\omega(s) \quad (36)$$

$$\Delta\omega(s)B_1 - \Delta P_{12}(s) = ACE(s) \quad (37)$$

$$ACE(s)(K_p + \frac{K_I}{s} + K_D) - \frac{1}{R}\Delta\omega(s) = \Delta P_g(s) \quad (38)$$

System data- as shown in Table 4.

Table 4. System parameters

T_{g1}	0.2 sec
T_{g2}	0.3 sec
T_{t1}	0.5 sec
T_{t2}	0.6 sec
H1	5
H2	4
D1	0.6
D2	0.9
Base power	1000 MVA
Ps (synchronizing power coefficient)	2.0 pu

APPENDIX B

From Figure 13. the equations of line ABM and DCM in x-y plane can be written as:

$$x = -\frac{1}{k}|y| \quad (39)$$

$$\frac{1}{k}|y| + x = 0 \quad (40)$$

Where is the modulus of the slope of line. The equation of the line BC can be written as:

x-a=0 (41)

Combining Equations (39) and (40) the equation of D-contour ABCD can be written as:

x–min(- ׀y ׀/k, a)=0 (42)

If -1/k=ζ, then in reference of complex plane the equation (41) becomes:

Re(z)–min(-ζ ׀Img(z) ׀, a)=0 (43)

Where x=Re(z), and y=Img(z). z=x+iy

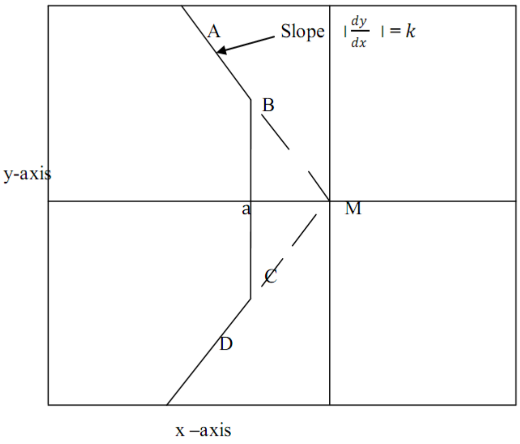

Figure 13. D-contour in x-y plane

Dii;63.

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