The International Journal Of Engineering And Science (IJES)
|| Volume || 5 || Issue || 4 || Pages || PP -25-32|| 2016 ||
ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805

# Particle Swarm Optimization Based AGC for Two Area Hydro-Thermal Interconnected System

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**ABSTRACT**

*This paper deals with Automatic generation control of two area interconnected hydro-thermal system using proportional plus integral controllers with Particles swarm optimization techniques (PSO). The parameters of PI controllers are tuned with the help of optimal control strategies such as Integral square error (ISE) and Integral time multiplied by absolute error (ITAE) by particles swarm optimization technique. Mismatch in the total generation to total demand plus losses results in the system frequency deviation from its nominal value and causes variation in the Tie-line power flow. System performance is examined considering perturbation of .1 pu step load change in thermal system. Simulation studies and a comparison of dynamic responses reveal the performance of particle swarm optimization in terms of the frequency and Tie-line power responses in both the areas. Comparison is also made between the two different performance indices criteria (ISE, ITAE).*

***Keywords*** *- Automatic Generation control, Particle swarm optimization, PI controllers and Performance Indices criteria.*

Date of Submission: 25 February 2016 Date of Accepted: 05 April 2016

## I. INTRODUCTION

An interconnected power system consists of different areas which are connected to each other by Tie-lines. In power system both the active and reactive demands are never the same and they continuously changes with time. Automatic Generation Control (AGC) of interconnected power systems is gaining importance in modern power systems. Mismatch between the total generation to total demand and associated system losses, results in deviation of system frequency from its nominal value and also changes in the Tie-line power flow from the desired value. In each area all the generators changes their speed to maintain the frequency and change in Tie-line power to the desired value in static as well as in dynamic conditions. The primary objectives of a control area are to satisfy its local consumer demands and to respond to the variation in demand of other control areas. Frequency and tie-line power exchange are the two variables of interest, and combination of these two called area control error (ACE). Automatic generation control (AGC) is the name given to a control system having three major objectives [1, 2, and 3]:

a. To hold system frequency at or very close to a specified nominal value.
b. To maintain the correct value of interchange power between control areas.
c. To maintain each units generation at the most economical value.

A literature survey shows that lot of research paper has been carried by linearized model of thermal as well as hydro units in both the single area and in interconnected areas [4, 5]. Most of the works concerned with AGC of interconnected power systems pertain to tie-line bias control strategy [6]. In past tuning of parameters of different controllers (PID, PI) is done by various methods like maximum peak resonance specification (MPRS) [7]. AGC problem for hydro thermal systems have also studied in [8,9,10].Tuning the parameters of PI controllers in the two area hydro-thermal system connected to each other are done by Genetic algorithm and other optimization techniques like PSO, and fuzzy logic control [11-12].

The objective function which is minimized by the use of optimization technique is the different performance indices criteria. These criteria are Integral of the squared error (ISE), Integral time multiplied by the absolute error (ITAE).

$$ISE = \int_0^\infty e^2(t)\,dt \qquad (1)$$

$$ITAE = \int_0^\infty t\,|e(t)|\,dt \qquad (2)$$

In this paper Particles swarm optimization (PSO) is used to tune the parameters of the PI controllers in the hydro-thermal system. The comparison is made between the two performance indices criteria of dynamic responses of the deviation in frequency and change in Tie-line power flow in terms of undershoot and settling time. The parameters which are tuned by optimization techniques (PSO) are Kpr1, Ki1, Kpr2 and Ki2. This paper is described as follows:
PI controller described in section II. In the section III State space modelling is carried out. In section IV test system is explained. Section V includes the explanation and application of PSO. Results and analysis are given in section VI. Section VII concludes the paper

## II. PID CONROLLER

Output of PID controller is given by: $u(t) = K_{pr} e(t) + K_i \int e(t)dt$ (3)

Where $e(t)$ is error input to PI controller i.e. area control error, $u(t)$ is the output of PI controller, $K_{pr}$ proportional gain and $K_i$ integral gain.

## III. STATE SPACE MODELING

### *3.1 Transfer Function*

A two area hydro-thermal interconnected power system is considered to tune the parameters of the PI controllers. Thermal area used is non-reheat turbine unit connected with hydro unit with supplementary controllers. Perturbation of 0.1 pu step load change is considered in thermal area. Transfer function model of the two area hydro-thermal system is shown in Fig (1). PI controller is used for the automatic generation control of the system. These PI controllers are used to bring the system frequency to the nominal value and also the Tie-line power to the desired value. The transfer function of the desired relation can be obtained by state space modeling of the system. Two area hydro-thermal systems can be described by standard state space equations

$$\dot{X} = AX + BU \tag{4}$$

$$Y = CX + DU \tag{5}$$

Where U is the input vector, X is the state vector and Y is the output vector. And A, B, C, D are the real constant matrices of appropriate dimensions which in turn depend on the system parameters. These vectors in equation (4) and (5) can be represented as:

$$X = \left[ \Delta f_1, \Delta P_{mech1}, \Delta P_{v1}, \Delta f_2, \Delta P_{mech2}, \Delta P_1, \Delta P_{v2}, \Delta P_{12}, \Delta P_{ref1}, \Delta P_{ref2} \right]^T \tag{6}$$

$$U = [\Delta P_{L1}, \Delta P_{L2}]^T \tag{7}$$

$$Y = [\Delta f_1, \Delta f_2, \Delta P_{12}]^T \tag{8}$$

State space matrix can be obtained by the use of differential equations. State equations for the different components of the interconnected power system can be shown by the following equation:

$$\dot{x}_1 = -\frac{1}{T_{p1}} x_1 + \frac{K_{p1}}{T_{p1}} x_2 - \frac{K_{p1}}{T_{p1}} x_8 - \frac{K_{p1}}{T_{p1}} u_1 \tag{9}$$

$$\dot{x}_2 = -\frac{1}{T_{t1}} x_2 + \frac{1}{T_{t1}} x_3 \tag{10}$$

$$\dot{x}_3 = -\frac{1}{R_1 T_{g1}} x_1 - \frac{1}{T_{g1}} x_3 + \frac{1}{T_{g1}} x_9 \tag{11}$$

$$\dot{x}_4 = -\frac{1}{T_{p2}} x_4 + \frac{K_{p2}}{T_{p2}} x_5 + \frac{K_{p2}}{T_{p2}} x_8 - \frac{K_{p2}}{T_{p2}} u_2 \tag{12}$$

$$\dot{x}_5 = -\frac{2T_2}{R_2 T_1 T_3} x_4 - \frac{2}{T_w} x_5 + \left( \frac{2}{T_w} + \frac{2}{T_3} \right) x_6 + \left( \frac{2T_2}{T_1 T_3} - \frac{2}{T_3} \right) x_7 - \frac{2T_2}{T_1 T_3} x_{10} \tag{13}$$

$$\dot{x}_6 = -\frac{T_2}{R_2 T_1 T_3} x_4 - \frac{1}{T_3} x_6 + \left( \frac{1}{T_3} - \frac{T_2}{T_1 T_3} \right) x_7 + \frac{T_2}{T_1 T_3} x_{10} \tag{14}$$

$$\dot{x}_7 = -\frac{1}{R_2 T_1} x_4 - \frac{1}{T_1} x_7 + \frac{1}{T_1} x_{10} \tag{15}$$

$$\dot{x}_8 = T_s x_1 - T_s x_4 \tag{16}$$

$$\dot{x}_9 = \left( \frac{B_1 K_{pr1}}{T_{p1}} - K_{pr1} T_s - K_{i1} B_1 \right) x_1 - \frac{B_1 K_{pr1} K_{p1}}{T_{p1}} x_2 + \ldots$$
$$\ldots K_{pr1} T_s x_4 + \left( \frac{B_1 K_{pr1} K_{p1}}{T_{p1}} - K_{i1} \right) x_8 + \frac{B_1 K_{pr1} K_{p1}}{T_{p1}} u_1 \tag{17}$$

$$\dot{x}_{10} = K_{pr2} T_s x_1 + \left( \frac{B_2 K_{pr2}}{T_{p2}} - K_{pr2} T_s - K_{i2} B_2 \right) x_4 - \ldots$$
$$\ldots \frac{B_2 K_{pr2} K_{p2}}{T_{p2}} x_5 + \left( -\frac{B_2 K_{pr2} K_{p2}}{T_{p2}} + K_{i2} \right) x_8 + \frac{B_2 K_{pr2} K_{p2}}{T_{p2}} u_2 \tag{18}$$

By the use of these differential equations state space matrix can be find out. These real constant matrices are:

$$B = \begin{bmatrix} -\frac{K_{P1}}{T_{P1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{B_1 K_{pr1} K_{P1}}{T_{P1}} & 0 \\ 0 & 0 & 0 & -\frac{K_{P2}}{T_{P2}} & 0 & 0 & 0 & 0 & 0 & \frac{B_2 K_{pr2} K_{P2}}{T_{P2}} \end{bmatrix}^T$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix} ; \quad D = 0 ;$$

$$A = \begin{bmatrix}
-\frac{1}{T_{P1}} & \frac{K_{P1}}{T_{P1}} & 0 & 0 & 0 & 0 & 0 & -\frac{K_{P1}}{T_{P1}} & 0 & 0 \\
0 & -\frac{1}{T_{t1}} & \frac{1}{T_{t1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-\frac{1}{R_1 T_{g1}} & 0 & \frac{1}{T_{g1}} & 0 & 0 & 0 & 0 & 0 & \frac{1}{T_{g1}} & 0 \\
0 & 0 & 0 & -\frac{1}{T_{P2}} & \frac{K_{P2}}{T_{P2}} & 0 & 0 & \frac{K_{P2}}{T_{P2}} & 0 & 0 \\
0 & 0 & 0 & \frac{2T_2}{R_2 T_1 T_2} & -\frac{2}{T_w} & (\frac{2}{T_w} + \frac{2}{T_3}) & (\frac{2T_2}{T_1 T_3} - \frac{2}{T_3}) & 0 & 0 & -\frac{2T_2}{T_1 T_3} \\
0 & 0 & 0 & -\frac{T_2}{R_2 T_1 T_2} & 0 & -\frac{1}{T_3} & (\frac{1}{T_3} - \frac{T_2}{T_1 T_3}) & 0 & 0 & \frac{T_2}{T_1 T_3} \\
0 & 0 & 0 & -\frac{1}{R_2 T_1} & 0 & 0 & -\frac{1}{T_1} & 0 & 0 & \frac{1}{T_1} \\
T_s & 0 & 0 & -T & 0 & 0 & 0 & 0 & 0 & 0 \\
A_{9,1} & -\frac{B_1 K_{pr1} K_{P1}}{T_{P1}} & 0 & K_{pr1} T_s & 0 & 0 & 0 & (\frac{B_1 K_{pr1} K_{P1}}{T_{P1}} - K_{i1}) & 0 & 0 \\
K_{pr2} T_s & 0 & 0 & A_{10,4} & -\frac{B_2 K_{pr2} K_{P2}}{T_{P2}} & 0 & 0 & (-\frac{B_2 K_{pr2} K_{P2}}{T_{P2}} + K_{i2}) & 0 & 0
\end{bmatrix}$$

$$A_{9,1} = (\frac{B_1 K_{pr1}}{T_{P1}} - K_{pr1} T_s - K_{i1} B_1) \quad A_{10,4} = (\frac{B_2 K_{pr2}}{T_{P2}} - K_{pr2} T_s - K_{i2} B_2)$$

With the help of these matrices, we get transfer function of the system as defined:

Transfer function $= C\left[SI - A\right]^{-1} B + D$

This transfer function is in the matrix form of order ($3\times 2$).

$$\Delta f_1 = \frac{\Delta f_1(s)}{\Delta P_{L1}(s)} \Delta P_{L1} + \frac{\Delta f_1(s)}{\Delta P_{L2}(s)} \Delta P_{L2} \tag{19}$$

$$\Delta f_2 = \frac{\Delta f_2(s)}{\Delta P_{L1}(s)} \Delta P_{L1} + \frac{\Delta f_2(s)}{\Delta P_{L2}(s)} \Delta P_{L2} \tag{20}$$

$$\Delta P_{12} = \frac{\Delta P_{12}(s)}{\Delta P_{L1}(s)} \Delta P_{L1} + \frac{\Delta P_{12}(s)}{\Delta P_{L2}(s)} \Delta P_{L2} \tag{21}$$

### 3.2 *Objective function*

For tuning of the parameters of the PI controller's different objective functions are used and then comparison is made so that best system response can be obtained. These different objective functions are:

$$ISE = \int_0^\infty (\Delta f_1^{\,2} + \Delta f_2^{\,2} + \Delta P_{12}^{\,2})\,dt \tag{22}$$

$$ITAE = \int_0^\infty t(|\Delta f_1| + |\Delta f_2| + |\Delta P_{12}|)\,dt \tag{23}$$

## IV. TEST SYSTEM

The two area hydro-thermal interconnected is considered with PI controllers. One area is non-reheat thermal system and other area is hydro system. Both the areas are having generating equipment with different parameters [13]. Simulation is carried out with the step load change of .1 pu in thermal area. This will affect the frequency response and tie-line power change. For controlling this PI controllers are used. Transfer function model of two area hydro-thermal interconnected system is shown in Fig. 1.

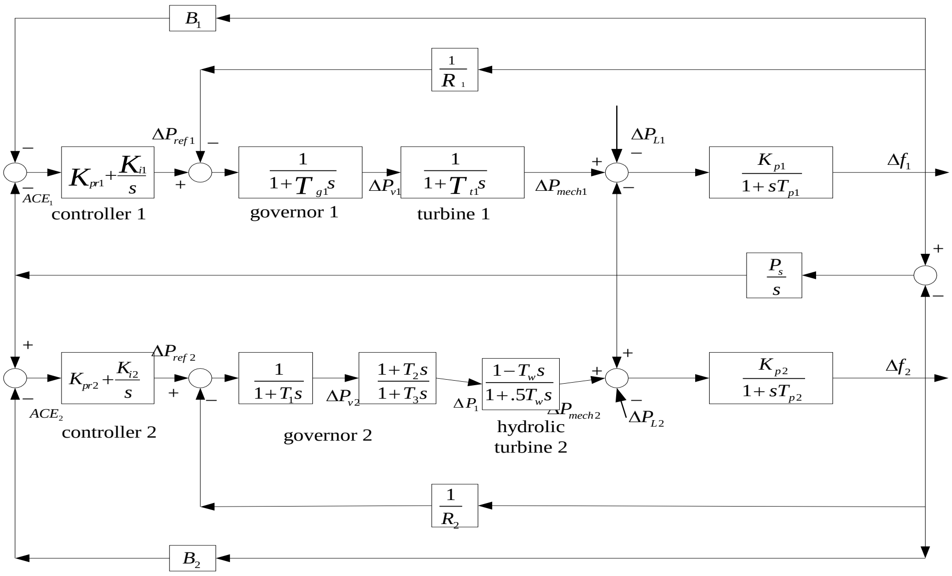


Fig 1. Transfer function model of hydro-thermal interconnected system

## V. PARTICLES SWARM OPTIMIZATION

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behaviour of bird flocking or fish schooling [15]. The system is initialized with a population of random solutions and searches for optima by updating generations.

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. A binary PSO algorithm has been developed in [16]. In the binary version the particle position is not a real value, but either the binary 0 or 1. The velocity is used as a probability threshold to determine whether $x_{id}$ , the dth component of $x_i$ should be evaluated as a zero or a one. They squashed $x_{id}$ in a logistic function

$$s(x_{id}) = \frac{1}{1 + \exp(-v_{id})} \tag{24}$$

Then generated a random number r for each bit-string site and compared it to $s(x_{id})$ . If r was less that the threshold, then $x_{id}$ was interpreted as 1, otherwise as 0. The velocity of the each particle can be updated by the equation given below:

$$v_{id}^{t+1} = v_{id}^{t} + r1 * c1(pbest^{t} - x_{id}^{t}) + r2 * c2(gbest^{t} - x_{id}^{t}) \tag{25}$$

*pbest* : Personal best of particle i
*gbest:* Global best (best of pbest of the group)
r1, r2: Random number in the [0, 1] interval
c1, c2: Acceleration coefficient
$x_{id}$ Position of $i^{th}$ particle in dimension d
$v_{id}$ Component in dimension d of the $i^{th}$ particle velocity in iteration t

Particle velocity is calculated by the formula shown previously and then with the help of random number, particles position is updated.

Binary Particle swarm optimization is used to minimize the objective function. . Procedure used for tuning of PI controllers with the help of BPSO is shown below:

1. Generate the initial particles position for each variable Kpr1, Kpr2, Ki1 and Ki2. Here 24 population size is used.
2. Find the value of the objective function (equation 22-23) with the help of each particles position, do it for all population and then find pbest and gbest.
3. Calculate the velocity of each particle with the help of equation (25).
4. Again find each particles position by equation (24).
5. Again evaluate the objective function with the help of new particles position and repeat step2, 3 and 4.

If no. of iteration > max generation then stop, and best solution formed, else go to next iteration.

## VI. RESULT AND DISCUSSIONS

Simulation has been done by taking the system given in Fig. 1 with one thermal area and other hydro area. Particle swarm optimization techniques used to tune the parameters of the PI controllers of both the area when there is .1 pu load perturbation occurs in area-1. The optimal criterion is taken as ISE (integral squared error) and ITAE (integral time multiplied by absolute error). The simulation results for the change in frequency in both areas and change in the Tie-line power flow for all performance indices criteria with Particles swarm optimization is properly analysed. Dynamic responses of interconnected hydro-thermal power system for ISE and ITAE are shown in Fig.3, 4.

The dynamic responses of $\Delta f_1$ , $\Delta f_2$ and $\Delta P_{12}$ for step load increase in thermal area with BPSO is shown in Fig. 3 and Fig. 4, and with Table 1 it is clear that ITAE shows good dynamic response than ISE in terms of settling time.

Table shows the parameters of PI controllers tuned by the BPSO. From the table it is clear that the objective function value ITAE is less than ISE. This is because ITAE is more selective performance index than other indices. Even though ITAE does not penalize large initial errors that are unavoidable but it does penalize large duration transient [17].

Table 1 tuning of PI controllers from BPSO with ISE and ITAE

| | | Kpr1 | Ki1 | Kpr2 | Ki2 | PI | $\Delta$PL1 | Settling time(s)f1 | Undershoot |
|---|---|---|---|---|---|---|---|---|---|
| Binary Particle swarm optimization | ISE | .4706 | .9412 | 0.00 | 0.00 | 17.548 | .1 p.u. | 60 | .2 |
| | ITAE | .1176 | .7059 | .9414 | 0.00 | 1523.0 | .1 p.u. | 30 | .22 |

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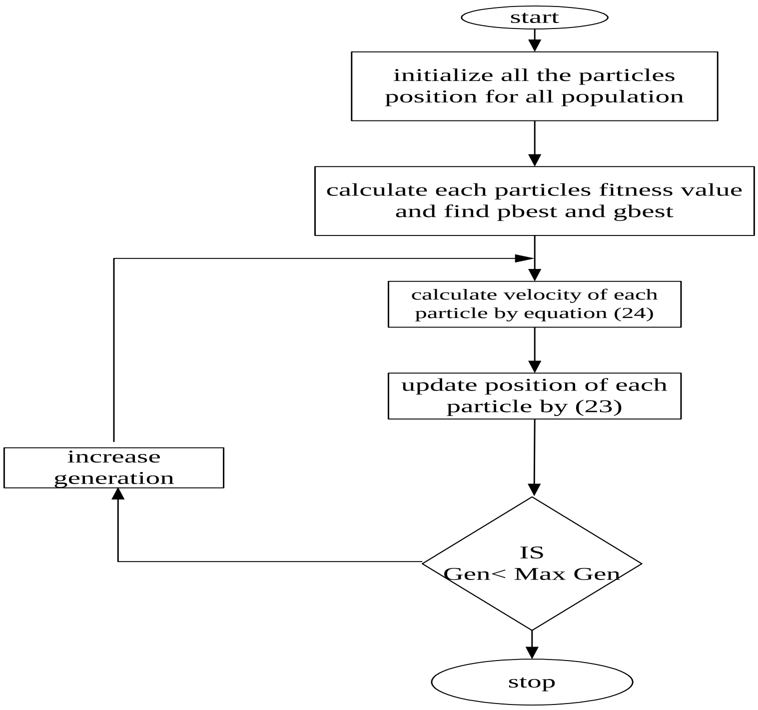
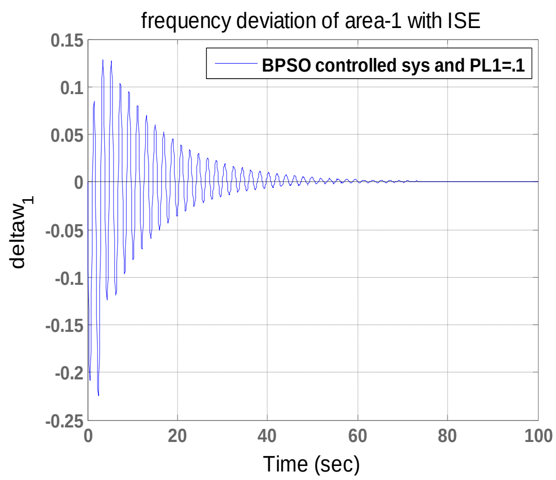
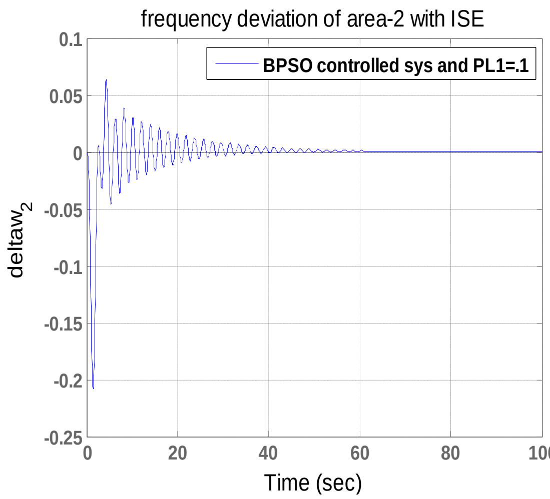


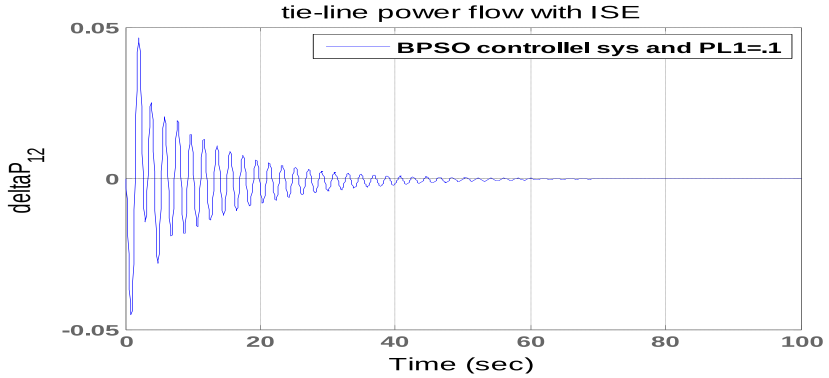

Fig 2. Flow chart of BPSO




(a)

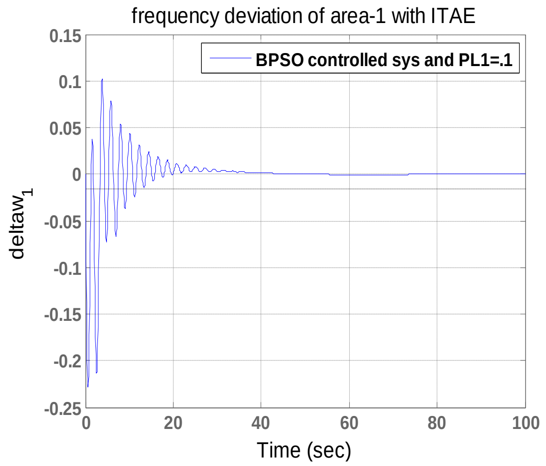



(b)

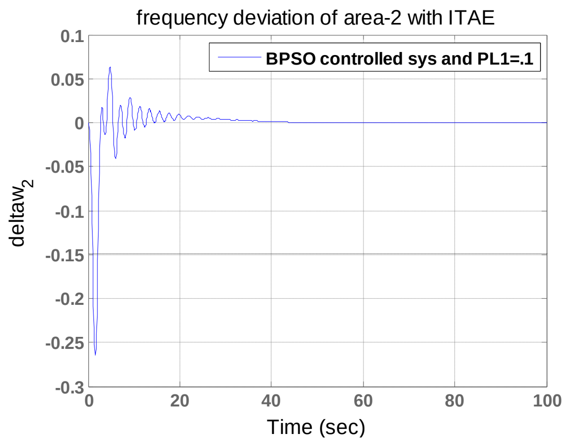



(c)

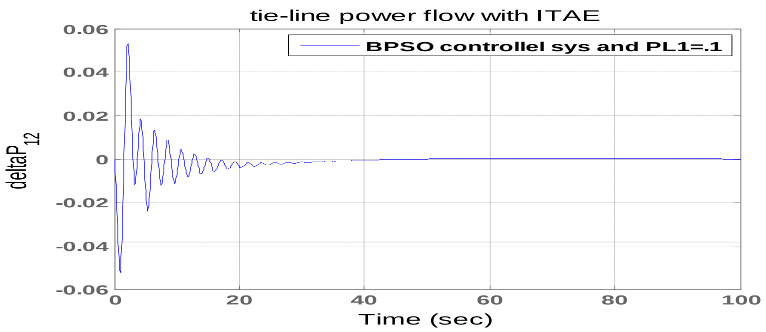
Fig.3 Dynamic responses of frequency and power by BPSO with ISE when .1 pu step load change in area-1




(a)




(b)




(c)

Fig.4 Dynamic responses of frequency and power by BPSO with ITAE when .1 pu step load change in area-1

## VII. CONCLUSION

Load frequency regulation characteristic of two different hydro-thermal area power system have been studied. Particle swarm optimization (PSO) has been successfully applied to tune the parameters of the PI controllers. Two performance indices criteria are taken (integral square error (ISE), integral time multiplied by absolute error (ITAE).Binary Particles swarm optimization (BPSO) has been successfully applied to tune the parameters of the PI controllers for hydro-thermal system. From the above results it concluded that for automatic generation control of hydro-thermal system ITAE performance indices criteria gives better dynamic performance in comparison with ISE for PSO controllers. Damping responses of ITAE are good in terms of under-shoot and settling times than ISE.

## VIII. APPENDIX

Typical values for the system parameters are [13]:

$K_{p1}$ = $K_{p1}$ = 120 Hz/p.u. MW

$T_{p1}$ = $T_{p2}$ = 20 sec

$R_1$ = $R_2$ = 2.4 Hz/p.u. MW

$B_1$ = $B_2$ = .4249

$T_g$ =.08 sec

$T_t$ =.3 sec

$T_{12}$ =0.0866

$T_1$ = 48.709

$T_2$ =.51308

$T_3$ = 10

$T_w$ =1

$P_{r1}$ = $P_{r2}$ =1200 MW

$D_1$ = $D_2$ =.00833 p.u. MW/Hz

Parameters of BPSO used to tune the PI controllers are shows below:
Acceleration coefficient c1=1.5; c2=2.5;
Damping coefficient =.99;
No. of iteration=100;
No. of Population=24;

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