A Particle Swarm Optimization Algorithm For Automatic Generation Control Of Two Area Interconnected Power System

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Abstract -The main objective of Automatic Generation Control (AGC) is used to maintain the balance between the total system generations against system load losses so that the desired frequency and power interchange with neighboring systems is maintained. If any mismatch occurs between generation and demand causes the deviation in the system frequency from its nominal value. Thus high frequency deviation may lead to system collapse. For this necessitates a very fast and accurate controller is used tomaintain the nominal system frequency.This paper presents the particle swarm optimization (PSO) technique to optimize the integral controller gains for the automatic generation control (AGC) of the interconnected twoarea power system. Each control area includes the dynamics of thermal systems.The Integral Square of the error and the integral of time-multiplied absolute value of the error performances indices are considered. The results reported in this paper demonstrate the effectiveness of the particle swarm optimizer in the tuning of the AGC parameters. The enhancement in the dynamic response of the power system is verified.

Keywords: Automatic generation control (AGC), Area control error(ACE),Integral squared error(ISE) Integral absolute time error(ITAE), Particle Swarm Optimization (PSO).

NOMENCLATURE

ΔF = Frequency deviation.
i = Subscript referring to area (i = 1,2 …)
$\Delta P_{tie\ (i,j)}$ = Change in tie line power.
ΔPdi = Load change ofi^{th} area.
$Di = \Delta_{PDi} / \Delta_{Fi}$
R_i = Governor Speed regulation parameter for i_{th} area.
T_{hi} = Speed governor time constant for ith area.
T_{ti} = Speed turbine time constant for ith area.
T_{Pi} = Power system time constant for ith area.

I INTRODUCTION

Automatic generation control is one of the most important issues in power system design. The purpose of AGC is fast minimization of area frequency deviation and mutual tie-line power flow deviation of areas for stable operation of the system. The overall performance of AGC in any power system is depends on the proper design of speed regulation parameters and gains of controller. A net interchange tie-line bias control strategy has been widely accepted by utilities. The frequency and the interchanged power are kept at their desired values by means of feedback of the area control error (ACE) containing the frequency deviation and the error of the tie line power and controlling the prime movers of the generators.

The controllers are so designed to regulate the area control error value to zero. For each area, a bias constant determines the relative importance attached to the frequency error feedback with respect to the tie-line power error feedback.

(a)The steady-state frequency error following astepload change should vanish. The transient frequency and time errors should be small.
(b) The static change in the tie power following a step load in any area should be zero, provided each area can accommodate its own load change.
(c) Any area in need of power during emergency should be assisted from other areas.

Many investigations in the area of AGC problem in interconnected power systems have been reported in the past six decades (Ibraheem and Kothari, 2005; Shayeghi et al., 2009). A number of control schemes have been employed in the design of AGC controllers in order to achieve better dynamic performance. Among the various types of AGC controllers, the most widely used are classical proportional-integral and proportional-integralderivative (PID) controller.

S.K. Sinha et.al [8] an optimal controller has been designed to ascertain zero steady state frequency deviation and tie-line power flow deviation under all operating conditions**.** And an integral controller has been designed and the performance of the two types of controllers has been compared.

Lalit Chandra Saikia, et.al [2] dealt with Powerful computational intelligence technique like BF to optimize effectively. Here several important parameters Ki and Bi for AGC of a three unequal area thermal system with reheat turbines and generation rate constraint. It does not provide dynamic response for the system but also reveals new knowledge that different areas can have different optimum values of R and several areas may have much higher values of R, with some area even having a value close to four times the value of 4% used in practice.

In this work, we seek the optimum adjustment of the classical AGC parameters using particle swarm optimization and two objective functions which are functions of error and time. These are the integral of the square of the error criterion (ISE), and the integral of time-multiplied absolute value of the error criterion (ITAE).

II. CONFIGURATION OF TWO-AREA POWER SYSTEM

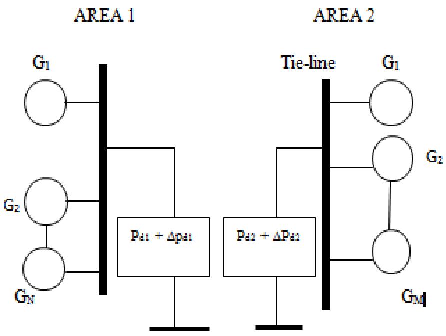

Fig. 1 Configuration of an uncontrolled two-area power system

III. PLANT MODEL DESCRIPTION

The two-area interconnected power system is taken as a test system in this study, which consists of reheat turbine type thermal unit in each area. The model of the system under consideration is as shown in Fig. 2, where symbols have their usual meanings. The conventional AGC scheme has two control loops: The primary control loop, which controls the frequency by self-regulating feature of the governor however frequency error is not fully eliminated and the supplementary control loop, which has a controller that can eliminate the frequency error with the help of conventional integral control action. The main objective of the supplementary control is to restore balance between each control area load and generation after a load perturbation so that the system frequency and the tie-line power flows are maintained at their scheduled values. So the control task is to minimize the system frequency deviation Δf1 in area 1, Δf2 in area 2 and the deviation in the tie-line power flow ΔPtie between the two areas under the load disturbances ΔPd1 and ΔPd2 in the two areas. This is achieved conventionally with the help of integral control action. The supplementary controller of the ith area with integral gain Ki is therefore, made to act on ACEi, given by (1), which is an input signal to the controller.

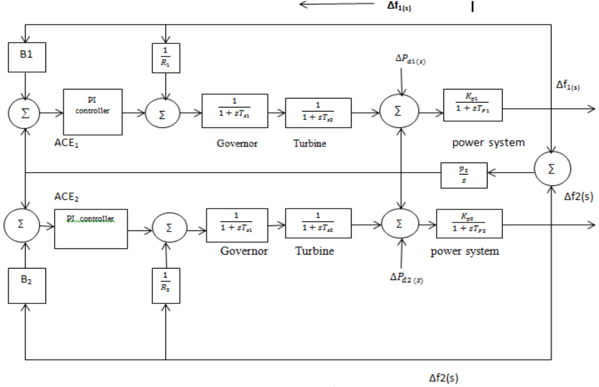

Fig. 2 Transfer function model of two-area reheat power system

IV. Conventional AGC system

Automatic control system of close loop system means minimizing the area control error (ACE) to maintain system frequency and tie-line deviation are set at nominal value. Block diagram of two area system is shown in fig. 2.

The ACE of each area is linear combination of biased frequency and tie-line error.

$$ACE_i = \sum_{j=1}^{n} \Delta p_{tie,ij} + \beta_i \Delta f_i \qquad (1)$$

Where,

ACE_i is the area control error of the i^{th} area

Δf_i = frequency error of i^{th} area

$\Delta p_{tie,ij}$ = tie- line power flow error between i^{th} and j^{th} area

B_i = frequency bias coefficient of i^{th} area.

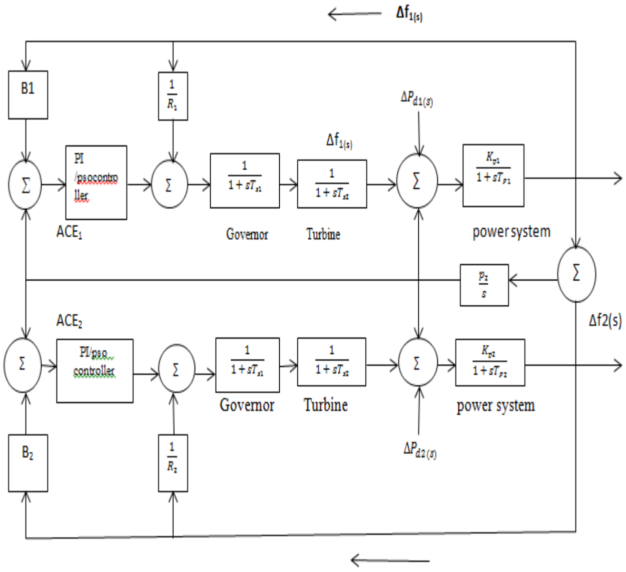

Fig 3: linear model of two area system.

V OPTIMIZATION OF THE INTEGRAL GAIN KI, AND FREQUENCY BIAS FACTORS BI

In this study, we have considered B1=B2=B and Ki1=Ki2=Ki. We need to optimize B and Ki values, in order to obtain good dynamic response of the AGC system. In this study B and Ki values are optimized using the integral squared error ISE (integral time area error) and ITAE technique by minimizing the quadratic performance index. Here the 0.01 p.u. step load change in area-1.
Where w_1 and w_2 are the weight factors both of which are chosen as 0.25 for the system considered. The optimal value of Ki = 0.4167 and B=0.8 which occurs at a minimum value of *PI* = 0.9821.
ISE **(**Integral square error):

$$\text{ISE} = \int_0^T ACE^2{}_1 + ACE^2{}_2 \, dt \qquad (2)$$

ITAE **(**Integral Time absolute error):

$$\text{ITAE} = \int_0^T t(|\text{ACE}_1| + |\text{ACE}_2|) \qquad (3)$$

VI OVERVIEW OF PSO TECHNIQUE

PSO is a population based optimization technique based on intelligent scheme developed by Kennedy and Eberhart (1995) (Kennedy et al., 2007). PSO has emerged as one of the most assuring optimizing schemes for effectively dealing near to global optimization tests. The inspiration of the mechanism is established by the social and cooperative nature represented by flying birds. The algorithm simulates a simplified social milieu in capable solutions of a swarm which means that a single particle bases its search on its own experience and information given by its neighbors in the specified region. Particles are flown in the solution region with their randomized assigned velocity. Among these particles, each particle keeps track of its coordinates in the solution region which are associated with the best fitness it has achieved so far. This value is known as 'pbest'. Another 'best' value that is tracked by the particle is the best value, obtained so far by any particle in the group of the particles. This best value is also known as a global best 'gbest' and the pattern is forwards to successful solutions.

This random velocity is usually limited to a certain maximum limit. PSO technique using equation [7] is known as the *gbest* structure. PSO is a population based EA that has many primitive benefits over other optimization techniques. A most attractive quality of the PSO approach is itssimplicity as it involves only two main reference equations.

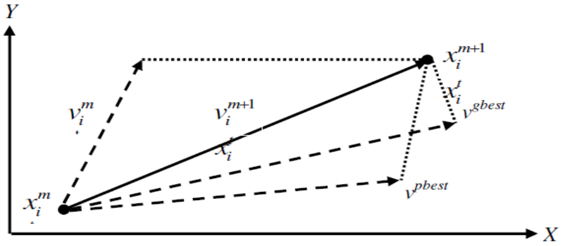

Fig 4. Concept of modification of searching point

Each particle coordinates represent a possible solution assisted with two real vectors.Andinitial velocity is vi = [vi1, vi2, vi3, vin…..]are the two vectors assistedwith each particle 'i' in N-dimensional search space.Number of particles or possible solutions of a swarm cango forward through the feasible solution place to explore optimal solutions. Each particle modifies its position based on its own best exploration, and overall experience of best particles. This particle also considers its previous velocity vector according to the following reference equations:

Velocity modifications

Each particle velocity can be modified by the following equation:

$$V_i^{k+1} = wV_i^k + c_1 \text{rand}_1 (\ldots) \text{ x } (\text{pbest}_i \text{-} s_i^k) + c_2 \text{rand}_2 (\ldots) \text{ x } (\text{gbest-}s_i^k) \qquad (4)$$

Position modifications

Positions of the particles are modified at each interval of the flying time. The position of the particle may bechange or not change, depending on the solution value.

$$x_i^{k+1} = x_i^k + v_i^{k+1} \qquad (5)$$

Where, $v_i$is velocity of particle 'i' at iteration *m*.

$$V_i^{m+1} = w^* V_i^m + c_1{}^* r_1{}^* \text{ x } (\text{pbest}_i \text{-} x_i{}^m) + c_2{}^* r_2{}^* \text{ x } (\text{gbest}_i \text{-} x_i{}^m) \qquad (6)$$

Typical values for the inertia parameter are in the range [0.5, 1]. On the other side several different approaches using a construction factor *s*, which increase the algorithm's capability to converge to a better solution and the equation used to modify the particle's velocity

$$V_i^{m+1} = s^* (V_i^m + c_1{}^* r_1{}^* (\text{pbest}_i \text{-} x_i{}^m) + c_2{}^* r_2{}^* \text{ x } (\text{gbest}_i \text{-} x_i{}^m))(7)$$

Where,

$$\frac{2}{\left|2-\varphi-\sqrt{\varphi^2-4\varphi}\right|},\ c_1 + c_2 = \varphi \leq 1 \quad (8)$$

The PSO algorithm with constriction factor can be considered as a special case of the algorithm with inertia weight since the parameters are interacted through the Eqn[8].From investigational studies, the best approach to use with PSO as a rule of thumb is to utilize the constriction factor approach or utilize the inertia weight approach while selecting w, $c_1$and $c_2$according to Eqn [8].

VII DESIGN OF PSO BASED CONTROLLER

Step 1: The minimum and maximum gain limits of PI controllers are specified from the conventional PI controller. The initial Particle matrix of(N X 4)is generated by selecting a value with a uniform probability over the search space (G_{min}=0, G_{max}=1).

Step 2: The initial Particle velocities are set to zero.

Step3: Evaluate the initial population by simulating the Load frequency Control block model with each particle row value as the PI controller gain value and calculate Performance index (ISE/ITAE) for each particle.

Step4: Initialize local minimum (P_{best}) for each particle.

Step5: Find the best particle (G_{best}) in initial particle matrix based on the minimum performance index.

Step 6: Start the iteration iter=1.

Step 7: Update the velocity of the particle using the equation shown below

Velocity=C*(w*velocity+c1*r1*(P_{best}-Particle)+c2*r2*((ones(N,1)*G_{best})-Particle))

Where
Constriction factor C=1
Cognitive parameter c1 =1
Social parameter c2 = 4-c1
inertia weight w=(maximum iter- iter)/maximum iter;
r1,r2 are the random numbers between 0 and 1

Step8: Create new particle from the updated velocity.

Step9: If any of the new Particles violate the search space limit then choose the particle and generate new values within the particle search space.

Step 10: Evaluate the performance index value for each new particle by simulating the LFC block model.

Step11: Update the best local position (P_{best}) for each particle based on the minimum value comparison between new particle performance index and old P_{best} performance index.

Step 12: Update Gbest Global minimum particle and its performance index.

Step 13: Iter=iter+1;

Step14: If iter <= maxiter go to step 7, otherwise go to next step.

Step 15: Print the global best PID controller gain values and its performance index value.

VIII SIMULATION RESULTS AND ANALYSIS

The objective of the simulations was to test the PSOcontrol algorithm proposed in this study for AGC of two-area interconnected power systems with reheat non linearity. Simulations were performed using Mat lab Simulink. The parameters of the power system simulated are given in appendix A. The step load disturbance of 0.01 p.u. is applied in area-1 for PSO based controller and the frequency oscillations and tie-line power flows are investigated. System dynamic performances, in terms of the deviations of frequencies of each area and tie-line power flows, are shown in Fig .It can be noticed from these figures that the PSO based controller is very effective in damping the frequency and tie-line power oscillations and reduces the settling time, overshoot and undershoot as compared to other controllers.

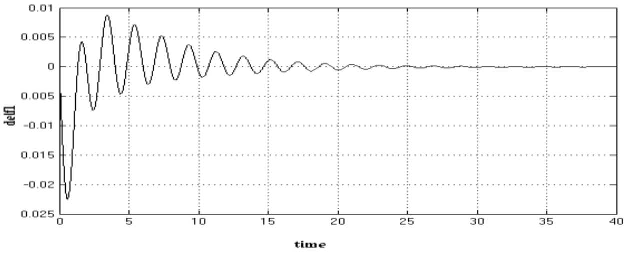

Fig 5 : Frequency deviations in area 1 with thermal reheat power system with pso controller.

TABLE I Dynamic response values in area1 during the disturbance.

PI	**PI Value**	**KP1**	**KI1**	**KP2**	**KI2**	**Del F1 Settling Time**	**Del F1 Peak Over shoot**	**Del F2- Settling Time**	**Del F2- Peak overshoot**	**Del Ptie- Settling Time**	**Del Ptie- Peak Over shoot**
ISE	0.505755123	0.982072	0.7526	0.994884	0.005241	21.32	0.0053	20.42	0.0055	22.35	0.006
ITAE	0.2396	0.1847	0.8657	0.9822	0.0044	17.96	0.01032	16.54	0.0059	18.32	0.009

TABLE II Dynamic response values in area2 during the disturbance.

PI	**PI VALUE**	**KP1**	**KI1**	**KP2**	**KI2**	**Del F1- Settling Time**	**Del F1- Peak Over shoot**	**Del F2- Settling Time**	**Del F2- Peak Over shoot**	**Del Ptie Settling Time**	**Del Ptie- Peak Over shoot**
ISE	0.507011	0.999387	0.060462	0.995164	0.774302	25.2	0.006	22.39	0.0055	21.94	0.005
ITAE	0.243611	0.966938	0.002688	0.15909	0.801862	17.2	0.0063	19.96	0.0093	18.12	0.00678

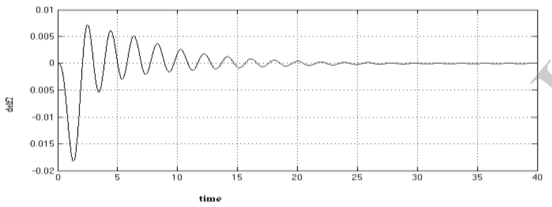

Fig 6: frequency Deviations in area 2 with thermal reheat power system with integral and pso controller for 1% step load disturbance.

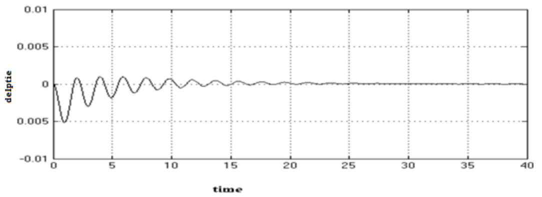

Fig 7: Tie-line power Deviations in a two area interconnected thermal reheat power system with pso controller.

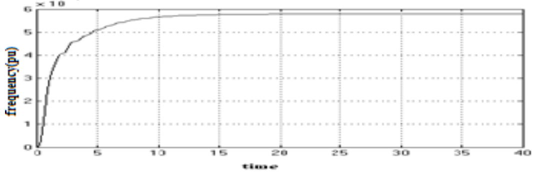

Fig 8: minimized frequency variation after integral squared error method

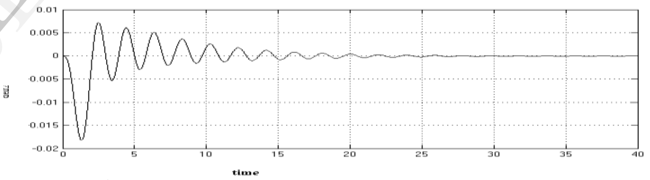

Fig 9:frequency Deviations in area 1 with thermal reheats power systemwith pso controller for using ITAE method.

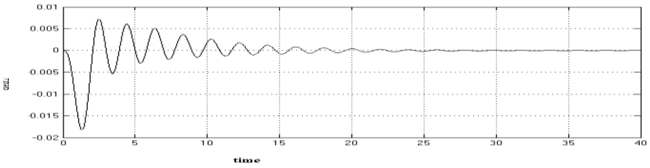

Fig 10: frequency deviations in area 2 with thermal reheat power system using pso controllerusing ITAE method.

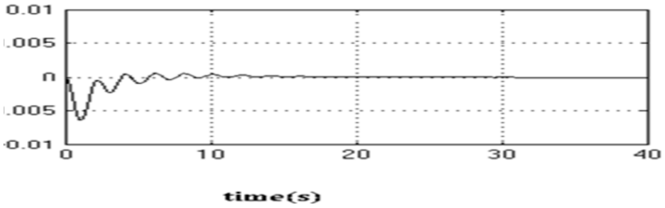

Fig11:Tie-linepower Deviations in a two area interconnected thermal reheat powersystem with pso controller using ITAE method.

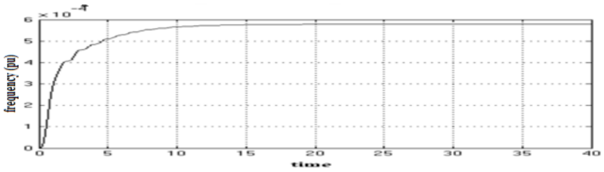

Fig 11: minimized frequency variation after ITAE method.

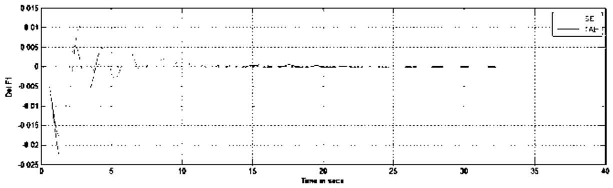

Fig 12: comparison of area frequency 1 for ISE and ITAE method.

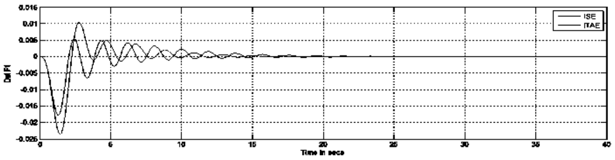

Fig 13: comparison of area frequency 2 for ISE and ITAE method.

IX CONCLUSION

Particle swarm optimization has been successfully applied to tune the parameters of automatic generation control systems of the integral and the integral-plus-proportional type. A two-area reheat thermal system was assumed to demonstrate the method. The integral square of the error (ISE) and the integral of time-multiplied absolute value of the error (ITAE) were used as objective functions. The superiority of the ITAE in the damping and settling of the transient responses was demonstrated. The effectiveness of the proposed controller in increasing the damping of local and inter area modes of oscillation is demonstrated in a two area interconnected power system. Also the simulation results are compared with a conventional PI controller. The result shows that the proposed PSO controller is having improved dynamic response and at the same time faster than conventional PI controller.

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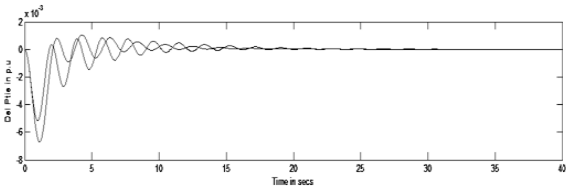

Fig 14: comparison of area tie line frequency for ISE and ITAE method.

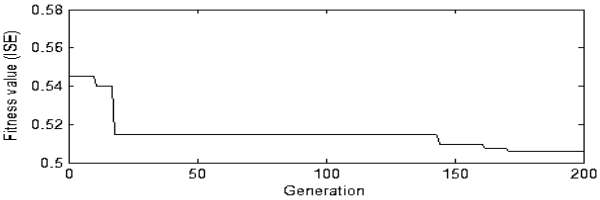

Fig 15: fitness value graph using ISE method.

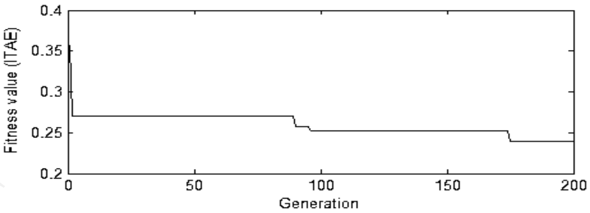

Fig 16: fitness value graph using ITAE method.

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