A PARTICLE SWARM OPTIMIZATION BASED LOAD FREQUENCY CONTROL FOR A DEREGULATED POWER SYSTEM

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Abstract-- *In this paper, Particle swarm optimization tuned Proportional Integral controller is proposed for Load Frequency Control (LFC) of a deregulated power system. As the electric power industry is currently in transition from vertically integrated utilities to a deregulated power system which will incorporate competitive companies. This increases the complexity of the LFC issue and calls for more insight and research. To ensure performance and robustness of the proposed control strategy and there by stabilizing frequency oscillations, the design process takes a wide range of operating conditions. The proposed PSO controller is designed for a two-area deregulated power system, and comparison was made between proposed PSO tuned PI with conventional PI controller. The simulation results are shown to demonstrate robust performance in comparison with the PI controllers through performance indices. The simulation is implemented in MATLAB-Simulink.*

Key Words-- **Deregulation, Bilateral contracts, Load Frequency Control, PI Control, Particle Swarm Optimization technique.**

I. INTRODUCTION

Successful operation of a power system is the process of properly maintaining several sets of balances. Two of these balances are between load-generation and scheduled, actual tie line flows [1] & [2]. These two balances are major factors to keep frequency constant. Constant frequency is identified as the primary key of healthy operation of system and the quality of supplied power to consumer as well. Both of these balances are maintained by adjusting generation keeping load demand in view. Since system conditions are always changing as load constantly varies during different hours of a day, precise manual control of these balances would be impossible.[3]

Currently, the electric power industry has been changed from vertically integrated utilities (VIU) provided that power at regulated rates to an restructured system which incorporates competitive companies for generation, transmission and distribution. In the new power system structure, LFC acquires a fundamental role to enable power exchanges and to provide better conditions for electricity trading. The common LFC objectives are to maintain frequency and the net interchanges to their desired values for each control area. So a lot of research has been made to modify the conventional LFC [4] & [5] and also to improve the dynamical transient response of the system under competitive conditions [6] & [9].

A detailed study on the control of generation in deregulated power systems is given in [10]. The concept of independent system operator (ISO) as an unbiased coordinator to balance dependability with economics is also discussed [11]. The assessment of Automatic Generation control (AGC) in a deregulated environment is shown in [12] and also provides a detailed review over this issue and explains how an AGC system could be simulated after deregulation.

II. PI CONTROLLER

The proportional integral (PI) controller because it has a simple structure and a high capability of solving many practical control problems. The PI controller improves the transient response so as to reduce an error and so the output is eventually settled to a final desired value and stability. The output equation for the PI controller is shown in Equation 1.

$$y(t)=K_p e(t)+K_i\int_0^t e(\tau)\,d\tau \tag{1}$$

The block diagram of PI controller is shown in Fig. 1. The output of the controller is y(t) and the error signal is u(t). K_p and K_i are proportional, integral gains of the controller. The limitations of conventional PI controllers are slow in response and less efficiency while handling non-linearity system. These gains values are tuned with the help of different optimizing methods such as Ziegler Nicholas method, Genetic algorithm, etc.

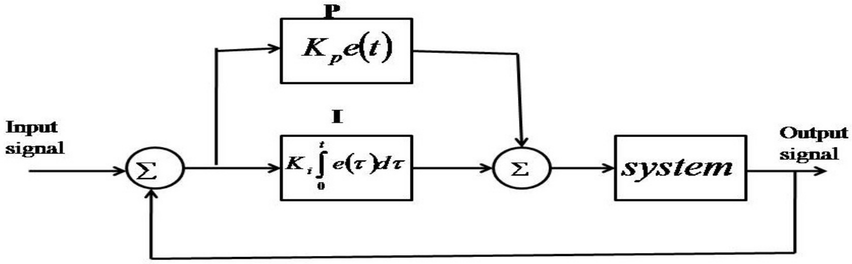

Fig 1. Block diagram of PI controller

III. TWO AREA DEREGULATED POWER SYSTEM FOR LFC

Deregulated power system will consist of generation companies (GENCO), distribution companies (DISCO), transmission companies (TRANSCO) and independent system operator (ISO). However, the common AGC goals, i.e. restoring the frequency and the net interchanges to their desired values for each control area, still remain. In this paper, two areas are considered in which each area consists of two GENCOs and two DISCOs and the block diagram of the two area deregulated power system is shown in Fig. 2. A DISCO can contract individually with any GENCO for power and these transactions are made under the supervision of ISO. To make the visualization of contracts easier, the concept of a “DISCO participation matrix” (DPM) will be used in [13]

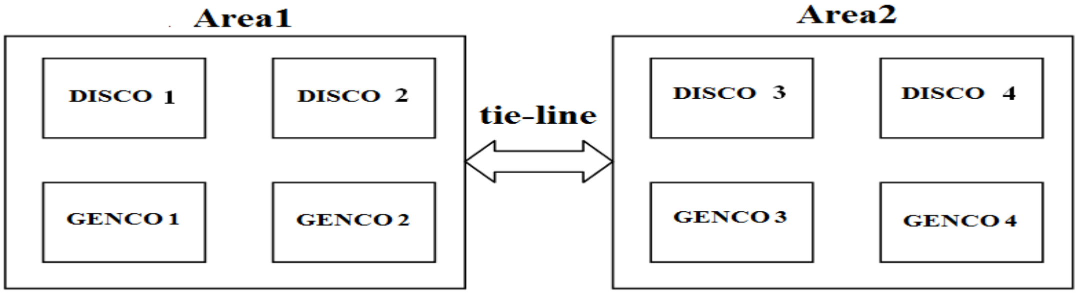

Fig 2. Two area Power System

DPM is a matrix with the number of rows equal to the number of GENCOs and number of columns equal to number of DISCOs in the system. It can be thought of as a fraction of a total load contracted by a DISCO (column) toward a GENCO (row). Equation (2) shows the DPM for the two area power system is considered. gpf_{ij} refers to "contract participation factor" and ij^{th} entry corresponds to the fraction of the total load power contracted by DISCO j from GENCO i. The sum of all the entries in a column of DPM is unity as shown in Equation (3).

$$DPM = \begin{bmatrix} gpf_{11} & gpf_{12} & gpf_{13} & gpf_{14} \\ gpf_{21} & gpf_{22} & gpf_{23} & gpf_{24} \\ gpf_{31} & gpf_{32} & gpf_{33} & gpf_{34} \\ gpf_{41} & gpf_{42} & gpf_{43} & gpf_{44} \end{bmatrix} \tag{2}$$

$$\sum_{i=1}^{4} \sum_{j=1}^{4} cpf_{ij} = 1 \tag{3}$$

IV. PARTICLE SWARM OPTIMIZATION

PSO is a population-based optimization method first proposed by Eberhart and Colleagues [14] & [15]. Some of the attractive features of PSO include the ease of implementation. It can be used to solve a wide array of different optimization problems. Like evolutionary algorithms, PSO technique conducts search using a population of particles, corresponding to individuals. Each particle represents a candidate solution to the problem at hand. In a PSO system, particles change their positions by flying around in a multidimensional search space until computational limitations are exceeded. This new approach features many advantages; it is simple, fast and can be coded in few lines. Also its strong requirement is minimal. Moreover, this approach is advantageous over evolutionary and genetic algorithm in many ways. First, PSO has memory. That is, every particle remembers its best solution (global best). Another advantage of PSO is that the initial population of the PSO is maintained and so there is no need for applying operators to the population, a process that is time-and memory-storage-consuming. In addition, PSO is based on constructive cooperation between particles, in contrast with the genetic algorithms, which are based on the survival of the fittest.

The PSO definition is presented as follows:

- The current positions,
- The current velocities,
- The distance between the current position and pbest
- The distance between the current position and gbest
- Each individual particle *i* has the following properties:
  - x_i = A current position in search space.
  - v_i = A current velocity in search space.
  - y_i =A personal best position in search space.
- The personal best position p_i corresponds to the position in search space, where particle *i* presents the smallest error as determined by the objective function f, assuming a minimization task.
- The global best position denoted by *g* represents the position yielding the lowest error among all the p_i's.

velocity update equation

$$v_i(k+1) = \{\omega \times v_i(k)\} + \{c_1 rand_1(\ ) \times (Pbest_i - x_i(k))\} + \{c_2 rand_2(\ ) \times (Gbest_i - x_i(k))\} \quad (3)$$

Position update equation

$$x_i(k+1) = x_i(k) + v_i(k+1) \quad (4)$$

Equation 2 and 3 define how the personal and global best values are updated at time k, respectively

Where

$v_i(k)$ = Velocity of *i*th particle at *k*th iteration.
$v_i(k+1)$ = Velocity of *i*th particle at *(k+1)*th iteration
$x_i(k)$ = Position of *i*th particle at *k*th iteration
$x_i(k+1)$ = Position of *i*th particle at (k+1)th iteration.
c_1, c_2 = Positive constants both equal to 2.
rand()1, rand()2. = Random no: selected between 0 and 1

Steps of PSO

Steps of PSO as implemented for optimization are:

Step 1: Initialize an array of particles with random positions and their associated velocities to satisfy the inequality constraints.

Step 2: Check for the satisfaction of the equality constraints and modify the solution if required.

Step 3: Evaluate the fitness function of each particle.

Step 4: Compare the current value of the fitness function with the particles previous best value (pbest). If the current fitness value is less, then assign the current fitness value to pbest and assign the current coordinates (positions) to pbestx.

Step 5: Determine the current global minimum fitness value among the current positions.

Step 6: Compare the current global minimum with the previous global minimum (gbest). If the current global minimum is better than gbest, then assign the current global minimum to gbest and assign the current coordinates (positions) to gbest.

Step 7: Change the velocities.

Step 8: Move each particle to the new position and return to step 2.

Step 9: Repeat step 2-8 until a stop criterion is satisfied or the maximum number of iterations is reached.

IV. SIMULATION MODEL OF TWO AREA POWER SYSTEM

Transfer function model of the two area deregulated power system is shown in Fig. 3.

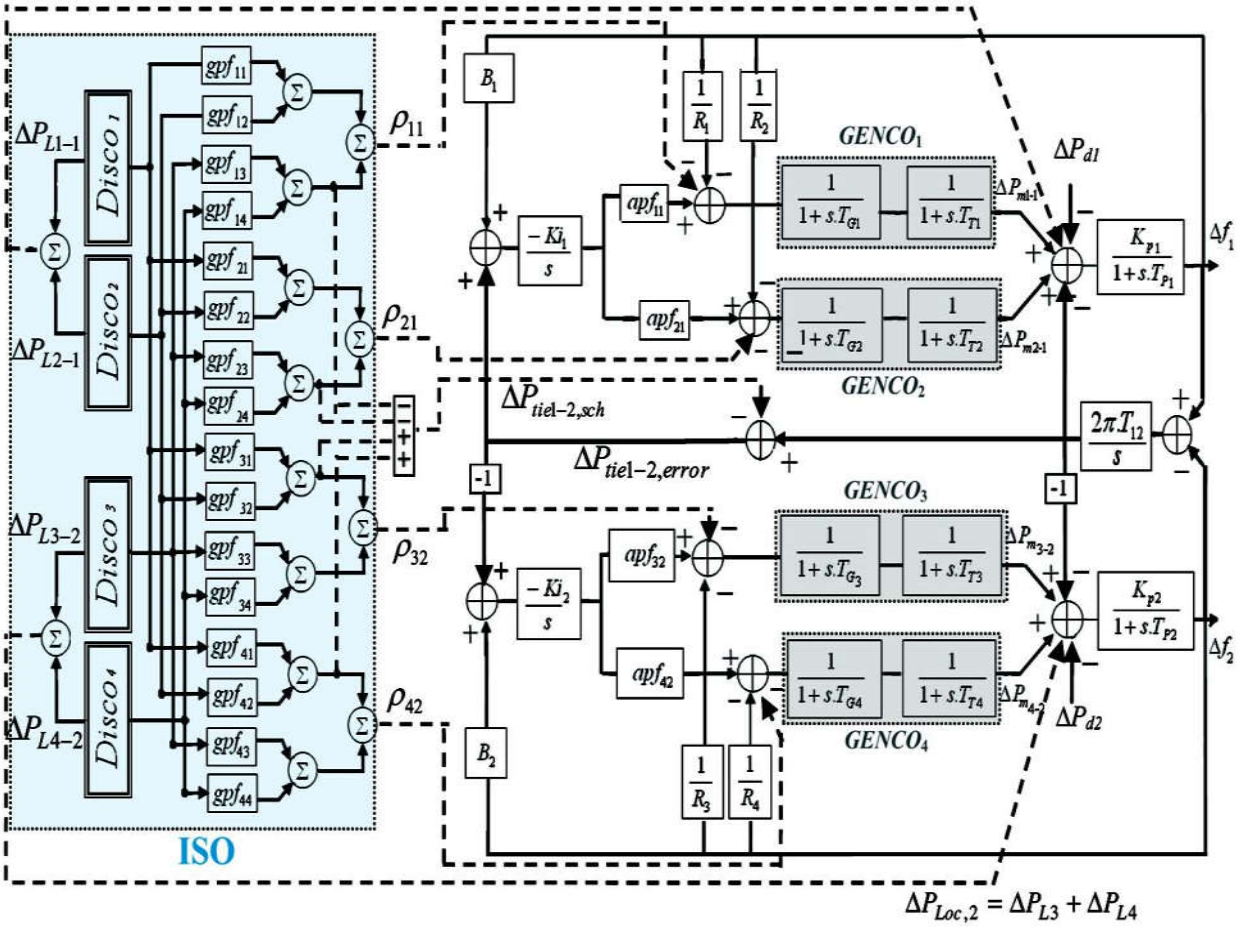

Fig. 3 Transfer function model of two area power system.

V.SIMULATION RESULTS

Consider a case where the GENCOs in each area participate equally in AGC, i.e. ACE participation factors are apf1 =0.5, apf2=1-apf1=0.5; apf3=0.5, apf4=1-apf3=0.5. Assume that the load change occurs only in area I. Thus, the load is demanded only by DISCO1 and DISCO2. Let the value of this load perturbation be 0.1 pu MW for each of them.

$$DPM = \begin{pmatrix} 0.5 & 0.5 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

Note that as DISCO3 and DISCO4 do not demand from any GENCOs, corresponding participation factors (columns 3 and 4) are zero. DISCO1 and DISCO2 demand identically from their local GENCOs viz. GENCO1 and GENCO2. The frequency deviations in area I and II, actual tie line power flow in a direction from area I to area II and the generated powers of various GENCOs following a step change in the loads of DISCO1 and DISCO2 are shown in figures.

The tie line power goes to zero in the steady state as there are no contracts of the DISCOs in one area with the GENCOs in other areas. In the steady state, the generation of each GENCO matches the demand of the DISCOs in contract with it. e.g. GENCO1 generates in equation (1).

As GENCO3 and GENCO4 are not contracted by any DISCOs, their generation change is zero in the steady state.

Fig. 4 (a), 4 (b) & 4 (c) show the dynamic response of areas 1 & 2 and the tie line power flow for case 1 with the PI controller whose settling time, overshoot and undershoot are shown. Fig. 5 (a), 5 (b) & 5 (c) show the dynamic response of areas 1 & 2 and the tie line power flow in the same case with PSO tuned PI controller. It is seen that the settling time, overshoot and undershoot are reduced when compared to the PI controller. TABLE 1 compares the settling time, overshoot and undershoot for the two controllers.

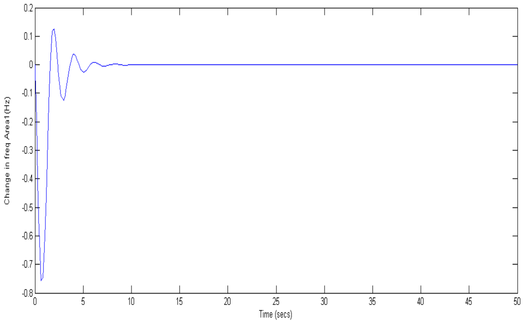

Fig. 4 (a) Dynamic response of frequency deviation in Area 1 for the PI controller

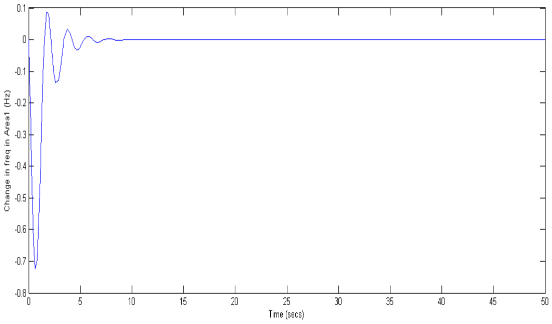

Fig. 5 (a) Dynamic response of frequency deviation in Area 1 for the PSO-PI controller

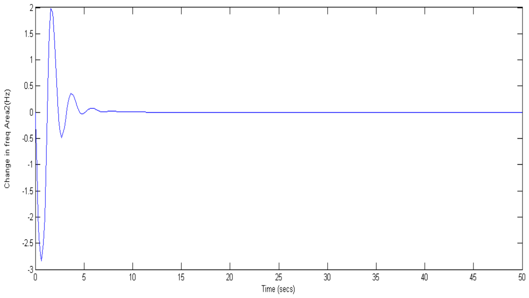

Fig. 4 (b) Dynamic response of frequency deviation in Area 2 for PI controller

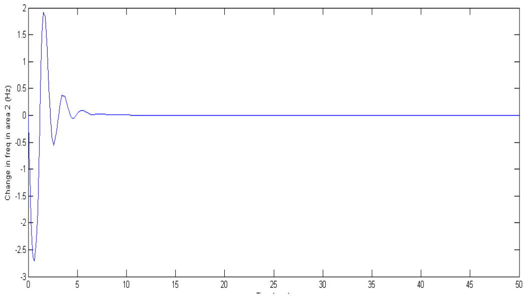

Fig. 5 (b) Dynamic Response of frequency deviation in Area 2 for PSO-PI controller

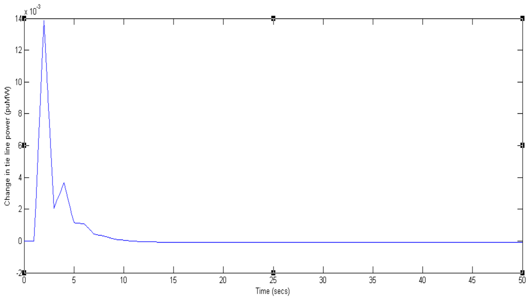

Fig. 4(c) Change in tie line power flow (pu MW) for PI controller

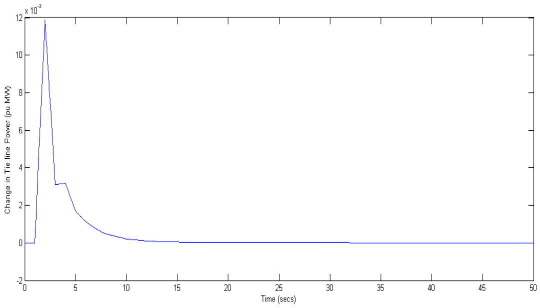

Fig. 5(c) Change in tie line power flow (pu MW) for PSO-PI controller

TABLE 1

COMPARISON OF THE FREQUENCY AND TIE LINE RESPONSES FOR THE PI CONTROLLER AND THE PSO TUNED PI CONTROLLER

Controller	Layout	Settling time (s)	Overshoot	Undershoot
PI	Area 1	9.8	0.125 (Hz)	-0.755 (Hz)
	Area 2	27.4	1.98 (Hz)	-2.9 (Hz)
	Tie line	14.2	0.015 (pu MW)	0 (pu MW)
PSO–PI	Area 1	8.9	0.088 (Hz)	-0.722 (Hz)
	Area 2	12	1.85 (Hz)	-2.7 (Hz)
	Tie line	11.9	0.0117(pu MW)	0 (pu MW)

TABLE 1 compares the response of the conventional PI controller with that of the PSO tuned PI controller for the deregulated power system. The settling time of the change in frequency in area1 for PSO-PI controller is 8.9 s, whereas for the PI controller it is 9.8 s. Similarly, the settling time of the change in frequency in area 2 for the PSO-PI controller 12 s, whereas it is 27.4 s for the PI controller. From the results, there is a reduction on settling time, overshoot and undershoot for PSO-PI controller when compared to PI controller.

VI. CONCLUSION

A tuning of PI controller using PSO for load frequency controller of two area interconnected power system has been presented. The system performance was observed on the basis of dynamic parameters i.e. settling time, overshoot and undershoot. The system performance characteristics reveals that the performance of PI tuning method better than PI controllers. As further study, it can be implemented in multi area power system with more constrains and controlled by using advanced controller systems.

REFERENCES

[1] P. Kundur, Power System Stability and Control, New York: McGraw-Hill, 1994.

[2] H. Saadat, Power System Analysis, New York: McGraw-Hill, 1999.

[3] C. Concordia and L. K. Kirchmayer, "Tie-Line Power and Frequency Control of Electric Power System - Part II", AIEE Transaction, vol. 73, Part- 111- A, pp. 133-146, April 1954.

[4] J. Kumar, and G. Sheble, "AGC simulator for price-based operation. Part 1: A model," IEEE Trans. Power Syst., Vol. 12, No. 2, pp. 527–532, May 1997.

[5] V. Donde, A. Pai, and I. A. Hiskens, "Simulation and optimization in a AGC system after deregulation," IEEE Trans. Power Syst., Vol. 16, No. 3, pp. 481–489, August 2001.

[6] H. Shayeghi, H. A. Shayanfar, and O. P. Malik, "Robust decentralized neural networks based LFC in a deregulated power system," Elect. Power Syst. Res., Vol. 77, pp. 241–251,April 2007.

[7] A. Huddar, and P. S. Kulkarni, "A robust method of tuning a decentralized proportionalintegral load frequency controller in a deregulated environment using genetic algorithms," Elect. Power Compon. Syst., Vol. 37, No. 3, pp. 265–286, February 2009.

[8] E. Rakhshani, and J. Sadeh, "Practical viewpoints on load frequency control problem in a deregulated power system," Energy Conversion Manag., Vol. 51, No. 6, pp. 1148–1156, 2010.

[9] E. Rakhshani, and J. Sadeh, "Reduced-order observer control for two-area LFC system after deregulation," Control Intell. Syst., Vol. 38, No. 4, pp. 185–193, 2010.

[10] P. Robert Schulte, "Automatic generation Control modification for present demands on interconnected power systems", IEEE Trans. On Power Systems, ,pp. 1286- 1291, August 1996.

[11] Jayant Kumar, Kah-Koeng and Gerald Sheble, "AGC simulator for price based operation Part1", IEEE Transactions on Power Systems,vol.12,no.2, ,pp. 527-532, May 1997.

[12] O. I. Elgerd, C. Fosha, "Optimum Megawatt- Frequency control of multiarea Electric Energy Systems", IEEE Transactions on Power Apparatus & Systems, Vol. PAS-89, No. 4, April 1970.

[13] Bjorn H. Bakken and Oves Grande, "Automatic generation control in a deregulated environment", IEEE Transactions on Power Systems, vol.13, no.4, ,pp. 1401-1406, Nov1998.

[14] J. Kennedy, R. C. Eberhart, Particles Swarm Optimization, Proc. IEEE International Conference on Neural Networks, Perth Australia, IEEE Service Center, Piscataway, NJ, IV: 1942-1948, 1995.

[15] R. C. Eberhart, J. Kennedy, A New Optimizer Using Particles Swarm Theory, Proc. Sixth International Symposium on Micro Machine and Human Science, Nagoya-Japan, IEEE Service Center, Piscataway, NJ, 39- 43, 1995.