第 49 卷第 09 期
2022 年 月

湖南大学学报（自然科学版）
Journal of Hunan University（Natural Sciences）

Vol. 49. No. 09
September 2022

Open Access Article

PSO BASED CONTROLLER FOR LFC OF DEREGULATED POWER SYSTEM

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Abstract: This paper describes a proposed Particle Swarm Optimization (PSO) based proportional plus integral plus derivative (PID) controller to solve the load frequency control (LFC) problem for two-area power system that operates under deregulated environment. Contractual conditions are based on the bilateral contract scheme. Here a PID controller parameter tuning technique is proposed. In each control area, the effects of the possible contracts are treated as a set of new input signals in a restructured power system dynamical model. The outstanding advantage of the proposed strategy is its high insensitivity to large and sudden load changes and unexpected disturbances, parameter manipulations and nonlinearities of the system. The controller developed using the PSO technique leads to a flexible with quite simple structure which is very easy to implement. Therefore, it might be very useful for the actual power systems. In order to check the performance of the designed controller, two area deregulated power system has been simulated under MATLAB/Simulink and dynamic responses obtained under various operating conditions. The results approve that the controller developed using PSO technique are capable of maintaining the frequency deviation in the specified range and also keep the tie line power exchange between the different areas as per the contracted conditions. The dynamic responses of the proposed controller is also compared with GA based controller.

***Key words* – PSO, Load Frequency Control, Contractual, deregulated, Tie-line, GA, PID controller.**

I. Introduction

There are two important objectives of load frequency control in interconnected power system, first to maintain the frequency of each area within specified limit and second to control the inter area tie-lines power exchanges within the scheduled values [3]. Due to the large size and complicated structure of power system, LFC has become more significant now a days. It can be seen that the engineering mechanisms of making plans and operation has been reformulated in a deregulated electrical power system in current years even though vital thoughts remain the same. To enhance the performance withinside the operation of the power system, few main adjustments into the shape of electrical power utilities are added by using deregulating the electric power industry and making it available for competition. The utilities no longer bundled as generation, transmission, and distribution;

Received: August,03, 2022 / Revised: August,22, 2022 / Accepted: 17, September, 2022 / Published: 30, September, 2022

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instead, there are three distinct entities, called as GENCO (Generation Companies), TRANSCOs (Transmission Companies) and DISCOs (Distribution Companies).

As there are numerous GENCOs and DISCOs withinside the deregulated shape, a DISCO has the liberty to have a agreement with any GENCO for transaction of electric power. A DISCO may also have a settlement with a GENCO in another control area. These transactions are termed as bilateral transactions. All the transactions ought to be cleared thru an independent entity known as an Independent System Operator (ISO). The ancillary services have to be controlled by the ISO. Load frequency control is also very important ancillary service. The predominant purpose of the Load frequency control is to maintain the frequency to its particular value by maintaining the zero steady state error for frequency deviation and minimizing the unscheduled tie-line power flows among neighbouring control areas.

II. Design and Modeling of power system in deregulated scenario

Generation companies (GENCOs) may or may not participate in the AGC task in the deregulated power system whereas, distribution companies (DISCOs) have the liberty to make contract with any of the GENCOs in their own or in other areas. This leads to various combinations contract scenarios between DISCOs and GENCOs. This paper uses the concept of distribution participation matrix (DPM) to express all possible contracts in the two-area deregulated power system model [3], [31]. In a DPM, the number of rows equal to the number of GENCOs and the number of columns equal to the number of DISCOs in the power system. Each entry in the DPM is called as contract participation factor (cpf). CPF represents the fraction of a DISCO contracted power demand being met by a GENCO [1]. The ijth entry cpfij corresponds to the fraction of the total electrical power contracted by DISCO j from a GENCO i. The addition of all the entries in a column of DPM lead to unity.
The DPM for a two-area system in which each area has two GENCOs and two DISCOs, is given as.

$$\text{DPM} = \begin{bmatrix} cpf11 & cpf12 & cpf13 & cpf14 \\ cpf21 & cpf22 & cpf23 & cpf24 \\ cpf31 & cpf32 & cpf33 & cpf34 \\ cpf41 & cpf42 & cpf43 & cpf44 \end{bmatrix}$$

(1)

Whenever a power demanded by a DISCO changes, it is reflected as a local load in the area to which DISCO belongs. This corresponds to the local loads ΔPL_1 and ΔPL_2 and should be reflected in the deregulated AGC system block diagram at the point of input to the power system block. As there are many GENCOs in each area, ACE signal has to be distributed among them in proportion to their participation in the AGC. Coefficients that distribute ACE to several GENCOs are termed as ACE participation factors (apf s).

Suppose that $DISCO_3$ demands 0.1 pu MW power, out of which 0.025 pu MW is demanded from $GENCO_1$, 0.03 pu MW from $GENCO_2$, 0.035 pu MW from $GENCO_3$ and 0.01 pu MW from $GENCO_4$. Then column 3 entries in (1) are easily defined as

$$cpf13 = \frac{0.025}{0.1} = 0.25\,, \qquad cpf23 = \frac{0.03}{0.1} = 0.3,$$

$$cpf33 = \frac{0.035}{0.1} = 0.35\,, \qquad cpf43 = \frac{0.01}{0.1} = 0.1$$

It is noted that $cpf_{13} + cpf_{23} + cpf_{33} + cpf_{43} = 1.0$, in general, $\sum cpf_{ij} = 1$.

The scheduled steady state power flow on the tie line is given as

$\Delta P_{tie1\text{-}2\ scheduled}$ = (demand of DISCOs in area II from GENCOs in area I) - (demand ofDISCOs in area I from GENCOs in area II)

(2)

$$\Delta P_{tie1\text{-}2scheduled} = \sum_{i=1}^{i=2}\sum_{j=3}^{j=4} CPFij\ \Delta PLj - \sum_{i=3}^{i=4}\sum_{j=1}^{j=2} CPFij\ \Delta PLj$$

(3)

At any given time, the tie line power error $\Delta P_{tie1\text{-}2,error}$ is defined as

$$\Delta P_{tie1\text{-}2,error} = \Delta P_{tie1\text{-}2,actual} - \Delta P_{tie1\text{-}2,scheduled}$$

(4)

For two area power system, contracted power supplied by i-th GENCO is given as

$$\Delta Pi = \sum_{j=1}^{n\ disco=4} CPFij\ \Delta PLj$$

(5)

For i=1, $\Delta P_1 = CPF_{11}\ \Delta P_{L1} + CPF_{12}\ \Delta P_{L2} + CPF_{13}\ \Delta P_{L3} + CPF_{14}\ \Delta P_{L4}$

(6)

Similarly, ΔP_2, ΔP_3 and ΔP_3 can be calculated easily.

The Simulation diagram of two area deregulated power system for load frequency control is shown in figure 1. Structurally it is based upon the idea of [1], [3] and [31]. The local loads in areas I and II are denoted by ΔP_{1LOC} and ΔP_{2LOC}, represent the local loads of area-1 and area-2 respectively. ΔP_{uc1} and ΔP_{uc2} represent uncontracted power (if any).

III. Controller Design

The PID controller is widely used in various applications in power system. In this control scheme there are three amending terms, proportional, integral, and derivative terms, whose sum give the manipulated variable (MV).

$$U(t) = MV(t) = K_P\ e(t) + K_i \int_0^t e(t)\ dt + K_d \frac{d}{dt} e(t)$$

(7)

Here U(t) is the controller output, the final form of the PID controller is given in equation (7).

Adjusting the parameters of PID controller is called as tuning of PID controller. It is necessary to adjust the parameters of PID controller to obtain the desired response. This is called tunning of PID controller. Tuning is necessary to get optimum value of the desired response [4],[5]. PID tuning is a difficult task even though there are only three parameters are need to tuned. Designing and tuning a PID controller appears to be conceptually intuitive, but can be hard in practice, if multiple and often conflicting objectives such as short transient and high stability are to be achieved. PID controllers often provide satisfactory control using manual tuning, but performance can usually be enhanced by cautious tuning

There are various methods for tuning the parameters of PID controller. Z-N method and IMC methods are used by [4] and 5]. Current research shows the use of soft computing methods in PID controller parameter tuning. These methods are very effective for finding proper values of K_P K_I and K_D. In this work, particle swarm optimization technique has been used for tuning of PID controller parameters for load frequency control problem of two area deregulated power system.

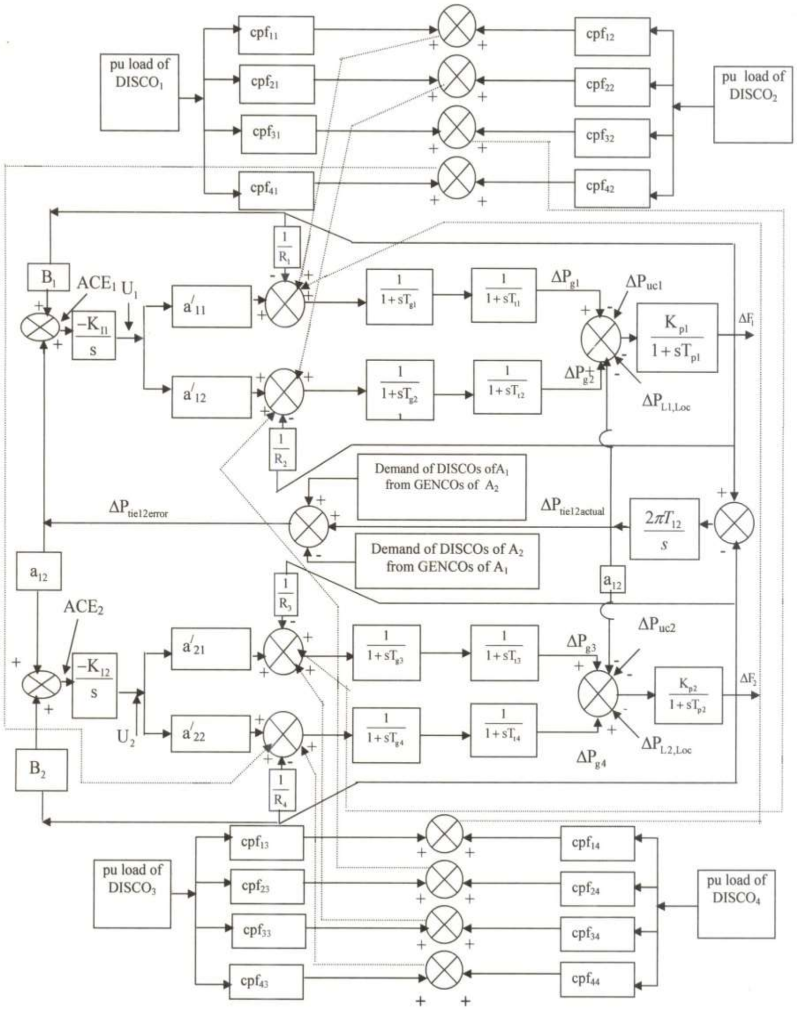

Figure 1: Block diagram of Two-Area power system in deregulated environment

IV. **Controller design using Particle Swarm Optimization Technique**

Particle Swarm Optimization (PSO) technique is very popular optimization technique which was developed by Eberhart & Kennedy (1995). It is basically encouraged by the social behavior of bird flocking. PSO technique is used in proposed work to explore possible solution to given problem to find the optimal values of controller parameters required to satisfy the LFC objectives. PSO is initialized with a group of random particles called solutions and then searches for optimal values of gains by updating the solutions iteratively. Each particle is represented by two vectors, known as position ‘xi’ and velocity ‘vi’. The position of each particle at a particular time is taken as a solution of the problem at that particular time. Then, to find the best position (the best solution) at each time, the particles fly around the search area and change their speed as well as position. All of the particles have fitness values which are evaluated by the fitness function to be optimized, and have velocities which direct the flying of the particles. The particles fly through the problem space by following the current optimum particles. In a physical d-dimensional search space, the position and velocity of individual ith particle are represented by the following vectors

$$x_i = [x_{i1}, x_{i2},\ldots,x_{id}]$$

(8)

$$v_i = [v_{i1}, v_{i2},\ldots,v_{id}]$$

(9)

Each particle is updated by following two "best" values, the best solution (fitness) it has achieved so far, pbest and another "best" value that is obtained so far by any particle in the population, gbest. pbest is the best position yielding the best fitness value for the ith particle, and gbesti is the global best position in the whole swarm population. Best values of ith particle are represented as follows:

$$pbest_i=[pbest^1_i, pbest^2_i,\ldots,pbest^d_i]$$

(10)

$$gbest_i=[gbest^1_i, gbest^2_i,\ldots,gbest^d_i]$$

(11)

The PSO algorithm updates its velocity and position using the following equation. The velocity updating equation is

$$v_i^d(j+1) = w(j)v_i^d(j) + c_1r_1\left[pbest_i^d(j) - x_i^d(j)\right] + c_2r_2\left[gbest_i^d(j) - x_i^d(j)\right]$$

……..(12)

V^d_i (j) represents the velocity of ‘i’th particle in ‘d’th dimension and at jth iteration.

Once the velocity for each particle has been calculated, each particle's position will be updated by applying the new velocity to the particle's previous position:

$$x^d_i\ (j + 1) = x^d_i\ (j) + v^d_i\ (j + 1) \quad \text{………(13)}$$

Performance index-based analysis is made to examine and highlight the effective application of PSO to optimize the proportional integral gains for LFC in a restructured power system that operates under bilateral-based policy scheme.It should be noted that choice of a proper fitness function is very important in synthesis procedure, because different fitness functions promote different PSO behaviors, which generate fitness value providing a performance measure of the problem considered.

The optimization problem is based on the minimization of the fitness function subject to the conditions that the PID gains K_P, K_I and K_D of both the controllers will lie within the minimum and the maximum limits.

PSO flow chart is shown in figure 2.

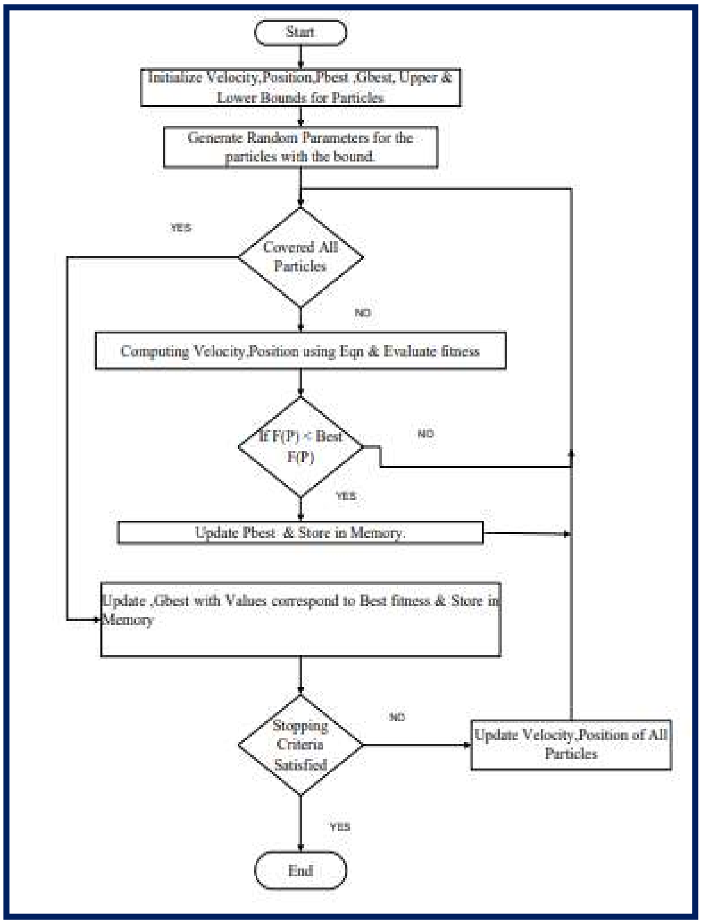

Figure 2: PSO flow chart

Steps of PSO algorithm which are repeated until some stopping condition is met, are given as follows.

Step 1: Initialization:

Set the iteration number k=0. Generate randomly n particles, xi ,i = 1, 2,..., n, where $x_i = [x_{i1}, x_{i2},...,x_{id}]$ and their initial velocities $V_i = [V_{i1}, V_{i2},...,V_{id}]$.

Step 2: Update iteration counter k=k+1.

Step 3: Update velocity of the particle using velocity equation as given in Eq. (12).

Step 4: Update position of the particle as per the position Eq. (13).

Step 5: Update particle best:

If $\text{eval}_i(x^k_i) > \text{eval}_i(pb^{k-1}_i)$ then $pb^k_i = x^k_i$ Else $pb^k_i = pb^{k-1}_i$

Step 6: Update global best: $\text{eval}(gb^k) = \max(\text{eval}_i(pb^{k-1}_i))$

If $\text{eval}(gb^k) > \text{eval}(gb^{k-1})$ then $gb^k = gb^k$ Else $gb^k = gb^{k-1}$

Step 7: Stopping criterion:

If the number of iterations exceeds the maximum numberiteration or accumulated coverage is 100% then stop, otherwise go to step 2.

Using the given algorithm, optimized parameters of the controllers are obtained.

V. Simulation & Results

5.1 Case-I: In this case, all the DISCOs have a total load demand of 0.005 pu MW. Comparative frequency response of both the areas, tie-line power response and genco responses of both the areas using GA based controller and PSO based controller are shown in figures from 3 to 7.

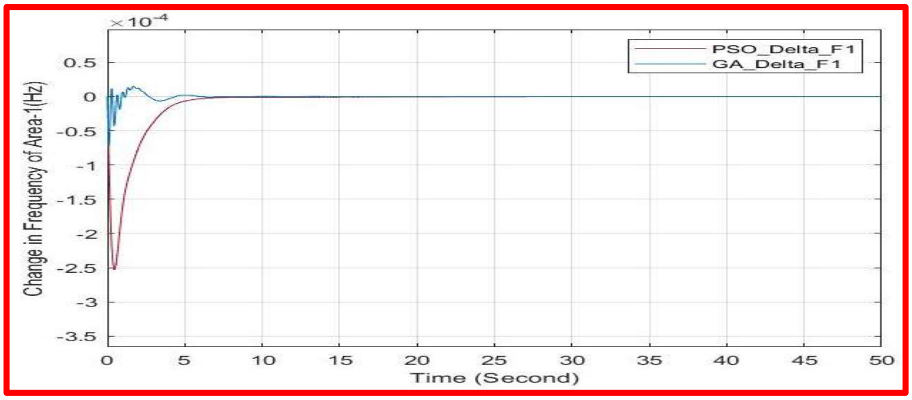

Fig. 3. Change in frequency of Area-1

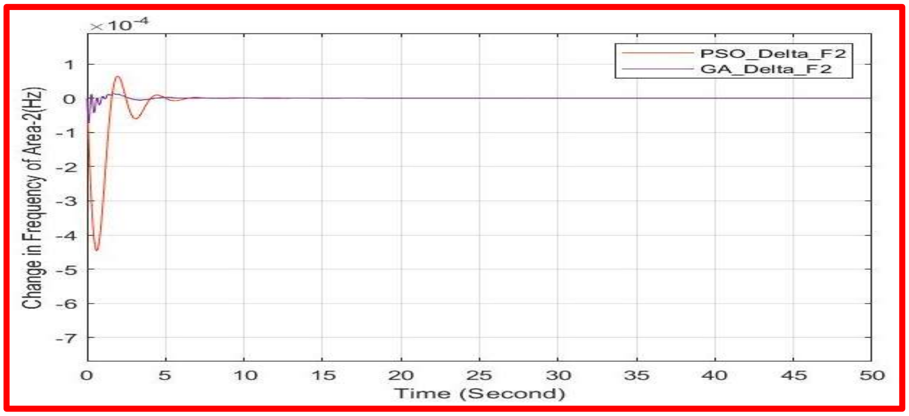

Fig. 4. Change in frequency of Area-2

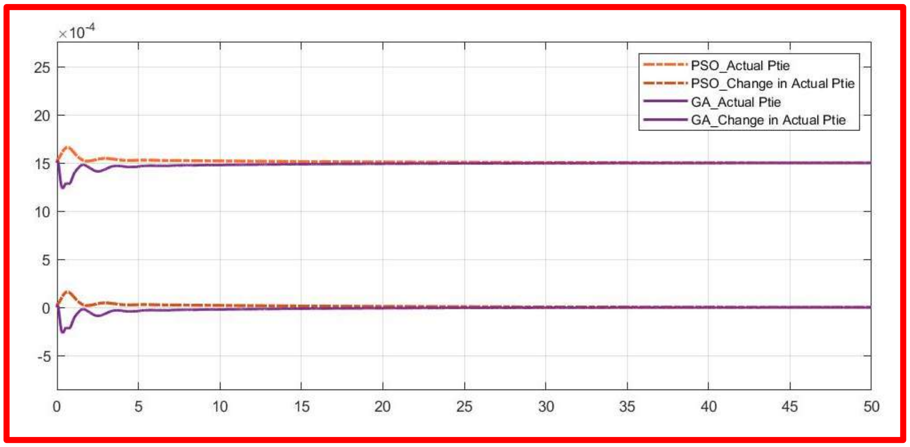

Fig. 5. Change in tie-line power and actual tie-line power

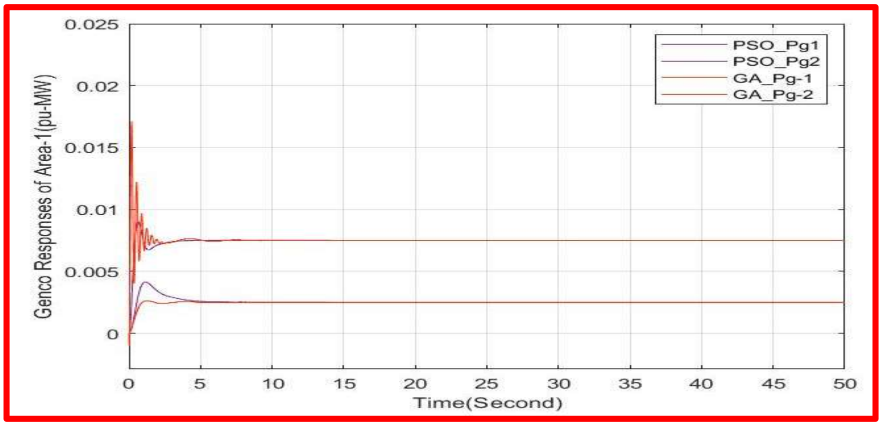

Fig. 6. Genco responses of area-1

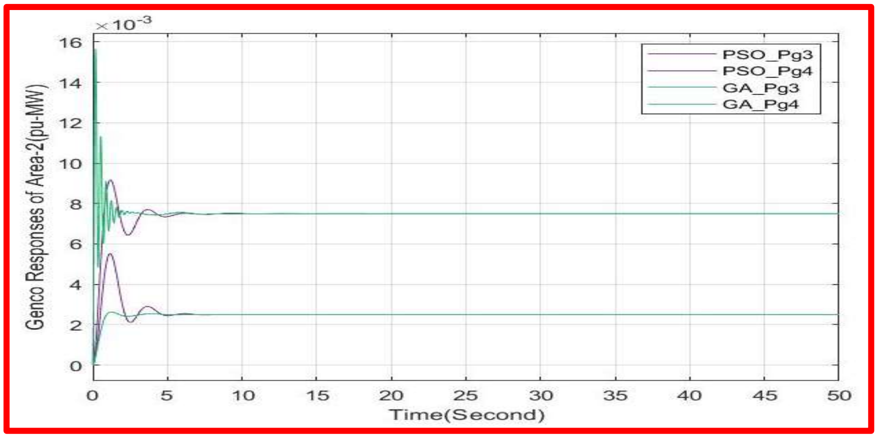

Fig. 7. Genco Responses of Area-2

5.2 Case-II

Additional load demand of 0.0025 pu-MW is raised by Area-1 at t=25 Sec. and it is supplied by only genco-1 of area-1. It is a contract violation case. Comparative frequency response of both the areas, tie-line power response and genco responses of both the areas using GA based controller and PSO based controller are shown in figures from 8 to 12.

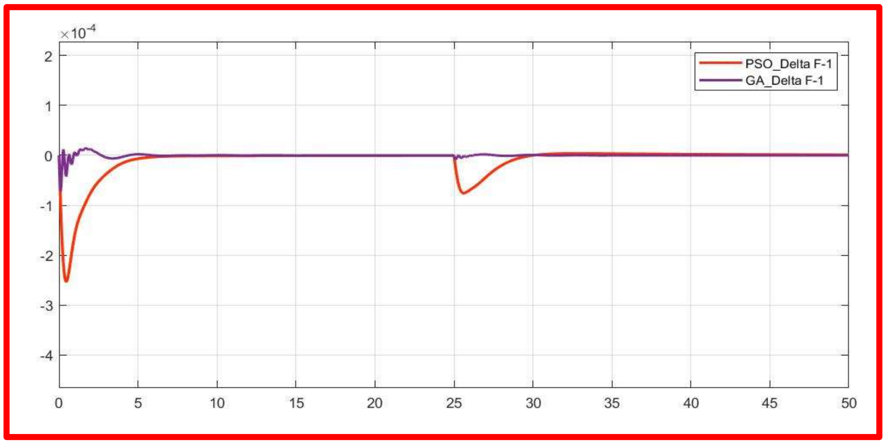

Fig. 8. Change in frequency of Area-1

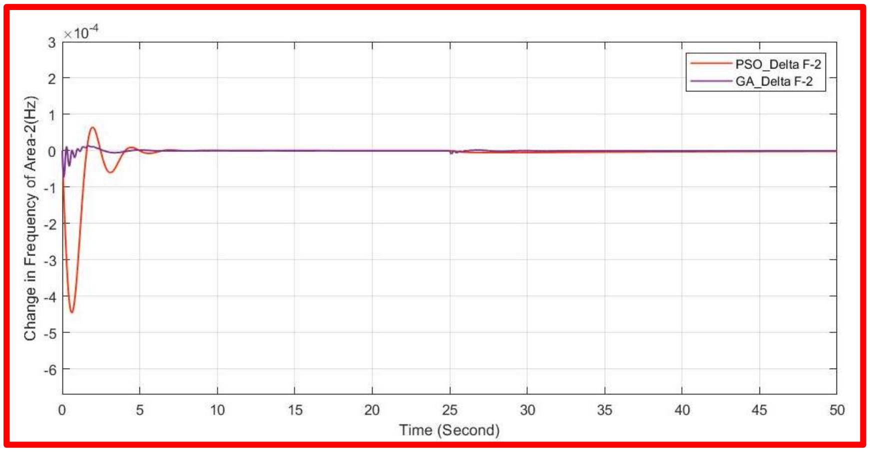

Fig. 9. Change in frequency of Area-2

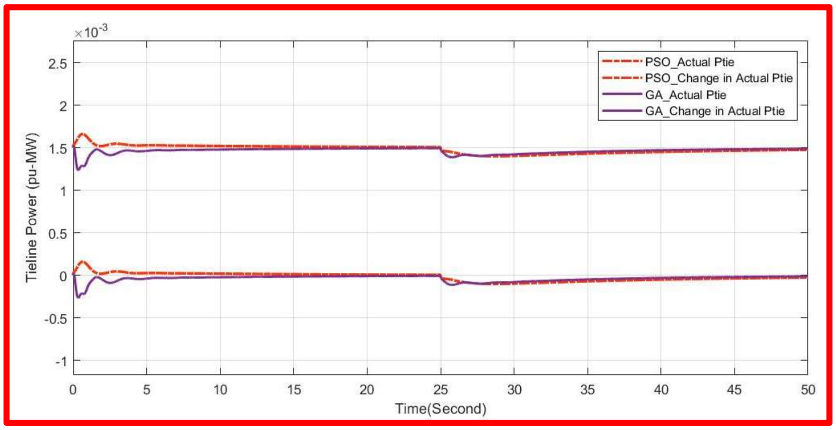

Fig. 10. Actual tie-line power and change in tie-line power of Area-1

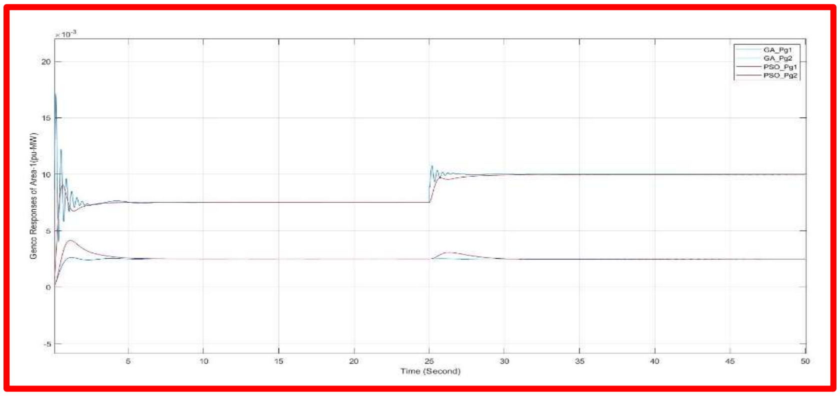

Fig. 11. Genco responses of Area-1

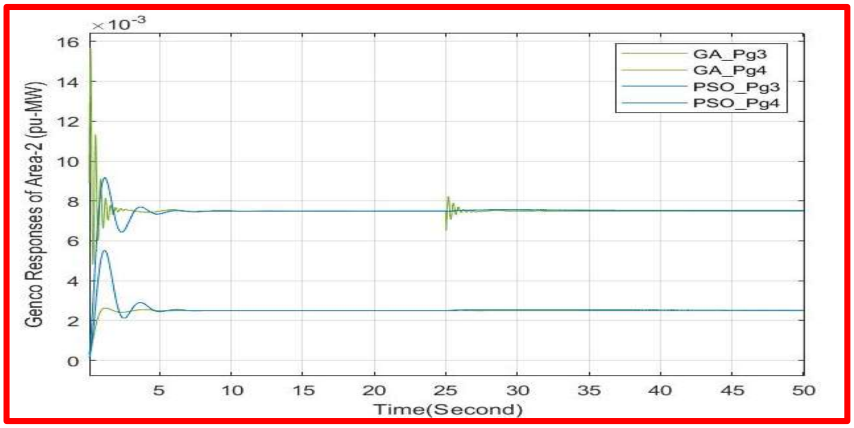

Fig. 12. Genco responses of Area-2

5.3 Comparison with respect to Time response specifications

Table 5-1: Time response specifications for Δf1 (Case-1)

S. No	Controller	Peak Overshoot Mp	Peak Time Tp (Seconds)	Rise Time Tr (Seconds)	Settling Time Ts (Seconds)	Comment
1	PSO	$-2.5*10^{-4}$	1.85s	1.56s	6.67s	Stable
2	GA	$-0.72 *10^{-4}$	0.27s	0.22	7.82s	Stable

Table 5-2: Time response specifications for Δf2 (Case-1)

S. No	Controller	Peak Overshoot Mp	Peak Time Tp (Seconds)	Rise Time Tr (Seconds)	Settling Time Ts (Seconds)	Comment
1	PSO	$-4.4 *10^{-4}$	1.94s	1.57s	6.48s	Stable
2	GA	$-0.725 *10^{-4}$	0.28s	0.23s	6.95s	Stable

Table 5-3: Time response specifications for Δf1 (Case-I1)

S. No	Controller	Peak Overshoot Mp	Peak Time Tp (Seconds)	Rise Time Tr (Seconds)	Settling Time Ts (Seconds)	Comment
1	PSO	$-2.58 *10^{-4}$	0.44s	6.54s	5.25s	Stable
2	GA	$-0.72 *10^{-4}$	0.27s	0.23s	7.5s	Stable

Table 5-4: Time response specifications for Δf2 (Case-I1)

S. No	Controller	Peak Overshoot Mp	Peak Time Tp (Seconds)	Rise Time Tr (Seconds)	Settling Time Ts (Seconds)	Comment

1	PSO	$-4.4*10^{-4}$	1.94s	1.57s	5.55s	Stable
2	GA	$-0.725*10^{-4}$	0.27s	0.23s	6.95s	Stable

CONCLUSION

The main goal of the load frequency control is to keep the power system frequency and the inter area tie line power exchange as close as possible to the scheduled values in interconnected restructured power system. It is possible to achieve the desired response with the help of proper control method. PSO technique is proposed in this research work to design a suitable controller to achieve the goals of LFC of two area restructured power system. The simulation model of a two-area interconnected power system in deregulated environment has been developed so that the dynamic performance and robustness of the proposed controller can be checked. The genetic algorithm based controller and PSO based controllers are applied to the developed MATLAB Simulink model of two area deregulated power system and dynamic responses such as frequency responses, tie-line power and genco responses have been obtain for different contractual conditions. It has been seen that the PSO based PID controller has given the better dynamic responses as compared to GA based controller. Comparison of PSO based controller and GA based controller has also been done with respect to time responses specifications. It is seen that PSO based controller gives better response with respect to genetic algorithm-based controller in all respect specially when oscillatory nature of responses are compared.

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