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ENHANCING LOAD FREQUENCY CONTROL IN TWO AREA DEREGULATED POWER SYSTEMS: OPTIMIZING CONTROLLER PARAMETERS WITH SOFT COMPUTING TECHNIQUES

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Abstract

It is very difficult to obtain the optimal parameter of controllers for load frequency control (LFC) problem of a multi area power system in deregulated environment. Deregulated power system contains multi sources and multi stakeholders therefore conventional LFC methods are not effective and competent. The main objective of LFC in deregulated system is to bring back the frequency to its nominal value as quickly as possible and minimize tie-line power flow oscillations between neighboring control areas and also monitoring the load matching contracts. PID controller can be used for this purpose. Parameters of PID controller are required to be optimized in order to achieve the objectives of LFC. This paper presents genetic algorithm and particle swarm optimization techniques for optimization of controller parameters to achieve the objective of load frequency control of two-area deregulated system taking suitable objective function that are to minimize the frequency deviations of both the areas and to maintain tie line power exchange according to contractual conditions. Responses of two area deregulated power system simulated under MATLAB/Simulink have been obtained and results confirm that the controllers designed using soft computing techniques are capable of keeping the frequency deviation in the specified range and maintain the tie line power exchange as per the contractual conditions. Random variable load has also been applied to check the robustness of the designed controller. A comparative analysis of load frequency control of two area deregulated power system using PSO based controller and GA based controller is also presented.

Keywords: LFC, PID, Deregulated, GA, PSO.

Introduction

LFC has been considered one of the most significant services in the interconnected power system. In an interconnected power system, LFC has two important objectives; maintain the frequency of each area within specified limit and controlling the inter area tie-lines power exchanges within the scheduled values as explained by Donde et. al. [1]. LFC has become more significant in recent time due to the size and complication of whole power system network. To improve the power system operation, some major changes have been made in the structure of the power system by means of deregulating the electrical power industry and opening it for competition. The engineering aspects of planning and operation have been reformulated in a deregulated power system although essential ideas remain the same.

In the deregulated power system, each control area must meet its own demand and its scheduled interchange power. Any mismatch between the generation and load can be observed by means of a deviation in frequency. This balancing between generation and load can be achieved by using Automatic Generation Control.

A lot of studies have been conducted about various LFC issues in a deregulated power system to overcome these situations. Donde et. al. [1] discussed about simulation and optimization in an AGC system after deregulation. Kothari M L et. al. [2] explained the automatic generation control of deregulated power system. The performance of PID controller directly depends on its parameters tuning as explained by Dharmendra Jain et.al. [3]. Decentralized load frequency control in deregulated environment was presented by Tan W et. al. [4]. G.C. Sekhar et. at. [5] used firefly algorithm or other methods for tuning of parameters in order to optimize the gain of controllers. Sood YR. [6] discussed evolutionary programming based optimal power flow and its validation for deregulated power system analysis. Intelligent demand response contribution in frequency control of multiarea power systems was explained by P. Babahajiani et. al. [7]. C. Concordia and L.K. Kirchmayer [8] described tie line power and frequency control of electric power systems. N. Cohn [9] explained the concept of tieline bias control. Dharmendra Jain et. Al [10], discussed the comparative analysis of different methods of tuning the pid controller parameters for load frequency control problem. Optimum megawatt LFC was presented by O. I. Elgerd and C. Fosha [11] and [12]. To solve LFC, many of the researchers used PID controllers because of its accuracy and high speed. IEEE report [13] represented operating problems associated with automatic generation control. Honey Bee Algorithm is used by Abedinia O et. al. [14]. P. Babahajiani et.al. S. Abd-Elazim and E. Ali [15] explained load frequency controller design of a two-area system composing of PV grid and thermal generator via firefly algorithm. P. K Sahoo [16] explained the application of soft computing neural network tools to line congestion study of electrical power systems. Reduced-order observer method was used by Rakhshani E et. al. [17]. Dharmendra jain et. al. [18] discussed the comparative analysis of load frequency control problem of multi area deregulated power system using soft computing techniques. In this paper Genetic Algorithm optimization technique and particle swarm optimization techniques are used to tune the parameters of the controller for LFC of two area interconnected power system in deregulated environment. The superiority of PSO based proposed controller is shown by comparing the results with GA based Controller in deregulated power system.

Interconnected Power System in Deregulated Environment

In a deregulated power market contracts are signed between companies based on rules and relationships in order to create balance between GENCOS and DISCOS. These contracts could be bilateral, Poolco or a combination of both. In the Poolco contract, each DISCO meets its power requirement only from the generators of its own area. But in the bilateral contract, each DISCO can deal with any GENCO in any area. In the present study, two areas are considered in deregulated power system. Area-1 and area-2 consists of 2-thermal generations units in each area.

Consider a two-area system in which each area has two GENCOs and two DISCOs in it. Let GENCO1, GENCO2, DISCO1, and DISCO2 be in area I and GENCO3, GENCO4, DISCO3, and DISCO4 be in area II as shown in fig. 1. The corresponding DPM will become as shown in equation 1.

$$\text{DPM} = \begin{bmatrix} cpf11 & cpf12 & cpf13 & cpf14 \\ cpf21 & cpf22 & cpf23 & cpf24 \\ cpf31 & cpf32 & cpf33 & cpf34 \\ cpf41 & cpf42 & cpf43 & cpf44 \end{bmatrix} \tag{1}$$

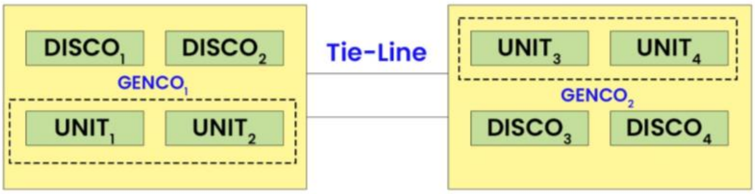

Figure 1: Schematic of a two-area system in restructured environment

Whenever a load demanded by a DISCO changes, it is reflected as a local load in the area to which this DISCO belongs. This corresponds to the local loads ΔPL1 and ΔPL2 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). Sum of all apfs of a column is unity as shown in equation 2.

Note that $\sum_{i=1}^{m} aji = 1$ (2)

Where, a_{ji} = participation factor of i-th GENCO in j-th area and m = number of GENCOs in j-th area. The scheduled steady state power flow on the tie line is given as in equation 3 & 4.

ΔPtie1-2 scheduled = (demand of DISCOs in area II from GENCOs in area I) - (demand of DISCOs in area I from GENCOs in area II) (3)

ΔPtie1-2scheduled = $\sum_{i=1}^{i=2}\sum_{j=3}^{j=4} CPFij\ \Delta PLj - \sum_{i=3}^{i=4}\sum_{j=1}^{j=2} CPFij\ \Delta PLj$ (4)

At any given time, the tie line power error ΔPtie1-2, error is defined as in equation 5.

$$\Delta P_{tie1-2,error} = \Delta P_{tie1-2\ actual} - \Delta P_{tie1-2,scheduled} \quad (5)$$

ΔPtie1-2, error vanishes in the steady state as the actual tie line power flow reaches the scheduled power flow. This error signal is used to generate the respective ACE signals as in the traditional scenario as shown in equation 6 & 7.

$$ACE_1 = B_1\,\Delta f_1 + \Delta P_{tie1-2,,error} \quad (6)$$

$$ACE_2 = B_2\,\Delta f_2 + \Delta P_{tie2-1,error} \quad (7)$$

Where, $\Delta P_{tie1-2,error} = -\left(\frac{P_{r1}}{P_{r2}}\right)\Delta P_{tie1-2,error}$ (8)

And Pr1, Pr2 are the rated powers of areas I and II, respectively.

Therefore

$$ACE_2 = B_2\Delta f_2 + \propto_{12}\ \Delta P_{tie1-2,error} \quad (9)$$

Where, α12 = - (Pr1 / Pr2) (10)

For two area system, contracted power supplied by i-th GENCO is given by equation 11 and 12.

$$\Delta Pi = \sum_{j=1}^{n\ disco=4} CPFij\ \Delta PLj \quad (11)$$

For i=1, ΔP1 = CPF11 ΔPL1 + CPF12 ΔPL2 + CPF13 ΔPL3 + CPF14 ΔPL4 (12)

Similarly, ΔP2, ΔP3 and ΔP3 can be calculated easily.

The Simulink diagram for LFC in two area (with reheat turbine) bilateral deregulated system is shown in figure 2. Structurally it is based upon the idea of Donde et. al. [1] and Dharmendra Jain et. al. [3]. Dashed lines show the demand signals. The local loads in areas I and II are denoted by ΔP1LOC and ΔP2LOC, respectively. ΔPuc1 and ΔPuc2 are uncontracted power (if any). Also note that local power of area-1 nad area-2 are given as in equations 13 and 14.

$$\Delta P_{1LOC} = \Delta P_{L1} + \Delta P_{L2} \quad (13)$$

$$\Delta P_{2LOC} = \Delta P_{L3} + \Delta P_{L4} \quad (14)$$

Controller and Tunning

The PID controller is named after its three correcting terms, whose sum constitutes the manipulated variable (MV). The proportional, integral, and derivative terms are summed to calculate the output of the PID controller. Defining U(t) as the controller output, the final form of the PID controller output is given in equation 15.

$$U(t)= MV(t)= Kp\ e(t) + Ki \int_0^t e(t)\ dt + Kd \frac{d}{dt} e(t) \quad (15)$$

It is necessary to adjust the parameters of PID controller to obtain the desired response. This is called tunning of PID controller Tuning a control loop is the adjustment of its control parameters i.e. proportional gain, integral gain and derivative gain to the optimum values for the desired control response. The performance of the system can generally be improved by careful tuning of PID controller parameters and on the other hand performance may be unacceptable with poor tuning of controller parameters.

There are several methods of tuning of PID controller parameters. Z-N method and IMC methods of tuning are used by Dharmendra Jain et. al. [10]. But now a days soft computing methods are more popular due to several advantages. In this paper, genetic algorithm and particle swarm optimization techniques are used for optimization of controller parameters.

Genetic Algorithm

Genetic Algorithms is a soft computing approach. GAs are general-purpose search algorithms, which use principles inspired by natural genetics to evolve solutions to problems. Genetic algorithms are one of adaptive systems that basically aim at learning, adopting and functioning biological or natural beings. The fundamental mechanism is described in the flowchart shown in figure 2. Tuning of the PID controller has been done using GA by minimizing the time multiplied absolute error (ITAE).

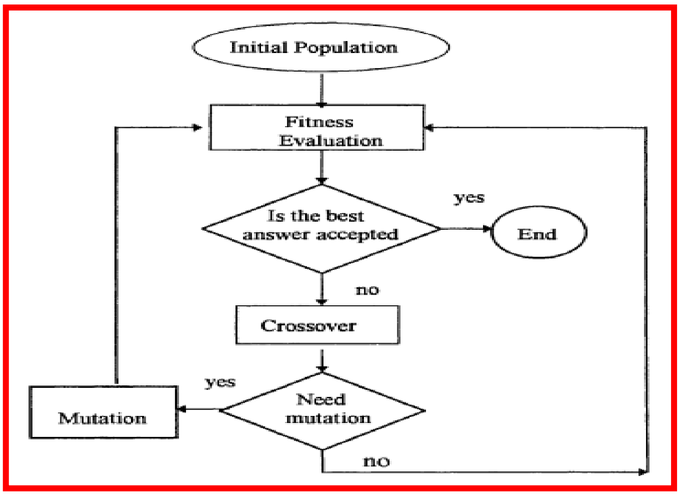

Figure 2: Flow chart of genetic algorithm

Particle Swarm Optimization Technique

Particle Swarm Optimization (PSO) is a popular stochastic optimization technique developed by Eberhart & Kennedy (1995). It is inspired by the social behavior of fish schooling or bird flocking. It is used in this work to explore the search space of a given problem to find the optimal gain values of controller parameters required to satisfy the LFC objectives. PSO is initialized with a group of random particles (solutions) and then searches for optimal gains by updating the solutions. Each particle is represented by two vectors, i.e., position ‘xi’ and velocity ‘vi’.

The position of each particle at a particular time is considered as a solution to the problem at that time. Then, to find the best position (the best solution) at each time, the particles fly around the search area and change their speed and 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

$$X_i = [X_{i1}, X_{i2}, \dots . X_{id}] \tag{16}$$

$$V_i = [V_{i1}, V_{i2}, \dots V_{id}] \tag{17}$$

Each particle is updated by following two "best" values, the best solution (fitness) it has achieved so far, pbest and another "gbest" value that is obtained so far by any particle in the population. 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:

$$pbest = [pbest_i^1, pbest_i^2 \dots\dots pbest_i^d] \tag{18}$$

$$gbest = [gbest_i^1, gbest_i^2, \dots\dots gbest_i^d] \tag{19}$$

The PSO algorithm updates its velocity and position using the following equation. The velocity updating equation is given as in equation 20.

$$v_i^d(j+1) = w(j)v_i^d(j) + c_1r_1\left[pbest_i^d(j) - x_i^d(j)\right] + c_2r_2[gbest_i^d(j) - x_i^d] \tag{20}$$

Vdi (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 as in equation 21.

$$x_i^d(j+1) = x_i^d(j) + v_i^d(j+1) \tag{21}$$

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 3. The PSO algorithm consists of just few steps as shown in flow chart, which are repeated until some stopping condition is met. Using this, optimized parameters of the controllers are obtained.

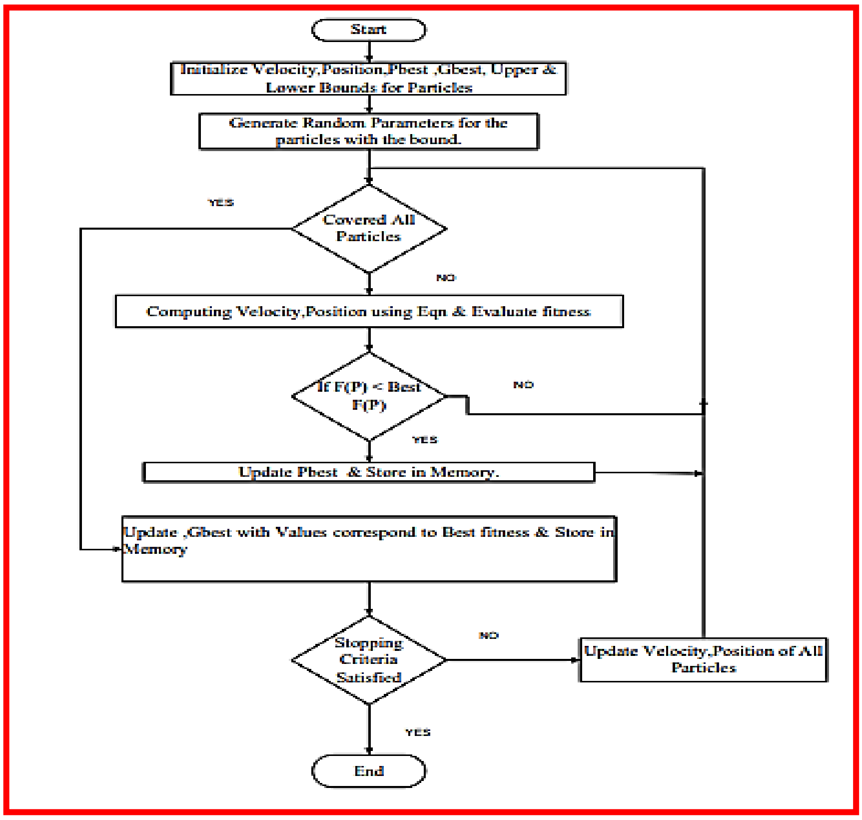

Figure 3: Flow chart of PSO

Simulation and Results

Controller based on genetic algorithm and particle swarm optimization are used and dynamic responses have been obtained for various contractual conditions.

Case-I

It is the base case. All the DISCOs have a total load demand of 0.005 pu MW. Comparative responses using PID controller, GA based controller and PSO based controller are shown in figures from 4 to 8.

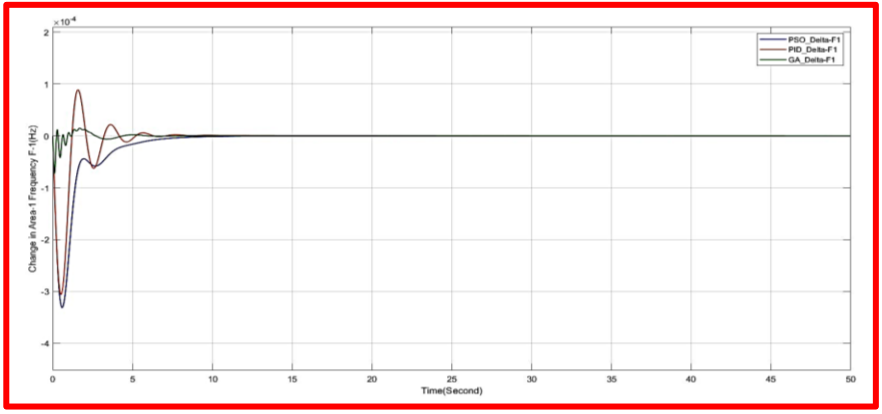

Figure 4: Change in frequency of Area-1

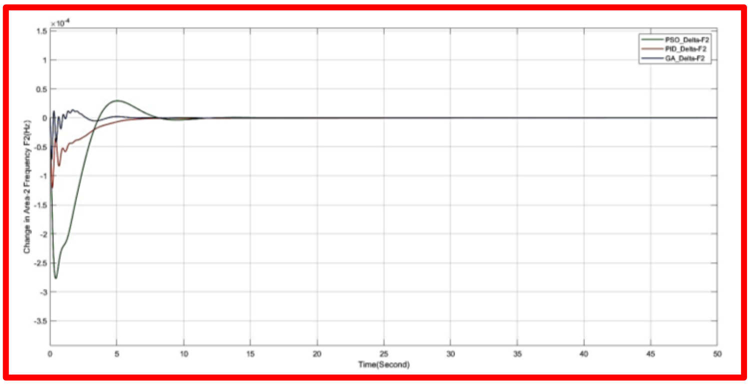

Figure 5: Change in frequency of Area-2

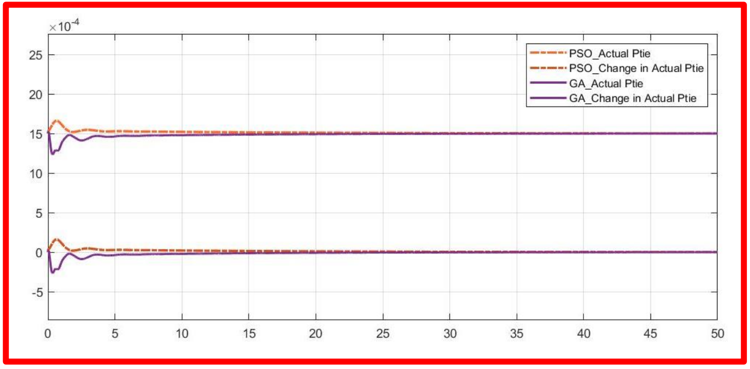

Figure 6: Change in tie-line power and actual tie-line power

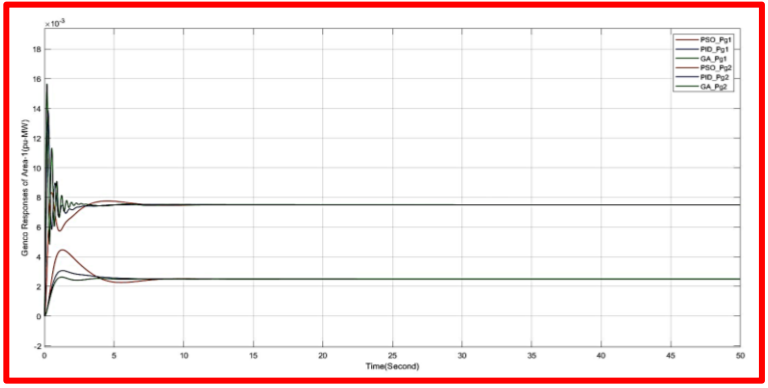

Figure 7: Genco responses of area-1

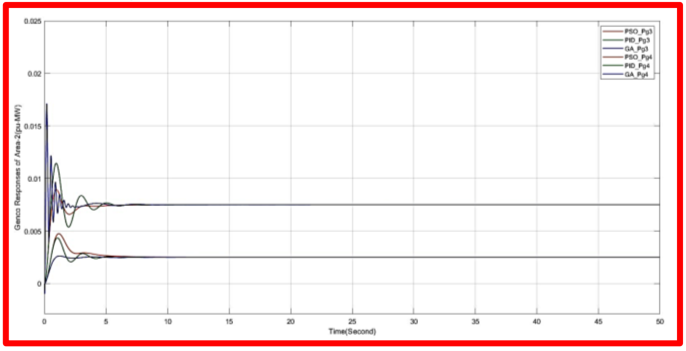

Figure 8: Genco Responses of Area-2

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 responses using GA based controller and PSO based controller are shown in figures from 9 to 13.

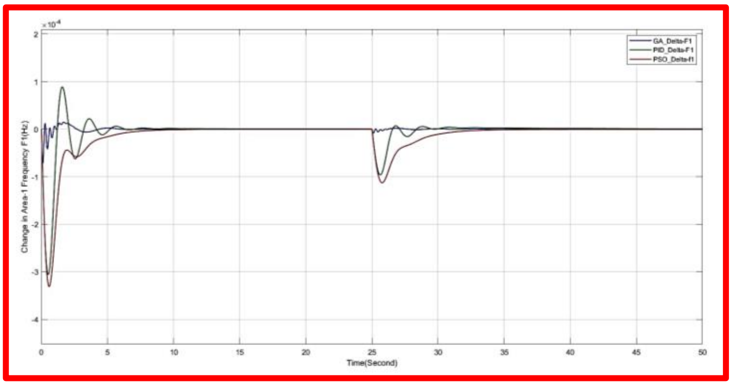

Figure 9: Change in frequency of Area-1

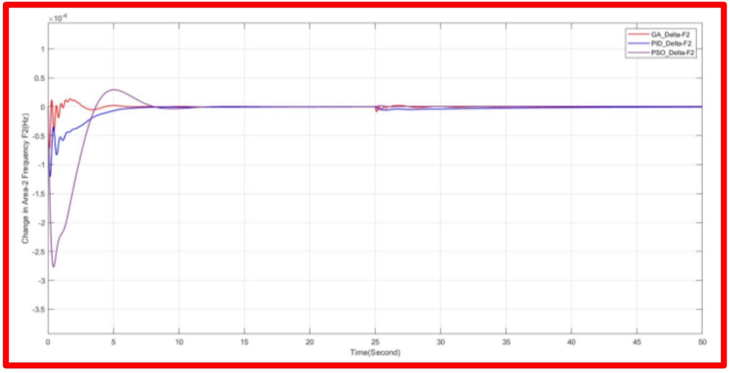

Figure 10: Change in frequency of Area-2

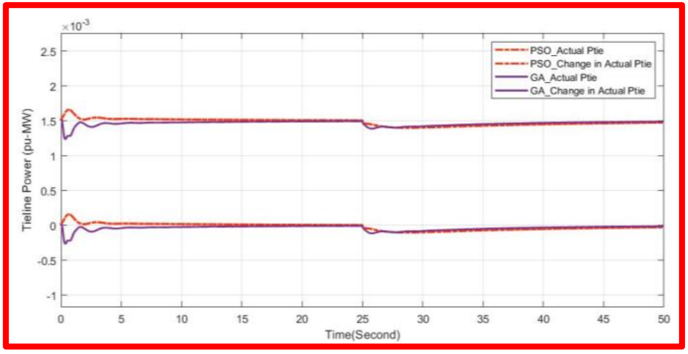

Figure 11: Actual tie-line power and change in tie-line power of Area-1

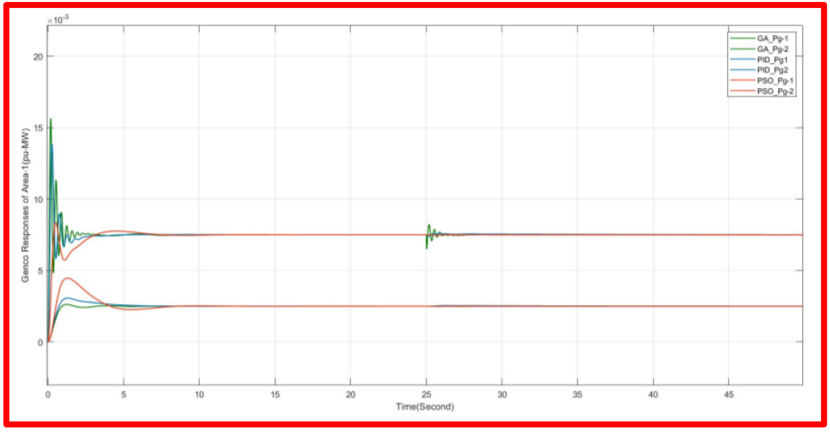

Figure 12: Genco responses of Area-1

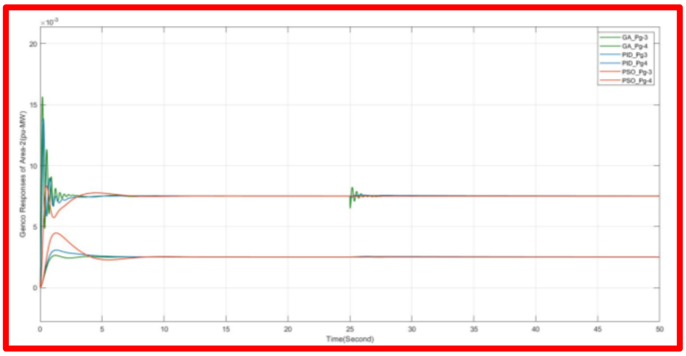

Figure 13: Genco responses of Area-2

Comparison with respect to Time Response Specifications

The time response specifications of frequency responses $\Delta f1$ and $\Delta f2$ for case-I are given in Table 1 and table 2 respectively.

Table 1: Time response specifications for $\Delta f1$ (Case-1)

S. No	Controller Type	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 2: Time response specifications for $\Delta f2$ (Case-1)

S. No	Controller Type	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

The time response specifications of frequency responses $\Delta f1$ and $\Delta f2$ for case-II are given in Table 3 and table 4 respectively.

Table 3: Time response specifications for $\Delta f1$ (Case-II)

S. No	Controller Type	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 4: Time response specifications for $\Delta f2$ (Case-II)

S. No	Controller Type	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

Effect of Random Load Variation

Now consider the random variation in load demand of area-1 and Area-2.

Case A

Consider the case-A, where the random load variation take place in area-1as given in table 5 and this is taken in account by genco-1 of area-1 as given in the table 6.

Table 5: Random load variation in area-1

S. No.	Time (Second)	Area-1 Load (pu-MW)	Area-2 Load (pu-MW)
1	0 to 25 Sec	0.0085	0.01
2	25 to 50 Sec.	0.0125	0.01
3	50 to 85 Sec.	0.0065	0.01
4	85 to 100 Sec.	0.0115	0.01

Table 6: Genco participation in load distribution

S. No.	Time (Second)	Area-1 Load (pu-MW)		Area-2 Load (pu-MW)	
		Genco-1	Genco-2	Genco-3	Genco-4
1	0 to 25 Sec	0.0050	0.0025	0.0085	0.0025
2	25 to 50 Sec.	0.0100	0.0025	0.0085	0.0025
3	50 to 85 Sec.	0.0040	0.0025	0.0085	0.0025
4	85 to 100 Sec.	0.0090	0.0025	0.0085	0.0025

Fig. 14 to 18 show the dynamic responses with the PSO based controller and 19 to 23 show the dynamic responses with the GA based controllers.

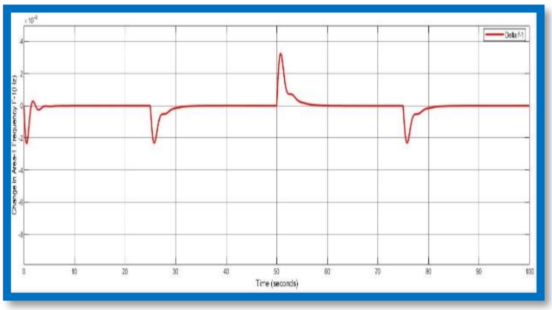

Figure 14: Δf₁ with PSO controller

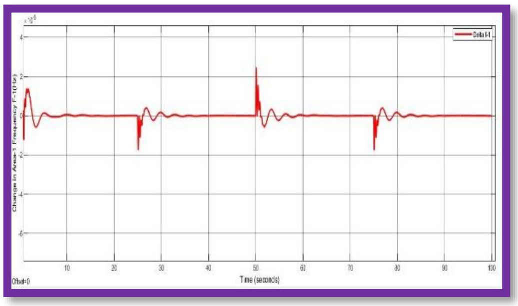

Figure 19: Δf1 with GA controller

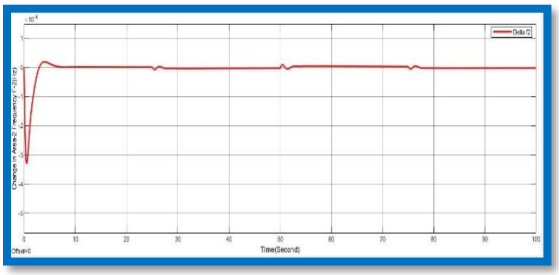

Figure 15: Δf2 with PSO controller

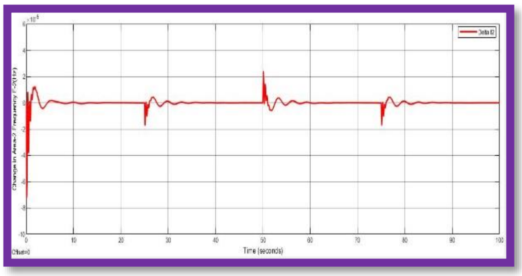

Figure 20: Δf2 with GA controller

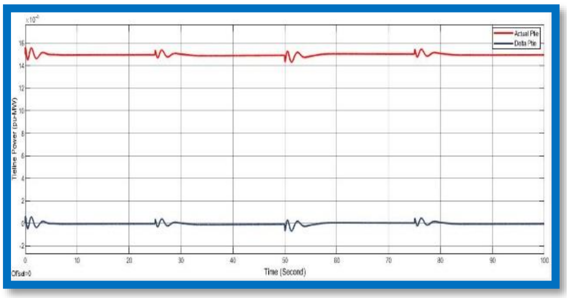

Figure 16: Actual tie-line power and change in tie-line power of Area-1 with PSO

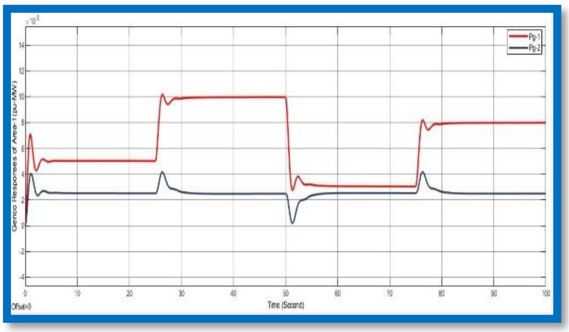

Figure 17: Genco responses of Area-1 with PSO

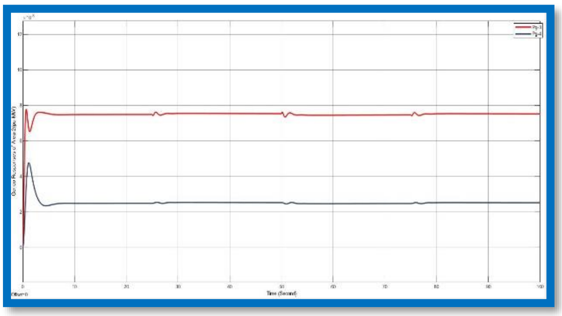

Figure 18: Genco responses of Area-2 with PSO

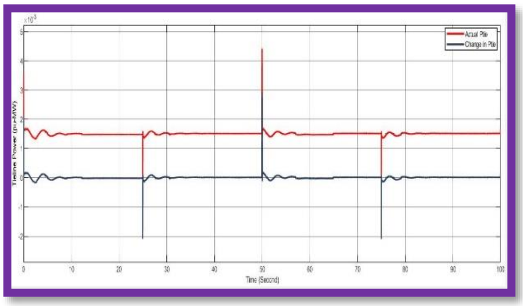

Figure 21: Actual tie-line power and change in tie-line power of Area-1 with GA

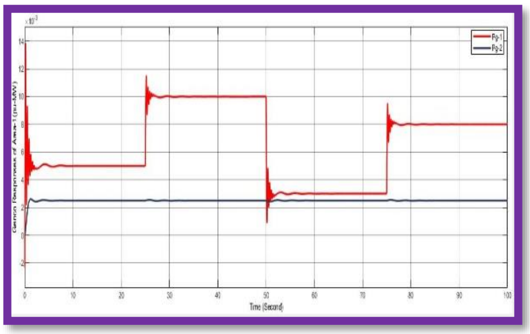

Figure 22: Genco responses of Area-1 with GA

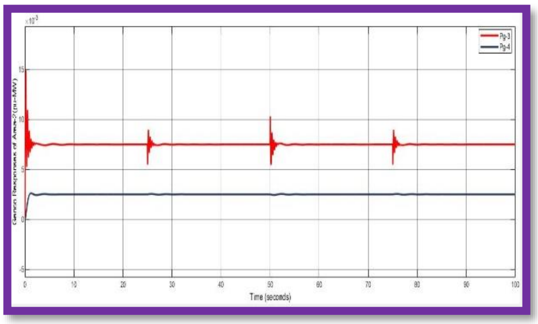

Figure 23: Genco responses of Area-2 with GA

Conclusion

For best operation of power system, frequency and the inter area tie line power has to stay almost constant or should be close to the scheduled values in interconnected deregulated power system. Frequency deviations have influence on a power system operation, system reliability and efficiency. Therefore, a proper control strategy is required. Soft computing techniques like genetic algorithm and particle swarm optimization techniques are used for optimization of the controller parameters. In order to apply the controller and check its responses, simulation model of a two-area interconnected power system in deregulated environment has been developed in MATLAB-Simulink. Comparative responses using various control strategies and various cases have been obtained and shown. Comparative analysis shows that PSO based controller provide the best response for two area deregulated power system as compared to other controllers used in this work. Random load variation has also been considered to check the reliability and robustness of the designed controller.

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