# Optimization of controllers using soft computing technique for load frequency control of multi-area deregulated power system

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**ABSTRACT**

Given the changing nature of power systems, it is challenging to optimize the controller for controlling load frequency problems. Distributed power generating sources and power system reorganization with multi-sources and multi-stakeholders make traditional load frequency control approaches unsuitable for current power systems. This research provides the comparative analysis of regulation of the load frequency in a multiple-area deregulated electricity system with the help of soft computing. In a reorganized electrical system, the major objectives of load frequency control (LFC) are to set up system frequency into acceptable limit, swiftly return the frequency to the setpoint, reduce tie-line power flow fluctuations across adjacent control zones, and track load demand agreements. To achieve LFC's goals, proportional integral derivative (PID) gain values must be tuned, for optimization purpose, soft computational methods are used in this present work. MATLAB/Simulink simulation results show that soft computing controllers can keep tie line power interchange within contracted constraints and frequency variation within the allowed range. This article compares auto tuned PID, genetic algorithm (GA), and particle swarm optimization (PSO) controllers in unregulated circumstances, load frequency regulation of two-area power systems.



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## 1. INTRODUCTION

The term "interconnected power system" refers to the tie line connection of many control zones. Interconnected network offers numerous advantages. But, whenever abrupt alteration of load occurs in any of the connected zone, tie-line power as well as frequency deviate from their predefined amount. In order to retain the frequencies and comparative power angles with respect to the particular values with acceptable boundaries for both dynamic and static circumstances, the generators inside a control region constantly change their speed in concert, either speeding up or slowing down. Whenever a load element is initially introduced, momentarily drawing on the system's kinetic energy, the necessary energy is obtained. Interconnected grids enable the distribution of power from various sources to meet varying demands. This load balancing helps stabilize the grid and ensures that power supply matches consumption, reducing the risk of blackouts due to sudden spikes in demand. There, should be some methods of control in the power system to restore the deviated tie-line power and frequency to desired values otherwise it may degrade the system performance and large changes may eventually result in system failure.

In the traditional electrical system, an individual firm known as a vertically integrated utility (VIU) owns the power generating, transmission, and distribution facilities. Consumers get power at a rate specified by VIU. Power system became more complex now a days due to introduction of distributed generation, restructuring of power system and uncertain environment. As the power system was restructured, many market participants, including generating companies (GENCOs), transmission companies (TRANSCOs), distribution companies (DISCOs), and independent system operators, assumed the role of VIU. In the deregulated electrical system, each control region is responsible for supplying its own requirement and planned interchange electricity. A shift in frequency can be detected when any imbalance between the power supply and the load occurs.

In a multiple-area competitive electrical system, the regulation of the load frequency often includes an appropriate control system that allows the zone frequency and tie-line power to be reset to their established values, whensoever a significant shift in load takes place in an interconnected power system. For the complete power system to operate economically, securely, and steadily, innovative and better control is necessary. The restructured power system's load frequency can be greatly aided by the application of new control techniques. Current advancements demonstrate the usage of soft computing techniques, which are highly adaptable to changing environments and also able to make quick judgements.

Many researchers are working in this area. Several investigations have been conducted for various load frequency control (LFC) issues in a liberalized power system to overcome these situations. Many of the researchers used proportional integral derivative (PID) controllers to solve load frequency control problem, because of its accuracy and high speed. The fine-tuning of the settings of a PID controller determines its effectiveness unswervingly. Therefore, many researchers used soft computing-based techniques like neural networks, fuzzy logic honey bee algorithm, firefly algorithm or other methods for tuning of parameters in order to significantly improve controller gains.

Donde *et al.* [1] discussed evaluation and optimizations in an automatic generation control (AGC) system post liberalization. The fundamental concept of autonomous generation regulation in a deregulated electricity market for a linked power system is also been discussed by Kothari *et al.* [2]. Tan *et al.* [3] has described decentralised load frequency regulation in restructured contexts. Jain *et al.* [4]–[6] discussed the use of PID controller is used to control for load frequency control of multi area conventional and restructured power network. Optimal firefly algorithm for LFC of electrical system in restructured scenario has been explained by Sekhar *et al.* [7]. Babahajiani *et al.* [8] described intelligent demand response for LFC. Sahoo [9] explained the use of neural network for line congestion study. Cohn [10] presented various tie-line bias control issues for multi area connected power systems. Fosha and Elgerd [11], [12] used optimal control theory for megawatt frequency control problem. Current operating problems associated with AGC have been described in [13]. Abedinia *et al.* [14] used fuzzy PID using honey-bee mating optimization (HBMO) for LFC. Abd-Elazim and Ali [15] constructed a load frequency controller for a two-zone system that consists of a photovoltaic (PV) grid and a thermal generator using the firefly algorithm. For power quality enhancements, Mishra *et al.* [16] used a particle swarm optimization-grey wolf optimization (PSO-GWO) optimised fractional order PID (FOPID) based hybrid shunt active power filter.

Suid and Ahmad [17] discussed how to tune a sigmoid PID controller for an autonomous voltage regulator using a nonlinear sine-cosine algorithm. PSO-PID controller was utilised by Dhanasekaran *et al.* [18] for the LFC of a standalone multi-source power system. Concordia and Kirchmayer [19] has discussed the frequency regulation and tie line power of electrical power systems. Sood [20] proposed optimal power flow based on evolutionary programming and its confirmation for deregulated electrical systems. Method of reduced order observer is used by Rakhshani and Sadeh [21] for AGC of two power zone system. Pathak *et al.* [22] given the realistic model of centralized AGC. Reinforced learning neural network controller has been used for LFC by Saikia *et al.* [23] and Pal *et al.* [24]. Shree and Kamaraj [25] suggested a hybrid neuro fuzzy technique for automatic generation control in a restructured electrical supply system. Bhateshvar and Mathur [26] employed a fuzzy logic-controlled SMES unit to stabilise frequency for a thermal-hydropower system in a restructured environment. Arya and Kumar [27] proposed fuzzy gain scheduling controller. Shankar *et al.* [28] have discussed impression of energy storing system on load frequency control. The detailed study of thyristor-controlled series compensator for load following in liberalized power system has been done by Deepak and Abraham [29]. Adaptive decentralized LFC of multi-zone power systems has been presented by Zribi *et al.* [30]. According to a memoizable and smoothed functional algo, Mok and Ahmad [31] explained how to tune a fractional order PID controller for an automatic voltage regulator (AVR) system to its best possible settings. Computational analysis of PID and PSO-PID optimization for MIMO process control system was covered by Shaikh *et al.* [32].

Genetic algorithm (GA) optimization technique and PSO technique are used to optimize the parameters of PID controller to solve LFC of two area interconnected deregulated electrical power system in this work with the objective to minimize the fitness function ITAE. Comparative analysis has also been made for different contractual conditions in deregulated power system which shows the superiority of the proposed PSO based controller over other controllers used in this work.

## 2. DEREGULATED POWER SYSTEM

A deregulated power system is one in which independent system operators (ISO), generating businesses (GENCOs), transmission companies (TRANSCOs), and distribution companies (DISCOs) take the place of vertically integrated utilities (VIUs). Though distribution companies (DISCOs) are permitted to enter into agreements with any of the GENCOs within their own or other parts of the deregulated electricity system, generation firms (GENCOs) are not required to engage in the AGC mission. As a result, there are numerous different contract scenario combinations that might be used by DISCOs and GENCOs. The two-area deregulated electricity system model is used to express different potential contracts using the distribution participation matrix (DPM) concept. DPM is a matrix having a row count that corresponds to the number of GENCOs in the system and a column count that corresponds to the number of DISCOs. Every element in the DPM, referred to as a contract participation factor (CPF), is a percentage of the total contracted load needs of a DISCO that a GENCO is meeting. As a result, the ijth entry cpfij represents the percentage of the total load power that DISCO j purchased from a GENCO i. Addition of all the elements of a column in a disco participation matrix is equal to one. Think about a two-region deregulated electricity system with two GENCOs and two DISCOs in each area. As illustrated in Figure 1, GENCO1, GENCO2, DISCO1, and DISCO2 are placed in Area I and GENCO3, GENCO4, DISCO3, and DISCO4 are placed in Area II.

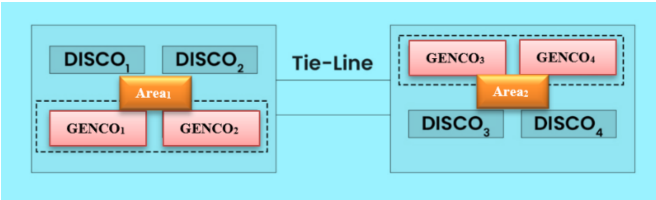


Figure 1. Power system with two areas in a newly organized setting

The associated DPM will be represented as (1).

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

A local load is reflected whenever a load needed by a DISCO shifts within the vicinity in which the DISCO corresponds. At the point of input to the power system block, this should be recorded in the deregulated AGC system block diagram as the local loads PL1 and PL2. Each area has a large number of GENCOs, thus the area control error (ACE) signal must be divided among them proportionately to their involvement in the AGC. ACE participation factors are coefficients that allocate ACE to numerous GENCOs. Noteworthy is the fact that:

$$\sum_{i=1}^{m} aji = 1 \tag{2}$$

where, participation factor of i-th GENCO in j-th area is represented as $a_{ji}$ and the number of GENCOs in j-th area is given by m. On the tie line, the estimated steady state power flow is indicated as in (3).

$$\Delta P_{tie1-2\ scheduled} = (Requested\ power\ of\ DISCOs\ in\ Second\ area\ through\ GENCOs\ in\ first\ area) - (Requested\ power\ of\ DISCOs\ in\ first\ area\ from\ GENCOs\ in\ second\ area) \tag{3}$$

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

The tie line power error $\Delta P_{tie1-2,error}$ is characterized at any specified instant as in (5).

$$\Delta P_{tie1-2,error} = \Delta P_{tie1-2,actual} - \Delta P_{tie1-2,scheduled} \tag{5}$$

As the real tie line power flow meets the designed power flow, the $\Delta P_{tie1-2,error}$disappears in the steady state. In the conventional case, this error value is used to create the corresponding ACE signals.

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

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

Where:

$$\Delta P_{tie2-1,error} = -(P_{r1}/P_{r2}) \, \Delta P_{tie1-2,error} \tag{8}$$

and $P_{r1}$, $P_{r2}$ are the rated powers of Areas I and II, respectively. Therefore:

$$ACE_2 = B_2 \, \Delta f_2 + \alpha_{12} \Delta P_{tie1-2,error} \tag{9}$$

where:

$$\alpha_{12} = -(P_{r1}/P_{r2}) \tag{10}$$

for a two-area system, the contractual power provided by i-th GENCO is stated as:

$$\Delta Pi = \sum_{j=1}^{n\ disco=4} CPFij \, \Delta PLj \tag{11}$$

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

Similarly, $\Delta P_2$, $\Delta P_3$, and $\Delta P_3$ can be calculated easily.

Figure 2 depicts the Simulink diagram for the bilaterally deregulated LFC in two area (with reheat turbine) system. It is structurally built on the notion of [1]. Demand signals are displayed on dashed lines. Areas I and II's local loads are identified by the symbols $\Delta P_{1LOC}$ and $\Delta P_{2LOC}$, respectively. $\Delta P_{uc1}$ and $\Delta P_{uc2}$ are uncontracted power. Also note that:

$$\Delta P_{1LOC} = \Delta P_{L1} + \Delta P_{L2} \tag{13}$$

$$\Delta P_{2LOC} = \Delta P_{L3} + \Delta P_{L4} \tag{14}$$

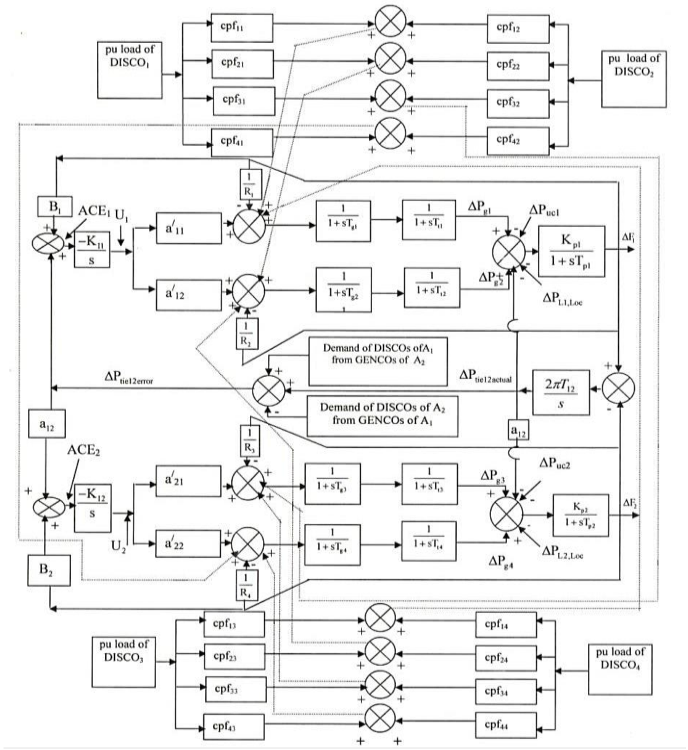


Figure 2. An illustration of a two-area restructured power system

## 3. PARAMETER TUNING OF PID CONTROLLER

PID controllers are most common and very effective controller. There are three separate parameters in PID controller and accordingly entitled as 3-element control: the proportional, the integral and derivative gains, denoted $K_P$, $K_I$, and $K_D$. The interpretation of these values in terms of error is that $K_P$ depends on the current error, $K_I$ on the cumulative of previous errors, and $K_D$ is a forecast of future errors based on the current rate of change. Through a control element, the process is modified using the weighted total of these three parameters. PID controller tuning is the process of determining the appropriate settings for $K_P$, $K_I$, and $K_D$. Although having only three parameters, PID tuning is a tough challenge.

In every system, fast response and good stability are the prime requirements. Unfortunately, faster the response, worse the stability, and better the stability, slower the response. So, for the proper control of the system, compromise has to be made between acceptable stability and fastness of response. By using preset tunings, PID controllers frequently offer enough control, but deliberate tuning can usually boost performance.

The PID controller's parameters can be adjusted using a variety of techniques. The majority of efficient techniques often entail the creation of some sort of process model, followed by the selection of KP, KI, and KD depending on the characteristics of the dynamic model. Manual tuning techniques may not be very effective, because it takes very long time. Z-N method and IMC methods are used by many researchers, are manual tuning methods. PID controller parameter adjustment can be done using soft computing techniques. For determining the correct values of $K_P$, $K_I$, and $K_D$, these techniques are highly useful.

### 3.1. Tuning by particle swarm optimization technique

Eberhart and Kennedy (1995) created the well-known stochastic optimization method known as particle swarm optimization (PSO). It takes its cues from social interactions between flocks of birds or schools of fish. It is used in this work to investigate the search space for a certain topic to find the optimal parameter values of controller required to satisfy the load frequency control objectives. The PSO commences with a collection of random particles (solutions), after which it updates the solutions to look for the best one. Every particle is represented by two vectors, position ‘xi’ and velocity ‘vi’.

Every particle's position at a specific moment is taken into account as a potential solution to the issue at hand. The particles move throughout the search region while varying their speed and position to always be in the ideal position. Each and every one of the particles contain fitness values that the fitness function evaluates in order to optimize, and they all have velocities that control how they fly. The particles follow the current optimal particles as they move through the problem space. The following vectors serve as representations for the position and speed of each ith particle in a practical d-dimensional solution space

$$\mathrm{x_i} = [\mathrm{x_{i1}},\ \mathrm{x_{i2}}, \ldots, \mathrm{x_{id}}] \tag{15}$$

$$\mathrm{v_i} = [\mathrm{v_{i1}},\ \mathrm{v_{i2}}, \ldots, \mathrm{v_{id}}] \tag{16}$$

There are two best value, first best outcome, or the fitness it has attained till the iteration, or $pbest$ (particular best), and the second best value that has been attained yet by any member of the population, or $gbest$ (global best)—are used to update each particle. $Pbest$ is the optimal location that produces the ith particle's best fitness value, and gbest is the optimal position over the entire swarm population. The following is a representation of the ith particle's best performances:

$$pbest_{\mathrm{i}} = \left[pbest_i^1, pbest_i^2, \ldots, pbest_i^d\right] \tag{17}$$

$$gbest_{\mathrm{i}} = \left[gbest_i^1, gbest_i^2, \ldots, gbest_i^d\right] \tag{18}$$

The (19), is used by the PSO algorithm to modify its velocity and location. The velocity updating equation is:

$$v_i^d(j+1) = w(j)v_i^d(j) + c_1 r_1\left[pbest_i^d(j) - x_i^d(j)\right] + c_2 r_2\left[gbest_i^d(j) - x_i^d\right] \tag{19}$$

the velocity of the 'i'th particle in the 'd'th dimension and during the jth iteration is represented by $v_i^d(j)$.

The (20) states that when the velocity for every particle has been determined, its position will be updated by adding the new velocity to its prior position. PSO flow chart is given in Figure 3.

$$v_i^d(j+1) = x_i^d(j) + v_i^d(j+1) \tag{20}$$

In order to investigate and emphasize the successful implementation of PSO to optimize the PID gains for LFC in a deregulated electricity system that runs under bilateral contractual conditions, performance index-based analysis is used. The performance index is given in (21) and performance index optimization curve is shown in Figure 4.

$$f(ITAE) = \int_0^T T|\Delta P_{tie-i} + B_i \Delta f_i|\, dT \quad (21)$$

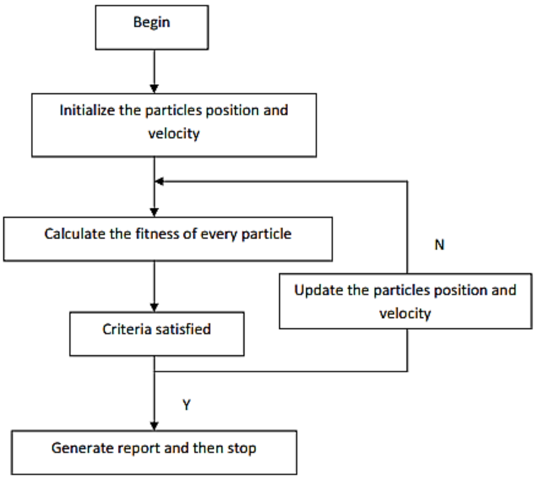


Figure 3. PSO flow chart

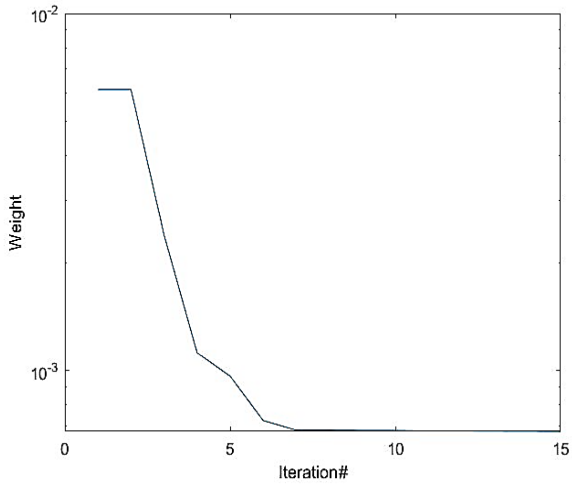


Figure 4. Optimization curve

There are only a few steps in the PSO algorithm, and they are continued unless a terminating requirement is fulfilled. The following are the steps:

- Step 1: the first step is to initialize the particles. Set the iteration number k to zero. Create n particles randomly, $X_i$, i = 1, 2,..., n, with $x_i = [x_{i1}, x_{i2},...,x_{id}]$ and starting velocities $V_i = [V_{i1}, V_{i2},...,V_{id}]$.
- Step 2: second step is to update the iteration counting as k=k+1.
- Step 3: use velocity (12) to update velocity of the particle as a next step.
- Step 4: in next step, use position (13) to update position of the particle.
- Step 5: now particle best can be updated:

$$If\ eval_i\ (x_i^k) > eval_i\ (pb_i^{k-1})\ then\ pb_i^k = x_i^k\ \ Else\ pb_i^k\ = pb_i^{k-1}$$

- Step 6: as a next step global best can be updated as:

$$eval\ (gb^k) = max\ (eval_i\ (pb_i^{k-1}))$$

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

- Step 7: last step is to reach decision to stop the algorithm: If the overall value of iterations reaches the highest number of iterations or the total reporting is 100%, halt; else, return to step 2.

These procedures result in the controllers' optimal values with the minimizing ITAE. Parameters are listed in the Table 1.

Table 1. Controller optimal tuned values by PSO algorithm

| Controller-I | | | Controller-II | | | Controller-III | | |
|---|---|---|---|---|---|---|---|---|
| $K_P$ | $K_I$ | $K_D$ | $K_P$ | $K_I$ | $K_D$ | $K_P$ | $K_I$ | $K_D$ |
| 0.3862 | 0.8755 | 0.3145 | 0.4989 | 0.8802 | 0.2414 | 0.0316 | 0.5102 | 0.1957 |

### 3.2. Tuning by genetic algorithm

GAs are a type of soft computing technique. GA is a commonly used optimization algorithm that evolves solutions to issues using ideas from natural genetics. Darwin's idea of evolution serves as a major inspiration for genetic algorithms. Several scientists and engineers have successfully used GA to solve a wide range of difficulties in their fields, including optimization, machine learning, automatic programming, transportation issues, and adaptive control.

One type of adaptive system that primarily aims to learn from, adopt from, and behave like biological or natural entities is the genetic algorithm. By using mathematical techniques to extract, construct, and explain a number of fundamental components, behaviors, and methods of biological processes and adaptation, GAs was presented as an alternative optimization strategy. The fundamental mechanism is described in flowchart shown in Figure 5.

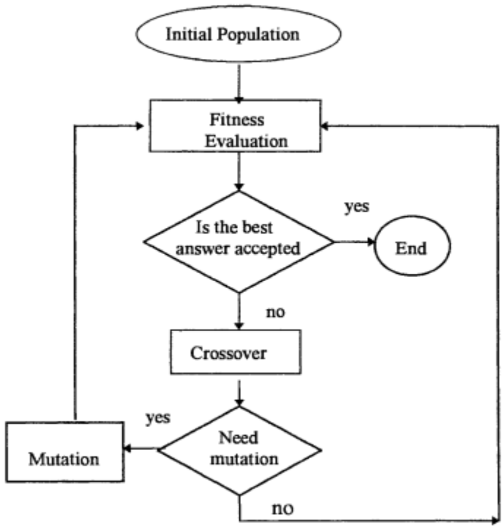


Figure 5. Flow chart of genetic algorithm

Tuning of the PID controller has been done using GA by minimizing the time multiplied absolute error. The various steps in finding the parameters of a PID controller are:
- Step 1: recognize the plant's transfer function or identify the system model.
- Step 2: initialize controller gains $K_P$, $K_I$, and $K_D$, and calculate ITAE.
- Step 3: obtain the values, particle finest value (pbest) and the global best value (gbest).
- Step 4: apply mutation to calculate new population.
- Step 5: obtain updated particle best (pbest1) and updated global best (gbest1) values.
- Step 6: compare previous and updated particle best values (pbest and pbest1).
- Step 7: compare previous and updated global best values (gbest and gbest1).
- Step 8: obtain the updated controller gains $K_P$, $K_I$, and $K_D$, and find out the response for the system.
- Step 9: if stopping criteria reached or maximum number of iterations reached: stop otherwise go to step 4.

Optimized parameters of the GA based controllers are obtained and given in Table 2, with the minimizing ITAE.

Table 2. Controller parameters tuned by GA algorithm

| Controller-I | | | Controller-II | | | Controller-III | | |
|---|---|---|---|---|---|---|---|---|
| $K_P$ | $K_I$ | $K_D$ | $K_P$ | $K_I$ | $K_D$ | $K_P$ | $K_I$ | $K_D$ |
| 9.6488 | 7.2247 | 1.5497 | 7.9835 | 5.1655 | 1.6694 | 8.9965 | 2.2321 | 9.081 |

## 4. SIMULATION AND RESULTS

### 4.1. Case-I

Case-I is the base case. Required load requirement across all DISCOs is 0.005 pu MW. Relative responses for frequencies of both the area and responses of GENCO 1 to 4 (all the GENCO in both areas) obtained using PID Controller, Figures 6 to 9 illustrate GA-based and PSO-based controller responses. Figures 6 and 7 give the comparison of time response of area frequency f-1 and f-2. Transient response due to sudden change die out in few seconds and change in frequencies of both the area settle to zero and frequencies of both the areas set back to desired or predefined values. Similarly, GENCO of bath the areas supply power as per the contractual conditions after the transient period.

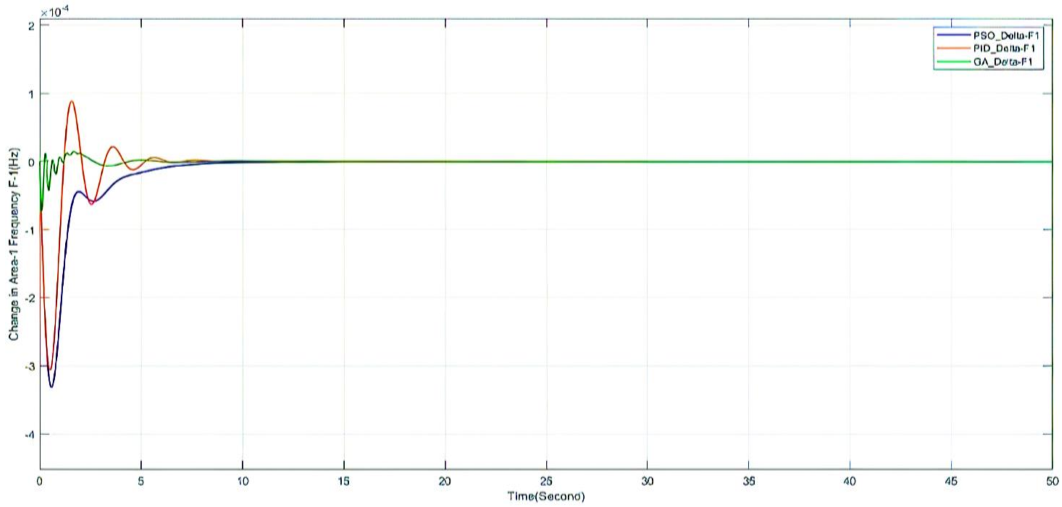


Figure 6. Area-1 frequency response (F-1)

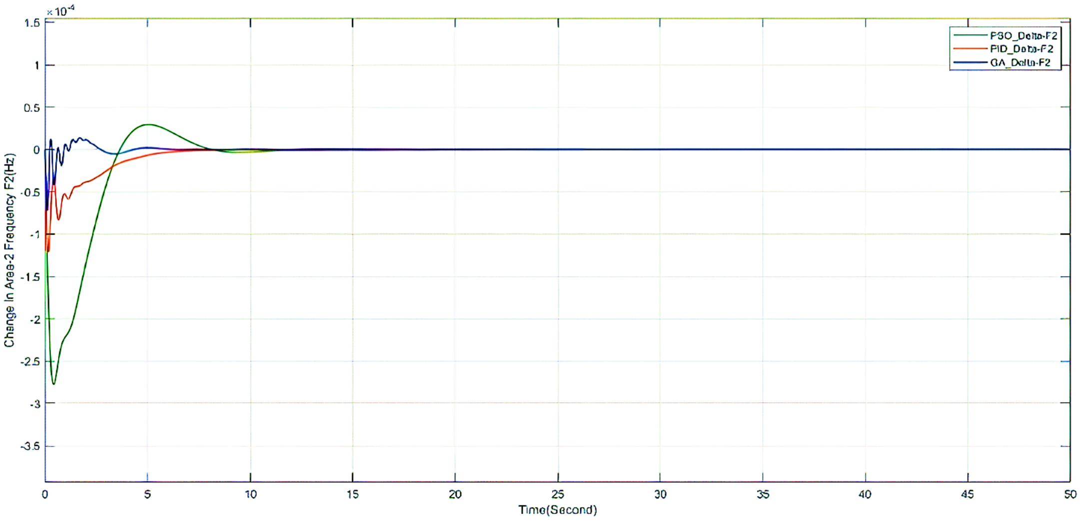


Figure 7. Area-2 frequency response (F-2)

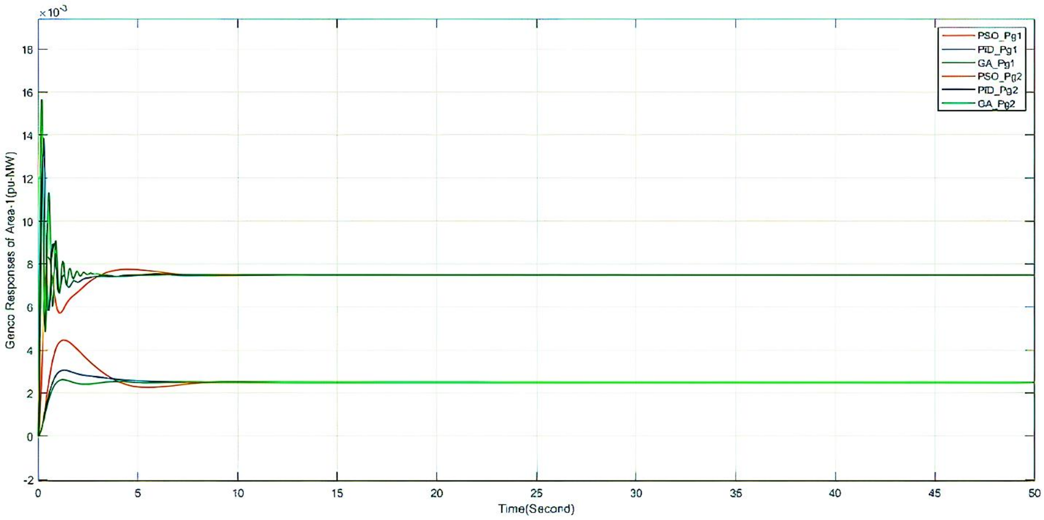


Figure 8. Outputs of GENCO of Area-1

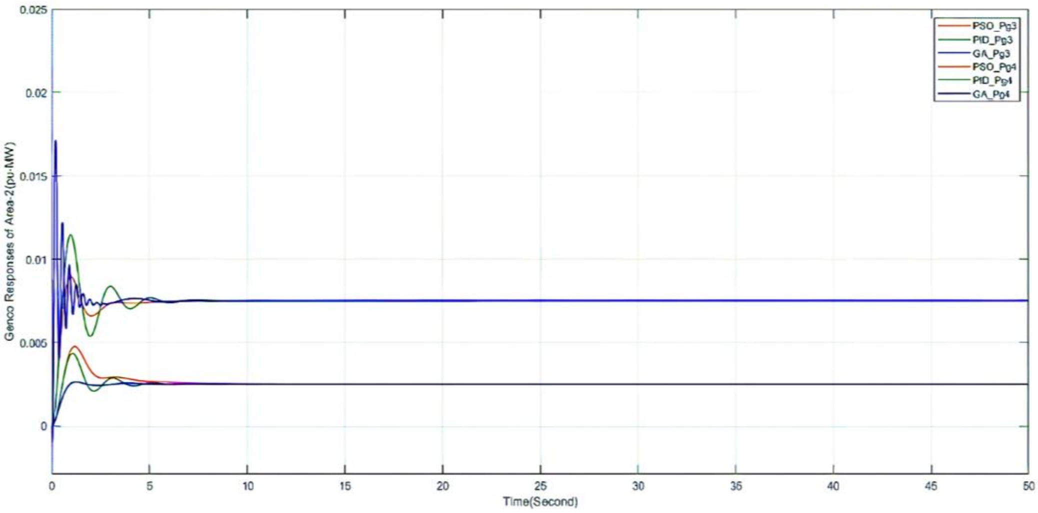


Figure 9. Outputs of GENCO of Area-2

### 4.2. Case-II

Case-II: at t=25 sec., Area-1 raises a new load requirement of 0.0025 pu-MW, but only GENCO-1 of Area-1 can meet it. This case is known as contract violation case. Relative responses for frequencies of both the area and responses of GENCO 1 to 4 (all the GENCO in both areas) obtained using PID controller, Figures 10 to 13 depict GA-based and PSO-based controllers responses. Figures 10 and 11 give the comparison of time response of area frequency f-1 and f-2. Transient response due to sudden change die out in few seconds due to controller action. And change in frequencies of both the area settle to zero and frequencies of both the areas set back to desired or predefined values. GENCO-1 of Area-1 supply additional power demanded by the disco of Area-1 after contract violation and all other GENCOs maintain supply as per the contractual conditions.

### 4.3. Case-III:

Case-III: at t=25 sec., Area-1 and Area-2 enhance their load demand by 0.0025 pu-MW, which is met only by the GENCOs in those two areas. GENCO-1 of Area-1 supply additional load demand od Area-1 and GENCO-3 of Area-2 supply the additional load demand of Area-2. Figures 14 to 17 compare the response characteristics of the system utilising a PID controller, a PSO and GA based controllers.

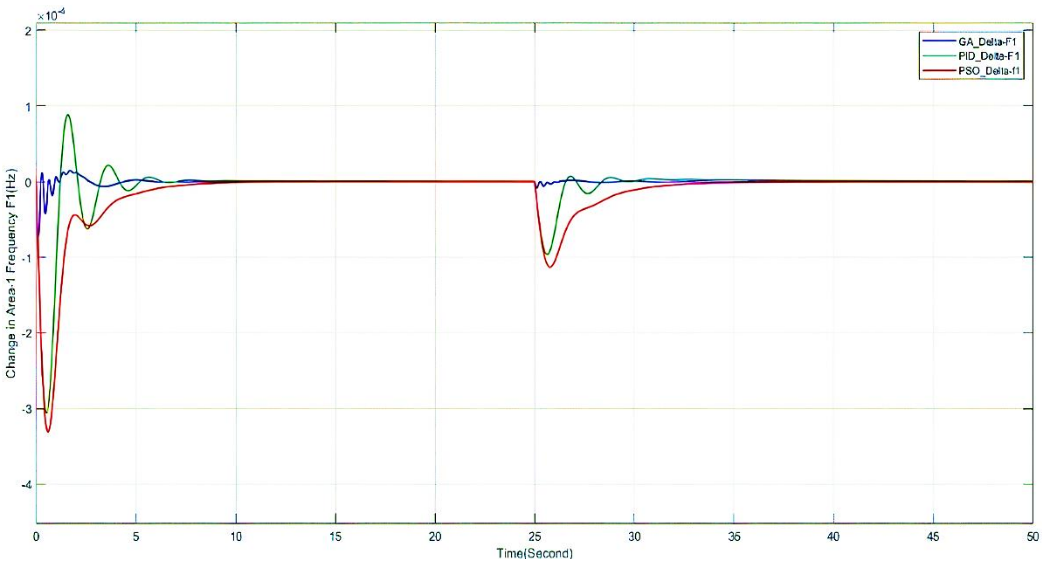


Figure 10. Comparative analysis of frequency F-1 of Area-1

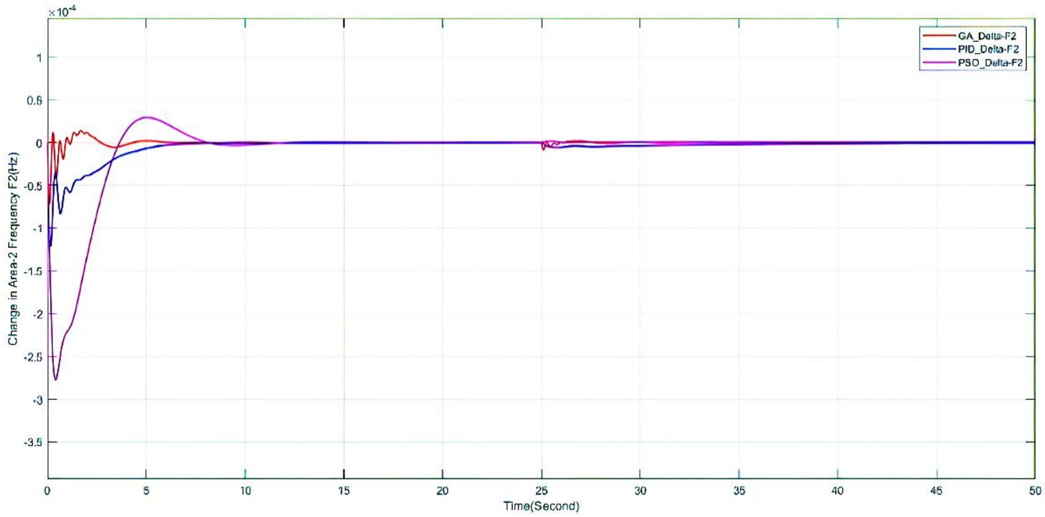


Figure 11. Comparative analysis of frequency F-2 of Area-2

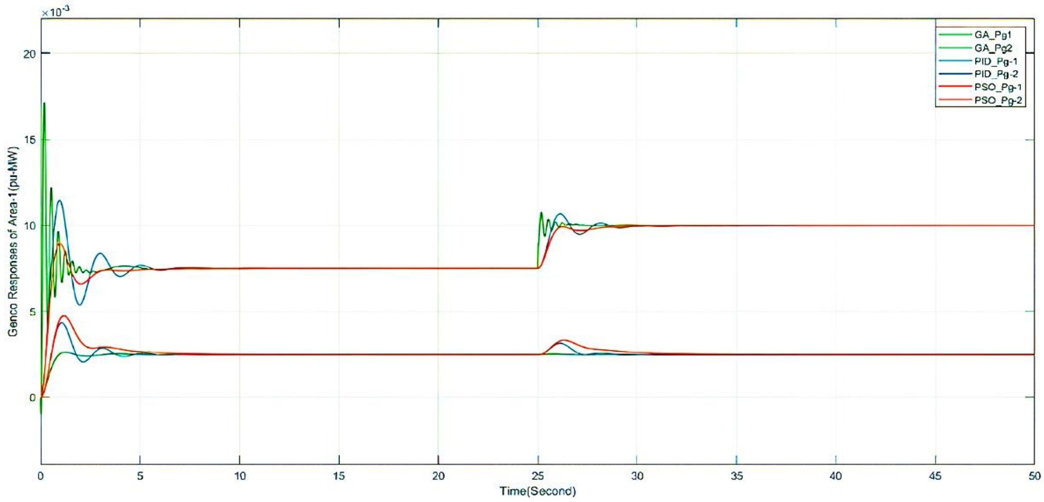


Figure 12. Outputs of GENCO of Area-1

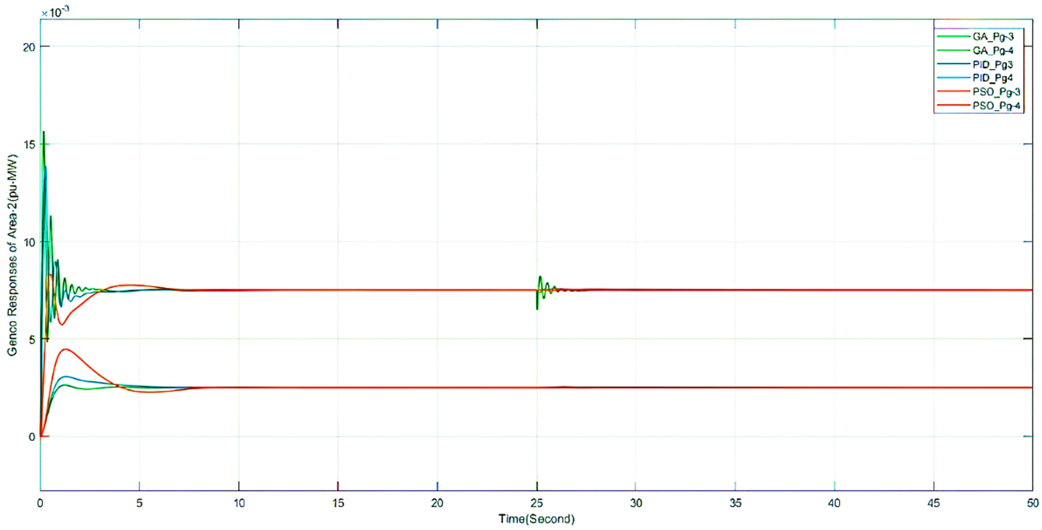


Figure 13. Outputs of GENCO of Area-2

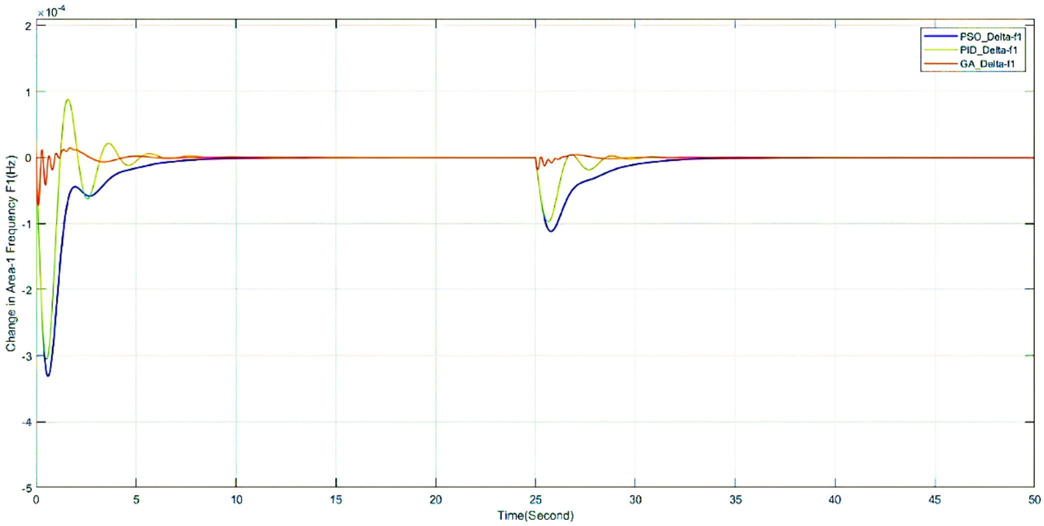


Figure 14. Comparative analysis of frequency F-1 of Area-1

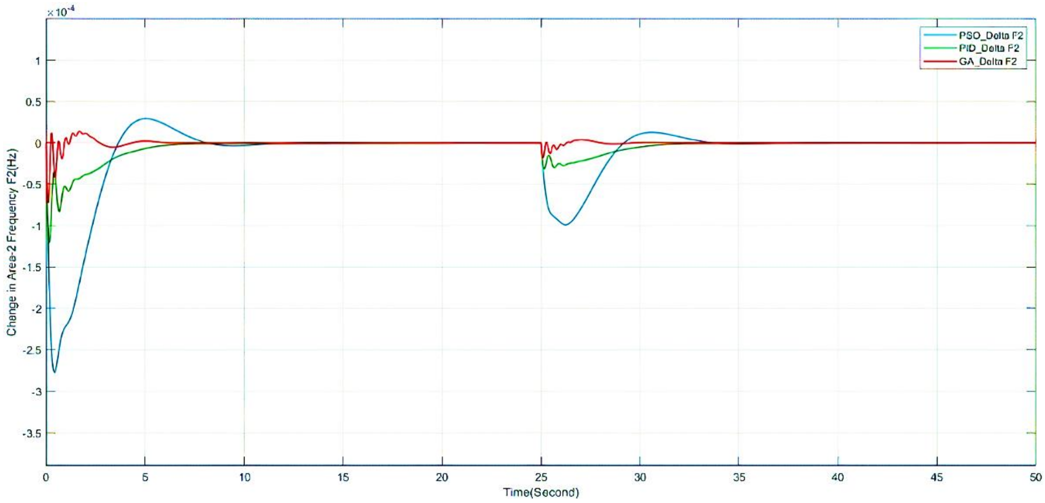


Figure 15. Comparative analysis of frequency F-2 of Area-2

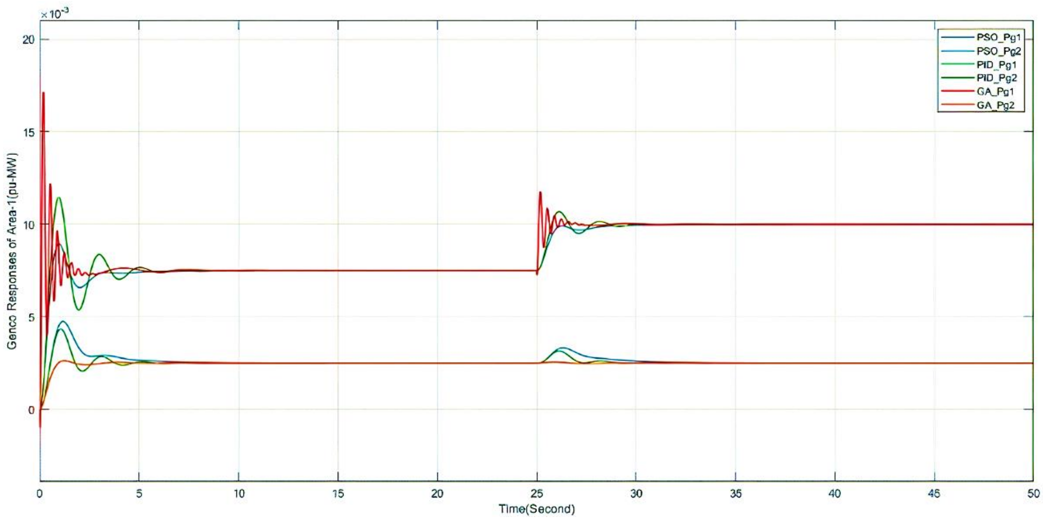


Figure 16. Outputs of GENCO of Area-1

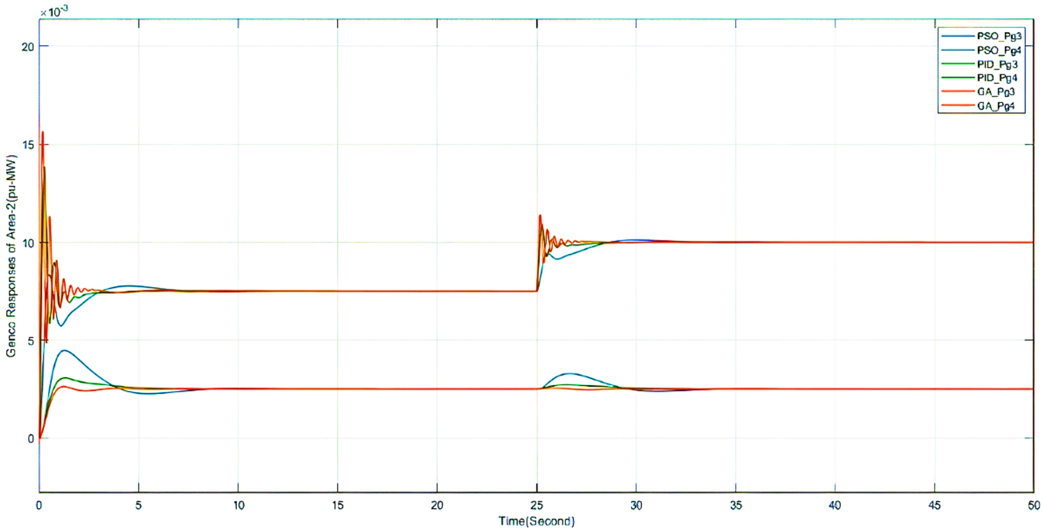


Figure 17. Outputs of GENCO of Area-2

### 4.4. Analysis in terms of time response parameters

Time-response parameters for change in frequency of Area-1, $\Delta f_1$ for Case-1, are given in Table 3. Time-response parameters of change in frequency of Area-2 for Case-1, are shown in Table 4. Time response specifications for Δf1 are represented in Table 5 and Δf2 are in Table 6 for Case-II. Time response specifications for Δf1 and Δf2 for Case-III, are listed in Tables 7 and 8 respectively.

Table 3. Comparison in terms of time-response parameters for frequency change of Area-1 for Case-1

| S. No. | Controller | MP | TP (Seconds) | TR (Seconds) | TS (Seconds) | Remark |
|---|---|---|---|---|---|---|
| 1 | GA | -0.71×10-4 | 0.27 s | 0.22 s | 7.82 s | Stable |
| 2 | PID | -3.05×10-4 | 1.58 s | 1.17 s | 8.44 s | Stable |
| 3 | PSO | -2.51×10-4 | 1.86 s | 1.57 s | 6.68 s | Stable |

Table 4. Comparison in terms of time-response parameters for frequency change of Area-2 for Case-1

| S. No. | Controller | MP | TP (Seconds) | TR (Seconds) | TS (Seconds) | Remark |
|---|---|---|---|---|---|---|
| 1 | GA | -0.73×10-4 | 0.28 s | 0.23 s | 6.95 s | Stable |
| 2 | PID | -1.15×10-4 | 0.12 s | 10.26 s | 11.59 s | Stable |
| 3 | PSO | -4.5×10-4 | 1.95 s | 1.58 s | 8.49 s | Stable |

Table 5. Comparison in terms of time-response parameters for frequency change of Area-1 for Case-II

| S. No. | Controller | MP | TP (Seconds) | TR (Seconds) | TS (Seconds) | Remark |
|---|---|---|---|---|---|---|
| 1 | GA | -0.51*10-4 | 0.28 s | 0.24 s | 7.71 s | Stable |
| 2 | PID | -3.1*10-4 | 1.57 s | 1.19 s | 14.05 s | Stable |
| 3 | PSO | -2.5*10-4 | 0.45 s | 6.55 s | 7.41 s | Stable |

Table 6. Comparison in terms of time-response parameters for frequency change of Area-2 for Case-II

| S. No. | Controller | MP | TP (Seconds) | TR (Seconds) | TS (Seconds) | Remark |
|---|---|---|---|---|---|---|
| 1 | GA | -0.73*10-4 | 0.28 s | 0.24 s | 6.2 s | Stable |
| 2 | PID | -1.2*10-4 | 0.16 s | 10.0 s | 11.10 s | Stable |
| 3 | PSO | -4.46*10-4 | 1.95 s | 1.56 s | 6.26 s | Stable |

Table 7. Comparison in terms of time-response parameters for frequency change of Area-1 for Case-III

| S. No. | Controller | MP | TP (Seconds) | TR (Seconds) | TS (Seconds) | Remark |
|---|---|---|---|---|---|---|
| 1 | GA | -0.72*10-4 | 0.27 s | 0.22 s | 6.83 s | Stable |
| 2 | PID | -3.05*10-4 | 1.19 s | 1.58 s | 8.58 s | Stable |
| 3 | PSO | -2.52*10-4 | 0.44 s | 6.61 s | 6.67 s | Stable |

Table 8. Comparison in terms of time-response parameters for frequency change of Area-2 for Case-III

| S. No. | Controller | MP | TP (Seconds) | TR (Seconds) | TS (Seconds) | Remark |
|---|---|---|---|---|---|---|
| 1 | GA | -0.72*10-4 | 0.28 s | 0.24 s | 6.84 s | Stable |
| 2 | PID | -1.2*10-4 | 0.16 s | 8.08 s | 8.08 s | Stable |
| 3 | PSO | -4.46*10-4 | 1.90 s | 1.58 s | 6.68 s | Stable |

## 5. CONCLUSION

The most important objective of the LFC to maintain connected area tie-line power and network frequency as near to a planned values as possible. So, appropriate control strategy is required in the interconnected deregulated power system. In a deregulated context, a system model of a two-area interconnected electrical network for simulation has been created. in order to apply the controllers and find their responses. The soft computing technique-based controllers like GA based controller and PSO based controller have been developed with minimizing ITAE. Comparative responses with PID, GA and PSO based controllers have been obtained with different contractual conditions and shown in figures. The comparative analysis with respect to time response specifications has also been done. It has been observed that the usage of a PID controller can enhance the system's ability to perform if parameter optimization is done properly. Comparative analysis shows that soft computing techniques are capable of providing the proper tuning of controller and can optimize the controller gains for load frequency control issues of liberalized power system. Also, the PSO based controller delivers the finest response for two area restructured electricity network as compared to other controllers used in this work.

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