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Comparative Analysis of Load Frequency Control Problem of Multi Area Deregulated Power System Using Soft Computing Techniques.

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Abstract

It is very challenging to obtain theoptimumload frequency control (LFC) of entirepower system with the emerging trend of power systems. Traditional centralized LFCmethods are not adaptive to modern power systems because of the development of distributed sources& restructured power system with multi-stakeholders. This paper presents a load frequency control (LFC) of multi-areapower system in deregulated environment using soft computing techniques.The main objective of LFC in deregulated system is to establish frequency regulation services i.e., restore 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. In order to achieve the objectives of LFC, gains of PID controller need to be optimized.Soft computing techniques are used for optimization purpose.The system has been simulated under MATLAB/Simulink 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.A comparative analysis of load frequency control using Integral controller, auto tuned PID controller, GA based controller, PSO based controller and ANFIS controlleris presented in this paper.

Keywords: LFC, restructured, deregulated, Tie-line ,GA, PID, PSO, ANFIS.

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 [1,4]. 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 a conventional power system, the power generation, transmission, distributions are owned by a single entity called vertically integrated utility (VIU). VIU supplies power to their consumers at a specified rate. After restructuring, the role of VIU is carried out by different market players like generating companies (GENCOs), transmission companies (TRANSCOs), distribution companies (DISCOs) and independent system operators (ISO).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 (AGC).

As there are several GENCOs and DISCOs in the deregulated structure, a DISCO has the freedom to have a contract with any GENCO for transaction of the power. A DISCO may have a contract with a GENCO in another control area. Such transactions are called “bilateral transactions.” All the transactions taken care by an impartial entity called an Independent System Operator (ISO). The ISO has to control a number of so called “ancillary services,” one of which is AGC. One of the most profitable ancillary services is the load frequency control. The generation and load demand are controlled by market players by keeping the entire power system stable under very competitive and distributed control environment. However, the critical function of LFC is still an unending task in the deregulated power system. The instability may spread to other control areas and may lead to a severe effect such as system black out due to absence of proper controller in interconnected power system in deregulated environment.

A lot of studies have been conducted about various LFC issues in a deregulated power system to overcome these situations. To solve LFC, many of the researchers used PID controllers because of its accuracy and high speed. The performance of PID controller directly depends on its parameters tuning [5]. 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 optimize the gain of controllers. In this paper Genetic Algorithm optimization technique is used to tune the parameters of PID controller to solve LFC of two area interconnected power system in deregulated environment. The superiority of the proposed approach is shown by comparing the results with Integral Controller in deregulated power system.

DESIGN OF LFC OF INTERCONNECTED POWER SYSTEM IN DEREGULATED ENVIRONMENT

In a deregulated power market contracts are signed between companies based on rules and relationshipsin 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.

In the deregulated power system, generation companies (GENCOs) may or may not participate in the AGC task whereas, distribution companies (DISCOs) have the freedom to contract with any of the GENCOs in their own or other areas. Thus, there can be various combinations of the possible contracted scenarios between DISCOs and GENCOs. The concept of distribution participation matrix (DPM) is used here to express possible contracts in the two-area deregulated model. DPM is a matrix with the number of rows equal to the number of GENCOs and the number of columns equal to the number of DISCOs in the system. Each entry in the DPM, known as a contract participation factor (cpf), represents the fraction of a DISCO total contracted load demands being met by a GENCO [1]. Thus, the ijth entry cpfijcorresponds to the fraction of the total load power contracted by DISCO j from a GENCO i. The sum of all the entries in a column in this matrix is unity.

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 figure 1.

The corresponding DPM will become

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

……….(1)

where the block diagonals of DPM correspond tolocaldemands and the off diagonal blocks correspond to the demands of the DISCOs in one area to the GENCOs in another area.

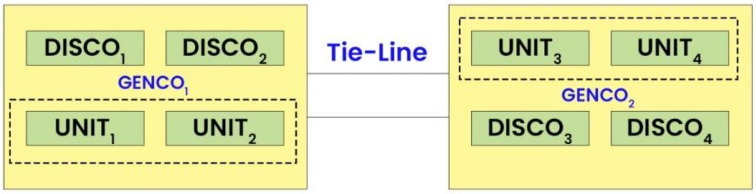


Figure 1: Schematic of a two-area system in restructured environment.

Whenever a load demanded by a DISCOchanges, 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). Note that $\sum_{i=1}^{m} aji = 1$

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

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

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

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

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

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

$ACE_1 = B_1\ \Delta f_1 + \Delta P_{\text{tie1-2,error}}$ ..…..…(4)

$ACE_2 = B_2\ \Delta f_2 + \Delta P_{\text{tie2-1,error}}$……….(5)

Where, $\Delta P_{\text{tie2-1,error}} = -\ (P_{r1} / P_{r2})\ \Delta P_{\text{tie1-2,error}}$ ……....(6)

And P_{r1}, P_{r2} are the rated powers of areas I and II, respectively.

Therefore

$ACE_2 = B_2\ \Delta f_2 + \alpha_{12}\Delta P_{\text{tie1-2,error}}$……….(7)

Where,$\alpha_{12} = -\ (P_{r1} / P_{r2})$ ...…..…(8)

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

$\Delta Pi = \sum_{j=1}^{n\ disco=4} CPFij\ \Delta PLj$……….(9)

For i=1, $\Delta P_1 = CPF_{11}\ \Delta P_{L1} + CPF_{12}\ \Delta P_{L2} + CPF_{13}\ \Delta P_{L3} + CPF_{14}\ \Delta P_{L4}$..……(10)

Similarly, ΔP_2, ΔP_3 and ΔP_3 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 [1], [3]. Dashed lines show the demand signals. The local loads in areas I and II are denoted by ΔP_{1LOC} and ΔP_{2LOC}, respectively. ΔP_{uc1} and ΔP_{uc2} are uncontracted power (if any).

Also note that

$\Delta P_{1LOC} = \Delta P_{L1} + \Delta P_{L2}$……..(11)

$\Delta P_{2LOC} = \Delta P_{L3} + \Delta P_{L4}$……...(12)

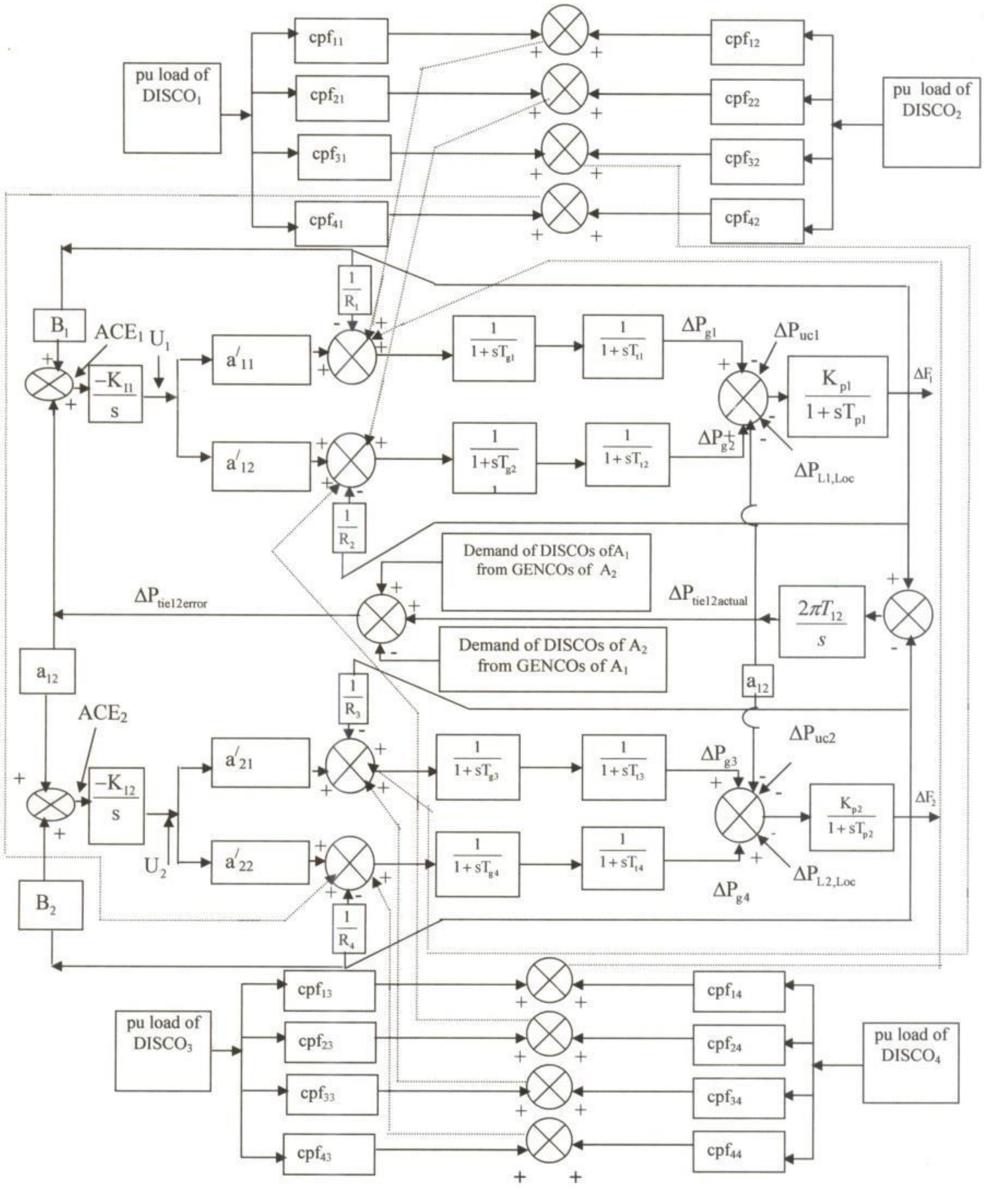


Figure 2: Block diagram of Two-Area power system in deregulated environment

I. PID CONTROLLER

The PID control scheme 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 is given in equation (13).

$$U(t) = MV(t) = K_P\ e(t) + K_i \int_0^t e(t)\ dt + K_d \frac{d}{dt} e(t) \quad \ldots\ldots\ldots(13)$$

A. Proportional Term

The proportional term produces an output value that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant Kp, called the proportional gain constant. The proportional term is given in equation (14).

Output = Pout = K_P e(t) ……...(14)

B. Integral Term

The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error. The integral in a PID controller is the sum of the instantaneous error over time and gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain Ki and added to the controller output. The integral term is given by equation (15).

$I_{out} = Ki \int_0^t e(t)\, dt$ ……..... (15)

The integral term accelerates the movement of the process towards set point and eliminates the residual steady-state error that occurs with a pure proportional controller. However, since the integral term responds to accumulated errors from the past, it can cause the present value to overshoot the set point value.

C. Derivative Term

The derivative of the process error is calculated by determining the slope of the error over the time and multiplying this rate of change by the derivative gain Kd. The magnitude of the contribution of the derivative term to the overall control action is termed the derivative gain, Kd. The derivative term is given by equation (16).

$D_{out} = K_d \frac{d}{dt} e(t)$……... (16)

Derivative action predicts system behaviour and thus improves settling time and stability of the system. An ideal derivative is not causal, so that implementations of PID controllers include an additional low pass filtering for the derivative term to limit the high frequency gain and noise. Derivative action is seldom used in practice because of its variable impact on system stability in real-world applications.

In the early history of automatic process control the PID controller was implemented as a mechanical device. These mechanical controllers used a lever, spring and a mass were often energized by compressed air. These pneumatic controllers were the industry standard at that time.

After development of mechanical controller researchers were working on the new controllers. As a result of their research, they have developed theelectronic analog controller. Electronic analogcontrollers can be made from a solid-state or tube amplifier or from a capacitor and a resistor. Electronic analog PID control loops were often found within more complex electronic systems, for example, the head positioning of a disk drive, the powerconditioning of a power supply or even the movementdetection circuit of a modern seismometer. Nowadays, electronic controllers have largely been replaced by digital controllers.

It is necessary to adjust the parameters of PID controller to obtain the desired response. This is called tunning of PID controller.

TUNING OF PID CONTROLLER

Tuning a control loop is the adjustment of its control parameters (proportional gain, integral gain and derivative gain) to the optimum values for the desired control response. Stability (no unbounded oscillation) is a basic requirement, but beyond that, different systems have different behaviour, different applications have different requirements and requirements may conflict with each other. [4,5]

PID tuning is a difficult problem even though there are only three parameters and its principle is simple to describe, because it must satisfy complex criteria within the limitations of PID control.

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 acceptable control using default tunings, but performance can generally be improved by careful tuning and performance may be unacceptable with poor tuning. Usually, initial designs need to be adjusted repeatedly through computer simulations until the closedloop system performs as desired.

There are accordingly various methods for tuning. Z-N method and IMC methods are used by [4,5]. Recent development shows the use of soft computing techniques in PID controller parameter tuning. These methods are very effective methods for finding proper values of K_P K_I and K_D. That is why, here genetic algorithm has been used for tuning.

GENETIC ALGORITHM

Genetic Algorithms (GAs) is a soft computing approach. GAs are general-purpose search algorithms, which use principles inspired by natural genetics to evolve solutions to problems [48]. As one can guess, genetic algorithms are inspired by Darwin's theory about evolution. They have been successfully applied to a large number of scientific and engineering problems, such as optimization, machine learning, automatic programming, transportation problems, adaptive control etc.

Genetic algorithms (GAs) are one of adaptive systems that basically aim at learning, adopting and functioning biological or natural beings. In order to find an alternative optimization method, GAs was proposed by utilizing mathematical tools to extract, generate and describe several key factors, behaviors, and mechanisms of biological processes and adaptation.The fundamental mechanism is described in the flowchart shown in figure 3.

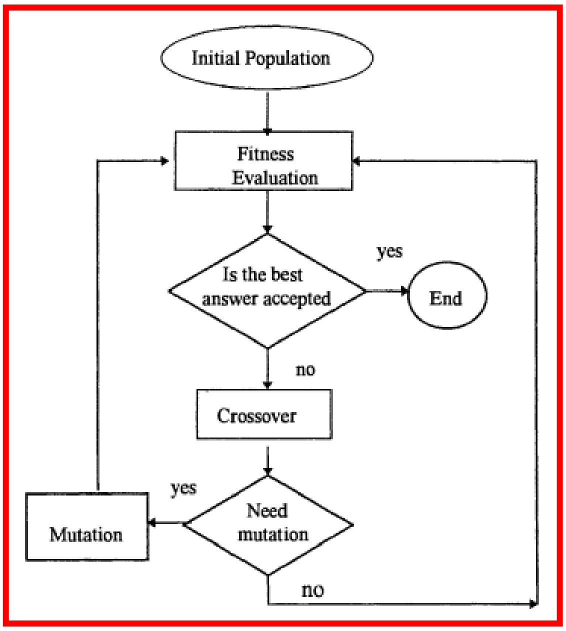


Figure 3: Flow chart of genetic algorithm

Tuning of the PID controller has been done using GA by minimizing the time multiplied absolute error (ITAE). The various steps in finding the parameters of a PID controller are:

Step 1: Define the Plant transfer function.

Step 2: Initialize K_P, K_I& K_D, and calculate ITAE.

Step 3: Obtain pbest and gbest values.

Step 4: Calculate new population using mutation.

Step 5: Obtain pbest1 and gbest1.

Step 6: Compare pbest and pbest1.

Step 7: Compare gbest and gbest1.

Step 8: Obtain the new values of K_P, K_I& K_D, and find out the response for the system.

PARTICLE SWARM OPTIMIZATION TECHNIQUE BASED CONTROLLER

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

$$x_i = [x_{i1}, x_{i2},...,x_{id}] \quad ....(17)$$

$$v_i = [v_{i1}, v_{i2},...,v_{id}] \quad ......(18)$$

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:

$$pbest_i=[pbest^1_i, pbest^2_i,...,pbest^d_i] \quad ....(19)$$

$$gbest_i=[gbest^1_i, gbest^2_i,...,gbest^d_i] \quad ....(20)$$

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

$$v_i^d(j+1) = w(j)v_i^d(j) + c_1 r_1\left[pbest_i^d(j) - x_i^d(j)\right] + c_2 r_2\left[gbest_i^d(j) - x_i^d(j)\right] \quad ....(21)$$

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:

$$x^d_i (j + 1) = x^d_i (j) + v^d_i (j + 1) \quad ....(22)$$

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 (Kennedy & Eberhart 1995). 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 as given below.

$$K_{Pmin} < K_P < K_{Pmax}; K_{Imin} < K_I < K_{Imax}; \text{ and } K_{Dmin} < K_D < K_{Dmax}$$

PSO flow chart is shown in figure 4.

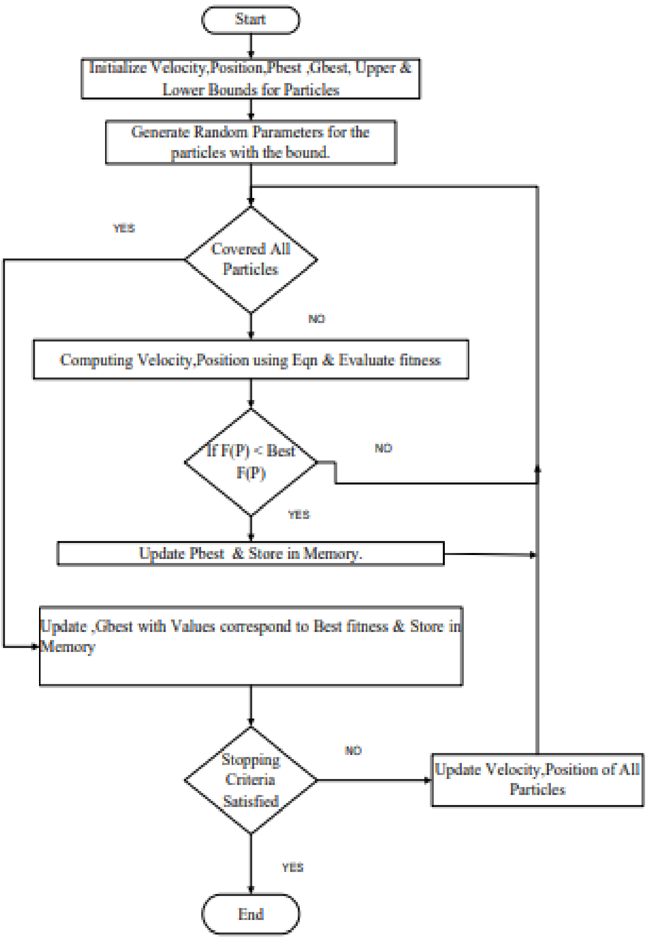


Figure 4: PSO flow chart

The PSO algorithm consists of just few steps, which are repeated until some stopping condition is met. The steps are as follow:

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 using Eq. (21).

Step 4: Update position using Eq. (22).

Step 5: Update particle best:

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

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

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

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 this, optimized parameters of the controllers are obtained.

ANFIS BASED CONTROLLER

ANFIS is basically the combination of neural network and fuzzy logic system. Many inputs are applied to the neural network depending upon the inputs the neural network has some standard output, so depending upon the input and the output the neural network is trained, after training the neural network the output is applied to the fuzzy logic which generates the IF THEN rules and membership functions, This has been done in MATLAB. The block diagram of ANFIS controller is shown in figure 5.

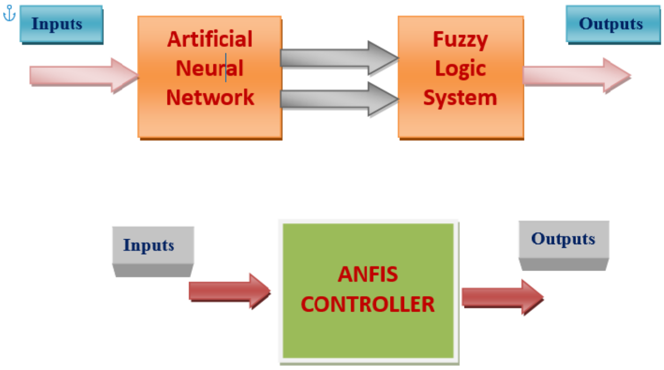
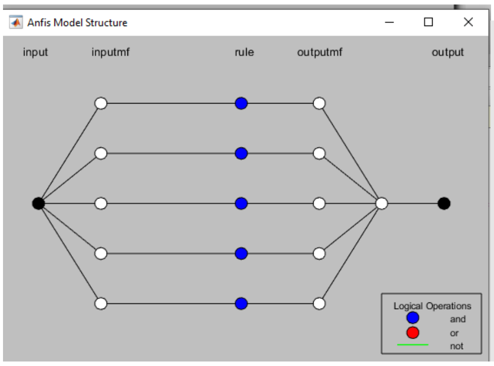


Figure 5: Block diagram of ANFIS

Basic ANFIS structure is shown in figure 6 and the rule base for ANFIS controller is shown in figure 7.



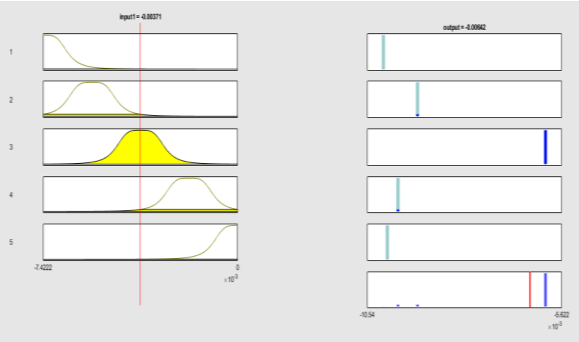


Figure 6: Basic ANFIS StructureFigure 7: Rule base for ANFIS controller

SIMULATION & RESULTS

8.1 Case-I: It is the base case. All the DISCOs have a total load demand of 0.005 pu MW. Comparative responses using Integral Controller, PID Controller, GA based controller, PSO based controller and ANFIS controller are shown in figures from 8 to 12.

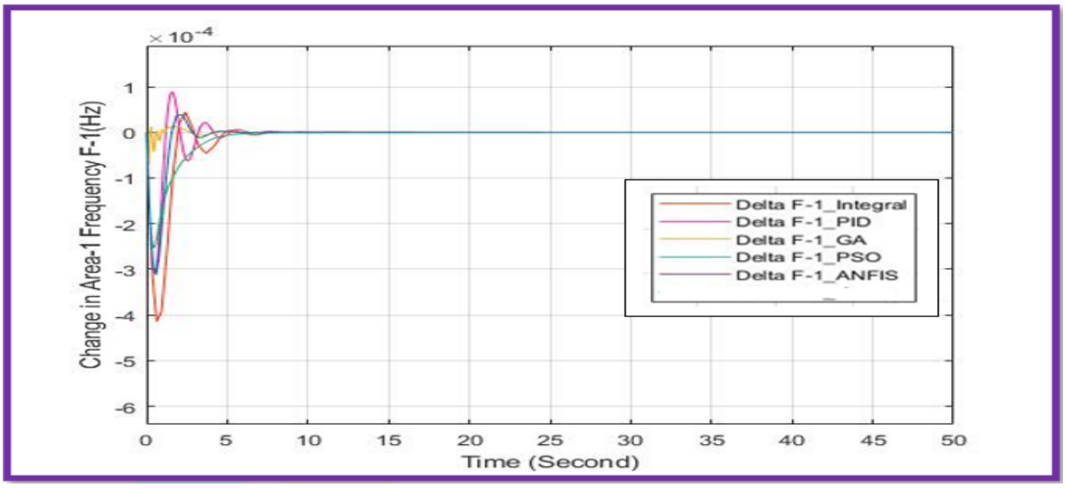


Figure 8: Δf₁ with different control strategies(case-1)

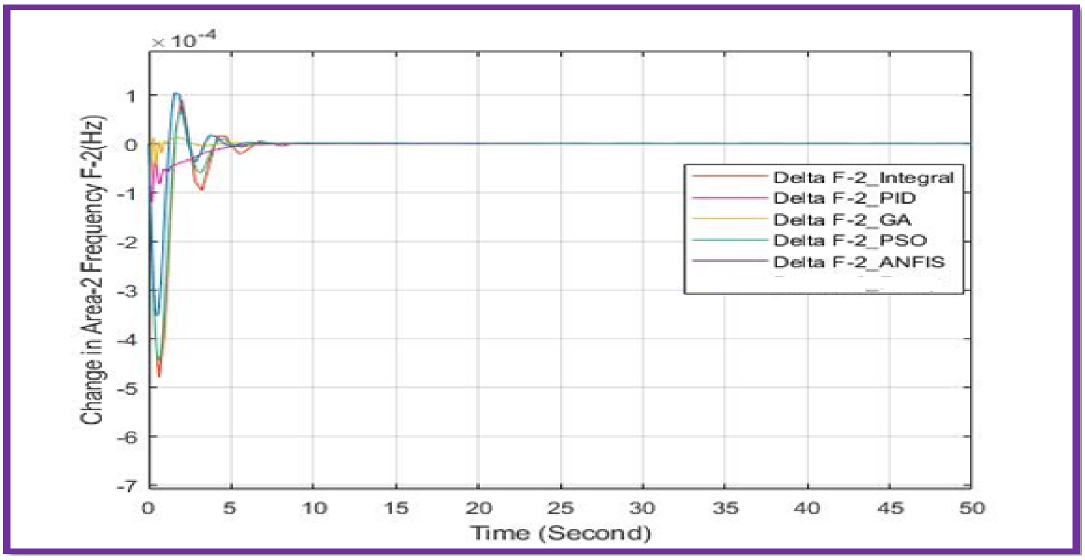


Figure 9: Δf2 with different control strategies (case-1)

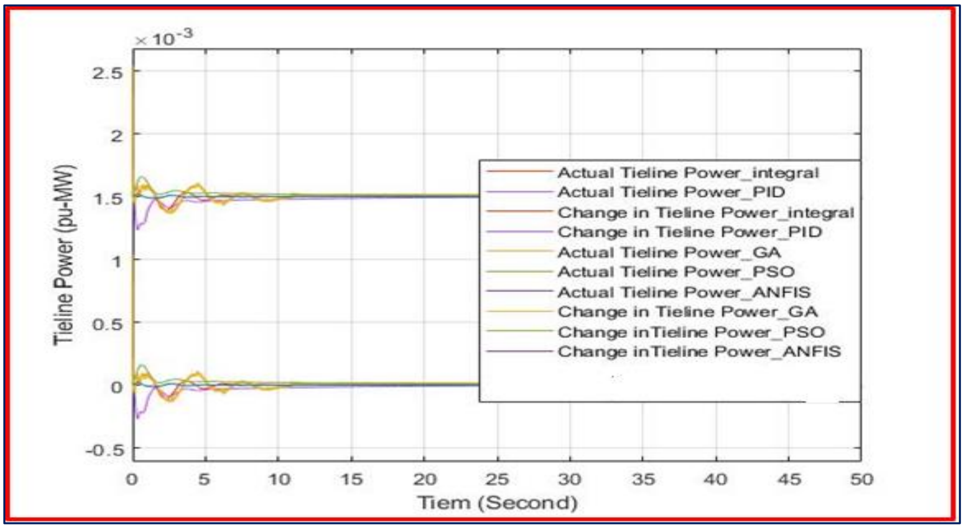


Figure 10: Change in Actual Ptie and ΔPtie error with different control strategies (case-1)

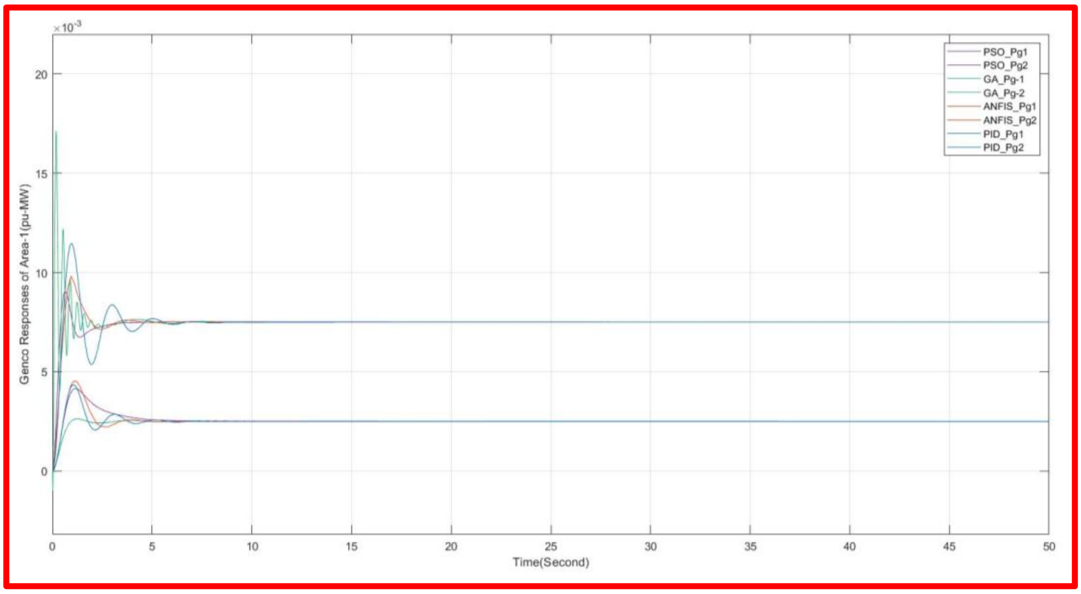


Figure 11: Genco Responses of area-1 with PSO, GA, ANFIS and PID controllers (case-I)

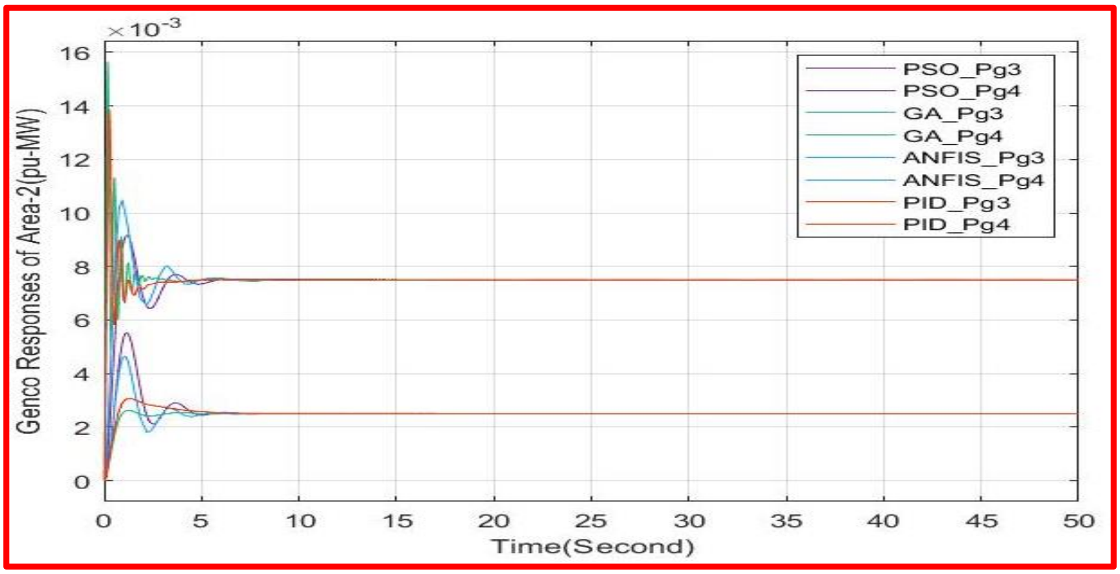


Figure 12: Genco Responses of area-2 with PSO, GA, ANFIS and PID controllers (case-I)

8.2 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. Comparative responses using Integral Controller, PID Controller, GA based controller, PSO based controller and ANFIS controller are shown in figures from 13 to 17.

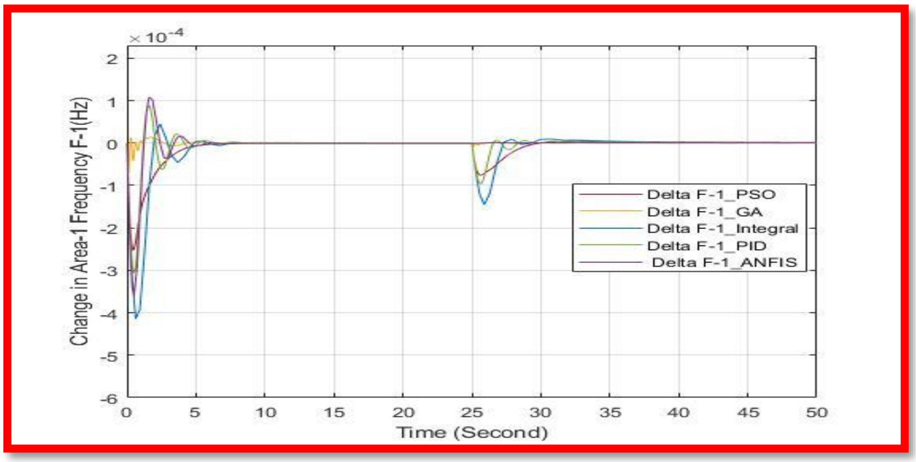


Figure 13: Δf1 with different control strategies (case-II)

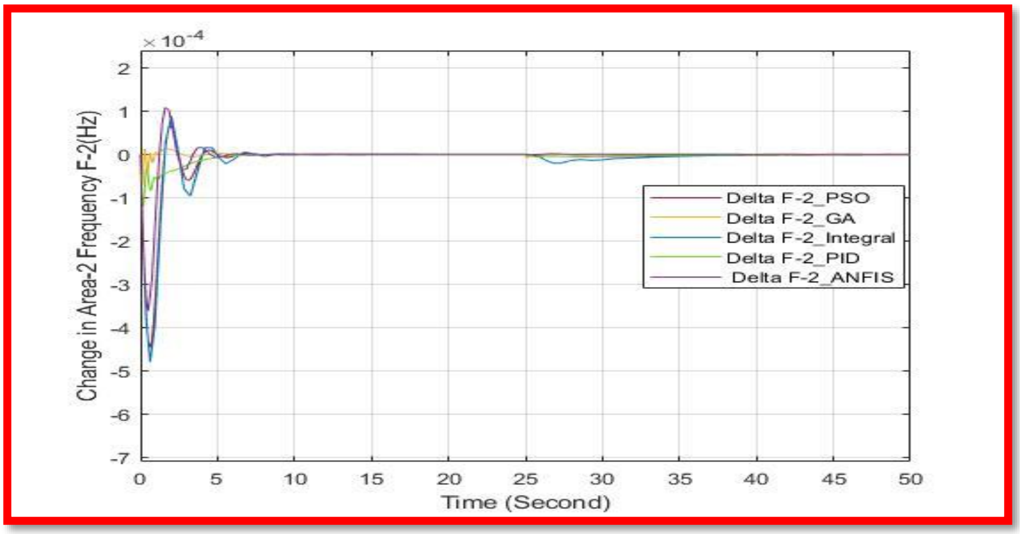


Figure 14: Δf2 with different control strategies (case-II)

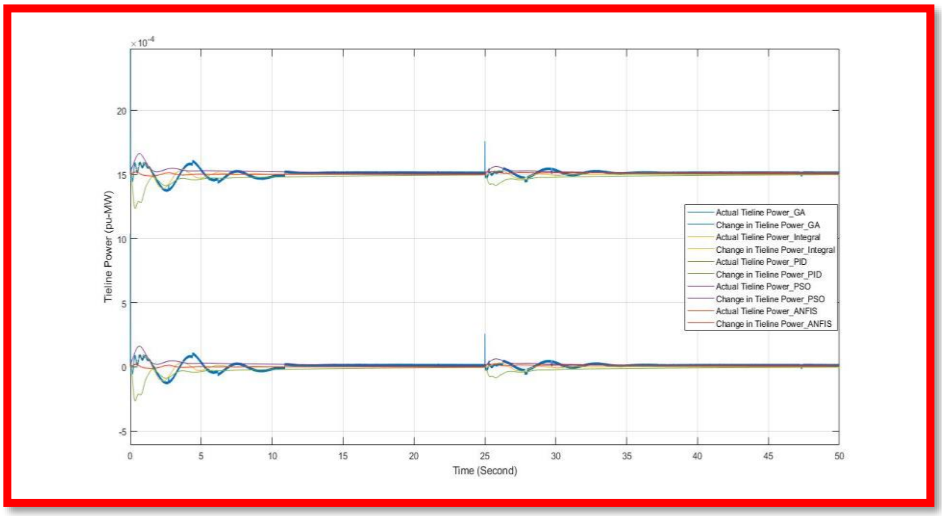


Figure 15: Change in Actual Ptie and ΔPtie error with different control strategies (case-II)

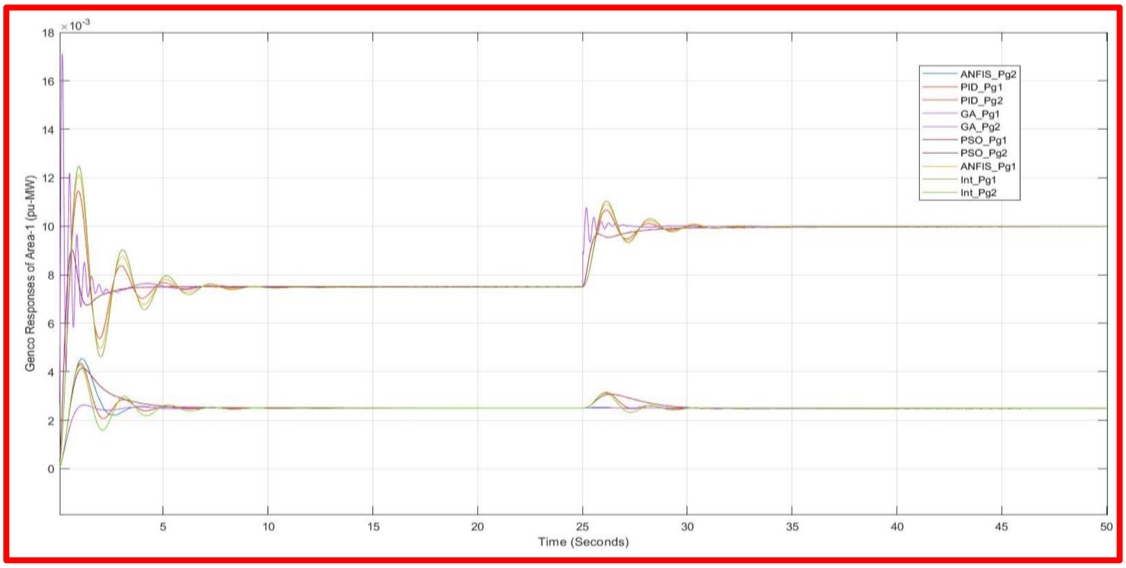


Figure 16: Genco Responses of area-1 with different control strategies (case-II)

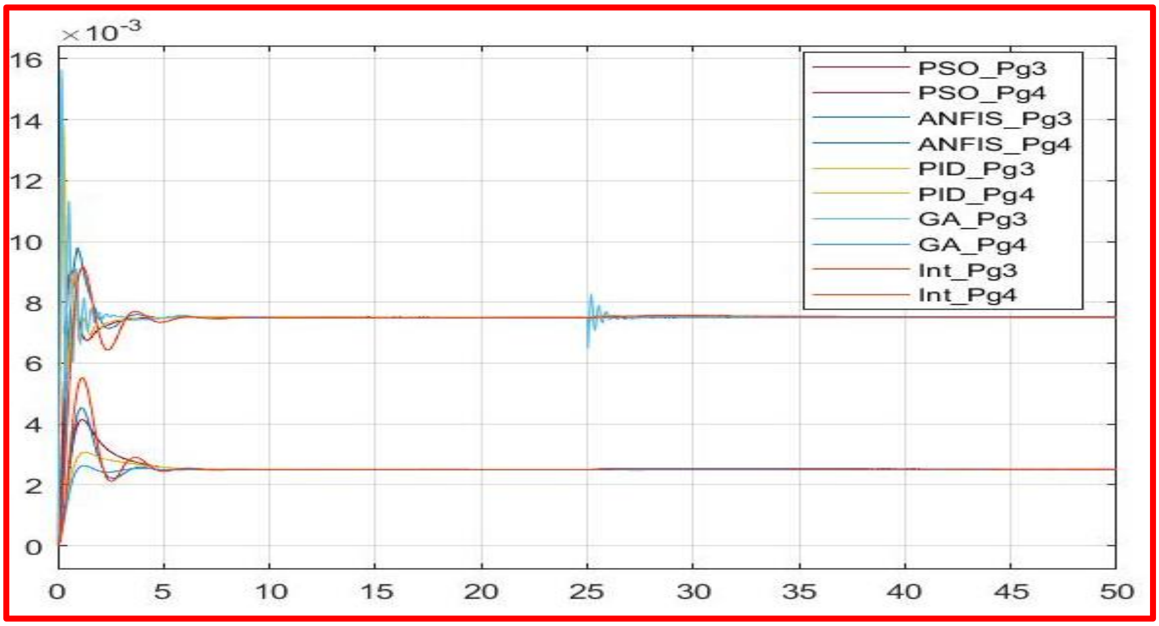


Figure 17: Genco Responses of area-2 with different control strategies (case-II)

CONCLUSION

It is important to keep the power system frequency and the inter area tie line power as close as possible to the scheduled values in interconnected deregulated power system. So, a proper control strategy is required.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. Different controllerslike GA, PSO and ANFIS have been developed using soft computing techniques.Comparative responses using various control strategies have been obtained and shown. It has also been seen that the use of PID controller can improve the dynamic performance of the system if proper tuning of parameter is done. 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.

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