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Load Frequency Control of Multi-Area Power Systems using Genetic Algorithm

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Abstract- **The proposed system describes a Genetic Algorithm (GA) based proportional integral derivative (PID) type controller is proposed to solve the Decentralized load frequency control (LFC) problem for multi-area power system that operates under deregulation based on the bilateral policy scheme. A decentralized PID tuning method is proposed by assuming that the tie-line power flows are disconnected. In each control area, the effects of the possible contracts are treated as a set of new input signals in a modified traditional dynamical model. The salient advantage of this strategy is its high insensitivity to large load changes and disturbances in the presence of plant parameter variations and system nonlinearities. This developed strategy leads to a flexible controller with simple structure that is easy to implement, and therefore, it can be useful for the real world power systems. The proposed method is tested on a three area power system with contracted scenario under various operating conditions to illustrate the GA based PID controller robust performance.**

Key words— **LFC, PID controller, Genetic algorithm.**

I. INTRODUCTION

Large scale power systems are normally managed by viewing them as being made up of control areas with interconnections between them. 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 [1]. This balancing between load and generation can be achieved by using Automatic Generation Control (AGC).

The engineering aspects of planning and operation have been reformulated in a restructured power system in recent years although essential ideas remain the same. To improve the efficiency in the operation of the power system some major changes into the structure of electric power utilities have been introduced by means of deregulating the industry and opening it up to private competition.The utilities no longer own generation, transmission, and distribution; instead, there are three different entities, viz.,GENCO (Generation Companies), TRANSCOs (Transmission Companies) and DISCOs (Distribution Companies).

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 power. A DISCO may have a contract with a GENCO in another control area. Such transactions are called "bilateral transactions." All the transactions have to be cleared through 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 main goal of the LFC is to maintain zero steady state errors for frequency deviation and minimize unscheduled tie-line power flows between neighbouring control areas.

II. DESIGN OF LFC IN DEREGULATED ENVIRONMENT

A) AGPM CALCULATION

In deregulated power systems, the vertically integrated utility (VIU) no longer exists. However, the common AGC goals, i.e. restoring the frequency and the net interchanges to their desired values for each control area, still remain. The generalized dynamics for the AGC scheme has been developed in based on the possible contracts in deregulated

$$\mathrm{AGPM} = \begin{bmatrix} \mathrm{AGPM}_{11} & \cdots & \mathrm{AGPM}_{1N} \\ \vdots & \ddots & \vdots \\ \mathrm{AGPM}_{N1} & \cdots & \mathrm{AGPM}_{NN} \end{bmatrix},$$

where

$$\mathrm{AGPM}_{ij} = \begin{bmatrix} \mathrm{gpf}_{(s_i+1)(z_j+1)} & \cdots & \mathrm{gpf}_{(s_i+1)(z_j+m_j)} \\ \vdots & \ddots & \vdots \\ \mathrm{gpf}_{(s_i+n_i)(z_j+1)} & \cdots & \mathrm{gpf}_{(s_i+n_i)(z_j+m_j)} \end{bmatrix}$$

for $i,j = 1,\ldots,N$ and $s_i = \sum_{k=1}^{i-1} n_i$, $z_j = \sum_{k=1}^{j-1} m_j$, $s_1 = z_1 = 0$.

This section gives a brief overview of this generalized model that uses all the information required in a VIU industry plus the contract data information. In the deregulated power system, generation companies (GENCOs) may or may not participate in the AGC task.

On the other hand, distribution companies (DISCOs) have the liberty to contract with any available GENCO in their own or other areas. Thus, there can be various combinations of the possible contracted scenarios between DISCOs and GENCOs. The concept of an augmented generation participation matrix (AGPM) is introduced to express these possible contracts in the generalized model. The number of rows and columns of an AGPM is equal to the total number of GENCOs and DISCOs in the overall power system, respectively

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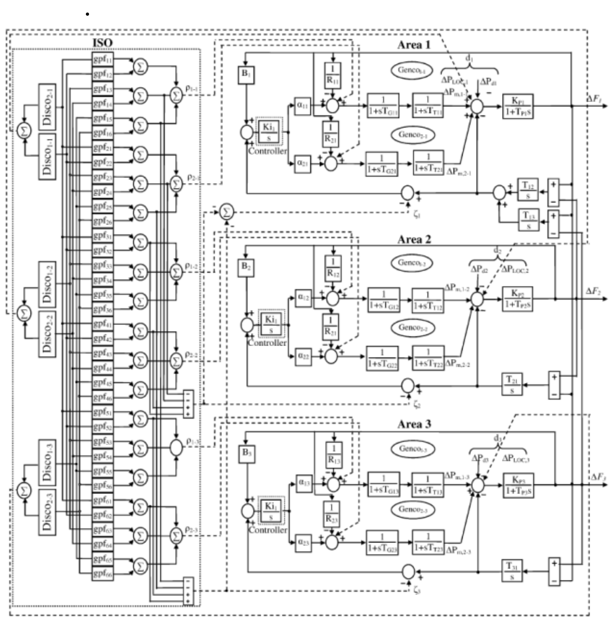

Fig.1 Modified control Area in Deregulated environment

$$d_i = \Delta P_{\mathrm{Loc},i} + \Delta P_{di}, \quad \Delta P_{\mathrm{Loc},i} = \sum_{j=1}^{m_i} \Delta P_{\mathrm{L}j-i}, \quad \Delta P_{di} = \sum_{j=1}^{m_i} \Delta P_{\mathrm{UL}j-i},$$

$$\eta_i = \sum_{\substack{j=1 \\ j\neq i}}^{N} T_{ij} \Delta f_j,$$

$$\zeta_i = \Delta P_{\mathrm{tie},ik,\mathrm{sch}} \sum_{\substack{k=1 \\ k\neq i}}^{N} \Delta P_{\mathrm{tie},ik,\mathrm{sch}},$$

$$\Delta P_{\mathrm{tie},ik,\mathrm{sch}} = \sum_{j=1}^{n_i} \sum_{t=1}^{m_k} \mathrm{apf}_{(s_i+j)(z_k+t)} \Delta P_{\mathrm{L}t-k} - \sum_{t=1}^{n_k} \sum_{j=1}^{m_i} \mathrm{apf}_{(s_k+t)(z_i+j)} \Delta P_{\mathrm{L}j-i},$$

$$\Delta P_{\mathrm{tie},i\text{-error}} = \Delta P_{\mathrm{tie},i\text{-actual}} - \zeta_i,$$

$$\rho_i = [\rho_{1i} \cdots \rho_{ki} \cdots \rho_{n_i i}]^{\mathrm{T}}, \quad \rho_{ki} = \sum_{j=1}^{N} \left[\sum_{t=1}^{m_j} \mathrm{gpf}_{(s_i+k)(z_j+t)} \Delta P_{\mathrm{L}t-j} \right].$$

$$\Delta P_{m,k-i} = \rho_{ki} + \mathrm{apf}_{ki} \sum_{j=1}^{m_i} \Delta P_{\mathrm{UL}j-i}, \quad k = 1, 2, \ldots, n_i.$$

The dotted and dashed lines show the demand signals based on the possible contracts between GENCOs and DISCOs that carry information as to which GENCO has to follow a load demanded by that DISCO. These new information signals were absent in the traditional AGC scheme. As there are many GENCOs in each area, the ACE signal has to be distributed among them due to their ACE participation factor in the AGC task and $\sum_{j=1}^{n_i} \mathrm{apf}_{ji} = 1$.

B) PID CONTROLLER

A Proportional–Integral–Derivative (PID) controller is a three-term controller that has a long history in the automatic control field, starting from the beginning of the last century (Bennett, 2000). Owing to its intuitiveness and its relative simplicity, in addition to satisfactory performance which it is able to provide with a wide range of processes, it has become in practice the standard controller in industrial settings. It has been evolving along with the progress of the technology and nowadays it is very often implemented in digital form rather than with pneumatic or electrical components. It can be found in virtually all kinds of control equipments, either as a stand-alone (single-station) controller or as a functional block in Programmable Logic Controllers (PLCs) and Distributed Control Systems (DCSs). Actually, the new potentialities offered by the development of the digital technology and of the software packages has led to a significant growth of the research in the PID control field: new effective tools have been devised for the improvement of the analysis and design methods of the basic algorithm as well as for the improvement of the additional functionalities that are implemented with the basic algorithm in order to increase its performance and its ease of use.

The success of the PID controllers is also enhanced by the fact that they often represent the fundamental component for more sophisticated control schemes that can be implemented when the basic control law is not sufficient to obtain the required performance or a more complicated control task is of concern. The PID controller block diagram is shown below,

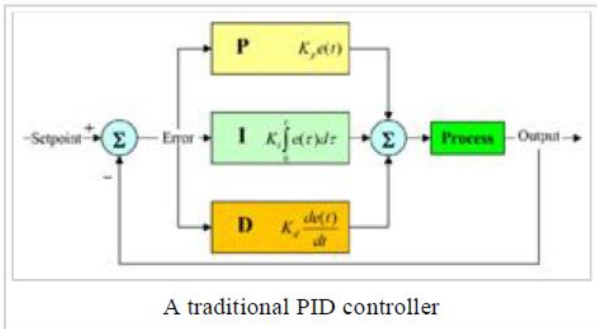

Fig.2 Block diagram of PID controller

C) PERFORMANCE INDEX

True optimal nominal performance for nominal system parameters (T_p,T_{12} and B) means minimum undershoot (US) , minimum overshoot(OS),minimum settling time(t_s) of Deltaf1,Deltaf2 of area 1 and area2 and tie line power floe deviation(Delta P_{tie}),minimum overall oscillations of the responses and good damping.

The following summed square error(SE) objective function, figure of demerit, ''FDM'' is adopted, FDM = $\sum((\mathrm{Deltaf1})^2+(\mathrm{Deltaf2})^2+(\mathrm{DeltaP}_{tie})^2)$ for 100 samples over a time span of 20s.

III. GENETIC ALGORITHM

A Genetic Algorithm (GA) is an iterative procedure which begins with a randomly generated set of solutions referred as initial population. For each solution in the set, objective function and fitness are calculated. On the basis of these fitness functions, pool of selected population is formed by selection operators; the solution in this pool has better average fitness then that of initial population. The crossover and mutation operator are used to generate new solutions with the help of solution in the pool. The process is repeated iteratively while maintain fixed number of solutions in pool of selected population, as the iteration progress, the solution improves and optimal solution is obtained. During the selection process of the GA, good solutions are selected from the initial generated population for producing offspring.

Good solutions are selected randomly from the initial generated population using a mechanism which favors the more fit individuals. Good individuals will probably be selected several times in a generation but poor solutions may not be selected at all.

The second GA operator is crossover. In the crossover two parents are selected randomly from the pool of selected/obtained population by the selection process. Crossover produces two offsprings which has some basic properties of the parents. The mutation operator generates an offspring using a random solution from pool.

Each new solution is evaluated i.e. objective function and fitness values are calculated. These newly created offsprings and the populations are combined. The combined population is put for selection by selection operator.

A) GA Algorithm

Step1: The intial Population matrix of NX 9 are generated by selecting a value with a probability over the search space (Gmin , Gmax).

Step2: Simulating the AGC Multisource block model by substituting each Chromosome values in the Gain parameter of PID controller and calculate Performance index for each Chromosome which is taken as fitness value.

Step3: Select the best Parent from the population pool using roulette wheel selection Method.

Step4: Reproduce child for next Generation using two-point Crossover method

Step5: Mutated the child for diversification and non-repeatability using Simple Mutation Method.

Step6: Select 20%of best Parent and 80%of best child for creating next population pool

Step7: Check the iteration exceeds maximum iteration

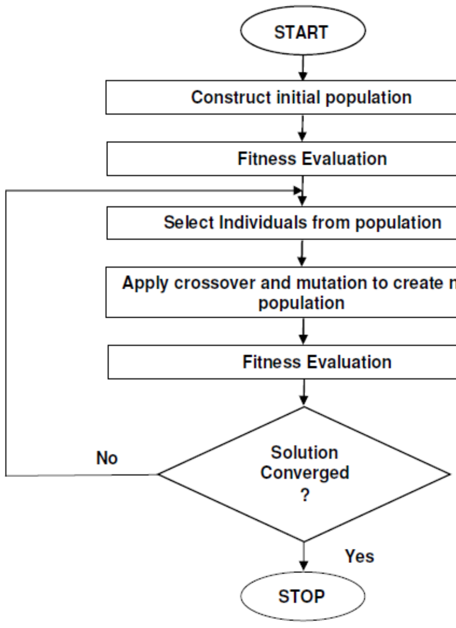

Fig.3 Genetic Algorithm flow chart

Step8:If yes Go to step2,otherwise the print best fitness value and best PID Gain values

IV.CASE STUDY

To illustrate the effectiveness of the modelling strategy and proposed control design, a three control area power system, shown in Fig. 4, is considered as a test system. It is assumed that each control area includes two Gencos and one Disco. The power system parameters are tabulated in Tables 1 and 2.

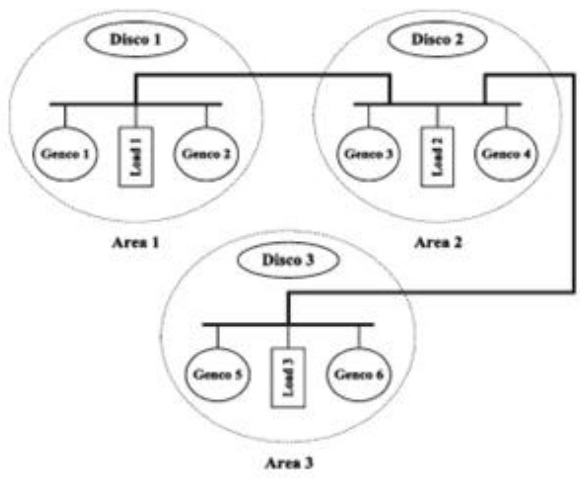

Fig.4 Three Control Area Power System

Table 1
Applied data for Gencos

Quantity	Genco 1	Genco 2	Genco 3	Genco 4	Genco 5	Genco 6
Rate (MW)	800	1000	1100	1200	1000	1000
R (Hz/pu)	2.4	3.3	2.5	2.4	3	2.4
Tt (s)	0.36	0.42	0.44	0.4	0.36	0.4
Tg (s)	0.06	0.07	0.06	0.08	0.07	0.08
Alpha	0.5	0.5	0.5	0.5	0.5	0.5

Table 2 Applied control area parameters

Quantity	Area 1	Area 2	Area 3
D (pu/Hz)	0.0084	0.014	0.011
M (pu s)	0.1667	0.2	0.1667
B (pu/Hz)	0.8675	0.795	0.870
Tij (pu/Hz)	T12 = T23 = 0.545		

V. SIMULATION RESULTS

Scenario 1: It is assumed that a large load demand (as a step load disturbance) is requested in each control area:

$$\Delta P_{L1} = 100 \text{ MW}, \quad \Delta P_{L2} = 70 \text{ MW}, \quad \Delta P_{L3} = 60 \text{ MW}$$

Assume each Disco demand is sent to its local Gencos only, based on the following GPM

$$\text{GPM} = \begin{bmatrix} 0.5 & 0 & 0 \\ 0.5 & 0 & 0 \\ 0 & 0.5 & 0 \\ 0 & 0.5 & 0 \\ 0 & 0 & 0.5 \\ 0 & 0 & 0.5 \end{bmatrix}$$

The frequency deviation (Df), power changes (DPm) and area control error (ACE) of the closed loop system.Using the proposed method, the area control error and frequency deviation of all the areas are quickly driven back to zero and the generated powers and tie line powers properly converge to specified values.

$$\Delta P_{m1} = \text{gpf}_{11}\Delta P_{L1} + \text{gpf}_{12}\Delta P_{L2} + \text{gpf}_{13}\Delta P_{L3} = 0.5(0.1) + 0 + 0 = 0.05 \text{ pu}$$

$$\Delta P_{m2} = 0.05 \text{ pu}, \quad \Delta P_{m3} = \Delta P_{m4} = 0.035 \text{ pu}, \quad \Delta P_{m5} = \Delta P_{m6} = 0.03 \text{ pu}$$

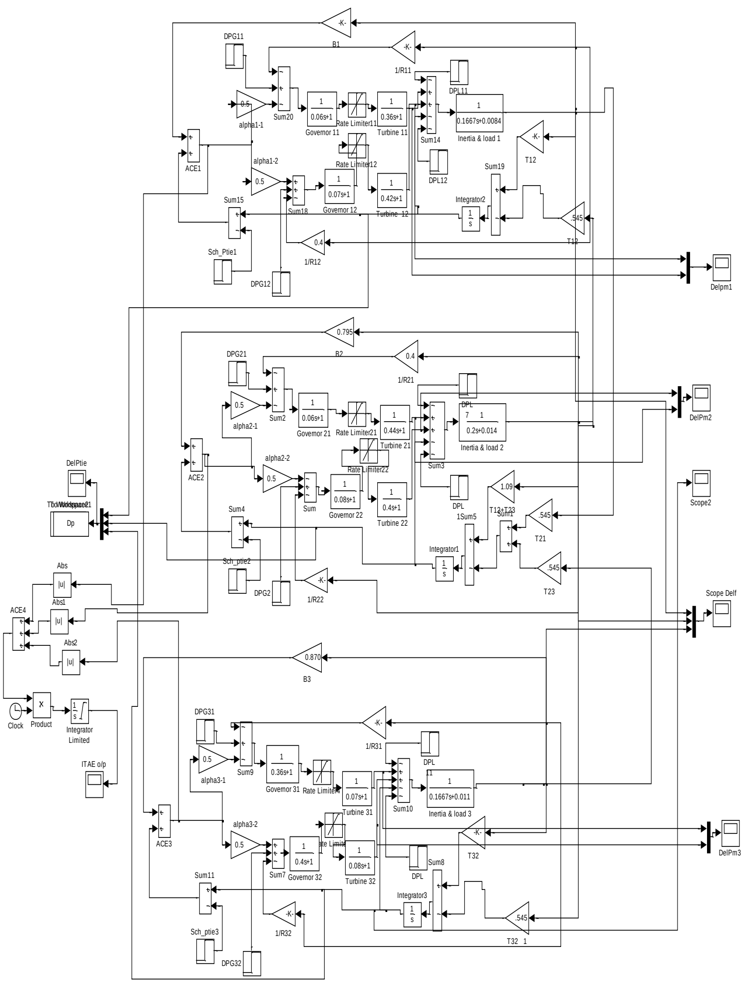

Fig.5 Simulation block diagram

A)OUTPUT WAVEFORMS

The simulation results show the proposed PID controller tracks the load change and achieves good robust performance for a wide range of load disturbances and possible contracted scenario in the presence of plant parameters changes and system nonlinearities

The following output waveforms shows the frequency deviations with and without GA PID controller.

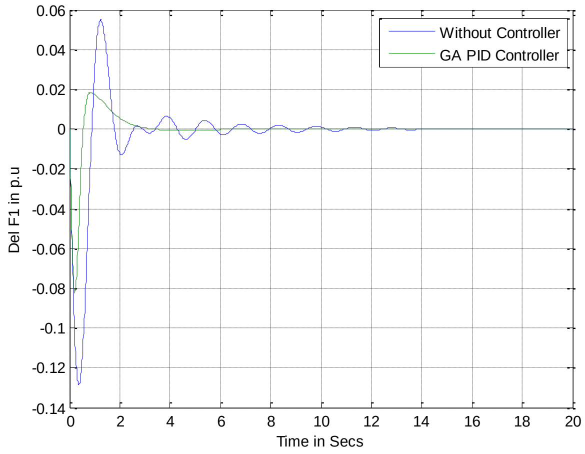

Fig.6 frequency deviation in area 1

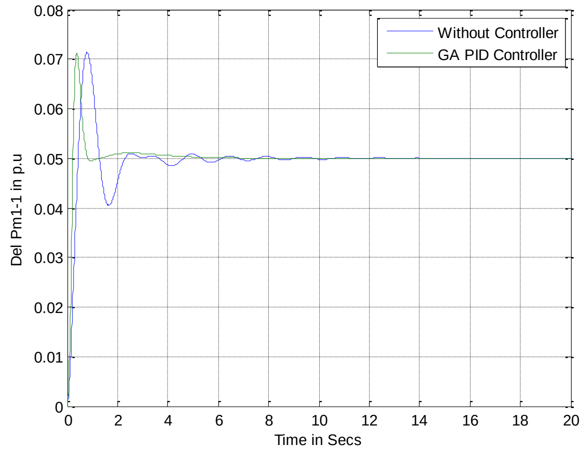

Fig.9 power flow 1-1

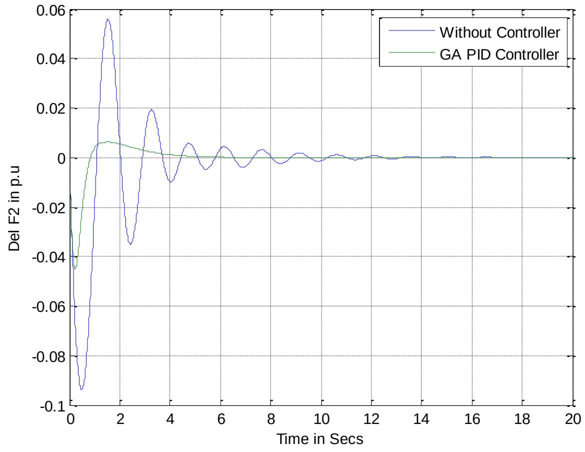

Fig.7 frequency deviation in area 2

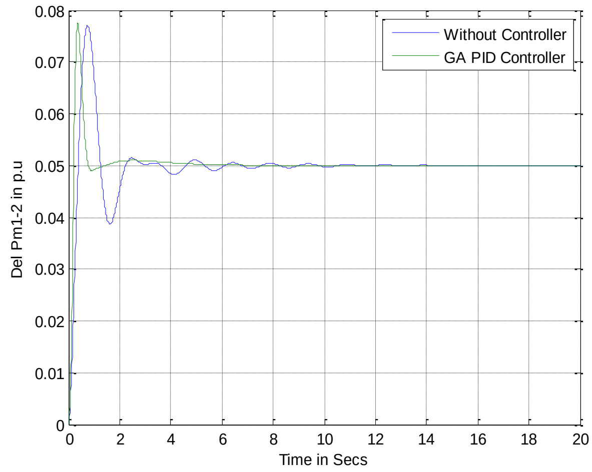

Fig.10 power flow 1-2

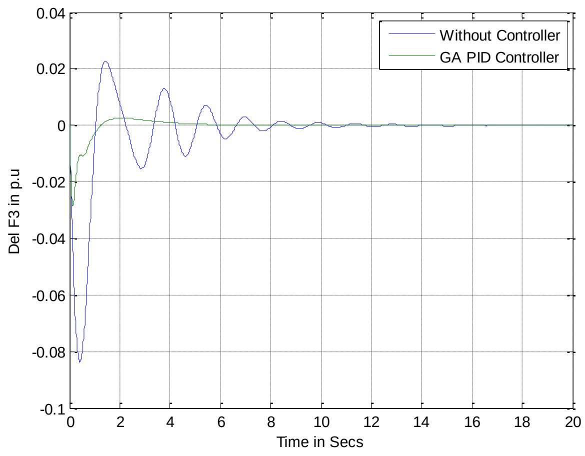

Fig.8 frequency deviation in area 3

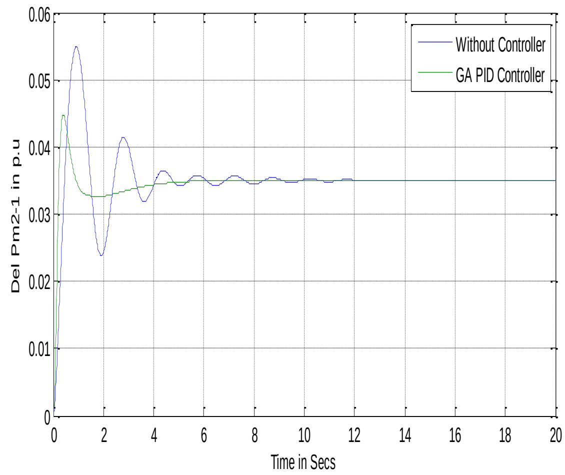

Fig.11 power flow 2-1

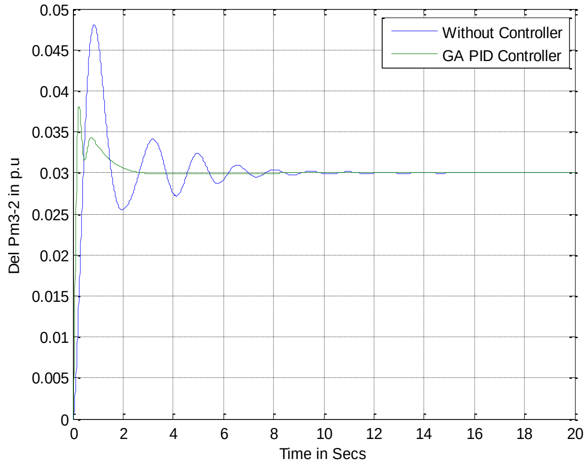

Fig.12 power flow 3-2

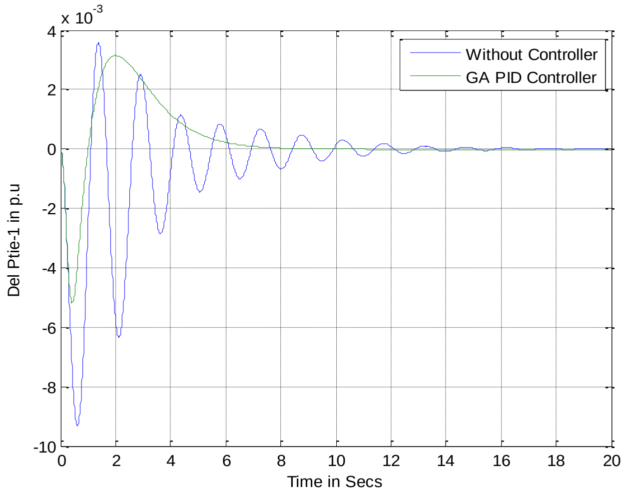

Fig.13 tie line power fiow in area1

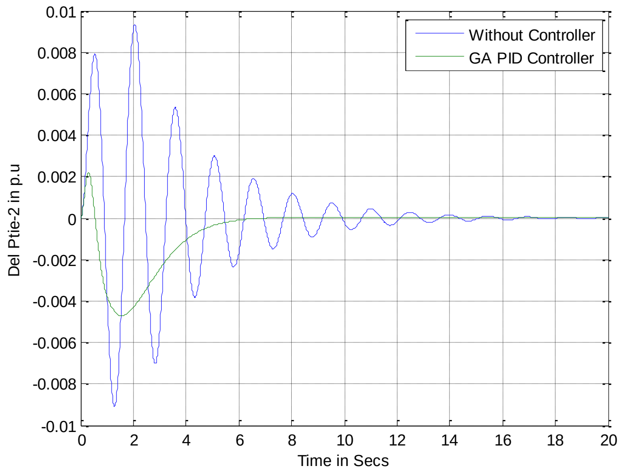

Fig.14 tie line power fiow in area2

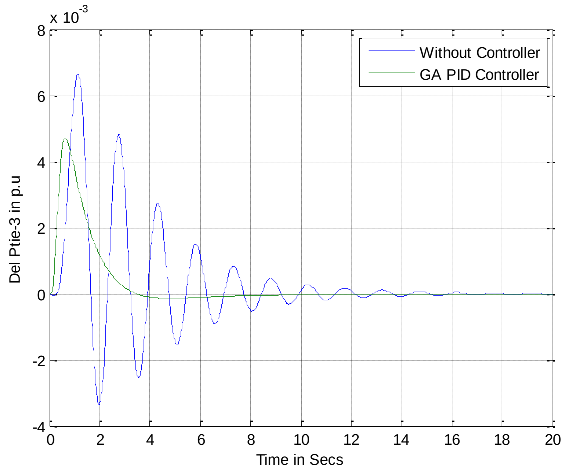

Fig.15 tie line power fiow in area3

Table 1
Final results comparison

	GA controller	**Without controller**	**GA controller**	**Without controller**
Parameter	**Settling time in secs**	**Settling time in secs**	**Peak overshoot in P.U**	**Peak overshoot in P.U**
DelF1	3.8	13.8	0.08	0.13
DelF2	6	16.5	0.04	0.09
DelF3	5.8	15	0.026	0.083

VII. CONCLUSION

A GA based PID type controller for the AGC problem in deregulated power systems is proposed using the modified AGC scheme in this paper. This control strategy was chosen because of the increasing complexity and changing structure of deregulated power systems. This newly developed control strategy combines the advantages of the GA based PID and integral controllers for achieving the desired level of robust performance, such as precise reference frequency tracking and disturbance attenuation under a wide range of area load changes and disturbances. Moreover, it has a simple structure and is easy to implement, which makes it ideally useful for the real world power systems. The GA-PID controller was tested on a three area deregulated power system to demonstrate its robust performance for the three possible contracted scenarios under different operating conditions. Simulation results show that the proposed strategy is very effective and guarantees good robust performance against parametric uncertainties, load changes. The system performance characteristics in terms of 'ITAE' indices reveal that the proposed GAPID is a promising control scheme for the AGC problem. Thus, it is recommended to generate good quality and reliable electric energy in deregulated power systems.

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