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Two Area Load Frequency Control Using GA Tuned PID Controller in Deregulated Environment

G. Konar, K. K. Mandal, and N. Chakraborty

Abstract— **Load frequency control of interconnected power system is important. This ensures the zero steady state error in frequency dynamics and proper sharing of load by generators of interconnected areas. Use of PID controllers enhances smooth and efficient control of area control error (ACE).The ACE in turn works as the control vector of automatic generation control. Nowadays, interconnected power system works under open market scenario called deregulated environment. Here individual DISCOs get power from GENCOs of all connected areas according to the contract made. In such a complex situation, proper tuning of individual area's PID controller became indispensable. In this work PID controllers tuned with Genetic Algorithm are used in two area Automatic Generation Control under deregulation. The system shows unstable response without controller due to change of load (0.1 pu) in one area. But the introduction of GA tuned PID controller improves the power system dynamic responses. It is observed that frequency reaches the steady state value within reasonable time (around 12 sec) and GENCOs of connected areas share the tie line power according to their participation factors. MATLAB codes are developed for GA based PID controller tuning, the results of which are used to study the system step response. All these are through in Simulink based background.**

Index Terms— ACE, DISCO, GENCO, genetic algorithm, PID controller

I. Introduction

IN recent years the power utilities have gone through a major change from monopoly to competition and deregulation has been initiated all over the world. In turn the electricity consumers have the opportunity to choose among several energy providers. With these changes, the electricity generation, transmission and distribution systems are needed to follow new strategies owing to deregulation [1, 2, 3].

Reliable and good quality power transfer is maintained in interconnected power system under deregulated environment through proper choice of automatic generation control components [4]. Sudden change in load introduces frequency fluctuations and tie-line power exchange. Suitable load frequency control with the consideration of bilateral contracts between participating areas nowadays became mandatory. Optimal output feedback, linear feedback, Kalman estimator [2, 5, 6, 7] are such few control strategies adopted elsewhere to accomplish the same.

Other than the classical control strategies, some soft computing techniques became popular in designing load frequency control. Several optimization techniques like Genetic algorithm, Particle Swarm Optimization, Bacterial Foraging are currently being applied for the automatic generation control in multi-area system under deregulation [8, 9, 10]. Such optimization techniques have also been used for automatic generation control of interconnected power system without deregulation [11, 12]. These techniques are used either to tune the different types of controllers or to set the parameters for power system stabilizers. These actions enable operators to improve the control of the frequency deviation situation and restoration of the tie line power fluctuations quickly. In deregulated environment participation contract between two or more areas are regulated by an 'independent system operator' (ISO) [13]. Contract violation and its effects are also important in these situations [2].

In this paper, two area automatic generation control has been studied in a deregulated environment to observe the effect of load change in system dynamics. One GENCO and one DISCO are considered in each area under study. GENCOS share load of its own area as well as that of the other area as demanded by the DISCOs. This participation is based on the contract made between the two systems as per the corresponding DISCO Participation Matrix (DPM) matrix. It is generally developed in restructured environment [13]. The PID controller is used here to nullify the effect of frequency and tie-line power deviations in both the areas. MATLAB code has been developed to achieve PID controller tuning based on genetic algorithm. PID controller tuning ensures the improvements in the system response in terms of settling time, rise time, overshoot and steady state value. Studies are made for different contract conditions. The results are compared with step response of similar system having a PID controller tuned with PSO in conventional interconnected power system [14] without

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deregulation. The results obtained for the problem in hand provide interesting load control scenario in comparison to the conventional situation. The block diagrams of two area load frequency control under deregulation and conventional scenario are drawn in Simulink and the overall system response is found for change of load in one area.

II. Two Area Load Frequency Control in Restructured Power System

A. *Two Area Power System In Restructured Environment*

Restructured power system consists of Generation companies – GENCOs, Transmission companies – TRANSCOs, Distribution companies - DISCOs, and independent system operators ISO. In this paper, the power system comprises two areas having one DISCO and one GENCO in each area as shown in Fig. 1. The corresponding DISCO Participation Matrix (DPM) is shown in (1). Each DISCO can buy power from the GENCOs according to the fractions assigned to the elements of the corresponding column of DPM matrix. Thus a GENCO sells a fraction of total load to a DISCO as per contract made between them. Hence, sum of all the elements in each column of DPM is unity i.e. $\sum_i cpf_{ij} = 1$, where *cpf* is the contract participation factor [13].

Fig. 2 depicts the block diagram of the two area load frequency control under deregulated environment. In this model the control vectors u_1 and u_2 are determined from the knowledge of the area control error (ACE) and frequency deviations of area 1 and 2 respectively. (2) and (3) represent the ACEs of both areas. ACEs are calculated based on the frequency deviation (ΔF_1) and the tie-line power deviation i.e. the difference between the scheduled power deviation ($\Delta P_{tie12sch}$) and the actual power deviation ($\Delta P_{tie12actual}$). The latter two are represented through (4) and (5).

$$DPM = \begin{bmatrix} cpf_{11} & cpf_{12} \\ cpf_{21} & cpf_{22} \end{bmatrix} \quad (1)$$

$$ACE_1 = B_1 \Delta F_1 + \Delta P_{tie12error} \quad (2)$$

$$ACE_2 = B_2 \Delta F_2 + \Delta P_{tie12error} \quad (3)$$

$$\Delta P_{tie12sch} = cpf_{12} \Delta P_{L2} - cpf_{21} \Delta P_{L1} \quad (4)$$

$$\Delta P_{tie12error} = \Delta P_{tie12actual} - \Delta P_{tie12sch} \quad (5)$$

Here $\Delta P_{tie12error}$ is the tie-line power error. Using ACE participation factor (*apf*), ACE signal is distributed among the GENCOs. These ACE signals are then fed into PID controller e sure that the symbols in your equation .

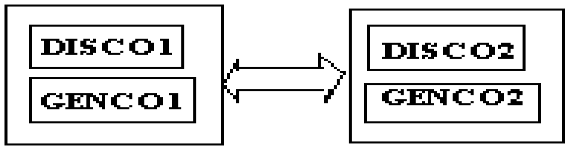

Fig. 1. Configuration of the power system

B. *PID controller design*

The PID controller design is the most important part of the Automatic Generation Control (AGC). The choice of proportional-integral-derivative (PID) controller than proportional plus integral (PI) controller ensures better system response in terms overshoot and settling time [15]. The ACE signals are controlled using the PID controller to produce control vectors for the AGC. In this work, the PID controller tuning is done through Genetic Algorithm (GA). The proportional (k_p), integral (k_i) and derivative (k_d) gains are set using GA. The transfer function of the PID controller (6) used for both the areas are considered to be identical.

To get the optimized values of the PID gains, suitable objective function is developed here. However the maximum and minimum values of the gains are appropriately chosen. This objective function (*OB*) can be defined as the sum of the squares of the area control errors (ACE_1 and ACE_2) in each area as shown in (7).

$$G_c(s) = k_p + \frac{k_i}{s} + k_d s \quad (6)$$

$$OB = \int_0^\infty \sum_{i=1}^{2} (ACE_i)^2 dt \quad (7)$$

The optimization problem is based on the minimization of the Objective 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 shown in (8).

$$k_p^{\min} \le k_p \le k_p^{\max}, k_i^{\min} \le k_i \le k_i^{\max}, k_d^{\min} \le k_d \le k_d^{\max} \quad (8)$$

Thus the PID controller parameters are obtained using (7) and (8) with the help of Genetic Algorithm as discussed in the next section.

III. P id Controller Parameter Tuning Using Genetic Algorithm

A combination of Darwinian Survival of the fittest principle and genetic operation is popularly known as Genetic Algorithm. This became an effective method of optimization. This global optimization technique involves stochastic search algorithm. Since the gains of PID controllers, k_p, k_i and k_d, are to be optimized using GA, three binary strings are assigned to each member of the population in this problem. To accommodate the entire range of possible solutions, large value of population size *(100)* is chosen. The implementation of GA starts with parameter encoding [16]. This is done with great care so that the link between the objective function and the strings are maintained properly.

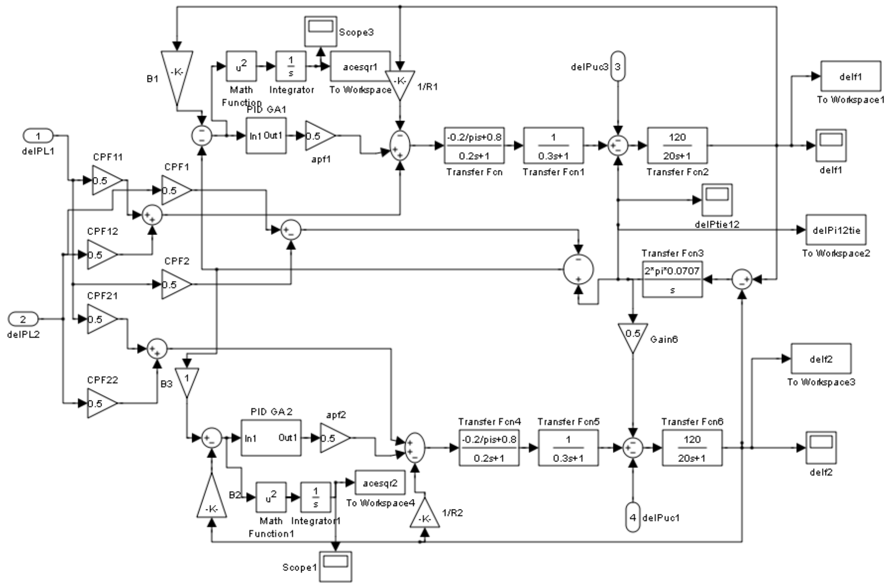

Fig.2 Block diagram of two area load frequency control under deregulation

The decimal integers of binary strings are obtained following (9).

$$y_j = \sum_{i=1}^{l} 2^{i-1} b_{ij} \, (\mathrm{j} = 1,2,\ldots\mathrm{L}) \tag{9}$$

Where

y_j is the decimal coded value of the binary string

b_{ij} is the ith binary digit of the *j*th string

l is the length of the string

L is the population size

Following a fixed mapping rule, the continuous variable x_j (10) is found in the search space where x_{min} and x_{max} are the minimum and the maximum values of the variable x_j.

Here, the minimum and maximum values of the PID gains are assigned as the minimum and maximum limits of the variables.

$$x_j = x_{\min} + \frac{x_{\max} - x_{\min}}{2^l - 1} y_j \, (j = 1,2,\ldots..L) \tag{10}$$

In the next step the most challenging task is done i.e. the evaluation of the best values of PID controller gains are obtained to minimize the objective function. This task ensures smallest overshoot, fastest rise time and quickest settling time.

Another important step in GA is to select the highly fit strings in population as the parents and a mating pool is formed. The probability [16] for selecting the i_{th} string is

$$p_i = \frac{f_i}{\sum_{j=1}^{L} f_j} \tag{11}$$

where f_i is the fitness here f_i is the fitness of the i_{th} population.

Another important step is the crossover operation. In this operation new strings are generated by exchanging the information among the strings of the mating pool. The mutation operator is also introduced to bring variations. Here mutation rate is chosen to be 0.5.

This newly tuned PID gains are used to form the PID controller transfer function. The controller transfer function is then used to simulate the overall system response of two area Load Frequency Control in deregulated environment for a given step input. The main objective is to find the smallest overshoot, fastest rise time and the settling time for frequency deviation and tie-line power characteristics.

The algorithm used for tuning PID controller is written below:

1. Set the population size, mutation rate, string size, generation counter, population counter, minimum and maximum values of variables etc.
2. Code the problem variables k_p, k_i and k_d into binary strings.
3. Create the initial population of 100 members using random number generation
4. Initialize the generation counter.
5. Increase the generation counter and initialize population counter.
6. Increase the population counter.
7. Decode the binary string using (9) and (10). Use these values of variables in PIDGA blocks of Simulink model to find out the objective function i.e. area control errors (*ACEs*). Send these values to MATLAB code.
8. Check the fitness.
9. If the population counter is less than population size, GOTO step 4 and repeat.

10. Select highly fit strings as parents and produce offsprings according to their fitness.
11. Generate new strings by mating current offsprings using crossover operation.
12. Introduce variations by using mutation operator and replace the existing strings by new strings.
13. Check if the generation counter is less the maximum iteration number. It true, GOTO step 5 and repeat. Otherwise,
14. Stop.

IV. Results And Discussions

The code for PID controller tuning is written in MATLAB. The best values of PID controller parameters i.e. the gains k_p, k_d and k_i obtained using GA are used in PIDGA blocks of two area LFC block diagram (Fig.2) drawn in MATLAB/Simulink. The power system parameters used here are given in Table I.

The DISCOs of this problem take power from the GENCOs according to the DPM. Here it is assumed that the each element of DPM has a value of 0.5. At the same time each GENCO participates in automatic generation control according to the area participation factors apf_1 = 0.5 and apf_2 = 0.5

Initially the system is run without the use of the controller due to the load change in area1 under deregulation. But it is found that the system is unstable. The tie line power deviation due to load change in area1 in two area load frequency control without controller is shown in Fig. 3. Hence with the application of PID controller the simulation is done again for the change of load in area1 by 0.1 pu in deregulated environment. The corresponding frequency deviations in area1 and area2 are shown in Fig. 4 and Fig. 5 respectively. The values of PID controller gains obtained through GA are shown in Table II. The tie line power deviation is depicted in Fig. 6.

TABLE I
Power System Data

Power System Data	Values
generator time constants T_{g1}, T_{g2}	0.2 s
turbine time constants T_{t1}, T_{t2}	0.3 s
power system gains K_{p1}, K_{p2}	120 Hz/pu MW
power system time constants	20 s
B_1, B_2	0.425pu MW/Hz
speed regulation of governors R_1, R_2	2.4 Hz/pu MW

s = second, W = watt, M = mega.

TABLE II
Values Of PID Gains

Area	k_p	k_i	k_d
1	0.224	0.414	0.231
2	0.224	0.414	0.231

TABLE III
Performance Study

Parameters	ΔF_1	ΔF_2	$\Delta P_{tie12actual}$
Settling time (s)	12.562	12.44	10.155
Rise time (s)	0.5086	0.466	4.3678
% Peak Overshoot	13	17	9

The two area power system without PIDGA was simulated initially and it showed unstable response. With the application of GA tuned PID controller, the system became stable. The system performances based on the settling time, rise time and % peak overshoot are shown in Table III.

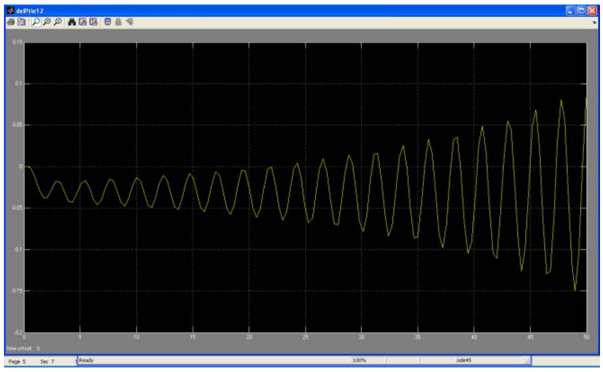

Fig. 3. Tie line power deviation (in pu) with respect to time (in sec) due to change in load of area1 without any PID controller.

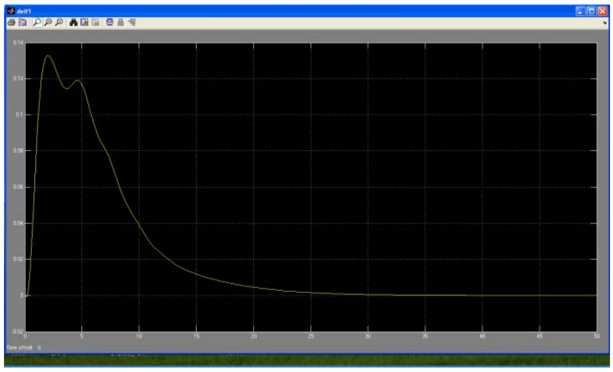

Fig. 4. Frequency deviation with respect to time (in sec) in area1 due to 0.1 pu load change in area1

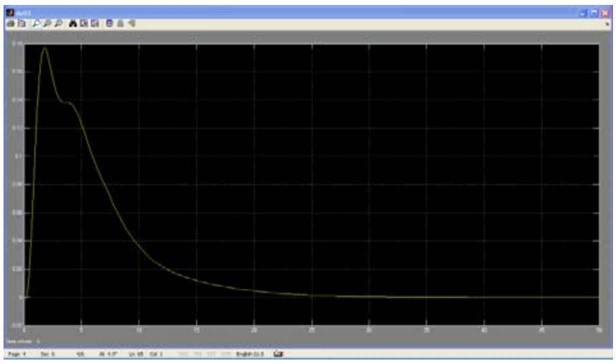

Fig. 5. Frequency deviation (in pu) with respect to time (in sec) in area 2 due to 0.1 pu load change in area1

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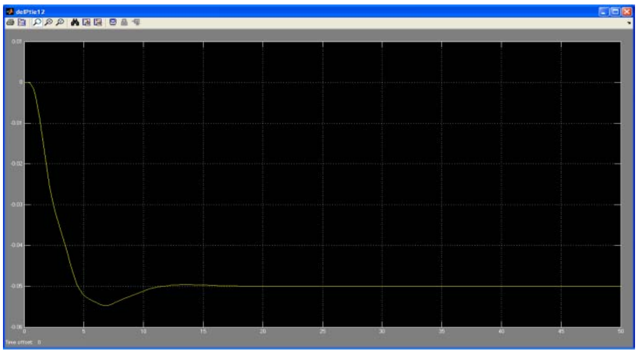

Fig. 6. Tie line power deviation (in pu) with respect to time (in sec)due to change in load of area1

It is observed from Table III that peak overshoot is well below 25%, settling time and rise time are also within limits i.e. the steady state frequency is restored within 12 sec (approximately) after the sudden change of load in area1. The tie line power characteristics shows that the 0.1 pu change of load in area 1 is shared by both the GENCOs as per the DPM matrix. It means that the 0.05 pu load will be supplied from GENCO 2 to DISCO 1. An interconnected power system having same parameters that of the power system chosen here was simulated using PSO based PID controller under deregulation in another work [14]. A comparison of the frequency deviation characteristics of these two works reveals that the numbers of oscillations have been reduced in case of PIDGA (Fig. 3 and 4) in deregulated environment.

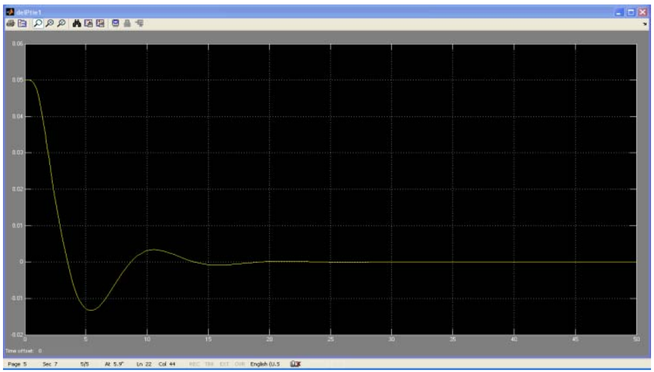

Fig. 7. Tie line power error i.e. $\Delta P_{tie12error}$ (in pu) with respect to time (in s) due to 0.1 pu change in load of area1 without deregulation

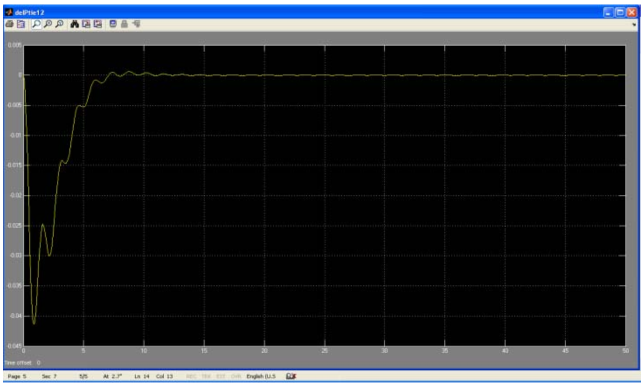

Fig. 8. Tie line power deviation (in pu) with respect to time (in sec) due to 0.1 pu change in load of area1 without deregulation.

Fig. 7 shows the tie line power error i.e. $\Delta P_{tie12error}$ versus time. It is clear from the plot that the steady state value of tie line power error is zero and its settling time is less than 4 sec (2% basis). Fig. 8 depicts the tie line power deviation in two area load frequency control system without deregulation, the steady state value of which is zero. But the corresponding tie line power deviation plot with deregulation is smooth and has less oscillations than that without deregulation.

V. Conclusion

In this work, two area load frequency control is established under deregulation. The PID controller which is used to bring the system dynamics within comfortable limits is tuned with the help of genetic algorithm. With the variation of load in one area, the deregulated system response is better than the system without deregulation in terms of numbers of oscillations and at the same time the load change is accommodated by the GENCOs of both the areas without overloading any one of them.

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