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OPTIMIZATION OF TWO AREA RESTRUCTURED POWER SYSTEM USING ANT COLONY ALGORITHM

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Abstract : In this paper, ant colony optimization algorithm (ACO) has been applied to design the controller parameters in the automatic generation control (AGC) problem in a two area restructured power system. In the considered power system, the conventional two-area system has been modified to include the effect of bilateral contracts in the system dynamics and each area contains two generation company (GENCO) and two distribution company (DISCO). After deregulation, to describe bilateral contract for three-area AGC, DISCO participation matrix is used. The dynamic responses of the system have been analyzed for different operating conditions considering area control error (ACE) controllers for which the values of the controller parameters have been optimized using ant colony optimization algorithm.

Keywords: Automatic generation control (AGC); ant colony optimization algorithm (ACO); area control error (ACE).

1. INTRODUCTION

Electric power utilities are currently moving towards a deregulated framework in which consumers will have an opportunity to make a choice among competing providers of electric energy. Deregulation is the collection of restructured rules and economic incentives that governments set up to control and drive the electric power industry [1]. Deregulated system will consist of generation companies (GENCOs), distribution companies (DISCOs), transmission companies (TRANSCOs) and independent system operator (ISO). GENCO, TRANSCO, DISCO, ISO and many ancillary services (AGC) of a vertically integrated utility will have a different role to play and therefore have to be modeled differently. There are crucial differences between the AGC operation in a vertically integrated industry (conventional case) and horizontally integrated industry (new case). In the reconstructed power system after deregulation, operation, simulation and optimization have to be reformulated although basic approach to AGC has been kept the same. In this case, a DISCO can contract individually with any GENCO for power and these transactions are made under the supervision of ISO. To understand how these contracts are implemented, DISCO participation matrix concept is used as in [2]. The information flow of the contracts is superimposed on the traditional AGC system. In the literature, there are some research studies on deregulated AGC [3–5].

In this paper, to achieve optimal gains, the authors have proposed Ant colony optimization algorithm (ACO) which was developed by Dorigo [6,7] and his associates in the early 1990s. The inspiring source of ant colony optimization is the foraging behavior of real ant colonies. This behavior is exploited in artificial ant colonies for the search of approximate solutions to discrete optimization problems to continuous optimization problems. Ant colony algorithm have also been applied to power system problems such as optimal power flow, analysis of system topologies, the design of power distribution and to solve the economic dispatch. In this study, ACO is used to optimize the parameters of AGC after deregulation in the power system. In the present work, first, the effects of bilateral contracts on the dynamics have been taken into account and then the tie-line bias, K_I and frequency bias factor, B of this deregulated AGC is optimized by using ant colony optimization algorithm.

2. RESTRUCTURED POWER SYSTEM FOR AGC WITH TWO AREAS

The present power system is assumed to contain two non-reheat turbine type thermal units in both area 1 and area 2. Therefore each area includes two GENCOs and also two DISCOs as shown in Fig.1. The detailed scheme of the system is also given in Fig. 2. In deregulated environment, any DISCO has the liberty to buy power at competitive prices from different GENCOs, which may or may not have contract in the same area as the DISCO. In the present scenario, any GENCO in any area may supply power to both DISCOs in its user pool and DISCOs in other areas through tie-lines. The transactions have to be implemented through an independent system operator (ISO). So contract can be represented by a matrix called 'DISCO participation matrix' (DPM). In DPM, the number of rows has to be equal to the number of GENCOs and the number of columns has to be equal to the number of DISCOs in the system. Any entry of this matrix is a fraction of total load power contracted by a DISCO toward a GENCO. As a result, total of entries of column belong to $DISCO_i$ of DPM is

$$\sum_{j=1}^{m} cpf_{ij} = 1 \tag{1}$$

where cpf is the contact participation factor.

In the present power system, as there are two areas and each of them including two DISCOs and two GENCOs, the DPM can be expressed as follows:

$$DPM = \begin{bmatrix} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \end{bmatrix} \tag{2}$$

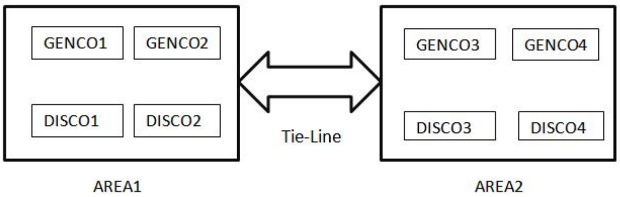


Fig1: Schematic of a two area restructured power system

In the deregulated environment, when the load demanded by a DISCO changes, a local load change is observed in the area of the DISCO. Since there are a lot of GENCOs in each area, area control error (ACE) signal must be shared by these GENCOs in proportion to their contributions. The coefficients, which represent this sharing, are called as "ACE participation factors (ap)" and $\sum_{i=1}^{m} ap_{ji} = 1$ where, m is the number of GENCOs in j^{th} area.

So, the scheduled steady state power flow on any tie-line can be written:

$\Delta P_{tie12}^{scheduled}$ = (Demand of DISCOs in area-2 from GENCOs in area-1) — (Demand of DISCOs in area-1 from GENCOs in area-2)

So, $\Delta P_{tie12}^{scheduled}$ the can be expressed as:

$$\Delta P_{tie12}^{scheduled} = \sum_{i-1}^{2}\sum_{j=3}^{4} cpf_{ij}\ \Delta PL_j - \sum_{j=3}^{4}\sum_{j=1}^{2} cpf_{ij}\ \Delta PL_j \quad (3)$$

where ΔPL is the load demand.

In the steady state condition, ΔP_{tie12}^{error} vanishes as the actual tie-line power flow reaches the scheduled power flow. This error signal is used to generate the respective ACE signals in the traditional scenario:

$$ACE_1 = B_1\Delta f_1 + \Delta P_{tie12}^{error}$$
$$ACE_2 = B_2\Delta f_2 - \Delta P_{tie12}^{error}$$

3. STATE SPACE REPRESENTATION OF THE TWO AREA POWER SYSTEM UNDER DEREGULATED ENVIRONMENT

In this case, the dynamic model in state space form can be given as

$$\dot{X} = AX + BU + \Gamma P + \gamma p \quad (4)$$

where A is 11×11 matrix, B is 11×2 matrix, Γ is 11×4 matrix and γ is 11×2 matrix. In this study, three different cases are considered.

In this study, three different cases are considered as follows:

3.1 CASE 1

In this case the GENCOs in each area participate equally in AGC, i.e., ACE participation factors are $a_{11} = 0.5$, $a_{12} = 0.5$, $a_{21} = 0.5$, $a_{22} = 0.5$ and the load change occurs only in area-1. So the load is demanded only by $DISCO_1$ and $DISCO_2$ and in this case, the values of the load demand are considered as $\Delta PL_1 = 0.05$ pu MW, $\Delta PL_2 = 0.05$ pu MW, $\Delta PL_3 = 0.0$, $\Delta PL_4 = 0.0$. Here the DISCO participation matrix (DPM) has been considered as follows:

$$DPM = \begin{bmatrix} 0.5 & 0.5 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad (5)$$

3.2 CASE 2

In this case, ACE participation factors are considered as $a_{11} = 0.75$, $a_{12} = 0.25$, $a_{21} = 0.60$, $a_{22} = 40$ and the values of this load demand are considered as $\Delta PL_1 = 0.05$ pu MW, $\Delta PL_2 = 0.05$ pu MW, $\Delta PL_3 = 0.05$, $\Delta PL_4 = 0.05$. Here the DISCO participation matrix (DPM) has been considered as follows:

$$DPM = \begin{bmatrix} 0.3 & 0 & 0.5 & 0.1 \\ 0.5 & 0.2 & 0.5 & 0.5 \\ 0.2 & 0.7 & 0 & 0.2 \\ 0.0 & 0.1 & 0.0 & 0.2 \end{bmatrix} \quad (6)$$

3.3 CASE 3

In this case excess power is not contracted out to any GENCO. Here the condition of second operation case is considered and the demand of $DISCO_1$ is considered as 0.1 pu MW excess power.

4. ANT COLONY OPTIMIZATION ALGORITHM (ACO)

The ant colony optimization process can be explained by representing the optimization problem as a multilayered graph, where the number of layers is equal to the number of design variables and the number of nodes in a particular layer is equal to the number of discrete values permitted for the corresponding design variable. Thus each node is associated with a permissible discrete value of a design variable. In this paper, first, taking into account

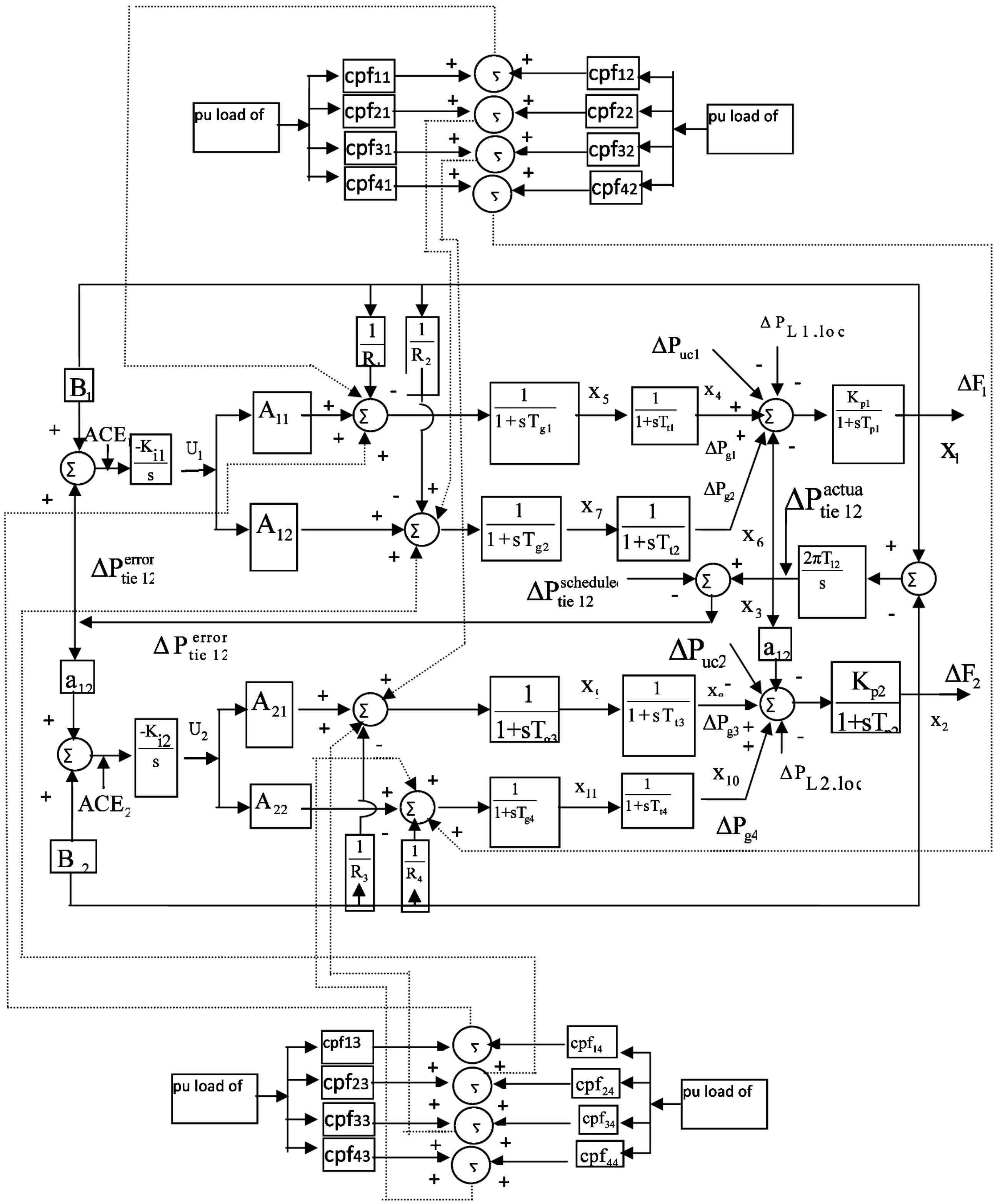


Fig.2: Block diagram of two area deregulated power system

the effects of bilateral contracts on the dynamics, modified AGC including two areas, each of which consisting of two GENCOs and two DISCOs, is given and then tie-line bias, K_I and frequency bias factor, B of this deregulated AGC is optimized by using Ant Colony algorithm.

The step-by-step procedure of the ACO algorithm for solving a minimization problem can be summarized as follows [9]:

Step 1

The number of ants in the colony is assumed as N and a set of permissible discrete values for each of the n variables and equal amounts of pheromone $T_{ij}^{(l)}$ initially along all the paths where '*l*' denotes the iteration number. For simplicity, $T_{ij}^{(l)} = 1$ can be assumed for all paths i-j. Now the iteration number is set *l*=1.

Step 2

(a) Next the probability p_{ij} of selecting the arc or ray (or the discrete value) x_{ij} is computed as

$$p_{ij} = \frac{T_{ij}^{\ l}}{\sum_{j \in N_i} T_{im}^{\ l}} \text{ for } j \in N_i \ \dots \qquad (7)$$

$$= 0 \qquad \text{for } j \notin N_i$$

where '*l*' denotes the degree of importance of the pheromones and N_i indicates the set of all the nodes directly connected to node i except the predecessor node (i.e., the last node visited before i).

(b) The specific path (or discrete values) chosen by the k^{th} ant can be determined using the roulette-wheel selection process in step 3(a).For this, the cumulative probability is found ranges associated with different paths based on the probabilities given by Eq.(1).

Step 3

(a) Then N random numbers, $r_1, r_2 \ldots r_N$ in the range (0,1), one for each ant, are generated. The path considered is assumed by ant k as the one for which the cumulative probability range [found in step 2(b)] includes the value r_i.

(b) Step 3(a) is repeated for all variables

(c) The objective function values corresponding to the complete paths is evaluated (design vectors $X^{(k)}$ chosen by ant k=1,2,…..,N)

$$f_k = f(\mathbf{X}^{(k)}); \ k = 1, 2, \ldots, N \qquad (8)$$

The best and worst paths among the N paths chosen by different ants can are determined as follows:

$$f_{best} = \min(f_k) \quad k=1,2,3,\ldots\ldots N \qquad (9)$$

$$f_{worst} = \max(f_k) \quad k=1,2,3,\ldots\ldots N$$

Step 4

The process is assumed to have converged if all N ants take the same best path. If convergence is not achieved, it is assumed that all the ants return home and start again in search of food. Set the new iteration number as *l* = *l* + 1, and update the pheromones on different arcs (or discrete values of design variables) as

$$T_{ij}^{(l)} = T_{ij}^{(left)} + \sum \Delta T_{ij}^{(k)} \qquad (10)$$

where $\tau_{ij}^{(left)}$ denotes the pheromone amount of the previous iteration left after evaporation, which is computed as

$$T_{ij}^{(left)} = (1 - d) T_{ij}^{(l-1)} \qquad (11)$$

and $\Delta T_{ij}^{(k)}$ is the pheromone deposited by the best ant k on its path and the summation extends over the best ants k (if multiple ants take the same best path). The evaporation rate d is assumed to be in the range 0.6 to 0.9 and the pheromone deposited $\Delta T_{ij}^{(k)}$ is computed using the following equation:

$$\Delta T_{ij}^{(k)} = \frac{\sigma f_{best}}{f_{worst}} \text{ if } (i,j) \in \text{ global best tour} \quad (12)$$

$$= 0; \text{ otherwise}$$

where σ denotes a pheromone scaling factor. With the new values of $T_{ij}^{(l)}$, it is to be moved to step 2. Steps 2, 3, and 4 are repeated until the process converges, that is, until all the ants choose the same best path. In some cases, the iterative process is stopped after completing a pre-specified maximum number of iterations (l_{max}).

5. OPTIMIZATION OF ACE PARAMETERS USING ACO

In the present work, to optimize the parameters of AGC controllers using ACO, the following objective function based on a quadratic performance index have been considered.

$$J = \int_0^\infty \left[-K_{I1}\Delta P_1^2 - K_{I1}B_1\Delta f_1^2 - K_{I2}\Delta P_2^2 - K_{I2}B_2\Delta f_2^2 \right] dt \quad (13)$$

where K_{Ii} and B_i (i = 1,2) are taken different from each other since all the areas in the power system have different configurations, and ΔP_i (i = 1, 2) are taken as

$$\Delta P_1 = \sum_{j=1}^{NDISCO=4} cpf_{ij}\Delta PL_j \quad (14)$$

Here the ant population size is taken as N = 40. No of permissible discrete values for each variable is taken as 21. $K_{i1}^{min} = K_{i2}^{min} = 0.5$; $K_{i1}^{max} = K_{i2}^{max} = 1.0$; $B_{i1}^{min} = B_{i2}^{min} = 0.2$; $B_{i1}^{max} = B_{i2}^{max} = 0.5$.

6. RESULTS AND DISCUSSION

The optimum values of K_I and B for the operation cases are given in Table 1. From Table 1, it is seen that the values of K_I and B are different for different operating conditions. But it is not practical to optimize the value of K_I and B for each operating condition. So, the values of K_I and B optimized for case 2 will be used for all other operating conditions. Fig.3-Fig.5, Fig.6- Fig.8 and Fig.9- Fig.11 show the responses of deviations of frequency of each area and tie-line powers for case 1, case 2 and case 3 respectively. From the results, it is seen that responses are satisfactory in terms of peak deviations and settling time.

Table 1: The optimum values of ACE parameters

Parameters	Case 1	Case 2	Case 3
K_{I1}	0.5000	0.5450	0.5217
K_{I2}	0.5227	0.5250	0.5652
B_1	0.2136	0.2150	0.2391
B_2	0.2682	0.2900	0.2652

CASE 1:

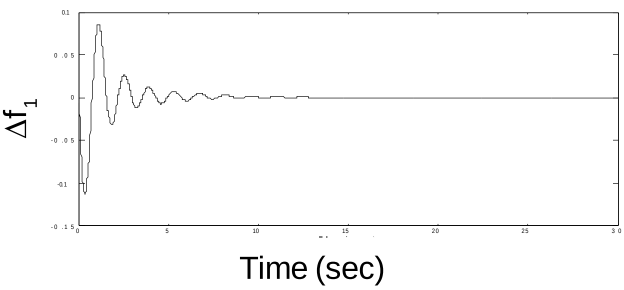


Fig.3: Deviation of frequency in area 1 in for the case 1

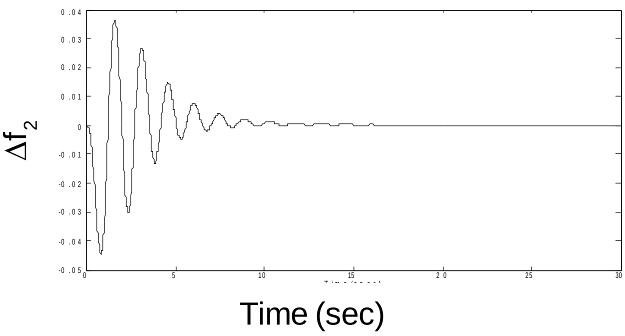
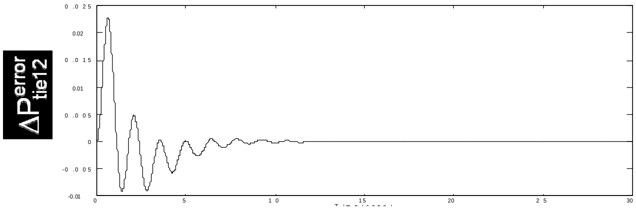


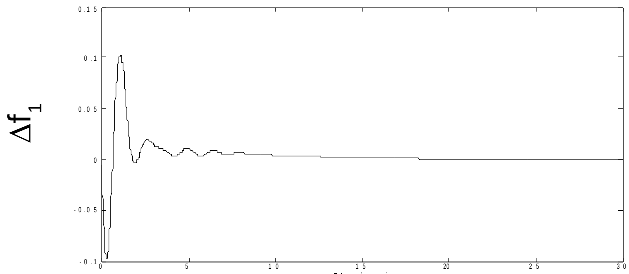
Fig.4: Deviation of frequency in area 2 in for the case 1



Time (sec)

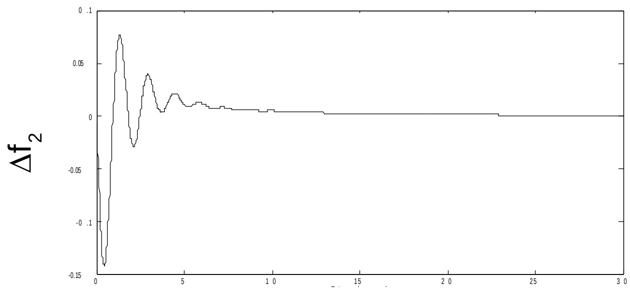
Fig.5: Plot of ΔP_{tie12}^{error} for the case 1

CASE 2:



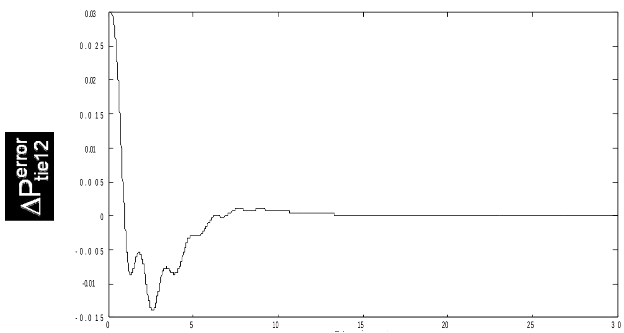
Time (sec)

Fig.6: Deviation of frequency in area 1 in for the case 2



Time (sec)

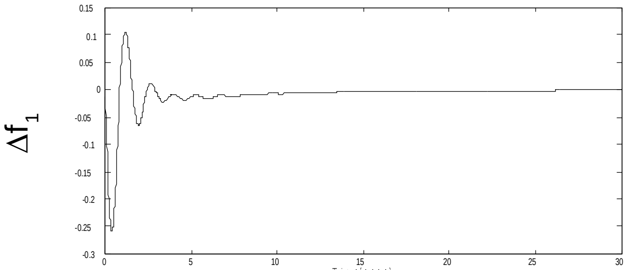
Fig. 7: Deviation of frequency in area 2 in for the case 2



Time (sec)

Fig. 8: plot of ΔP_{tie12}^{error} for the case 2

CASE 3:



Time (sec)

Fig. 10: Deviation of frequency in area 1 in for the case 3

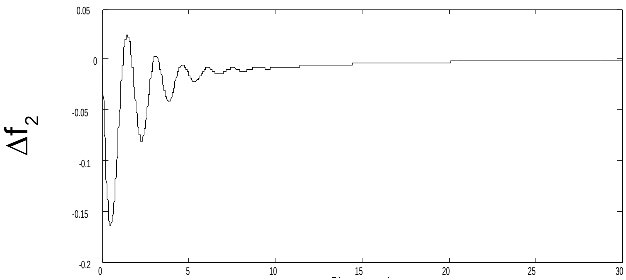


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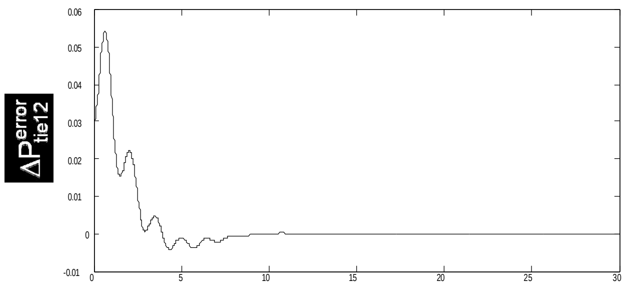
Fig. 11: Deviation of frequency in area 2 in for the case 3



Time (sec)

Fig. 12: Plot of ΔP_{tie12}^{error} for the case 3

6. CONCLUSION

In this paper, AGC of the power system after deregulation including bilateral contracts has been investigated and ACE parameters have been optimized for an appropriate performance index by using ant colony optimization algorithm. It is found that the optimized values of K_I and B are different for different operating conditions. The simulation results show that the ACE parameters values obtained from optimization are satisfactory for different operating conditions in terms of peak deviations and settling time in modified AGC after deregulation.

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