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Design of Integral Controller for Automatic Generation Control in Deregulated Environment

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Abstract

In this paper, the concept of automatic generation control (AGC) in a deregulated power system is dealt with. The traditional AGC two area system is modified to take into account the role of AGC in open market power system. Open transmission access and the evolving of more socialized companies for generation, transmission and distribution affects the formulation of AGC problem to accommodate new constraints associated with territorial functionality of each company. So the traditional AGC two-area system is modified to take into account the effect of bilateral contracts on the dynamics. The concept of DISCO Participation Matrix to simulate these bilateral contracts is introduced and reflected in the two-area block diagram. Computer simulations results reveal the impact of this structure on the functionality of AGC in the presence of nonlinearities like Dead band and GRC. This work also uses GENETIC algorithm to optimize the value of integral controller in order to achieve better dynamic response of the system.

Keywords: Automatic generation control (AGC), Area control error (ACE), Deregulation, Disco participation matrix, Genco, Disco and Transco.

Introduction

As deregulation in electric industry is a fast approaching reality, the operation of the power system in this new type of environment will be different as it was in the regulated scheme. In the regulated market, the electric power network was vertically integrated and a single utility monopolized generation, transmission and distribution in a certain geographic region. Interconnection between networks and interaction between companies was usually voluntary to improve system reliability and performance. Tariffs however were limited and customers were limited to choose the supplier of their electricity. Under deregulation the power system structure changed in such a way that would allow the evolving of more specialized industries for generation (Genco), transmission (Transco) and distribution (Disco). In the context of open access, increased competition two questions have been consistently rising; (i) how can system reliability and security be maintained and (ii) how can be economic efficiency maintained?. As a result, the concept of independent system operator (ISO) as an unbiased coordinator to balance reliability with economics has emerged[2-3]. A detailed study on the control of generation in deregulated power systems is given in [1]. The assessment of Automatic Generation control in a deregulated environment is given in detail in [4- 6] and [7] provides a detailed review over this issue and explains how an AGC system could be simulated and optimized after deregulation. However these authors have not considered the presence of nonlinearities like deadband and generation rate constraint and hence their work does not explain the working of AGC in deregulated environment in the presence of nonlinearities.

In view of this the main aim of this work are: (1)to develop a realistic AGC model along with nonlinearities under open market system (2) to take into account the effect of bilateral contracts on the system.(3) to include the concept of DISCO Participation matrix in a two area reheat system. (4)to optimize the gain of integral controller under deregulated environment using Genetic algorithm.

This paper is organized as follows. In Section II, we explain how the bilateral transactions are incorporated in the traditional AGC system leading to a new block diagram. In Section III we discuss the performance index used in optimization of integral controller K_I using Genetic algorithm. Simulation results are presented in Section IV.

Disco Participation Matrix

Unlike the traditional system in this restructured environment, GENCOs sell power to various DISCOs at competitive prices. Thus, DISCOs have the liberty to choose the GENCOs for contracts. They may or may not have contracts with the GENCOs in their own area. This makes various combinations of GENCO-DISCO contracts possible in practice. Introduce the concept of a “DISCO participation matrix” (DPM) according to [7] to make the visualization of contracts easier. 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 this matrix can be thought of as a fraction of a total load contracted by a DISCO (Column) toward a GENCO (row). The sum of all the entries in a Column in this matrix is unity. DPM shows the participation of a DISCO in a contract with GENCO; hence the name “DISCO participation matrix”. So for a two area system consisting of three GENCOs and two DISCOs in each area the DISCO participation matrix can be represented as

$$DPM=\begin{array}{cccccc} & 1 & 2 & 3 & 4 & \text{DISCO} \\ 1 & cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} & \\ 2 & cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} & \\ 3 & cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} & \text{GENCO} \\ 4 & cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} & \\ 5 & cpf_{51} & cpf_{52} & cpf_{53} & cpf_{54} & \\ 6 & cpf_{61} & cpf_{62} & cpf_{63} & cpf_{64} & \end{array}$$

Where cpf refers to “contract participation factor”.

A. Block Diagram Formulation

In this section, we formulate the block diagram for a two area AGC system in the deregulated scenario. Whenever a load demanded by a DISCO changes it is reflected as a local load in the area in which this DISCO belongs. This corresponds to the local loads ΔP_{L1} and ΔP_{L2} 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” (apfs). It should be noted that $\sum_{j=1}^{m} apf_j = 1$ where m is the number of GENCOs. As a particular set of GENCOs are supposed to follow the load demanded by a DISCO, information signals must flow from a DISCO to a particular GENCOs specifying corresponding demands. The demands are specified by cpf’s (elements of DPM) and the p.u MW load of a DISCO. These signals carry information as to which GENCO has to follow a load demanded by which DISCO. Unlike in the traditional system the actual tie-line power flow also includes the demand from DISCOs in one area to GENCOs in another area. It can be represented as follows.

$\Delta P_{tie\ 1\text{-}2,\ actual} = \Delta P_{tie\ 1\text{-}2}+$ (demand of DISCOs in area 1 from GENCOs in area 2)
(demand of DISCOs in area 2 from GENCOs in area 1)

In the steady state the generation of each GENCO matches the demand of DISCOs in contract with it. For example if a DISCO demands 0.1pu MW from $GENCO_1$ then at the steady state it would generate as follows

$$\sum_{d=1}^{n} (\text{p.u\_ MW load of DISCO‘d’})*cpf_{1d} = 0.1\text{pu MW}$$

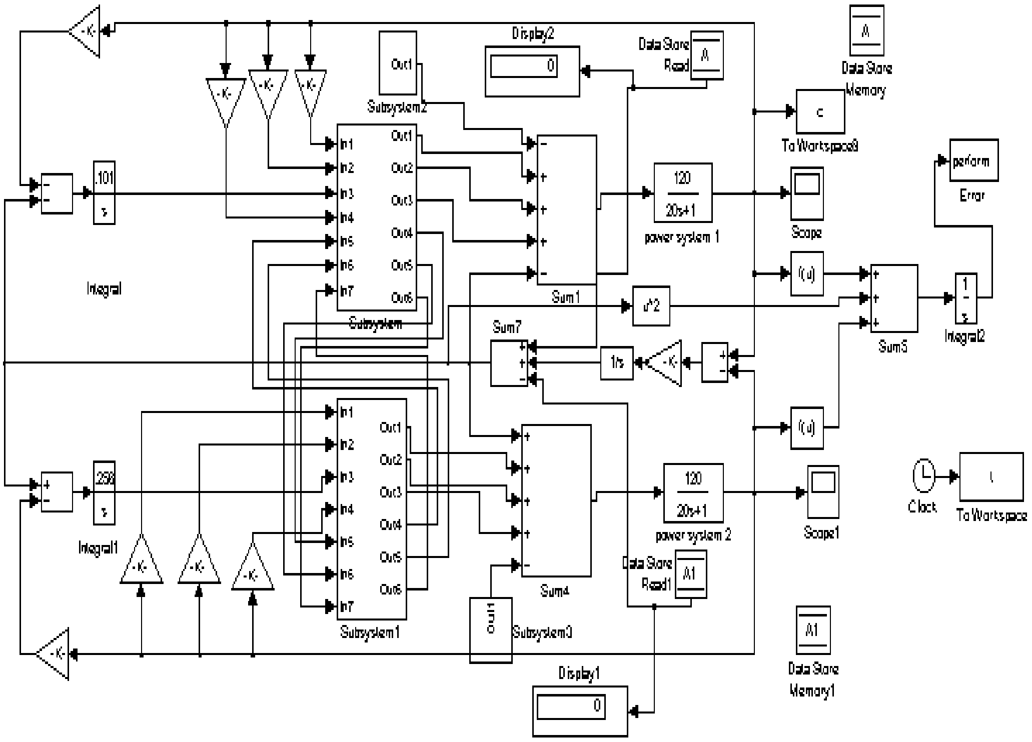


Figure 1: Two-area AGC system block-diagram in restructured scenario.

Performance Index

The two area system in the deregulated case with identical areas can be optimized with respect to system parameters to obtain the best response. The parameter involved in the feedback is the integral controller (K_I). The optimal value of K_I depend upon the cost function used for optimization. The integral of squared error criterion (ISE) is used in this case,

$$ISE = \int_0^\infty ((\Delta P_{tie})^2 + \alpha(\Delta f_1)^2 + \gamma((\Delta f_2)^2)dt$$

Here α and γ are the penalty factors for the frequency deviation in both areas.

Both the values equal to 0.065 are considered in this work. A more systematic approach to the optimization can be achieved by using Genetic algorithm to optimize the value of K_I. The steps to optimize the value of integral controller can be summarized as follows:

(1) As the genetic algorithm takes into account random pairs of strings, we create a random number of strings depending upon our necessity and also note down their decoded values along with setting a maximum allowable generation number t_{max}.

(2) Using the mapping rule we next find out the corresponding values of K_I for the corresponding decoded values.

(3) Using these values of K_I the fitness function values are found out

(4) Next the process of reproduction is carried out on the strings to create a mating pool.

(5) The process of crossover and mutation is also carried out on the strings with probabilities of 0.8 and 0.05 respectively

(6) After the termination criteria is met with, the value of K_I with minimum fitness function value is considered as optimum value.

Simulation and Results

A two area system is used to illustrate the behavior of the proposed AGC scheme. Both the areas are assumed to be identical and also the governor-turbine units in each area are also assumed to be identical.

A. Case 1: Base case

Consider a case where all the GENCOs in each area participate equally in AGC. Here in the two-area system we consider 3 generators in each area. So here we have 6 generators in total we consider only 3 GENCOs with 2 DISCOs in each area. Assume that the total load of each Disco is perturbed by 0.002 p.u Mw and each Genco participates in AGC as defined by following area participation factors (apfs):

apf_1=0.5, apf_2=0.25; apf_3=0.25; apf_4=0.5; apf_5=0.25; apf_6=0.25 and the Discos contract with the GENCOs as per the following disco participation matrix.

$$\mathbf{DPM} = \begin{bmatrix} 0.1 & 0.0 & 0.3 & 0.4 \\ 0.0 & 0.1 & 0.0 & 0.2 \\ 0.3 & 0.4 & 0.1 & 0.0 \\ 0.2 & 0.0 & 0.2 & 0.1 \\ 0.2 & 0.3 & 0.0 & 0.1 \\ 0.2 & 0.2 & 0.4 & 0.2 \end{bmatrix}$$

As explained in II in the steady state, the GENCOs must generate ΔP_{m1} = 0.1*0.002 + 0.3*0.002 + 0.4*0.002 = 0.0016 p.u MW. Similarly ΔP_{m2} = 0.0006 p.u MW, ΔP_{m3} = 0.0016 p.u MW and ΔP_{m4} = 0.0010 p.u MW, ΔP_{m5} = 0.0012 p.u MW, ΔP_{m6} = 0.0020 p.u MW.

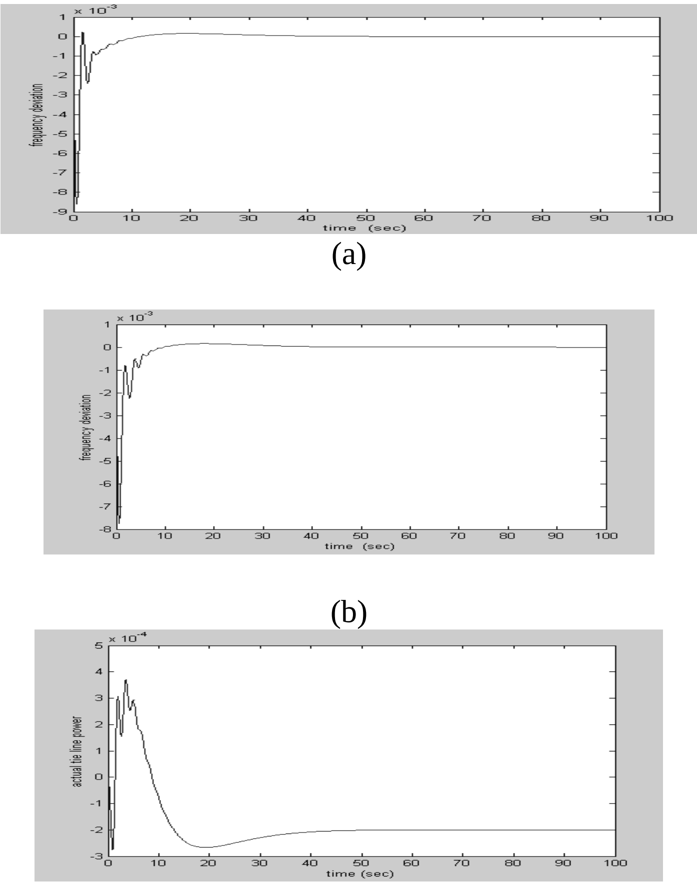
Table-1 shows the error value between the theoretical values and simulated values for the above case.

The tie line power scheduled in the direction from area1 to area 2 can be written as $\sum_{i=1}^{3}\sum_{j=3}^{4} cpf_{ij}\Delta P_{Lj} - \sum_{i=4}^{6}\sum_{j=1}^{2} cpf_{ij}\Delta P_{Lj}$ which gives the result as -0.0002 p.u MW and the same result is obtained through the Simulink values also.

Figure 2 shows the frequency and actual tie line power deviations for the above case. Figure 2.1 and Figure 2.2 shows the change in generations of GENCOs in both area 1 and area 2 for the above load change

Table 1: Error value between theoretical and simulated values.

Type of GENCO	Theoretical Values	Simulated Values	Error value
GENCO 1	0.0016	0.002	0.0004
GENCO 2	0.0006	0.0005	-0.0001
GENCO 3	0.0016	0.0015	-0.0001
GENCO 4	0.0010	0.0012	0.0002
GENCO 5	0.0012	0.001	-0.0002
GENCO 6	0.0020	0.0018	-0.0002

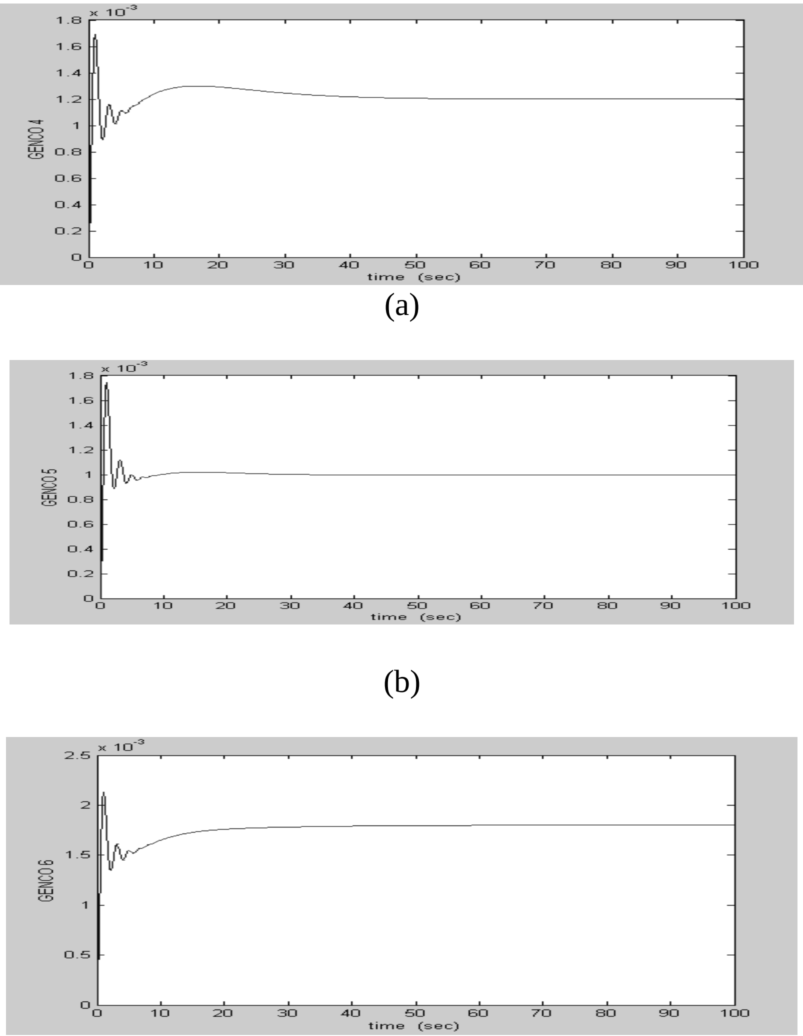


(a)

(b)

(c)

Figure 2: (a) Frequency deviation of area1; (b) frequency deviation in area 2 and (c) the tie line power deviations.

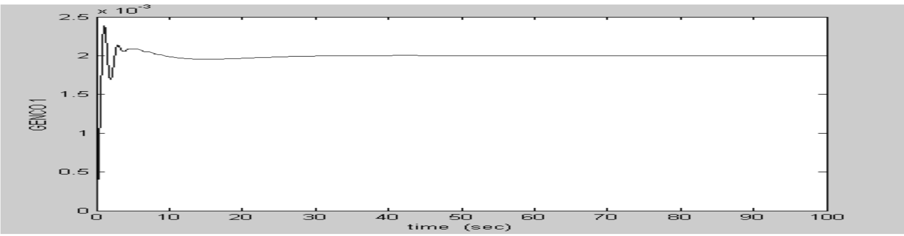


(a)

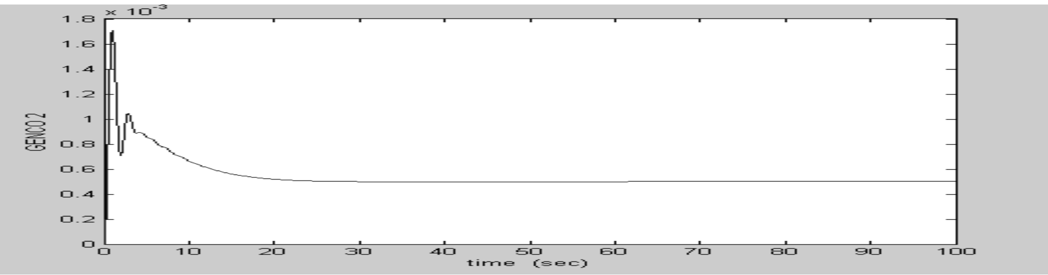
(b)

(c)

Figure 2.1: (a),(b),(c) Generations of GENCOs in area 1 as demanded by DISCOs in both areas.



(a)



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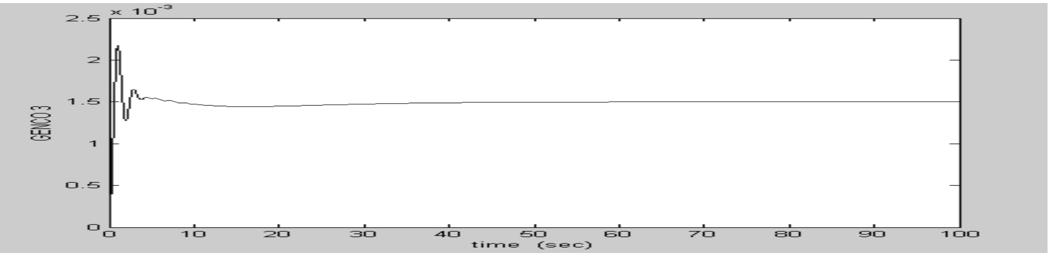


(c)

Figure 2.2: (a),(b),(c) Generations of GENCOs in area 2.

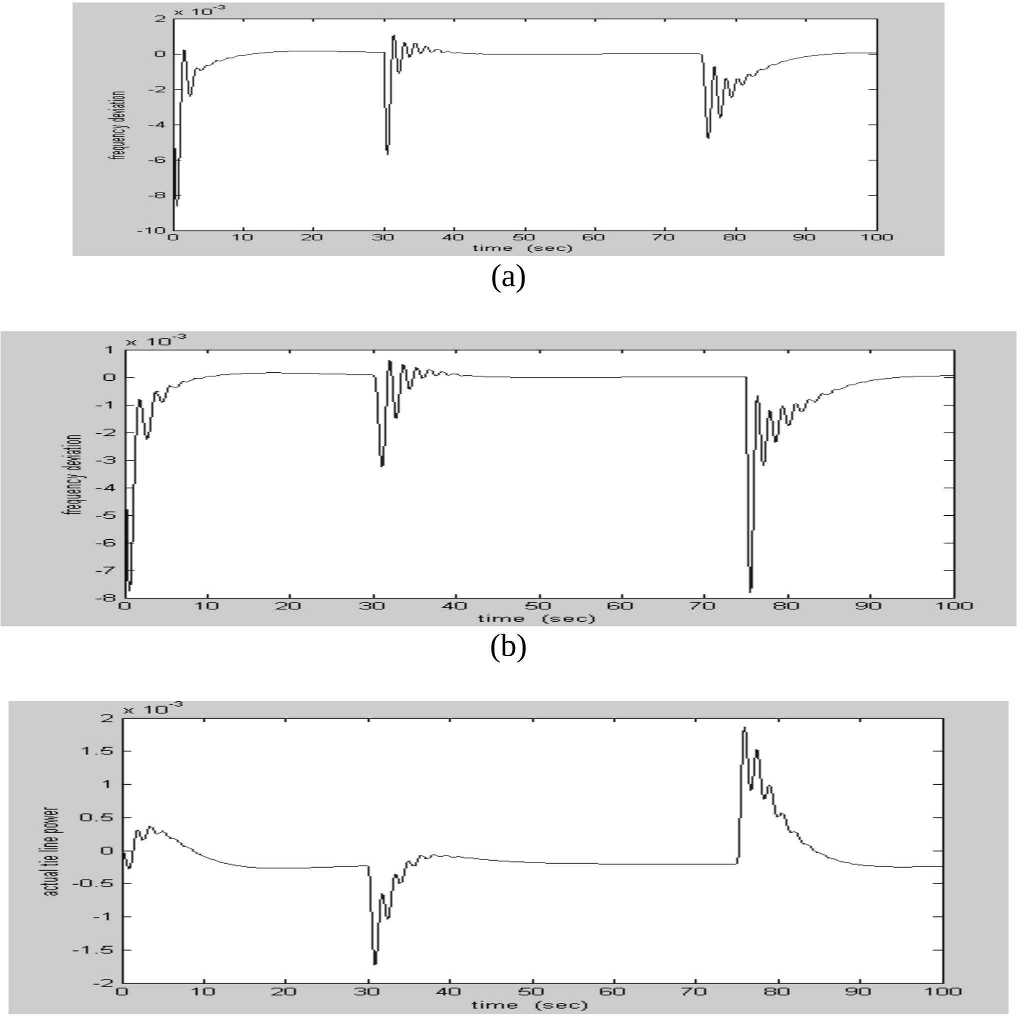
B. Case 2: Contract Violation in both areas

Consider the same case once again except that $DISCO_1$ demands additional load after 30 sec and $DICSO_4$ in area 2 demands additional load after 75 sec. The change of generations of all GENCOS in both areas can be seen in the table-2 shown below. Figure 3 shows the frequency and actual tie line power deviations for the above contract violation case Figure 3.1, 3.2 shows the generation of GENCOs of both areas for the above contract violation case

Table 2: Generations of GENCOs during contract violation.

Type of GENCO	Simulated Values
GENCO 1	0.003479
GENCO 2	0.001249
GENCO 3	0.002249
GENCO 4	0.003202
GENCO 5	0.00201
GENCO 6	0.00281

The tie line power scheduled in the direction from area1 to area 2 can be written as $\sum_{i=1}^{3}\sum_{j=3}^{4} cpf_{ij}\Delta P_{Lj} - \sum_{i=4}^{6}\sum_{j=1}^{2} cpf_{ij}\Delta P_{Lj}$ which gives the result as -0.0002 p.u MW in this case also and the same result is obtained through the Simulink values also as seen in figure 3.

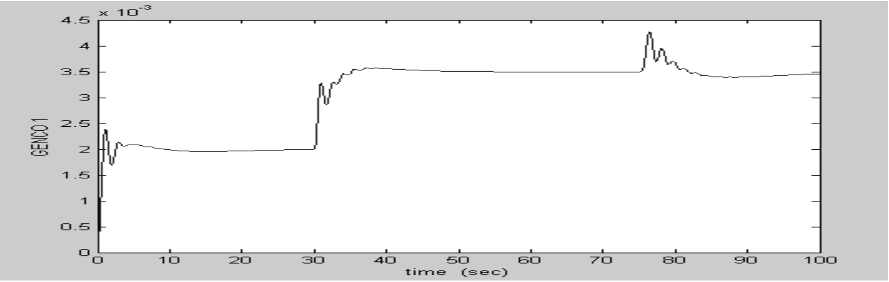


(a)

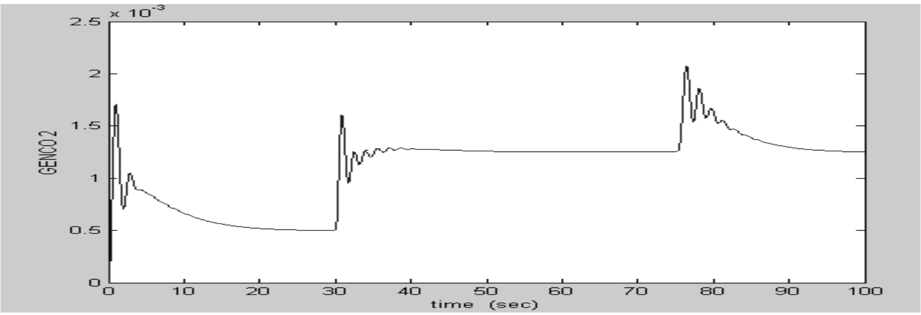
(b)

(c)

Figure 3: (a) Frequency deviation of area1; (b) frequency deviation in area 2 and (c) the tie line power



(a)



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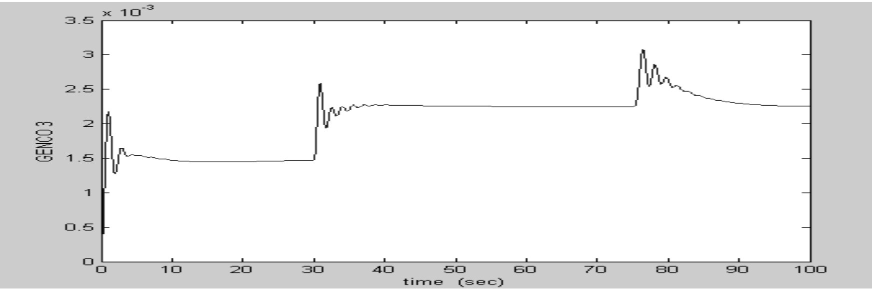
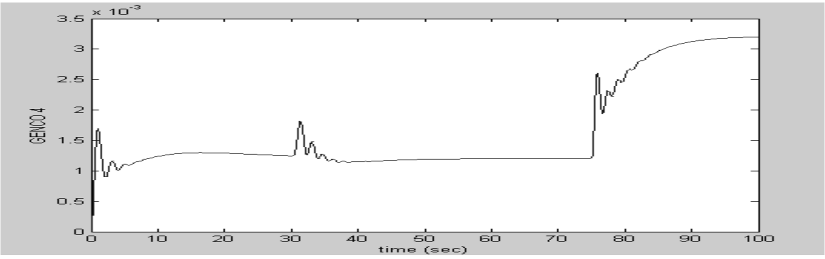
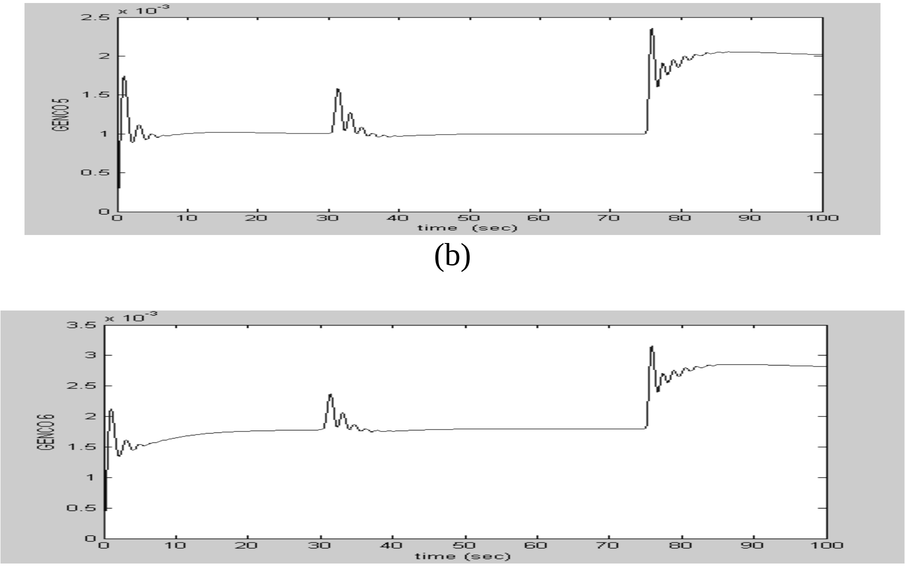


(c)

Figure 3.1: (a),(b),(c) Generations of GENCOs in area 1 as demanded by DISCOs in both areas.



(a)



(b)

(c)

Figure 3.2: (a),(b),(c) Generations of GENCOs in area 2 as demanded by DISCOs in both areas.

Conclusion

The integral gain has been optimized by GENETIC algorithm and the performance of the controller both in traditional and deregulated power system has been reported. The determination of actuating signal to governor is rather easier in traditional environment because the only goal is to satisfy the load demand at all time. But the task of AGC is becoming complicated as because to satisfy different bilateral contracts between different entities of the system. The author has considered all the aspects both in traditional and deregulated power system.

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