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A Modified Model for Automatic Generation Control in Deregulated Power Systems

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Abstract—This paper presents a new simplified AGC model for deregulated power systems. New AGC model facilitates us to design the controller without considering bilateral contracts. And also concentrates only the load disturbances not on the contracted loads. New AGC in deregulated power system is modeled by modifying conventional model with inclusion of bilateral contracts. Bilateral contracts will allow DISCOs in one area to get power from another area. This inclusion complicates the design of the controller by adding the contracted power also along with the disturbance power. The proposed new AGC model is simulated in MATLAB environment and results were presented.

Index Terms — Automatic Generation Control, Bilateral Contracts, Power Systen Control, Deregulation.

1 INTRODUCTION

In the traditional power systems, the generation, transmission and distribution are owned by a single entity called a vertically integrated utility (VIU), which supplies power at regulated rates. Such VIUs are interconnected by tie lines to other VIU's to enhance reliability. Following a load disturbance within a VIU, the frequency of that VIU experiences a transient change, and the feedback mechanism comes into play and generates an appropriate rise/lower signal to the turbine to make the generation follow the load. In steady state, the generation is matches with the load, driving the tie line power and frequency deviations to zero.

In the restructured power systems, the VIU no longer exists. However, the common operational objectives, i.e. restoring the frequency and the net interchanges to their desired values for each control area remain. In the vertically integrated power system structure, some generation units are equipped with secondary control and frequency regulation requirements, but in an open energy market, even such GENCOs may or may not participate in the AGC. Deregulated power systems consists of generation companies (GENCO), distribution companies (DISCO), transmission companies and Independent System Operator (ISO). In this open market based in bilateral contracts, DISCOs have the freedom to contract with any of the GENCO in the own area or other area and these contracts are made under supervision of ISO. ISO is also responsible for managing the ancillary services like AGC etc. Same as DISCOs, ISO will also have freedom to get power from the same or other area to provide ancillary services to the system. Therefore, in system with an open access policy, there is a need for an AGC model which can be used for analysis as well as development of a efficient control strategies. Attempts have been made in recent past to study AGC issues in deregulated environment. Most of the studies essentially use a model proposed by M.A.Pai [1] for AGC in deregulated power systems.

The aim of this paper is to propose a simplified model of AGC in deregulated power systems which consider only disturbance power instead of considering the frequency deviation due to the bilateral contracts. This paper is organized as follows, In section 2 we first briefly present the AGC model proposed in [1] and which is used by several other researchers. We highlight its limitations and indicate the desirable features that an AGC model for the deregulated environment should possess. In the section 3 and 4 we proposed a new model which incorporates these features. Simulation results are given in section 5, to highlight the difference between the proposed model and existing AGC models. We also demonstrate design of a simple control strategy which can be adopted in the deregulation scenario. However this control is available for any of the well known alternate control strategies.

2 CONVENTIONAL AGC MODEL FOR DEREGULATED POWER SYSTEMS

2.1 Conventional Model

The conventional model, that's being used by several researchers [….] is essentially a simple extinction of traditional Elgerd model [1]. In this AGC model, the concept of disco participation matrix (DPM) is included to the conventional AGC model to incorporate the bilateral load contracts. The DPM gives the extent of consumption of a DISCO from a particulate GENCO. In a power system with m DISCOs and n GENCOs, the DPM is given as

$$DPM = \left[\begin{array}{cc:cc} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ \hdashline cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \end{array}\right]$$

cpf_{ij} is the "generation participation factor", which shows the participation factor of GENCO i in the load following of DISCO j. The sum of all the entries in a column in this matrix is unity $i.e. \sum_{i=1}^{n} cpf_{ij} = 1$). Whenever a load demanded by a DISCO changes, it is reflected as a local load in the area to which this DISCO belongs.

These information signals which are not present in the conventional AGC. In [1] introduction of these signals are justified arguing that these signals give an indication regarding which generator has to follow to which DISCO. This expectation is not valid in a deregulated environment.

As there are many GENCOs in each area, AGC signal has to be distributed among them according to their participation in the AGC. "ACE (Area Control Error) participation factors (apf)" are the coefficient factors which distributes the ACE among GENCOs. If there are 'm' number of GENCOs then $\sum_{i=1}^{m} apf_i = 1$. The block diagram for two area AGC in a deregulated system is shown in figure1.In this model, the scheduled value of steady state tie line power is given as

$\Delta P_{1-2,scheduled}$ = (demand of DISCOs in area II from GENCOs in area I) - (demand of DISCOs in area I from GENCOs in area II)

Then the tie line power error $\Delta P_{1-2,error}$ is expressed as

$$\Delta P_{1-2,error} = \Delta P_{1-2,actual} - \Delta P_{1-2,scheduled}$$

$\Delta P_{1-2,error}$ is used to generate the respective ACE signals as in traditional model. ACE of ith area will be given as

$$ACE_1 = B_1 \Delta F_1 + \Delta P_{1-2tie,error}$$

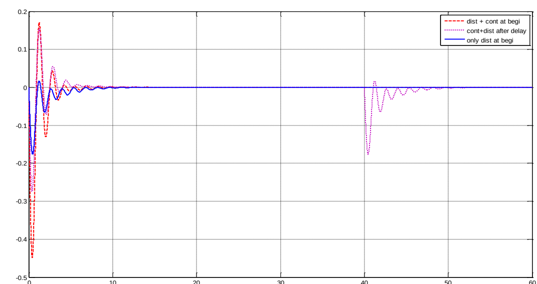
$$ACE_2 = B_2 \Delta F_2 + \Delta P_{1-2tie,error}$$

Where n is the number of neighbor areas.

2.2 Limitations of the model

As indicated earlier, the introduction of DPM into the conventional AGC model is the most significant change that has been incorporated in the above model. The other features are the requirement that there must be atleast one GENCO in each area to provide AGC, making Bilateral Contracts are included in the AGC model by use of DPM and different controllers have been designed for this model. But the fact is that the Bilateral Contracts are the known demands and design of controllers including bilateral contracts.

Simulation results for the existing model which includes bilateral contracts are presented with and without controller in the figure2. From figure2 it is evident that the performance of the system with and without the controller is same in all possible cases.



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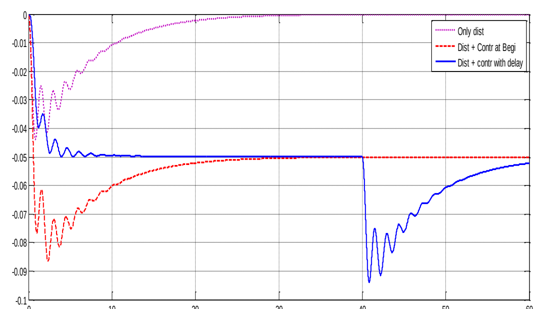

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Figure2. Frequency response and Tie line power deviation for the existing model which includes bilateral contracts with and without controllers.

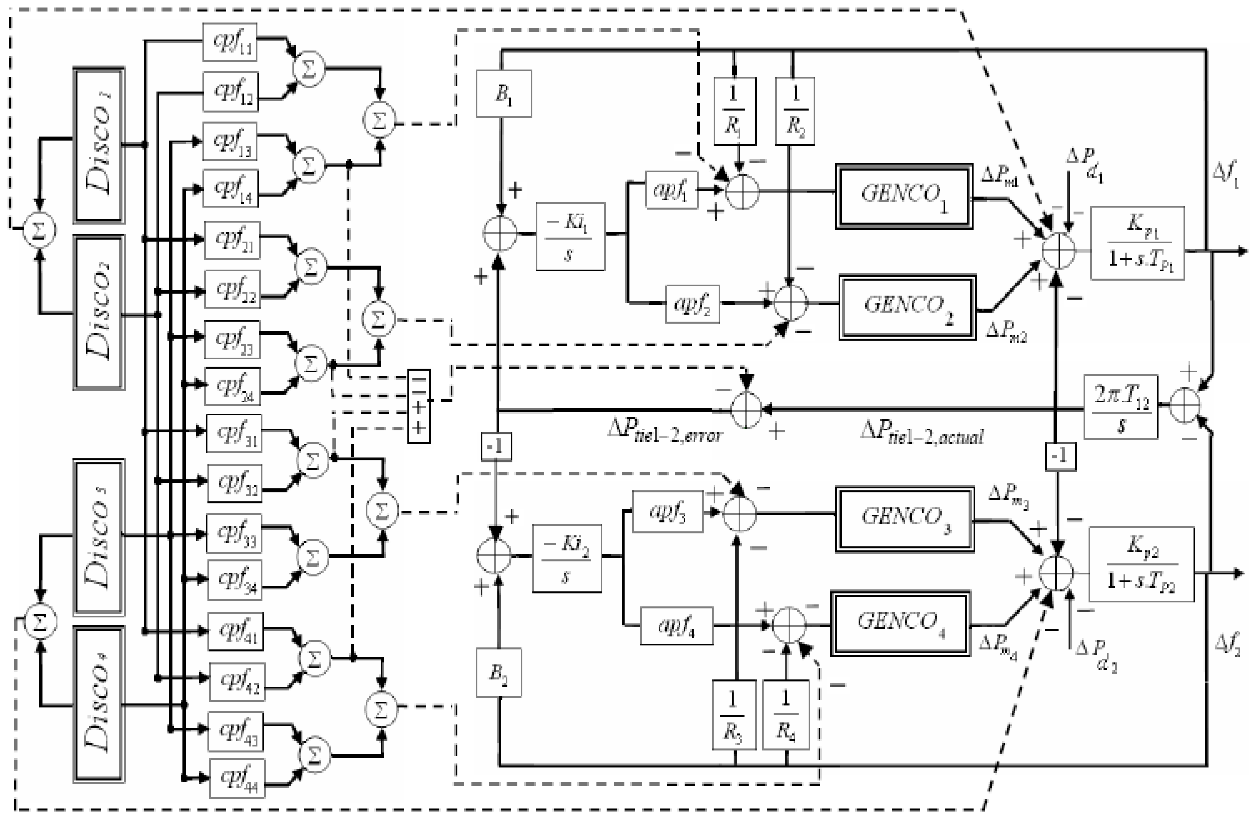


Figure 1.Two area AGC model in deregulated power system

$$A=\begin{bmatrix}
-\frac{1}{T_{P1}} & 0 & \frac{K_{P1}}{T_{P1}} & \frac{K_{P1}}{T_{P1}} & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{K_{P1}}{T_{P1}} \\
0 & -\frac{1}{T_{P2}} & 0 & 0 & \frac{K_{P2}}{T_{P2}} & \frac{K_{P2}}{T_{P2}} & 0 & 0 & 0 & 0 & \frac{K_{P2}}{T_{P2}} \\
0 & 0 & -\frac{1}{T_{T1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -\frac{1}{T_{T2}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -\frac{1}{T_{T3}} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -\frac{1}{T_{T4}} & 0 & 0 & 0 & 0 & 0 \\
-\frac{1}{2\Pi R_1 T_{G1}} & 0 & 0 & 0 & 0 & 0 & -\frac{1}{T_{G1}} & 0 & 0 & 0 & 0 \\
-\frac{1}{2\Pi R_2 T_{G2}} & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{1}{T_{G2}} & 0 & 0 & 0 \\
0 & -\frac{1}{2\Pi R_3 T_{G3}} & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{1}{T_{G3}} & 0 & 0 \\
0 & -\frac{1}{2\Pi R_4 T_{G4}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{1}{T_{G4}} & 0 \\
\frac{T_{12}}{2\Pi} & -\frac{T_{12}}{2\Pi} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$B=\begin{bmatrix}
0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\
\frac{apf_1}{T_{G1}} & 0 \\
\frac{apf_2}{T_{G2}} & 0 \\
0 & \frac{apf_3}{T_{G3}} \\
0 & \frac{apf_4}{T_{G4}} \\
0 & 0
\end{bmatrix}
\Gamma=\begin{bmatrix}
-\frac{K_{P1}}{T_{P1}} & 0 \\
0 & -\frac{K_{P2}}{T_{P2}} \\
0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0
\end{bmatrix}
\beta=\begin{bmatrix}
-\frac{K_{P1}}{T_{P1}} & -\frac{K_{P1}}{T_{P1}} & 0 & 0 \\
0 & 0 & -\frac{K_{P2}}{T_{P2}} & -\frac{K_{P2}}{T_{P2}} \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
\frac{cpf_{11}}{T_{G1}} & \frac{cpf_{12}}{T_{G2}} & \frac{cpf_{13}}{T_{G3}} & \frac{cpf_{14}}{T_{G4}} \\
\frac{cpf_{21}}{T_{G2}} & \frac{cpf_{22}}{T_{G2}} & \frac{cpf_{23}}{T_{G2}} & \frac{cpf_{24}}{T_{G2}} \\
\frac{cpf_{31}}{T_{G3}} & \frac{cpf_{32}}{T_{G3}} & \frac{cpf_{33}}{T_{G3}} & \frac{cpf_{34}}{T_{G3}} \\
\frac{cpf_{41}}{T_{G4}} & \frac{cpf_{42}}{T_{G4}} & \frac{cpf_{43}}{T_{G4}} & \frac{cpf_{44}}{T_{G4}} \\
0 & 0 & 0 & 0
\end{bmatrix}$$

3 PROPOSED AGC MODEL

The two area AGC system considered has two individual areas connected with a tieline. The deviation in each area frequency is determined by considering the dynamics of the governors, turbines, generators and loads represents in that area. The tie line deviation between the areas is computed as the product of the tie line constant and the frequency deviation difference between two areas. fig. 1 shows the AGC model of the two area system considered. The state space representation of AGC model is given by

$$\dot{x} = Ax + Bu + \Gamma p + \beta q \quad (1)$$

Where x is state vector, u is control vector and p is disturbance vector. A, B and Γ and β are the constant matrices associated with state, control, disturbance and bilateral contract vectors respectively. In the state vector x, the secondary suffixes t, ps and g indicates the states of the turbine, power system and governor. The tie line power in two area AGC is given as

$$\Delta P_{tie12} = \frac{T_{12}}{s}\left(\Delta f_1 - \Delta f_2\right) \quad (2)$$

The scheduled power on the tie line in the direction from area I to area II is

$$\Delta P_{1-2tie,scheduled} = \sum_{i=1}^{2}\sum_{j=3}^{4} cpf_{ij}\Delta P_{Lj} + \sum_{i=3}^{4}\sum_{j=1}^{2} cpf_{ij}\Delta P_{Lj}$$

From the AGC model, frequency and tie line power error signals are used to generate the ACE signal in respective area [1]. This ACE of the area is written as

$$ACE_1 = B_1.\Delta f_1 + \Delta P_{tie12} \quad (3)$$

$$ACE_2 = B_2.\Delta f_2 + \Delta P_{tie21} \quad (4)$$

4 CONTROLLER DESIGN

In this paper we propose a PI state feedback controller for this system. A similar controller has been proposed in [9] and demonstrated only for thermal AGC model. Here, an outline of the controller is presented. Consider a v-dimensional output vector yc as

$$y_C = Hx \quad (5)$$

Consider the integral of yC as the state ρ of the integral controller

$$\rho = \int y_C.dt = \int Hx.dt \quad (6)$$

Since the control strategy used in the paper is based on the integral of the ACE as a control signal. After combining equations (1) and (6),we can write

$$\dot{x}_a = A_a x_a + B_a u \quad (7)$$

Where

$$x_a = \begin{bmatrix} x \\ \rho \end{bmatrix}; A_a = \begin{bmatrix} A & 0 \\ H & 0 \end{bmatrix}; B_a = \begin{bmatrix} B \\ 0 \end{bmatrix}$$

The objective of this controller is achieved by minimizing a performance index (J). Where J is given as

$$J = \int\left(x_a^T Q x_a + u_a^T R u_a\right).dt = \int\left(\Delta f_1^{\,2} + \Delta f_2^{\,2} + \Delta P_{tie12}^{\,2}\right).dt \quad (8)$$

Where Q and R are symmetric positive semi-definite, symmetric positive definite and control weightage matrices respectively. Then the solution of this control problem is given by

$$u = K_a x_a \quad (9)$$

Where the optimal feedback matrix Ka is defined as

$$K_a = R^{-1} B_a P \quad (10)$$

Where P is the steady solution of the matrix "Reccati equation".

$$A_a^{\,T} P + P A_a - P B_a R^{-1} B_a^{\,T} P + Q = 0 \quad (11)$$

After finding the controller matrix Ka, the control law of the equation (13) is partitioned into its proportional and integral components as fallows

$$u = K_a x_a = \begin{bmatrix} K_p & K_i \end{bmatrix} \begin{bmatrix} x \\ \rho \end{bmatrix} \quad (12)$$

$$u = K_p x + K_i \rho \quad (13)$$

Where Kp and Ki are the proportional and integral feedback matrices respectively.

5 SIMULATION RESULTS

Case 1:

Two area AGC model is used to illustrate the performance of the present model. To study this model, consider a case where all the DISCOs contract with the GENCOs for power as per the bellow DPM:

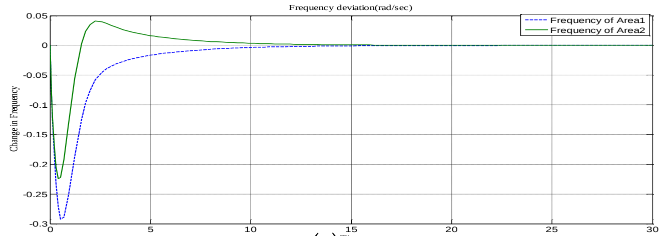
$$DPM = \begin{bmatrix} 0.5 & 0.25 & 0 & 0.3 \\ 0.2 & 0.25 & 0 & 0 \\ 0 & 0.25 & 1 & 0.7 \\ 0.3 & 0.25 & 0 & 0 \end{bmatrix}$$

It is assumed that each DISCO demands 0.1pu MW power from GENCOs as defined in DPM and each GENCO participated in AGC as defined by following apfs: apf1=0.75, apf2=0.25, apf3=0.5, apf4=0.5.

For the DPM mentioned above GENCOs generation must be

$\Delta P_{m1} = 0.105; \Delta P_{m2} = 0.045; \Delta P_{m3} = 0.195; \Delta P_{m4} = 0.055.$

Along with the contracted load, assume that the DISCO1 violates the contract and demands the excess power. This uncontracted power must be supplied by the GENCOs in the same area. This must be reflected as a local load of the area but not the contracted demand. The disturbance power is supplied by GENCOs in the area1 according to apfs. The response of the system is shown in figure 3.



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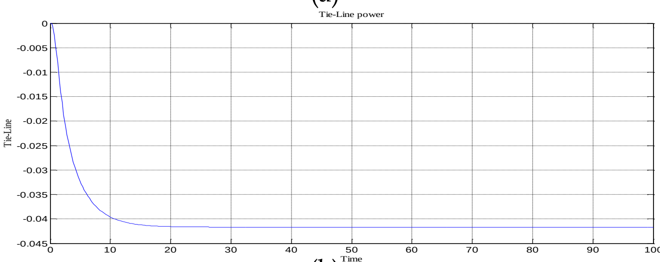

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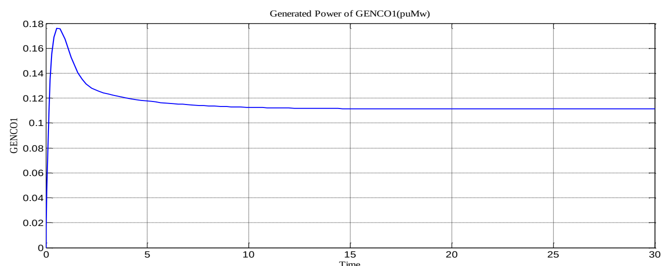

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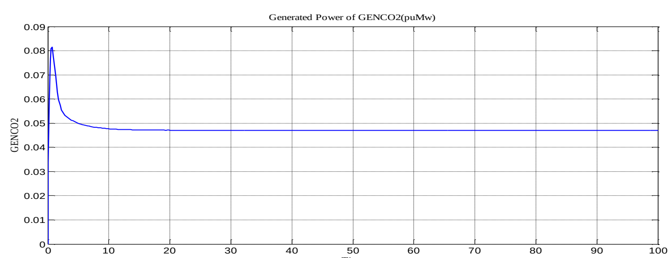

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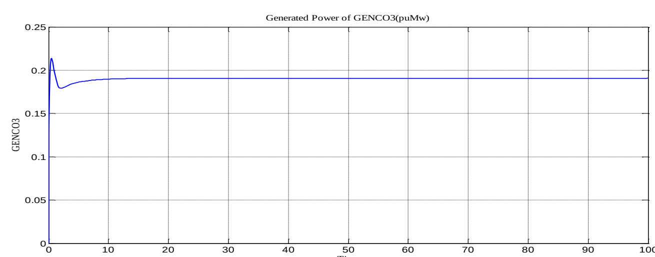

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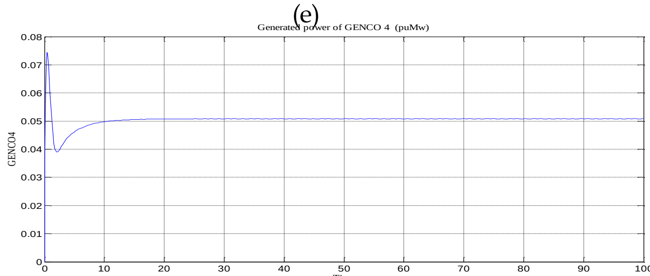

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Figure 3 (a) Frequency deviations (rad/s). (b) Tie line power. (c,d,e,f) Generated power for case 1.

Case 2: Contract Violation

It may happen that a DISCO violates a contract by demanding more power than that specified in the contract. This excess power is not contracted out to any GENCO. This uncontracted power must be supplied by the GENCOs in the same area as the DISCO. It must be reflected as a local load of the area but not as the contract demand. Consider case 1 again with a modification that DISCO demands 0.1 pu MW of excess power. The response of the system is shown in figure 4 with this contract violation. The total local load in area 1

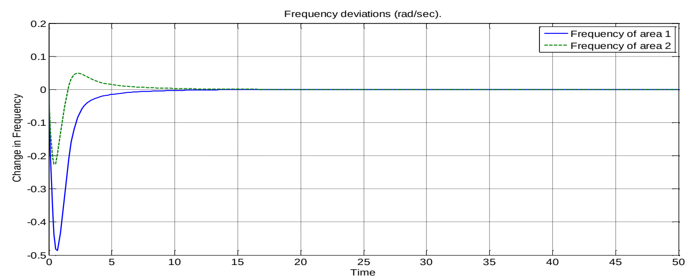
$$\Delta P_{L1,LOC} = LoadofDISCO1 + LoadofDISCO2$$

=(0.1+0.1)+0.1 pu MW=0.3 pu MW

Similarly, the total local load in area 2

$$\Delta P_{L2,LOC} = LoadofDISCO3 + LoadofDISCO4$$

=0.2 pu MW (no un contracted load)



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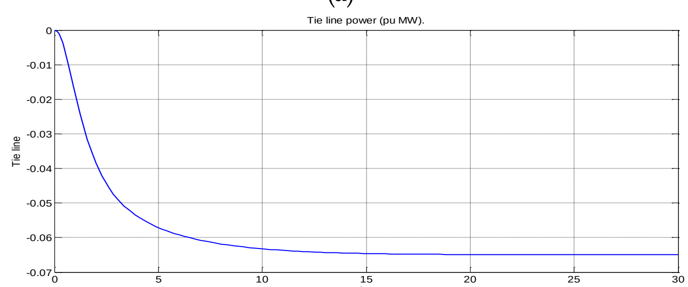

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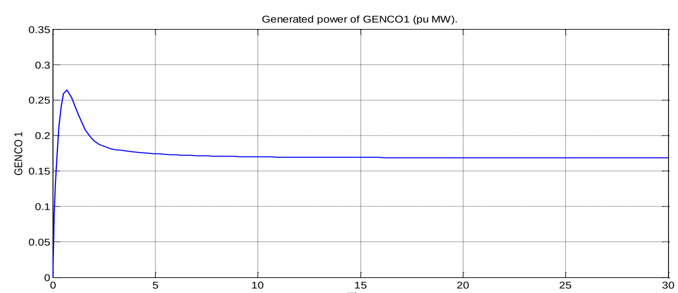

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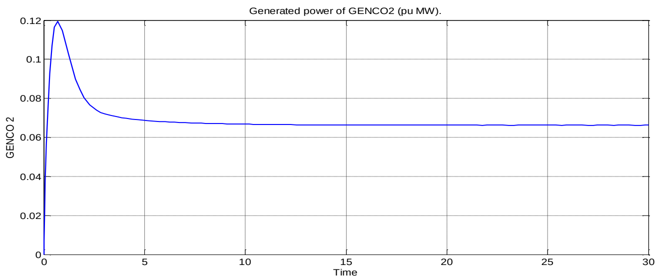

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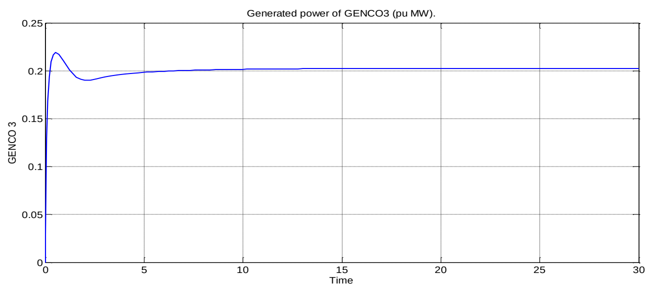

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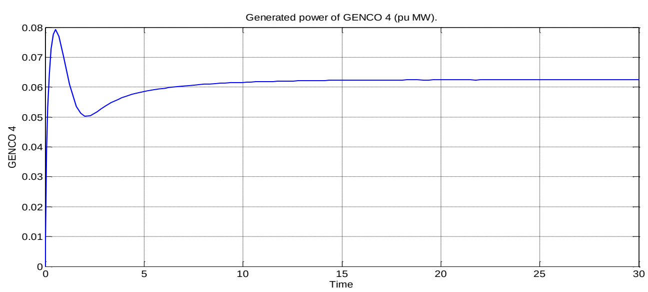

(f)

Figure 4 (a) Frequency deviations (rad/s). (b) Tie line power (puMW) (c) Generated power (puMW) for case 2.

4 Conclusion

AGC in deregulated power systems is modeled by modifying conventional model. Bilateral contracts will allow DISCOs in one area to get power from another area. The concept of DPM facilitated the simulation of bilateral contracts. A new simplified AGC model in deregulated power systems has been proposed. Simulation results replicts that the new model is depicting the actual system even without bilateral contracts included in the controller design

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