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Design of Full Order Optimal Controller for Interconnected Deregulated Power System for AGC

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Abstract

This paper presents the design and simulation of full order optimal controller for deregulated power system for Automatic Generation Control (AGC). Traditional AGC of two-area system is modified to take in to the effect of bilateral contracts on the system dynamics. The DISCO participation matrix defines the bilateral contract in a deregulated environment. This paper reviews the main structures, configurations, modeling and characteristics of AGC in a deregulated environment and addresses the control area concept in restructured power Systems. To validate the effectiveness of full order optimal controller, a simulation has been performed using MATLAB and results are presented here. The results for LFC and AGC for a deregulated interconnected power systems shows that the optimal full order controllers perform better than classical integral order controllers .

Keywords: *Automatic Generation Control, Area Control Error, ACE Participation Factor, Bilateral Contracts, Contract Participation Factor, Deregulation, DISCO Participation Matrix, Full Order Optimal Controller, Load Frequency Control.*

I. Introduction

In the electric power system load demand of the consumer always keeps on changing, hence the system frequency varies to its nominal value and the tie line power of the interconnected power system changes to its scheduled value. AGC is responsible to control the frequency to its nominal value and maintain the tie line power to its scheduled value, at the time of load perturbation in the system. In the conventional power system the generation, transmission and distribution are owned by a single entity called a Vertically Integrated Utility (VIU). In the deregulated environment Vertically Integrated Utilities no longer exist. However, the common operational objective of restoring the frequency at its nominal value and tie line power to its schedule value remain the same. In the deregulated power system the utilities no longer own generation, transmission and distribution. In this scenario there are three different entities generation companies (GENCOs), transmission companies (TRASCOs), distribution companies (DISCOs). As there are several GENCOs and DISCOs in the deregulated environment, a DISCO has the freedom to have a contract with any GENCO for transaction of power. A DISCO has freedom to contract with any of the GENCOs in their own area or another area. Such transactions are called "bilateral transactions" and these contracts are made under the supervision of an impartial entity called Independent System Operator (ISO). ISO is also responsible for managing the ancillary services like AGC etc. The objective of this paper is to modify the traditional two area AGC system to take into account the effect of Bilateral Contracts. The concept of DISCO participation matrix is used that helps in the visualization and implementation of Bilateral Contracts. Simulation of the bilateral contracts is done and reflected in the two-area block diagram. The full order optimal controller is used for accomplish the job of AGC i.e to achieve zero frequency deviation at steady state, and to distribute generation among areas so the interconnected tie line power flow match the prescribed schedule and to balance the total generation against the total load.

II. Formulation of Model of AGC for deregulated power system

Consider a two-area system in which each area has two GENCOs (non reheat thermal turbine) and two DISCOs in it. Let GENCO1 GENCO2, DISCO1 and DISCO2 be in area 1 and DISCO3, and DISCO4 be in area 2 as shown in Fig. 1.

Fig.1: Schematic of a two-area thermal system in deregulated environment

For LFC or AGC conventional model is used which is just the extension of the traditional Elgerd model [3]. In this AGC model, the concept of disco participation matrix (DPM) is included to incorporate the bilateral load contracts. DPM is a matrix with the number of rows equal to the number of GENCOs and number of columns equal to the number of DISCOs in the system. The DPM shows the participation of a DISCO in a contract with GENCO. For the system described in Fig 1, the DPM is given as

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

Where Cpf refers to "contract participation factor." $cpf_{ij} = \frac{\text{Demand of DISCOj from GENCOi}}{\text{Total Demand of DISCOj}}$,

Thus ijth entry corresponds to the fraction of the total load power contracted by DISCO j from GENCO i. The sum of all the entries of particular column of DPM is unity.

Whenever the load demanded by a DISCO changes, it is reflected as a local load in the area to which this DISCO belongs. As there are many GENCOs in each area, ACE signal has to be distributed among them in proportion to their participation in the AGC. "ACE (Area Control Error) participation factor (apf)" are the coefficient factors which distributes the ACE among GENCOs. If there are m no of GENCOs then $\sum_{i=1}^{m} apf_i = 1$.

In deregulated scenario a DISCO demands a particular GENCO or GENCOs for load power. These demands must be reflected in the dynamics of the system. Turbine and governor units must respond to this power demand. Thus, 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 GENCO specifying corresponding demands. Here, we introduce the information signals which were absent in the conventional scenario. The demands are specified by (elements of DPM) and the pu MW load of a DISCO. These signals carry information as to which GENCO has to follow a load demanded by which DISCO.

The block diagram for two area AGC in a deregulated power system is shown in Fig 2. In this model the schedule value of steady state tie line power is given as

$\Delta P_{tie1\text{-}2,scheduled}$ =(demand of DISCOs in area 2 from GENCOs in area1)-(demand of DISCOs in area 1 from GENCOs in area2)

At any given time, the tie line power error, ΔPtie1-2,error is defined as-

$\Delta P_{tie1\text{-}2,error} = \Delta P_{tie1\text{-}2,actual} - \Delta P_{tie1\text{-}2,scheduled}$

This error signal is used to generate the respective ACE signals as in the traditional scenario

$$ACE_1 = B_1 \Delta f_1 + \Delta P_{tie\ 1-2,error}$$

$$ACE_2 = B_2 \Delta f_2 + \Delta P_{tie\ 2-1,error}$$

Where

$$\Delta P_{tie\ 2-1,error} = -\frac{P_{r1}}{P_{r2}} \Delta P_{tie\ 1-2,error}$$

P_{r1} and P_{r2} are the rated powers of area 1 and area 2, respectively. Therefore

$$ACE_2 = B_2 \Delta f_2 + a_{12} \Delta P_{tie\ 1-2,error}$$

Where $\alpha 12 = -\frac{Pr1}{Pr2}$

In the block diagram shown in figure 2, $\Delta P_{L1,LOC}$ and $\Delta P_{L2,LOC}$ represents the local loads in area 1 and area 2 respectively.

ΔP_{L1}, ΔP_{L2}, ΔP_{L3} and ΔP_{L4} represents the contracted load of DISCO1, DISCO2, DISCO3 and DISCO4 respectively.

III. Design of full order optimal Controller

The theory of optimal control is concerned with operating a dynamic system at minimum cost. The case where the system dynamics are described by a set of linear differential equations and the cost is described by a quadratic functional is called the LQ problem. The optimal control problem for a linear multivariable system with the quadratic criterion function is one of the most common problems in linear system theory. it is defined below:

$$\dot{x} = Ax + Bu \quad ....(1)$$

Given the completely controllable plant, where x is the n×1 state vector, u is the p×1 input vector. A is the $n \times n$ order of real constant matrix and B is the $n \times p$ real constant matrix. Desired steady -state is the null state x=0

The control law

$$u = -K\,x \quad ....(2)$$

Where K is $p \times n$ real constant unconstrained gain matrix, that minimizes the quadratic performance index .

The design of a state feedback optimal controller is to determine the feedback matrix 'K' in such a way that a certain Performance Index (PI) is minimized while transferring the system from an initial arbitrary state $x(0) \neq 0$ to origin in infinite time i.e., $x(\infty) = 0$ .Generally the PI is chosen in quadratic form as:

$$\mathrm{PI} = \frac{1}{2}\int_0^\infty (\mathrm{x^T\,Q\,x + u^T R\,u})\mathrm{dt} \quad ....(3)$$

where, 'Q' is a real, symmetric and positive semi-definite matrix called as 'state weighting matrix' and 'R' is a real, symmetric and positive definite matrix called as 'control weighting matrix'.

The matrices A, B, Q & R are known. The optimal control is given by $u = -Kx$,'K' is the feedback gain matrix given by;

$$\mathrm{K = R^{-1}\,B^T\,S} \quad ....(4)$$

where, 'S' is a real, symmetric and positive definite matrix which is the unique solution of matrix Riccati Equation:

$$\mathrm{A^T\,S + S\,A - S\,B\,R^{-1}\,B^T\,S + Q = 0} \quad ....(5)$$

The closed loop system equation is;

$$\dot{x} = Ax + B(-Kx) = (A - BK)x = A_C\,x \quad ....(6)$$

The matrix $A - B\,K = A_C$ is the closed loop system matrix. The stability of closed loop system can be tested by finding eigen values of A_C .

IV. State Space Modeling AGC System in Deregulated Environment

The two area AGC system considered has two individual area connected with a tie line. The deviation in each area frequency is determined by considering the dynamics of governor, turbines, generators and load represented in that area. The state space model of representation of AGC model is given by

$$\dot{x} = Ax + Bu + \Gamma p + \beta q ....(7)$$

This model of AGC is shown in Fig.2 .Where x is state vector, u is control vector p is disturbance vector and q is the bilateral contract vector. A, B, Γ and β are the constant matrix associated with state control, disturbance and bilateral contract vector respectively.

In our system we can identify total 13 states. All these vectors and matrix are given by -

The State Vector 'x' (13×1), $x = [x_1 \quad x_2 \quad x_3 \quad x_4 \quad x_5 \quad x_6 \quad x_7 \quad x_8 \quad x_9 \quad x_{10} \quad x_{11} \quad x_{12} \quad x_{13}]^T$ where

$$x = [f_1 \quad f_2 \quad \Delta P_{GV1} \quad \Delta P_{GV2} \quad \Delta P_{GV3} \quad \Delta P_{GV4} \quad \Delta P_{M1} \quad \Delta P_{M2} \quad \Delta P_{M3} \quad \Delta P_{M4} \quad \int ACE_1 dt \quad \int ACE_2 dt \quad \Delta P_{tie\,1-2}]^T \;;$$

.............(8)

Control Vector 'u' (2×1) $u = [u_1 \quad u_2]^T$; ....(9)

Disturbance vector 'p' (2×1) $p = [P_{d1} \quad P_{d2}]^T$;............................(10)

Bilateral Contract Vector 'q' (4×1) $q = [\Delta P_{L1} \quad \Delta P_{L2} \quad \Delta P_{L3} \quad \Delta P_{L4}]^T$ ....(11)

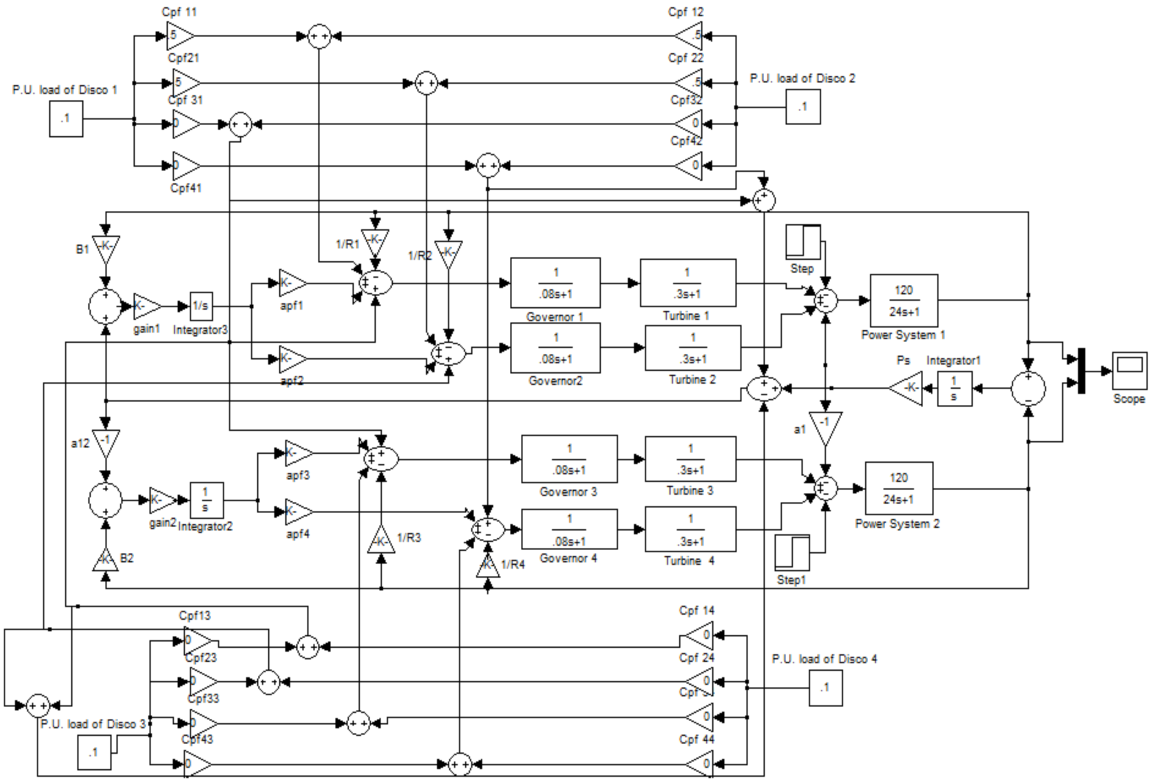


Fig.2: Two area AGC model in deregulated power system

$$
A = \begin{bmatrix}
\frac{-1}{T_{P1}} & 0 & 0 & \frac{k_{P1}}{T_{P1}} & \frac{k_{P1}}{T_{P1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{k_{P1}}{T_{P1}} \\
0 & \frac{-1}{T_{P2}} & 0 & 0 & \frac{k_{P2}}{T_{P2}} & \frac{k_{P2}}{T_{P2}} & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{a_{12}k_{P2}}{T_{P2}} \\
0 & 0 & \frac{-1}{T_{T1}} & 0 & 0 & 0 & \frac{1}{T_{T1}} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{-1}{T_{T2}} & 0 & 0 & 0 & \frac{1}{T_{T2}} & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \frac{-1}{T_{T3}} & 0 & 0 & 0 & \frac{1}{T_{T3}} & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{T4}} & 0 & 0 & 0 & \frac{1}{T_{T1}} & 0 & 0 & 0 \\
\frac{-1}{R_1T_{g1}} & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{g1}} & 0 & 0 & 0 & 0 & 0 & 0 \\
\frac{-1}{R_2T_{g2}} & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{g2}} & 0 & 0 & 0 & 0 & 0 \\
0 & \frac{-1}{R_3T_{g3}} & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{g3}} & 0 & 0 & 0 & 0 \\
0 & \frac{-1}{R_4T_{g4}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{g4}} & 0 & 0 & 0 \\
-B_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 \\
0 & -B_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -a_{12} \\
2\pi T_{12} & -2\pi T_{12} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
$$

……….(12)

$$B = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ apf_1/Tg_1 & 0 \\ apf_2/Tg_2 & 0 \\ 0 & apf_3/Tg_3 \\ 0 & apf_4/Tg_4 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}, \quad \text{................(13)}$$

$$\Gamma = \begin{bmatrix} k_{p1}/T_{p1} & 0 \\ 0 & k_{p2}/T_{p2} \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \text{....................(14)}$$

$$\beta = \begin{bmatrix} \frac{-k_{P1}}{T_{P1}} & \frac{-k_{P1}}{T_{P1}} & 0 & 0 \\ 0 & 0 & \frac{-k_{P2}}{T_{P2}} & \frac{-k_{P2}}{T_{P2}} \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \frac{cpf_{11}}{T_{g1}} & \frac{cpf_{12}}{T_{g1}} & \frac{cpf_{13}}{T_{g1}} & \frac{cpf_{14}}{T_{g1}} \\ \frac{cpf_{21}}{T_{g2}} & \frac{cpf_{22}}{T_{g2}} & \frac{cpf_{23}}{T_{g2}} & \frac{cpf_{24}}{T_{g2}} \\ \frac{cpf_{31}}{T_{g3}} & \frac{cpf_{32}}{T_{g3}} & \frac{cpf_{33}}{T_{g3}} & \frac{cpf_{34}}{T_{g3}} \\ \frac{cpf_{41}}{T_{g4}} & \frac{cpf_{42}}{T_{g4}} & \frac{cpf_{43}}{T_{g4}} & \frac{cpf_{44}}{T_{g4}} \\ -(cpf_{31}+cpf_{41}) & -(cpf_{32}+cpf_{42}) & +(cpf_{13}+cpf_{23}) & +(cpf_{14}+cpf_{24}) \\ -a_{12}(cpf_{31}+cpf_{41}) & -a_{12}(cpf_{32}+cpf_{42}) & a_{12}(cpf_{13}+cpf_{23}) & a_{12}(cpf_{14}+cpf_{24}) \\ 0 & 0 & 0 & 0 \end{bmatrix},$$

..........(15)

V. Design of full Optimal controller for AGC in Deregulated Environment

The design of a state feedback optimal controller is to determine the feedback matrix 'K' in such a way that a certain Performance Index (PI) is minimized while transferring the system from an initial arbitrary state $x(0) \neq 0$ to origin in infinite time i.e., $x(\infty) = 0$.

Generally the PI is chosen in quadratic form as given by equation (3)

$$\mathrm{PI} = \frac{1}{2}\int_0^{\infty}(x^T Q\, x + u^T R\, u)dt$$

where, 'Q' is a real, symmetric and positive semi-definite matrix called as 'state weighting matrix' and 'R' is a real, symmetric and positive definite matrix called as 'control weighting matrix'. The matrices Q and R are determined on the basis of following system requirements.

1) The excursions (deviations) of ACEs about steady values are minimized. In this model, these excursions are;

$$ACE_1 = B_1\Delta f_1 + \Delta P_{tie\ 1-2} = B_1x_1 + x_{13} \quad \text{and} \quad ....(16)$$

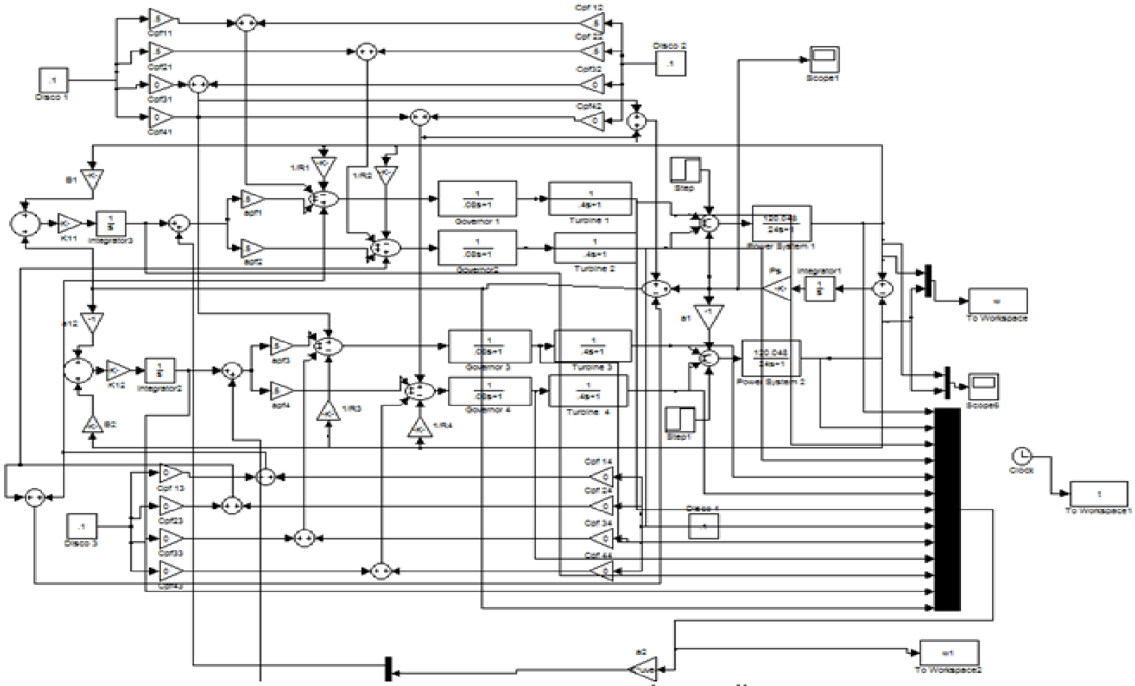
$$ACE_2 = B_2\Delta f_2 + \Delta P_{tie\ 2-1} = B_2x_2 + a_{12}x_{13} \quad ....(17)$$

2) The excursions of $\int ACE\ dt$ about steady values are minimized. In this model, these excursions are x_{11} & x_{12} .

3) The excursions of control inputs u_1 and u_2 about steady values are minimized.

Under these considerations, the PI takes a form;

$$\mathrm{PI} = \frac{1}{2}\int_0^{\infty}[(B_1x_1 + x_{13})^2 + (B_2x_2 + a_{12}x_{13})^2 + (x_{11})^2 + (x_{12})^2 + ({u_1})^2 + (u_2)^2]dt \qquad .....(18)$$



Optimal Controller

Fig. 3 Simulation model of two area AGC in deregulated system with Optimal Controller

This gives the matrices Q (13×13) and R (2×2) as:

$$Q = \begin{bmatrix} B_1^2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & B_1 \\ 0 & B_2^2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{12} B_2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ B_1 & a_{12} B_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 + a_{12}^2 \end{bmatrix} \qquad \text{..................(19)}$$

$$R = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \qquad \text{..................(20)}$$

The matrices A, B, Q & R are known. The optimal controller gain matrix can be obtained by using equations (4) to (6).

VI. Simulation Result

A. Case 1:

Consider a case where all the DISCOs contract with the GENCOs for power as per the following DPM:

$$DPM = \begin{bmatrix} .3 & .5 & .1 & .35 \\ .2 & .5 & .25 & .3 \\ .1 & 0 & .4 & .1 \\ .4 & 0 & .25 & .25 \end{bmatrix}$$

It is assumed that each DISCO demand s 0.1 pu MW power from GENCO as defined by *cpfs* in DPM matrix and each GENCO participates in AGC as defined by following *apfs*: $apf_1 = 0.75$, $apf_2 = 0.25$, $apf_3 = 0.5$ and $apf_4 = 0.5$.
The system in figure 3 simulated using the above data and the system parameters given in Appendix -I . The result of the simulation has shown in Figure 4.
The off diagonal elements of DPM corresponds to the contract of a DISCO in one area with a GENCO in another area.

The schedule power on the tie line in the direction from area1 to area2 is -

$$\Delta P_{tie1-2,scheduled} = [\Delta P_{L3}(cpf_{13} + cpf_{23}) + \Delta P_{L4}(cpf_{14} + cpf_{24})] - [\Delta P_{L1}(cpf_{31} + cpf_{41}) + \Delta P_{L2}(cpf_{32} + cpf_{42})]$$
$$= [0.1(0.1+0.25)+0.1(0.3+0.35)] - [0.1(0.1+0.4)+0.1(0+0)]$$
$$= 0.05 \text{ pu MW}$$

The desired generation of a GENCO in pu MW can be expressed in terms of Contract Participation Factor (cpfs) and the total demand of DISCOs as

$$\Delta P_{Mi} = \sum_{1}^{j} cpf_{ij} \Delta P_{Lj}$$

Where ΔP_{Lj} is the total demand of DISCO j and cpf_s are given by DPM.

At steady state power generated by GENCOs -

$\Delta P_{M1} = 0.3(0.1) + 0.5(0.1) + 0.1(0.1) + 0.35(0.1) = 0.125$ pu MW
$\Delta P_{M2} = 0.125$ pu MW; $\Delta P_{M3} = 0.06$ pu MW; $\Delta P_{M4} = 0.09$ pu MW

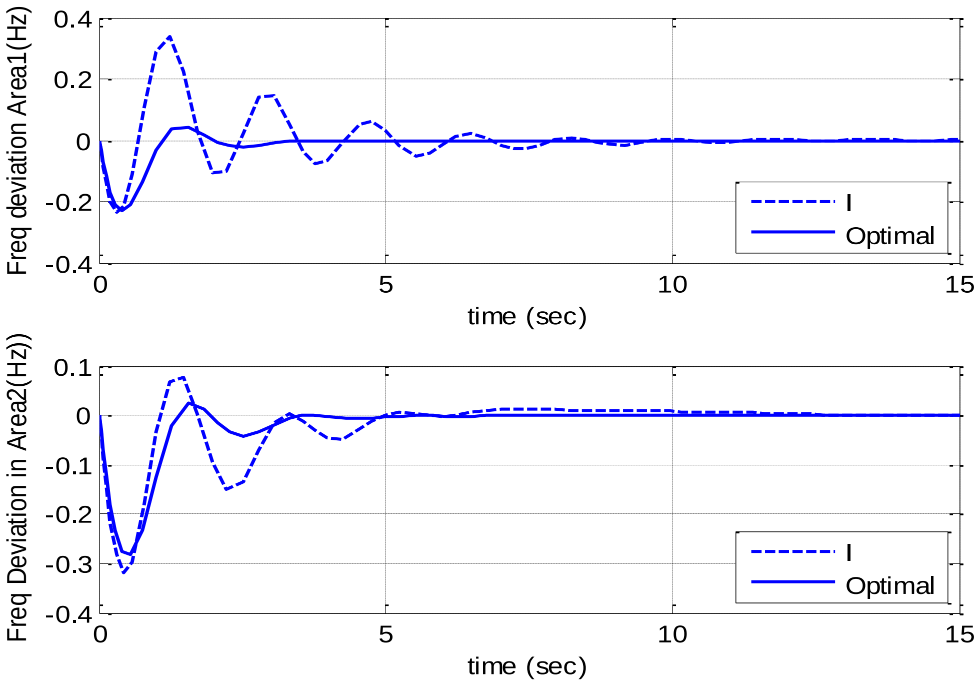


Fig. 4a: Frequency Deviations (Hz) for area 1 & area 2, case1

Fig. 4a shows the dynamic responses of frequency deviations in two areas (i.e., Δf1 and Δf2).The frequency deviation in each area goes to zero in the steady state.
The schedule power on the tie line in the direction from area1 to area2 is .05 pu MW. Fig. 4b shows the actual Tie line power flow between two area at steady state is also .05 pu MW. So the deviation in tie line power at steady state become zero .
Fig. 4c & 4d show the power generated by GENCO1, GENCO2, GENCO3 & GENCO4 in steady state. The results are matching from our calculations.

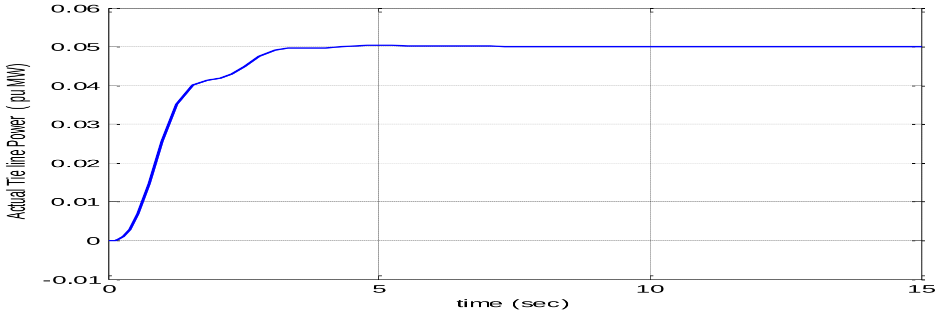


Fig.4b: Actual Tie line power (pu MW), case 1

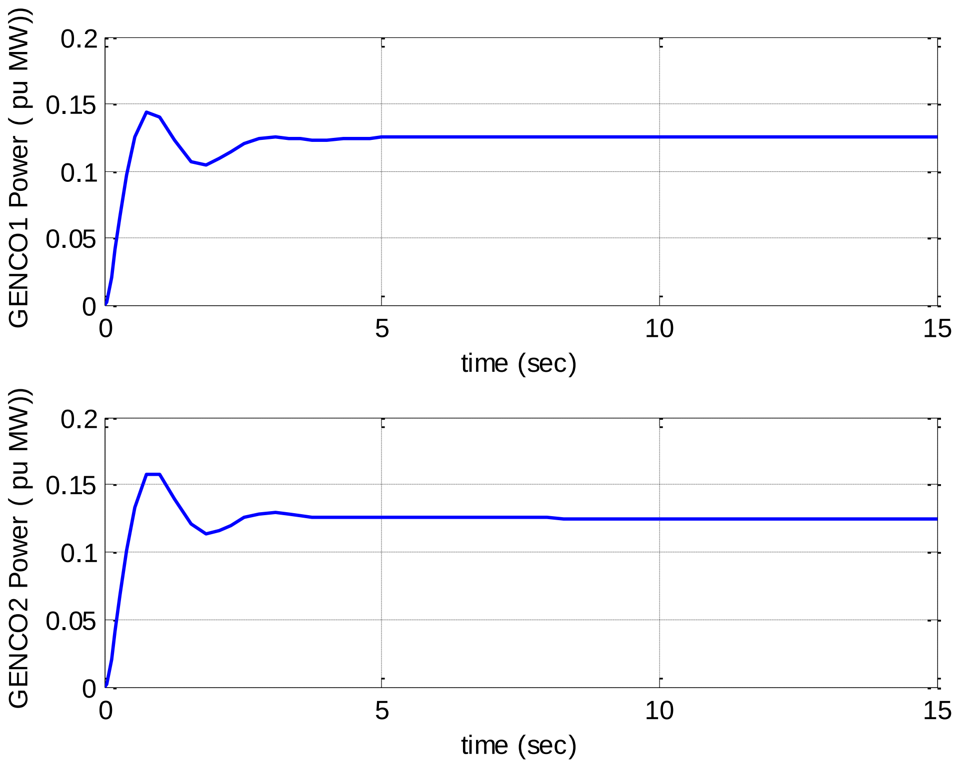


Fig.4c: Generated Power by GENCO1 & GENCO2 (pu MW) case 1

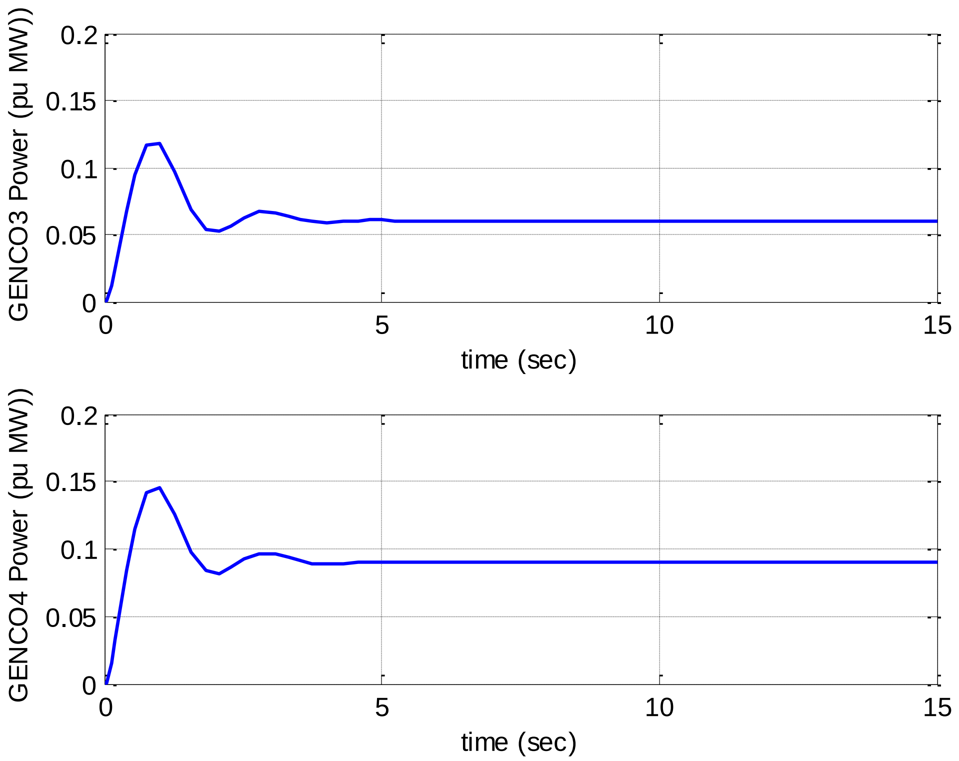


Fig.4d: Generated Power by GENCO3 & GENCO4 (pu MW), case 1

B. Case 2: Contract Violation

It may be happen that a DISCO violate 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 contracted demand.Now consider DPM as below

Now in this case all the Discos contract with the Gencos for power as per the following DPM-

$$DPM = \begin{bmatrix} .5 & .25 & 0 & .3 \\ .2 & .25 & 0 & 0 \\ 0 & .25 & 1 & .7 \\ .3 & .25 & 0 & 0 \end{bmatrix}$$

It is assumed that each DISCO demand s 0.1 pu MW power from GENCO as defined by *cpfs* in DPM matrix and DISCO1 demand 0.1 pu MW of excess power. ACE participation factors are apf1=0.75, apf2=1-apf1= 0.25, apf3= 0.5, apf4=1-apf3=0.5.

The total local load in area I = Load of DISCO1 + Load of DISCO2

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

Similarly, the total local load in area II = Load of DISCO3 + Load of DISCO4

= (0.1 + 0.1) = 0.3 pu MW (no un contracted load)

Schedule tie line power flow is 0.05 from area 2 to area 1.

The system in figure 3 simulated again ,using the above data and the system parameters given in Appendix -I . The result of the simulation has shown in figure 5.

Fig. 5a: shows the dynamic responses of frequency deviations in two areas (i.e., Δf1 and Δf2).The frequency deviation in each area goes to zero in the steady state.

Fig. 5b: shows the tie line power deviation between two area. The actual tie line power .05 pu MW which flows from area 2 to area 1.Scheded tie tie line power is also .05, in the steady state deviation goes to zero.

Fig 5c & 5d show the power generated by GENCO1, GENCO2,GENCO3 & GENCO4 in the steady state. The generation of GENCO3 & GENCO4 are not affected by the excess load of DISCO1. The un contracted load of

DISCO1 is reflected in generation of GENCO1 & GENCO2. The ACE participation factor decide the distribution of un contracted load in the steady state. Thus this excess load is taken up by the GENCOs in the same area as that of the DISCO making the un contracted demand.

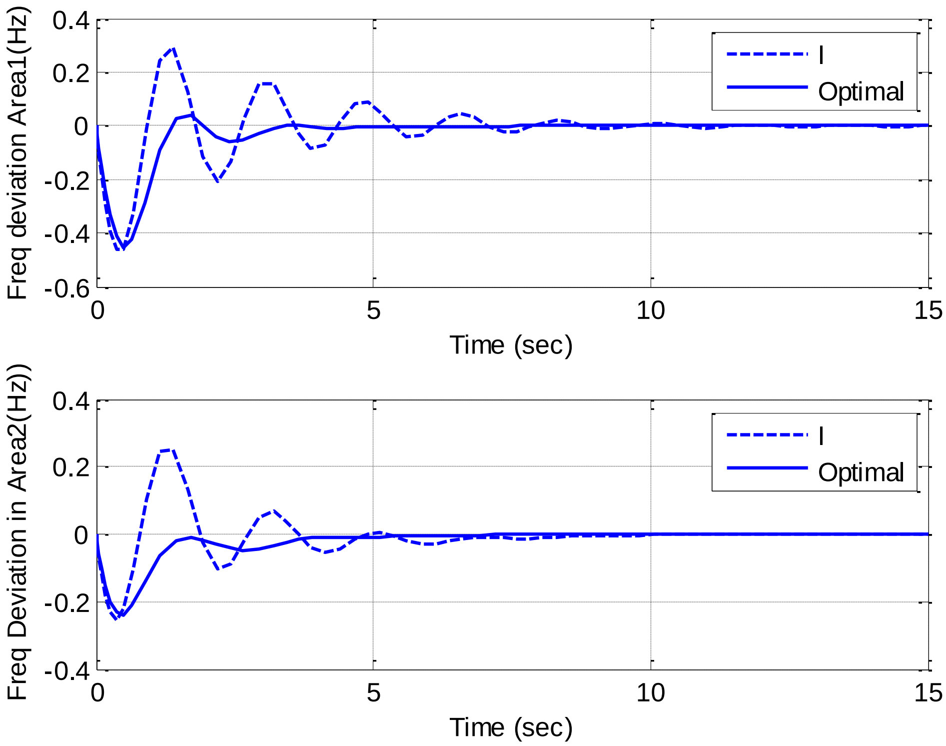


Fig. 5a: Frequency Deviations (Hz) for area 1 & area 2, case2

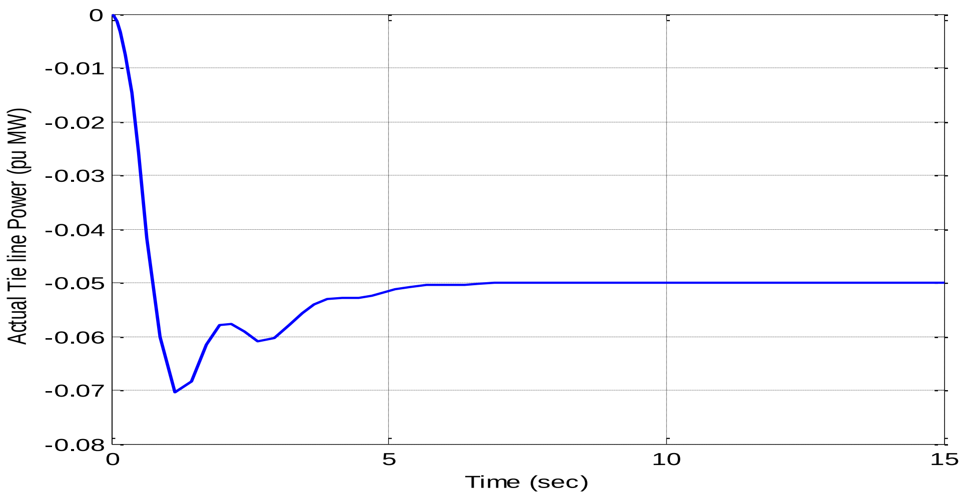


Fig.5b: Actual Tie line power (pu MW), case 2

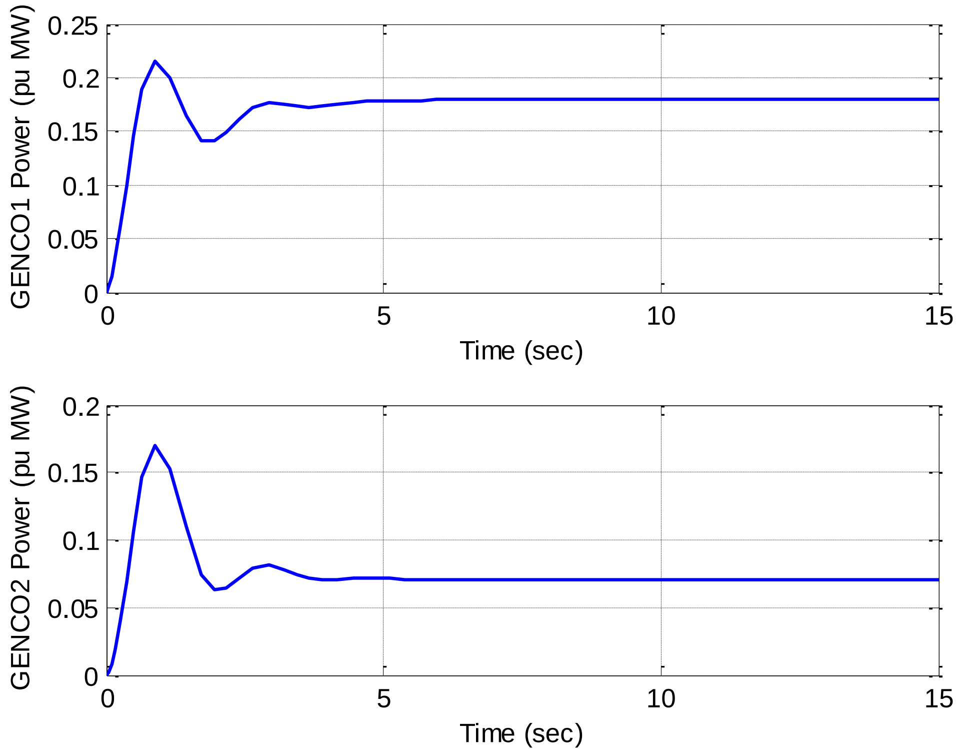


Fig.5c: Generated Power by GENCO1 & GENCO2 (pu MW), case 2

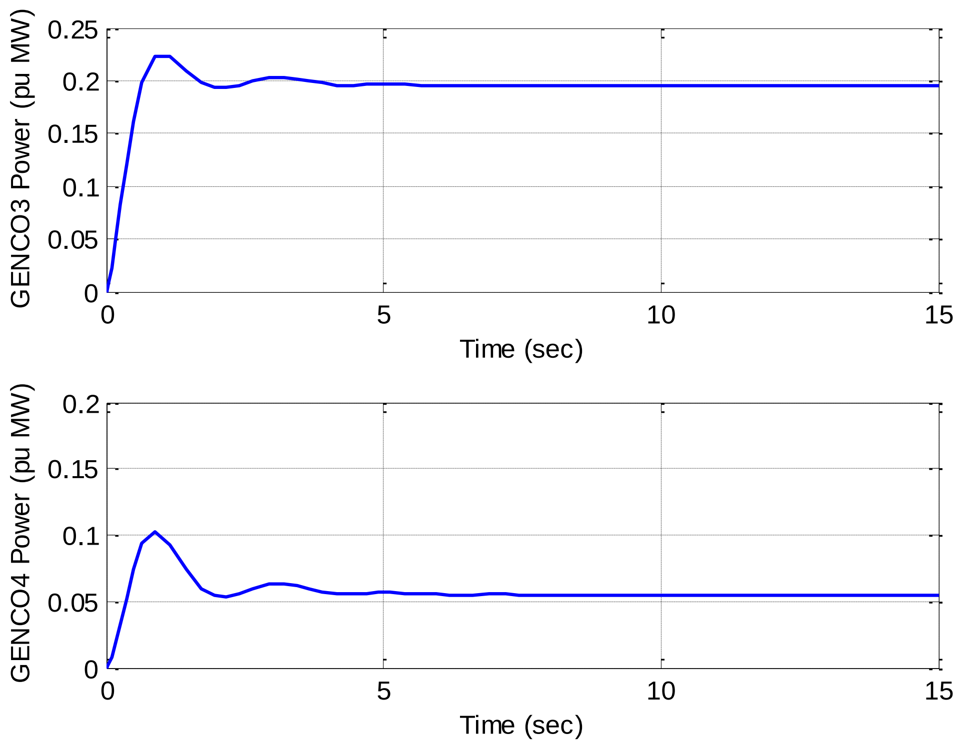


Fig.5d: Generated Power by GENCO3 & GENCO4 (pu MW), case 2

The value of 'k' optimal controller gain matrix, find out with the help of MATLAB program is given below.

$$k = \begin{bmatrix} .312 & -.080 & .571 & .571 & -.128 & -.128 & .108 & .108 & -.023 & -.023 & -1 & 0 & .147 \\ -.080 & .312 & -.128 & -.128 & .571 & .571 & .023 & -.023 & .108 & .108 & 0 & -1 & -.147 \end{bmatrix}$$

Hence the control inputs:
$u_1 = -.312\ x_1 + .08\ x_2 - .571\ x_3 - .571\ x_4 + .128\ x_5 + .128\ x_6 - .108\ x_7 - .108\ x_8 + .023\ x_9 + .023\ x_{10} + x_{11} - .147\ x_{13}$
$u_1 = .080\ x_1 - .312\ x_2 + .128\ x_3 + .128\ x_4 - .571\ x_5 - .571 x_6 - .023\ x_7 + .023\ x_8 - .108\ x_9 - .108\ x_1 + x_{12} + .147\ x_{13}$

The eigen values of 'A' open loop system are
[0, 0, -0.444 + 3.63i, -0.444-3.63i, -0.823 + 3.02i, -0.823 - 3.02i, -0.778, -13.4, -13.4, -2.50, -2.50, -12.5, -12.5]
Two eigen values are zero and remaining have negative real parts indicating that, the system is marginally stable before applying the optimal control strategy.

The eigen values of 'Ac' closed loop system are
[-13.3996 -13.3804 -0.8468 + 3.7432i -0.8468 - 3.7432i -1.1232 + 3.1450 -1.1232 - 3.1450i -0.8032 + 0.2435i
-0.8032 - 0.2435i -0.4590 -12.5000 -12.5000 -2.5000 -2.5000]
All eigen values of ‘Ac’ have negative real parts indicating that the system is asymptotically stable after applying optimal control strategy.

APPENDIX I

$P_{r1} = P_{r2}$	2000 MW
$R_1 = R_2 = R_3 = R_4$	2.4 Hz /pu MW
$K_1 = K_2$	.6558
$K_{p1} = K_{p2}$	120
$T_{p1} = T_{p2}$	24
$B_1 = B_2$	.429
T_{12}	.0707 MW / radian
$T_{T1} = T_{T2} = T_{T3} = T_{T4}$	.4
$T_{g1} = T_{g2} = T_{g3} = T_{g4}$	.08
$P_{tie\ max}$	200 MW

VII. CONCLUSION

This work gives an overview of AGC in deregulated environment which acquires a fundamental role to enable power exchanges and to provide better conditions for the electricity trading. The important role of AGC will continue in restructured electricity markets, but with modifications. Bilateral contracts can exist between DISCOs in one control area and GENCOs in other control areas. The use of a “DISCO Participation Matrix” facilitates the simulation of bilateral contracts. Models of interconnected power systems in deregulated environment have been developed for integral as well as optimal control strategies. The state equations and control equations have been successfully obtained and full State feedback optimal controller has designed .The models have also been tested for system stability before and after applying closed loop feedback control and it has been observed performance is much better in case of full state feedback optimal controller as compare to integral controller.

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