Modelling And Simulation Of Automatic Generation Control In A Deregulated Environment And Its OptimizationU LQR Based Integral Controller

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Modelling And Simulation Of Automatic Generation Control In A Deregulated Environment And Its OptimizationU LQR Based Integral Controller

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***Abstract-* Automatic generation control is a significant control process that operates constantly to balance the generation and load in power systems at a minimum cost. The AGC system is responsible for frequency control, power interchange and economic dispatch. This paper reviews the main structures, configurations, modeling and characteristics of Automatic Generation Control systems in a deregulated environment and addresses the control area concept in restructured Power Systems. The concept of DISCO participation matrix is introduced and reflected in the two-area diagram to make the visualization of contract easier. The modification by superimposition of information flow on the Traditional AGC two-area system is done to take into account the effect of bilateral contracts on the dynamics and the simulations reveal some interesting patterns. The Linear Quadratic Regulator (LQR) with Integral action (LQRI) is designed and implemented to solve the Load Frequency Control problem in a restructured power system that operates under deregulation based on bilateral policy. To validate the effectiveness of LQR robust controller, the simulation has been performed using proposed controller and comparison has done with conventional Integral type controller.**

***Keywords—* Automatic generation control, bilateral contracts, deregulation, frequency control, optimization, Linear Quadratic Regulator.**

I. INTRODUCTION

In a restructured power system, the engineering aspects of planning and operation have to be reformulated although essential ideas remain the same. With the emergence of the distinct identities of Generating Companies (GENCOs), Transmission Companies (TRANSCOs), Distribution Companies (DISCOs) and the Independent System Operator (ISO), many of the ancillary services of a vertically integrated utility will have a different role to play and hence have to be modeled differently. Among these ancillary services is the automatic generation control (AGC).

Large scale power systems are normally managed by viewing them as being made up of control areas with interconnections between them.

Each control area must meet its own demand and its scheduled interchange power. Any mismatch between the generation and load can be observed by means of a deviation in frequency.

This balancing between load and generation can be achieved by using Automatic Generation Control (AGC). The objective of this paper is the modification of the traditional two area system to take into account the effect of Bilateral Contracts. The concept of DISCO participation matrix is used that helps the visualization and implementation of contracts. Simulation of the bilateral contracts is done and reflected in the two-area block diagram..Formulation and Implementation of Linear Quadratic Regulator robust controller is done by optimizing the parameters.

II. AUTOMATIC GENERATION CONTROL

In an interconnected power system, as the load varies, the frequency and tie-line power interchange also vary. To accomplish the objective of regulating system electrical frequency error and tie-line power flow deviation to zero, a supplementary control action, that adjusts the load reference set points of selected generating units, is utilized. This control process is referred to as Automatic Generation Control (AGC).

A. Significance of Automatic Generation Control In Deregulated Environment

The Significance of AGC in deregulated environment is three-fold;

(i) to achieve zero static frequency;

(ii) to distribute generation among areas so that interconnected tie line flows match a prescribed schedule; and

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(iii) to balance the total generation against the total load and tie line power exchanges.

B. Power System Frequency Control

Frequency deviation is a direct result of the imbalance between the electrical load and the active power supplied by the connected generators. A permanent off-normal frequency deviation directly affects power system operation, security, reliability, and efficiency by damaging equipment, degrading load performance, overloading transmission lines, and triggering the protection devices.
The primary control performs a local automatic control that delivers reserve power in opposition to any frequency change. The supplementary loop gives feedback via the frequency deviation and adds it to the primary control loop through a dynamic controller. The resulting signal is used to regulate the system frequency. Load shedding is an emergency control action to ensure system stability, by curtailing system load. The load shedding will only be used if the frequency (or voltage) falls below a specified frequency (voltage) threshold.

C. Automatic Generation Control in a Two Area System

A power system comprising of two control areas interconnected by a weak lossless tie-line is considered.

Each control area is represented by an equivalent generating unit interconnected by a Tie-line with reactance X_{12}. Under steady state operation, the transfer of power over the Tie-line P_{12} can be written as

$$P_{12} = \frac{E_1 E_2}{X_{12}} \sin(\delta_1 - \delta_2)$$

Where E1 and E2 are the magnitudes of the end voltages of control areas 1 and 2 respectively, and δ1 and δ2 are the voltage angles of E1 and E2, respectively.

For a small change $\Delta\delta_1$ and $\Delta\delta_2$ in voltage angles, the change in Tie-line power, ΔP_{12} is shown as

$$P_{12} = \frac{E_1 E_2}{X_{12}} \cos(\delta_1 - \delta_2)\,(\Delta\delta_1 - \Delta\delta_2)$$

Where T_{12} is defined as the synchronizing coefficient and is given as

$$T_{12} = \frac{E_1 E_2}{X_{12}} \cos(\delta_1 - \delta_2)$$

Expressing in term of Δf, gives

$$\Delta P_{12}(s) = 2\pi T_{12}\,[\int \Delta f_1 dt - \int \Delta f_2 dt]$$

Taking Laplace Transform of above Equation

$$\Delta P_{12}(s) = 2\pi T_{12}\,[\Delta F_1(s) - \Delta F_2(s)]$$

The transfer of power over the Tie-line is expressed as

$$\Delta P_{12} = -\Delta P_{21}$$

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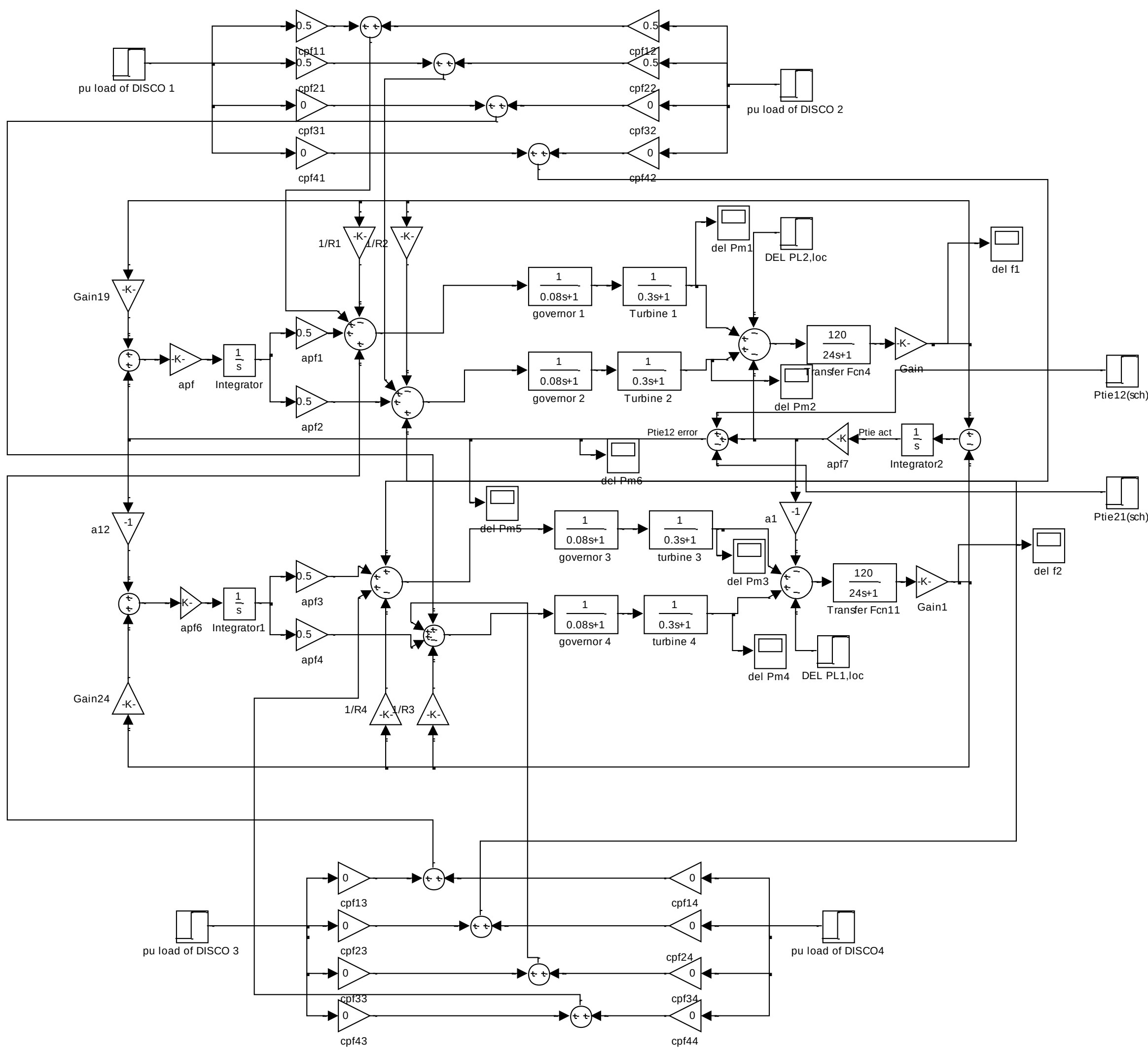

Figure 1: Two-Area AGC System Block Diagram in Restructured Scenario.

III. AGC In Deregulated Environment

For the electric industry, deregulation means the generation portion of electricity service will be open to competition.

However, the transmission and distribution of the electricity will remain regulated and our local utility company will continue to distribute electricity to us and provide customer services to us. [19]

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A. Formulation of State Model

The formulation of the block diagram for a two-area AGC system in the deregulated scenario is shown in Figure 1. The demands are specified by Contract Participation Factor (elements of *DPM*) and the puMW load of a DISCO. These signals carry information as to which GENCO has to follow a load demanded by which DISCO.

The scheduled steady state power flow on the tie line is given as

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

At any given time, the tie line power error, $\Delta P_{tie1\text{-}2,error}$ is defined as

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

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

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

P_{r1} and P_{r2} are the rated powers of areas I and II, respectively.

$$ACE_1 = B_1\Delta f_1 + \alpha_{12}\Delta P_{tie\ 1-2,error}$$
$$\alpha_{12} = -\frac{P_{r1}}{P_{r2}}$$

B. State Space Characterization of Two-Area System in Deregulated Environment

A two-area system is used to illustrate the behavior of the proposed AGC scheme. The same data as in [3], [4] is used for simulations. Both the areas are assumed to be identical. Considering the state space vectors;

$$x_1 = \Delta w_1$$
$$x_2 = \Delta w_2$$
$$x_3 = \Delta P_{GV1}$$
$$x_4 = \Delta P_{GV2}$$
$$x_5 = \Delta P_{GV3}$$
$$x_6 = \Delta P_{GV4}$$
$$x_7 = \Delta P_{M1}$$
$$x_8 = \Delta P_{M2}$$
$$x_9 = \Delta P_{M3}$$
$$x_{10} = \Delta P_{M4}$$
$$x_{11} = \int ACE_1\, dt$$
$$x_{12} = \int ACE_2\, dt$$
$$x_{13} = \Delta P_{tie\ 1-2}$$

$$x_1 = (\Delta P_{L1,Loc} - x_3 + x_4)\frac{K_{P1}}{1 + sT_{P1}}$$

$$\dot{x_1} = \frac{1}{T_{P1}}x_1 - \frac{K_{P1}}{T_{P1}}x_3 + \frac{K_{P1}}{T_{P1}}x_4 - \Delta P_{L1,Loc}\frac{K_{P1}}{T_{P1}}$$

$$x_2 = (\Delta P_{L2,Loc} - a_{12}x_3 + x_6)\frac{K_{P2}}{1 + sT_{P2}}$$

$$\dot{x_2} = \frac{1}{T_{P2}}x_1 - a_{12}\frac{K_{P2}}{T_{P2}}x_3 + \frac{K_{P2}}{T_{P2}}x_6 - \Delta P_{L1,Loc}\frac{K_{P2}}{T_{P2}}$$

$$x_3 = \frac{1}{1+sT_{T1}}x_4$$

$$\dot{x_3} = \frac{1}{T_{T1}}(x_4 - x_3)$$

$$x_4 = \frac{1}{1 + sT_{T2}}x_5$$

$$\dot{x_4} = \frac{1}{T_{T2}}(x_5 - x_4)$$

$$x_5 = \frac{1}{1 + sT_{T3}}x_6$$

$$\dot{x_5} = \frac{1}{T_{T3}}(x_6 - x_5)$$

$$x_6 = \frac{1}{1 + sT_{T4}}x_7$$

$$\dot{x_6} = \frac{1}{T_{T4}}(x_7 - x_6)$$

$$\dot{x_7} = -\frac{x_1}{T_{G1}R_1} - \frac{x_5}{T_{G1}} + (-K_1 apf_1)\frac{1}{T_{G1}}.$$

$$\dot{x_8} = -\frac{x_1}{T_{G2}R_2} - \frac{x_6}{T_{G2}} + (-K_1 apf_2)\frac{1}{T_{G2}}$$

$$\dot{x_9} = -\frac{x_2}{T_{G3}R_2} - \frac{x_7}{T_{G3}} + (-K_2 apf_3)\frac{1}{T_{G3}}$$

$$\dot{x_{10}} = -\frac{x_2}{T_{G4}R_2} - \frac{x_8}{T_{G4}} + (-K_2 apf_4)\frac{1}{T_{G4}}.$$

$$\dot{x_{11}} = B_1x_1 + x_{13}.$$

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$\dot{x_{12}} = B_2 x_2 + a_{12} x_{13}$
$\dot{x_{13}} = \frac{T_{12}}{2\pi}(x_1 - x_2)$

The thirteen equations from can be organized in the following vector matrix form and substituting the values from the Table 3.

The closed loop system in Fig. 1 is characterized in state space form as

$\frac{dx}{dy} = A^{cl} + B^{cl}$

Table 1
Matrix A^{cl}

A^{cl}	1	2	3	4	5	6	7	8	9	10	11	12	13
1	-0.008	0	0.167	0.167	0	0	0	0	0	0	0	0	-0.167
2	0	-0.008	0	0	0.1667	0.1677	0	0	0	0	0	0	0.167
3	0	0	-3.33	0	0	0	3.33	0	0	0	0	0	0
4	0	0	0	-3.33	0	0	0	3.33	0	0	0	0	0
5	0	0	0	0	-3.33	0	0	0	3.33	0	0	0	0
6	0	0	0	0	0	-3.33	0	0	0	3.33	0	0	0
7	-0.829	0	0	0	0	0	-12.5	0	0	0	-4.115	0	0
8	-0.829	0	0	0	0	0	0	-12.5	0	0	-4.115	0	0
9	0	-0.829	0	0	0	0	0	0	-12.5	0	0	-4.115	0
10	0	0.829	0	0	0	0	0	0	0	-12.5	0	-4.115	0
11	0.069	0	0	0	0	0	0	0	0	0	0	0	1
12	0	0.069	0	0	0	0	0	0	0	0	0	0	-1
13	0.0136	-0.013	0	0	0	0	0	0	0	0	0	0	0

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Table 2
Matrix B^{cl}

B^{cl}	**1**	**2**	**3**	**4**
1	-0.1667	-0.1667	0	0
2	0	0	-0.1667	-0.1667
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	6.25	3.125	0	3.75
8	2.5	3.125	0	0
9	0	3.125	12.5	0
10	0	3.125	0	17.857
11	0.3	0.5	0	-0.3
12	-0.3	-0.5	0	0.3
13	0	0	0	0

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C. Simulation Results of a Two- Area System in a Deregulated Environment

Scenario I

Consider a case where the GENCOs in each area participate equally in AGC; i.e., ACE participation factors are

apf_1=0.5, apf_2=1-apf_1= 0.5,
apf_3= 0.5, apf_4=1-apf_3=0.5.

It is assumed that the load change occurs only in area I. Thus, the load is demanded only by $DISCO_1$ and $DISCO_2$. Let the value of this load demand be 0.1 pu MW for each of them.

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

The corresponding Disco Participation Matrix will become

$$\mathrm{DPM} = \begin{bmatrix} 0.5 & 0.5 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$DISCO_3$ and $DISCO_4$ do not demand power from any GENCOs, and hence the corresponding participation factors (columns 3 and 4) are zero.

Fig. 2 shows the results of this load change: area frequency deviations, actual power flow on the tie line, and the generated powers of various GENCOs, following a step change in the load demands of $DISCO_1$ and $DISCO_2$. The frequency deviation in each area goes to zero in the steady state. As only the DISCOs in area I, *viz.* $DISCO_1$ and $DISCO_2$, have nonzero load demands, the transient dip in frequency of area I is larger than that of area II.

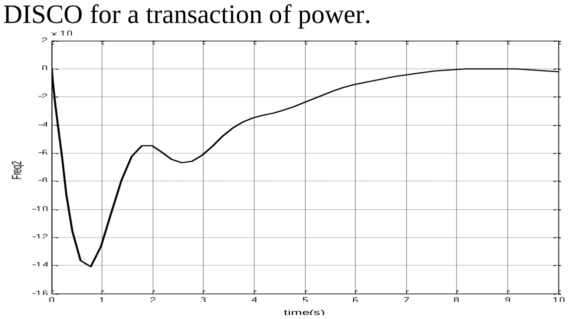
The desired generation of a GENCO in pu MW can be expressed in terms of Contract Participation Factor (cpf's) and the total demand of DISCOs as

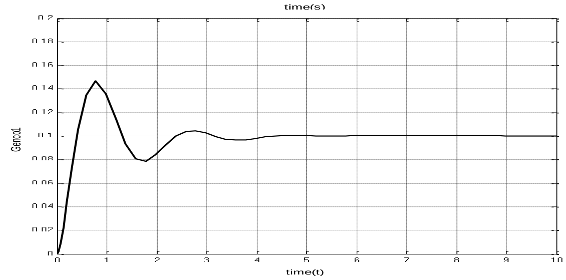
$$\Delta P_{M1} = \sum_j cpf_{ij} \Delta P_{Lj}$$

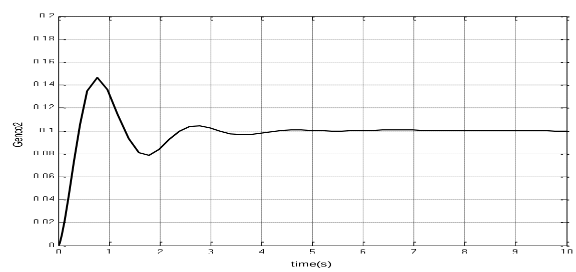
Where ΔP_{Lj} is the total demand of DISCO j and cpfs are given by DPM.

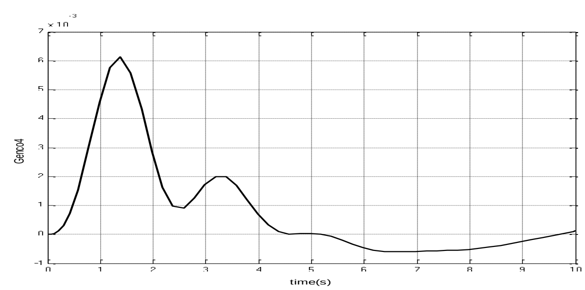
$\Delta P_{M1} = 0.5 * \Delta P_{L1} + 0.5 * \Delta P_{L2}$
$= 0.1$puMW
$\Delta P_{M2} = 0.1$ pu MW; $\Delta P_{M3} = 0$ pu MW;
$\Delta P_{M4} = 0$ pu MW

$GENCO_3$ and $GENCO_4$ are not contracted by any DISCO for a transaction of power.









EXPLORING RESEARCH AND INNOVATIONS

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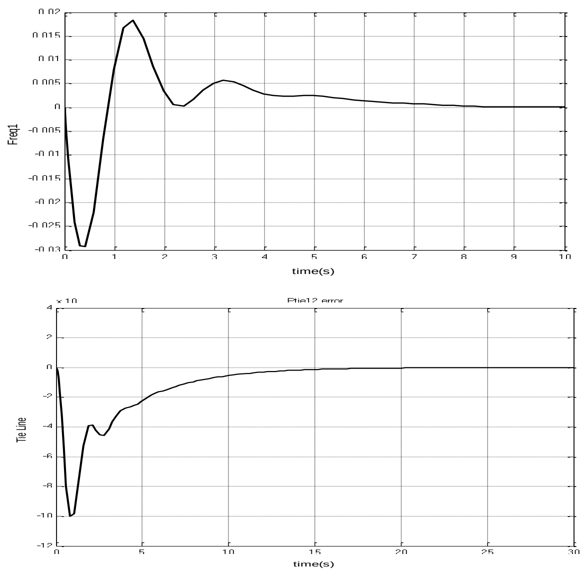


Figure 2: Frequency Deviations (rad/s) and Generated Power (pu MW)

Scenario II

Consider a case where all the DISCOs contract with the GENCOs for power as per the following 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 0.1 pu MW power from GENCOs as defined by Contract Participation Factor in DPM matrix and each GENCO participates in AGC as defined by following ACE Participation Factors (apfs) are

apf_1=0.75; apf_2=1-apf_1= 0.25;
apf_3= 0.5; apf_4=1-apf_3=0.5

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

Hence, $\Delta P_{tie\ 1-2,scheduled}$ = -0.05pu MW

In the steady state, the GENCOs must Generate

ΔP_{M1} = 0.5 (0.1) + 0.25(0.1) + 0 + 0.3(0.1)
= 0.105puMW

ΔP_{M2} = 0.045 pu MW; ΔP_{M3} = 0.195 pu MW;
ΔP_{M4} = 0.055 pu MW.

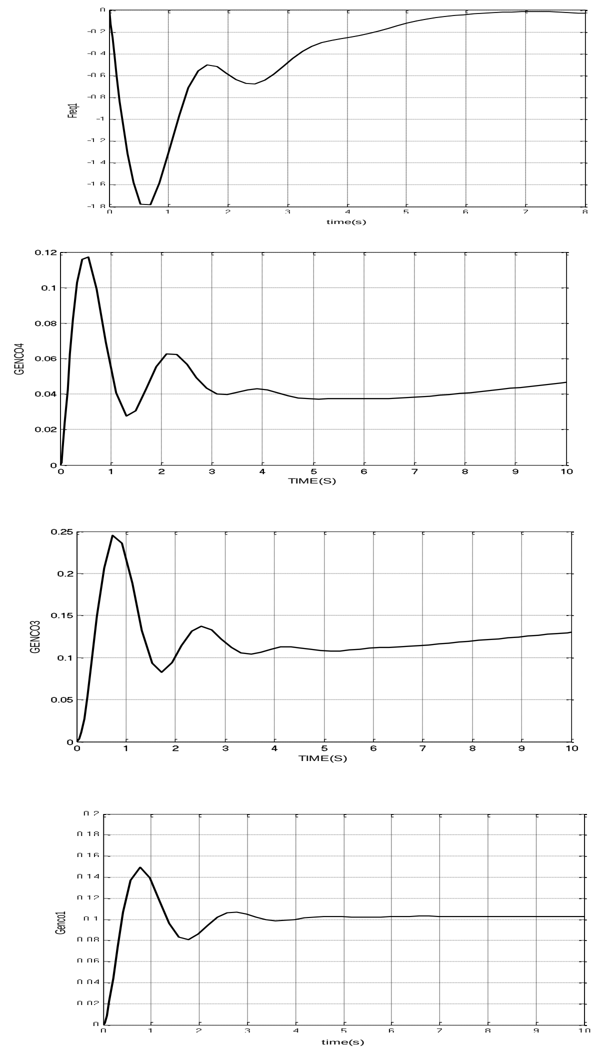


Figure 3: Frequency Deviations (rad/s) and Generated Power (pu MW)

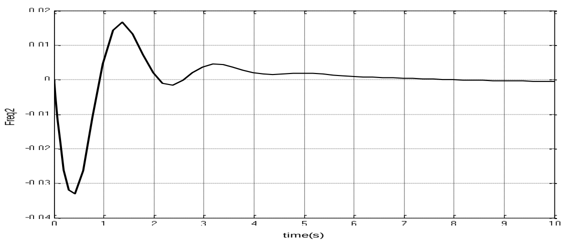
Scenario III (Contract Violation)

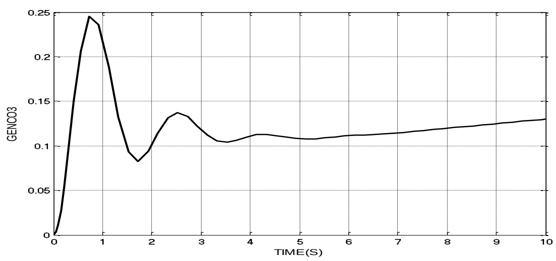
If a DISCO violates a contract by demanding more power than that specified in the contract, the excess power is not contracted out to any GENCO. This subcontracted power must be supplied by the GENCOs in the same area as the DISCO.

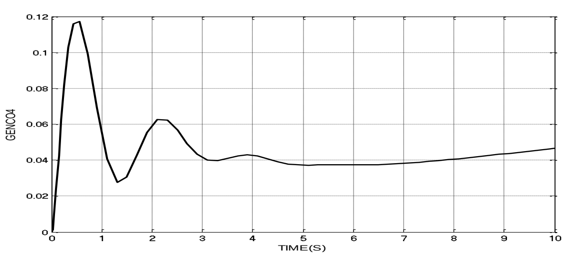
The total local load in area I $\Delta P_{L1,Loc}$ = Load of $DISCO_1$ + Load of $DISCO_2$ = (0.1 + 0.1) + 0.1 pu MW = 0.3 pu MW

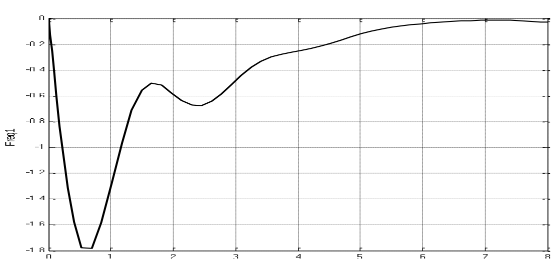
The total local load in area II $\Delta P_{L2,Loc}$ = Load of $DISCO_3$ + Load of $DISCO_4$ = 0.2 pu MW

The frequency deviations vanish in the steady state [Fig. 4]. The generation of GENCOs 3 and 4 is not affected by the excess load of DISCO.









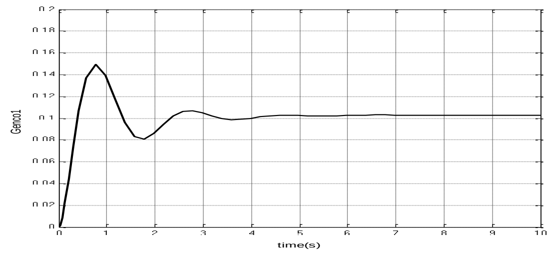


Figure 4: Frequency Deviations (rad/s) and Generated Power (pu MW)

IV. OPTIMIZATION OF INTEGRAL CONTROLLER GAIN SETTING

A. Linear Quadratic Regulators

For the design of an optimal quadratic regulator the Algebraic Riccati Equations (ARE) are used to calculate the state feedback gains for a chosen set of weighting matrices. The closed loop system is characterized in state space form as:

$$\frac{d}{dt}(x) = A^{cl} + B^{cl}$$

Where 'x' is the state vector and 'u' is the vector of power demands of the DISCOs. A^{cl} and B^{cl} matrices are constructed.

In order to have a LQR formulation with the system, the following Quadratic cost function (J) is minimized-

$$J = \int_0^{inf} [x^T(t)Qx(t) + u^T(t)Ru(t)]dt$$

Where 'Q' and 'R' are the state and control weighting matrices, respectively which are square and symmetric.

A convenient PI has the quadratic form

$$PI = \frac{1}{2}\int_0^{inf} [x'^T Qx' + u'^T Ru']dt$$

K is obtained from solution of the reduced matrix Riccati equation given below

$$A^T S + SA - SBR^{-1}B^T S + Q = 0$$
$$K = R^{-1}B^T S$$

The acceptable solution of K is that for which the system remains stable. Considering the system parameters shown in Table 3, the computer solution using MATLAB R2009a for the feedback matrix is presented.

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Performance index = 6.7306

Matrix k obtained is [4*14] and then divided into two parts Kp[4*13] which represents proportional matrix and Ki[4*1] is the integral action.[21]
For this study, following system data is used:

Table 3
System Data

$P_{r1} = P_{r2}$	2000 MW
$H_1 = H_2$	5 seconds
$D_1=D_2$	$8.33 * 10^{-3}$pu MW/Hz
$T_{T1}=T_{T2}$	0.3 seconds
$T_{G1}=T_{G2}$	0.08 seconds
R_1	2.4 Hz/ pu MW
$P_{tie\ max}$	200 MW
$\delta_1^* - \delta_2^*$	30 Degrees
T_{12}^*	0.545 pu MW/Hz
ΔP_{d1}	0.01 pu MW

V. Conclusion

This thesis 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. It is emphasized that the new challenges will require some adaptations of the current AGC strategies to satisfy the general needs of the different market organizations and the specific characteristics of each power system.

VI. Future Scope

In this research, a scheme for automatic generation control indulges the effect of voltages and market structure has been developed. This approach is the real solution for power system problem. It is expected that the research will add the world of AGC structure on demand side management.

The new framework will be required for AGC scheme based on market structure with intelligence controller to solve complex problem and need another technical issues to be solved.

In general, a variety of technical scrutiny will be needed to ensure secure system operation and a fair market place. Optimization of linear controller gain setting can be done by using Genetic Algorithm techniques.

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