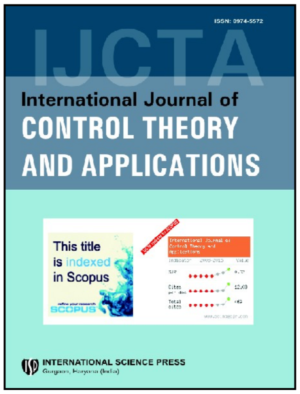

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Dynamic Analysis of Two Area Interconnected Power System with EHVAC-HVDC Tie-Lines using Optimal Regulator under Deregulated Environment

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Abstract: This paper provides the investigation of mechanical generation control of two region interrelated power system functioning in deregulated environment. An EHVAC Tie-line parallel with HVDC Tie-line is considered as an interrelation among the two fields. Optimal regulator has been employed to further improve in dynamic system show with respect to settling time, peak amplitude and overshoot. A special market scenario along with bilateral transactions has been used to examine the dynamic system performance. Analysis reveal that optimal regulator along with HVDC tie-line is quite able in advancing the dynamic system performance.

Keywords: AGC, EHVAC Tie-lines, HVDC Tie-lines, optimal regulator.

1. INTRODUCTION

The electrical power trade has been ruled over years by huge utilities that has generally authority in Generatin, Transmission and Distribution such utilities often been referred to vertical integral utilities (VIU). This VIU served In the earlier day's electrical power industry used to follow vertical integral utilities (VIU) structure. Due to vast increase in utilization of electricity the concept of VIU no longer exits. Electrical deregulation is the method of varying regulations to manage the electric industry to offer costumers electricity suppliers choice whether retailers or traders to permit competition [6]. Deregulation progress the production economic and electricity. Because of the cost competition in electricity which are probably to low down for the consumers benefits. In deregulated power system the independent power producers (IPP) are allowed to send the power through utility transmission and distribution.

The major goals of the deregulated power markets [11]:

- To offer electricity in all sensible demands
- To enhance the competition in the generation and provide and the quality of service
- To progress the supply continuity and the quality of service

- To encourage the efficiency and economy of the power system

The significant approach in deregulation is the competition. The competition is in two levels which are whole sale generation and retail distribution. Under Deregulation power system industry has been divided into three entities such as GENCOs (generation companies), TRANSCOs (transmission companies) and DISCOs (distribution companies). Each area having more than one GENCO and DISCO in deregulated environment there is a freedom provided for DISCO to have a contract with other GENCO in similar region or in some another region of power transaction. Depending upon the demand a DISCO may contract with GENCO in similar region or in other Area. DISCO having contact in other area is called Bilateral transactions [19]. The advantages related to deregulation are [3]

- System capacity will be employed effectively
- Optimization of energy supply will exists
- Consumer choice will improved
- Price of electricity will be clear
- Power flow will occurs from excess to scarcity areas.

2. AUTOMATIC GENERATION CONTROL

We know that power changes will takes place at loads for that we have to adjust the power output from multiple generators located at different areas. To adjust these generation output Automatic generation control is used. Power grid requires generation and load to be balanced frequency alterations to the generated outputs are essential. If frequency increases generating power is more than to be used this makes all machines in the system to accelerate. Decrease in frequency indicates more load is present on the system which makes all generators to decelerate than the normal speed. As the grid having tie line connections between two areas automatic generating control [12] helps in maintaining the power interchanges over the tie-lines [2].

The major goal in the automatic generation control is

- To maintain frequency as close to specified range

To maintain changes in tie-line power to zero value.

The fundamental control problem approach of a system is to accomplish the particular objectives for the meant system functioning in restrictions by physical and scientific restraints. The usual traditional control systems, mainly on the basis of frequency domain analysis, are preserved for linear time invariant single input-single output systems permits the designer greater freedom in instinct and knowledge. The modern control theory pertain the time domain concept in problem formation known as state space concept.

3. DYNAMIC POWER SYSTEM MODELS

The following configurations are recognized for power system model [5]:

- EHVAC tie-line is utilized as a system interconnection (PM-I).
- EHVAC link in parallel with HVDC link [9] is employed as a system interconnection (PM-II).

In PM-I Two areas are interconnected with EHVAC tie-lines and dynamic performance is studied by considering different market transactions [7]. In PM-II Two areas are interconnected with EHVAC parallel with HVDC tie-lines and dynamic performance is studied.

4. DISCO PARTICIPATION MATRIX

In the deregulated situation [4], GENCOs trade power to several DISCOs at spirited costs. Hence, DISCOs select the GENCOs for contracts. There are multiple contracts combinations among DISCOs and GENCOs are expediently envisaged by 'Disco Participation Matrix' (DPM) approach. The DPM matrix rows correspond to GENCOs and columns to DISCOs which contract power. The entire matrix is as of DISCOs total load (columns) contracted with all GENCO (row). The entire entries sum in columns in a matrix is unity. In a two area system DPM will have the following structure:

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

Where cpf_{id} refers to "Contract Participation Factor of jthGENCO in supplying the load of d^{th} DISCO. The DPM block diagonals keep up a correspondence with local demands. Off diagonal blocks communicate to the DISCOs demands in one region to the GENCOs in another region. DPM shows the DISCO participation in contract with other GENCO. Hence it is called "DISCO PARTICPATION MATRIX". Suppose that $DISCO_3$ demands 0.1 pu MW powers, out of which 0.025 pu MW is demanded from $GENCO_1$, 0.03 pu MW from $GENCO_2$, 0.035 pu MW from $GENCO_3$ and 0.01 pu MW from $GENCO_4$. Then column 3 entries in (1) are easily defined as

$$cpf_{13} = \frac{0.025}{0.1} = 0.25,\ cpf_{23} = \frac{0.03}{0.1} = 0.3,\ cpf_{33} = \frac{0.035}{0.1} = 0.35,\ cpf_{43} = \frac{0.01}{0.1} = 0.1$$

Other $cpf\,'s$ are defined similarly to get the whole DPM. It is noted that $\sum_i cpf_{ij} = 1$

Block Diagram Formation

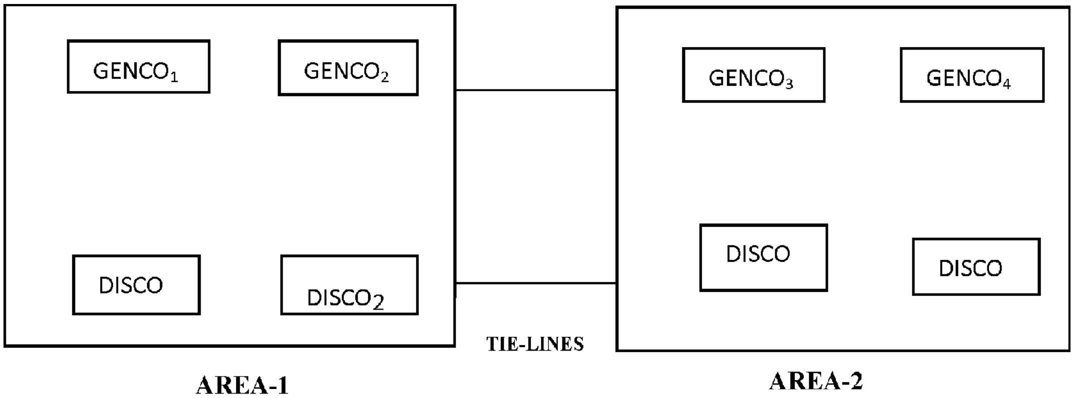


Figure 1: Dynamic Power system model with AC tie-lines

5. DISCO PARTICIPATION MATRIX

The closed loop system in Fig. 2 is characterized in state space form as

$$\dot{X} = A^{cl}x + B^{cl}u,\ \ Y = Cx + Du$$

Where X is the state vector, u is the vector of power demands of the Discos, Y is the output vector. A^{cl} is the system matrix and B^{cl} is the input distribution matrix are constructed from state space equations.

State vector:

$$\dot{X} = [\Delta\omega_1 \Delta\omega_2\ \Delta P_{G1}\ \Delta P_{G2}\ \Delta P_{G3}\ \Delta P_{G4}\ \Delta P_{M1}\ \Delta P_{M2}\ \Delta P_{M3}\ \Delta P_{M4} \int ACE_1 \int ACE_2\ \Delta P_{tie1-2}\ \Delta P_{DC}]^T$$

Control vector:

$$U = [\Delta P_{L1}\ \Delta P_{L2}\ \Delta P_{L3}\ \Delta P_{L4}]^T$$

Each element in state vector matrix represents the output of each block in the transfer function model. Control vector represents the demands of the corresponding DISCOs in the two areas respectively.

In this model ,the expressions for actual and scheduled steady-state power flows on the tie-line are given as

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

$$\Delta P_{tie\,12,schedul} = \sum_{i=1}^{2}\sum_{j=3}^{4} cpf_{ij}\ \Delta P_L - \sum_{i=3}^{4}\sum_{j=1}^{2} cpf_{ij}\ \Delta P_{Lj}$$

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

The tie-line power error $(\Delta Ptie_{12,error})$ is defined by

$$\Delta P_{tie12,error} = \Delta P_{tie12,actual} - \Delta P_{tie12,scheduled}$$

The area control errors (ACEs) in a deregulated power system in both areas are defined as [10]

$$ACE_1 = B_1\,\Delta f_1 + \Delta Ptie_{12,error}\,;\ ACE_2 = B_2\,\Delta f_2 + \alpha_{12}\,\Delta Ptie_{12,error}$$

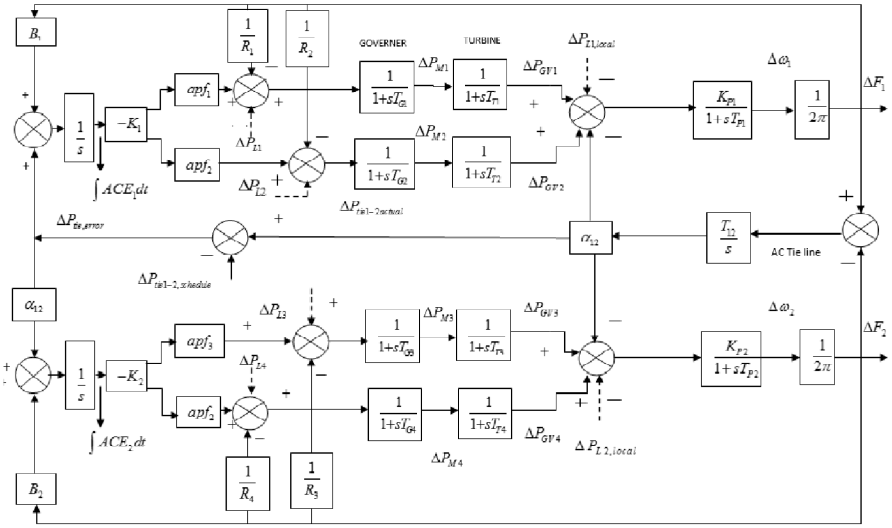


Figure 2: Dynamic Model of Two area Interconnected power systems with EHVAC tie lines

From Fig. 2 dashed lines $\Delta P_{L1}, \Delta P_{L2}, \Delta P_{L3}, \Delta P_{L4}$ are the market signals from power market signals. In the steady state, the demand of DISCOs in a contract must match with GENCOs generation, expressed as:

$$\Delta P_{L1,Loc} = \Delta P_{L1} + \Delta P_{L2},$$

$$\Delta P_{L2,Loc} = \Delta P_{L3} + \Delta P_{L4},$$

$$\Delta P_1 = cpf_{11}\Delta P_{L1} + cpf_{12}\Delta P_{L2} + cpf_{13}\Delta P_{L3} + cpf_{14}\Delta P_{L4},$$

$$\Delta P_2 = cpf_{21}\Delta P_{L1} + cpf_{22}\Delta P_{L2} + cpf_{23}\Delta P_{L3} + cpf_{24}\Delta P_{L4},$$

$$\Delta P_3 = cpf_{31}\Delta P_{L1} + cpf_{32}\Delta P_{L2} + cpf_{33}\Delta P_{L3} + cpf_{34}\Delta P_{L4},$$

$$\Delta P_4 = cpf_{41}\Delta P_{L1} + cpf_{42}\Delta P_{L2} + cpf_{43}\Delta P_{L3} + cpf_{44}\Delta P_{L4}.$$

Also $\Delta P_{L1,Loc}$, $\Delta P_{L2,Loc}$ are the load demands from DISCOs.

$$A^{cl} = \begin{bmatrix}
\frac{-1}{T_{P1}} & 0 & \frac{K_{P1}}{T_{P1}} & \frac{K_{P1}}{T_{P1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{K_{P1}}{T_{P1}} \\
0 & \frac{-1}{T_{P2}} & 0 & 0 & \frac{K_{P2}}{T_{P2}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{K_{P2}}{T_{P2}} \\
0 & 0 & \frac{-1}{T_{T1}} & 0 & 0 & 0 & \frac{1}{T_{T1}} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{-1}{T_{T2}} & 0 & 0 & 0 & \frac{1}{T_{T2}} & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \frac{-1}{T_{T3}} & 0 & 0 & 0 & \frac{1}{T_{T3}} & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{T4}} & 0 & 0 & 0 & \frac{1}{T_{T4}} & 0 & 0 & 0 \\
\frac{-1}{2\pi R_1 T_{G1}} & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{G1}} & 0 & 0 & 0 & \frac{-K_1 apf_1}{T_{G1}} & 0 & 0 \\
\frac{-1}{2\pi R_2 T_{G2}} & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{G2}} & 0 & 0 & \frac{-K_2 apf_2}{T_{G2}} & 0 & 0 \\
0 & \frac{-1}{2\pi R_3 T_{G3}} & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{G3}} & 0 & 0 & \frac{-K_3 apf_3}{T_{G3}} & 0 \\
0 & \frac{-1}{2\pi R_4 T_{G4}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{G4}} & 0 & \frac{-K_4 apf_4}{T_{G4}} & 0 \\
\frac{B_1}{2\pi} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & \frac{B_2}{2\pi} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 \\
\frac{T_{12}}{2\pi} & \frac{-T_{12}}{2\pi} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

Where state matrix (A) obtained from state space representation

Case 1: Base Case: Demands by DISCO'S only with GENCO'S Area 1

Consider a case where the GENCOs in all the areas contribute uniformly in AGC; i.e., ACE participation factors are $apf_1 = 0.5,$

Suppose that the change in load exists just in area I. Thus, the load is required only by DISCO$_1$ and DISCO$_2$ [1]. Let the value of this load demand be 0.1 pu MW for each of them. Referring to (1), DPM becomes,

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

B. Case 2: All GENCO's are in contract with DISCO's

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

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

C. Case 3: Contract Violation: DISCO's may demand more power than specified:

It may occur when a DISCO infringes a contract through demanding extra power than in the contract. This extra power is not constricted out to other GENCO. This unconstructed power has to provide through the GENCOs in the similar region as the DISCO. It should be imitated as a local load area but not as the contracted demand.

Due to incremental power flow through HVDC tie-line causes several changes in state vector [31]. The size of state vector increased, due to change in power through HVDC tie-line. It also affects the other state variables. The changes caused from power system model 1to power system model 2 are given as:

$$\dot{X}_1 = \frac{-1}{T_{P1}} x_1 + \frac{K_{P1}}{T_{P1}} x_3 + \frac{K_{P1}}{T_{P1}} x_4 - \frac{K_{P1}}{T_{P1}} x_{13} - \frac{K_{P1}}{T_{P1}} x_{14} - \frac{K_{P1}}{T_{P1}} \Delta P_{L1} - \frac{K_{P1}}{T_{P1}} \Delta P_{L2},$$

$$\dot{X}_2 = \frac{-1}{T_{P2}} x_2 + \frac{K_{P2}}{T_{P2}} x_5 + \frac{K_{P2}}{T_{P2}} x_6 + \frac{K_{P2}}{T_{P2}} x_{13} - \frac{K_{P2}}{T_{P2}} x_{14} - \frac{K_{P2}}{T_{P2}} \Delta P_{L3} - \frac{K_{P2}}{T_{P2}} \Delta P_{L4}$$

6. CASE STUDIES

Table 1
Ace Participation Factors and Demands of Discos

Case Studies	*Contract Types*	*Area participation factor*	*DISCOs load demand*	*Distribution participation matrix*
Case 1	DISCOs in each area participate equally	$\text{apf}_1 = 0.5$ $\text{apf}_2 = 0.5$ $\text{apf}_3 = 0.5$ $\text{apf}_4 = 0.5$	$\Delta P_{L1} = 0.1$ $\Delta P_{L2} = 0.1$ $\Delta P_{L3} = 0$ $\Delta P_{L4} = 0$	$\begin{bmatrix} 0.5 & 0.5 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$
Case 2	DISCOs contract with GENCOs	$\text{apf}_1 = 0.75$ $\text{apf}_2 = 0.25$ $\text{apf}_3 = 0.5$ $\text{apf}_4 = 0.5$	$\Delta P_{L1} = 0.1$ $\Delta P_{L2} = 0.1$ $\Delta P_{L3} = 0.1$ $\Delta P_{L4} = 0.1$	$\begin{bmatrix} 0.5 & 0.25 & 0 & 0.3 \\ 0.2 & 0.25 & 0 & 0 \\ 0 & 0.25 & 1 & 0.7 \\ 0.3 & 0.25 & 0 & 0 \end{bmatrix}$

Case 3	Contract violation of DISCO by demanding more power	apf $_1$ = 0.75 apf $_2$ = 0.25 apf $_3$ = 0.5 apf $_4$ = 0.5	$\Delta P_{L1} = 0.2$ $\Delta P_{L2} = 0.1$ $\Delta P_{L3} = 0.1$ $\Delta P_{L4} = 0.1$	$\begin{bmatrix} 0.5 & 0.25 & 0 & 0.3 \\ 0.2 & 0.25 & 0 & 0 \\ 0 & 0.25 & 1 & 0.7 \\ 0.3 & 0.25 & 0 & 0 \end{bmatrix}$

7. DESIGN OF OPTIMAL REGULATOR

The optimal control theory is alarmed with working dynamic system at low cost. The holder where the dynamics system is need through linear differential equations sets and the cost is explained through a quadratic task is called the Linear Quadratic issue. The major outcomes offered are by Linear Quadratic Regulators (LQR). Traditionally, AGC [8] is concerned to start with the frequency control of a power system through the flywheel synchronous machine governor. While this system was consequently established to be inadequate, an additional control was attached with a signal to the governor proportional to the frequency deviation and it's integral. For power system the aim and execution of AGC regulators with hydro turbines proposes scientific complexity because of greater time constants related to hydropower plants. The examinations showed that concerning incremental dc power flow in AGC approach as a control variable is verified to be an efficient in progressing power system dynamic improvement and attaining the AGC goals.

The fundamental control problem approach of a system is to accomplish the particular objectives for the meant system functioning in restrictions by physical and scientific restraints. The usual traditional control systems, mainly on the basis of frequency domain analysis [18], are preserved for linear time invariant single input-single output systems permits the designer greater freedom in instinct and knowledge. The modern control theory pertain the time domain concept in problem formation known as state space concept

This concept has been suitable in real time execution using digital computers and few minimum variables set which are necessary to complete the internal system status. The regulator plan through optimal control theory allows the designers to encompass optimum system design regarding known performance condition. The significant aspects in modern control are the organization of logical index performance and its optimization creates the system control more significant in optimality sense.

The continuous time-invariant system dynamic model in the state variable form is given as

$$\dot{X} = AX + BU$$

$$Y = CX + DU$$

The control signal U is such that it minimizes the performance index (I):

$$I = \int_0^\infty \frac{1}{2}[X^T QX + U^T RU]dx$$

In the application of optimal control theory, the term in $\dot{X}$ is eliminated by redefining the states and controls in terms of their steady-state values occurring after the disturbance. Equation below can be written as:

$$\dot{X} = AX + BU, \ \dot{X}(0) = X_0$$

Moreover $\dot{X}$, Y will stay the same. With a full state vector feedback control problem

$$U^* = -\Psi^* X$$

In the application of optimal control theory, the term ΓP_d in Eq. above is removed by redefining the states and controls in terms of their steady-state values occurring after the disturbance.

Which minimizes the cost function given by Eq above .Forthe infinite time problem, the application of Pontryagin's minimum principle results in the following matrix Riccati equation?

$$PA + A^T P - PBR^{-1}B^T P + Q = 0$$

The solution of Eq.above gives a positive definite symmetric matrix P, and the optimal control is given by:

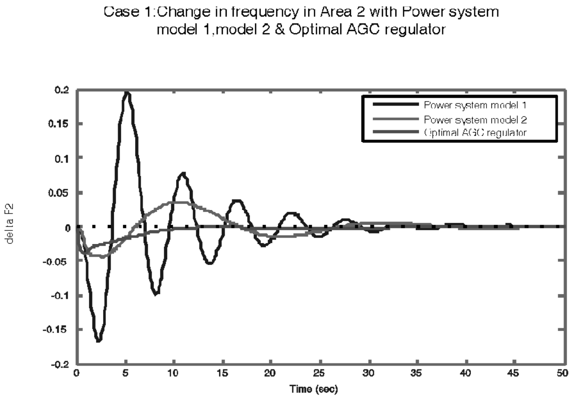
$$U^* = -R^{-1}B^T PX$$

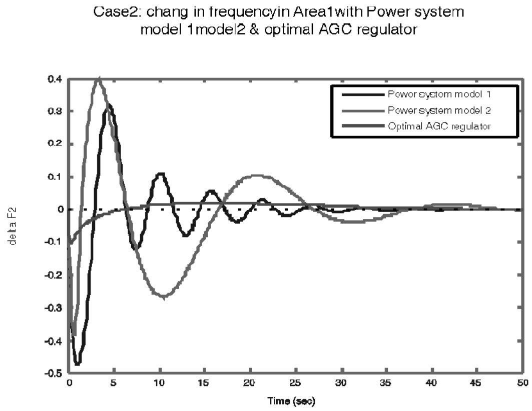
The desired optimal feedback gain matrix is given by:

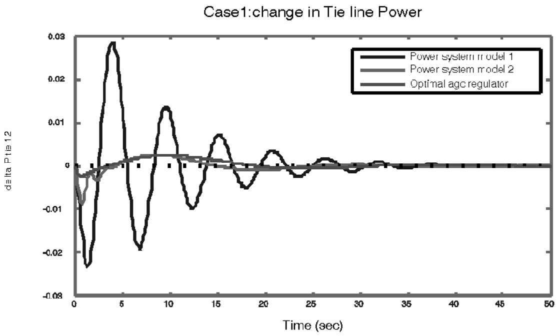
$$\Psi^* = R^{-1}B^T P$$

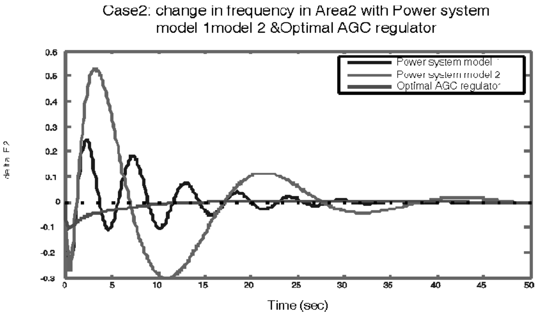
8. RESULTS COMPARISON FOR DIFFERENT CASE STUDIES

a) Case 1: Base case:

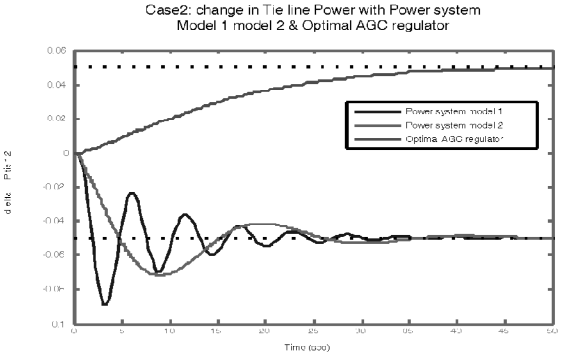

Case 1:Change in frequency in Area 2 with Power system model 1,model 2 & Optimal AGC regulator

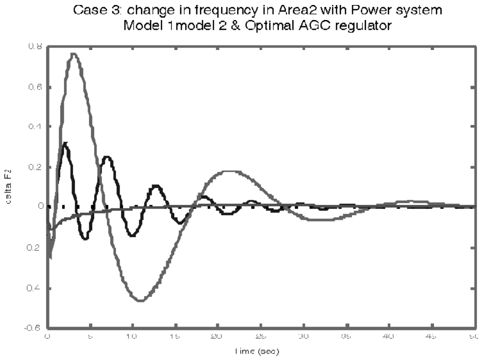

Case2: chang in frequencyin Area1with Power system model 1model2 & optimal AGC regulator


Case1:change in Tie line Power

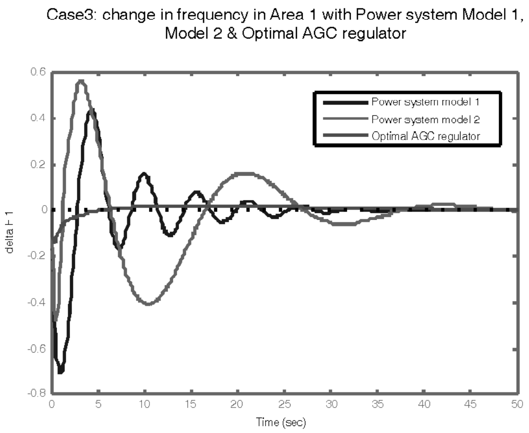

Case2: change in frequency in Area2 with Power system model 1model 2 &Optimal AGC regulator

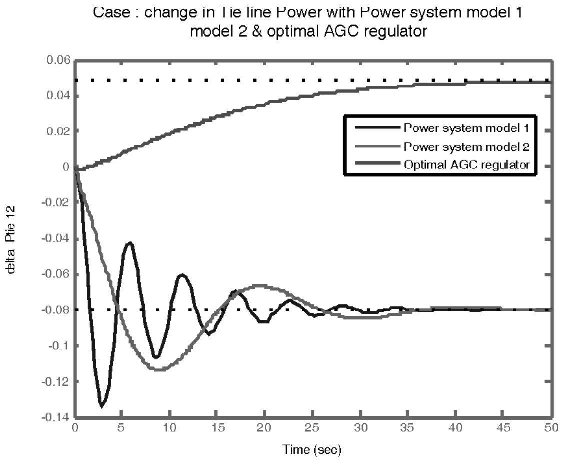
b) Case 2:


Case2: change in Tie line Power with Power system Model 1 model 2 & Optimal AGC regulator


Case 3: change in frequency in Area2 with Power system Model 1model 2 & Optimal AGC regulator

c) Case 3:


Case3: change in frequency in Area 1 with Power system Model 1, Model 2 & Optimal AGC regulator


Case : change in Tie line Power with Power system model 1 model 2 & optimal AGC regulator

9. ANALYSIS OF RESULTS

a) Case:1

Change in frequency in Area 1

DYNAMIC PARAMETERS	*MODEL1*	*MODEL 2*	*OPTIMAL REGULATOR*
Settling time	30.8	32.5	27.6
Peak Amplitude	-0.325	-0.211	-0.0848
Over shoot (%)	4.64e+15	-1.8e+15	-2.7e+15
Change in frequency in Area 2			
Settling time	30.8	32.5	27.6
Peak Amplitude	-0.325	-0.211	-0.0848
Over shoot (%)	4.64e+15	-1.8e+15	-2.7e+15
Change in Tie-line power			
Settling time	35.1	33.7	56.9
Peak Amplitude	0.0287	-0.00869	-0.000247
Over shoot (%)	-4.23e+14	8.21e+14	-7.95e+12

b) Case:2

Change in frequency in Area 1

DYNAMIC PARAMETERS	*MODEL 1*	*MODEL 2*	*OPTIMAL REGULATOR*
Settling time	30	45.7	48.6
Peak Amplitude	-0.476	0.394	-0.104
Over shoot (%)	7.02e+15	2.07e+15	9.96e+14
Change in frequency in Area 2			
Settling time	33.1	45.7	42.4
Peak Amplitude	-0.269	0.527	-0.102
Over shoot (%)	1.41e+16	4.37e+15	-1.48e+14
Change in Tie-line power			
Settling time	31.8	42.9	44.1
Peak Amplitude	-0.0893	-0.0719	————
Over shoot (%)	8.43e+15	3e+015	————

c) Case:3

Change in frequency in Area 1

DYNAMIC PARAMETERS	*MODEL 1*	*MODEL 2*	*OPTIMAL REGULATOR*
Settling time	27.4	45.9	45.1
Peak Amplitude	-0.706	0.56	-0.145
Over shoot (%)	7.75e+15	1.13e+15	-1.43e+15
Change in frequency in Area 2			
Settling time	35.5	46	41.1
Peak Amplitude	0.314	0.762	-0.112
Over shoot (%)	-2.9e+15	-9e+15	-8.69e+15
Change in Tie-line power			
Settling time	31.4	42.7	43.8
Peak Amplitude	-0.134	-0.114	>=0.04
Over shoot (%)	-67.2	42.1	0.0327

10. CONCLUSION

In all the case studies the settling time of PM-I less than the PM-II but the peak over shoot and under shoot is less with HVDC tie line combination. With optimal regulator the oscillations are reduced but tie line response takes more time to settle, but a smooth response can be obtained with optimal regulator. In order to improve the response in spite of HVDC tie line a FACT device can be kept in series with tie line, hence the response can settle at least time and overshoot can be reduced. The oscillation's and peak over shoot is more with only EHVAC tie line. With contract violation case the tie line oscillations are more with regulator. The responses generally depend upon cpf's and apf's.The dynamic response characteristics such as settling time, peak amplitude and overshoots are obtained by state space representation technique. The dynamic characteristics are less with optimal regulator but more in case where the GENCOS violates the contract. With HVDC tie-line the peak amplitude is reduced. The patter of eigenvalue analysis shows the system is stable irrespective of additional HVDC tie line in parallel with AC tie-line.

11. DISCUSSIONS

In the case 1 the change in frequency in area 1, the settling time of optimal AGC regulator [13] is less compared to model 1 and model 2 at the same time peak amplitude and overshoot percentage is less for the optimal AGC regulator only. In the case 1 area 2, the settling time is less for model 1 and peak amplitude is less for optimal AGC regulator and over shoot percentage is less for model 2. In the case 1 tie line, the settling time is more with optimal regulator compared to model 1 and model 2 but the peak amplitude is less for optimal regulator compared to model 1 and model 2. In the case 2, the settling time is less for model 1 compared with model 2 and AGC regulator but the peak amplitude is less with optimal regulator compared with model 1 and model 2. In case 2 area 2the settling time is less for model 1 and peak amplitude is less for optimal regulator In case 2 tie line ,the settling time and overshoot percentage is less for model 1 compared with model 2 and AGC regulator In case 3 area 1the settling time is less but the overshoot percentage is more with model 1 but overshoot percentage is less with model 2. In case 3 area 2the overshoot percentage is less with model 1 compared with model 2 and AGC regulator. In case 3 tie line powers the settling time is less with model 1 but the overshoot percentage is more, with optimal regulator the overshoot percentage is less but the settling time is more.

12. APPENDIX

(a) System parameters

$K_{P1} = 120.048$, $T_{P1}=20.008$, $T_{G1} = T_{G2}= 0.08$ s, $T_{T1}= T_{T2} =0.3$,

$B_1= B_2= 0.425$ Pu Mw/Hz, $R_1= R_2 = 2.4$ Hz/Pu MW, $-\alpha_{12} = -1$

(b) HVDC link parameters: $K_{dC} =1.0$, T dc=0.5sec.

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