Automatic Generation Control of Two Area Thermal Power System with PI Controllers Using State Space Approach

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Abstract

Automatic Generation Control (AGC), which monitors the power system operation, may control whole power grid without blackouts. Here a two area thermal power system is simulated using integral and PI controllers by changing the loads of two areas simultaneously. A state space model is developed for the same system. For this model Linear Quadratic Regulator (LQR) is implemented to get better performance.

Keywords — *Automatic generation control, two area power system, integral controller, PI controller, state space model, Quadratic optimal regulator.*

I. INTRODUCTION

Automatic Generation Control (AGC) is an essential aspect of power system operation and control that ensures frequency constraints of the power system. Here AGC of a two area thermal power system is modelled with per unit frequency and per unit power so that the resulting frequencies and powers are expressed in per unit [1,2]. Power system modelling may be linear or nonlinear. State space modelling can handle linear or nonlinear models effectively [4,5,6,7]. Powerful state space techniques can be implemented for this model ensuring better performance. AGC may be obtained with Integral control alone. However relative stability (transient response) of the system may not be satisfactory. With state space optimal control methods like Linear Quadratic Regulator (LQR) may be employed for robust stability along with integral controller.

II. INTEGRAL CONTROLLER

In a power system governor is used as primary controller where the frequency may not be at acceptable limits. Hence a secondary controller like Integral controller which decreases the static error in frequency to zero is used. It will bring the system frequency into the acceptable limits. However transient response may not be satisfactory.

III. AGC OF TWO AREA THERMAL POWER SYSTEM WITH INTEGRAL CONTROLLER

Two areas are connected by a high voltage tie line so that power can be shared between them. With suitable secondary controllers the frequencies of both the areas can be maintained at rated value with zero tie-line power deviation.Fig. 1 shows a two area thermal power system with integral controller whose data is shown in Table 1. An integral controller is employed as secondary controller.

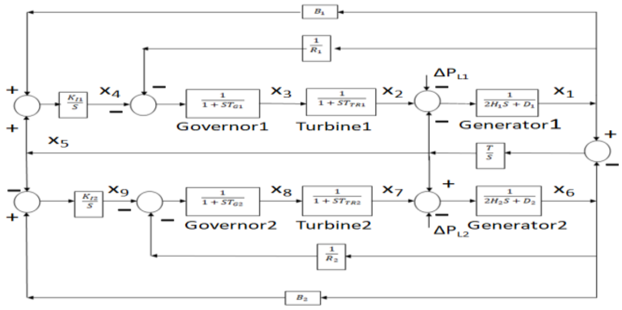

Fig 1: Two area thermal power system with integral controller

IV. AGC OF TWO AREA THERMAL POWER SYSTEM WITH PI CONTROLLER

Two area thermal power system with PI control is shown in Figure 2 whose data is shown in Table 1. Secondary controller is PI controller

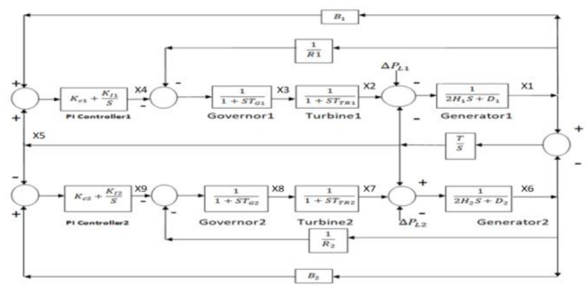

Fig 2: two area thermal power system with PI controller

V. STATE SPACE MODEL

The states selected for the two area thermal power system model are

$x_1 = \Delta\omega_1$= Frequency deviation of area 1 in pu
$x_2 = \Delta P_{m1}$=Change in mechanical power of turbine 1
$x_3 = \Delta P_{v1}$= Change in steam valve setting of area 1
$x_4 = \Delta P_{ref1}$ = Change in P_{ref} of area 1
$x_5 = \Delta P_{12}$ = Tie-line power deviation, pu
$x_6 = \Delta\omega_2$ = Frequency deviation of area 2 in pu
$x_7 = \Delta P_{m2}$ =Change in mechanical power of turbine 2
$x_8 = \Delta P_{v2}$=Change in steam valve setting of area 2
$x_9 = \Delta P_{ref2}$=Change in P_{ref} of area 2

The state space model of the two area thermal power system with integral controller is obtained as,

$$\dot{x_1} = -\frac{D_1}{2H_1}x_1 + \frac{1}{2H_1}x_2 - \frac{1}{2H_1}x_5 - \frac{1}{2H_1}\Delta P_{L1} \quad (1)$$

$$\dot{x_2} = -\frac{1}{T_{TR1}}x_2 + \frac{1}{T_{TR1}}x_3 \quad (2)$$

$$\dot{x_3} = -\frac{1}{R_1T_{G1}}x_1 - \frac{1}{T_{G1}}x_3 - \frac{1}{T_{G1}}x_4 \quad (3)$$

$$\dot{x_4} = -B_1K_{I1}X_1 - K_{I1}X_5 \quad (4)$$

$$\dot{x_5} = T_{12}x_1 - T_{12}x_6 \quad (5)$$

$$\dot{x_6} = \frac{1}{2H_2}x_5 - \frac{D_2}{2H_2}x_6 + \frac{1}{2H_2}x_7 - \frac{1}{2H_2}\Delta P_{L2} \quad (6)$$

$$\dot{x_7} = -\frac{1}{T_{TR2}}x_7 + \frac{1}{T_{TR2}}x_8 \quad (7)$$

$$\dot{x_8} = -\frac{1}{R_2T_{G2}}x_6 - \frac{1}{T_{G2}}x_8 - \frac{1}{T_{G2}}x_9 \quad (8)$$

$$\dot{x_9} = K_{I2}X_5 - B_2K_{I2}X_6 \quad (9)$$

The resulting A, B, C, D matrices are,

$$A = \begin{bmatrix} -\frac{D_1}{2H_1} & \frac{1}{2H_1} & 0 & 0 & -\frac{1}{2H_1} & 0 & 0 & 0 & 0 \\ 0 & -\frac{1}{T_{TR1}} & \frac{1}{T_{TR1}} & 0 & 0 & 0 & 0 & 0 & 0 \\ -\frac{1}{R_1T_{G1}} & 0 & -\frac{1}{T_{G1}} & -\frac{1}{T_{G1}} & 0 & 0 & 0 & 0 & 0 \\ -B_1K_{I1} & 0 & 0 & 0 & -K_{I1} & 0 & 0 & 0 & 0 \\ T_{12} & 0 & 0 & 0 & 0 & -T_{12} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{2H_2} & -\frac{D_2}{2H_2} & \frac{1}{2H_2} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -\frac{1}{T_{TR2}} & \frac{1}{T_{TR2}} & 0 \\ 0 & 0 & 0 & 0 & 0 & -\frac{1}{R_2T_{G2}}x_6 & 0 & -\frac{1}{T_{G2}} & -\frac{1}{T_{G2}} \\ 0 & 0 & 0 & 0 & K_{I2} & -B_2K_{I2} & 0 & 0 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} -\frac{1}{2H_1} & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & -\frac{1}{2H_2} \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix}$$

$$D = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}$$

The state space model of the two area thermal power system wit PI controller is obtained as,

$$\dot{X}_1 = -\frac{D_1}{2H_1}X_1 + \frac{1}{2H_1}X_2 - \frac{1}{2H_1}X_5 - \frac{1}{2H_1}\Delta P_{L1} \quad (1)$$

$$\dot{X}_2 = -\frac{1}{T_{TR1}}X_2 + \frac{1}{T_{TR1}}X_3 \quad (2)$$

$$\dot{X}_3 = -\frac{1}{R_1T_{G1}}X_1 - \frac{1}{T_{G1}}X_3 - \frac{1}{T_{G1}}X_4 \quad (3)$$

$$\dot{X}_4 = \left(-\frac{B_1K_{C1}D_1}{2H_1} + K_{C1}T_{12} + B_1K_{I1}\right)X_1 + \left(\frac{B_1K_{C1}}{2H_1}\right)X_2 + \left(-\frac{B_1K_{C1}}{2H_1} + K_{I1}\right)X_5 + (-K_{C1}T_{12})X_6 + \left(-\frac{B_1K_{C1}}{2H_1}\right)\Delta P_{L1} \quad (4)$$

$$\dot{X}_5 = T_{12}X_1 - T_{12}X_6 \quad (5)$$

$$\dot{X}_6 = \frac{1}{2H_2}X_5 - \frac{D_2}{2H_2}X_6 + \frac{1}{2H_2}X_7 - \frac{1}{2H_2}\Delta P_{L2} \quad (6)$$

$$\dot{X}_7 = -\frac{1}{T_{TR2}}X_7 + \frac{1}{T_{TR2}}X_8 \quad (7)$$

$$\dot{X}_8 = -\frac{1}{R_2T_{G2}}X_6 - \frac{1}{T_{G2}}X_8 - \frac{1}{T_{G2}}X_9 \quad (8)$$

$$\dot{X}_9 = (-K_{C2}T_{12})X_1 + \left(\frac{B_2K_{C2}}{2H_2} - K_{I2}\right)X_5 + \left(K_{C2}T_{12} - \frac{B_2D_2K_{C2}}{2H_2} + B_2K_{I2}\right)X_6 + \left(\frac{B_2K_{C2}}{2H_2}\right)X_7 - \left(\frac{B_2K_{C2}}{2H_2}\right)\Delta P_{L2} \quad (9)$$

The resulting A,B,C,D matrices are,

$$A= \begin{bmatrix} -\frac{D_1}{2H_1} & \frac{1}{2H_1} & 0 & 0 & -\frac{1}{2H_1} & 0 & 0 & 0 & 0 \\ 0 & -\frac{1}{T_{TR1}} & \frac{1}{T_{TR1}} & 0 & 0 & 0 & 0 & 0 & 0 \\ -\frac{1}{R_1T_{G1}} & 0 & -\frac{1}{T_{G1}} & -\frac{1}{T_{G1}} & 0 & 0 & 0 & 0 & 0 \\ -\frac{B_1K_{C1}D_1}{2H_1} + K_{C1}T_{12} + B_1K_{I1} & \frac{B_1K_{C1}}{2H_1} & 0 & 0 & -\frac{B_1K_{C1}}{2H_1} + K_{I1} & -K_{C1}T_{12} & 0 & 0 & 0 \\ T_{12} & 0 & 0 & 0 & 0 & -T_{12} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{2H_2} & -\frac{D_2}{2H_2} & \frac{1}{2H_2} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -\frac{1}{T_{TR2}} & \frac{1}{T_{TR2}} & 0 \\ 0 & 0 & 0 & 0 & 0 & -\frac{1}{R_2T_{G2}} & 0 & -\frac{1}{T_{G2}} & -\frac{1}{T_{G2}} \\ -K_{C2}T_{12} & 0 & 0 & 0 & \frac{B_2K_{C2}}{2H_2} - K_{I2} & K_{C2}T_{12} - \frac{B_2D_2K_{C2}}{2H_2} + B_2K_{I2} & \frac{B_2K_{C2}}{2H_2} & 0 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} -\frac{1}{2H_1} & 0 \\ 0 & 0 \\ 0 & 0 \\ -\frac{B_1K_{C1}}{2H_1} & 0 \\ 0 & 0 \\ 0 & -\frac{1}{2H_2} \\ 0 & 0 \\ 0 & 0 \\ 0 & \frac{B_2K_{C2}}{2H_2} \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix}$$

$$D = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}$$

VI. QUADRATIC OPTIMAL REGULATOR [3]

The basics of LQR, applied to the state model, are

$$\dot{x} = Ax + Bu \quad (10)$$

$$y = cx \quad (11)$$

The performance of the system is specified in terms of a performance index (J):

$$J = \frac{1}{2}\int_{0}^{\infty}(x^T Qx + u^T Ru)dt \quad (12)$$

where, $Q$is a positive-definite (or positive-semidefinite) real symmetric matrix and R is a positive-definite real symmetric matrix. The matrices Q and R decide the comparative importance of the error and the spending of this energy.

Optimal control law for the full state feedback controller is given by

u=-Kx (13)

The optimal gain matrix K may be obtained from the reduced matrix Riccati equation by solving P

$$A^T P + PA - PBR^{-1}B^T P + Q = 0 \quad (14)$$

And optimal gain matrix K is given as,

$$K = R^{-1}B^T\text{P} \quad (15)$$

VII. RESULTS

The parameter data of the two area thermal power system is provided in Table1 and the simulation is carried out as shown in Fig. 3 for Integral control. The simulation model for PI control is replace the PI control in the place of integral controller in figure 3.The PI controller gains are taken as $K_{P1} = 0.4$,$K_{C1} = 0.4$,$K_{P2} = 0.4$,$K_{C2} = 0.4$,

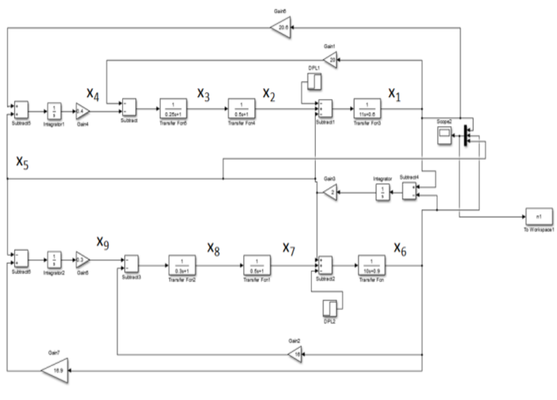

Fig 3: Simulation model of Two Area Thermal Power System with integral controller

TABLE I
Data of Two Area Thermal Power System

Control Area	**1**	**2**
Speed droop, pu	$R_1 = 0.05$	$R_2 = 0.0625$
Frequency sensitive load coefficient, pu	$D_1 = 0.6$	$D_2 = 0.9$
Inertia constant, s	$H_1 = 5.5$	$H_2 = 5$
Time constant of Governor, s	$T_{G1} = 0.25$	$T_{G2} = 0.3$
Time constant of Turbine, s	$T_{TR1} = 0.5$	$T_{TR2} = 0.5$
Bias factors	$B_1 = 20.6$	$B_2 = 16.9$

Consider the generic case of simultaneous load changes in both the areas with $\Delta P_{L1} = 0.1$ pu and $\Delta P_{L2} = 0.05$ pu. The results are shown in Figs. 4,5,6,7,8 and 9.Frequency deviations of control area1 and 2 are shown in figures 4,5,7 and 8 respectively.Deviation in tie line power is shownin Fig.6 and 9.Figures4,5 and 6 show comparison of integral control performance and LQR method of two area thermal power system.Integral controller gains are selected as 0.4 and 0.3 for areas 1 and 2 respectively by trial and error.Here the settling time is 18s with undershoots and overshoots indicating inadequate transient response. Steady state response is zero in all the figures as required.

Frequency and tie line power deviations of the thermal power system with Integral control action along with LQR are shown in Fig. 4 using MATLAB programming. Here Q and R matrices selected by trial error as

Q =[4 0 0 0 0 0 0 0 0 ; 0 4 0 0 0 0 0 0 0 ; 0 0 4 0 0 0 0 0 0; 0 0 0 4 0 0 0 0 0; 0 0 0 0 4 0 0 0; 0 0 0 0 0 4 0 0 0; 0 0 0 0 0 0 4 0 0; 0 0 0 0 0 0 0 4 0; 0 0 0 0 0 0 0 0 4]

R = [0.01 0; 0 0.01]

Here the settling time is 3s without overshoots indicating good transient response.

As data shown in Table 1 considered for two area thermal power system with PI control the results are shown in Figures7,8,9.

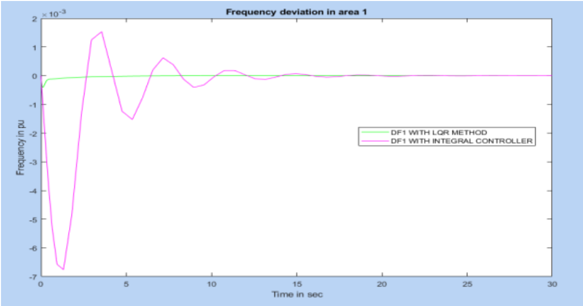

Fig4: Frequency deviation in area1 with integral control and LQR method

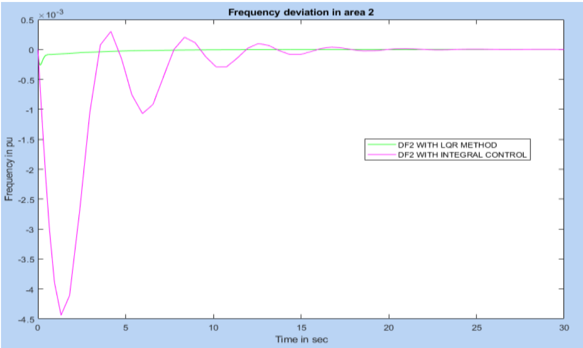

Fig 5: Frequency deviation in area2 with integral controller and LQR method

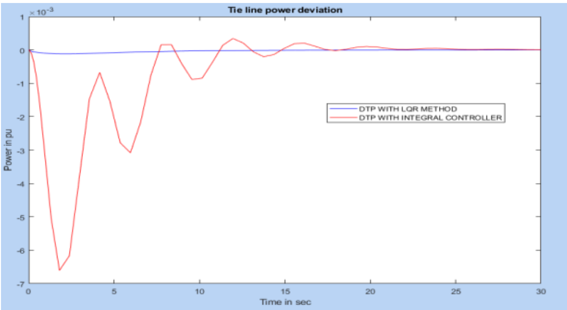

Fig 6: Tie line power deviation with integral controller and LQR method

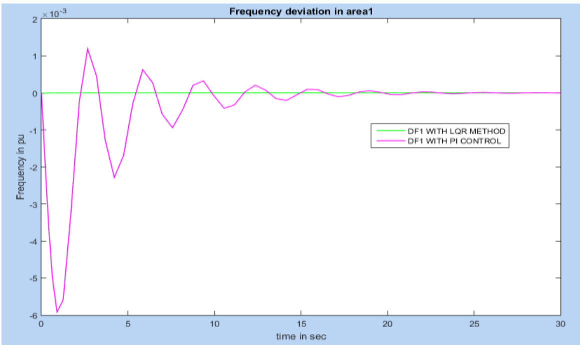

Fig 7: Frequency deviation in area1 with PI controller and LQR method

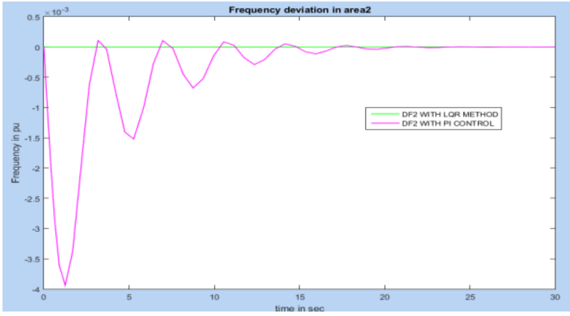

Figure 8: frequency deviation in area2 with PI controller and LQR method

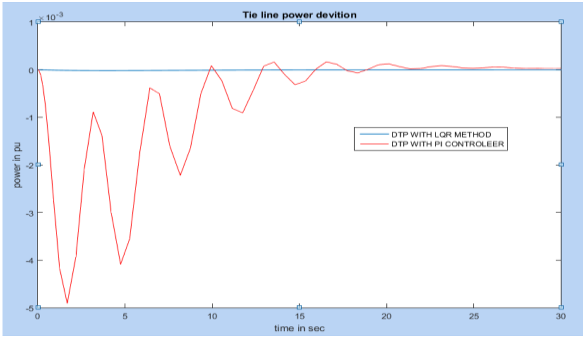

Figure 9: Tie line power deviation with PI controller and LQR method

VIII. CONCLUSION

State space modelling has advantages like dealing of both linear and nonlinear systems without sacrificing initial conditions. Sophisticated control techniques are available in state space approach.Firstly a two area power system modelled in per unit frequency and per unit power is considered. AGC of this model is obtained with integral control alone using simulation.However he results are not so satisfactory in terms of transient response.Then a state space model is acquired with nine state variables for this two area model and LQR optimal control is applied to this state space model. As shown in Results section, these results are superior to basic AGC with integral control alone. Also the steady state deviations of frequencies of both areas and tie-line power become zero almost in zero time as required.

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