

# AGC OF TWO AREA INTERCONNECTED POWER SYSTEM WITH DIVERSE SOURCES IN EACH AREA

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**Abstract:** This paper presents dynamic modelling for Automatic Generation Control of two area interconnected power system considering diverse sources in each area. The two areas are interconnected by AC tie- line. The hydro, thermal and gas power plants constitute the generation. To carry out the investigations, PI control strategy based optimal AGC regulators are designed. To assess the stability of the system, pattern of open-loop and closed-loop system eigenvalues are computed. The dynamic performance of system with optimal AGC regulators is obtained for 1% step load disturbance in one of the control area.

**Key word:** Automatic Generation Control, Dynamic Modelling, State Space Model, Eigenvalue Analysis, Dynamic Performance

## 1. Introduction

The power system consists of large numbers of generators interconnected by networks of transmission lines, which provide power to consumers at rated voltage and frequency. The maintenance of these parameters at the rated values is necessary for having high efficiency and minimum wear and tear of the consumer equipment. Therefore, main parameters to be controlled are the system frequency and voltage, which determine stability and quality of the power supply.

In a power system, frequency deviations are mainly due to real power mismatch between generation and load, where as voltage variations are due to reactive power imbalance in the system. The reactive power is produced close to requirements as involves only capital cost but no fuel cost and it is not exported on the lines to avoid large transmission losses.

In a power system active power balance can be achieved by controlling the generation and it is called automatic generation control (AGC). The control loops of these two parameters, therefore, assumed to be decoupled [1-2].

The fossil fuels such as coal, oil and natural gas, nuclear energy, and falling water are commonly used

energy sources at the power plant. Since fossil fuels are depleting day by day, therefore, a wide and growing variety of non-conventional energy sources have also been developed, including cogeneration, solar energy, wind generators, and waste materials. Thus in present day scenario, the control areas are supposed to have various types of energy sources.

A large number of papers have been appeared in literature relating various aspects of AGC of power systems during over last five decades [1-14] and these literatures of AGC are well reviewed in [3-5] by Ibraheem et al. A novel approach to solve the matrix Riccati equation for designing the optimal AGC regulators is presented in [6]. Dynamic performance enhancement of power system with optimal AGC regulators in interconnected power system using AC/DC links has investigated in [7-9].

However, in [1-9] the power system models considered for studies were of single or multi area interconnected power system having single energy source like hydro, thermal, gas, nuclear or any other fuel based power plants. But, in real situations, each control area has generating plants of variable characteristics and types, which generates power by using various sources of energy such as hydro, thermal, gas, nuclear and etc. Therefore, to consider a more realistic model of power system, all these types of generating plants must be considered while developing a power system model for investigation point of view.

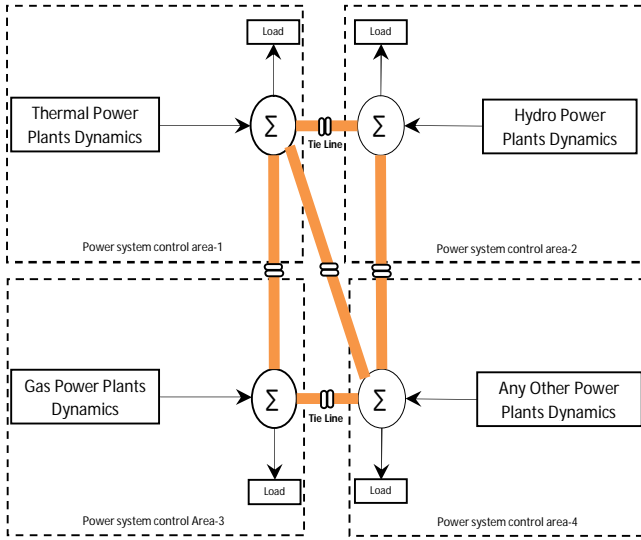
The sampled data AGC of single area power system has been investigated by considering multi sources of power generation by K.S.S. Ramakrishna et al. in [10]. Whereas AGC of two area interconnected power system with diverse energy sources has been presented in [11].

Since optimal AGC regulators are simple to design, less costly and offer robust performance. Therefore, this work presents the design and implementation of optimal AGC regulators for a two area interconnected power system consisting of hydro, thermal and gas power plants for generation. The patterns of open-loop and closed-loop

system eigenvalues are obtained to investigate the stability margins of the system.

## 2. Power System Model with Diverse Power Generation Sources

The conventional multi area power system model with a single source of power is shown in Fig. 1. Hydro, thermal, gas and any other types of energy source based power generation sources is considered in area-1, area-2, area-3 and area-4 respectively. However, in real situations, each control area having many numbers of generating stations, which generates power by using various sources of energy such as hydro, thermal, gas, nuclear and etc. The more practical model of this type is shown in Fig. 2 and this type of power system model can be named as “Multi area power systems model with **diverse** or **multi** source of power generation”.



**Fig. 1. Multi area power systems with single source of generation**

Suppose for  $i^{th}$  area  $K_{ti}$ ,  $K_{hi}$ ,  $K_{gi}$ ,  $K_{ni}$ ,  $K_{wi}$ ,  $K_{di}$ ,  $K_{si}$  and  $K_{aoi}$  are share of power generation by thermal, hydro, gaseous, nuclear, wind, diesel, solar and any other type of fuel respectively. The value of share factor depends upon the total load and economic load dispatch. Suppose  $P_{Gti}$ ,  $P_{Ghi}$ ,  $P_{Gi}$ ,  $P_{Gni}$ ,  $P_{Gwi}$ ,  $P_{Gdi}$ ,  $P_{Gsi}$  and  $P_{Gaoi}$  are power generation in MW by thermal, hydro, gas, nuclear, wind, diesel, solar and any other type of fuel in the  $i^{th}$  area respectively. Under normal operating conditions, there is no mismatch between generation and load; the total generations in the  $i^{th}$  area say  $P_{Gi}$  is given by:

$$P_{Gi} = P_{Gti} + P_{Ghi} + P_{Gi} + P_{Gni} + P_{Gwi} + P_{Gdi} + P_{Gsi} + P_{Gaoi} \quad (1)$$

For small perturbation, eqn. (1) can be written as;

$$\Delta P_{Gi} = \Delta P_{Gti} + \Delta P_{Ghi} + \Delta P_{Gi} + \Delta P_{Gni} + \Delta P_{Gwi} + \Delta P_{Gdi} + \Delta P_{Gsi} + \Delta P_{Gaoi} \quad (2)$$

Where,  $P_{Gti} = K_{ti}P_{Gi}$ ,  $P_{Ghi} = K_{hi}P_{Gi}$ ,  $P_{Ggi} = K_{gi}P_{Gi}$ ,  $P_{Gni} = K_{ni}P_{Gi}$ ,  $P_{Gwi} = K_{wi}P_{Gi}$ ,  $P_{Gdi} = K_{di}P_{Gi}$ ,  $P_{Gsi} = K_{si}P_{Gi}$  and  $P_{Gaoi} = K_{aoi}P_{Gi}$  and eqn. (1) can be rewritten as;

$$K_{ti} + K_{hi} + K_{gi} + K_{ni} + K_{wi} + K_{di} + K_{si} + K_{aoi} = 1 \quad (3)$$

The various transfer function model of power systems using single source of power generation is given in [12-14]. The Transfer function model of two area interconnected power systems with diverse power generation sources is shown in Fig. 3. In this model each area having hydro, thermal and gas power plants.

## 3. State Space Model of Power System

The power system model considered being a linear continuous-time dynamic system can be represented by the standard state space model as;

$$\frac{d}{dt} \underline{X} = \underline{A} \underline{X} + \underline{B} \underline{U} + \underline{\Gamma} \underline{P}_d \quad (4)$$

$$\underline{Y} = \underline{C} \underline{X} \quad (5)$$

Where;  $\underline{X}$ ,  $\underline{U}$ ,  $\underline{P}_d$  and  $\underline{Y}$  are the state, control, disturbance and output vectors respectively and  $\underline{A}$ ,  $\underline{B}$ ,  $\underline{\Gamma}$  and  $\underline{C}$  are the system, input, disturbance and output matrices, respectively. These matrices are constant with compatible dimensions depend upon the system parameters and the operating point. The various vectors and matrices are considered for power system model under investigation in Fig. 3 can be obtained in the following section.

### 3.1 Power System Control Vector

The state, control and disturbance vectors for power system model under investigation are given by;

#### State Vector

$$[\underline{X}]^T = [x_1 \ x_2 \ x_3 \ \dots \ x_{24} \ x_{25}]$$

The state from transfer function model of power system can be written as;

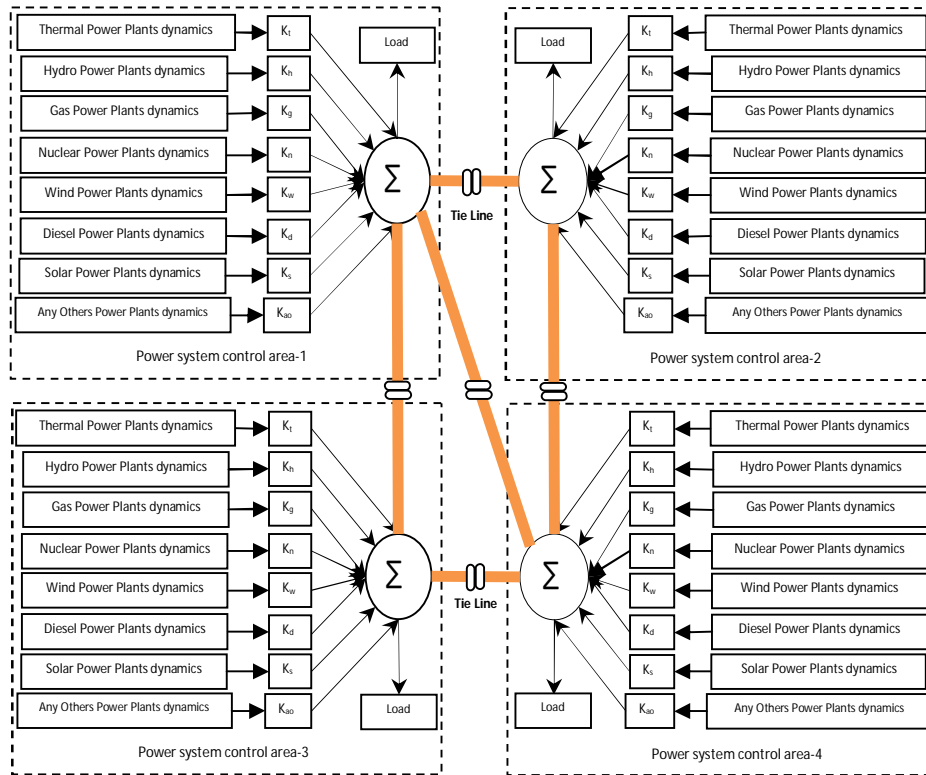
$$[\underline{X}]^T = [\Delta F_1 \quad \Delta P_{tie12} \quad \Delta F_2 \quad \Delta P_{Gt1} \quad \Delta P_{Rt1} \quad \Delta X_{t1} \\ \Delta P_{Gh1} \quad \Delta P_{Rh1} \quad \Delta X_{h1} \quad \Delta P_{Gg1} \quad \Delta P_{Rg1} \quad \Delta P_{VP1} \\ \Delta X_{g1} \quad \Delta P_{Gt2} \quad P_{Rt2} \quad \Delta X_{t2} \quad \Delta P_{Gh2} \quad \Delta P_{Rh2} \\ \Delta X_{h2} \quad \Delta P_{Gg2} \quad \Delta P_{Rg2} \quad \Delta P_{VP2} \quad \Delta X_{g2} \quad \int ACE_2 dt]$$

#### Control vector

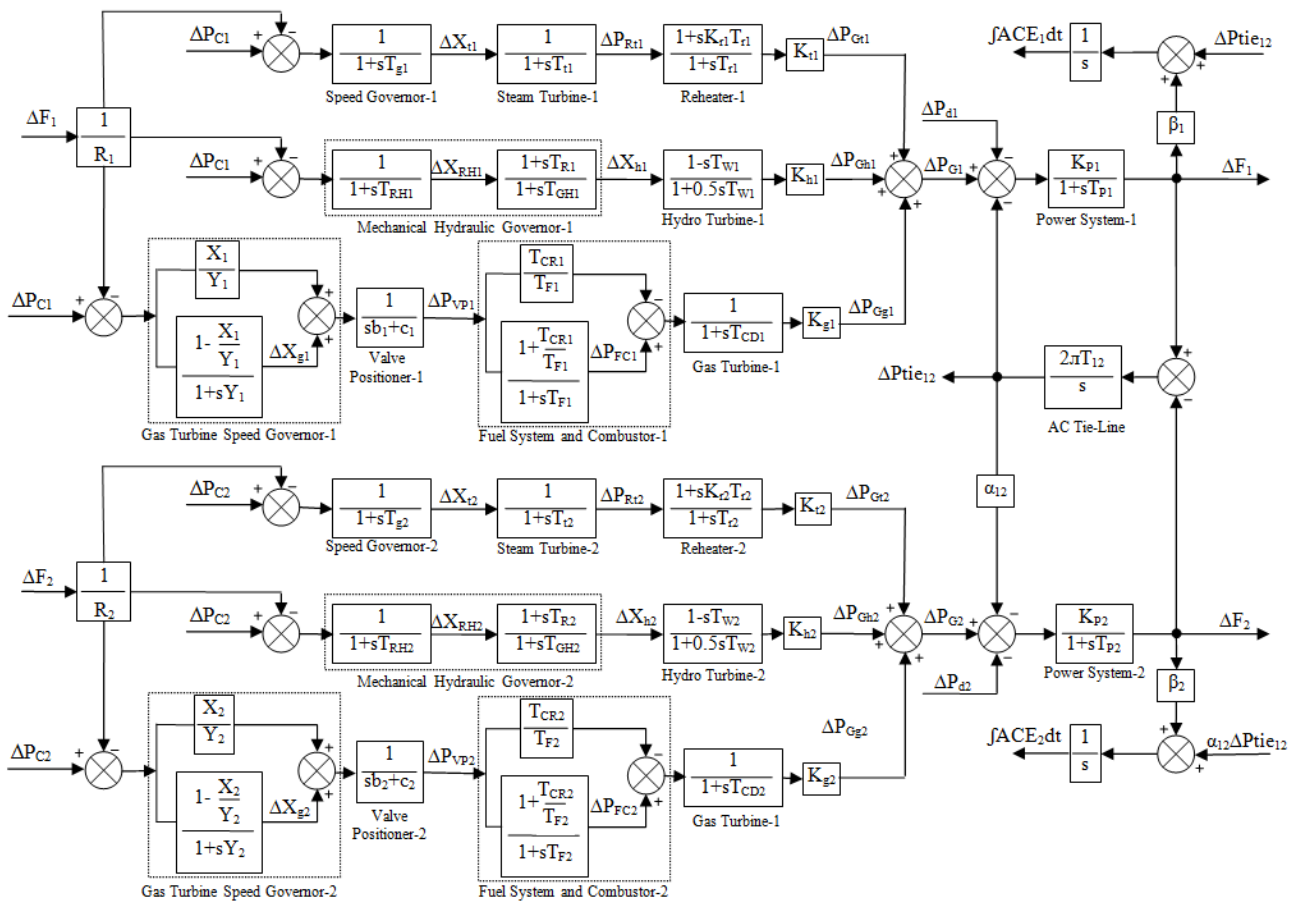
$$[\underline{U}]^T = [\Delta P_{C1} \ \Delta P_{C2}]$$

#### Disturbance Vector

$$[\underline{P}_d]^T = [\Delta P_{d1} \ \Delta P_{d2}]$$



**Fig. 2. Multi area power systems with diverse sources of generation**



**Fig. 3. Transfer function model of two area interconnected power system with diverse energy sources**

### 3.2 Power Generating Eqns.

The dynamic equations for power systems model under investigation are obtained in this section. Under normal operating conditions, the generation in area-1 is given by;

$$P_{G1} = P_{Gt1} + P_{Gh1} + P_{Gg1} \quad (6)$$

For small perturbation eqn. (7) can be written as:

$$\Delta P_{G1} = \Delta P_{Gt1} + \Delta P_{Gh1} + \Delta P_{Gg1} \quad (7)$$

Where,  $P_{Gt1} = K_{t1} P_{G1}$ ,  $P_{Gh1} = K_{h1} P_{G1}$  and  $P_{Gg1} = K_{g1} P_{G1}$

Therefore, eqn. (7) can also be written as:

$$K_{t1} + K_{h1} + K_{g1} = 1 \quad (8)$$

Similarly for area-2

$$\Delta P_{G2} = \Delta P_{Gt2} + \Delta P_{Gh2} + \Delta P_{Gg2} \quad (9)$$

$$K_{t2} + K_{h2} + K_{g2} = 1 \quad (10)$$

### 3.3 Dynamic Equations

The dynamic eqns. associated with Fig. 3 are derived as follows;

$$\begin{aligned} \frac{d}{dt}(x_1) = & -\frac{1}{T_{P1}}x_1 - \frac{K_{P1}}{T_{P1}}x_2 + \frac{K_{P1}}{T_{P1}}x_4 + \frac{K_{P1}}{T_{P1}}x_7 \\ & + \frac{K_{P1}}{T_{P1}}x_{10} - \frac{K_{P1}}{T_{P1}}\Delta P_{d1} \end{aligned} \quad (11)$$

$$\frac{d}{dt}(x_2) = 2\pi T_{12}x_1 - 2\pi T_{12}x_3 \quad (12)$$

$$\begin{aligned} \frac{d}{dt}(x_3) = & -\frac{\alpha_{12}K_{P2}}{T_{P2}}x_2 - \frac{1}{T_{P2}}x_3 + \frac{K_{P2}}{T_{P2}}x_{14} \\ & + \frac{K_{P2}}{T_{P2}}x_{17} + \frac{K_{P2}}{T_{P2}}x_{20} - \frac{K_{P2}}{T_{P2}}\Delta P_{d2} \end{aligned} \quad (13)$$

$$\begin{aligned} \frac{d}{dt}(x_4) = & -\frac{1}{T_{r1}}x_4 + K_{t1}\left(\frac{1}{T_{r1}} - \frac{K_{r1}}{T_{t1}}\right)x_5 \\ & + \frac{K_{t1}K_{r1}}{T_{t1}}x_6 \end{aligned} \quad (14)$$

$$\frac{d}{dt}(x_5) = -\frac{1}{T_{t1}}x_5 + \frac{1}{T_{t1}}x_6 \quad (15)$$

$$\frac{d}{dt}(x_6) = -\frac{1}{R_1 T_{g1}}x_1 - \frac{1}{T_{g1}}x_6 + \frac{1}{T_{g1}}\Delta P_{C1} \quad (16)$$

$$\begin{aligned} \frac{d}{dt}(x_7) = & \frac{2K_{h1}T_{R1}}{T_{GH1}R_1T_{RH1}}x_1 - \frac{2}{T_{w1}}x_7 + \left(\frac{2K_{h1}}{T_{w1}} + \frac{2K_{h1}}{T_{GH1}}\right)x_8 \\ & + \left(\frac{2K_{h1}T_{R1}}{T_{GH1}T_{RH1}} - \frac{2K_{h1}}{T_{GH1}}\right)x_9 - \frac{2K_{h1}T_{R1}}{T_{GH1}T_{RH1}}\Delta P_{C1} \end{aligned} \quad (17)$$

$$\begin{aligned} \frac{d}{dt}(x_8) = & -\frac{T_{R1}}{T_{GH1}R_1T_{RH1}}x_1 - \frac{1}{T_{GH1}}x_8 + \left(\frac{1}{T_{GH1}}\right. \\ & \left. - \frac{T_{R1}}{T_{GH1}T_{RH1}}\right)x_9 + \frac{T_{R1}}{T_{GH1}T_{RH1}}\Delta P_{C1} \end{aligned} \quad (18)$$

$$\frac{d}{dt}(x_9) = -\frac{1}{R_1 T_{RH1}}x_1 - \frac{1}{T_{RH1}}x_9 + \frac{1}{T_{RH1}}\Delta P_{C1} \quad (19)$$

$$\frac{d}{dt}(x_{10}) = -\frac{1}{T_{CD1}}x_{10} + \frac{K_{g1}}{T_{CD1}}x_{11} - \frac{K_{g1}T_{CR1}}{T_{F1}T_{CD1}}x_{12} \quad (20)$$

$$\frac{d}{dt}(x_{11}) = -\frac{1}{T_{F1}}x_{11} + \left(\frac{1}{T_{F1}} + \frac{T_{CR1}}{T_{F1}^2}\right)x_{12} \quad (21)$$

$$\frac{d}{dt}(x_{12}) = -\frac{X_1}{b_1 R_1 Y_1}x_1 - \frac{c_1}{b_1}x_{12} + \frac{1}{b_1}x_{13} + \frac{X_1}{b_1 Y_1}\Delta P_{C1} \quad (22)$$

$$\frac{d}{dt}(x_{13}) = \left(\frac{X_1}{R_1 Y_1^2} - \frac{1}{R_1 Y_1}\right)x_1 - \frac{1}{Y_1}x_{13} + \left(\frac{1}{Y_1} - \frac{X_1}{Y_1^2}\right)\Delta P_{C1} \quad (23)$$

$$\frac{d}{dt}(x_{14}) = -\frac{1}{T_{r2}}x_{14} + K_{t2}\left(\frac{1}{T_{r2}} - \frac{K_{r2}}{T_{t2}}\right)x_{15} + \frac{K_{t2}K_{r2}}{T_{t2}}x_{16} \quad (24)$$

$$\frac{d}{dt}(x_{15}) = -\frac{1}{T_{t2}}x_{15} + \frac{1}{T_{t2}}x_{16} \quad (25)$$

$$\frac{d}{dt}(x_{16}) = -\frac{1}{R_2 T_{g2}}x_3 - \frac{1}{T_{g2}}x_{16} + \frac{1}{T_{g2}}\Delta P_{C2} \quad (26)$$

$$\begin{aligned} \frac{d}{dt}(x_{17}) = & \frac{2K_{h2}T_{R2}}{T_{GH2}R_2T_{RH2}}x_3 - \frac{2}{T_{w2}}x_{17} + \left(\frac{2K_{h2}}{T_{w2}}\right. \\ & \left. + \frac{2K_{h2}}{T_{GH2}}\right)x_{18} + \left(\frac{2K_{h2}T_{R2}}{T_{GH2}T_{RH2}} - \frac{2K_{h2}}{T_{GH2}}\right)x_{19} \\ & - 2\frac{K_{h2}T_{R2}}{T_{GH2}T_{RH2}}\Delta P_{C2} \end{aligned} \quad (27)$$

$$\begin{aligned} \frac{d}{dt}(x_{18}) = & -\frac{T_{R2}}{T_{GH2}R_2T_{RH2}}x_3 - \frac{1}{T_{GH2}}x_{18} + \left(\frac{1}{T_{GH2}}\right. \\ & \left. - \frac{T_{R2}}{T_{GH2}T_{RH2}}\right)x_{19} + \frac{T_{R2}}{T_{GH2}T_{RH2}}\Delta P_{C2} \end{aligned} \quad (28)$$

$$\frac{d}{dt}(x_{19}) = -\frac{1}{R_2 T_{RH2}}x_3 - \frac{1}{T_{RH2}}x_{19} + \frac{1}{T_{RH2}}\Delta P_{C2} \quad (29)$$

$$\frac{d}{dt}(x_{20}) = -\frac{1}{T_{CD2}}x_{20} + \frac{K_{g2}}{T_{CD2}}x_{21} - \frac{K_{g2}T_{CR2}}{T_{F2}T_{CD2}}x_{22} \quad (30)$$

$$\frac{d}{dt}(x_{21}) = -\frac{1}{T_{F2}}x_{21} + \left(\frac{1}{T_{F2}} + \frac{T_{CR2}}{T_{F2}^2}\right)x_{22} \quad (31)$$

$$\frac{d}{dt}(x_{22}) = -\frac{X_2}{b_2R_2Y_2}x_3 - \frac{c_2}{b_2}x_{22} + \frac{1}{b_2}x_{23} + \frac{X_2}{b_2Y_2}\Delta P_{C2} \quad (32)$$

$$\frac{d}{dt}(x_{23}) = \left(\frac{X_2}{R_2Y_2^2} - \frac{1}{R_2Y_2}\right)x_3 - \frac{1}{Y_2}x_{23} + \left(\frac{1}{Y_2} - \frac{X_2}{Y_2^2}\right)\Delta P_{C2} \quad (33)$$

$$\frac{d}{dt}(x_{24}) = \beta_1x_1 + x_2 \quad (34)$$

$$\frac{d}{dt}(x_{25}) = \alpha_{12}x_2 + \beta_2x_3 \quad (35)$$

### 3.4 State Space Matrices

The importance of these equations is that the state space power system matrices can be developed. The state space matrices associated with power system model under investigation are obtained by arranging eqns. (11-36).

The input matrix [A] is of order of 25x25 and its non-zero element  $\alpha_{i,j}$  of matrix [A] is obtained as;

$\alpha_{1,1} = -\frac{1}{T_{P1}}$	$\alpha_{1,2} = -\frac{K_{P1}}{T_{P1}}$	$\alpha_{1,4} = \frac{K_{P1}}{T_{P1}}$	$\alpha_{8,8} = -\frac{1}{T_{GH1}}$	$\alpha_{8,9} = \frac{1}{T_{GH1}} - \frac{T_{R1}}{T_{GH1}T_{RH1}}$	$\alpha_{9,1} = -\frac{1}{R_1T_{RH1}}$
$\alpha_{1,7} = \frac{K_{P1}}{T_{P1}}$	$\alpha_{1,10} = \frac{K_{P1}}{T_{P1}}$	$\alpha_{2,1} = 2\pi T_{12}$	$\alpha_{9,9} = -\frac{1}{T_{RH1}}$	$\alpha_{10,10} = -\frac{1}{T_{CD1}}$	$\alpha_{10,11} = \frac{K_{g1}}{T_{CD1}}$
$\alpha_{2,3} = -2\pi T_{12}$	$\alpha_{3,2} = -\frac{\alpha_{12}K_{P2}}{T_{P2}}$	$\alpha_{3,3} = -\frac{1}{T_{P2}}$	$\alpha_{10,12} = -\frac{K_{g1}T_{CR1}}{T_{F1}T_{CD1}}$	$\alpha_{11,11} = -\frac{1}{T_{F1}}$	$\alpha_{11,12} = \frac{1}{T_{F1}} + \frac{T_{CR1}}{T_{F1}^2}$
$\alpha_{3,14} = \frac{K_{P2}}{T_{P2}}$	$\alpha_{3,17} = \frac{K_{P2}}{T_{P2}}$	$\alpha_{3,20} = \frac{K_{P2}}{T_{P2}}$	$\alpha_{12,1} = -\frac{X_1}{b_1R_1Y_1}$	$\alpha_{12,12} = -\frac{c_1}{b_1}$	$\alpha_{12,13} = \frac{1}{b_1}$
$\alpha_{4,4} = -\frac{1}{T_{r1}}$	$\alpha_{4,5} = K_{t1}\left(\frac{1}{T_{r1}} - \frac{K_{r1}}{T_{t1}}\right)$	$\alpha_{4,6} = \frac{K_{t1}K_{r1}}{T_{t1}}$	$\alpha_{13,1} = \frac{X_1}{R_1Y_1^2} - \frac{1}{R_1Y_1}$	$\alpha_{13,13} = -\frac{1}{Y_1}$	$\alpha_{14,14} = -\frac{1}{T_{r2}}$
$\alpha_{5,5} = -\frac{1}{T_{t1}}$	$\alpha_{5,6} = \frac{1}{T_{t1}}$	$\alpha_{6,1} = -\frac{1}{R_1T_{g1}}$	$\alpha_{14,15} = K_{t2}\left(\frac{1}{T_{r2}} - \frac{K_{r2}}{T_{t2}}\right)$	$\alpha_{14,16} = \frac{K_{t2}K_{r2}}{T_{t2}}$	
$\alpha_{6,6} = -\frac{1}{T_{g1}}$	$\alpha_{7,1} = \frac{2K_{h1}T_{R1}}{T_{GH1}R_1T_{RH1}}$	$\alpha_{7,7} = -\frac{2}{T_{w1}}$	$\alpha_{15,15} = -\frac{1}{T_{t2}}$	$\alpha_{15,16} = \frac{1}{T_{t2}}$	$\alpha_{16,3} = -\frac{1}{R_2T_{g2}}$
$\alpha_{7,8} = 2K_{h1}\left(\frac{1}{T_{w1}} + \frac{1}{T_{GH1}}\right)$	$\alpha_{7,9} = 2K_{h1}\left(\frac{T_{R1}}{T_{GH1}T_{RH1}} - \frac{1}{T_{GH1}}\right)$	$\alpha_{8,1} = -\frac{T_{R1}}{T_{GH1}R_1T_{RH1}}$	$\alpha_{16,16} = -\frac{1}{T_{g2}}$	$\alpha_{17,3} = \frac{2K_{h2}T_{R2}}{T_{GH2}R_2T_{RH2}}$	$\alpha_{17,17} = -\frac{2}{T_{w2}}$
			$\alpha_{17,18} = 2K_{h2}\left(\frac{1}{T_{w2}} + \frac{1}{T_{GH2}}\right)$	$\alpha_{17,19} = 2K_{h2}\left(\frac{T_{R2}}{T_{GH2}T_{RH2}} - \frac{1}{T_{GH2}}\right)$	$\alpha_{18,3} = -\frac{T_{R2}}{T_{GH2}R_2T_{RH2}}$
			$\alpha_{18,18} = -\frac{1}{T_{GH2}}$	$\alpha_{18,19} = \frac{1}{T_{GH2}} - \frac{T_{R2}}{T_{GH2}T_{RH2}}$	$\alpha_{19,3} = -\frac{1}{R_2T_{RH2}}$
			$\alpha_{19,19} = -\frac{1}{T_{RH2}}$	$\alpha_{20,20} = -\frac{1}{T_{CD2}}$	$\alpha_{20,21} = \frac{K_{g2}}{T_{CD2}}$
			$\alpha_{20,22} = -\frac{K_{g2}T_{CR2}}{T_{F2}T_{CD2}}$	$\alpha_{21,21} = -\frac{1}{T_{F2}}$	$\alpha_{21,22} = \frac{1}{T_{F2}} + \frac{T_{CR2}}{T_{F2}^2}$
			$\alpha_{22,3} = -\frac{X_2}{b_2R_2Y_2}$	$\alpha_{22,22} = -\frac{c_2}{b_2}$	$\alpha_{22,23} = \frac{1}{b_2}$
			$\alpha_{23,3} = \frac{X_2}{R_2Y_2^2} - \frac{1}{R_2Y_2}$	$\alpha_{23,23} = -\frac{1}{Y_2}$	$\alpha_{24,1} = \beta_1$

$\alpha_{24,2} = 1$	$\alpha_{25,2} = \alpha_{12}$	$\alpha_{25,3} = \beta_2$
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The control matrix **[B]** is of order of 25x2 and its non-zero elements  $b_{i,j}$  can be given by:

$b_{6,1} = \frac{1}{T_{g1}}$	$b_{7,1} = -2 \frac{K_{h1} T_{R1}}{T_{GH1} T_{RH1}}$	$b_{8,1} = \frac{T_{R1}}{T_{GH1} T_{RH1}}$
$b_{9,1} = \frac{1}{T_{RH1}}$	$b_{12,1} = \frac{X_1}{b_1 Y_1}$	$\alpha_{13,1} = \frac{1}{Y_1} - \frac{X_1}{Y_1^2}$
$b_{16,2} = \frac{1}{T_{g2}}$	$b_{17,2} = -2 \frac{K_{h2} T_{R2}}{T_{GH2} T_{RH2}}$	$b_{18,2} = \frac{T_{R2}}{T_{GH2} T_{RH2}}$
$b_{19,2} = \frac{1}{T_{RH2}}$	$b_{22,2} = \frac{X_2}{b_2 Y_2}$	$\alpha_{23,2} = \frac{1}{Y_2} - \frac{X_2}{Y_2^2}$

The disturbance matrix **[Γ]** is of order of 25x2 and its non-zero elements  $P_{i,j}$  can be given by:

$P_{1,1} = -\frac{K_{P1}}{T_{P1}}$	$P_{3,2} = -\frac{K_{P2}}{T_{P2}}$
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The output matrix **[C]** is of order of 25x25, output matrix is an identity matrix and matrix **[Q]**=[C].

#### 4 Simulation and Discussion of Results

In the present work, the full state feedback theory is applied to design of PI structure based optimal AGC regulator. The designing of these AGC regulators is carried out as given in [6-9]. The power system model under consideration is simulated using MATLAB software. Using optimal control theory, the optimal gains of feedback matrix **[Ψ\*]** are given in Table-I.

**Table-I: Optimal Feedback Gain Matrix [Ψ\*]**

Elements of [Ψ*]				
[ 0.8810	-2.5746	0.2083	7.2609	-0.7221
0.4790	2.7813	1.5566	-0.1667	1.2926
0.3537	0.3027	0.3996	1.2240	-0.1791
0.0057	0.3581	0.2062	-0.0451	0.1500
0.0139	0.0012	-0.0079	1.0000	-0.0000;
0.2083	2.5746	0.8810	1.2240	-0.1791
0.0057	0.3581	0.2062	-0.0451	0.1500
0.0139	0.0012	-0.0079	7.2609	-0.7221
0.4790	2.7813	1.5566	-0.1667	1.2926
0.3537	0.3027	0.3996	0.0000	1.0000]

. The patterns of open-loop and closed-loop system eigenvalues are given in Table-II.

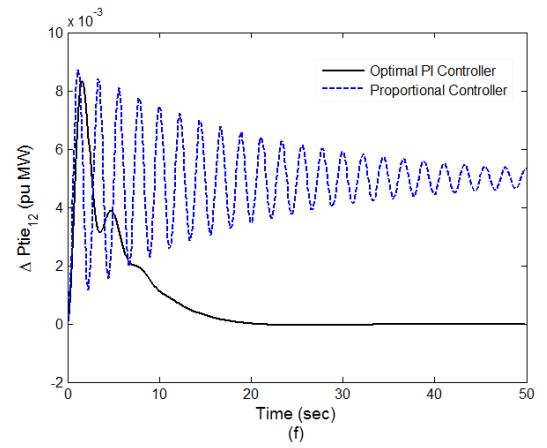
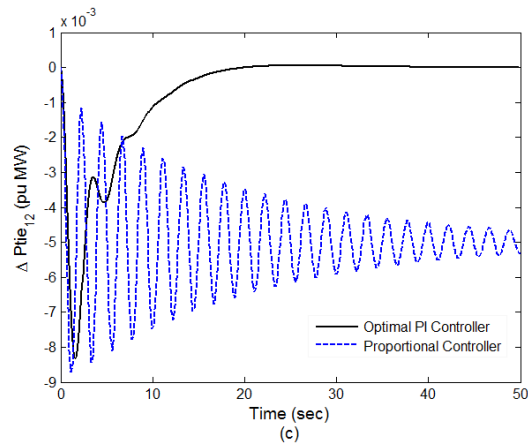
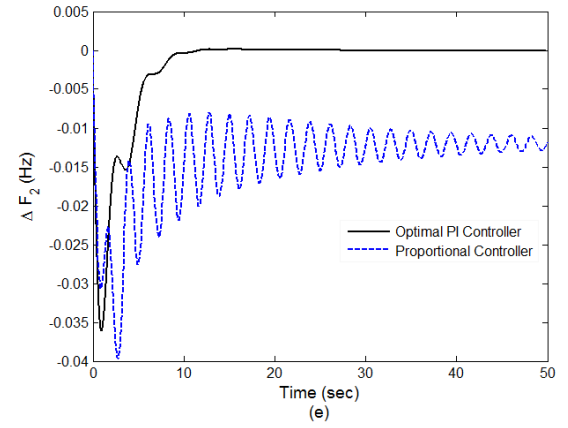
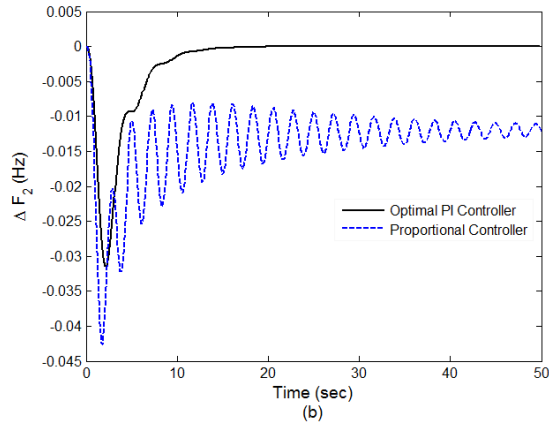
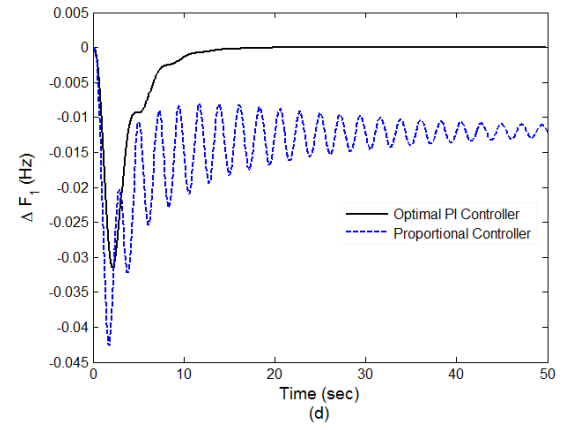
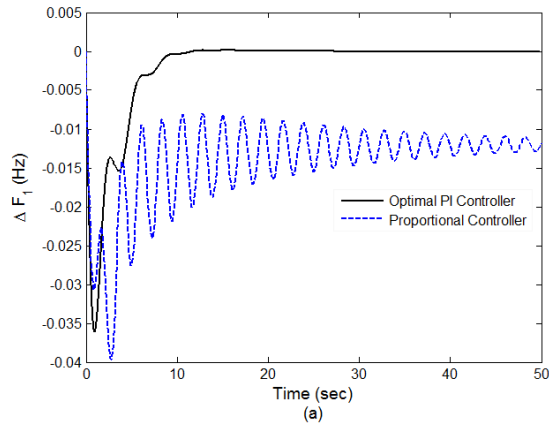
**Table-II: Pattern of Eigenvalues**

Open-loop eigenvalues	Closed-loop eigenvalues
-19.9754	-24.7136
-19.9756	-24.7135
-12.6616	-15.5177
-12.6583	-15.5168
-5.8737	-5.7660
-5.8275	-5.7306
-0.1397 + 2.1421i	-0.4893 + 1.8879i
-0.1397 - 2.1421i	-0.4893 - 1.8879i
-3.9228	-4.0545
-3.9009	-3.9455
-2.9518	-3.7581
-2.8611	-3.7675
-0.7164 + 0.9397i	-1.3931 + 0.3731i
-0.7164 - 0.9397i	-1.3931 - 0.3731i
-1.6970	-1.8728
-1.3768	-1.2133
-0.9222	-1.1747
-0.0967	-0.4326
-0.2420	-0.2154
-0.0417	-0.0417
-0.0346	-0.0417
-5.0000	-5.0000
-5.0000	-5.0000
0.0000	-0.1643 + 0.0902i
0.0000	-0.1643 - 0.0902i

The observation of open-loop eigenvalues as shown in Tables-II infers that the eigenvalues corresponding to 24<sup>th</sup> & 25<sup>th</sup> system states are zero i.e. lies on imaginary axis of 's' plane. Therefore, the above power system model is marginally stable for open-loop stability.

The pattern of closed-loop system eigenvalues shows that none of the eigenvalues is in the right half of 's' plane, therefore, the closed-loop system is stable. A few closed-loop eigenvalues have higher negative real parts as compared to open-loop eigenvalues. These increments in the eigenvalues improve stability margins of the power system. It has been also observed that the real parts of the closed-loop eigenvalues for most of the system states are highly negative as compared to that of open-loop system. Therefore, the closed-loop system has appreciably higher stability margins with good damping. However, the reduced magnitudes of imaginary parts of closed-loop eigenvalues may result in fast and smooth decay of system dynamic responses.

The system dynamic responses for 1% step load in area-1 and area-2 are shown in Figs. 4-5, respectively. It has been observed from investigation of Fig. 4 that PI structured optimal AGC regulators are capable to mitigate small load disturbance in area-1 with less oscillations and small settling time. Similar results for the dynamic responses of the system have been obtained for 1% step load in area-2 and are shown in Fig. 5.



**Fig. 4. Dynamic performance of power system model under investigation with PI as AGC regulator with 1% load disturbance in area-1 (a)  $\Delta F_1$  Vs. Time, (b)  $\Delta F_2$  Vs. Time and (c)  $\Delta P_{tie_{12}}$  Vs. Time**

**Fig. 5. Dynamic performance of power system model under investigation with PI as AGC regulator with 1% load disturbance in area-2 (d)  $\Delta F_1$  Vs. Time, (e)  $\Delta F_2$  Vs. Time and (f)  $\Delta P_{tie_{12}}$  Vs. Time**

## 5. Conclusions

The paper discusses an overview on interconnected two area power systems consisting of diverse energy generation sources. The transfer function model of two area interconnected power system with diverse power generation sources has been developed. From the patterns of eigenvalues, it has been revealed that power system model is marginally stable in open-loop mode while it is stable with appreciably improved stability margins in closed-loop mode. Furthermore, few eigenvalues are found to be very sensitive as far as the dynamic stability margins of the system is concerned. It has been observed that the PI structured optimal AGC regulators are capable to mitigate small load disturbances.

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