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Dynamic Response Analysis of Automatic Generation Control in a 2-Area (Reheat & Non-Reheat) Interconnected Power System and a Scheme for Improvement of Response for the Same

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Abstract: *In the present work, we focus on the study of dynamic behavior of an interconnected two-area power system and a scheme for improvement of response for the same. Here, two-area system with one non-reheat thermal units & one reheat thermal units is considered. The frequency and tie-line power deviation of two units are studied using MATLAB-SIMULINK in continuous time domain and also in discrete time domain. The paper focus on the study of frequency & tie-line power deviation for step load changes of 1% in both areas with conventional Proportional-Integral control and improvement in dynamic performances while replaced with discrete controller.*

Keywords: *Automatic Generation Control, Modeling of Interconnected Power system, Dynamic performance study of both the areas, MATLAB – SIMULINK.*

I. INTRODUCTION

Now-a-days, modern power systems are divided into number of areas. For example, in our country, eastern grid, western grid etc. and each area are interconnected among themselves through transmission lines, called tie-line.

Interconnected power system or power grid provides following advantages over the control area operated individually,

i. It stabilizes the grid which in turn increases stability, reliability & security of the overall system.
ii. Maintaining frequency to a fixed value which reduces voltage collapse & chances of undesirable load-shed situation.

Earlier days, one generating unit in a system would be designed as the regulated unit & it was manually adjusted to Control the balance between the net generation & load demand. But now with automatic Generation system, many units are participated in regulation, improving overall system efficiency & economy.

The main function of power system operation and control is to provide continuous power supply to all consumers connected to it. Automatic Load frequency control (ALFC) or Automatic Generation control (AGC) regulates real power flow between different control areas while keeping frequency constant.

The main features of ALFC loops are

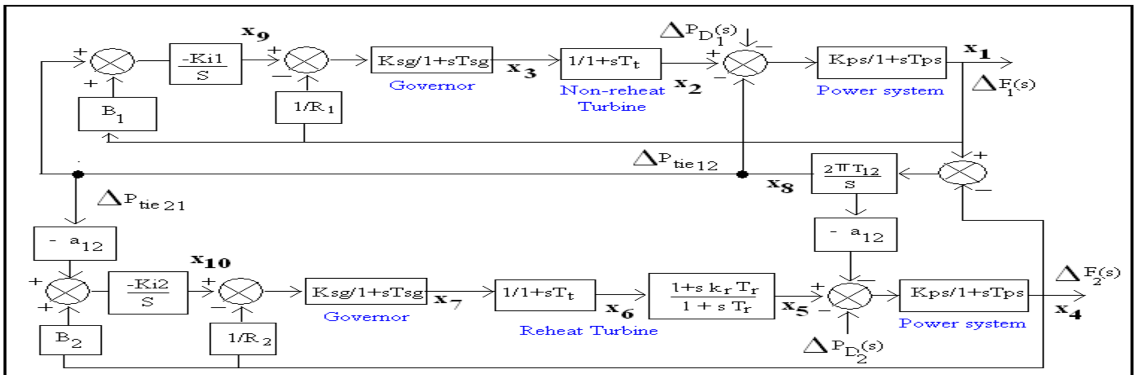
i. Keeping frequency to its steady state value.
ii. To control power flow between interconnected control areas.
iii. Maintain equal load distribution among the participating units.

Tie-line bias is carefully monitored & represented for all tie-lines. Bias is the accepted standard operating constraint that controls the area control error (ACE), monitoring & adjusting tie-line flows to keep the system stable. Stability is the term to describe how far a power grid handles a system disturbances or power system fault.

The main objective of the present work is to perform a comparative study of dynamic response of interconnected power system with reheat & non-reheat type turbines and also an improvement for dynamic performance of inter-connected power system after replacing the PI controller with discrete PI controller.

II. SYSTEM INVESTIGATED

The MW frequency or ALFC system investigated comprises an interconnected power system of two-area (a) non-reheat control area-1 & (b) reheat control area-2,shown in fig:(1). The nominal values of the parameters are given in appendix – 2.



Fig(1) T.F representation of load frequency control of two-area stem

III. MODELING OF DESIRED POWER SYSTEM

The continuous time dynamics behavior of the AGC system is described by the linear vector differential equations

$$\dot{x} = Ax + Bu + Gw \text{ ------[1]}$$

For formulating the state space model, output of all blocks having either integrator or a time constant assumed to be state variable [7].

State space models of single area system with above assumption of reheat & non-reheat thermal units are given below, respectively

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} -\frac{1}{T_{sg}} & 0 & -\frac{1}{RT_{sg}} \\ \frac{1}{T_t} & -\frac{1}{T_t} & 0 \\ 0 & \frac{K_{ps}}{T_{ps}} & -\frac{1}{T_{ps}} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} \frac{1}{T_{sg}} \\ 0 \\ 0 \end{bmatrix} u + \begin{bmatrix} 0 \\ 0 \\ -\frac{K_{ps}}{T_{ps}} \end{bmatrix} w$$

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \end{bmatrix} = \begin{bmatrix} -\frac{1}{T_{ps}} & \frac{K_{ps}}{T_{ps}} & 0 & 0 \\ 0 & -\frac{1}{T_r} & \left(\frac{1}{T_r} - \frac{K_r}{T_t}\right) & \frac{Kr}{T_t} \\ 0 & 0 & -\frac{1}{T_t} & \frac{1}{T_t} \\ -\frac{1}{RT_{sg}} & 0 & 0 & \frac{1}{T_{sg}} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{1}{T_{sg}} \end{bmatrix} u + \begin{bmatrix} -\frac{K_{ps}}{T_{ps}} \\ 0 \\ 0 \\ 0 \end{bmatrix} w$$

Whereas, state space model of our concerned interconnected power system is defined as, calculations are given in appendix – 1.

A =

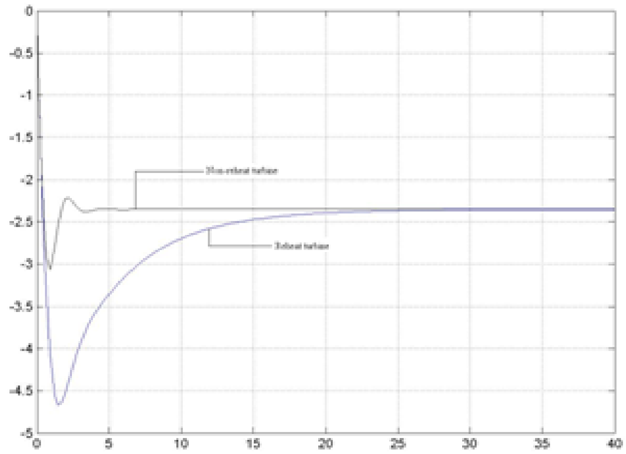
$$\begin{bmatrix} -\frac{1}{T_{ps1}} & \frac{k_{ps1}}{T_{ps1}} & 0 & 0 & 0 & 0 & 0 & -\frac{k_{ps1}}{T_{ps1}} & 0 & 0 \\ 0 & -\frac{1}{T_{t1}} & \frac{1}{T_{t1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -\frac{1}{R_1 T_{sg1}} & 0 & -\frac{1}{T_{sg1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\frac{1}{T_{ps2}} & \frac{k_{ps2}}{T_{ps2}} & 0 & 0 & \frac{a_{12}k_{ps2}}{T_{ps2}} & 0 & 0 \\ 0 & 0 & 0 & 0 & -\frac{1}{T_r} & \left(\frac{1}{T_r} - \frac{k_r}{T_{t2}}\right) & \frac{k_r}{T_{t2}} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -\frac{1}{T_{t2}} & \frac{1}{T_{t2}} & 0 & 0 & 0 \\ 0 & 0 & 0 & -\frac{1}{R_2 T_{sg2}} & 0 & 0 & -\frac{1}{T_{sg2}} & 0 & 0 & 0 \\ 2\pi T_{12} & 0 & 0 & -2\pi T_{12} & 0 & 0 & 0 & 0 & 0 & 0 \\ b_1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & b_2 & 0 & 0 & 0 & -a_{12} & 0 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 & 0 & \frac{1}{T_{sg1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{T_{sg2}} & 0 & 0 & 0 \end{bmatrix}^T$$

$$G = \begin{bmatrix} \frac{-K_{ps1}}{T_{ps1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{-K_{ps2}}{T_{ps2}} & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}^T$$

IV. SIMULINK RESULT

Dynamic response of single area system for both reheat & non-reheat type thermal system shown in fig(2).



Fig(2) Dynamic response of single area system

- **Minimization of steady state error:**

It is observed from fig: (2) that the system has pronounced steady state error of e_{SS}= 51.89% (-ve). There are number of methods available to reduce steady state error, here we used conventional PI-controller, since the implementation of PI-controller is very easy.

Effect of PI-controller to reheat & non-reheat single area system shown in fig: (3).

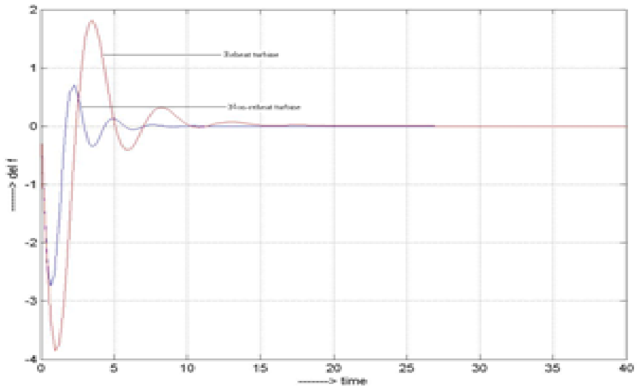


Fig:(3) Dynamic response of single area system with PI-controller

Fig: (4) to fig: (7) depict $\Delta f_1(t)$, $\Delta f_2(t)$, $\Delta P_{tie,12}(t)$ & $\Delta P_{tie,21}(t)$ responses in continuous time domain using SIMULINK.

In the present study, we divided our result into three cases:

Case1: Continuous time domain analysis of interconnected power system without any controller & frequency bias setting.

Case2: Continuous time domain analysis of interconnected power system with PI-controller of K_i = 0.4 & frequency bias setting, B_i = 0.

Case3: Continuous time domain analysis of interconnected power system with PI-controller of K_i = 0.4 & frequency bias setting, B_i = 0.425.

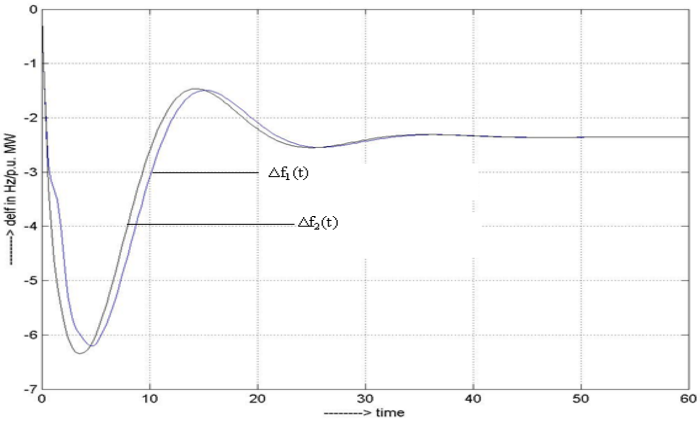


Fig:(4) Frequency deviation of two-area system with B_i=0 & K_i=0

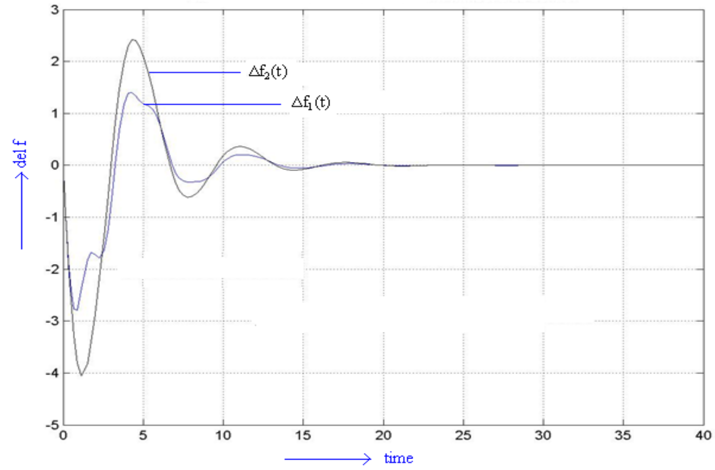


Fig:(5) Frequency deviation of two-area system with B_i=0 & K_i=0.4

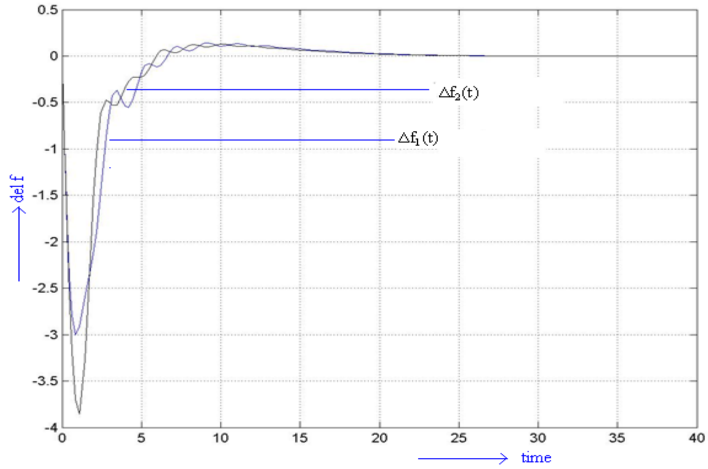
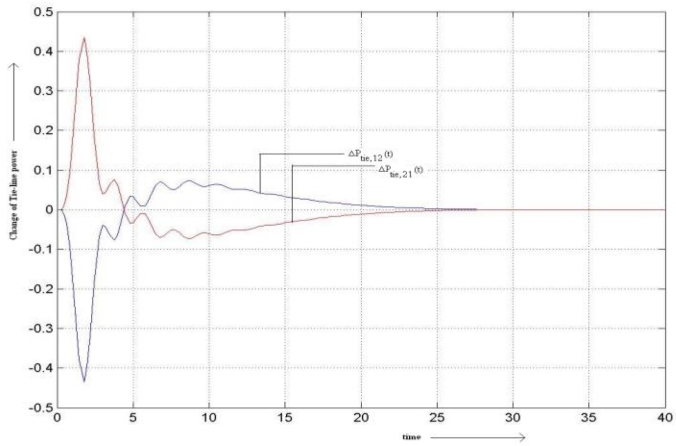


Fig: (6) Frequency deviation of two-area system with B_i=0.425 & K_i=0.4



Fig(7) Tie-line power deviation of two area system with B_i = 0.425 & K_i = 0.4

V. OBSERVATION

In this paper, the interconnected two-area power system theory is studied with SIMULINK in continuous domain. The frequency & tie-line power deviation have been observed for the same system.

Following points are observed from the SIMULINK results-

1. Both single area & two-area systems are non-minimum phase system, which exhibits a high undershoot near at the origin, fig.(2).
2. By observation of fig.(2) & fig.(3), the steady state error is reduced using conventional PI-controller but it has no effect on transient response of the system.
3. By observation of fig.(3), settling time of Non – Reheat thermal & Reheat thermal system are, respectively, 7sec & 11sec, approximately, which shows that reheat system has sluggish dynamic response compare to non-reheat system.

4. In comparison to the single area system interconnected power system has less no. of oscillation that make the system more stable, refer to fig.(6).
5. In fig.(5), the system has high peak overshoot which is highly minimized with proper choice of frequency bias constraint, B_i as shown in fig.(6).
6. It is observed from fig.(7) that tie-line power flow deviates from nominal setting, with sudden load changes in both the area and it takes 10-12 sec to settle down.
7. From the investigation carried out in this paper, it is relevant that PI-controller strategy offers ameliorated system dynamic performance compared to P-controller.

VI. DEVELOPMENT / MODIFICATION SUGGESTED

To improve the sluggish response of the reheat cycle area, we suggest the following improvement to be done

1. This paper is completely based on the study of dynamic performance of the system in CT – domain. But if the same study is done in DT – domain, by discretezition of controller signal further improvement of dynamic response is possible. Under figure shows the suggested model

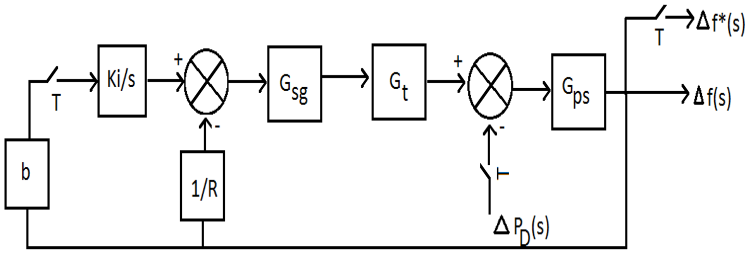


Fig: (8) Proposed block diagram in discrete medium

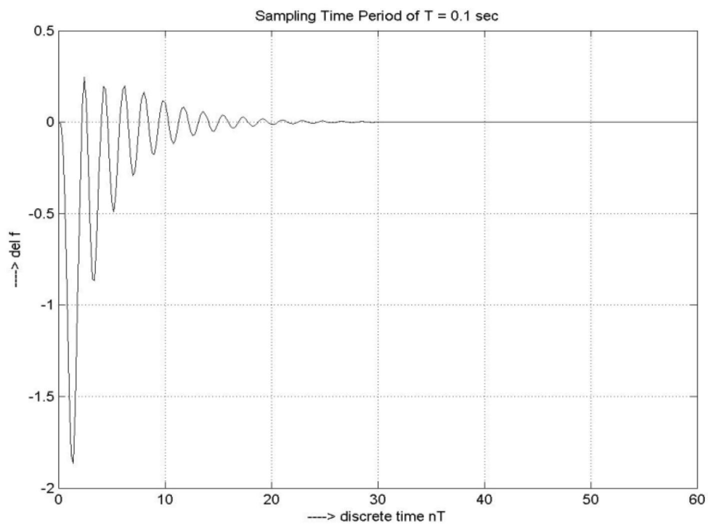


Fig: (9) Frequency deviation of two area system with $B_i = 0.425$ & $K_i = 0.4$ in Discrete domain

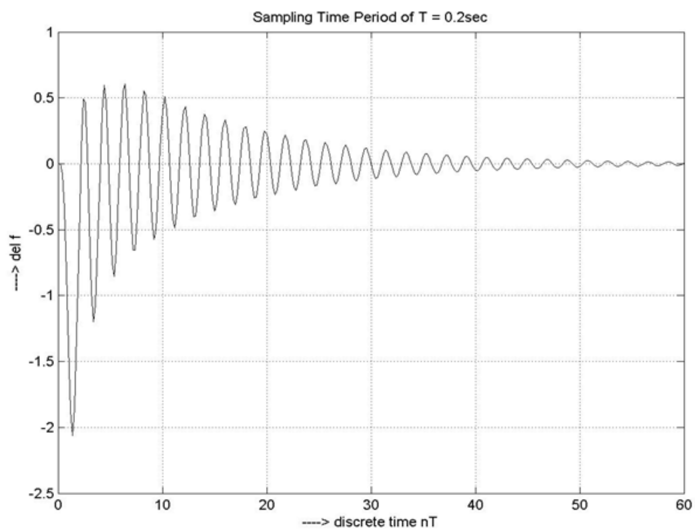


Fig: (10) Frequency deviation of two area system with $B_i = 0.425$ & $K_i = 0.4$ in Discrete domain

Fig: (9) & (10) shows frequency deviation of interconnected power system with two different sampling times. It is observed that if sampling rate is made high then dynamic response analysis gives good result as long as system stability retained.

2. This paper completely focused on the study of conventional PI – controller which exhibits poor dynamic performance due to parameters variation and other controller exhibits poor dynamic response due to parameter variation and other system uncertainties. If, PI – controller replaced by some intelligent controllers, like based on Fuzzy logic theory, optimal controller theory etc, then again further improvement of system response is possible.

VII. CONCLUSION

With the advent of new regulation, (2003 electricity act) distributed & dispersed system generation are recommended and performed for National Power development. One of the main reasons India should be able to achieve a smooth transition from fossil fuel economy to sustainable renewable – energy based economy for sustainable development which compiles

(i) Energy for all
(ii) Energy for ever
(iii) For equitable
(iv) Environment friendly

If above is available and possible we must have a control area where some units will be having non-reheat turbine (smaller area) and other areas (bigger area) of reheat type. Hence, this paper suggests discretization of the control area for better control of system frequency & tie-line power flow.

Appendix-1

$$x_1 = \frac{K_{ps1}}{1 + sT_{ps1}}(x_2 - x_8 - w_1)$$

$$\Rightarrow x_1 + T_{ps1}\dot{x}_1 = K_{ps1}x_2 - K_{ps1}x_8 - K_{ps1}w_1$$

$$\Rightarrow \dot{x}_1 = \frac{-x_1}{T_{ps1}} + \frac{K_{ps1}}{T_{ps1}}x_2 - \frac{K_{ps1}}{T_{ps1}}x_8 - \frac{K_{ps1}}{T_{ps1}}w_1 \text{ -------------- (1)}$$

$$X_2 = (1/1+sT_{t1})\,x_3$$

$$\Rightarrow X_2 + T_{t1}\dot{x}_2 = x_3$$

$$\Rightarrow \dot{x}_2 = \frac{x_3}{T_{t1}} - \frac{X_2}{T_{t1}} \text{ --------- (2)}$$

$$X_3 = 1/1+sT_{sg1}\left(u_1 - \frac{x1}{R_1}\right)$$

$$\Rightarrow \dot{x}_3 = \frac{-x_3}{T_{sg1}} - \frac{x_1}{R_1 T_{sg1}} + \frac{u_1}{T_{sg1}} \text{ ----------- (3)}$$

$$X_4 = \left[K_{ps2}/1+sT_{ps2}\right](x_5 - w_2 + a_{12}x_8)$$

$$\Rightarrow X_4 + T_{ps2}\dot{x}_4 = K_{ps2}(x_5 - K_{ps2}w_2 + a_{12}K_{ps2}x_8)$$

$$\Rightarrow \dot{x}_4 = -x_4/T_{ps2} + (K_{ps2}/T_{ps2})\,x_5 - (K_{ps2}/T_{ps2})\,w_2 + (a_{12}K_{ps2}/T_{ps2})\,x_8 \text{ ----------- (4)}$$

$$X_6 = 1/1+sT_{t2}x_7$$

$$x_6 + T_{t2}\dot{x}_6 = x_7$$

$$\Rightarrow \dot{x}_6 = x_6/T_{t2} + x_7/T_{t2} \text{ ------- (6)}$$

$$X_7 = 1/1+s+T_{sg2}(u_2 - 1/R_2 x_4)$$

$$X_7 + \dot{x}_7 T_{sg2} = (u_2 - 1/R_2 x_4)$$

$$\Rightarrow \dot{x}_7 = -X_7/T_{sg2} + u_2/T_{sg2} - 1/T_{sg2}R_2 x_4 \text{ ------- (7)}$$

$$x_8 = \frac{2\pi T_{12}\,(x1 - x4)}{s}$$

$$\Rightarrow \dot{x}_8 = 2\pi T_{12}\,(x1 - x4) \text{ ----------- (8)}$$

$$\dot{x}_9 = b_1 x_1 + x_8 \text{ ---------- (9)}$$

$$\dot{x}_{10} = b_2 x_4 - a_{12} x_8 \text{ ----------- (10)}$$

Appendix-2
Numerical data -

Sl. No.	Notations	Full name	Numerical value
1	i	Subscript referring to area i (i=1,2)	-
2	Pr_i	Rating of i-th generator in MW	2000
3	T_t (or T_{CH})	Turbine time constant in sec	0.3 sec
4	T_{sg}	Time constant speed governor in sec	0.08 sec
5	K_{PS}, T_{PS}	Time constant & gain of power system, respectively	120, 20 sec respectively
6	K_r,T_r	Reheat coefficient & time constant , respectively	0.5, 10 sec respectively
7	T_{12}	Synchronizing coefficient	$\frac{0.545}{2\pi}$
8	R_i	Governor speed regulation parameter in Hz per p.u. MW	$\frac{1}{2.4}$
9	ΔP_{tie}	Incremental change in tie-line power	-
10	ΔF_i	Incremental change in frequency deviation	-
11	ΔP_{Di}	Incremental change in load demand	-
12	ΔP_{Ci}	Incremental change in speed governor position	-
13	ΔY_{Ei}	Incremental change in valve position	-
14	D	Load frequency constant in p.u MW per Hz ($\delta P_D/\delta f$)	-
15	B_i	Frequency bias constant	0.425
16	δ	Nominal phase angle of voltages ($\delta_{12} = \delta_1 - \delta_2$)	-
17	K_{ii}	Integration time constant	0.4

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