# Dynamic Analysis and Stability of the Load Frequency Control in Two Area Power System with Steam Turbine

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***Abstract***— **The aim of this paper is to model, analysis and simulation of load frequency control in two area power system and parameters variation effects. State equations of a LFC in two area power system for a steam turbine are proposed. Then by examining some factors such as tie-line stiffness, turbine time constant, inertia constant and damping factor, the frequency control methods and influence of a small load variation are discussed. Finally, the steady state change in frequency in different cases using Matlab is calculate and compared.**

***Keywords-load frequency control; dynamic analysis; integral controller.***

## I. INTRODUCTION

The objective of modern power systems is to transfer enough high quality real and reactive power produced by generating units to customers through transmission lines. In an interconnected power system, the synchronous generators should rotate at the same speed and power flows over tie-lines should remain constant under normal operating conditions. Load frequency control (LFC) is a very important in power system operation and control for supplying sufficient and reliable electrical power with good quality, especially interconnected power systems [1-2]. Automatic generation control (AGC) or LFC is the mechanism by which the energy balance is maintained. The following summarizes the basic AGC objectives for an interconnected power system [3-4]:

1. Regulating system frequency error to zero and keep the system frequency in its scheduled value
2. Maintain accurate real time
3. Any area in need of power during emergency should be assisted from other areas.
4. Maintain net interchange power equal to scheduled values
5. Minimize equipment wear

Each of two areas as shown in Fig. 1 including steam turbines contains governor, reheated stage of steam turbine and generation rate constraints [5]. The tie line power flow appears as a load increase in one area and a load decrease in the other area, depending on the direction of the flow. When a load change occurs in any area, a new steady state operation can be obtained only after the power output of every turbine generating unit in the interconnected system reaches a constant value. In a power system consisting of interconnected areas, each area agrees to export or import a scheduled amount of power through transmission line interconnections to its neighboring areas. The LFC problems are characterized by stochastic disturbances, variable and unpredictable inputs, unknown parameters, nonlinearity and changes in plant transfer function. In order to improve LFC system problem, advance control techniques such as adaptive control [6], variable structure control [7], fuzzy PI controller [8, 9] and linear feedback optimal control [10], have been proposed. A completely decentralized controller for the LFC operated as a load following service proposes in [11]. An application of layered artificial neural network controller to study LFC problem in three-area interconnected power system that two areas include steam turbines and the other area includes a hydro turbine is shown in [12]. A fuzzy control scheme for a LFC in two-area power system, which accepts change in frequency and changes in generator output as its inputs and generates a required control signal, is proposed in [13].

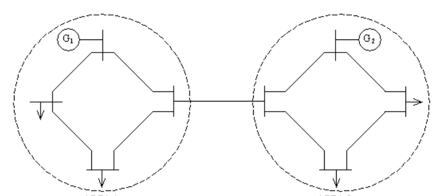



Figure 1. Two connected area

The aim of this paper is to model, analysis and simulation of load frequency control in two area power system and parameters variation effects. The remainder part of this paper is organized as follows. In section II the plant model and equation of the system is described. The various transfer functions in section III are studied. Finally, the steady state change in frequency in different cases using Matlab are calculate and compared in section IV and discussed in section V.

978-0-7695-3925-6/09 $26.00 © 2009 IEEE
DOI 10.1109/ICCEE.2009.95

## II. SYAYTEM EQUATION

In this section, an analytical approach is given for the investigation of two area power system dynamics. The LFC system consists of four parts: turbine, governor, electrical system and controller. A block diagram representation for the two area system with LFC containing integral controller is shown in Fig. 2, where $G_T(s)$, $G_G(s)$ and $G_P(s)$ denote the transfer functions of turbine, governor and electrical systems respectively. Changes in load are accompanied by changes in system frequency, generation and tie line power flows. The system frequency and tie line power flows must be kept within specified limits. The inputs to the system are changes to the electric load $\Delta P_{D1}$ and $\Delta P_{D2}$ in each area. Quantities of interest are the mechanical power output of the turbine, $\Delta P_{T1}$ and $\Delta P_{T2}$, changes to the plant set point, $\Delta P_{C1}$ and $\Delta P_{C2}$, output change of governor, $\Delta P_{G1}$ and $\Delta P_{G2}$, and the system frequency increment, $\Delta P_{F1}$ and $\Delta P_{F2}$, of the each area system. Other quantity of interest is the deviation of tie line power flow out of the area from the scheduled power flow, $\Delta P_{TIE}$. It is known that LFC systems include an integral control as secondary controller, in conventional control configurations.

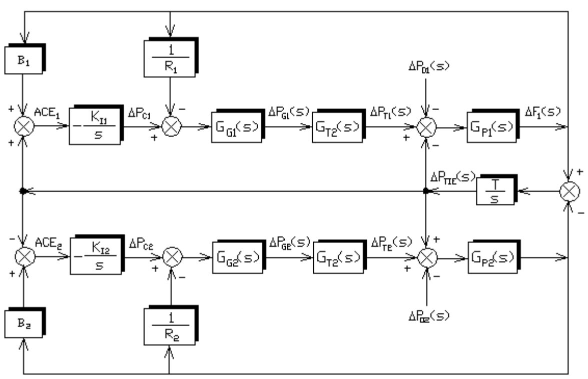



Figure 2. Two area system with LFC with integral controller

In practice the adjustment of $\Delta P_{C1}$ and $\Delta P_{C2}$ is done automatically by the tie line bias control or secondary control. Each area supplies its user pool and allows electric power to flow between areas. The control error for each area consists of a linear combination of frequency error and tie-line error [9]. The area control error (ACE) must be kept close to zero in each control area. The ACE is used as the input of the PI controller of LFC, while the output is the raise/lower signal ($\Delta P_C$) sent to generating units to adjust their generated power to meet the demand [14]. The ACE for a two area system is:

$$ACE_N = (-1)^{N+1} \Delta P_{TIE} + B_N \Delta f_N \qquad N=1, 2 \tag{1}$$

where N is number of area and $B_N$ is frequency bias setting. The $B_N$ should be high enough such that each area adequately contributes to frequency control. The choosing $B_N$ equal to the area frequency response characteristic ($\beta$), gives satisfactory performance of interconnected system. The value of $\beta$ varies according to electric load characteristic, governor performance and speed regulation settings [15]. If speed regulation factor and damping factor system for an each area is represented by $R_N$ and $D_N$ respectively, then the $\beta_N$ is:

$$\beta_N = D_N + \frac{1}{R_N} \tag{2}$$

The value of $\Delta f_N$ in (1) represents the amount of frequency variation, which can be calculated as below:

$$\Delta f_N = f - f_o \tag{3}$$

where $f_o$ is the nominal frequency and f is the operating frequency. The frequency bias $B_N$ determines the amount of interaction during a disturbance in the neighboring areas. The $B_N$ should be high enough such that each area adequately contributes to frequency control. The ACEs are used as actuating signals to activate changes in the reference power set points, and when steady state is reached, $\Delta P_{TIE}$ and $\Delta f_N$ is returned to zero and $ACE_1$=$ACE_2$. Sate equation of two area system with controller and without reheat with nine variables:

$$X = [\Delta f_1\ \Delta P_{T1}\ \Delta P_{G1}\ \Delta P_{C1}\ \Delta P_{TIE}\ \Delta f_2\ \Delta P_{T1}\ \Delta P_{G1}\ \Delta P_{C1}]^T \tag{4}$$

and two inputs:

$$U = [\Delta P_{D1} \quad \Delta P_{D2}]^T \tag{5}$$

are obtained. The equation systems for N=1, 2 are:

$$\frac{d}{dt}\Delta P_{GN} = -\frac{1}{T_{GN}}\Delta P_{GN} + \frac{K_{GN}}{T_{GN}}\Delta P_{CN} + \frac{K_{GN}}{T_{GN} R_N}\Delta f_N \tag{6}$$

$$\frac{d}{dt}\Delta f_N = -\frac{1}{T_{PN}}\Delta f_N + (-1)^N \frac{K_{PN}}{T_{PN}}\Delta P_{TIE} - \frac{K_{PN}}{T_{PN}}\Delta P_{DN} + \frac{K_{PN}}{T_{PN}}\Delta P_{TN} \tag{7}$$

$$\frac{d}{dt}\Delta P_{TN} = -\frac{1}{T_{TN}}\Delta P_{TN} + \frac{K_{TN}}{T_{TN}}\Delta P_{GN} \tag{8}$$

$$\frac{d}{dt}\Delta P_{CN} = -K_{IN} B_N \Delta f_N + (-1)^N K_{IN} \Delta P_{TIE} \tag{9}$$

where $K_{TN}$ and $T_{TN}$ are steady state gain and time constant of turbine, $K_{GN}$ and $T_{GN}$ are gain and time constant of generator, $K_{IN}$ is integration constant. The steady state gain ($K_{PN}$) and time constant of electrical system ($T_{PN}$) are:

$$K_{PN} = \frac{1}{D_N} \tag{10}$$

$$T_{PN} = \frac{2H_N}{D_N} \tag{11}$$

where $H_N$ is inertia constant. The equation of tie-line power is:

$$\frac{d}{dt}\Delta P_{TIE} = T(\Delta f_1 - \Delta f_2) \tag{12}$$

where T is tie-line stiffness or the slope of the power angle curve at the initial operating angle. If T=0, tie-line is open and for T>0, tie-line is in operation. The LFC process also controls the power flow on the tie line.

## III. DYNAMIC ANANLYSIS

LFC is a fundamental method to stabilize system frequencies and tie-line power flows in an interconnected system [16]. Without LFC, the frequency of power supply may not be able to be controlled within the required limit band, therefore it is very important that when a fault occurs in the control loop. In this section various transfer functions describing the step response of the frequency variation following step change in load each area. The transfer functions are studied using Matlab and the step response verified by time domain simulation. Key parameters of the two area systems are listed in Table I.

TABLE I. MAIN PARAMETERS FOR TWO AREA POWER SYSTEM

| Parameter | Area 1 | Area 2 |
|---|---|---|
| $H_N$ | 5 | 4 |
| $D_N$ | 0.6 | 0.9 |
| $T_{TN}$ | 0.5 | 0.6 |
| $K_{TN}$ | 1 | 1 |
| $T_{GN}$ | 0.2 | 0.3 |
| $K_{GN}$ | 1 | 1 |
| $R_N$ | 0.05 | 0.06 |
| $K_{IN}$ | 0.3 | 0.3 |
| T | 2 | |

## IV. PARAMETERS CHANGE EFFECTS AND SIMULATION RESULTS

The role of LFC has the controlled role in the frequency of the standard in perceiving the change of the load to the load that changes every time, and operating kinds of governor with thermal power and the hydroelectric power plant with kinds of governor. The comparison of the dynamic response of first area frequency deviation with integral control for a step change in the load in area 1 in terms of parameters changes of first area shown in Figs. 3, 4 and 5.

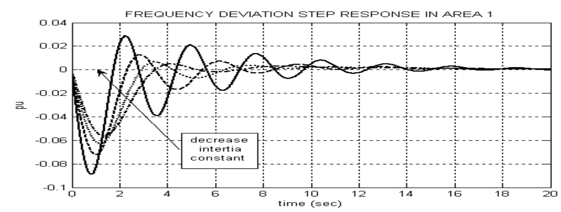
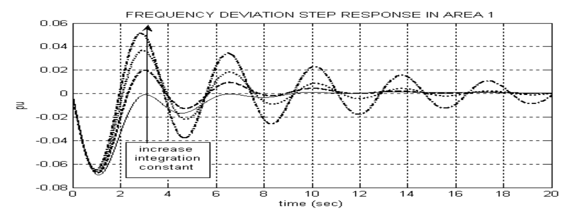
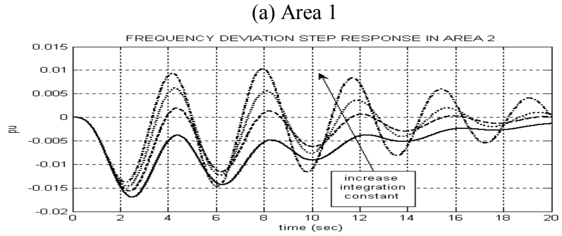



Figure 3. Frequency deviation in area 1 in terms of inertia constant changes of first area




(a) Area 1




(b) Area 2

Figure 4. Frequency deviation in terms of integration constant changes of first area

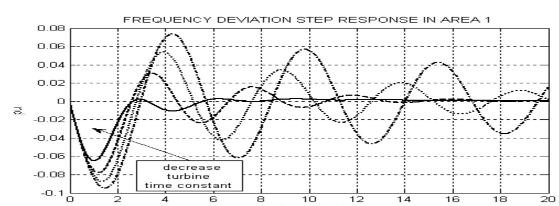



Figure 5. Frequency deviation in terms of turbine time constant of first area

The characteristics of the dynamic response of first area frequency deviation with integral control for a step change in the load in area 1 in terms of parameters changes are shown in Table II. The comparison of the dynamic response of tie line power flow deviation with integral control for a step change in the load in area 1 in terms of parameters changes of first area shown in Figs. 6, 7 and 8.

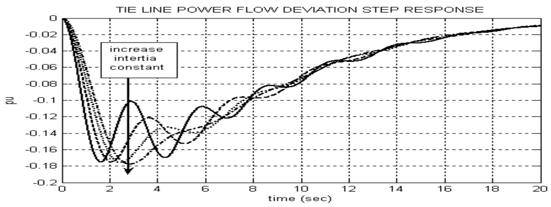



Figure 6. Tie line power flow deviation in terms of inertia constant changes of first area

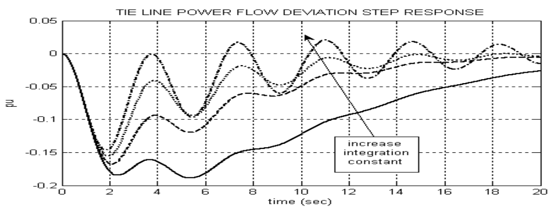



Figure 7. Tie line power flow deviation in terms of integration constant changes of first area

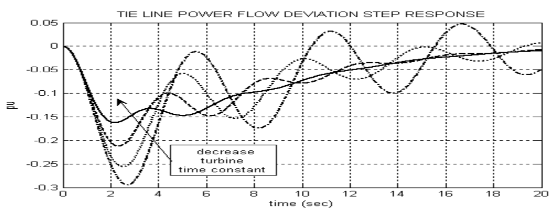



Figure 8. Tie line power flow deviation in terms of turbine time constant of first area

The characteristics of the dynamic response of tie line power flow with integral control for a step change in the load in area 1 in terms of parameters changes are shown in Table III. The comparison of the frequency response of first area frequency deviation with integral control in terms of parameters changes of first area shown in Figs. 9 and 10. The comparison of the frequency response of tie line power flow deviation with integral control in terms of parameters changes of first area are shown in Figs. 11 and 12.

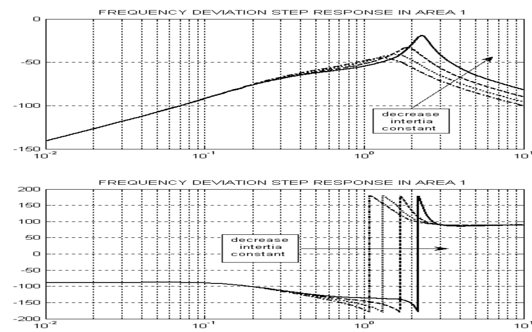



Figure 9. Frequency response of frequency deviation in terms of inertia constant changes of first area

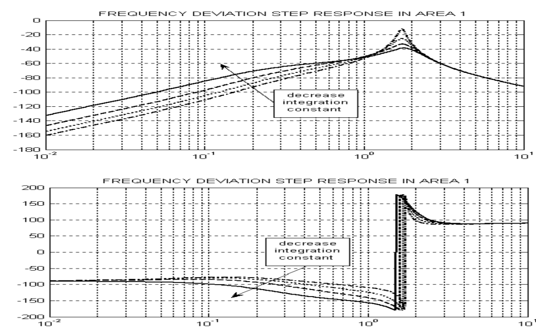



Figure 10. Frequency response of frequency deviation in terms of integration constant changes of first area

TABLE II. CHARACTERISTICS OF THE DYNAMIC RESPONSE OF TIE FIRST AREA FREQUENCY DEVIATION IN AREA 1 IN TERMS OF PARAMETERS CHANGES

| Response / Increase | Overshoot | Settling time | Oscillation |
|---|---|---|---|
| $K_{G1}$ | increase | small change | decrease |
| $K_{I1}$ | decrease | small change | increase |
| $D_1$ | increase | increase | increase |
| $H_1$ | decrease | decrease | decrease |
| $T_{T1}$ | increase | increase | increase |

TABLE III. CHARACTERISTICS OF THE DYNAMIC RESPONSE OF TIE LINE POWER FLOW IN TERMS OF PARAMETERS CHANGES

| Response / Increase | Overshoot | Settling time | Oscillation |
|---|---|---|---|
| $K_{G1}$ | increase | small change | decrease |
| $K_{I1}$ | increase | increase | increase |
| $D_1$ | small change | decrease | increase |
| $H_1$ | small change | small change | increase |
| $T_{T1}$ | increase | small change | increase |

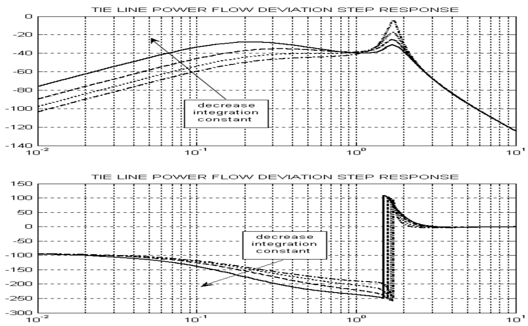



Figure 11. Tie line power flow deviation in terms of integration constant changes of first area

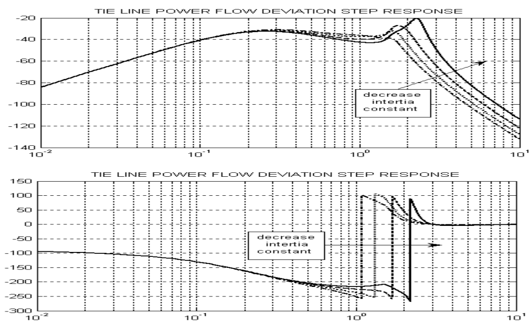



Figure 12. Tie line power flow deviation in terms of inertia constant changes of first area

## V. CONCULSION

Modern power systems are interconnected for a variety of economic and technical reasons. In this paper dynamic analysis of load frequency control in two area power system is presented by deriving the state space and control model. The response of the system is studied for load each area and parameters changes. The analysis is validated by time domain simulation and bode plot.

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