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DESIGN OF AN EFFICIENT PI CONTROLLER FOR ENHANCING SOLITARY-AREA POWER SYSTEM

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ABSTRACT

Load frequency control (LFC) of a solitary area power system with multi-source power generation is presented in this paper. The solitary area power system comprises of reheat turbine thermal power plant, hydro power plant with mechanical hydraulic governor and a gas turbine power plant. This paper proposes a proportional plus integral (PI) controller for the purpose of load frequency control. The frequency deviation response of thermal, hydro and gas units is also presented. The simulation results show that the proposed control scheme works well. Simulations area carried out using MATLAB R2021

Key Words- LFC, PI controller, multi-source, ISE

1. INTRODUCTION

In a power system the load demand is continuously changing in accordance with it the input also has to vary. If the input output balance is not maintained properly then a change in frequency will occur. Any mismatch between generation and load can be observed by deviation in frequency. This balancing between load and generation can be achieved by using Automatic Generation Control (AGC) or Load Frequency Control (LFC). In an isolated power system, regulation of interchange power is not a control issue, and the LFC task is limited to restore the system frequency to the specified nominal value [1].

LFC is a simple mechanism to maintain or restore the frequency. The fundamental objectives of load frequency control are to maintain system frequency at nominal value, to hold the interchange power among areas at scheduled values and to share the amount of required generation among generating units in a pre-set manner [2]. Many advanced design techniques have been applied to design load frequency controllers.

Many researchers have studied the LFC problem. Parmar et al [3] have presented an optimal output feedback controller for the load frequency control of a realistic power system with multi-source generation. It also describes the findings that helps to analysis and design of controller for two area thermal-hydro-gas AGC system. This analysis is aimed at finding the proper governor speed regulation parameter and participation factors for each of the generator types [4]. Alireza et al have presented a decentralized load frequency control using a new robust optimal MISO PID controller based on Characteristic Matrix Eigen values and Lyapunov method for LFC problem [5,6]. Muthana and Zribi have presented a decentralized load frequency controller for a multi-area interconnected power system. They have described a controller in which each local area network is overlapped with states representing the interconnections with the other local area networks in the global system.[7]

When an electrical load change occurs, the turbine-generator rotor accelerates or decelerates, and frequency undergoes a transient disturbance. The controller should not allow transient oscillations or overshoot, which in-turn trips the under-frequency relay connected in the system. Oscillations, settling time and overshoot are interrelated, changes in one parameter will affect the other parameter. Hence, it is important that the designed controller must be efficient in selecting the optimum gains in order to achieve better results. In this paper a proportional plus integral controller (PI) is designed for load frequency control of the power system. The design procedure is based on Integral Square Error (ISE) criterion. [8]

2. PROBLEM FORMULATION

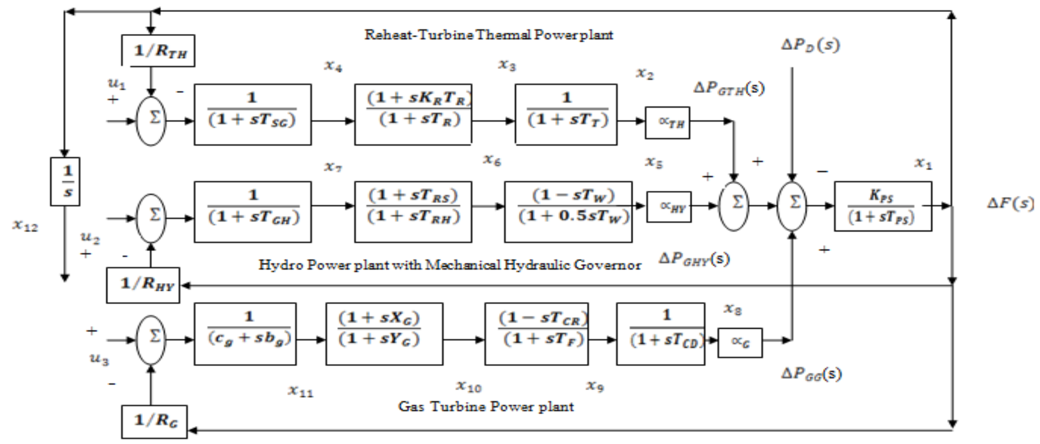

Fig. 1. Block diagram of single area power system comprising reheat thermal, hydro and gas generating units

The block diagram of solitary area power system comprising reheat thermal, hydro and gas generating units are shown in Fig. 1. Definitions and symbols used in the description of the model of the power system are given in Appendix A. For simulation and LFC study of the power system, the linearized models of governors, reheat turbines, hydro turbines and gas turbines are used. Here x_1 to x_{12} represents the state variables and u_1, u_2, u_3 represents the control inputs to the thermal, hydro and gas power plants respectively [9]. Simulations are carried out to obtain dynamic responses of ΔF, ΔP_{GTH}, ΔP_{GHY} and ΔP_{GG} for 1% step load change in the area. The generalized linear model of the power system may be described in state space form as

$$\dot{x} = Ax + Bu + \gamma d \quad (1)$$

$$y = Cx \quad (2)$$

where x is a state vector of dimension n x 1,u is a control vector of dimension m x 1, d is a disturbance vector of dimension 1 x 1, y is a output vector of dimension p x 1. A, B, γ, C are constant matrices of dimension n x n, n x m, n x 1 and p x n respectively [10].

A. REHEAT-TURBINE THERMAL POWER PLANT

By inspection method the state variable equations of the reheat turbine model of the block diagram shown in Fig. 1. can be expressed as follows

$$x_1 = \frac{K_{PS}}{1+sT_{PS}}[\alpha_{TH}x_2 + \alpha_{HY}x_5 + \alpha_G x_8 - \Delta P_D] \quad (3)$$

$$x_2 = \frac{1}{1+sT_T}x_3 \quad (4)$$

$$x_3 = \frac{1+sK_RT_R}{1+sT_R}x_4 \quad (5)$$

$$x_4 = \frac{1}{1+sT_{SG}}\left[u_1 - \frac{1}{R_{TH}}x_1\right] \quad (6)$$

B. HYDRO POWER PLANT WITH MECHANICAL HYDRAULIC GOVERNOR

By inspection method the state variable equations of the hydro turbine model of the block diagram shown in Fig. 1. can be expressed as follows

$$x_5 = \frac{1-sT_W}{1+0.5\,sT_W}x_6 \quad (7)$$

$$x_6 = \frac{1+sT_{RS}}{1+sT_{RH}}x_7 \quad (8)$$

$$x_7 = \frac{1}{1+sT_{GH}}\left[u_2 - \frac{1}{R_{HY}}x_1\right] \quad (9)$$

C. GAS TURBINE POWER PLANT

By inspection method the state variable equations of the gas turbine model of the block diagram shown in Fig. 1. can be expressed as follows

$$x_8 = \frac{1}{1+sT_{CD}}x_9 \quad (10)$$

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$$x_9 = \frac{1 - sT_{CR}}{1 + sT_F}\, x_{10} \qquad (11)$$

$$x_{10} = \frac{1 + sX_G}{1 + sY_G}\, x_{11} \qquad (12)$$

$$x_{11} = \frac{1}{c_g + b_g}\left[u_3 - \frac{1}{R_G} x_1 \right] \qquad (13)$$

$$x_{12} = \frac{1}{s}\, x_1 \qquad (14)$$

By taking inverse Laplace transform of the above equations from (3) – (14), the model can be described in the state space form given by (1). System matrices A, B, γ and C for the power system are described below:

$$[A] = \begin{bmatrix}
-\frac{1}{T_{PS}} & \frac{K_{PS}\cdot\alpha_{TH}}{T_{PS}} & 0 & 0 & \frac{K_{PS}\cdot\alpha_{HY}}{T_{PS}} & 0 & 0 & \frac{K_{PS}\cdot\alpha_G}{T_{PS}} & 0 & 0 & 0 & 0 \\
0 & -\frac{1}{T_T} & \frac{1}{T_T} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-\frac{K_R}{T_{SG}R_{TH}} & 0 & -\frac{1}{T_R} & \frac{1}{T_R} - \frac{K_R}{T_{SG}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-\frac{1}{T_{SG}R_{TH}} & 0 & 0 & -\frac{1}{T_{SG}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\frac{2T_{RS}}{T_{RH}T_{GH}R_{HY}} & 0 & 0 & 0 & -\frac{2}{T_W} & \frac{2}{T_W} + \frac{2}{T_{RH}} & \frac{2T_{RS}}{T_{RH}T_{GH}} - \frac{2}{T_{RH}} & 0 & 0 & 0 & 0 & 0 \\
-\frac{T_{RS}}{T_{RH}T_{GH}R_{HY}} & 0 & 0 & 0 & 0 & -\frac{1}{T_{RH}} & \frac{1}{T_{RH}} - \frac{T_{RS}}{T_{RH}T_{GH}} & 0 & 0 & 0 & 0 & 0 \\
-\frac{1}{T_{GH}R_{HY}} & 0 & 0 & 0 & 0 & 0 & -\frac{1}{T_{GH}} & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{1}{T_{CD}} & \frac{1}{T_{CD}} & 0 & 0 & 0 \\
\frac{T_{CR}X_G}{T_F R_G Y_G\cdot b_g} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{1}{T_F} & \frac{1}{T_F} + \frac{T_{CR}}{T_F Y_G} & \frac{T_{CR}X_G\cdot c_g}{T_F Y_G\cdot b_g} - \frac{T_{CR}}{T_F Y_G} & 0 \\
-\frac{X_G}{R_G Y_G\cdot b_g} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{1}{Y_G} & \frac{1}{Y_G} - \frac{X_G\cdot c_g}{Y_G\cdot b_g} & 0 \\
-\frac{1}{R_G\cdot b_g} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{c_g}{b_g} & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$[B^T] = \begin{bmatrix}
0 & 0 & \frac{K_R}{T_{SG}} & \frac{1}{T_{SG}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \frac{-2T_{RS}}{T_{RH}T_{GH}} & \frac{T_{RS}}{T_{RH}T_{GH}} & \frac{1}{T_{GH}} & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-T_{CR}X_G}{T_F Y_G b_g} & 0 & \frac{1}{b_g}
\end{bmatrix}$$

$$[\gamma^T] = \begin{bmatrix} \frac{-K_{PS}}{T_{PS}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

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

where

$$[x] = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 & x_5 & x_6 & x_7 & x_8 & x_9 & x_{10} & x_{11} & x_{12} \end{bmatrix}$$

$$[u] = [\ u_1 \ \ u_2 \ \ u_3\ ]^T$$

$$[d] = [\Delta P_D]$$

3. DESIGN OF PI CONTROLLER

In load frequency controller design, an Integral Square Error (ISE) criterion is used as a cost function which is convenient measure of dynamic performance. ISE is a measure of system performance formed by integrating the square of the system error over a fixed interval of time. This performance measure and its generalizations are frequently used in linear optimal control and estimation theory. This is used to find out the optimum controller gain [11].

The formula to find performance index J is

$$J = \int_0^t \Delta F^2 dt$$

The proportional plus integral (PI) controller is a device that produces an output consisting of two terms, one proportional to input signal and other proportional to the integral of the input signal. A PI controller is a special case of PID controller in which the derivative (D) of the error is not used. The advantages of both P-controller and I-controller are combined in PI-controller. The proportional action increases the loop gain and makes the system less sensitive to variations of system parameters. The integral action eliminates or reduces the steady state error [12].

Keeping Kp constant and varying Ki, the performance index J is evaluated for different values of Ki and the cost curve is drawn between Ki and J as shown in Fig. 2.

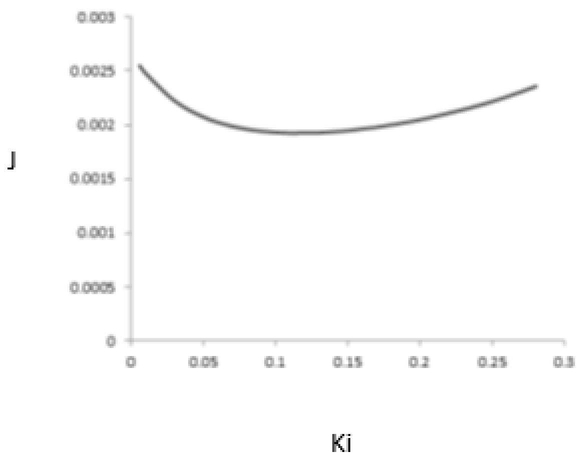

Fig. 2. Solitary area multi-source power system –PI controller design

4. SIMULATION RESULTS

Simulations are carried out for solitary area power system for a disturbance of 1% pu step load change using PI controller. The results are shown in Fig. 3.

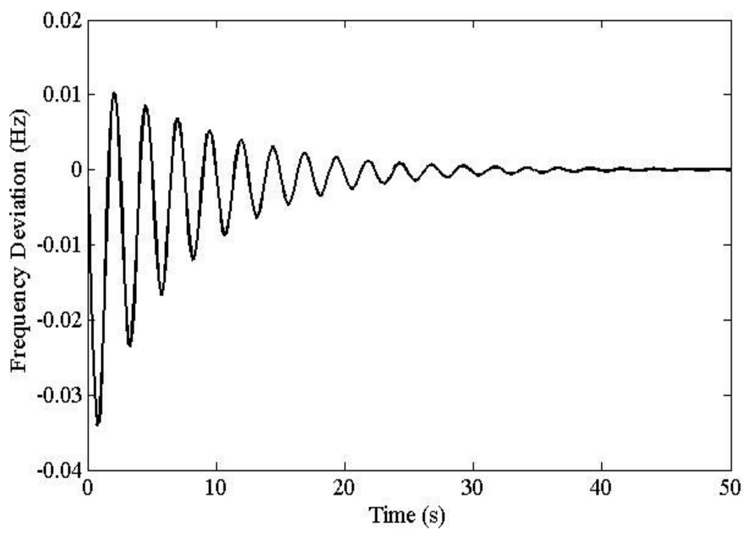

Fig 3. Frequency deviation response to 1% step load perturbation in the area with PI controller

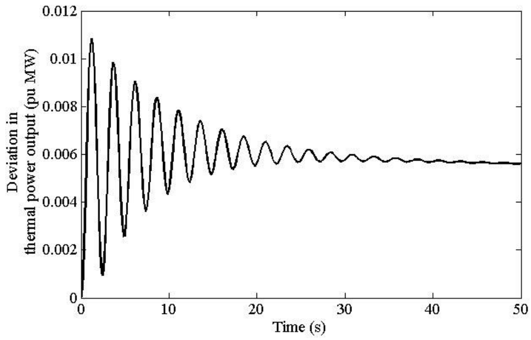

Fig 4. Thermal unit power output deviation response to 1% step load perturbation in the area with PI controller

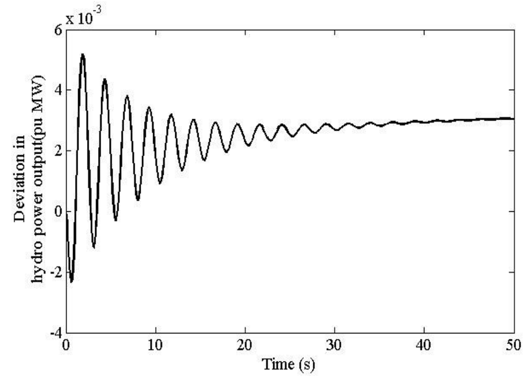

Fig 5. Hydro unit power output deviation response to 1% step load perturbation in the area with PI controller

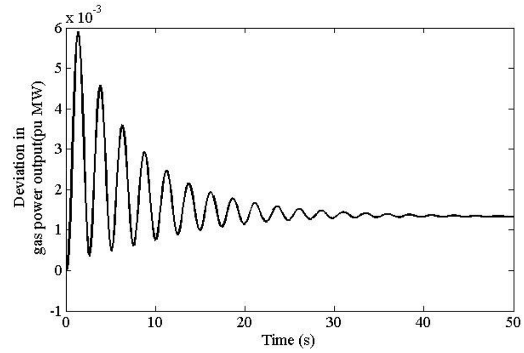

Fig 6. Gas unit power output deviation response to 1% step load perturbation in the area with PI controller

5. CONCLUSION

In this paper a Proportional plus Integral (PI) controller is designed for load frequency control of a solitary area power system with multi-source power generation. The design procedure is based on Integral Square Error (ISE) criterion. Simulation studies are carried out for solitary area power system with PI controller. Simulations are carried out to obtain the dynamic responses of ΔF, ΔP_{GTH}, ΔP_{GHY} and ΔP_{GG} for 1% step load change in the area. Results indicated that the proposed controller design minimizes the overshoot, settling time and oscillations. To validate the proposed control scheme, simulations are carried out on a solitary area power system. The simulation results indicate that the proposed control scheme works well. Moreover, the simulations results show that the controller is robust in the presence of input disturbance and changes in the parameters of the power system.

APPENDIX A

K_{PS}	Power system gain,Hz/pu MW
K_R	System turbine reheat time constant
T_{SG}	Speed governor time constant
T_R	Steam turbine reheat time constant,s
T_{CD}	Gas turbine compressor discharge volume-time constant,s
T_{CR}	Gas turbine combustion reaction time delay,s

T_F	Gas turbine fuel time constant,s
b_g	Gas turbine constant of value positioner,s
c_g	Gas turbine valve positioner
Y_G	Lag time constant of gas turbine speed governor, s
X_G	Lead time constant of gas turbine speed governor, s
T_{GH}	Hydro turbine speed governor main servo time constant
T_{RH}	Hydro turbine speed governor transient droop time constant, s
T_{RS}	Hydro turbine speed governor reset time,s
T_W	Nominal starting time of water in penstock, s
f	Nominal system frequency, Hz
T_{PS}	Power system time constant, s
T_T	System turbine time constant, s
R_{TH}, R_{HY}, R_G	Governor speed regulation parameters of thermal ,hydro, and gas generating units ,respectively, Hz/ pu MW
$\alpha_{TH},\alpha_{HY},\alpha_G$	Participation factors of thermal, hydro and gas generating units
Δf	Incremental change in frequency, Hz
ΔP_{GTH} ,ΔP_{GHY}, ΔP_{GG}	Incremental change in power outputs of thermal, hydro and gas generating units, pu MW
ΔP_D	Incremental load change, pu MW

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