Load Frequency Control in Power System with Hydro Turbine under Various Conditions

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***Abstract*—In this paper describe the small signal stability of the load-frequency control with hydro-turbine. The effects of parameter variation on the dynamic behavior of the power system have been investigated. Application of compensation in response water turbine with eigenvalues analysis and behavior dynamic simulation of the power system is shown. Also, using transfer function, PID controller for load-frequency control in power system is design and the change of the gains controller is investigated.**

Keywords—load frequency control; hydro turbine; PID controller.

I. INTRODUCTION

The dynamic behavior of many power systems and resulted in industrial loads heavily depends on disturbances and in particular on changes in the operating point. Load-frequency control (LFC) or automatic generation control is a very important in power system control and operation for supplying sufficient and both good quality and reliable electrical power. The goal of the LFC is to maintain real power balance and zero steady state errors in a multi area interconnected power system. In addition, the power system should fulfill the proposed dispatch conditions. The synchronous machine with two controllers is show in Fig.1 [1,2]. Power systems are divided into control areas connected by tie lines. All generators are supposed to constitute a coherent group in each control area. From the experiments on the power system, it can be seen that each area needs its system frequency to be controlled.

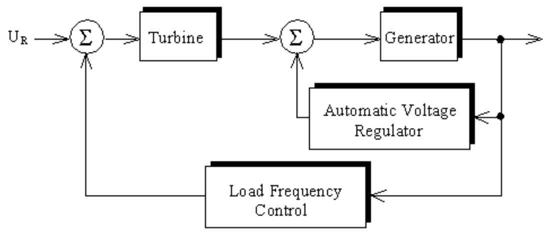

Fig. 1. Synchronous machine with controllers in power system

Several control technique for LFC were proposed in the papers [3-7]. A fractional order PID in [8] is designed for single area LFC for all three types of turbines, which the optimization of controller parameters and robustness evaluation of the control technique is done on the basis of the integral error criterion. Based on the active disturbance rejection control concept, a robust decentralized LFC scheme is proposed in [9] for an interconnected three-area power system. The prospective of parameter space methods for robust control and algorithm for a robust controller based a pole shifting adaptive control technique are presented in [10]. In [11], the design and analysis of a robust PID controller for a hydraulic turbine generator governor using a frequency response technique are presented. A discrete-time sliding mode controller for LFC in control four-area of a power system with different turbine units, such as non-reheat in area 1 and area 2 while hydro unit in area 3 and area 4 is discussed in [12].

Proportional integral derivative (PID) controllers are widely utilized in industries. In this paper presents a PID controller in power system with hydro turbine for load frequency control. The system dynamic performance is analyzed through simulating various load and parameter variation such as inertia constant, water starting time and constant speed over a wide range. The dynamic performance of the closed-loop system is analyzed base on its eigenvalues.

II. HYRO-TURBINE

Power change and structure of hydro turbine depend on the height of water fall. Hydro turbine characteristic is very complex. It changes with the variation of operation conditions. In the hydro turbine, the water pressure response is opposite to the gate position change at first and recovers after the transient response. For the load frequency control, at hydro power plant generating units are normally adjusted as the response is faster to raise/lower the power. Fig. 2 depict the functional block diagram model of the hydro power plant generating unit. Hydro turbine is non-minimum phase units due to the water inertia. If the hydro system operates with small load perturbations and the hydraulic coupling is ignored, in the simplest form, the transfer function of an ideal turbine is as follows [13]:

$$G_T(s) = \frac{\Delta P_M(s)}{\Delta X_G(s)} = \frac{1 - T_W\, s}{1 + 0.5\, T_W\, s} \qquad (1)$$

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where ΔP_M is incremental change in turbine mechanical power deviation and ΔX_G is incremental change in gate position. The mechanical power is controlled by opening or closing valves regulation water flow. When more water passes through the turbine mechanical output on the shaft of the turbine increases.

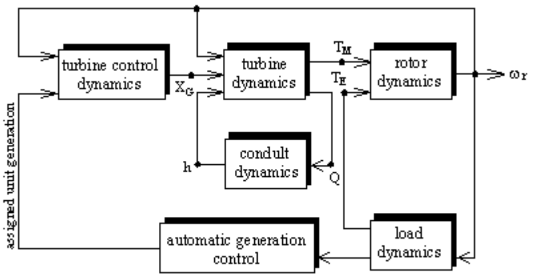

Fig. 2. Functional block diagram of hydro power plant generating unit

The transfer function of transient droop compensation can be written as [14]:

$$G_C(s) = \frac{\Delta X_G(s)}{\Delta P_G(s)} = \frac{1 + T_R\, s}{1 + \alpha T_R\, s} \tag{2}$$

where ΔP_G is incremental change in gate position in the system without compensation. Also α is slopes ratio and T_R is resetting time and both of them is dependent on the T_W [15].

III. MATHEMATICAL MODEL

Fig. 3 show the mathematical relationships between incremental variables and inputs in single-machine infinite-bus (SMIB) power system involves AVR, turbine, governor and synchronous machine for study the small signal stability. The constants K_1-K_6 are dependant to system parameters and operation point of the synchronous machine. Fig.4 shows the transfer-function block diagram of a single-area small perturbation model of a hydro-plant system. The mathematical model of the power system with hydro-turbine as can be described by the following state equations:

$$\frac{d}{dt}x_1 = -\frac{D_M}{J_M}x_1 + \frac{1}{J_M}x_2 - \frac{1}{J_M}u_1 \tag{3}$$

$$\frac{d}{dt}x_2 = \frac{2K_G}{\alpha R_P T_G}x_1 - \frac{2}{T_W}x_2 + \left(\frac{2}{T_W} + \frac{2}{\alpha T_R}\right)x_3 + \frac{2}{\alpha}\left(\frac{1}{T_G} - \frac{1}{T_R}\right)x_4 - \frac{2K_G}{\alpha T_G}u_2 \tag{4}$$

$$\frac{d}{dt}x_3 = \frac{-K_G}{\alpha R_P T_G}x_1 - \frac{1}{\alpha T_R}x_3 + \frac{1}{\alpha}\left(\frac{1}{T_R} - \frac{1}{T_G}\right)x_4 + \frac{K_G}{\alpha T_G}u_2 \tag{5}$$

$$\frac{d}{dt}x_4 = -\frac{K_G}{T_G R_P}x_1 - \frac{1}{T_G}x_4 + \frac{K_G}{T_G}u_2 \tag{6}$$

where the state variables are $x_1=\Delta f$ is incremental frequency deviation, $x_2=\Delta P_M$, $x_3=\Delta X_G$, $x_4=\Delta P_G$. $u_1=\Delta P_D$ is the incremental change in load disturbance (p.u. MW) and $u_2=\Delta P_R$ is the incremental change in a reference power setting (p.u. MW). Also T_W is water starting time or time constant of hydro turbine, T_R is reset time or dashpot time constant, R_T is transient droop, J_M is inertia constant, D_M is load damping constant, T_G is governor time constant and K_G is governor gain. Typical parameter values are T_W in the rang 0.5 to 5, T_R in the range 2.5 to 15 sec and J_M in the range 6 to 12. The change in the frequency signal is traditionally defined as a linear combination of reference power and power demand changes as:

$$\Delta F(s) = H_{PR}(s)\,\Delta P_R(s) - H_{FD}(s)\,\Delta P_D(s) \tag{7}$$

The transfer function relating the incremental frequency to change in demand load is:

$$H_{PR}(s) = \frac{K_C}{\Delta_O(s)}(1 + T_R s)(1 - T_W s) \tag{8}$$

where constant K and characteristic equation $\Delta_o(s)$ are depend on gains, operation point and constants time of the power system:

$$\Delta_O(s) = s^4 + p_3 s^3 + p_2 s^2 + p_1 s + p_0 \tag{9}$$

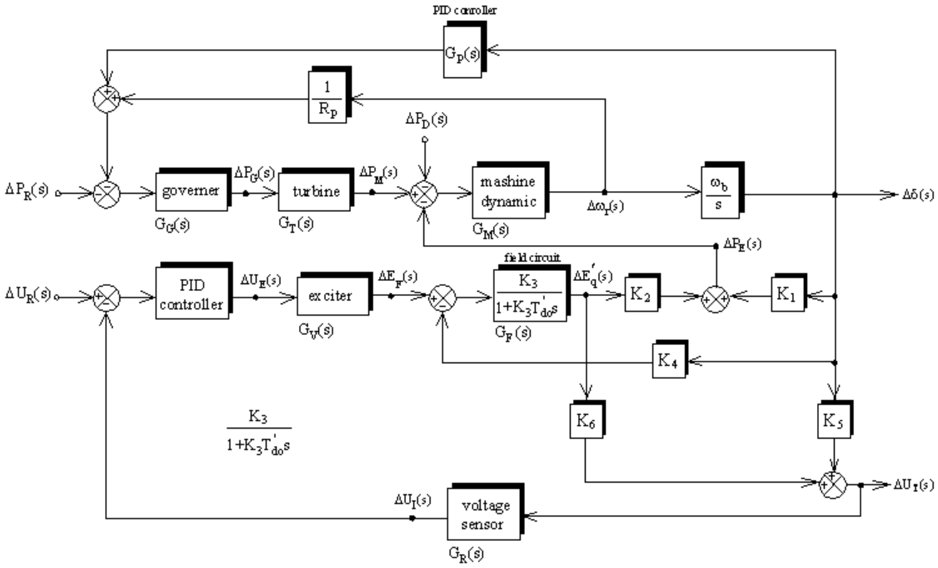

Fig. 3. The mathematical relationships between incremental system variables and inputs in SMIB power system

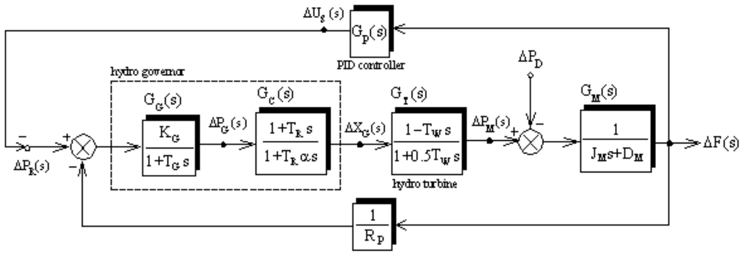

Fig. 4. Block diagram of hydro turbine

$$K_C = \frac{2K_G}{\alpha T_G T_R T_W J_M} \tag{10}$$

The transfer function relating the incremental frequency to change in turbine power output is:

$$H_{FD}(s) = \frac{K_C}{K_G \Delta_O(s)}(1+T_G s)(1+0.5T_W s)(1+\alpha T_R s) \tag{11}$$

The transfer function $H_{PR}(s)$ is important for design of the LFC system. It has a zero is in the right half at $s=1/T_W$ and a zero is in the left half at $s=-1/T_R$ of the s plane located. The steady-state frequency deviation following a load step change ΔP_D when $\Delta P_R=0$ is given by:

$$\Delta f(\infty) = \frac{R_P}{D_M + K_G} \tag{12}$$

IV. Close-Loop Transfer Function

The stability and damping properties depend on the location of the modes of the power system. The characteristics equation in close-loop system with PID controller is given by:

$$\begin{aligned} \Delta_C(s) &= s^5 + (p_3 - KK_D T_R T_W)s^4 \\ &+ [p_2 + KK_D(T_R - T_W) - KK_P T_R T_W]s^3 \\ &+ [p_1 + KK_D - KK_I T_R T_W + KK_P(T_R - T_W)]s^2 \\ &+ [p_0 + KK_P + KK_I(T_R - T_W)]s + KK_I \end{aligned} \tag{13}$$

where K_P is proportional gain, K_I is integral gain and K_D is derivative gain. The transfer function in the close-loop system is given by:

$$H_C(s) = \frac{\Delta F(s)}{\Delta P_D(s)} = \frac{-H_{FD}(s)}{1 + G_P(s)H_{PR}(s)} \tag{14}$$

If $K_P=0$, the necessary conditions for stability of the close loop system are given by:

$$K_D < min\left(\frac{p_3}{KT_R T_W}, \frac{p_2}{K(T_W - T_R)}\right) \tag{15}$$

$$K_I < \frac{p_0}{K(T_W - T_R)} \tag{16}$$

V. Simulation Results

Load frequency control is an important consideration in power system design. The simulation results of the frequency control of the SMIB with hydro-turbine using the proposed controller will be shown in this section in order to demonstrate the efficiency of the controller. The power system parameters are selected as given in Table I. The system modes with PID controller are -0.1662, -1.6357±j2.0205 and -0.2371±j0.3414.

The system modes equipped with hydro turbine is shown in Table II for different values of the T_W. Figs. 5 and 6 shows the step response of the frequency deviation and output mechanical power for values of the water starting gain. A lower value of T_W would be a faster response. The effect of the change in inertia constant on system modes with compensation are shown in Table III. Fig. 7 show the step response of the frequency deviation for values of the inertia constant. The comparison of step response of the frequency deviation between I controller and PID controller is shown in Figs. 8-9.

TABLE I. POWER SYSTEM PARAMETERS

Parameters	Typical values
reset time (T_R)	5.00
governor time constant (T_G)	0.20
governor gain (K_G)	1.00
water starting time (T_W)	1.00
permanent droop (R_P)	0.05
transient droop (R_T)	0.38
inertia constant (J_M)	6
damping constant (D_M)	1
proportional gain (K_P)	2
integral gain (K_I)	5
derivative gain (K_D)	15

TABLE II. T_W CHANGE EFFECT ON SYATEM MODES

T_W	System modes
1	-0.2146, -6.2004,-0.3888±j0.7314
3	-0.0437, -5.3826, -0.2052±j0.3559
5	-0.0210, -5.2576, -0.1447±j0.2688

TABLE III. J_M CHANGE EFFECT ON SYATEM MODES

J_M	System modes
6	-0.2146, -6.2004,-0.3888±j0.7314
9	-0.2404, -6.1940, -0.3579±j0.6964
12	-0.2508, -6.1918, -0.3465±j0.6840

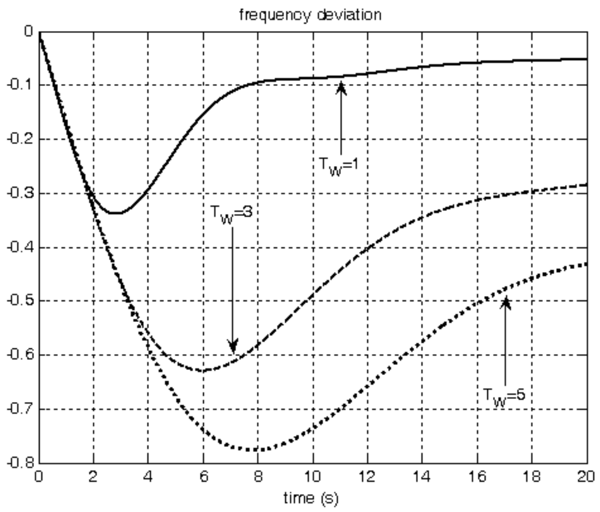

Fig. 5. Frequency deviation step response for different values of the T_W

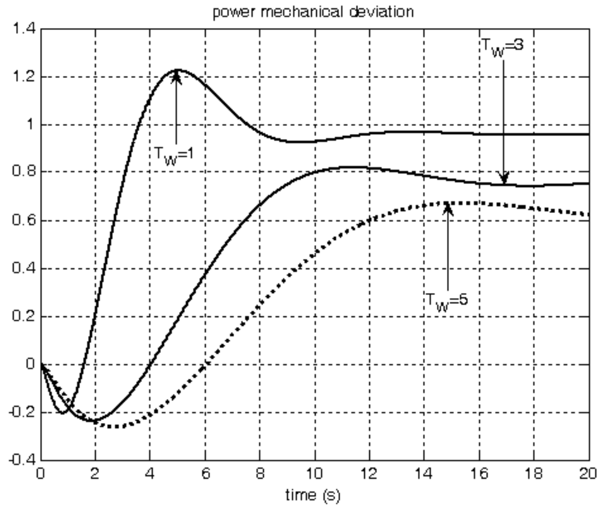

Fig. 6. Output power deviation step response for different values of the T_W

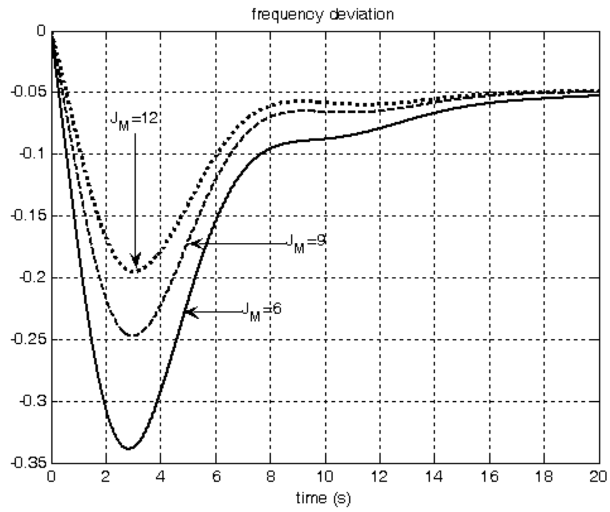

Fig. 7. Frequency deviation step response for different values of the J_M

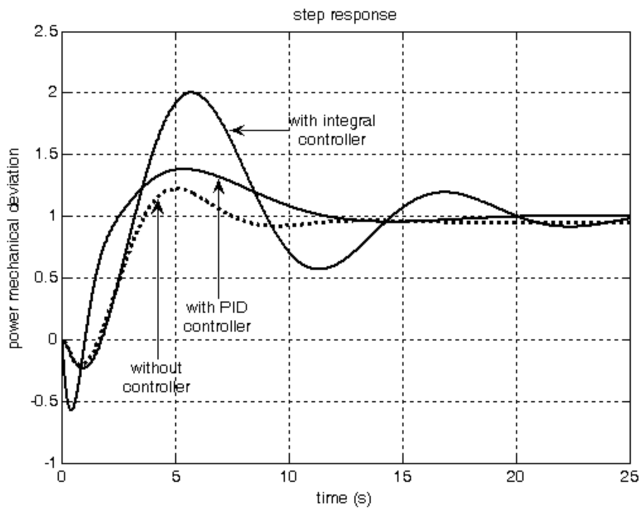

Fig. 8. Output power deviation step response for different states

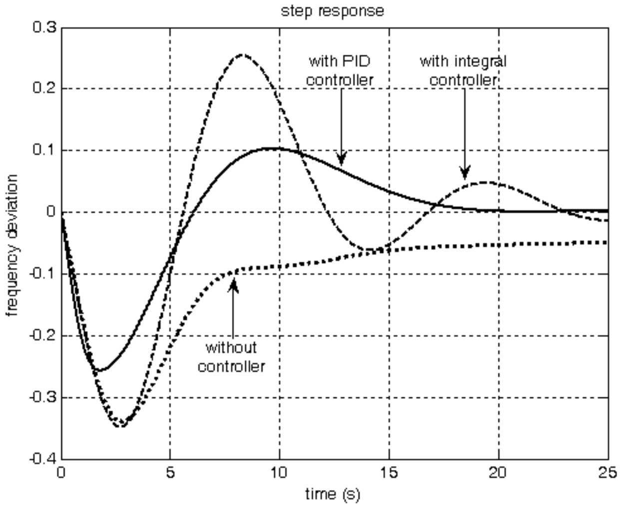

Fig. 9. Frequency deviation step response for different states

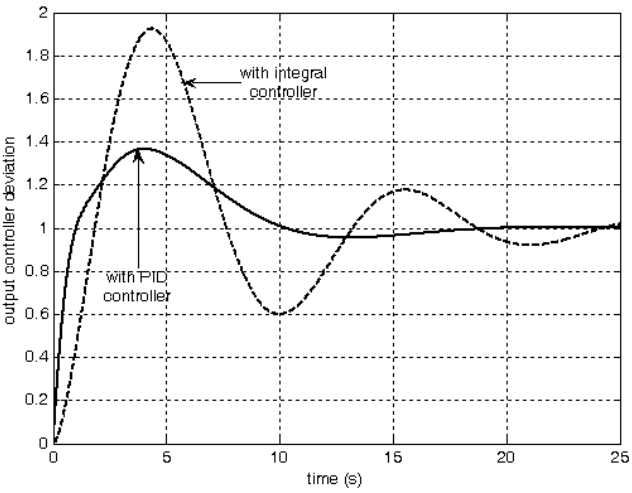

Fig. 10. Output controller deviation

An increase in the water time constant decreases the damping ratio and increasing error frequency. Conversely, increasing the machine inertia constant decreases the damping ratio. The change of the J_M has not effect on the error frequency. An integral control will have the effect of eliminating the steady state error but it may make the transient response worse.

VI. CONCLUSION

The main objective of load frequency control (LFC) is to maintain real power balance in the power system through control of frequency and return the steady-state frequency error to zero. The dynamic responses considering LFC system equipped with a PID controller and integral controller are compared with considering LFC system equipped with compe-nsation.

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