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SIMULATION MODEL OF NONLINEAR HYDRO POWER SYSTEM WITH SLIDING MODE CONTROL USING SIMULINK

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ABSRACT

Sliding mode control has received much attention due to its major advantages such as guaranteed stability, robustness against parameter variations, fast dynamic response and simplicity in the implementation and therefore has been widely applied to control nonlinear systems. This paper discus the sliding mode control technic for controlling hydropower system and generalized a model which can be used to simulate a hydro power plant using MATLAB/SIMULINK. This system consist hydro turbine connected to a generator coaxially, which is connected to grid. Simulation of the system can be done using various simulation tools, but SIMULINK is preferred because of simplicity and useful basic function blocks. The Simulink program is used to obtain the systematic dynamic model of the system and testing the operation with different PID controllers, SMC controller with additional integral action.

Keywords: hydropower system, integral action,Simulink,sliding mode controller,system uncertainties.

I. INTRODUCTION

Hydro power has a major percentage of world's renewable energy. This paper discusses the roll of sliding mode control in the control system of hydropower plant. Sliding mode control must be applied with more care to nonlinear systems because the actuators have time delays and other uncertainties. The sliding mode can chatter energy loss, plant damage and excitation of un-modeled dynamics. In history sliding mode control for hydropower system is studied by several. [1] And [2] presented the general method of sliding mode control.Nonlinear system with high speed discussed by [3]. Later [4] introduced the chattering free sliding mode control of hydropower system followed by [5] also. Modeling of the hydropower plant presented by [3] which followed by [6] and introducing the additional integral action. [5] also discussed the brief modeling of hydropower system. [7] Discussed the Simulink model of the system with three fault case. First order and second order sliding mode control for hydropower system is discussed by [8] and [9] respectively.This paper elaborate the hammer effect of water, application of surge tank and sliding mode control with integral action.

II. HYDRO POWER SYSTEM

Hydro power system converts the potential and kinetic energy of moving water into electricity. This system is coaxial conjunction of hydro turbine and synchronous generator. Continuous water flow provided by penstock rotates the turbine blades which transfer this mechanical rotation to synchronous generator. Synchronous generator converts this mechanical energy into electrical energy. In 2015 hydropower generated 16.6% of the world's total electricity and 70 % of all renewable electricity, and was expected to increase about 3.1% each year for the next 25 years. India is the 7th largest power producer of hydroelectric power in the world, and ranked 3rd in the total no. of dams. On March 31, 2016, the installed utility scale capacity was 42783 MW, which is 14.35% of India's total utility electricity generation capacity. Hydropower uses hydraulic turbines to convert energy in flowing water into electricity. Usually a hydropower plant is made up of the reservoir, water tunnel, surge tank, penstock, hydraulic turbine, speed governor, generator and grid. Hydropower system having long penstock produces 'hammer effect'. When continuous water flow is interrupted or stopped suddenly, the kinetic wave of flowing water make a knocking sound in penstock at the inlet gate of hydro turbine. This can harm the turbine blades permanently causing system failure. Hammer effect is removed by the application of surge tank. Surge tank is a vertical pipe which absorbs the extra power of water flow and provides it at the time of need. When less electricity is required by load, surge tank store the water and when the need of electricity increases, surge tank releases additional water to hydro turbine.

III. MODELING OF HYDROPOWER SYSTEM

Modeling of hydropower system has four subsystems. For these two parts, state space equations of hydropower plant are required. So second order equations of the key-parts of hydropower plant like water turbine, penstock system, servomechanism and electric generator system are described.

1. Modeling of hydro turbine

Water turbine is a nonlinear system described by moment function and flow function. After approximating it by Taylor decomposition equation, the linear model is

$$m_t = ex * x + ey * y + eh * h \tag{1}$$

$$q = eqx * +eqy * y + eqh * h \tag{2}$$

Where m_t is mechanical torque of turbine, q is water flow rate of turbine, y is deviation of guide vane, h is hydraulic head at gate, and x is deviation of turbine speed.$eh = \partial mt/\partial h, ex = \partial mt/\partial x, ey = \partial mt/\partial y, eqh = \partial mt/\partial y, eqx = \partial q/\partial h, eqy = \partial q/\partial y$,and these six transfer coefficients can be obtained in associated with the moment and flow characteristic curves.

2. Modeling of Penstock System

Penstock is a gate structure which controls water flow. It is an enclosed pipe that delivers water to hydro turbines. When the elasticity of water and tube wall shows no significant effects on water hammer, the relationship of water head h and flow q is shown [19] as:

$$h = -Tw * \frac{dq}{dt} \tag{3}$$

Where Tw is water starting time.$h$is normalized value of change in water head. $dq$is normalized value of change in turbine water flow.

3. Modeling of Servomechanism

The servomechanism is the actuator of water turbine. It is made by major servomotor and auxiliary servomotor. Simplified model of servomechanism is a one order system of major servomotor.

$$Ty\frac{dy}{dt}+y=u \tag{4}$$

Where T_y is major servomotor response time and u is control output.

4. Modeling of generator system.

The first-order generator model only considers the generator as a rotational rigid-body with certain inertia tensor, which cannot meet the requirement of modern power system simulation, thus in this paper, second-order generator model is adopted, where the relationship of electromagnetic torque and generator torque angle is taken into consideration. The nonlinear equation of the synchronous generator system is shown as:

$$\dot{\delta}= \quad \omega_0\omega \tag{5}$$

$$\dot{\omega}=\frac{1}{T_a}(mt-m_e-D\omega) \tag{6}$$

Where δ is generator rotor angle relative deviation and ω is generator speed deviation. In the dynamic character analysis of generator system, the electromagnetic torque $m_e$is equal to the electromagnetic power $P_e$once the impact that unit speed variation acts on the torque is taken into the account of generator damping constant D. The state equations of nonlinear hydropower system are

$$P_e=\frac{E_d'V_s}{x_{d\Sigma}'}\sin\delta+\frac{V_s^2}{2}\frac{x_{d\Sigma}'-x_{q\Sigma}}{x_{d\Sigma}'*x_{q\Sigma}}\sin 2\,\delta \tag{7}$$

Where $x'_{d\Sigma}$ and $x_{q\Sigma}$ are the reactance sum of d-axis and q axis which is defined as;

$$x'_{d\Sigma}=x_q+x_T+\frac{1}{2}x_L \tag{8}$$

$$x_{q\Sigma}=x_d'+x_T+\frac{1}{2}x_L \tag{9}$$

$$\dot{\delta}= \quad \omega_0\omega+d_1 \tag{10}$$

$$\dot{\omega}=\frac{1}{T_a}(mt-m_e-D\omega)+d_2 \tag{11}$$

$$\dot{m_t}=\frac{1}{eqh*Tw}*\left[-m_t+ey*y-\frac{e_m*ey*Tw}{Ty}(u-y)\right]+d_3 \tag{12}$$

$$\dot{y}=\frac{1}{Ty}(u-y) \tag{13}$$

Where d_1, d_2, d_3, d_4 are the disturbances of hydropower system. Generally, they are random and bounded. To facilitate the controller design, the system model can be formally rewritten the formation as follows:

$$\dot{X}=f(x)+g(x).u+d \tag{14}$$

$$Y=h(x) \tag{15}$$

Where $X=[x_1\ \ x_2x_3x_3]^T=[\delta\quad\omega\quad m_t\quad y]^T$is the system state vector, $d=[d_1d_2d_3d_4]^T$stands for the uncertain system state perturbation, Y is the system output vector. The functions f (x), g(x) and h(x), respectively, are given as follows:

$$f(x) = \begin{bmatrix} \omega_0 x_2 \\ \frac{1}{T_a}\left(x_3 - Dx_2 - \frac{E_d V_s}{x'_{d\Sigma}} sin x_1 - \frac{V_s^2}{2}\frac{x'_{d\Sigma} - \dot{x}_{q\Sigma}}{x_{d\Sigma} * x_{q\Sigma}} sin2\, x_1\right) \\ \frac{1}{eqh * Tw}(-x_3 + ey * x_4 + \frac{e_m * ey * Tw}{Ty} x_4) \\ -\frac{1}{Ty} \end{bmatrix} \tag{16}$$

$$g(x) = \begin{bmatrix} 0 \\ 0 \\ -\frac{e_m * ey}{eqh * Ty} \\ \frac{1}{Ty} \end{bmatrix} \tag{17}$$

$$h(x) = x_2 \tag{18}$$

IV. SLIDING MODE CONTROL

Sliding mode control also known as variable structure control is a high speed switching control with feedback. The gain in each feedback path switches between two values according to control law which depends on the value of the state each time. This state is called sliding mode states depend on a control law provided by the system's states. Taking into account the control objective of Hydropower system is to force the compensating speed x_2 to track the reference value x_2^* we design a sliding mode manifold with partial actions as

$$e = x_2^* - x_2 \tag{19}$$

$$s = c * e + \dot{e} \tag{20}$$

Assuming that the uncertain part in model is limited in a certain range, i.e. $|B| \leq Dr$, and the control output u with input/output sliding mode method can be valued as follows:

$$u = \frac{eqh * Ty * Ta}{e_m * ey}(\vartheta - A(x) + \eta * sgn(s)) \tag{21}$$

Where

$$\vartheta = \ddot{x}_2 + c\dot{e} \tag{22}$$

ηis a positive constant larger than Dr, sgn(s) presents the sign function, for sgn(s) = 1 when s >0, sgn(s) = 0 when s = 0 and sgn(s) = −1 when s <0.

To eliminate chattering phenomenon is to use a continuous approximation of sgn(s). Here, we approximate the sign function sgn(s) by a high-slope saturation function, that is, the SMC controller is taken as:

Where is $sat\left(\frac{s}{\xi}\right)$the saturation function defined by:

$$sat\left(\frac{s}{\xi}\right) = \begin{Bmatrix} s & if|s| \leq 1 \\ sgn(s) & if|s| \geq 1 \end{Bmatrix} \tag{23}$$

ξis a positive constant. Good approximation requires smallest ξ, the slope of linear portion of sat (s/ξ) is 1/ξ, so in the limitation, as ξ → 0, the saturation function sat (s/ξ) approaches the sign function sgn(s).

Now an additional integral action is added in control signal completing control action as

$$u = u_s + u_{eq} \tag{24}$$

$$u_{eq} = ge + gd \tag{24}$$

Provided that $g = [g_1\ \ g_2\ \ g_3\ \ g_4]^T$

V. SIMULATION RESULT

Hydro power system is simulated and a comparison of SMC controller with PID controller is presented. The fixed point is chosen as $x_2* = 1(t)$ for a case, PID controller and SMC controller are employed to adjust the response of HGRS system, the parameter gains of PID controller with PSO optimization is set as: kp = 12.4595, ki = 1.7283, kd = 3.3779, the parameter gains of proposed SMC controller is set as: c = 5, $\eta = 3$

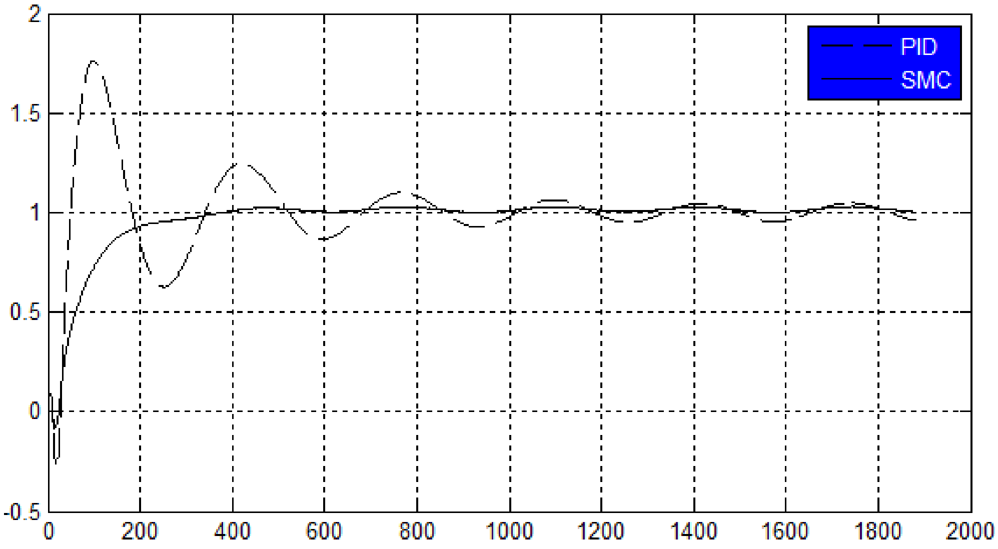

Fig. 1. Position tracking of ω with PID and SMC controller

VI. CONCLUSION

This paper concluded that sliding mode control have huge advantage over PID controllers for controlling nonlinear hydro power plant. Simulink model of hydropower plant is formulated and tested with system uncertainties and external disturbances. Every time sliding mode controller gave batter result then PID controller. The effect of introducing additional integral action is that system has less chattering. So overall we can sum up that sliding mode control is the most useful controlling technique for non-linear systems with system uncertainties.

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