IJBPAS, December, 2014, 3(12): 2734-2743

ISSN: 2277–4998

International Journal of Biology, Pharmacy and Allied Sciences (IJBPAS)

'A Bridge Between Laboratory and Reader'

www.ijbpas.com

DESIGNING, SIMULATION AND CONTROL OF HYDROELECTRIC PUMPED STORAGE POWER STATION

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ABSTRACT

In this article, STIMULINK model of Dinorwing hydroelectric pumped storage power station is controlled by Model Predictive Control (MPC). Response of the plant toward MPC is compared with proportional and integral controller (pi). The results show that constrained multivariable MPC has good control on the operating envelope of the plant. This control is constant in SISO and MIMO cases in tuning parameter. Also the advantageous of constrained MPC with profiler in decreasing of cross-coupling interaction has been shown.

Keywords: Hydroelectric Power, Power Station Control, Practical Planning Of Control, Control Application, and Multivariable Control

INTRODUCTION

Hydropower is used for generation of electricity by gravitation- force between sun and earth. Water is evaporated by heat which the main source of it is sun and will rise into the atmosphere. So it falls in shape of rain and snow. The water which place on the mountains flows in shape of small streams and then large river. After that, it traverses its course and its potential energy is changed to kinetic energy. There is hydropower naturally or it can be made by gathering water and to increase the height of it behind dam in order to supply the needs for electricity. Requirement to energy changes during the weeks and seasons .also generation and consumption of energy is different in holidays and working days. The main issue is that the most consumption power by power station is generated using fossil fuels that it takes half an hour or more to achieve its maximum capacity. This time is more in nuclear power plant. We need to a power that can be achieved immediately from zero to its maximum energy. Pumped-storage hydroelectricity is a system for generation of electricity from water energy. At times of low electrical demand, excess generation capacity is used to pump water into the higher reservoir. When there is higher demand, water is released back into the lower reservoir through a turbine, generating electricity. The method used is an in directional method since there is not an optimal method. Direction method is method that can directly store the electricity. There are two different types of pumped storage power station. One of these power stations can be used for storage energy exclusively and other beside its own duty can generate power. So it is a hydropower that not only generates the power from water of river but also it stores and releases the power energy. In hydropower, pumped storage can saves energy for days, weeks, natural days and weekends or seasons. This storage in US works in which at the time of surplus of electricity energy ,turbines acts as a plumb and transfers water to a reservoir in higher height. For this reason, Francis turbines are better option. Working station is placed in good condition in basement and if this situation cannot be possible, it placed on lower storage. Considering the losses of evaporation of water, frictional losses and the losses of conversation of energy, the efficiency of this process is between 70 to 85 percent. Despite of some ideas that asserts this method is efficient method considering its cost; it is important to pay attention capital cost and selection of suitable area. Density of energy is low in water carrier, it means each 1000 kg of water with height differences (about 100 meter) between 2 upper and lower reservoir only saves 0.22 Kw/h of energy. As it mentioned before, it is necessary to select large upper and lower reservoirs, also the distance between them should be long. A propulsion generator consists of a tube and a water reservoir. Turbine characteristics and blue pool is defined by 3 equitation which is determined the water speed in the pools. Increase of water speed depends on the gravitational force and generation of mechanical power in turbine can be simulated **(Figure 1)**.

Dinorwig is a large pumped storage hydroelectric that is placed on north Wales and it is executed by first hydro company. It has 6 300 mw turbines and driving synchronous generator that feed power to national grid. When peak demand take place, Dionorwig shows rapid react toward frequency control. This hydroelectric station has a channel which drags water from upper reservoir (Marchlyn Lake) into a manifold where main follow is divided into6 penstocks. Every penstock provides demands of a turbine to generate power by a guide vane to regulate the flow. The generated power in every unit is controlled using feedback loops. Reference input of power loop is the network frequency deviation from its 50 Hz set point, so it makes an outer frequency control loop. The model of hydroelectric power plant is according the work in **[2, 7]** which it is derived from a multivariable simulation of nonlinear plant. It makes a better comprehension about its features. Its basic features consist of: non minimum phase (NMP) dynamics, weekly damped poles (related to water hummer in reservoir channel and electrical synchronous) and nonlinear connection between flow and power. Also there is a significant hydroelectric coupling between turbines. Predictive control is used for common power system **[3, 4, 10, and 12]**. Recently, this controller is used for hydroelectric systems **[9, 11, and 13]**.

Pumped hydroelectric system can be considered as a multivariable system **[5]** and different controllers is designed for it **[8]**. In this article, a linear system is considered **[14] (Figure 2)**.

Description of Model

For system modeling it is required that the model is divided into subsystem and then all of models is collected into a model **(Figure 3)**.

Hydroelectric section: consists of water reservoir, column dynamics and guide vanes.

Electrical section: contains power system, generator and energy converter.

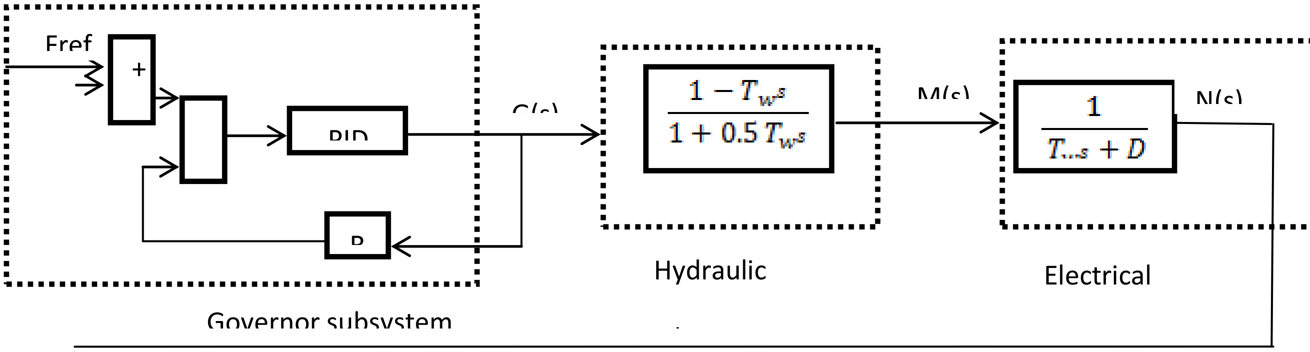
Control subsystem: consists of speed control system.

Transfer function of system can be written as follows:

$$\frac{\left(\mathbf{K_p}s + \mathbf{K_i} + \mathbf{K_d}s^2\right)(\mathbf{1} - \mathbf{T_w}^s)}{\mathbf{s}(\mathbf{1} + \mathbf{0.5T_w}^s)(\mathbf{T_m}s + \mathbf{D})}.$$

The hydroelectric plant model can be divided into three subsystems: guide vane, hydroelectric turbine and generator. In this work, a liner model of hydroelectric system has been used. Every subsystem is examined in fallow. The transfer function of the guide vanes model is used to control the water flow is determined in equation.

$$\mathbf{G} = \frac{\mathbf{1}}{(\mathbf{0.19s} + \mathbf{1})(\mathbf{0.4s} + \mathbf{1})}\left(\mathbf{set_{position}}\right)$$



$K_P = 0.97\frac{T_m}{T_w}$ $K_i = 0.39\frac{T_m}{T_w^2}$ $K_d = 0.4T_m$.

T_m= 7.99

T_w= 0.3066

D=2

As the **Figure 4** shows, the system response to input step has an overshoot. The system has undershoot and frequency error because of non minimum phase (NMP) which it cause unsuitable reaction of system.

The value of T_{mt}, T_w and T_{wt} directly depends on the main tunnels and penstock dimensions. A_t is turbine gain which the value of it directly depends on MW power turbine and inversely depends on the MVA generator power. Electrical system is based on SWING equations and it contains moment synchronous effects. In order to reduce noise, a first-order filter has been contrived in a feedback loop. The model is presented in each unit ant the value of 300 MW and 50 HZ is defined for it.

Non-Minimum Phase Systems

Transfer functions that their zeros and poles is stable (all zeros and limited poles is placed on left side of imaginary axis) is transfer function of minimum phase and the system which have minimum phase functions is called minimum phase system.

If transfer function has one or more zero and unstable poles, it is non-minimum phase function. Also the systems which have non-minimum phase transfer functions (non-minimum phase systems with unstable zero) are called invariable functions. It is simple to show that amplitude characteristics of minimum and non-minimum phase transfer functions are equals. One of the other main features of non-minimum phase unstable systems is slower response than minimum phase systems, thus there need more control in comparison with common controllers.

Predictive Control

Predictive control or control based on the forecast model is not a special controller but it is a popular name of a group of computer control algorithm that has common features .a desirable predictive control is a controller in which M input is defined to predict future outputs and the optimum direction will be minimized in given time interval. It is obvious that this action needs a model in addition to the process in order to predict the output behavior of process by applying future input. Now the inputs must be obtained in a way that the outputs as possible as approach to the optimal direction. For this reason, a cost function should be defined and this optimization solution must be solved. One of the main parameters of predictive control is prediction horizon. Prediction horizon means the period numbers that controllers try to minimize the errors between output and main direction. Usually, there is a maximum value for prediction horizon and more increase of it has no positive effect on controller function. In practice, suitable value for prediction horizon is value that is near to rise time of process in open loop state. For process which has no at least phase and it has response with initial negative gradient, it is necessary that prediction horizon become large in a way that samples of outside with positive gradient will be appeared in cost function.

Designing of prediction controller based on the state space for system:

At first a model of system should be considered that is state space model of system. Also the direction which output should follows, must be determined. In addition, the provision of solution can be determined for prediction control which we suppose that the equitation has no provision.

$$\boldsymbol{x_m(k+1) = A_m x_m(k) + B_m u(k),}$$
$$\boldsymbol{y(k) = C_m x_m(k),}$$

At first, it is necessary to transfer equitation to ARIMAX form since it is based on U form.

$$\boldsymbol{x_m(k+1) - x_m(k) = A_m\big(x_m(k) - x_m(k-1)\big) + B_m\big(u(k) - u(k-1)\big)}$$

$$\overbrace{\begin{bmatrix}\Delta xm(k+1)\\ y(k+1)\end{bmatrix}}^{z(K+1)} = \overbrace{\begin{bmatrix}A_m & o_m^T\\ C_m A_m & 1\end{bmatrix}}^{A}\overbrace{\begin{bmatrix}\Delta xm(k)\\ y(k)\end{bmatrix}}^{x(k)} + \overbrace{\begin{bmatrix}B_m\\ C_m B_m\end{bmatrix}}^{B}\Delta uk \; y(k) = \overbrace{[o_{m}\,1]}^{C}\begin{bmatrix}\Delta xm(k)\\ y(k)\end{bmatrix},$$

After transfer to Arimax form, the solution will be change to prediction form:

$$x\left(k_i+1\,\middle|k_i\right)=Ax(K_i)+B\Delta u(k_i+1)$$

$$x\left(k_i+2\,\middle|k_i\right)=Ax\left(k_i+1\,\middle|k_i\right)+B\Delta u(k_i+1)=A^2x(K_i)+B\Delta u(k_i)+B\Delta u(k_i+1)$$

$$\mathrm{x}\left(k_i+N_p\,\middle|k_i\right)=A^{N_P}x(k_i)+A^{N_P-1}B\Delta u(k_i)+A^{N_P-2}B\Delta u(k_i+1)$$

$$+\cdots+A^{N_P-N_C}B\Delta u(k_i+N_C-1).$$

$$y\left(k_i+1\,\middle|k_i\right)=CAx(K_i)+CB\Delta u(k_i)$$

$$y\left(k_i+2\,\middle|k_i\right)=CA^2x(K_i)+CAB\Delta u(k_i)+CB\Delta u(k_i+1)$$

$$y\left(k_i+3\,\middle|k_i\right)=CA^3x(K_i)+CA^2B\Delta u(k_i)+CAB\Delta u(k_i+1)$$

$$+CB\Delta u(k_i+2)$$

$$\mathrm{y}\left(k_i+N_p\,\middle|k_i\right)=CA^{N_P}x(k_i)+CA^{N_P-1}B\Delta u(k_i)+CA^{N_P-2}B\Delta u(k_i+1)$$

$$+\cdots+CA^{N_P-N_C}B\Delta u(k_i+N_C-1).$$

$$x_m(k+1)=A_mx_m(k)+B_mu(k),$$

$$y(k)=C_mx_m(k),$$

$$x_m(k+1)-x_m(k)=A_m\big(x_m(k)-x_m(k-1)\big)+B_m\big(u(k)-u(k-1)\big)$$

The follow equitation is obtained by data:

$$Y=Fx(k_i)+\Phi\Delta U,$$

$$F=\begin{bmatrix}CA\\CA^2\\CA^3\\\vdots\\CA^{N_P}\end{bmatrix};\Phi=\begin{bmatrix}CB&0&0&\dots&0\\CAB&CB&0&\dots&0\\CA^2B&CAB&CB&\dots&0\\\vdots&&&&\\CA^{N_P-1}B&CA^{N_P-2}B&CA^{N_P-3}B&\dots&CA^{N_P-N_C}B\end{bmatrix}$$

Prediction horizon and control horizon are equal and the value of N is 30.

Thus the equitation is changed to prediction horizon. Using prediction controller can solve the solution.

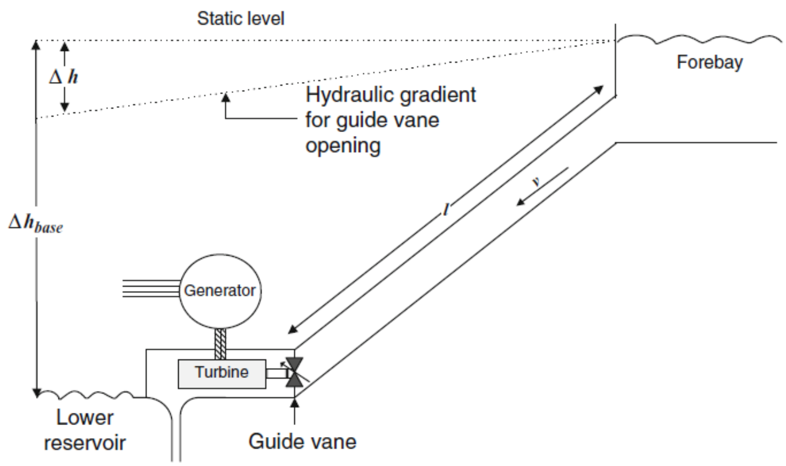


Figure 1: Schematic of a Pump Storage Plant

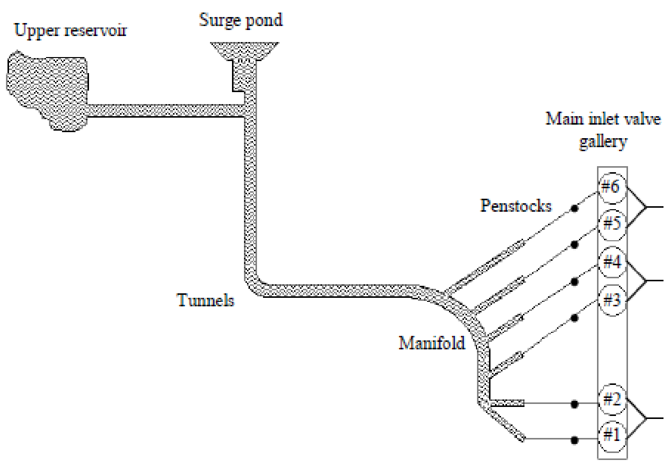


Figure 2: A Schematic of Pumped Hydroelectric Power Station

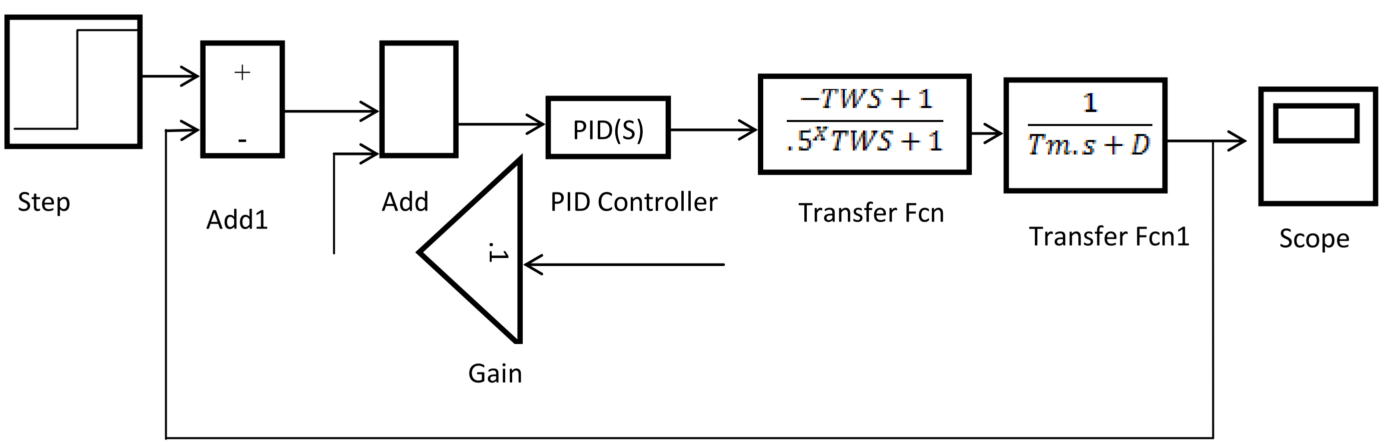


Figure 3: Simolink Model of Three Subsystem of Hydroelectric Plant

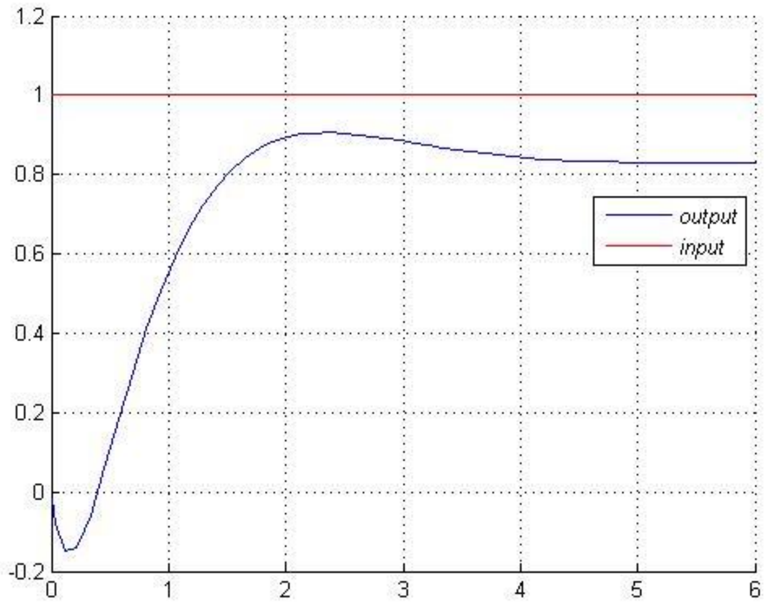


Figure 4: Response of the System to Input Step Without Controller

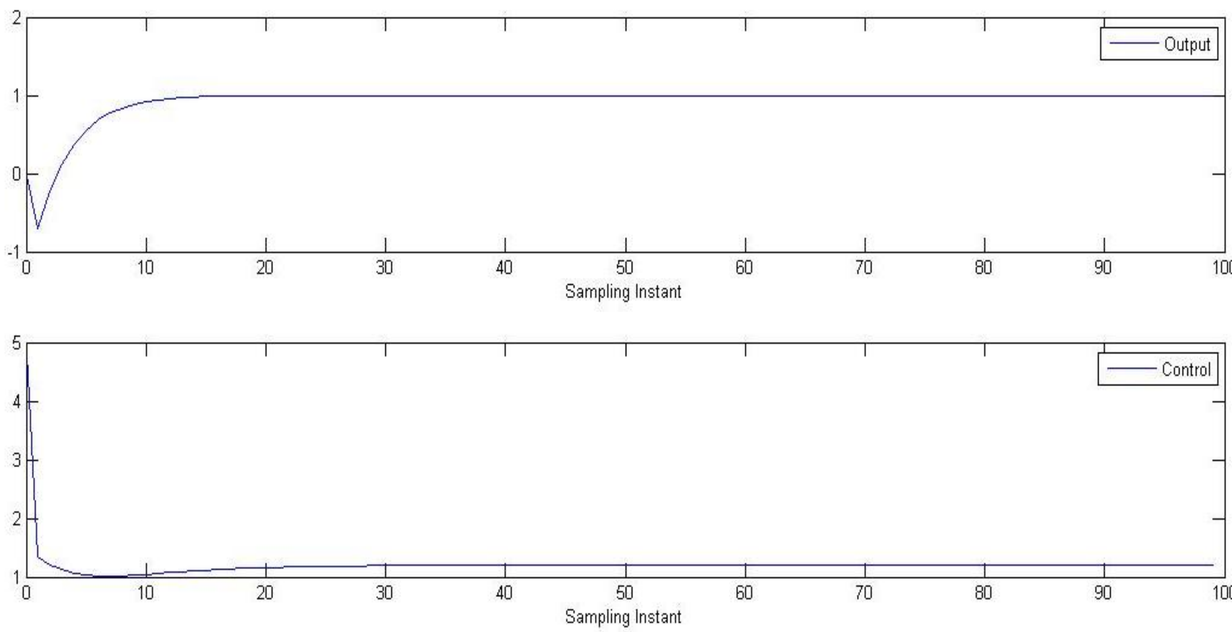


Figure 5: Response System Using Prediction Control

Table 1: Dinorwing Parameters Used in Simulations

Symbol	Name	Subsystem	Value
T_{wt}	Water starting time of the main tunnel	Hydraulic	0.388 s
T_w	Water starting time of a single penstock	Hydraulic	0.3066 s
T_{em}	Wave travel (propagation) time in the main tunnel	Hydraulic	0.642 s
T_e	Wave travel (propagation) time in one penstock	Hydraulic	0.148 s
A_t	Turbine gain	Hydraulic	Max 1.18 Avr. 1.12 Min 1.05
f_{pt}	Head loss coefficient in main tunnel	Hydraulic	0.00002873 m/(m^3/s)^2
f_{pn}	Head loss coefficient in penstock	Hydraulic	0.00052 m/(m^3/s)^2
Z_{0T}	Surge impedance main tunnel	Hydraulic	0.6044
Z_0	Surge impedance single penstock	Hydraulic	2.1
D_n	Turbine-damping coefficient	Hydraulic-electric	0.5
T_m	Machine starting time	Hydraulic-electric	7.99 s
K_D	The per-unit coefficient of damping torque	Electric	8.38
H	Turbine/generator inertia constant	Electric	3.995 J nm^2/MVA
K_s	Synchronising torque coefficient	Electric	0.7071
ω_0	Base rotor electrical speed	Electric	314.1592 rad/s

CONCLUSION

According to the results of tests, it is seen that prediction control has suitable results in comparison with traditional controllers.

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