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Turbine Penstock Model for analyzing variation of Length of penstock on mechanical power of Hydropower plant

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ABSTRACT

Modeling of hydraulic turbine and its governor system is essential for analyzing the system response during load change. Hydroelectric power plants with long conduits may have sever water hammer and governing stability problem. In this paper hydraulic turbine is modeled both with and without surge tank using penstock and turbine characteristics. Simulation model is developed using MATLAB SIMULINK. Dynamic response of system for load change and for penstock parameter variation is studied.

Keywords: Turbine- penstock, Surge tank, Mechanical power, Mathematical model.

INTRODUCTION

The regulating system of hydroelectric power plant is a complex system concerning hydraulic dynamics due to water hammer. The dynamic characteristics of hydraulic turbine and its governor affect the power system performance during occurrence of fault or load change. The non linear turbine model is suitable for studies of large variation in power output and frequency. An accurate modeling of system component such as turbine and its governing system helps to study dynamic response.

For stability of power system minimization of hydraulic transient is necessary. The hydro turbine has different features due to water inertia, its column compressibility and penstock-wall elasticity. The water inertia result in turbine flow lag behind the gate opening and elasticity effect leads to rise of traveling pressure waves in the system. The elastic affect is represented by a delay e^{-s2Te} in hydraulic system, where Tep is penstock elastic time and is given by,

$$T_{ep} = \frac{L}{\sqrt{\frac{a_g}{\alpha}}}$$

When load change occur change in mechanical power is occur due to sudden opening of gate or due to sudden flow of water in the penstock system effect on the mechanical power is reduce by changing parameter of the penstock and also by adding surge tank in the system. In this paper the effect has been analyzed by developing the hydraulic turbine penstock transfer function.

The MATLAB Simulink and programming provides a relatively easy to use, versatile and powerful simulation environment for the dynamic research on hydro plants. The linear model of hydraulic turbine and non elastic water hammer effect of pressure water supply penstock are considered in the modeling.

mathematical model for turbine -penstock

Basic hydro power plant scheme is shown in Fig 1

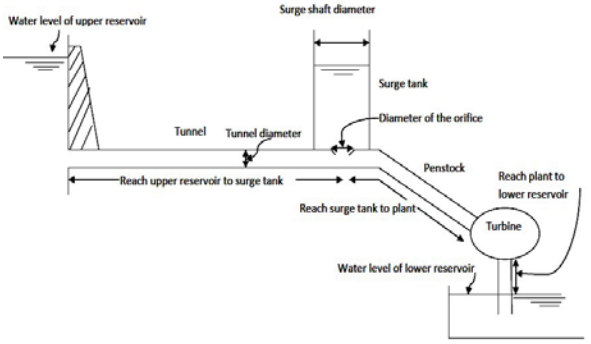

Figure 1: Layout of Power Plant

Water from the reservoir enters the tunnel and flows through the penstock and then reached the hydro turbine inlet gate then it flows into scroll casing which distribute water around the runner blades. The runner is mounted on common shaft with electric generator. The water flows in to the turbine is regulated by means of gates opened and closed by an oil hydro servomechanism controlled by the governor the governor acts whenever there is load change occur and mismatch generated

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between torque developed and electrical demand on the generator.

The linear model of the turbine is written as follows:

$$\Delta q=a_{11}\Delta h+a_{12}\Delta z+a_{13}\Delta\omega \tag{1}$$

$$\Delta p=a_{21}\Delta h+a_{22}\Delta z+a_{23}\Delta\omega \tag{2}$$

The turbine constant aij are the partial derivatives of flow (Δq) and power (Δp) with respect to (Δh), gate position (Δz) and turbine speed (Δω). aij is depend on the turbine loading and can be evaluated from the characteristic of turbine at the operating point. These values have to be measured accurately or taking from turbine model tests. The basic idea is to define for each hydraulic component an equivalent electric component.

The penstock of hydropower plant is considered as a hydraulic transmission line. This hydraulic transmission line is considered to terminate by using an open circuit at the turbine and short circuit at the reservoir.

The basic hydraulic equations, which determine the flow of a compressible fluid through a uniform elastic pipe, with friction neglected is given by:

$$H_1=H_2\cosh(T_e s)+Q_2 Z_p\sinh(T_e s) \tag{3}$$

$$Q_1=Q_2\cosh(T_e s)+\frac{1}{Z_p}\sinh(T_e s) \tag{4}$$

Where, the subscript 1 and 2 refer to the condition at the end of the conduit of upstream and downstream.

Here in the study, firstly tunnel and surge tank effect have not been considered after that considering tunnel and surge tank effect modeling is done. The penstock transfer functions relating to the incremental head and flow in terms of complex frequency can be written as follow:

$$\frac{\Delta H(s)}{\Delta Q(s)}=-Z_p\tanh(sTe+F) \tag{5}$$

This relation depends only on the length of penstock and independent of turbine's characteristics. An irrational Equation (6) of penstock-turbine with elastic water column effect derived from basic Equations relating to the ratio of incremental torque to changes in guide vane position is given as:

$$\frac{\Delta P_m(s)}{\Delta G(s)}=\frac{a_{23}+(a_{11}a_{23}-a_{21}a_{13})Z_p\tanh(sT_e+F)}{1+a_{11}Z_p\tanh(sT_e+F)} \tag{6}$$

Assuming an ideal model and neglecting the hydraulic friction losses, equation (6) can be reduced as:

$$\frac{\Delta P_m(s)}{\Delta G(s)}=\frac{1-Z_p\tanh(sT_e)}{1+\frac{1}{2}Z_p\tanh(sT_e)} \tag{7}$$

This equation is without considering surge tank and tunnel effect.

When surge tank effect is considered equation become

$$\frac{\Delta P_m(s)}{\Delta G(s)}=\frac{1+\frac{F_1(s)F_2(s)}{Z_p^2}-[F_1(s)+F_2(s)]}{1+\frac{F_1(s)F_2(s)}{Z_p^2}-0.5[F_1(s)+F_2(s)]} \tag{8}$$

Where

$$F_1(s)=\frac{\phi_c+sT_{wc}}{1+sT_s\phi_c+s^2T_{wc}T_s}$$

F₂(s)= Zptanh(TepS)

Where,

Tep=Te is penstock elasticit time;

ϕ_c is tunnel friction constant;

ΔPm is the mechanical power generated by the tubine;

ΔG is the gate opening;

Z_p is the normalized hydraulic impedance of penstock and given by Twp/Tep , Twp is the water starting time in the penstock and is given by (LQ)/(AagH);

α is a constant & is given by:

$$\rho a_g\left(\frac{1}{K}+\frac{D}{Ef}\right)$$

L is the length of the penstock (m);

Q is the flow rate in the penstock (m^3/sec)

A is the cross sectional area of the penstock (m^2)

H is the head (m);

ag is acceleration due to gravity (m/sec^2);

ρ is the density of water (kg/m^3);

K is the Bulk modulus of compressed water (N/m^2);

E is the Young's modulus of elasticity of penstock material, (N/m^2);

f is the thickness of the penstock (m).

Methodology

It is difficult to use Equation () in its present form for system stability studies. Therefore for an ideal lossless turbine at full load : a_{11}=0.5,a_{13}=1.0, a_{21}=1.5, a_{23}=1.0 and F=0, Equation (6) is reduced to Equation(7).

It is difficult to use Equation (6) in its present form for system stability studies. It is often helpful to have a finite dimensional approximation. The representation of Equation (6) could alternatively be approximated as lumped parameter equivalent. Expanding the transfer function into a general n^{th} order model by using the relationship:

$$\tanh(sT_e)=\frac{1-e^{-2sTep}}{1+e^{-2sT_{ep}}} \tag{9}$$

leads to the finite approximation:

$$\tanh(sT_e)=\frac{sT_{ep}\prod_{n=1}^{n=\infty}\left[1+\left(\frac{sT_{ep}}{n\pi}\right)^2\right]}{\prod_{n=1}^{n=\infty}\left[1+\left(\frac{2sT_{ep}}{(2n-1)\pi}\right)^2\right]} \tag{10}$$

For n=1 (i.e. with the fundamental component of the column represented), the Equation (10) is used in Equation (7) and (8) to derive the rational transfer function which is the form of containing term Tep and Twp for only turbine penstock model and for turbine penstock and surge tank model is is also containing Twc (tunnel water starting time) and Ts (surge tank storage constant).

To ensure stable frequency regulation under isolated condition, hydro turbine governors are designed to have relatively large transient droop with long resetting time because a change in gate position at the penstock may produce short term power change. The block diagram of a generating unit with hydraulic turbine is shown in fig 2.

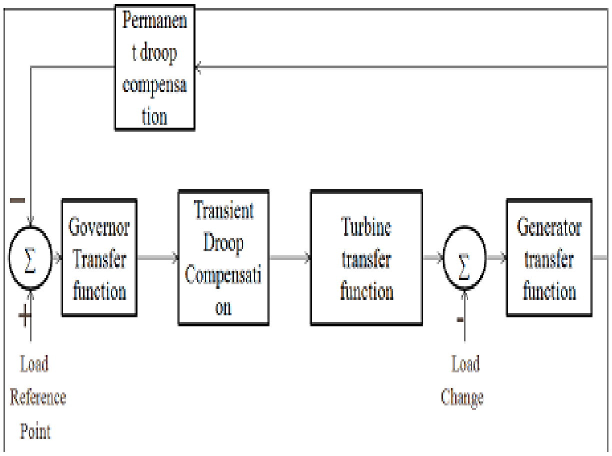

Figure 2: Block Diagram of Hydraulic System

Result and discussion

The static and dynamic behavior of hydropower plant must be known to understand the characteristics. Here in this paper static behavior is studied. The static behavior is studied by the relationship between the steady state value of gate position and turbine developed power. The hydraulic turbine generating unit was in standstill and ready to start up as initial. The simulation start at first then the turbine generating unit received signal after that.

Fig.3 shows the effect of water hammer on mechanical power with change in the length of penstock without considering the surge tank effect. Due to sudden opening of the gate the water will flow towards the turbine blade with a force this force is called water hammer. Due to water hammer there will be production of pressure wave effect on the generation of mechanical power. This change in mechanical power also affects the output of generator Fig4. shows change of output of generator.

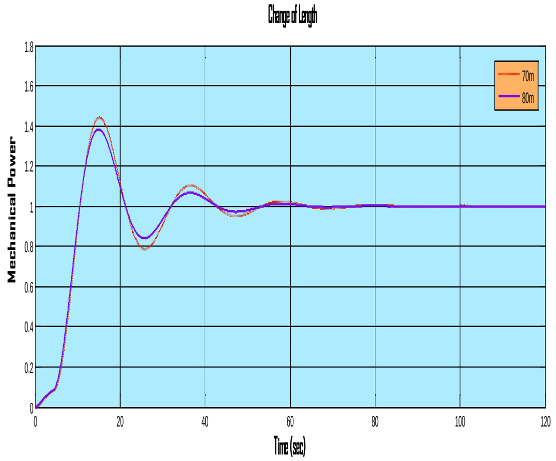

Figure 3: Effect of water hammer with change in length without surge tank

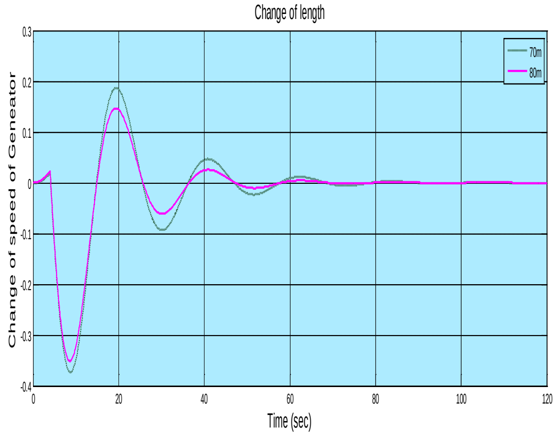

Figure 4: Effect of water hammer on change of speed of generator without surge tank

Fig 5. Shows the effect of change of length of penstock parameter when surge tank and tunnel effect is considered.

Fig 6. Shows the effect on the output of generator when surge tank is considered.

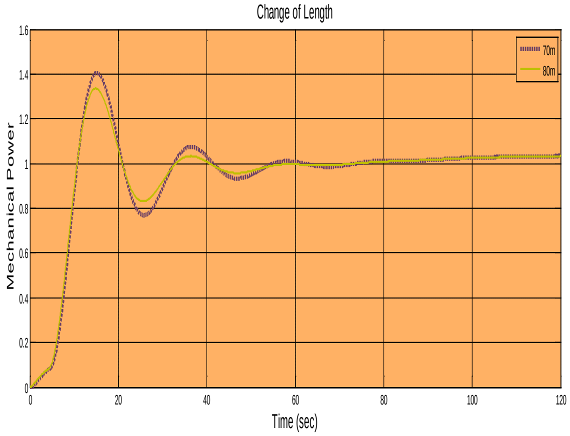

Figure 5: Effect of water hammer on Mechanical power with surge tank

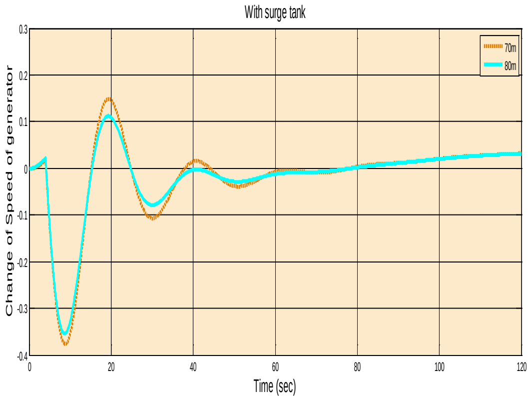

Figure 6: Effect of water hammer on change of speed of generator without surge tank

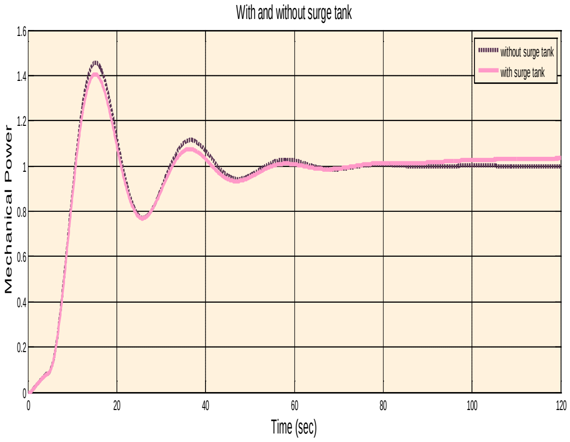

Figure 7: Effect of water hammer on mechanical power with and without surge tank

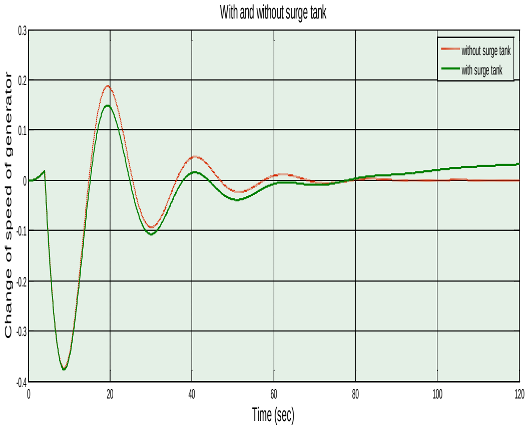

Figure 8: Effect of water hammer on change of speed of generator with and without surge tank

Conclusion

In the present study, a turbine penstock transfer function has been developed and the analysis of transfer function has been done with variation in length of penstock. And then turbine penstock transfer function with surge tank and tunnel has been developed and the analysis of transfer function is done with variation in length of penstock.

The simulation model and programming is done in MATLAB. The result has been obtain of different lengths. These results shows that with increase in length of the penstock transient developed are less as well magnitude of water hammer is reducing.

Also with surge tank magnitude of water hammer is reduce effectively with lesser length of penstock.It is hence concluded

That for a particular head an optimal length of the penstock must be considered for reducing the effect of the water hammer on the mechanical power. With surge tank at lesser length of penstock magnitude of water hammer is reduced effectively.

APPENDIX

Parameter of the system studied are as follows: Rp=0.05 T_G=0.2 sec, M=6.0 sec, R_T=0.38, T_R=5.0sec, D=1.0, H=40m, Q=1.5m^3/sec, E=48x10^9N/m2, K=2.2x10^9N/m^2, ρ=997.296kg/m^3

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