Simulation of Turbine Governing in Hydro Power Plants

[O.P.Rahi, Sanjeev Kumar Gagrai and Sumit Kumar Rawat]

Abstract—**Power system performance is affected by dynamic characteristics of hydraulic governor turbines during and following any disturbance, such as occurrence of a fault, loss of a transmission line or a rapid change of load. Accurate modelling of hydraulic system is essential to characterize and diagnose the system response. In this paper the mathematical modelling and simulation of the hydraulic turbine and governing system by using MATLab SISOTOOL has been presented. In addition, stability of turbine has been simulated in MATLab environment and has been shown by various stability plots like, Bode plot, root locus plot, and Nyquist plot**

Keywords—**Governor, sisotool, turbine, zozzle, stability plot**

I. Introduction

Hydraulic turbines extract energy from water which has a high head. The use of hydraulic turbines for the generation of power has a very strong historical tradition. The first truly effective inward flow reaction turbine was developed and tested by Francis and his collaborators around 1850 in Lowell, Massachusetts. Modern Francis turbine developed into very different form that from the original, but they all retain the concept of radial inward flow. Governing characteristics of such turbines makes hydro power most suitable for peak demand management due to their quick response as compared to thermal power plants. In this paper, modeling has been presented assuming the turbines to be inelastic. Also, hydraulic resistance has been neglected. Alternators of the grid cause deviation between turbine power output and the load. For a load decrease the excess power accelerates the rotating masses of the unit according to a higher rotational speed.

II. Turbine Governing Requirements

To keep the rotational speed stable and constant of the turbine – generator unit at any grid load and prevailing conditions in the water conduit. At load rejections or emergency stops the turbine admission have to be closed down according to acceptable limits of the rotational speed rise of the unit and the pressure rise in the water conduit.

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Alternators of the grid cause deviation between turbine power output and the load. For a load decrease the excess power accelerates the rotating masses of the unit according to a higher rotational speed. The following governor reduction of the turbine admission means deceleration of the water masses in the conduit and a corresponding pressure rise.

To keep the rise of the rotational speed below a prescribed limit at load rejection, the admission closing rate must be equal to or higher than a certain value. For the pressure rise in the water conduit the condition is opposite, e.g., the closing rate of the admission must be equal to or lower than a certain value to keep the pressure rise as low as prescribed value.

For power plants where these two demands are not fulfilled by one single control, the governors are provided with dual control functions, one for controlling the rotational speed rise and further for controlling the pressure rise. This is normal for high head Pelton and Francis turbines.

A. *Governing Principle for Pelton turbines*

To set the closing rate of the needle control of the nozzles to a value that satisfies the prescribed pressure rise and to bend the jet flow temporarily away from the runner by a deflector so that the speed rise does not exceed the accepted level.

B. *Governing Principle for Francis turbines*

To set the closing rate of the guide vanes opening to the value, that satisfies the rotational speed rise limits and to divert as much of the discharge through a controlled by-pass valve so that the pressure rise in the conduit is kept below the prescribed level.

III. Turbine Modeling

The hydraulic turbine and water column in transient performance study is usually based on the certain assumptions:

The hydraulic resistance is neglected, the penstock pipes are considered as inelastic and water as incompressible, the velocity of water in penstock varies directly with gate opening, and the turbine output power is proportional to the product of head and velocity of flow.

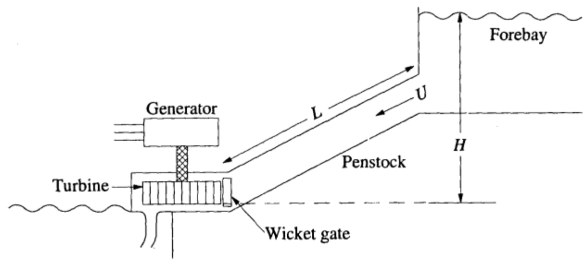

Fig.1 Schematic Diagram of Hydroelectric Plant

IV. Block Diagram

The three main parts of the modelled block diagram are speed governor, turbine and generator or load as shown in Fig. 2 given below:

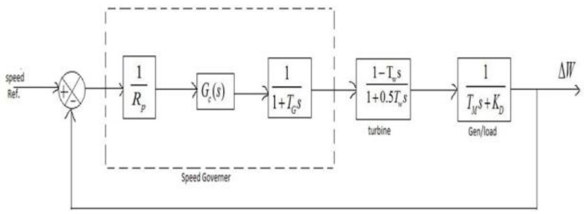

Fig. 2 Model of the Speed Governing System

Constants used in the block diagram are as following:
$G_C(s)$ = Transient droop compensator.
T_W= Water starting time.
T_G= Wicket gate opening time.
R_P= Permanent droop.
K_D= Derivative constant.
T_M= Mechanical time constant.

Water Starting Time (T_W)

It is the time required for the head H_O to accelerate the water in the penstock from standstill to velocity U_O. It lies between 0.5 to 4 sec.

Permanent Droop (R_P)

It is defined as the percentage change in frequency for a 100% change of power output from the unit. It is adjustable and chosen in the range of 0-6%.

A. *Reduced block diagram*

Fig. 3 given next is the reduced block diagram of model of the speed governing system shown in Fig. 2.

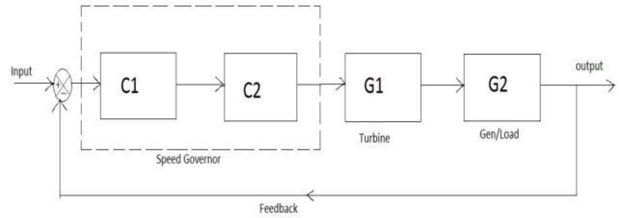

Fig. 3 Reduced Block Diagram

Where in the Fig. 3 above,

$$C1 = \frac{1+T_R S}{1+(\frac{R_T}{R_P})} \qquad C2 = \frac{R_P^{-1}}{1+T_G S}$$

$$G1 = \frac{1-T_W s}{1+0.5T_W s} \qquad G2 = \frac{1}{T_M s + K_D}$$

V. SISO Design Tool

The SISO design tool facilitates the design of compensators for single-input, single-output feedback loops. Following tasks have been performed by the SISOTOOL:

- Manipulate closed-loop dynamics using root locus techniques.
- Shape open-loop Bode responses.
- Add compensator poles and zeros.
- Inspect closed-loop responses (using the LTI Viewer).
- Adjust phase and gain margins.
- Convert models between discrete and continuous time.
- Automate compensator design.

VI. Description of Control Architecture

MATLab Sisotool opens a SISO Design GUI for interactive compensator design. This GUI allows designer to design a single-input/single-output (SISO) compensator using root locus, Bode diagram, Nichols and Nyquist techniques. One can also automatically design a compensator using this GUI.

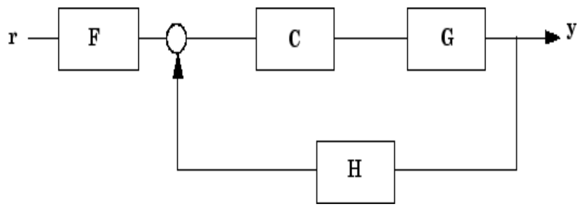

Fig.4 Default Control Architecture

VII. Results and Discussions

The following results have been obtained after simulation of the turbine with reference to the operating environment.

A. *Root locus plot*

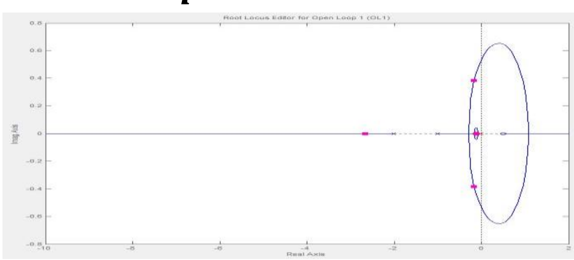

Fig.5 Root locus Plot

B. *Bode plot*

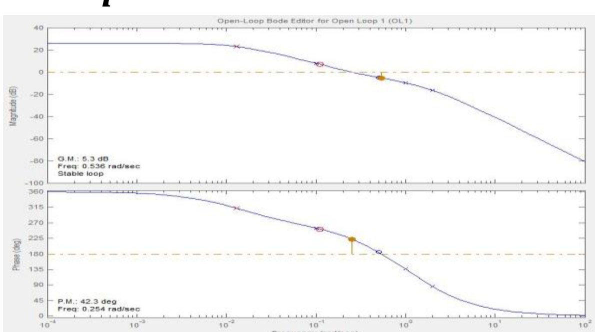

Fig.6 Bode Plot

C. *Nyquist plot*

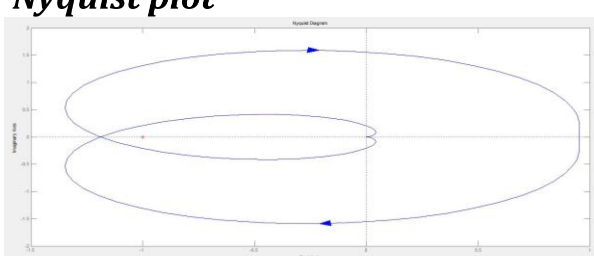

Fig. 7 Nyquist Plot

VII. Conclusion

Hydro turbines are nonlinear and have time varying parameters. The hydrodynamics of the tunnel, penstock and turbine are complex due to nonlinear relationship, which exist between water velocity, turbine inlet pressure and developed power. The performance of hydro turbine is strongly influenced by characteristics of water inertia, water compressibility and penstock wall elasticity. The dynamic characteristics of hydro turbine power depend on changes in the set point and load disturbances.

In this research work, modelling and simulation of hydro turbine has been attempted with a new tool, i.e., SISOTOOL using MATLab Version 7.9(a). After mathematical modeling, stability of turbine has been simulated and has been shown by various plots like, bode plot, root locus plot and Nyquist plot.

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