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Simplified modeling of hydraulic governor-turbine for stable operation under operating conditions

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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, a rapid change of load or hydraulic transients. Accurate modeling of hydraulic governor-turbines is essential to characterize and diagnose the system response during an emergency.

In this paper, the identification/development and implementation of hydraulic systems in power plants via literature survey and computer based simulations have been described and it has been analyzed with comparing different models.

This article examines the responses of different models through simulation in MATLAB/SIMULINK. The results obtained provide an insight into the interaction between electrical and hydraulic system of hydro power plant governed by different governor settings, so that the system may remain unaffected during any disturbance.

Introduction

The demand on modeling requirements for power system components has become more onerous due to the increasing complexity of power system networks Power system components such as the governor, turbine and generator need to be represented by a detailed model.

Classical representations of a hydraulic system, which assume an ideal lossless turbine, are limited to small perturbations around an initial operating point. They depict the actual characteristics at only very low frequencies.

For large signal stability studies, the classical model does not capture the dynamic behavior accurately and leads to erroneous responses.

Moreover, conventional governor tuning is performed based on the classical model, hence the optimal and stable governor settings obtained by the classical model differ substantially from the settings obtained from comprehensive models.

It is thus vital to represent the hydraulic model in detail in order to determine the practical dynamic responses as accurately as possible for a wide variety of system studies.

Figure 2 shows the systematic diagram of hydro power plant.

Assumptions:

The following assumptions have been taken.

- Incompressible fluid
- Penstock treated as a single static element
- Rigid penstock
- Density of fluid constant
- Constant surface area of penstock = surface area of inflow tunnel = surface area of outflow tunnel.
- Free outflow downstream (hence, no water hammer effect, Qin = Qout)

Laminar flow

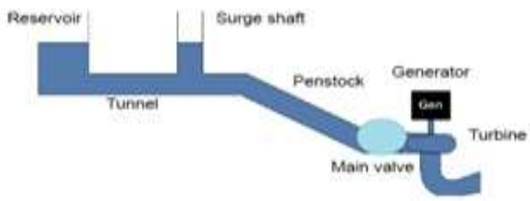

Figure1: Systematic Diagram of Hydro Power Plant

Mathematical representations of hydraulic system:

In this section, a mathematical representation of a hydraulic system, including both turbine-penstock and the governing system, is introduced.

Figure 2 shows a general layout of Hydro power Plant. The primary source for the electrical power provided by utilities is the kinetic energy of water which is converted into mechanical energy by the prime movers.

The electrical energy to be supplied to the end users is then transformed from mechanical energy by the synchronous generators. The speed governing system adjusts the generator speed based on the input signals of the deviations of both system frequency and interchanged power with respect to the reference settings. This is to ensure that the generator operates at or near nominal speed at all times.

➢ Steady state:

K.E. = P.E.

=> v = (2gh) ^0.5

➢ Transient state:

F=-dp/dt

=> h = hin - (L/gA) dQ/dt

➢ Losses in head due to Drag forces

Losses are directly proportional to Q^2

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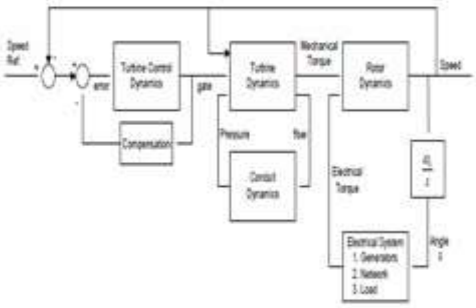
Hydraulic turbine model:



The dynamic performance of a hydraulic system is affected by the turbine-penstock characteristics which are determined by water inertia, water compressibility, and pipe wall elasticity in the penstock. The effects of each component need to be modeled carefully to study their impact on the system dynamic performance. For example, water inertia causes changes in turbine flow to lag behind changes in turbine gate opening, and the travelling waves of pressure and flow involving a compressible fluid in an elastic pipe lead to the water hammer phenomenon.

Realistic nonlinear turbine-penstock model

An IEEE working group [6] and Kundur [7] discussed the model for a detailed representation of hydraulic dynamics in the penstock. The terms for the physical design of the plant describe the water starting time constant for rated conditions when characteristics equations are normalized using the per unit system [4]

A hydro power plant can be represented by the following subsystems as per figure 2:

- Penstock including any surge tank hydraulic machine
- Speed governor
- Generator and the electrical power system
- Tailrace

Hydraulic turbine model:

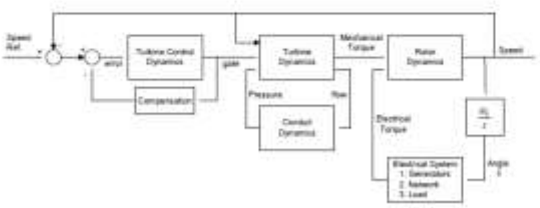


Figure2: Block Diagram of Hydro Power Plant

Hydro Power Plant:

The following three hydro power plant models with different characteristics and limitations are as follows:

Model	Description
1.	Classical Penstock-Turbine Model for ideal lossless Hydraulic Turbine
2.	Turbine Model with Surge Tank assuming Elastic Water Column in Penstock and Inelastic Water Column in Tunnel
3.	Turbine Model with Surge Tank including Elastic Water Column in Penstock and turbine coefficients

Classical Penstock-Turbine Model for ideal lossless Hydraulic Turbine

The classical penstock-turbine model is widely used in relevant literature related to power system stability and in standard model libraries in power system analysis software. This is the most simplified model.

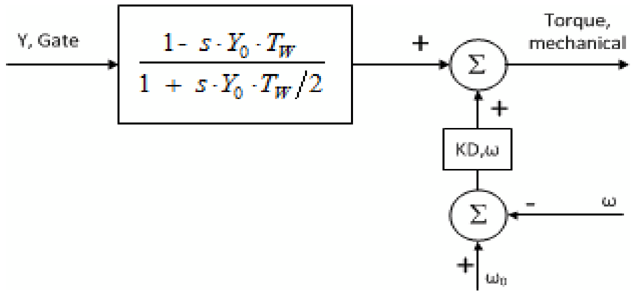


Figure3: Classical Penstock-Turbine Model for ideal lossless Hydraulic Turbine [3]

Turbine Model with surge tank assuming Elastic Water Column in Penstock and Inelastic Water Column in Upstream Tunnel:

The model includes elastic water column in penstock and inelastic water column in upstream tunnel. The nonlinear characteristics of hydraulic turbine are not considered in this model

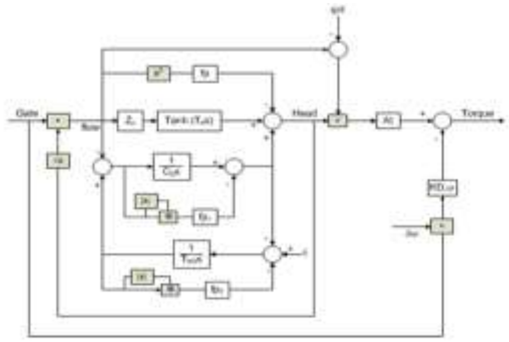


Figure 4: Turbine Model with surge tank assuming Elastic Water Column in Penstock and Inelastic Water Column in Upstream Tunnel [2]

Turbine Model with surge tank including Elastic Water Column in Penstock and Turbine Coefficients:

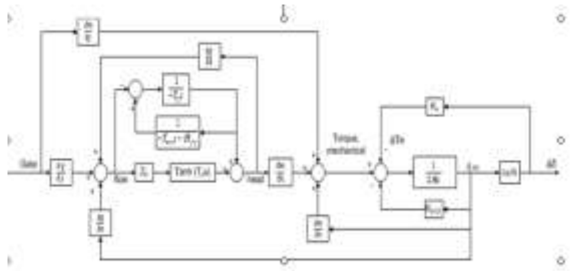


Figure 5: Turbine Model with surge tank including Elastic Water Column in Penstock and Turbine Coefficients [1]

Simulation Analysis & Graphs - Case I

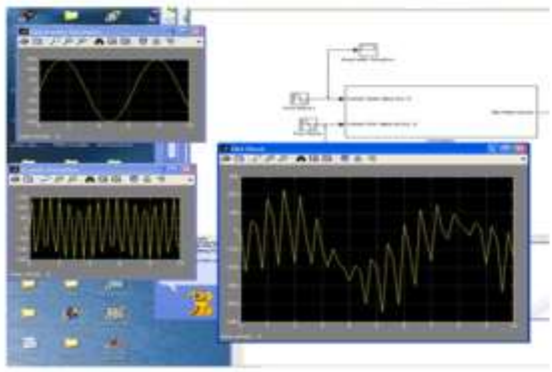


Figure 6: Simulation analysis of Classical Penstock-Turbine Model for ideal lossless Hydraulic Turbine

Simulation Analysis & Graphs - Case II

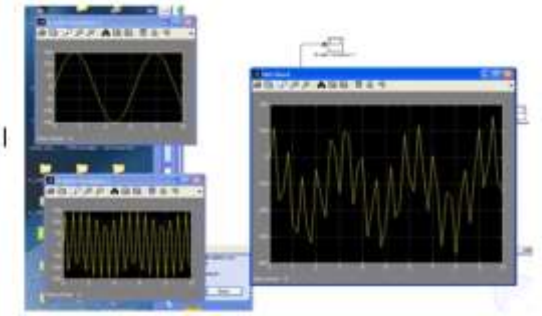


Figure 7: Simulation analysis of Turbine Model with Surge Tank assuming Elastic Water Column in Penstock and Inelastic Water Column in Tunnel

Simulation analysis and graph- case -III

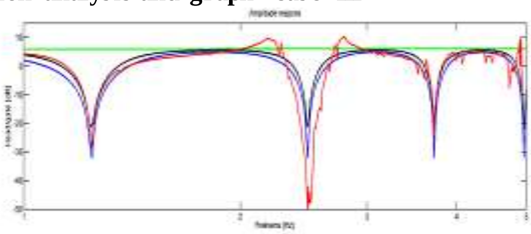


Figure 8: Simulation analysis of Turbine Model with Surge Tank including Elastic Water Column in Penstock and turbine coefficients

Results & Conclusions:

- The Classical model fails to give accurate results, and does not represent the (possible) interaction between the electric side and the hydraulic side.
- The models including the water hammer effect and surge tank gives good correspondence simulations (believed to have the highest accuracy and best representation of actual conditions)
- Model 2 shows best performance at lower frequencies (<1 Hz), while model 3 shows best performance at higher frequencies (> 1 Hz).
- Proper representation of the (possible) interaction between the electrical system and the hydraulic system is achieved by using model 3 – i.e. model which includes the turbine coefficients

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