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MODELS OF HYDRAULIC SYSTEMS IN HYDRO POWER PLANTS

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- Problem
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- Hydro Power Plants – general layout, modelling and models
- Simulation tools
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About the work

- This work has been carried out follows:
  - As part of an internal project at SINTEF Energy Research
  - As part of Project and Master-thesis work at NTNU, Department of Electric Power Engineering:
    - Alexandra Lucero: autumn 2009 (Project) - spring 2010 (Master)
    - Ola Helle: autumn 2010 (Project) - spring 2011 (Master)
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Background

- Small-signal (or small-disturbance) problems in interconnected power systems involve rotor angle stability, such as:
  - Electromechanical (rotor angle) oscillations of a generator swinging against the rest of the power system (local plant mode osc)
  - Oscillations of a group of generators swinging against another group of generators (interarea mode oscillations)
  - Typical frequency range: 0.3 – 2.5 Hz
- Hydraulic systems in hydro power plants may show oscillatory behaviour with resonant frequencies in the same range - typically elastic mode "waterhammer" oscillations for medium to large head plants

Problem

- **Based on the above observations:**
  - Can interaction occur between the electric power system and the hydraulic system for this frequency range?
  - Which possible consequences can such interaction have?
  - How to mitigate such interaction?

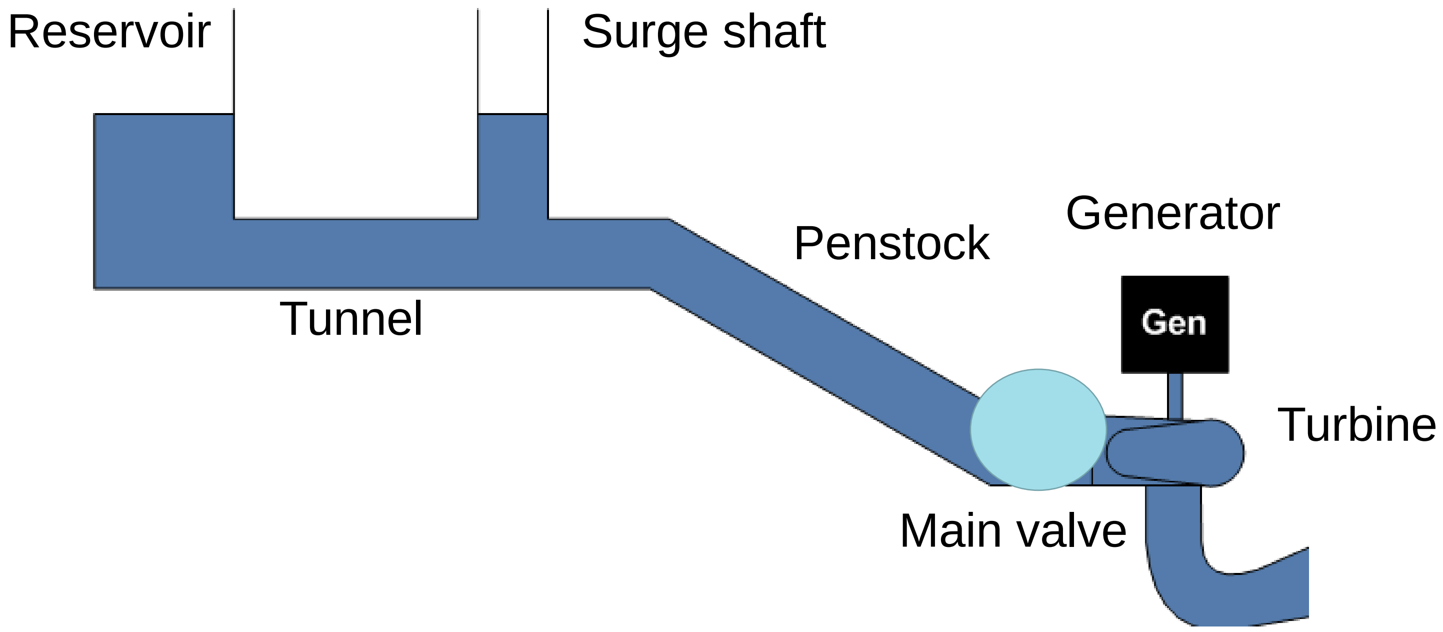
Objective

- To identify and/or develop, analyse, implement and test models of hydraulic systems in power plants via literature survey and computer based simulations

- Identify the <u>characteristics</u> necessary to be met on the models in order to recreate the (possible) low-frequency interaction between the electric power system and the hydraulic system

- The work should be limited to turbines of type Francis

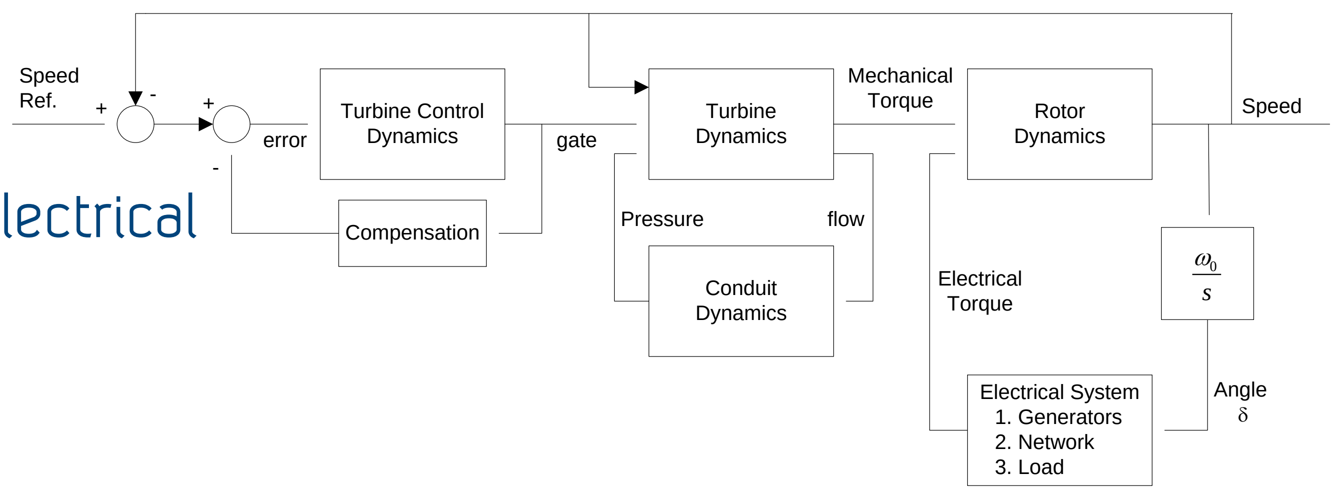
Hydro Power Plants – General layout



Hydro Power Plants - Modelling

A hydro power plant can be represented by the following subsystems:

- penstock including any surge tank
- hydraulic machine
- speed governor
- generator and the electrical power system
- tailrace



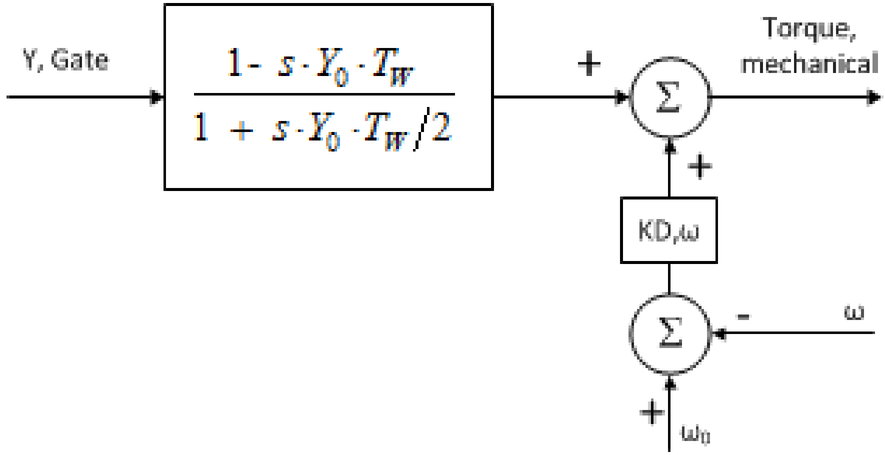
Hydro Power Plants - Models

The following three hydro plant models with different characteristics and limitations, are discussed in this presentation:

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

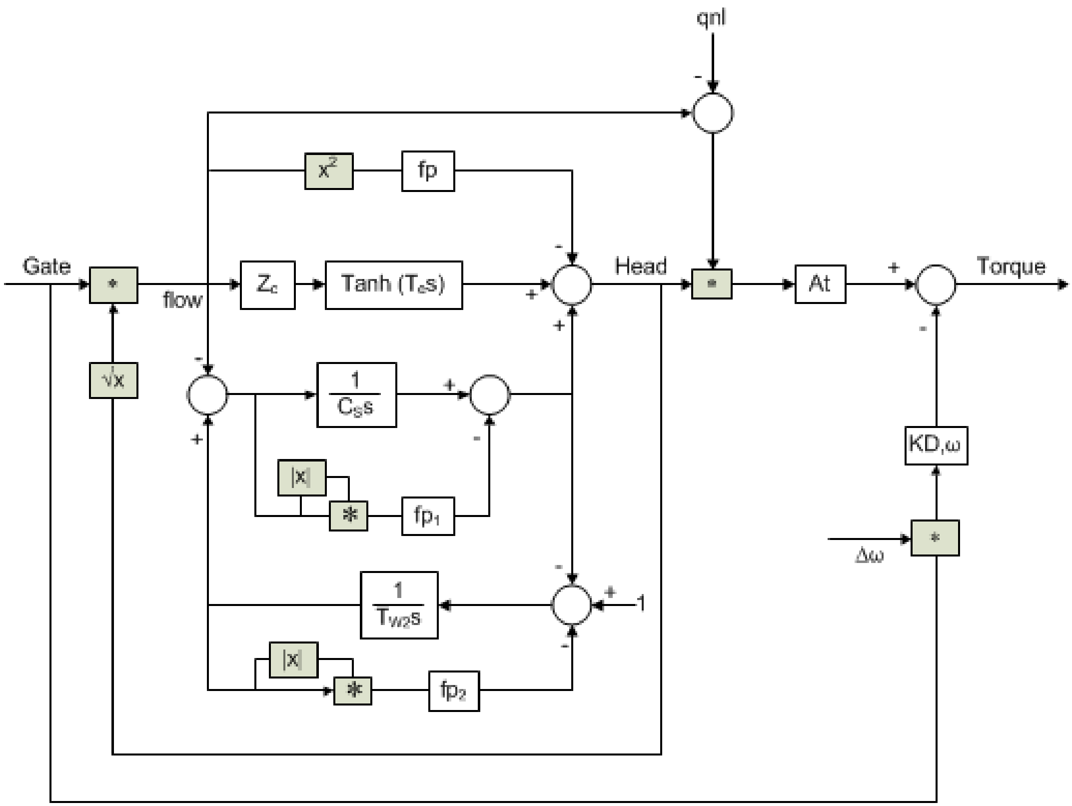
Classical Penstock-Turbine Model for ideal lossless Hydraulic Turbine

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.



Ref. Machowski, J., J. Bialek, and D.J. Bumby, *Power System Dynamics: Stability and Control*.

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

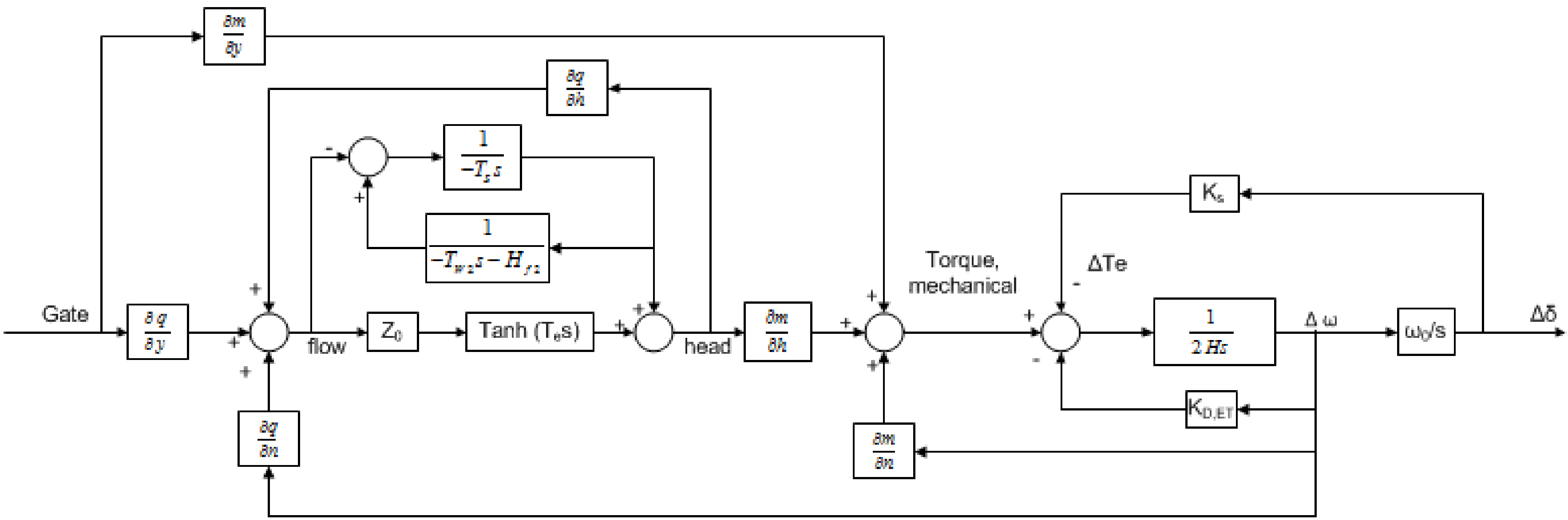


The model includes elastic water column in penstock and inelastic water column in upstream tunnel. The nonlinear characteristics of hydraulic turbine are not considered in this model.

Ref. *Hydraulic turbine and turbine control models for system dynamic studies. Power Systems*, IEEE Transactions on, 1992

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

This model includes the hydraulic turbine coefficients extracted from the Hill Charts. (See e.g. Ref. [4]).

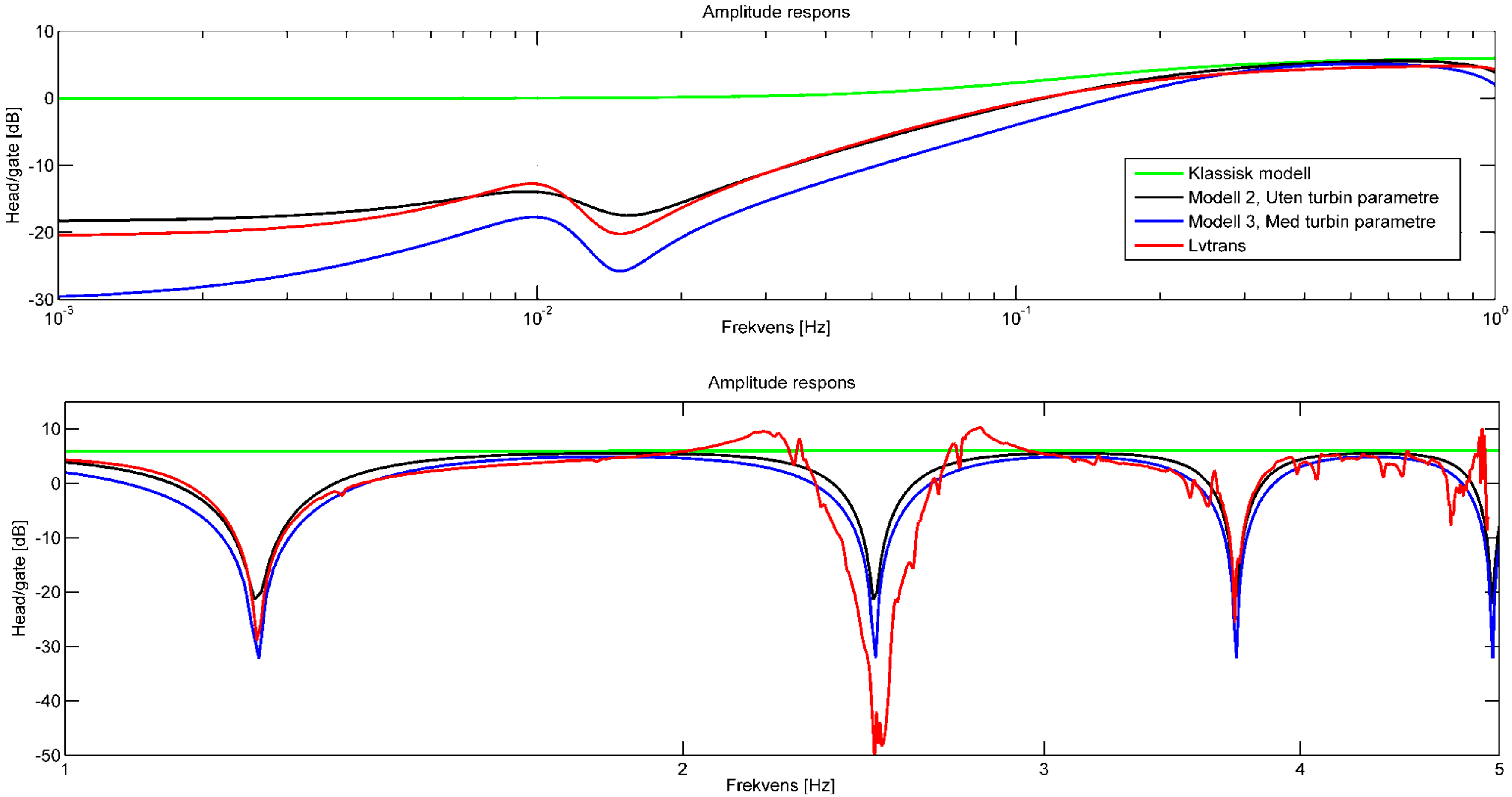


Ref. Hongqing, F., et al., *Basic Modeling and Simulation Tool for Analysis of Hydraulic Transients in Hydroelectric Power Plants*. Energy Conversion, IEEE Transactions on, 2008.

Simulation tools

- **LVTrans**
  - Tool for modelling and simulation of hydro Power Plants
  - Developed at SINTEF Energy Research
- **SIMPOW®**
  - Power system simulation and analysis tool
  - Developed by STRI (originally by ABB)
- **Matlab/SIMULINK**
  - MATLAB® is a high-level language for technical computing. The uses include math and computation, modeling, simulations, etc.

Simulations - 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 with LVTrans 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

Further Work

- Improve the model including the turbine parameters - **model 3** - for lower frequencies, as well as for the resonance peaks at 2.2 and 2.78 Hz
- Integrate the hydraulic system models into a dynamic power system simulation model with the aim to study possible low-frequency interaction
- Measurements in real-life power plant(s)
- Identify consequences of such (possible) interaction phenomena in hydro power plants

References

[1] Machowski, J., J. Bialek, and D.J. Bumby, *Power System Dynamics: Stability and Control*. 2nd ed2008: John Wiley & Sons, Ltd.

[2] *Hydraulic turbine and turbine control models for system dynamic studies.* Power Systems, IEEE Transactions on, 1992. **7**(1): p. 167-179.

[3] Hongqing, F., et al., *Basic Modeling and Simulation Tool for Analysis of Hydraulic Transients in Hydroelectric Power Plants.* Energy Conversion, IEEE Transactions on, 2008. **23**(3): p. 834-841.

[4] J. Fraile-Ardanuy et al., *Speed Optimisation Module of a Hydraulic Francis turbine based on Artificial Neural Networks.* Applications to the Dynamic Analysis and Control of an Adjustable Speed Hydro Plant, IEEE 2006.