Using Mathematical Models to Determine the Performance Characteristics of Hydrokinetic Turbines to Investigate Their Suitability as Pressure Reduction Tools for the Scottish Water Supply Network.

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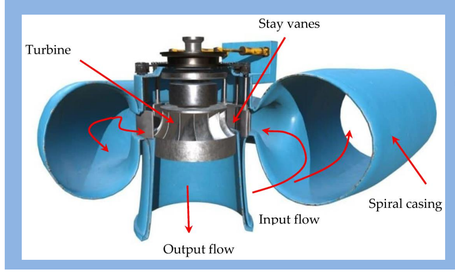
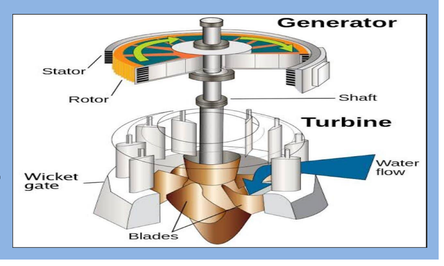
Goals:

- **Investigate a hydrokinetic turbine system that controls pressure in the Scottish water network (SWN), replacing pressure reduction valves (PRVs).**
  - Must be efficient and operate safely in the varying conditions that are present in the SWN.
  - It must control pressure to satisfy the requirements being fulfilled by the PRVs it is replacing.
- **Identified turbine technology for investigation:**



< Francis Turbine

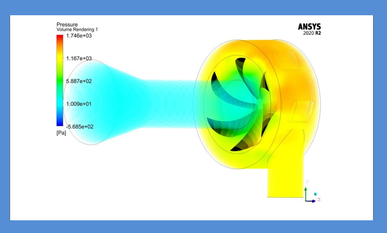
Kaplan turbine >



Solutions:

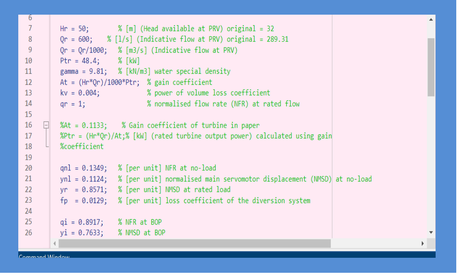
- **Model a hydraulic system, and the performance of turbines.**
  - For use in a control system.
  - To investigate the effectiveness/suitability of different turbine technologies.
- **How to model/compare turbines?**

Real life testing – expensive, time consuming, accurate



CFD – inexpensive, time consuming, accurate

Mathematical model of turbine – inexpensive, fast, less accurate.



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Hr = 50;          % [m] (Head available at PRV) original = 32
Qr = 600;     % [l/s] (Indicative flow at PRV) original = 289.31
Qr = Qr/1000;   % [m3/s] (Indicative flow at PRV)
Ptr = 48.4;     % [kW]
gamma = 9.81;  % [kN/m3] water special density
At = (Hr*Qr)/1000*Ptr;  % gain coefficient
kv = 0.004;              % power of volume loss coefficient
qr = 1;                  % normalised flow rate (NFR) at rated flow

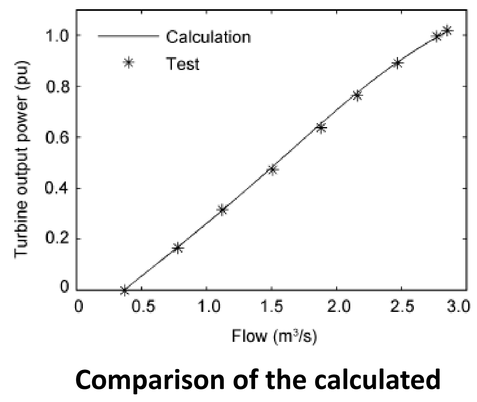
%At = 0.1133;   % Gain coefficient of turbine in paper
%Ptr = (Hr*Qr)/At;% [kW] (rated turbine output power) calculated using gain
%coefficient

qnl = 0.1349;  % [per unit] NFR at no-load
ynl = 0.1124;  % [per unit] normalised main servomotor displacement (NMSD) at no-load
yr  = 0.8571;  % [per unit] NMSD at rated load
fp  = 0.0129;  % [per unit] loss coefficient of the diversion system

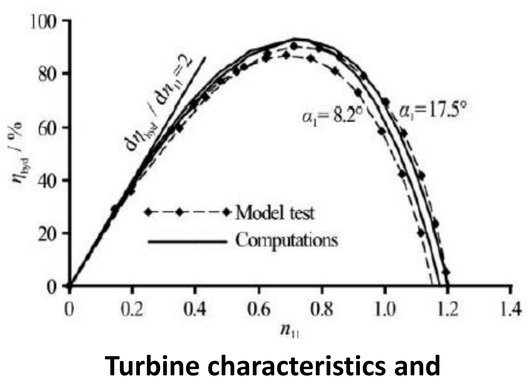
qi = 0.8917;   % NFR at BOP
yi = 0.7633;   % NMSD at BOP
```

Turbine models

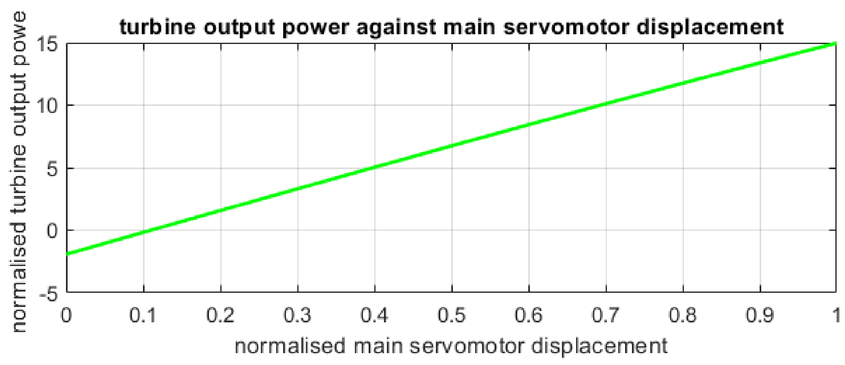
- **Torque loss model using inner energy loss characteristics to define a turbine [1].**
  - Can be used to make direct comparisons between turbine's characteristics.
  - Requires an existing performance curve of a turbine.
  - Does not derive the impact loss at turbine inlet, or swirling flow loss at turbine exit.
- **Master equation of a Francis turbine [2].**
  - Computes the complete characteristics of a Francis turbine
    - directly computes the impact and swirling losses.
  - Links geometrical design and regulation settings (guide vane angle and rotational speed) to discharge and power output.



Comparison of the calculated and measured turbine output power vs flow [1]



Turbine characteristics and comparison between computations and measurements. [2]



Simple torque model simulation run on MATLAB

Progress

- Basic simulation modelling turbine using Zeng's method without the impact losses, or mechanical friction loss. Simulated for steady and transient flow rates.
  - Measured data for turbine performances now required to finish a code that produces the turbine's characteristics.
- Visited key Scottish Water sites where similar technologies are already implemented, to learn and improve upon what has been done.
- Measured flow data being collected for selected sites.

Key terms:

- **CFD –** computational fluid dynamics; computer program that can simulate complex flow.
- **Impact loss –** also known as shock loss; the energy lost in the turbine when the fluid encounters the guide vanes and impeller.
- **Performance curve –** Measured data in graphical form; the power output or efficiency of a turbine against flow rate.

References

[1]Y. Zeng, Y. Guo, L. Zhang, T. Xu, and H. Dong, "Torque model of hydro turbine with inner energy loss characteristics," Science China Technological Sciences, vol. 53, no. 10, pp. 2826–2832, Sep. 2010, doi: https://doi.org/10.1007/s11431-010-4098-x.

[2]Zh. Zhang, "Master equation and runaway speed of the Francis turbine," Journal of Hydrodynamics, vol. 30, no. 2, pp. 203–217, Apr. 2018, doi: https://doi.org/10.1007/s42241-018-0026-5.

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