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Bayesian approach for real-time parameters inference of unsteady cavitating flows in hydroelectric turbines

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ABSTRACT

As utilities incorporate an increasing share of intermittent renewable resources into their energy mix, hydropower is expected to play a pivotal role in the energy transition by providing a growing array of ancillary services to the Electrical Power System (EPS). This evolving role translates into more frequent transient sequences and operation under off-design conditions. Under such conditions, hydropower generating units (HGUs) are subject to the development of unsteady, cavitating flows in the draft tube at the turbine outlet. In certain cases, these hydrodynamic phenomena may act as a pressure excitation source for the hydraulic circuit, inducing undesirable pressure pulsations and vibrations. Meanwhile, the presence of cavitation decreases the local wave speed, thereby increasing the risk of hydro-acoustic resonance of the complete system. Consequently, hydroelectric utilities apply operational restrictions to prevent the machine from operating in such damaging conditions, thereby reducing the operational flexibility of the unit.

Pressure pulsation predictions and resonance risk assessments are therefore crucial for the safe extension of the hydroturbine operating range in off-design conditions. This may be realized through 1D hydro-acoustic models of draft tube cavitation flow. These models are characterized by several unknown parameters which can be calibrated through Computational Fluid Dynamics simulations or experimental modal analysis performed during reduced-scale model tests. Both approaches may, however, be time-consuming, and the latter cannot be implemented on the full-scale machine.

To address these limitations, we propose a Bayesian approach for real-time inference of 1D hydro-acoustic model parameters of hydroturbine draft tube during HGU operations. It combines sparse pressure data from monitoring systems with non-linear Kalman filters (KFs). KFs are recursive approaches able to merge data and physics to estimate the actual underlying dynamics of the hydraulic system. By using a so-called augmented state-space model, KFs can jointly perform parameter identification and state estimation, allowing the online calibration of hydro-acoustic models.

A proof of concept is demonstrated using synthetic data from a SIMSEN model of a 140 MW Francis turbine unit, including a lumped model of the draft tube flow in part-load conditions. The SIMSEN simulation is performed at a specific part-load operating point, with predefined values of model parameters. The resulting pressure signals are used as ground truth for the inference step. For the latter, draft tube model parameters are initially considered unknown and are then estimated in real-time with a Kalman filter. Results show that our approach successfully retrieved the targeted parameters with low uncertainty, paving the way for real-time calibration of HGU physics-based digital twins using monitoring data.

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