Data-Driven Scalable Emulation of Hydropower Using Real-Time Hardware-in-the-Loop

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Introduction

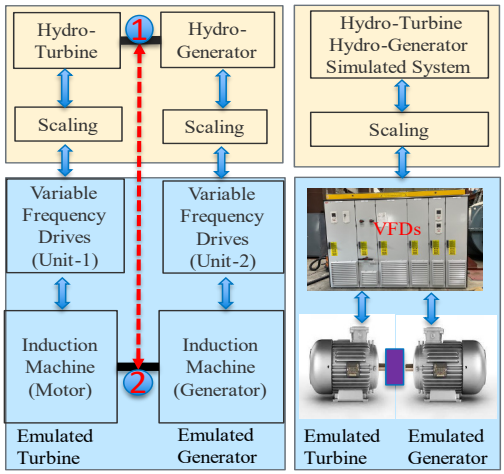
Motivation

With the increased grid integration of inverter-based resources, hydropower plays a crucial role in maintaining the bulk power system reliability and resilience.

- A more dynamic response and new control designs are required to meet the grid requirements.
- To evaluate any modification, control-prototyping, performance validation and de-risking grid integration of hydropower, a high-fidelity environment is required.

Objectives

- To develop data-driven emulation of hydropower using hardware-in-the-loop for different size, types of hydro plants.
- To characterize hardware and obtain accurate dynamic response for shaft speed, torque, and power.
- Provide a mechanical power interface with emulated dynamics of a hydro-turbine shaft that can be coupled to electrical generators for mechanical and electrical PHIL.

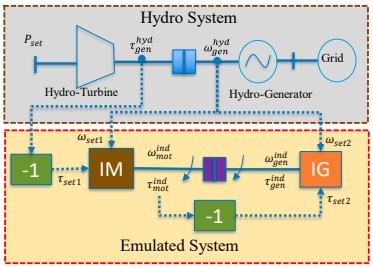


Hydropower emulation using real-time simulation (left) and variable frequency drives and induction machines (right).

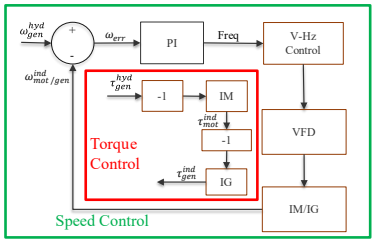
Technical Approach and Potential Impact

- A data-driven approach is developed for hydropower emulation using signal-interfaces from real-time simulation that can be transferred to hardware-in-the-loop.
- Hydropower plant shaft dynamics under various operations is investigated to check emulation fidelity.
- Emulation platform will help in reducing the cost of development and evaluation of new designs and reduce the risk of field deployment of hydro technologies.

Emulation Control Strategy



Real-time signal-based interfacing between simulated hydro plant and emulation setup.



Closed-loop speed control (Volt-Hertz) and open-loop torque coupling of emulated turbine and generator in real-time simulation.

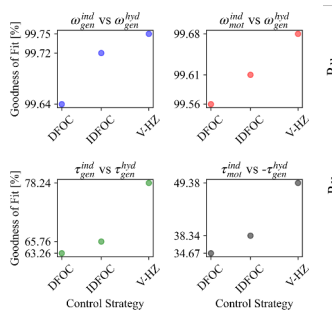
Simulation Setup

- A real-time simulation model of a 300 MW adjustable speed pumped storage hydro is used.
- To emulate shaft dynamics (speed, torque), real-time data signals are used to drive two induction motors through variable frequency drives.
- Hydro-Turbine is emulated with Induction Motor + VFD
- Hydro-Generator is emulated with Induction Generator + VFD
- Per-unitized quantities are used for scalability.
- Both *back-to-back* and *tandem-compound* operation checked. Results for back-to-back configuration are presented.

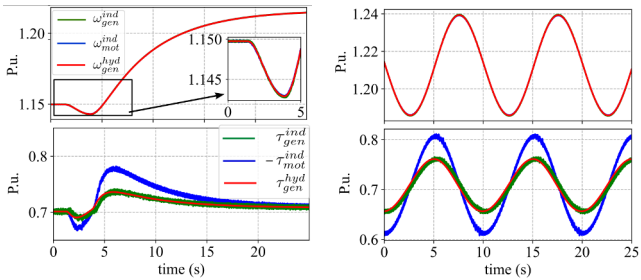
Results

Simulation and Performance Quantification

- Some typical response behavior from hydro plants simulated.
- Step change: P_{set} changed from 1.0 to 1.05 p.u.
- Oscillatory: P_{set} made oscillatory at 1.05 p.u. by adding sine wave with frequency 0.5 Hz and amplitude 0.05 p.u.
- In both case, shaft speed and torque of hydro system is mimicked successfully in the emulated system.
- Correlation coefficient between ω_{gen}^{hyd} and ω_{mot}^{ind} is **0.997** and ω_{gen}^{hyd} and ω_{gen}^{ind} is **0.998** and τ_{gen}^{hyd} and τ_{mot}^{ind} is **0.947** and τ_{gen}^{hyd} and τ_{gen}^{ind} is **0.866**.



Goodness of fit for three control strategies.



Hydro simulation and emulation response based on real-time signals

Evaluation of three VFD control strategies

- Direct Field Oriented Control (DFOC)
- Indirect Field Oriented Control (IDFOC)
- Volt-Hertz Control (V-Hz)
- Performance via goodness of fit.
- V-Hz control performs better than other control approaches.

Conclusions and Future Work

- Emulation performance was quantified for steady-state and dynamic operational scenarios for hydropower plant.
- The approach and platform will offer advantages of scalable and flexible emulation for different plant design in real-time.
- Supports variable speed operation can be used for integrated testing of new variable-speed hydropower configurations.
- **Future Work:** real-time simulation of the emulation platform will be replaced by actual hardware at NREL.

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