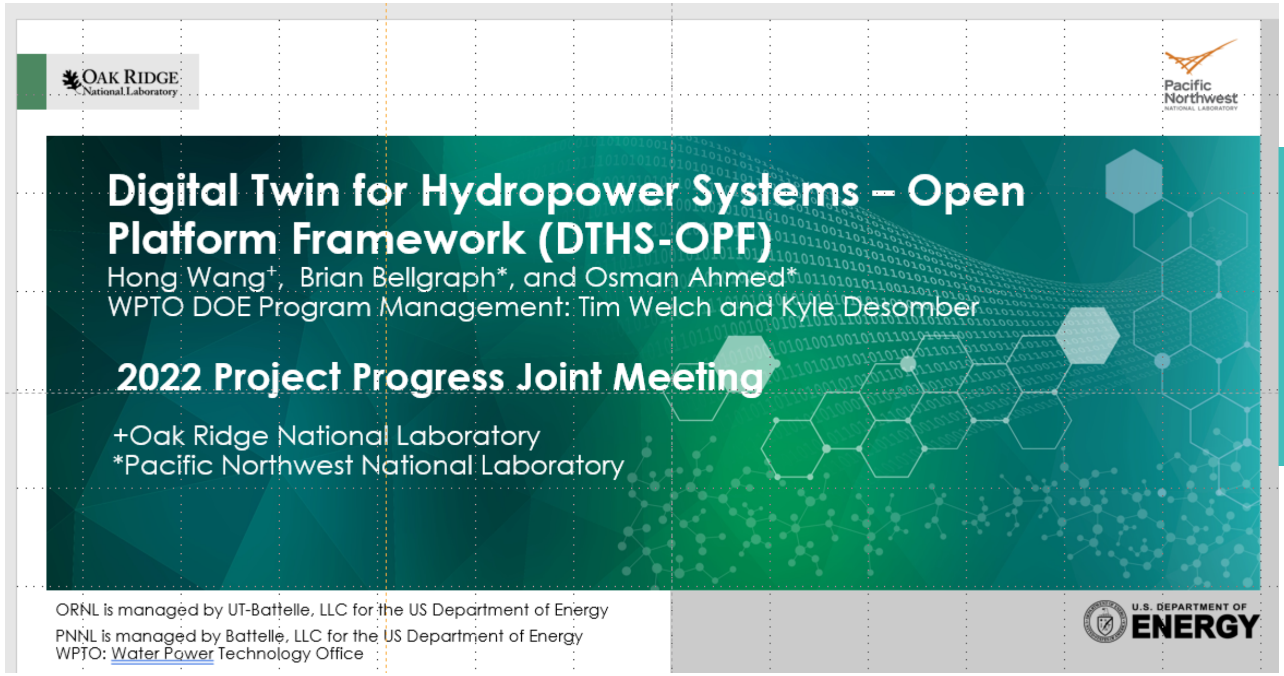
77072– Digital Twin for Hydropower System (DTHS-OPF)



Principal Investigator: Hong Wang, ORNL

Principal Investigator: Osman Ahmed, PNNL

osman.ahmed@pnnl.gov

wangh6@ornl.gov

July 27th, 2022

Project Overview

Project Summary

DTHS is a virtual platform that mimics the behavior of real plant, allows utilities, end-users, OEMs, etc. to extract deep insights from the real system, and enhances operational performance through simulations and predictive or prescriptive analytics. With its novel open platform, DTHS will be affordable to own and operate. DT is expected to be a valuable offering for hydropower plants that faces challenges to modernize operation while serve as a dependent renewable source as power market dynamics becomes more complex.

Intended Outcomes

- Design and open platform DTHS. Form and engage Industry advisory Group
- Implement an open platform DT, and prototype and demonstrate value added predictive applications using data from US reference plants
- Implement 1D Linear DT using Norwegian – NTNU Data- FY'22 goal

Project Academic Partners:

- Prof. Ole Gunnar Dahlhaug and Pål-Tore- NTNU. Hans Ivar Skjelbred and Ingrid Vilberg- SINTEF

Project Industry Advisory Board: Representatives from OEM and Utilities:

- OEM/Solutions: GE, AWS, Andritz, Amazon, Nustreem, Voith, Emerson, Wartsila, Michell Bearings, Avista
- Utilities/Govt.: Tacoma Power, Chelan County PUD, Ameren, Eagle Creek, Mavel, NYPA, Southern Co., USBR, USACE

Project Information

Principal Investigator(s)

- N/A

Project Partners/Subs

- Norwegian University of Science and Technology
- Please see below

Project Status

Ongoing, Started in FY' 21

Project Duration

- October 01, 2021
- Project End Date: September 30, 2024

Total Costed (FY21–FY22)

$1.55 million

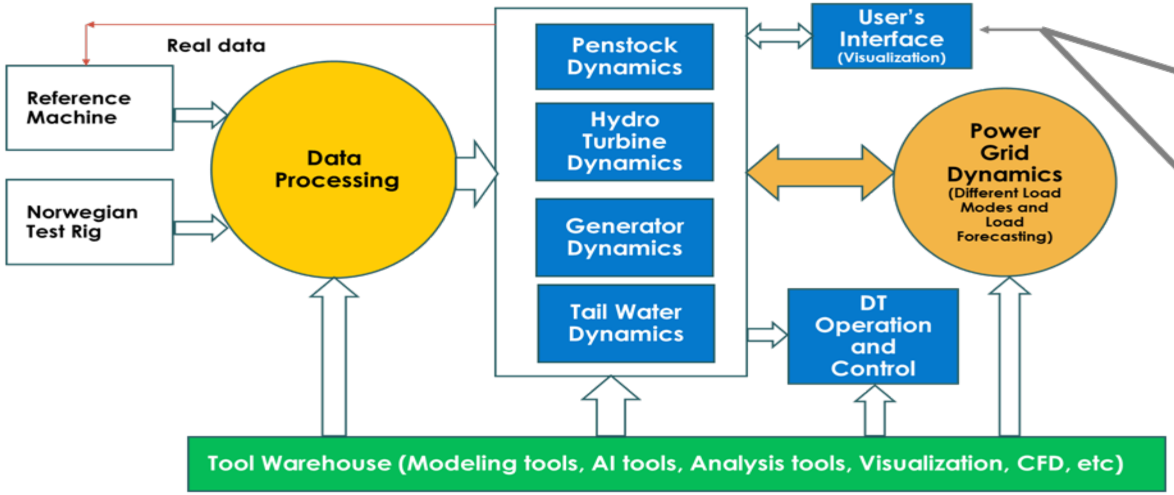
Project Objectives: Relevance

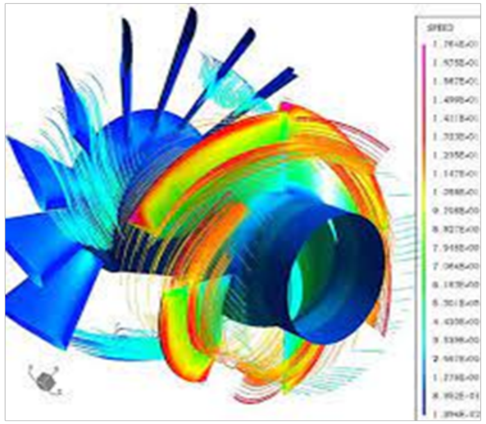
Relevance to Program Goals:

- ***Aligns well with WPTO's Program Activity 3 on Fleet Modernization, Maintenance, and Cybersecurity. Our project specifically addresses WPTO's goal of "Develop digitalization systems and advanced sensor suites to enabler data-driven O&M" . With such goal,*** ORNL and PNNL conducted a comprehensive feasibility study of Open Platform Digital Twin for Hydropower System in FY'21.
- The study delivered a design that uses open system architecture, modeling by means of objects, information, and data. It is expected that open platform design will make DT simple and affordable to own and operate.
- The study also found key project expected value propositions that includes
  - Predictive analytics to improve operational performance
  - Simulate "if-then" scenarios for design, investment decision, understanding equipment stress due to dynamic operation and developing price models in response to market bids and dynamics such as participating in Electricity Imbalance market.
- In FY'22, one dimensional digital twin hydropower model utilizing open platform design and specification that was developed in FY'21 will be implemented using data from Norwegian University of Science and Technology's lab-scale plant.

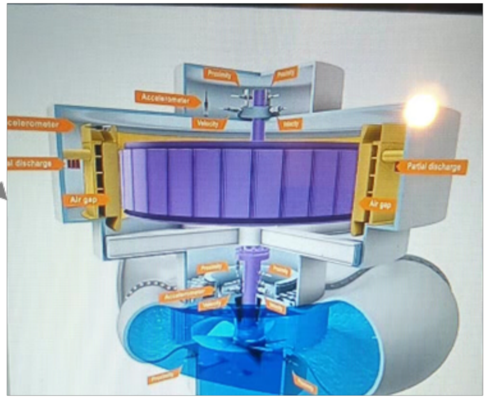
Performance: Accomplishments and Progress

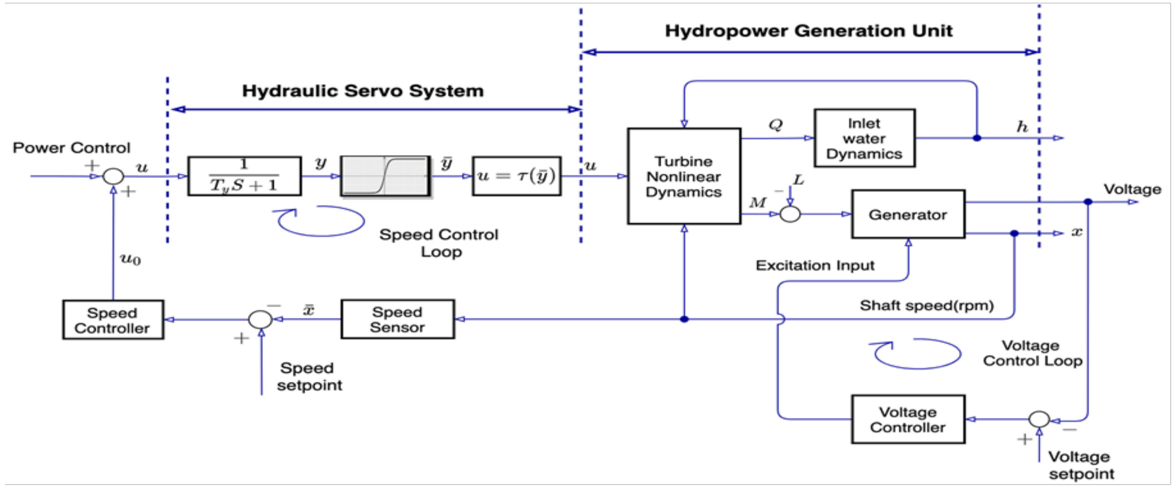
DT Model and Virtual Reality Display – a dynamic model driven insights to various components





3D internal dynamic images driven by DT models





DT is capable of

1) Helping the plant operators to optimize the unit/plant operation
2) Helping in condition monitoring
3) Displaying all the variables in DCS systems
4) Displaying internal 3D dynamic imagines such as turbulent flows in turbine chamber

Project Objectives: Approach to DTHS-OPF

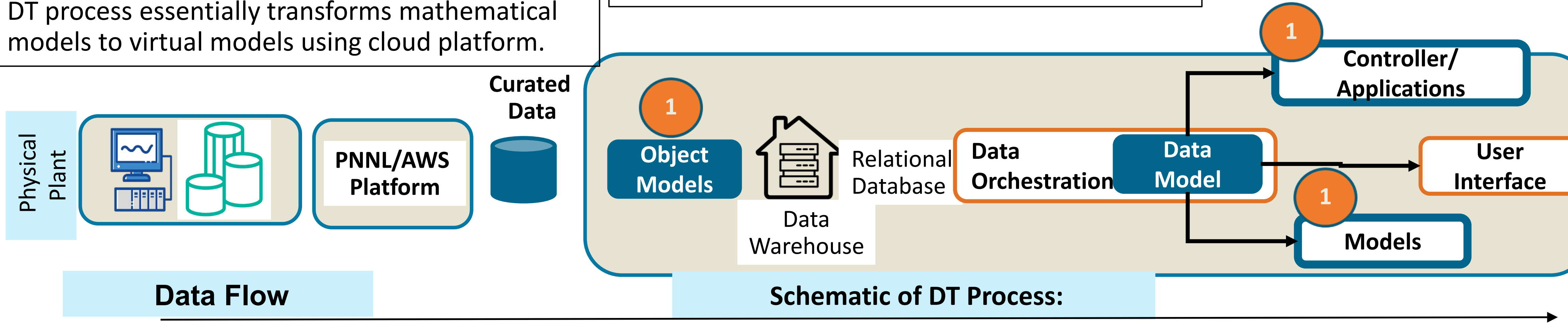
Approach:

- *Although DT is impacting all energy sectors, its market penetration remains slow due to cost and simplicity.*
- *Our DT approach has several novel functionalities[1], which will make DTHS simple, adaptable, scalable, plug-n-play and affordable:*
    1. *Develop a variety of modeling- physics-based, AI driven, CFD, and hybrid- use computationally efficient algorithms*
    2. *Develop and Implement open platform.*

1. Feed Plant data to physical and controller models
2. Execute the physical models and create performance output automatically.
3. DT process essentially transforms mathematical models to virtual models using cloud platform.

Modeling and Simulation 1

- Models: Python Code with proper definitions
- Input, Output, Parameters, Range



- *DTHS-OPF shall allow development and deployment of controls, optimization, and predictive O&M applications*
- *DTHS-OPF is a playground to simulate scenarios, market dynamics, uncertainties, and other possibilities.*
- *DTHS is a critical driver for modernizing hydropower fleet, reduce operating cost, and providing resiliency- all affordably.*

Project- FY'22 Objectives: Expected Outputs and Intended Outcomes

Outputs:

- 1D linear modeling and algorithms that can mimic performance and behavior of a lab scale hydropower plant and systems using real plant data.
- Applications for controls.
- A platform that uses open system architecture, computer models, data orchestration, relational database in order to transform mathematical models to virtual models simply and affordably.
- A simple dashboard that can show performance of a real plant and user interface.

Outcomes:

- Demonstrating to the industry how an open platform can be constructed.
- Demonstrating how plant data can be virtually presented by modeling and simulation
- Demonstrating the value of applications that can be developed cost effectively using DTHS

Project Timeline:

2021

Key Deliverables:

- Feasibility of developing mathematical models was completed to represent the performance of Hydropower systems including turbine, generator, water flow-pressure dynamics, grid dynamics, and controls.
- Design of complete open platform[1] for Hydropower System was completed including:
- Formation of Industry Advisory Group (IAG)that has about 20 representatives from OEM, other govt. agencies, and utilities and end-users.
- Value proposition (VP) study with IAG was completed: Key VPs
  - Predictive O&M and asset management
  - Simulation of scenarios such as impact of EIM

2022

Key Deliverables: June 30th, 2022

- 1D linear physical models to represent turbine, generator, governor controls are developed and simulated with pilot data from NTNU.
- An operational Digital Twin[2] that virtually displays NTNU Lab-scale Plant performance using open Platform.
- A simple dashboard is implemented for User Interface

Key Deliverables: September 30th, 2022

- Digital Twin of NTNU lab-scale Hydropower Plant is complete and operational. Simulation and capturing performance of hydropower systems.
- Open platform is installed and operational
- UI dashboarding is complete and operational
- Publish DTHS-OPF products and web pages at DTHS-OPF website

Go/No Go Decision: Sep 30, 2022

- DT Prototype of 1D Linear model is fully functional
- Validation will be sought from IAG

Project Budget:

FY19	FY21	FY22	Total Actual Costs FY19–FY21
Costed	**Costed**	**Costed**	**Total Costed**
$0K	$550K	$1.0 Million	$1.55 Million

- No variants between project budget and actual is reported

End-User Engagement and Dissemination

- Stakeholders and/or end-user engagement strategy:
  - Hydropower plant owners and end users will benefit. Such benefits will help to accelerate the market penetration of DTHS and creating market pull. Market penetration is absolutely necessary for the modernization of hydropower fleet.
  - An Industry Advisory Group was formed in FY'21 that has large representation from utility companies and OEM. About 20 representatives represent both sectors. The IAG reviews project scope and methodology and advises on value proposition that DTHS can offer. IAG helps to identify and prioritize applications portfolio,
  - Shall develop plan in FY'23-24 in reaching out to targeted underrepresented groups for engagement, participation, and capturing active feedback
- Through publications, presentations, workshops, and launching DTHS website using cloud platform. Potential conferences will include CEATI, HRA, European/ Norwegian conferences. Collaborate with US Utilities on site visits and publications and presentations.

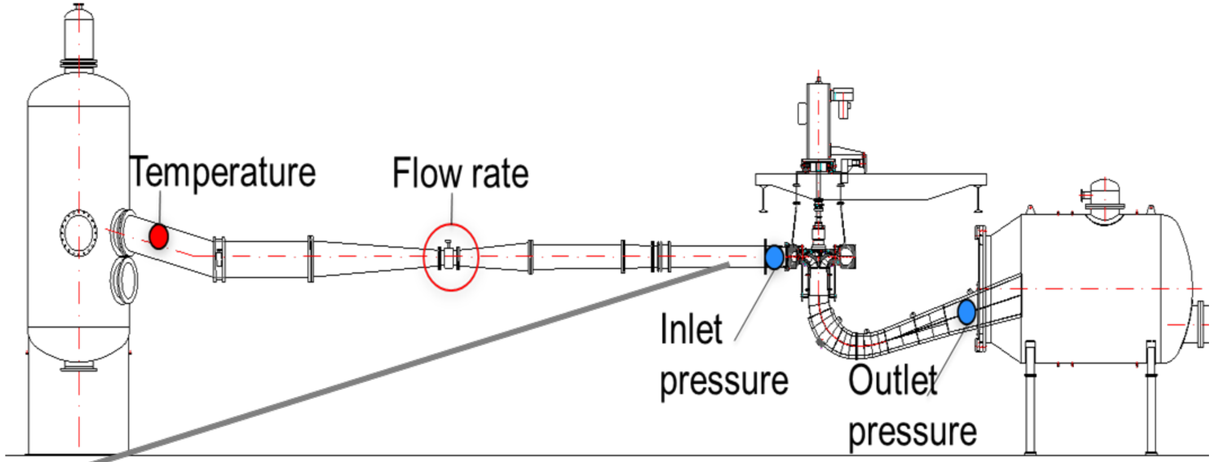
Performance: Accomplishments and Progress

1. It is possible to capture system dynamics and performance of major components such as turbines, generator, water-pressure relationship using simple 1D linear model.
2. It is possible to capture the performance of control applications with linear models.
3. It is feasible to construct the entire value chain of data stream-acquisition, curation, object modeling, data orchestration, and data modeling using open system architecture and open-source software
4. It is feasible to use existing cloud platform to design, develop, and launch Digital Twin that is secured but accessible to the industry users.
5. It is possible to construct simple dashboard for capturing hydropower system performance and providing simple user interface.

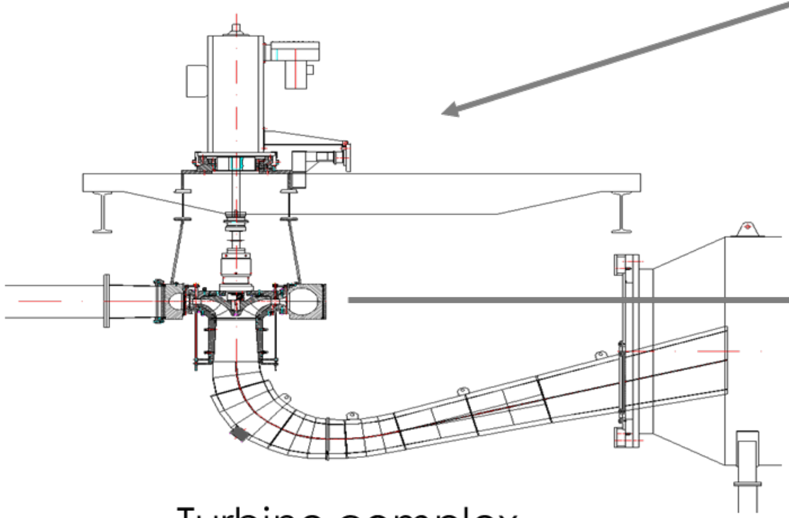
Performance: Accomplishments and Progress (cont.)

Testing System in Norway (NTNU)

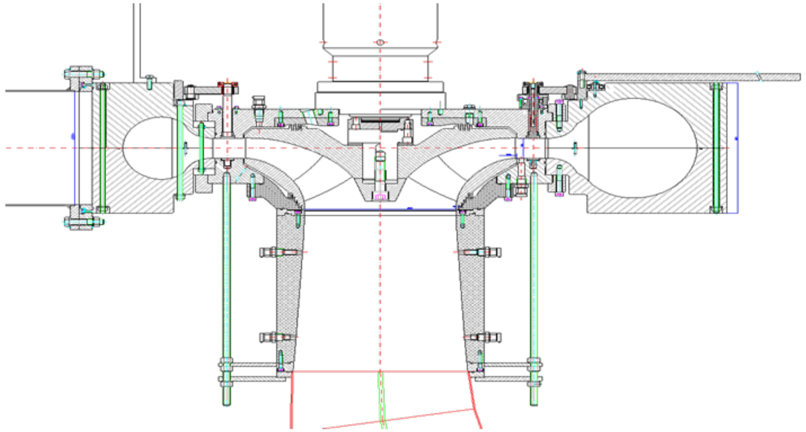
- Model data
  - Head: 12-30 meter
  - Flow rate; 0,1 – 0,4 m³/s
  - Geometrical scale: 1: 5,1
  - Available data:
    - Complete 3D-geometry
    - Complete hill diagram
    - Pressure pulsations
    - CFD-mesh



Overall system structure



Turbine complex



Turbine complex

Performance: Accomplishments and Progress (cont.)

Data are only from open loop test and consist of :

- pressure difference (water head),
- generator torque,
- friction torque,
- shaft speed,
- flow rate,
- guided vane opening

Data processing:

1) Selected the least sampled variable (i.e., the shaft speed) as the reference data column
2) Sampling interval = 0.2 seconds
3) Use batch least square algorithms to obtain the six-coefficients for the 1D models

The following average six-coefficients are obtained:

$$e_x = -0.1438,\ e_u = 0.1178,\ e_h = 0.1513,\ e_{qx} = -0.0222,\ e_{qu} = 0.0026,\ e_{qh} = 0.0646$$

Other parameters are:

$$T_w = 0.0415, \quad J = 32, \quad Sampling\ interval = 0.2$$

The inlet gate-servo transfer function in the discrete-time form and PI gains are

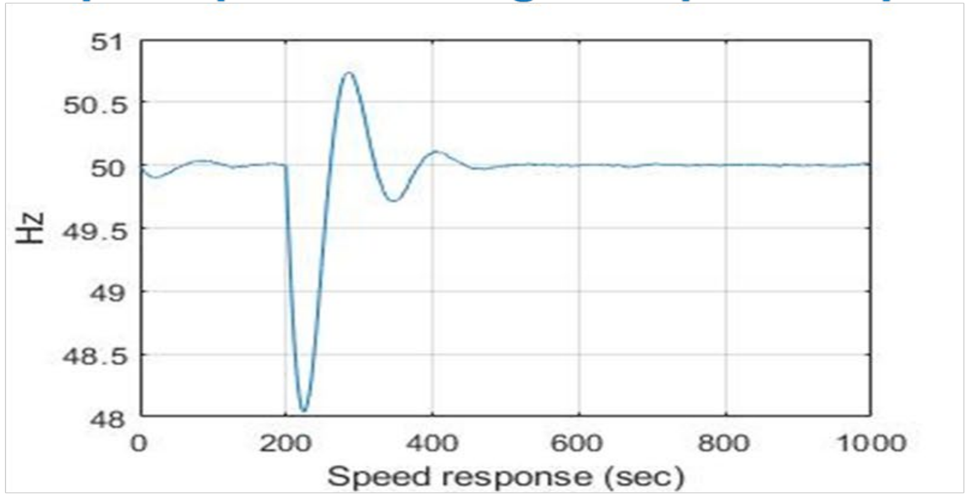
$$\frac{u(k)}{u_0(k)} = \frac{0.5}{1 - z^{-1} + 0.5z^{-2}},$$

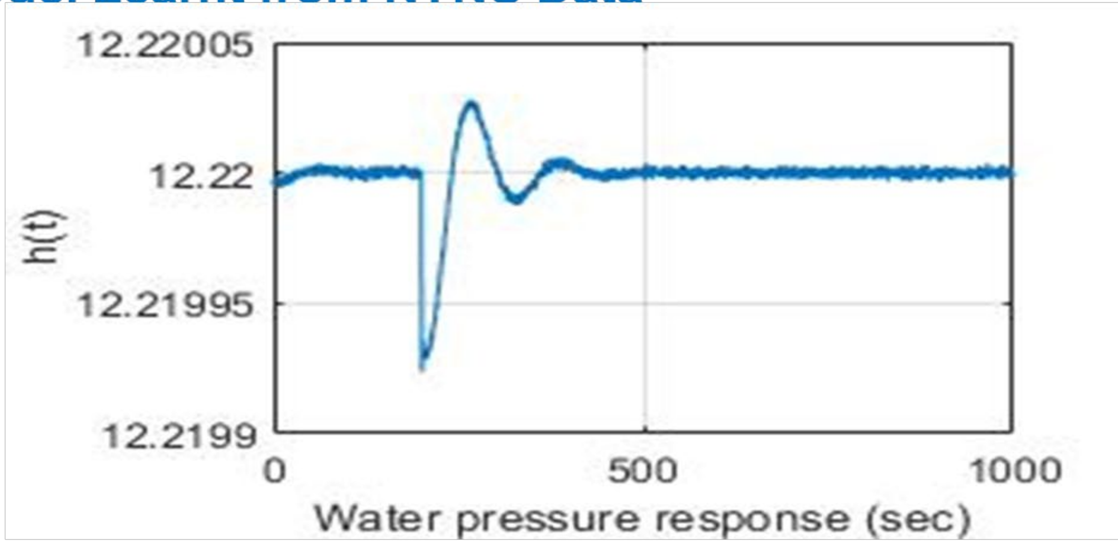
$$u_0 = K_p(0 - x) + K_I \int_0^t (0 - x)dt,\ K_p = 7.5,\ K_I = 0.8$$

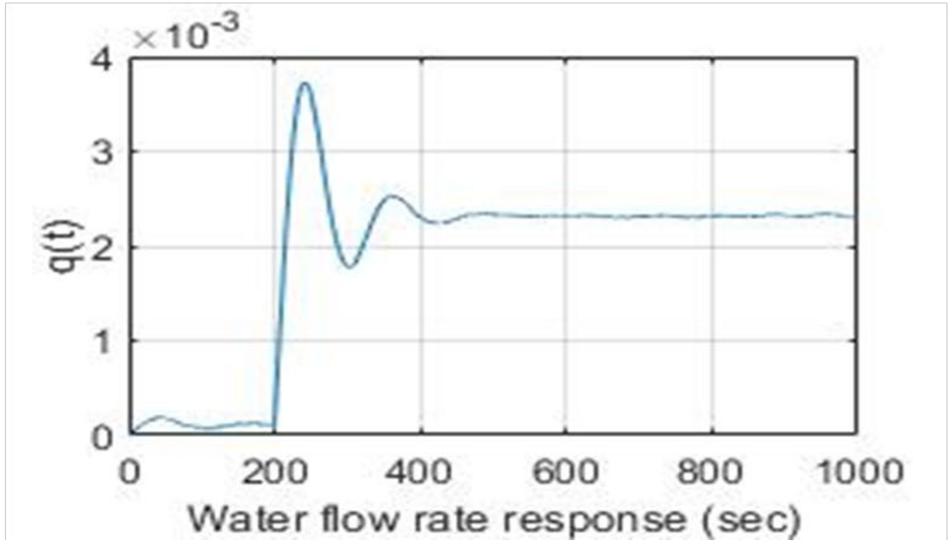
Load noise level = 0.01*rand(1)

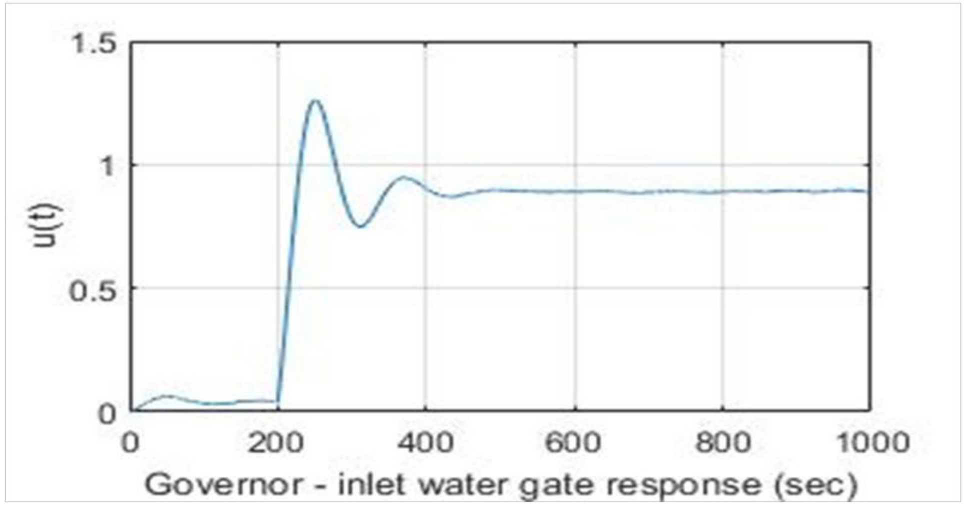
Performance: Accomplishments and Progress (cont.)

Frequency Regulation Subjected to 10% Load Increase at 200 seconds – Closed Loop Responses using the Open-Loop Model Learnt from NTNU Data









Performance: Accomplishments and Progress

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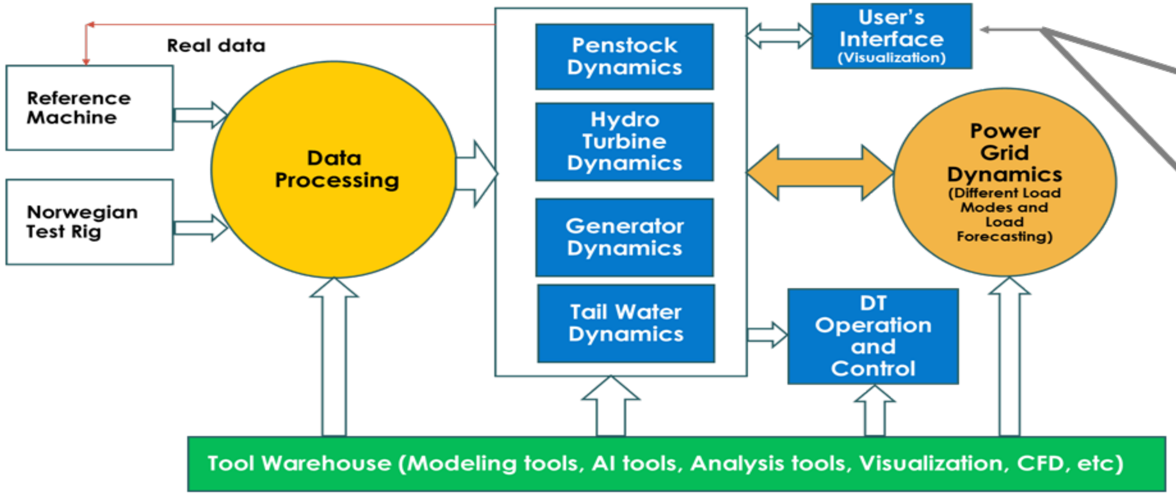

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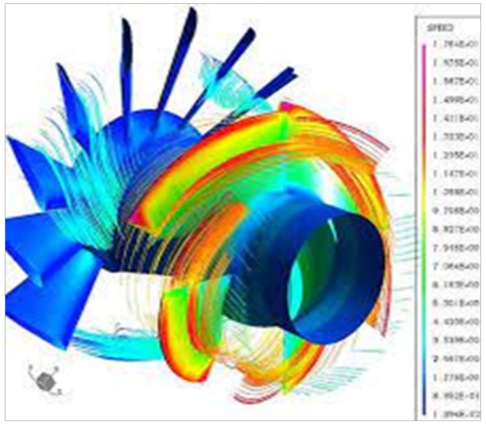

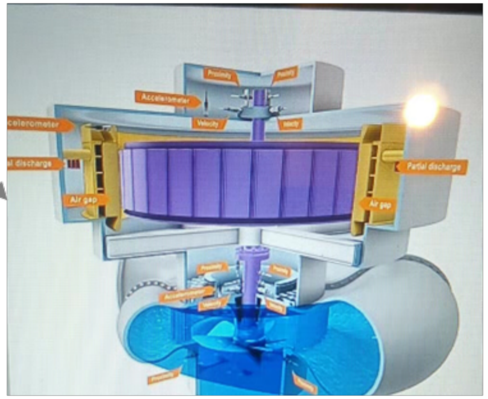

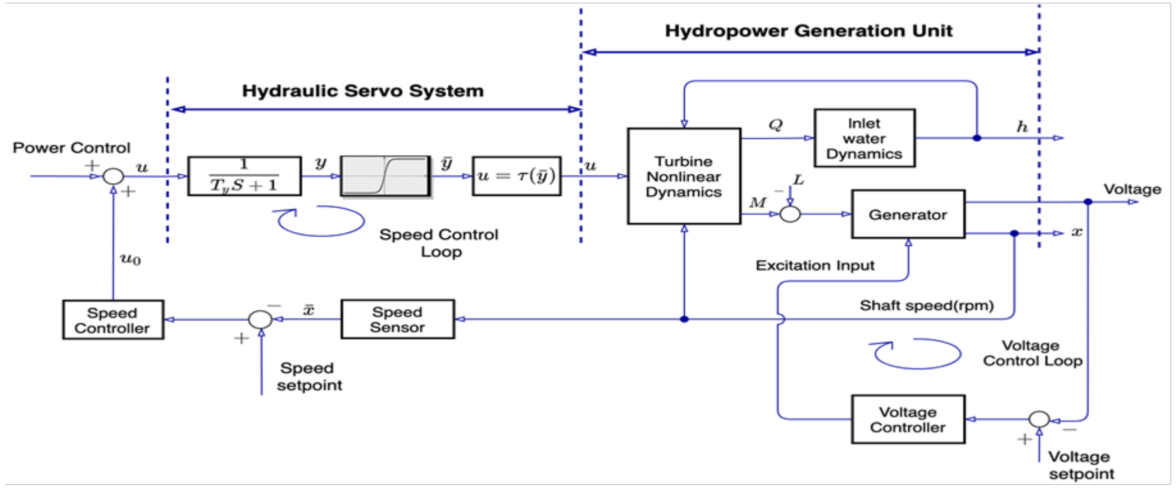

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Performance: Accomplishments and Progress (cont.)

- Develop and implement a comprehensive IP plan in FY'23-24.
- Recognized by industry associations such as NHRA and CEATI.

Future Work

Summary of FY'23 Deliverables:

- A full scale DTHS-OPF with models, data processing and user's interface, and with dynamic models being validated using the real-time data flows from the selected US reference hydropower system at less than 5% modeling error of 90% of confidence interval.

- An open platform that can be used to design, develop, and operate a DT and demonstrate applications that can create significant value in enhancing operational efficiency, asset management, service and maintenance, and response to grid dynamics.

Summary of FY'24 Deliverables:

- Successful demonstrations on the use of DTHS-OPF for operational optimization, and fault diagnosis, prognosis, reliability-centered maintenance, and asset management for a set of operating hydropower facilities.

- At least one use- case, where we demonstrate the open platform's scalability and adaptability by utilizing the platform in a different hydropower plant.

Decision making process:

- Consult with US reference plant owners, Industry Advisory Group, and DOE Program Manager in discussing key milestones, deliverables, any challenges, and risks. Make decisions that shall provide maximum value based on pre-determined criteria,

Q&A