Digital Twin for Hydropower Systems Overview – Open Platform Framework (DTHS-OPF)

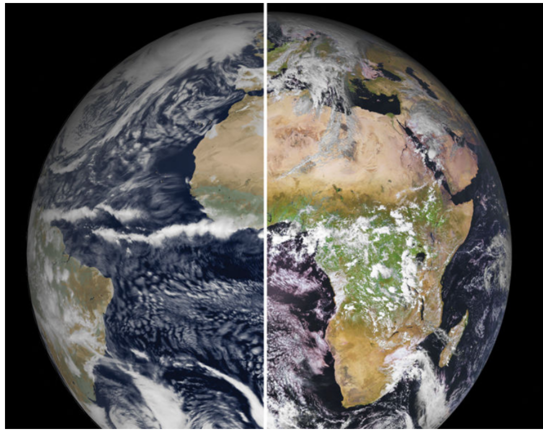
Hong Wang+, Osman Ahmed* ,Brennan Smith+ and Brian Bellgraph*

+Oak Ridge National Laboratory
*Pacific Northwest National Laboratory

The World of Digital Twin

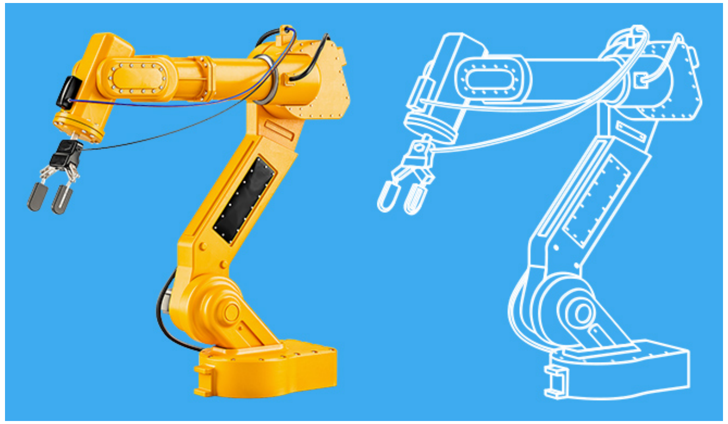
Notre Dame Cathedral, Paris is being re-built using DT

Digital Twin (DT) is simply a virtual representation of a real-world system.

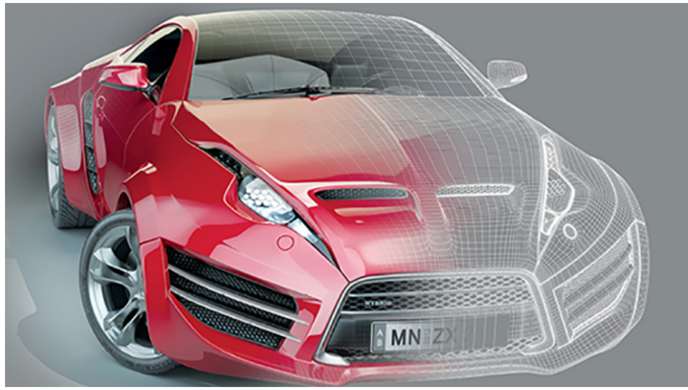


EU's Earth DT to conduct earth and environmental science research

Honeywell's DT to improve O&G production's energy performance



Singapore Govt.'s DT service for critical machines to improve operational performance



Tesla's Prescriptive Service using DT

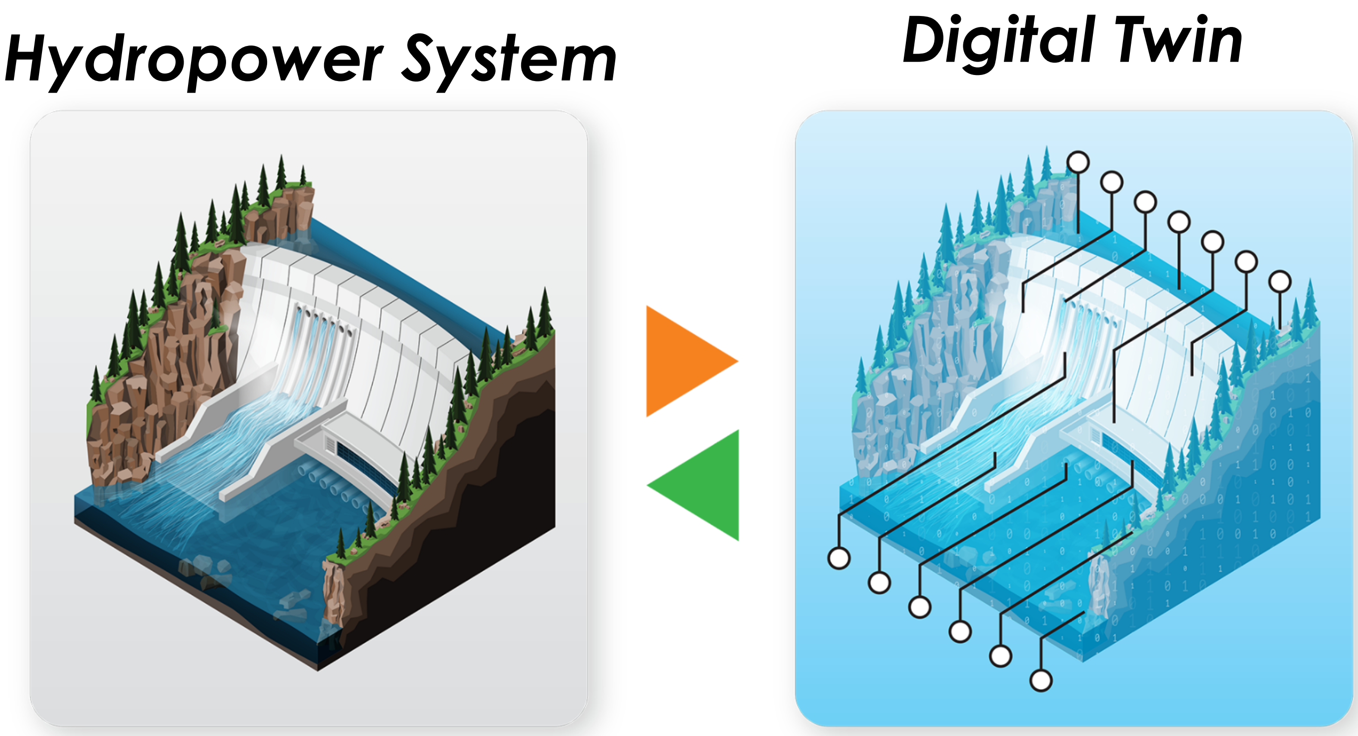
Oak Ridge National Laboratory

Pacific Northwest National Laboratory

Proposed Digital Twin (DT) for Hydropower System- Open Platform (DTHS-OPF)

- Objective: Key research initiative in addressing nation's Hydropower

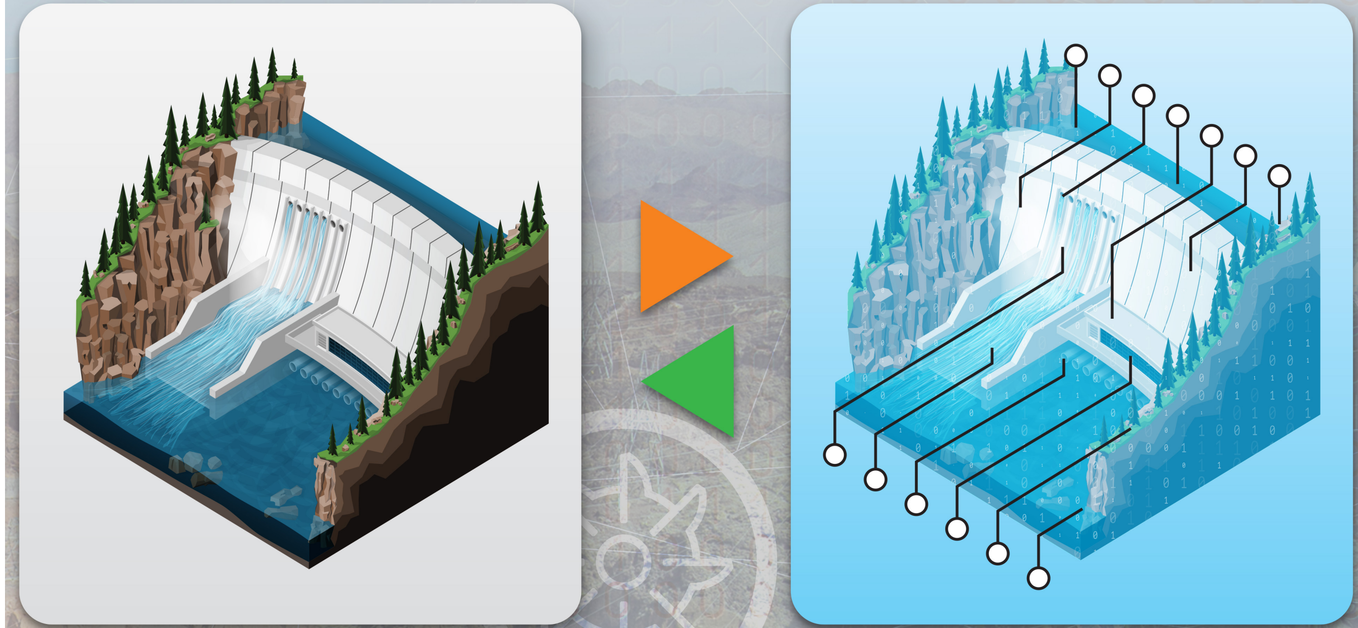
- Digitalization Challenge:
  - Modernizing nation's aging hydropower plant fleet affordably
  - Reduce operating cost, improve reliability
  - Addressing increasing operational complexity
  - Providing grid resiliency in the face increasing use of renewables



- Key deliverables:
  - Request for information to capture industry needs and value propositions
  - Value proposition: Capture and articulate DTHS-OPF Value propositions for the industry
  - Design Framework: Design and specifications of DTHS-OPF

Predictive and Prescriptive Applications

PREDICTIVE APPLICATIONS



Hydropower Plant   Digital Twin

- **Predictive O&M**
- **Controls**
- **Optimization**
- **Cybersecurity**

Digital Twins obtains sensors data, performs analytics, develops strategies, and sends output to the plant.

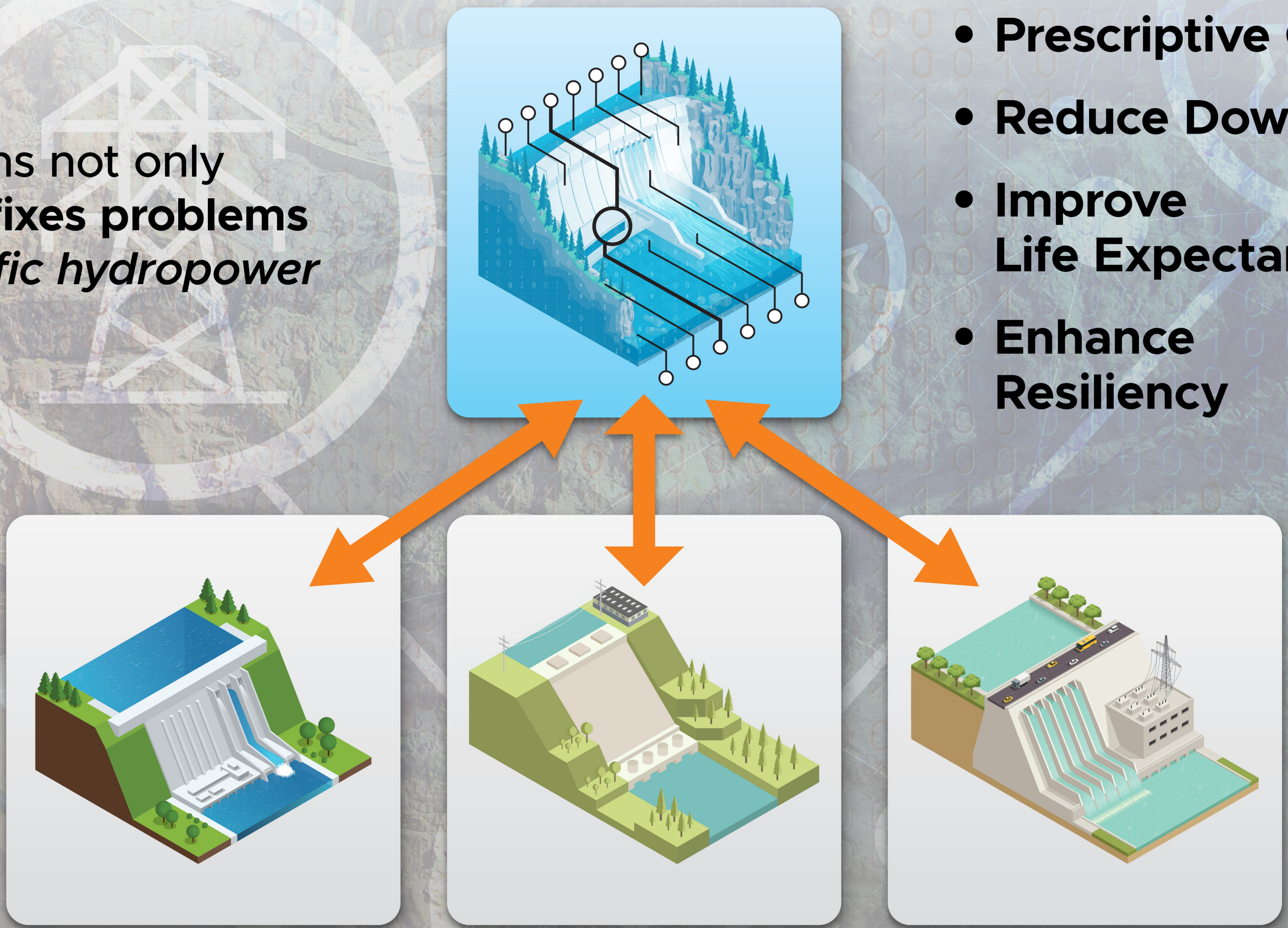
Oak Ridge National Laboratory

Pacific Northwest National Laboratory

Predictive and Prescriptive Applications

PRESCRIPTIVE APPLICATIONS

Digital Twins not only **finds and fixes problems** for a *specific hydropower plant…*



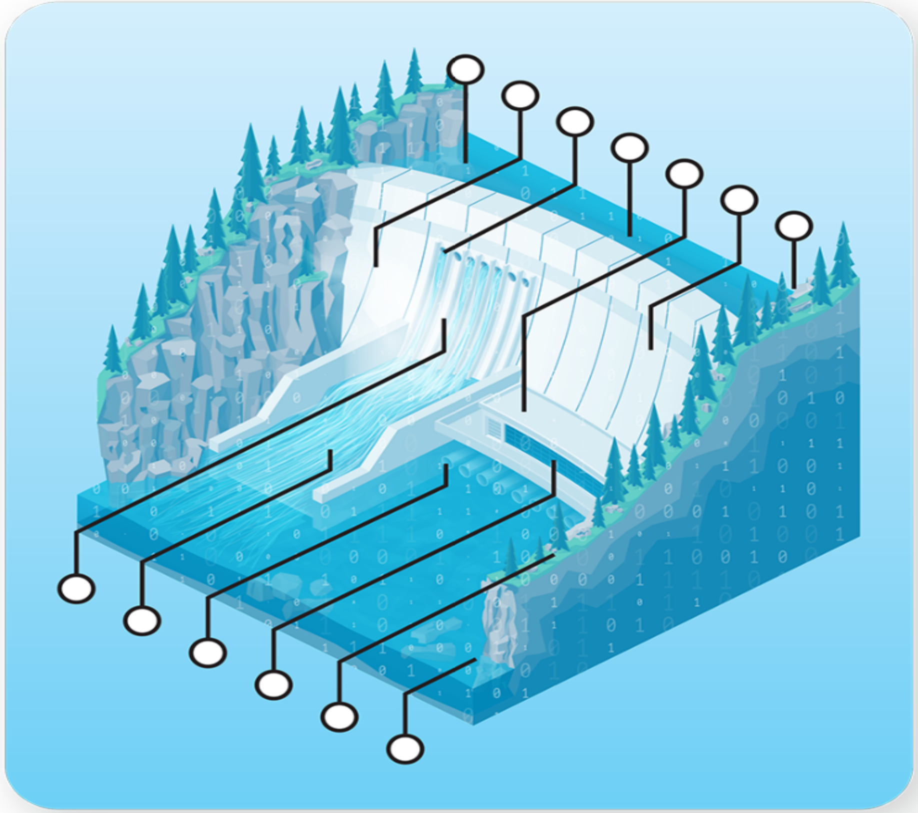
- **Prescriptive O&M**
- **Reduce Downtime**
- **Improve Life Expectancy**
- **Enhance Resiliency**

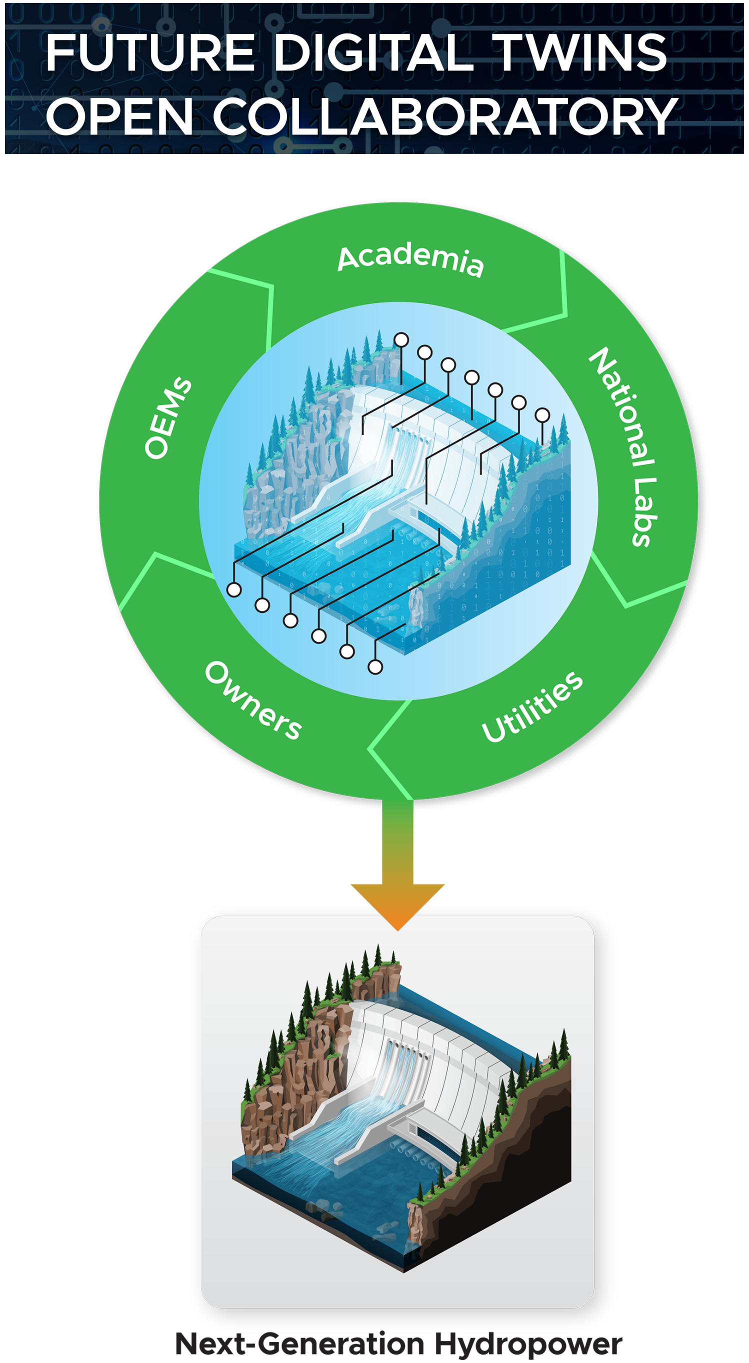
…but also **proactively identifies similar problems** and **prescribes fixes** well-in-advance to *other hydropower plants.*

DTHS-OPF Open Platform

- Goals
  - Open System Architecture
  - Open Sourcing
  - Open data integration platform
  - Open interoperability
  - Easy custom configuration using user graphical interface
  - Object modeling (i.e. BIM)
  - Parametric modeling

- Expected Value Proposition:
  - Affordability to own
  - Affordability to operate
  - Simple to operate
  - Flexible and adaptable

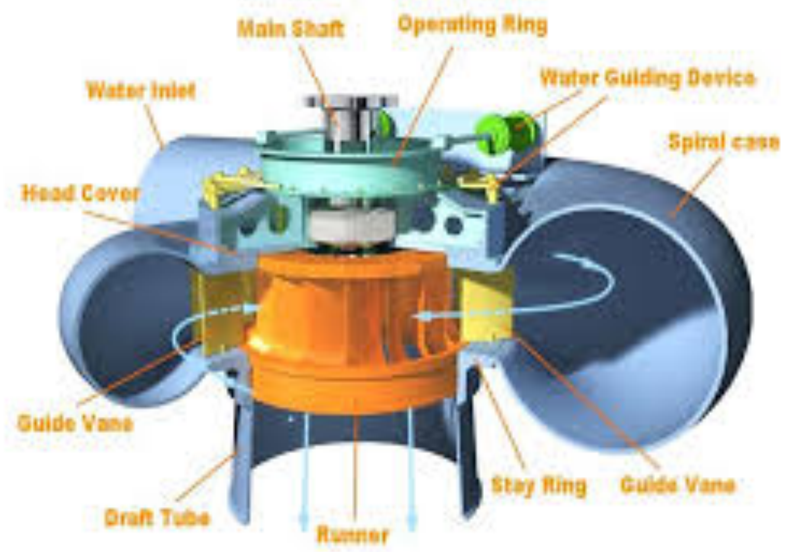




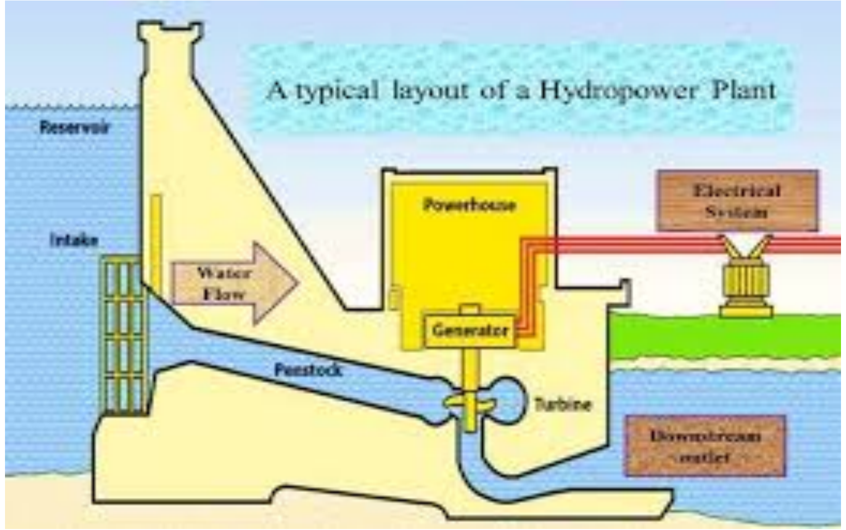
Proposed DTHS-OPF is a strategic initiative that can serve as an "open playground" for research and innovation for Hydropower Industry

Modeling Scope - system information and possible data

- ❑ Water system data
- ❑ Grid interaction data
- ❑ Operational data
- ❑ Condition monitoring data
- ❑ Meta data (location, geographic)
- ❑ Weather data,
- ❑ Historic data (plant archived data)
- ❑ Upstream and down streams data
- ❑ Other data



Francis Turbine



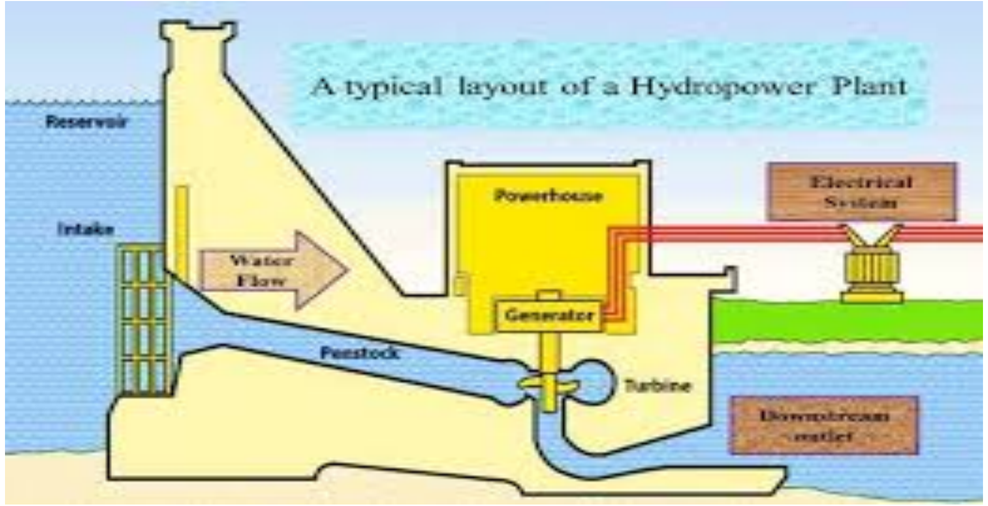
Water Systems Dynamics

When the water height is larger than 20m, water elasticity and "pressure wave propagation" factors need to be considered, these would require the solutions (CFD) to the following partial differential equations

$$V\frac{\partial H}{\partial x}+\frac{\partial H}{\partial t}+\frac{a_w^2}{g}\frac{\partial V}{\partial x}+\frac{a_w^2 V}{gA}\frac{\partial A}{\partial x}-Vsin\theta=0$$

$$g\frac{\partial H}{\partial x}+V\frac{\partial V}{\partial x}+\frac{\partial V}{\partial t}+f_D\frac{V|V|}{2D_p}=0$$

$$Q=AV$$



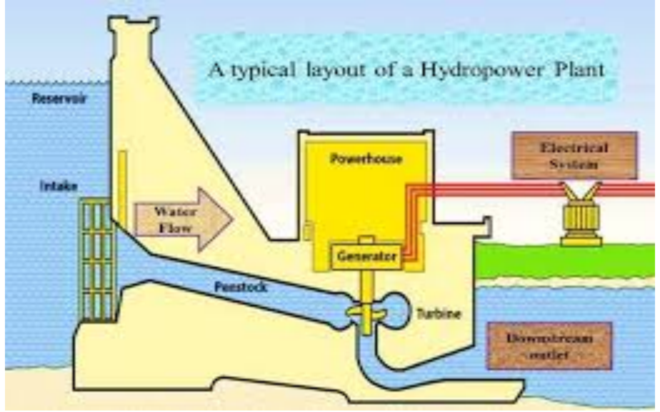
where in the penstock, V is average flow velocity, g is gravity, a_w is the velocity of pressure wave, A is the cross-sectional area, θ is the slope angle, f_D is the friction resistance, D_p is the inner diameter

Water System and Turbine Torque Models (data driven + first principles)

- **Water system dynamics**: Water system includes reservoir, penstock, turbine chamber and discharge (tail water stream)

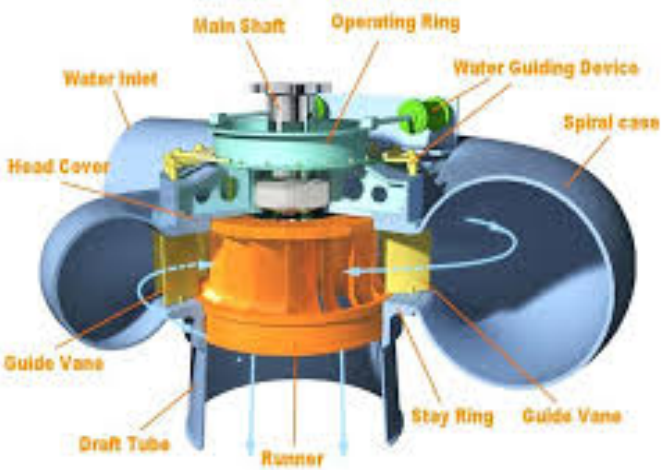
$$Q = f(H, \omega, u)$$

where H = the operating water height,
u = the inlet valve opening to the turbine from penstock,
ω = the turbine shaft speed,



- **Water system dynamics**

$$\frac{dQ}{dt} = \pi(H)$$



Francis Turbine

- **Mechanical torque to turbine shaft**

$$M = g(H, \omega, u)$$

f(…), π(…) and g(…) require physical + data driven (A

Power Generation Systems – Voltage Control Models

➢ **Turbine system dynamics**:

$$J\frac{d\omega}{dt} = M - L$$

where L is the load torque related to the power supplied to the grid

➢ Interaction with grid via load torque:

$$L \sim P_e$$

where P_e is the active power represented by

$$\begin{bmatrix} P_e \\ Q_e \end{bmatrix} = \begin{bmatrix} V_{gd} & V_{gq} \\ V_{gq} & -V_{gd} \end{bmatrix} \begin{bmatrix} I_d \\ I_q \end{bmatrix}$$

$$\begin{bmatrix} V_{gd} \\ V_{gq} \end{bmatrix} = \begin{bmatrix} E_d^{"} \\ E_q^{"} \end{bmatrix} - \begin{bmatrix} 0 & -X_q^{"} \\ X_d^{"} & 0 \end{bmatrix} \begin{bmatrix} I_d \\ I_q \end{bmatrix}, E = \begin{bmatrix} E_d^{"} \\ E_q^{"} \end{bmatrix}, I = \begin{bmatrix} I_d \\ I_q \end{bmatrix}$$

$$\frac{dE}{dt} = \aleph(E, I, X_q^{"}, X_d^{"}, v)$$

where v is the excitation control input of the generator, others are generators variables,

Two control inputs, for generation unit (turbine + synchronous generator system), are

$$\{u = valve\ openning, v = excitation\ control\ input\}$$

Concluding Remarks

- A summary is given on issues related to the development of Digital Twin for Hydropower Systems Overview – Open Platform Framework (DTHS-OPF)

- We look forward to receiving your feedback and comments …

Hydropower System *Digital Twin*