Advanced Research on Integrated Energy Systems – Overview

Singapore 2022 Symposium on Microgrids

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November 1st , 2022

ARIES

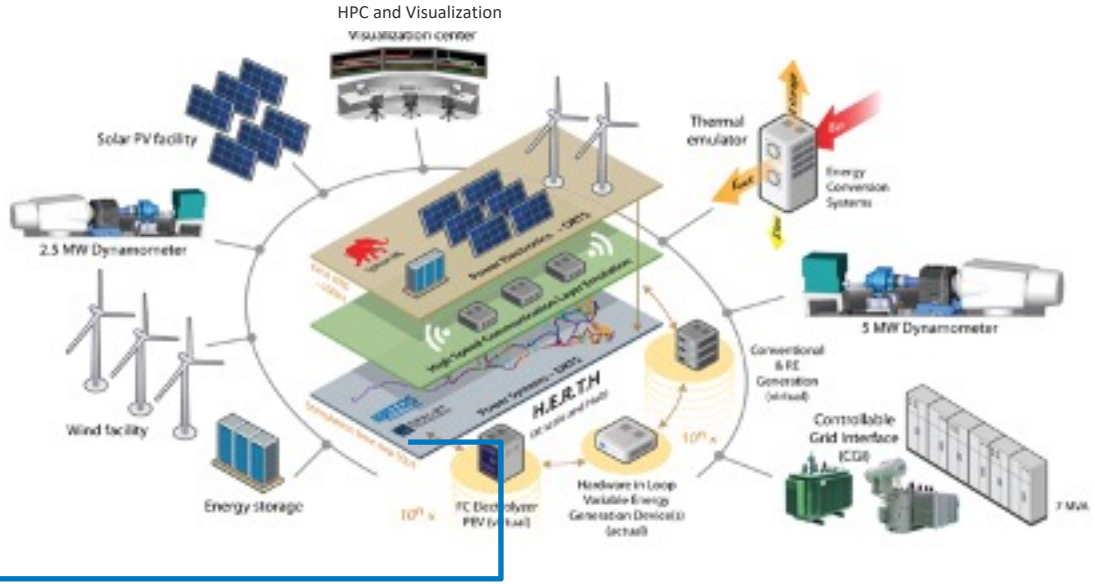
ARIES is a research platform designed to de-risk, optimize, and secure current energy systems and to provide insight into the design and operation of future energy systems. It will address the fundamental challenges of:

- Variability in the **physical size** of new energy technologies being added to energy system
- Controlling **large numbers** (millions to tens of millions) of interconnected devices
- Integrating **multiple diverse technologies** that have not previously worked together

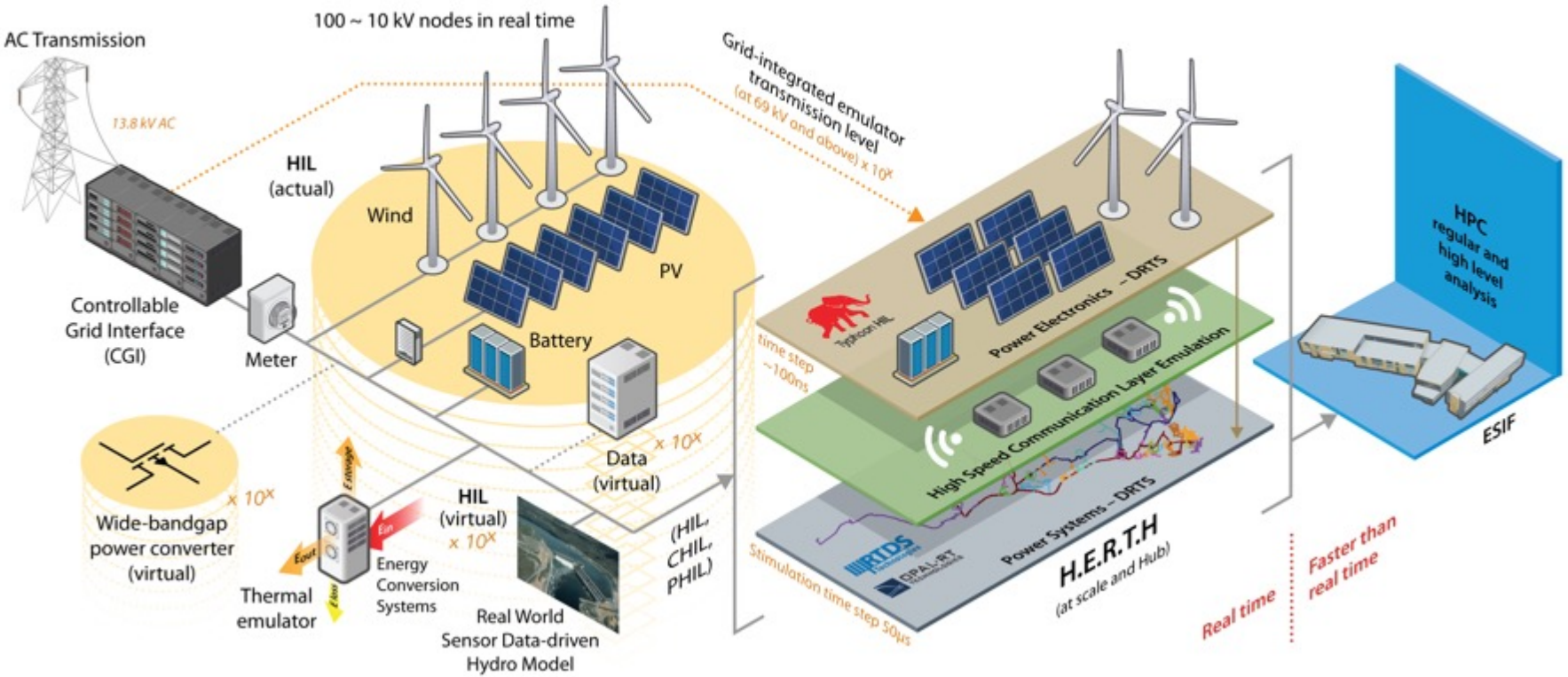
NREL ARIES – DRTS Cluster at HERTH

(Hybrid Energy Real-Time Hub)

1	***Increasing variability*** **in the physical size of new energy technologies**
2	**Controlling large numbers of *interconnected devices***
3	***Integrating diverse technologies*** **that have not previously worked together**

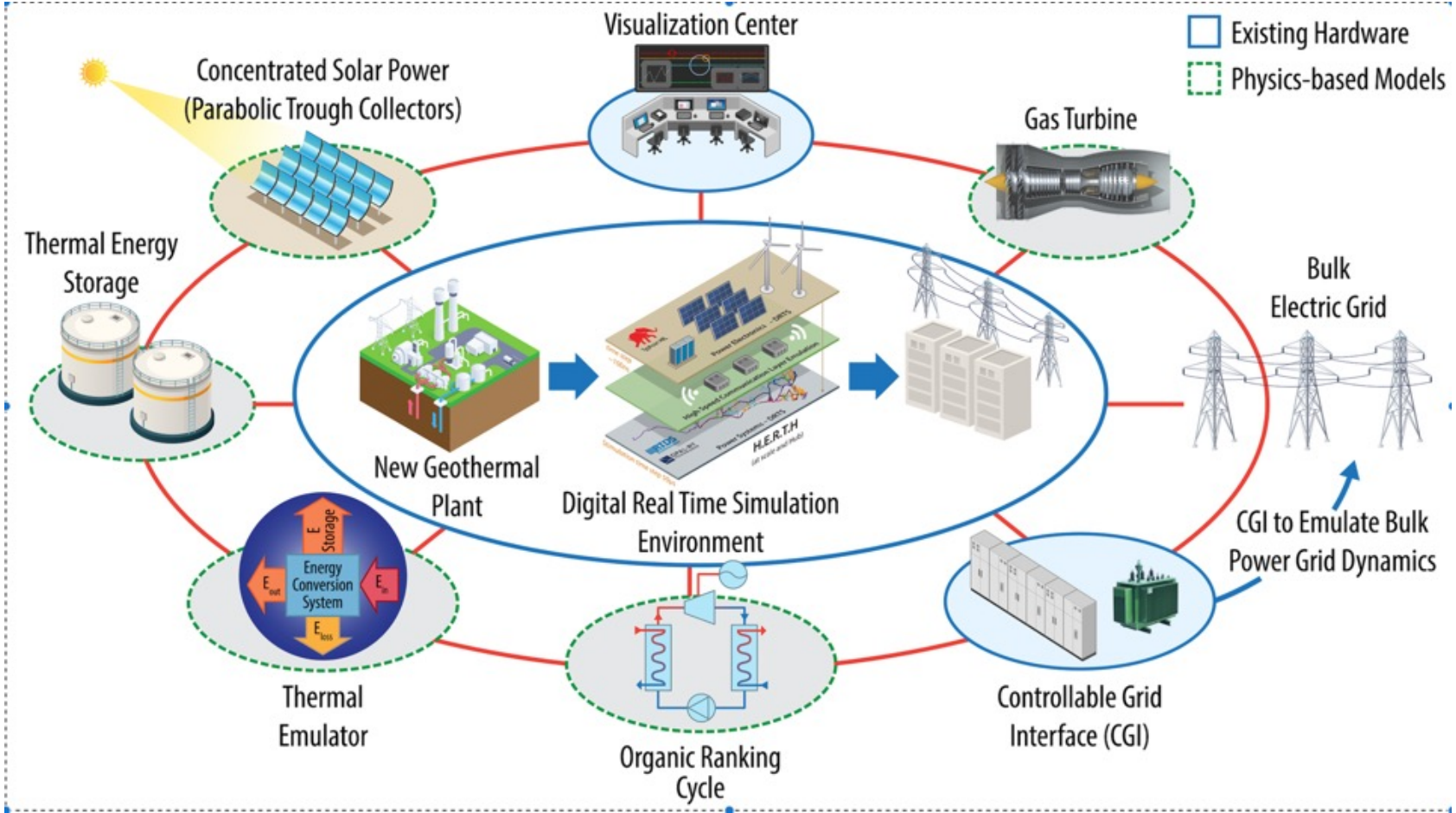


A large cluster of Digital Real-Time Simulation (DRTS) to simulate regional power grid use-cases



NREL Integrated DRTS Capabilities

High-Fidelity Thermal , Multi-Physics Emulation Platform



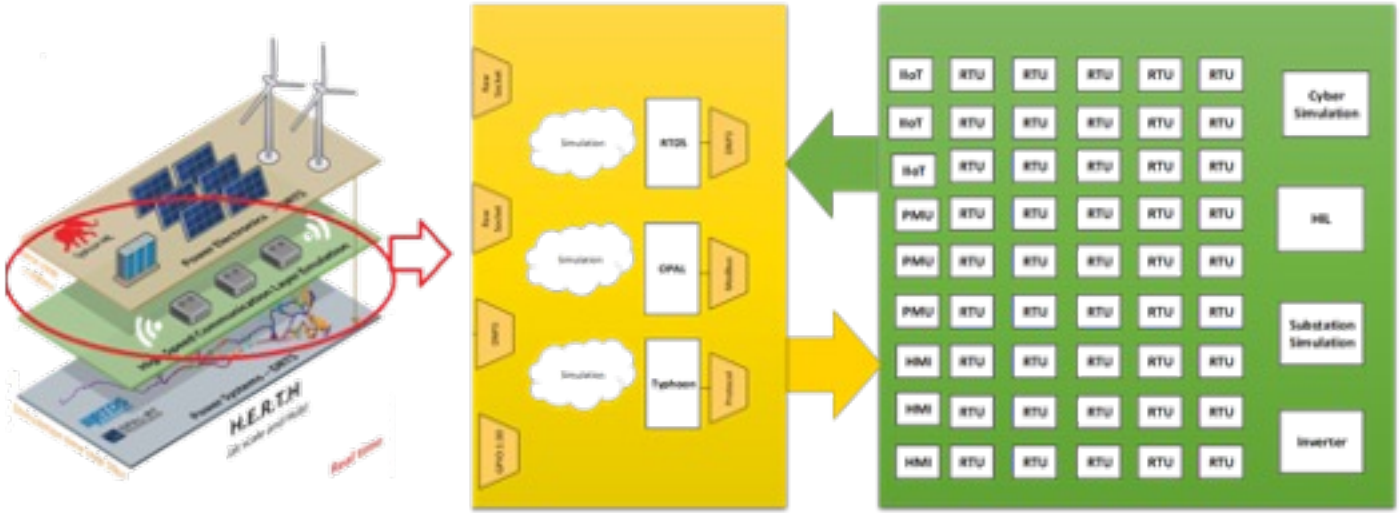
ARIES Flatirons Capabilities

Pre-FY18 | **FY18 - FY22**

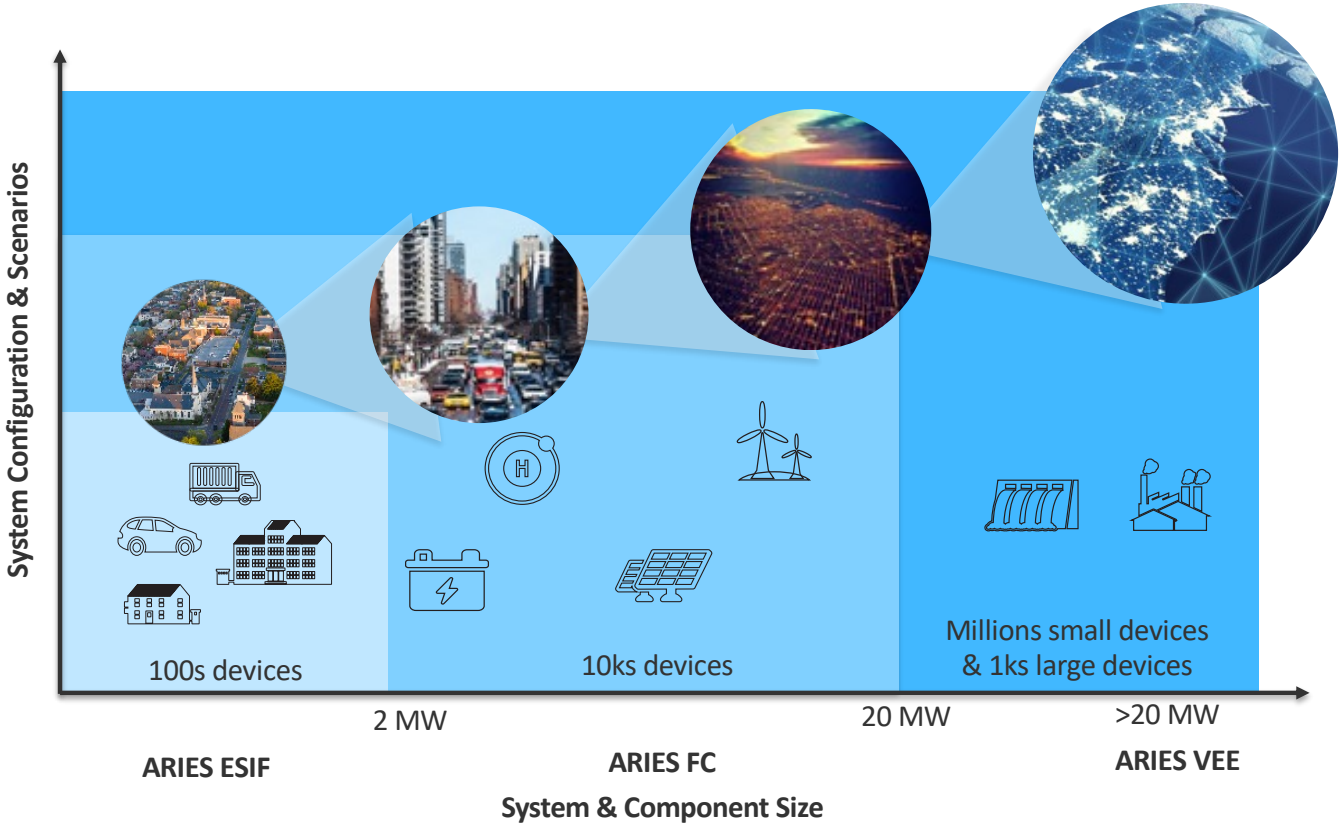
- 1.5 MW Industrial Scale Wind Turbine (Additional ~5 MW turbines)
- 730 kW (total) PV Arrays
- 1MW / 1MWh Li-ion Battery
- 3MW Programmable Load Bank
- +Six Grid Integration Research Pads
- Eight Digital Real Time Simulators (DRTS)
- +34.5 kV upgrade (phase 1), +20 MW power upgrade, 115 kV to 13.2 kV Substation and 115 kV Transmission Line
- 5 MW and +Synchronous Generator Upgrade 2.5 MW Dynamometers
- Virtual Emulation Environment Visualization and Control Room
- Control Center Facility
- 7 MW Controllable Grid Interface (CGI-1)
- 20 MW Controllable Grid Interface (CGI-2)
- 2 MW Power Electronics Grid Interface (PEGI)
- 1.25 MW Hydrogen Hub and 1 MW Fuel Cell
- 1 MW Behind the Meter Storage and EV Fast Charge
- ESnet 100 Gbps Connection to ESIF
- 500 kW Distributed Integrated Energy Laboratory (DIEL)

Integration with IoT/RTU/ Controllers at Scale

Data packets from different categories of devices (IOTs, RTUs, PMUs) can be ingested at a city/regional scale and passed on the HERTH platform for at-scale simulation of distribution automation, microgrids and nano-grids



Expansion of at-scale Hardware-in-the-Loop Analysis Capability



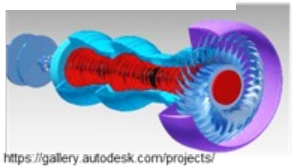
The Science of Scaling for MW Devices

- Inertia
- Non-linearity
- Response time
- Transfer mechanisms

Challenges

- Dynamic behavior
- System integration
- Lifetime and performance

Lab/ESIF Scale



https://gallery.autodesk.com/projects/steam-turbine-generator---g6

MW/Flatiron Scale

http://www.mechscience.com/steam-turbine

Real world

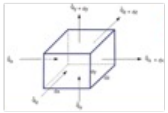
https://www.powerengineeringint.com/articles/2016/02/

- Fundamental physics modelling

$$\frac{d}{dx}\left(k\frac{dT}{dx}\right)+\dot{q}=\rho c_p\frac{dT}{dt}$$

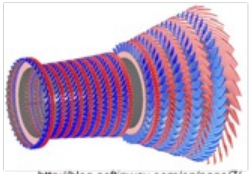
$$\rho\left(\frac{\partial u}{\partial t}+u.\nabla u\right)=-\nabla p+\mu\nabla^2 u+\frac{1}{3}\mu\nabla(\nabla.u)+\rho g$$

- Numerical Analysis and simulation



* Up-scale modelling
* Dimensionless approach
* Order of magnitude analysis (scale analysis)

- Dynamic analysis
- Optimization
- System based analysis



http://blog.softinway.com/cn/page/7/

Disruptive solution

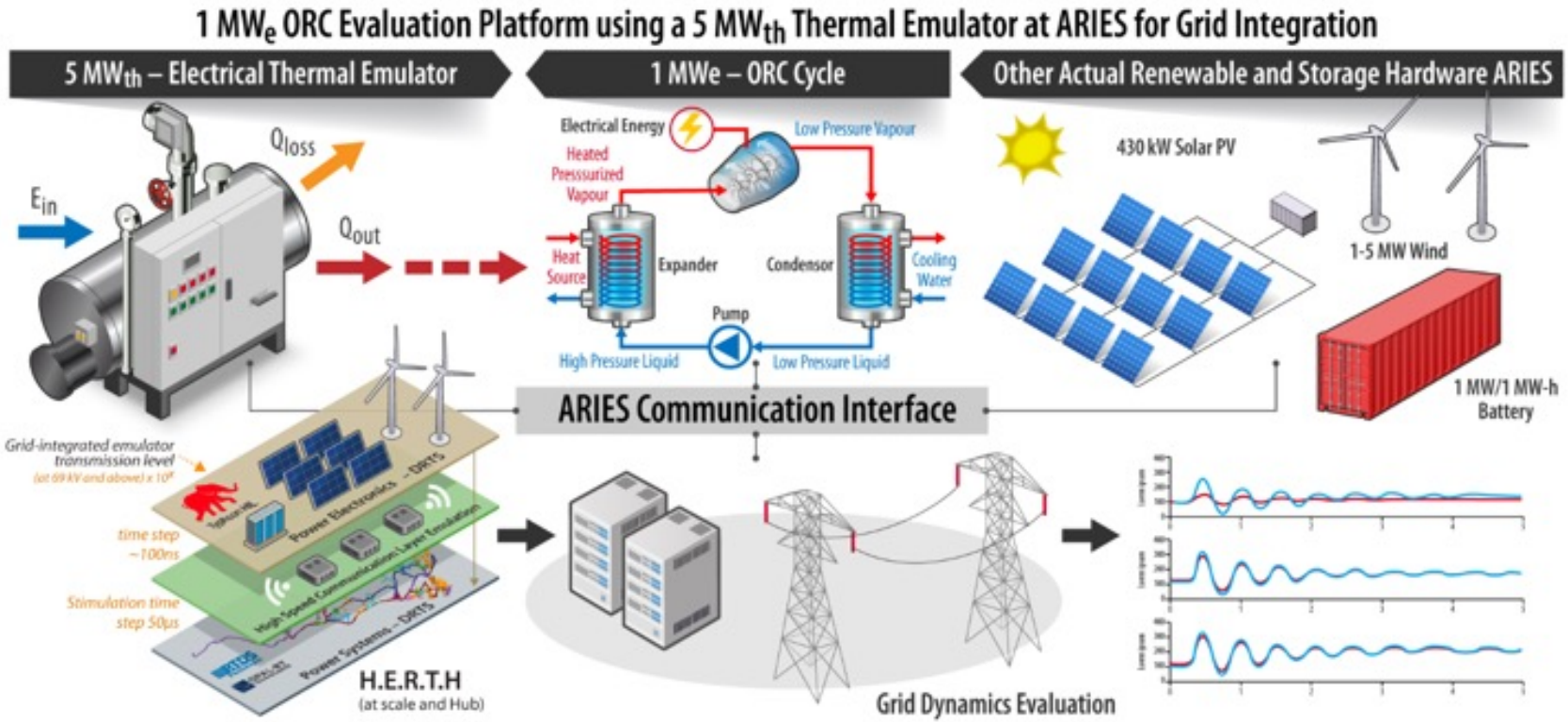
Integration

Bejan. Convection heat transfer, 4th Ed, Wiley, 2013

Hovsapian et al. Int. J. Ener Res 32 (13), 1210-1227

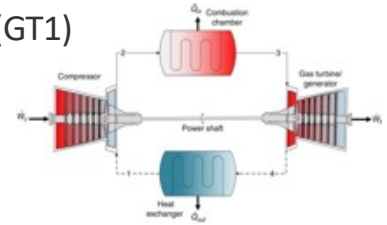
Electrical | **Thermal** | **Mechanical** | **Communication** | **Control**

DOE AMO Megawatt – Hardware Evaluation using Thermal Emulation



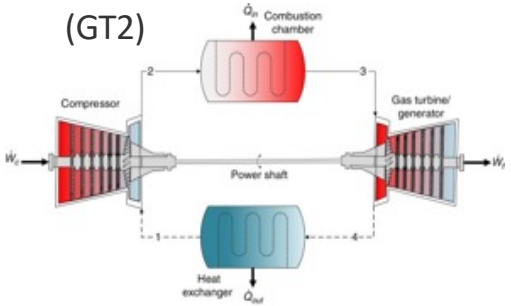
Scaling Approach Using Machine Learning

Gas turbine 1
(GT1)



Capacity GT1 ≠
Capacity GT2

Gas turbine 2
(GT2)

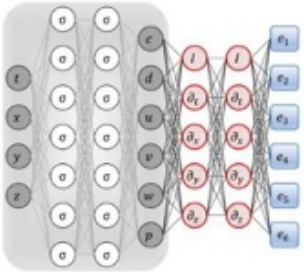


Digital Real Time Simulation

Input parameters
(0 < t < t₁)

Output Parameters
(0 < t < t₁)

Training



Neural network

Testing

Input parameters
(t₁ < t < t₂)

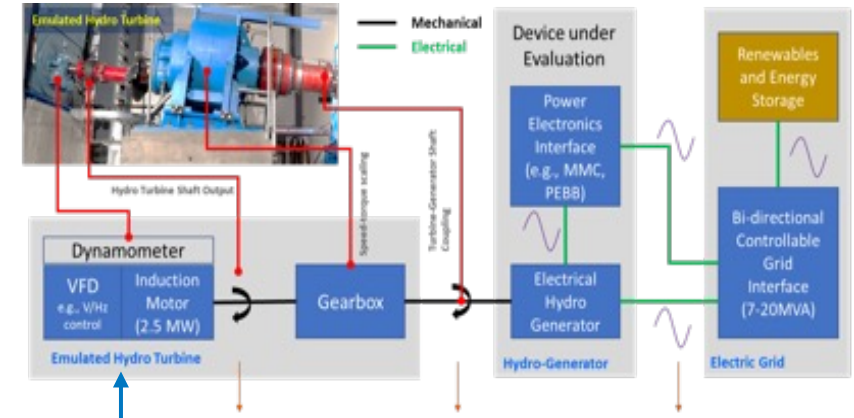
Machine learning
model prediction

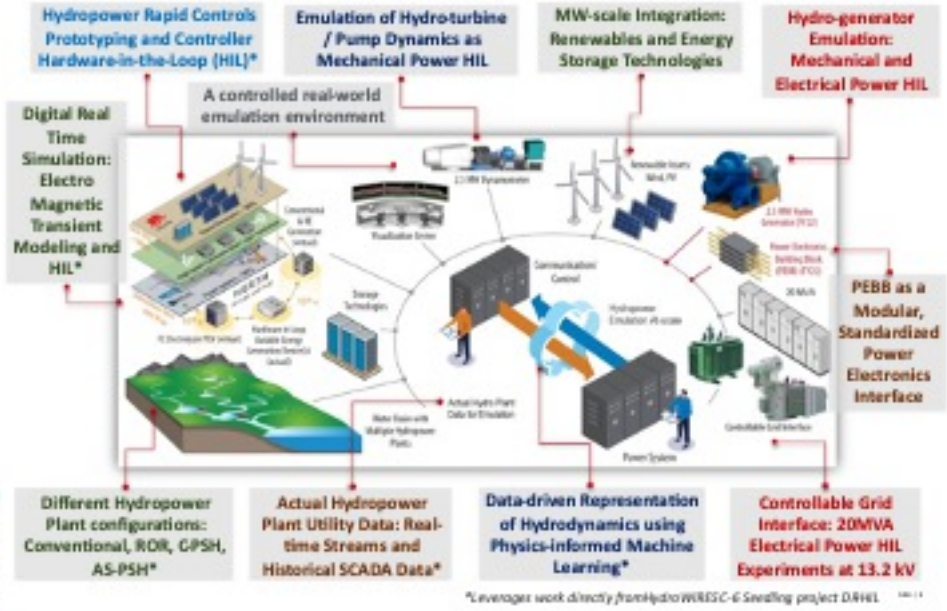
Output parameters
(t₁ < t < t₂)

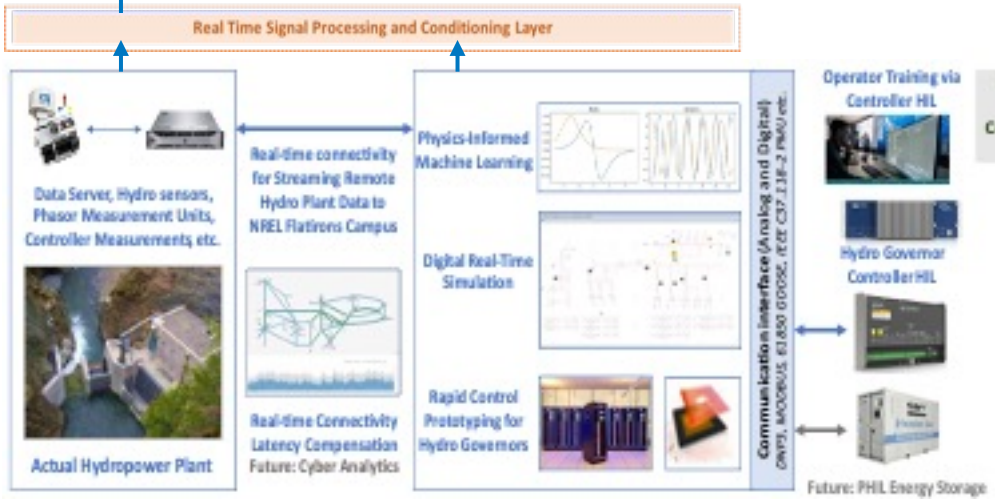
Digital Real Time Simulation

NREL
Transforming ENERGY

US DOE/NREL – Norway Collaboration on Advancing Hydropower Modernization Research







U.S. Dept. of Energy EERE Water Power Technologies Office: Sam Bockenhauer

National Renewable Energy Laboratory: Mayank Panwar, Rob Hovsapian, Greg Stark

Univ. of South-eastern Norway: Thomas Oyvang

NTNU: Kjetil Uhlen, Jonas K. Nøland

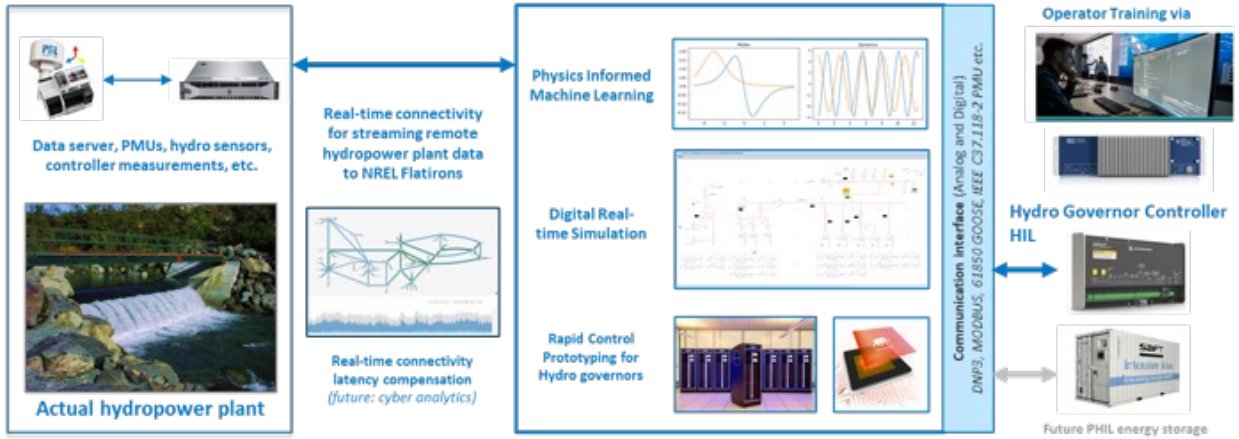
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

WATER POWER TECHNOLOGIES OFFICE

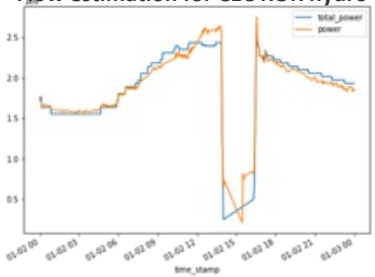
NREL Transforming ENERGY

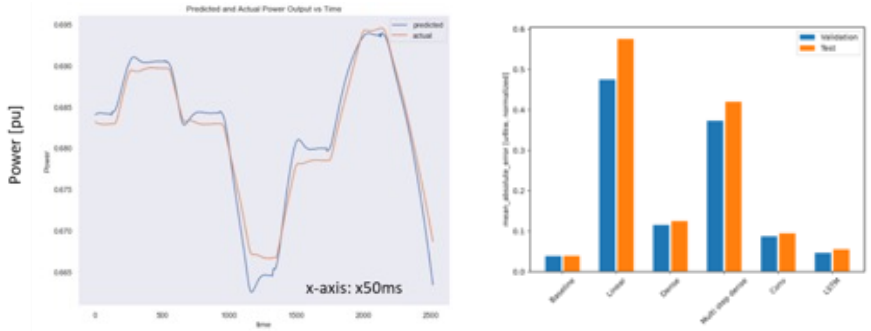
USN University of South-Eastern Norway

ARIES HydroWIRES *DR-HIL – Hydro power Prediction Using ML*



Flow estimation for CEC ROR hydro





RTDS PSH model output power prediction using reservoir computing (left); and ROR hydro power prediction using machine learning in Tensorflow2 (right)

- Working on PIML implementation

Resilient Alaskan Distribution system Improvements using Automation Network analysis, Control, and Energy storage (RADIANCE) – MG Use Case

Humpback Creek Hydroelectric Plant
1250kW (2 x 500 kW + 1 x 250 kW)
17,000 foot UG and submarine transmission line

Power Creek Hydroelectric
6248kW (2 x 3124 kW)
25 kV transmission ties to Eyak Substation, Inflatable dams

City of Cordova
2300 customers, 18MW
One Substation
78mi UG distribution lines

Orca Power Plant
10.8 MW Diesel
Control Center, CEC

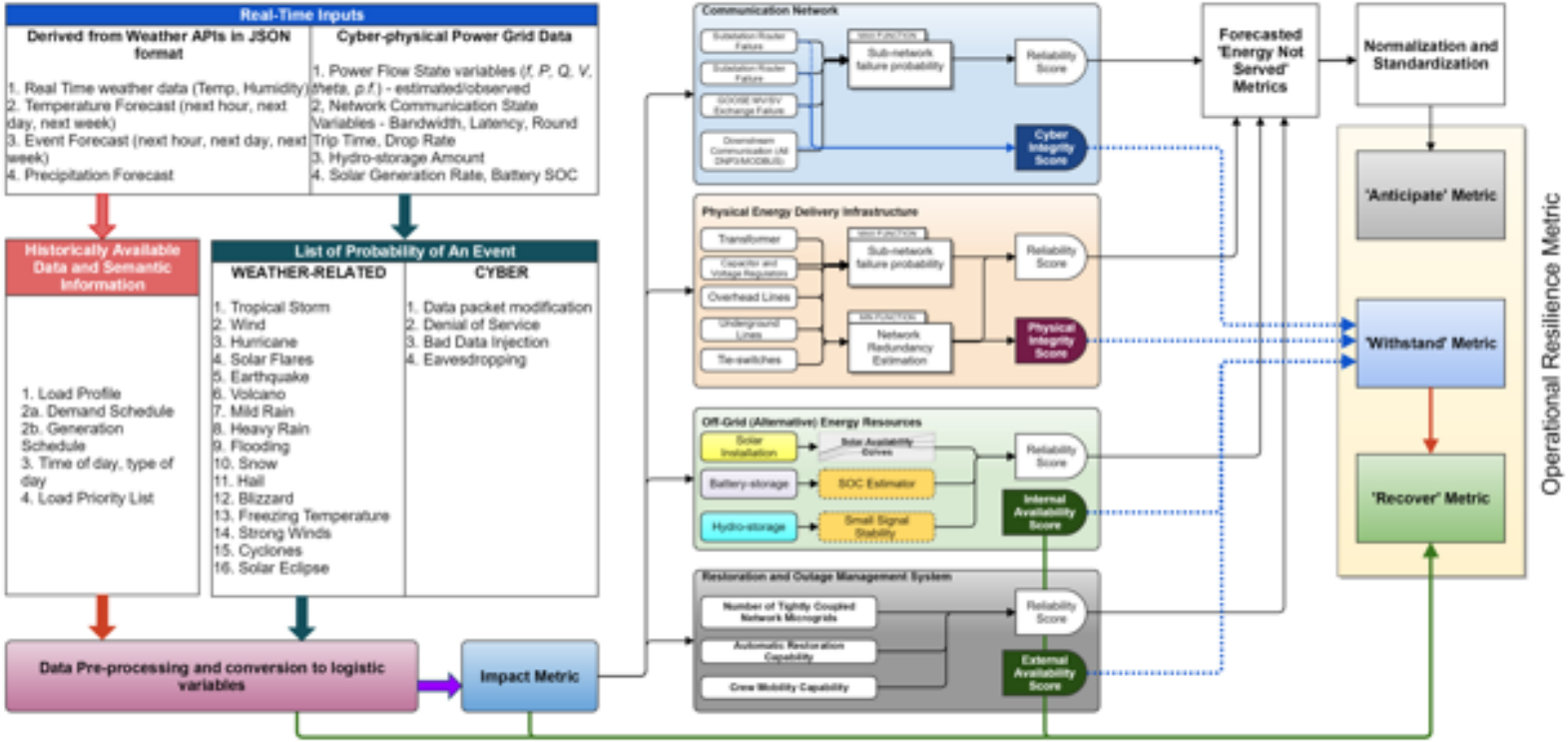
Raging Creek – future hydro site
Potentially pumped hydro storage

- **1MW-1MWh ABB-Saft BESS installed and commissioned**
- **Zonal reconfiguration using AMI and dispatchable electric boiler to be installed and commissioned**
- **Upgrade to digital governors for diesel plant**

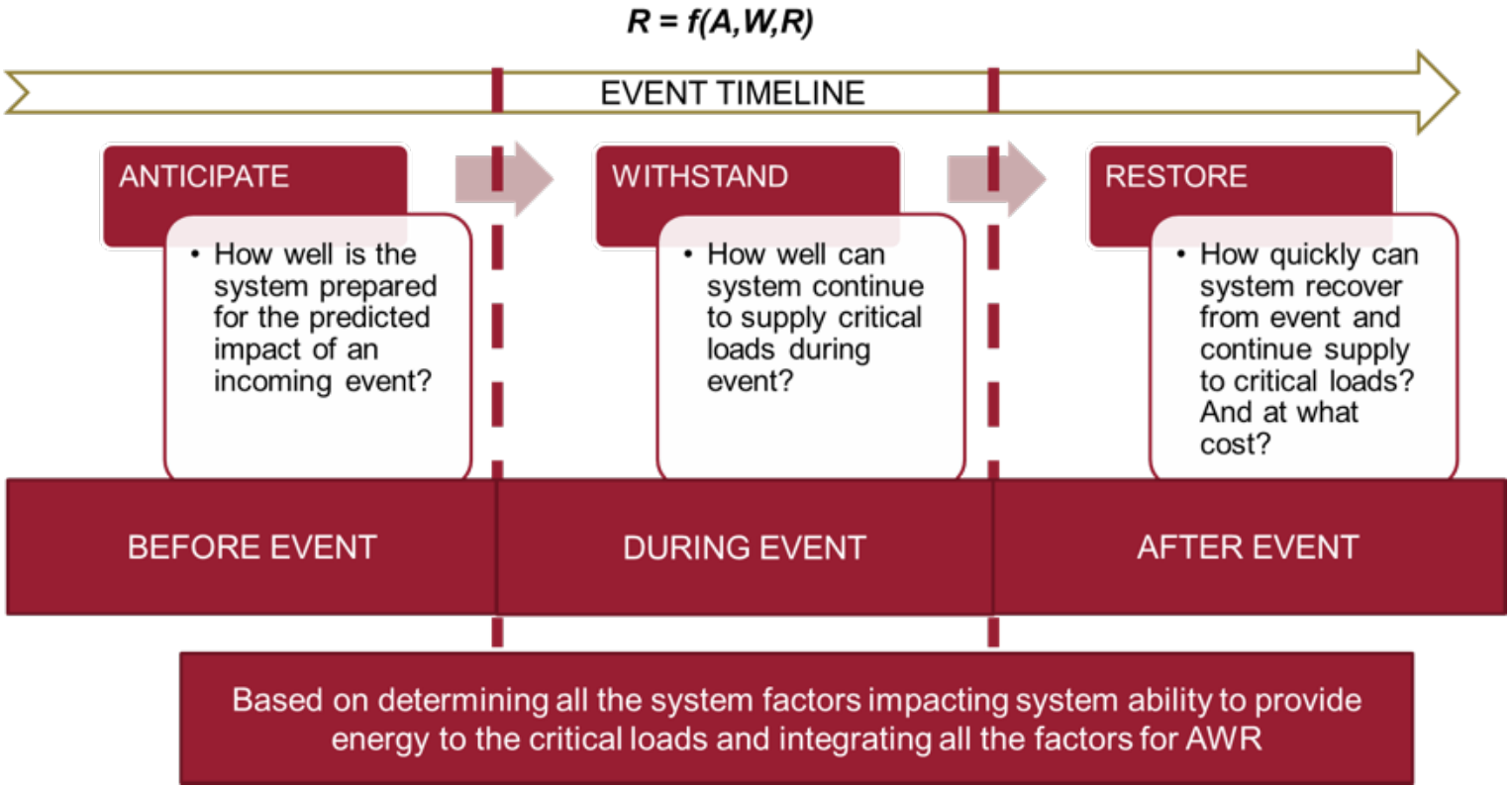
Resilient Alaskan Distribution system Improvements using Automation Network analysis, Control, and Energy storage (RADIANCE)

RADIANCE – Resilience by Design

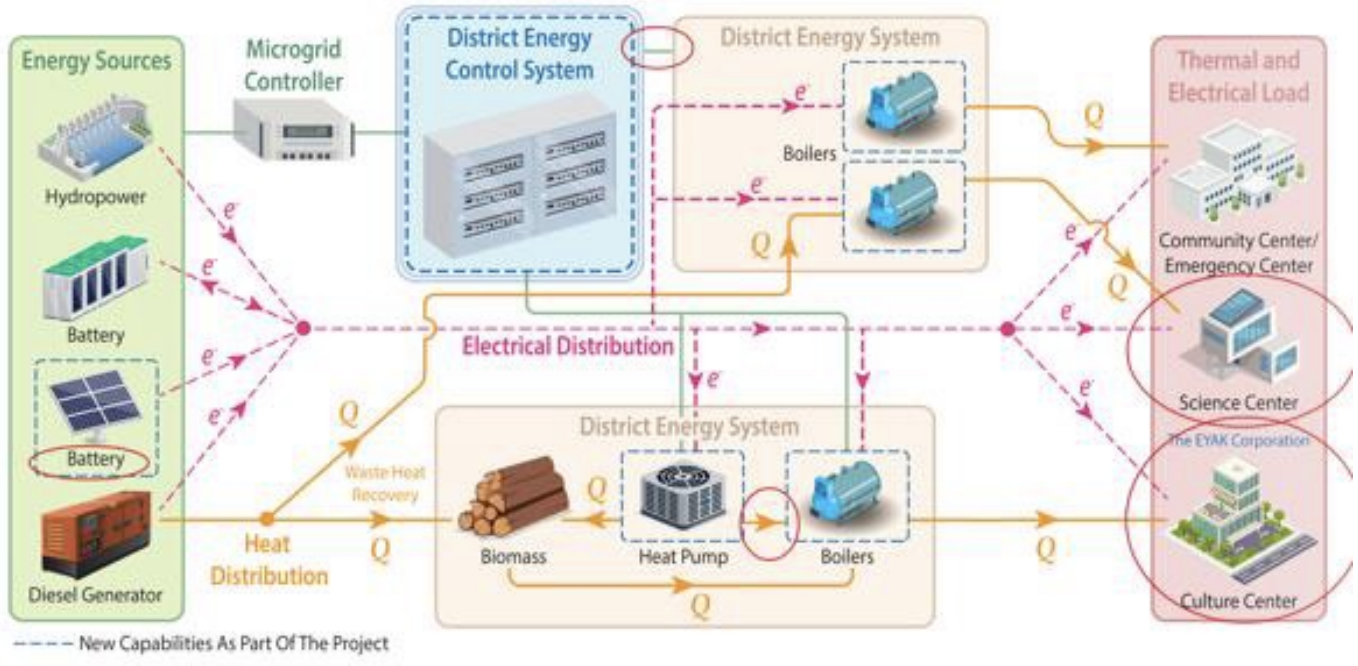
- **Resilience by design** – using **zonal approach** in **networked microgrids**
  - **Operational Resilience Metrics Computation for Resilience**



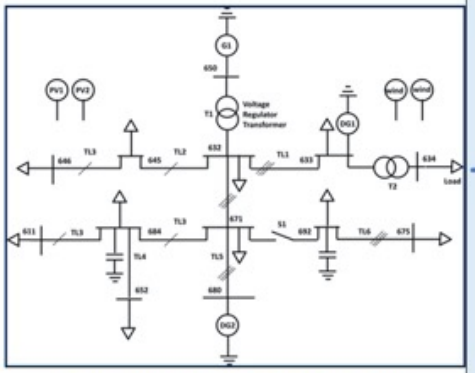
RADIANCE - Approach – Resilience Metrics Definition



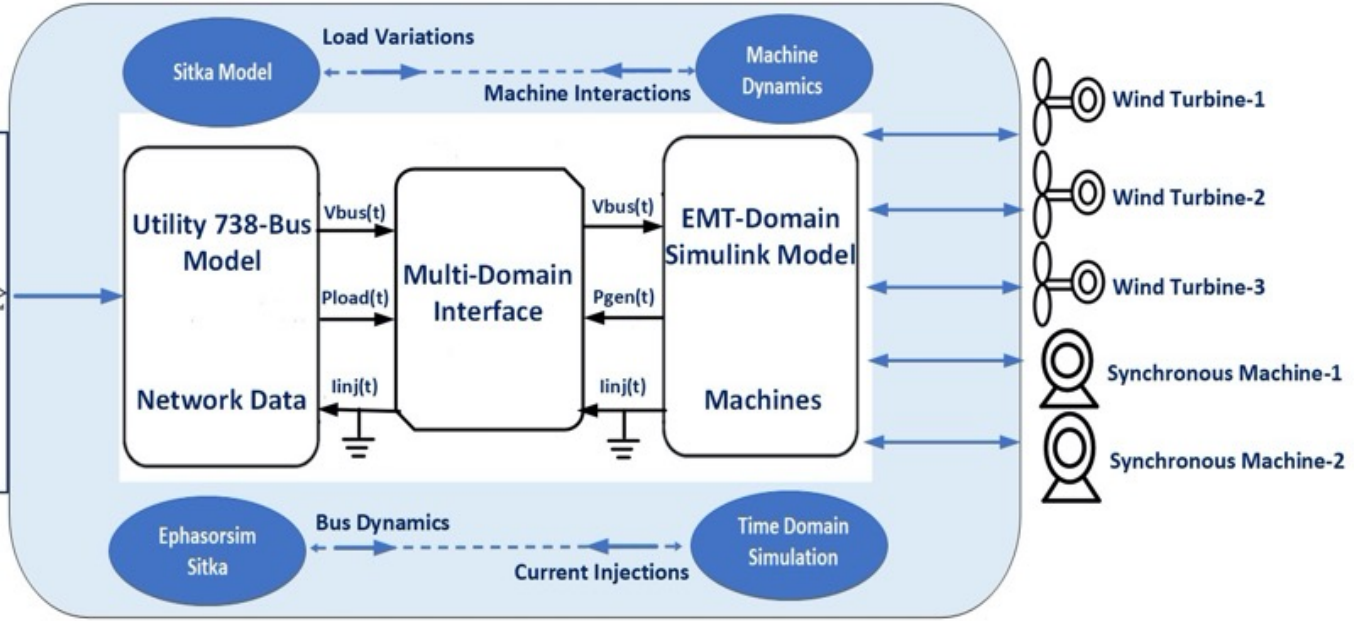
(REDSEA) -REsilientDistrict heating for Sustainable Energy Adoption in Cordova Community Emergency Center



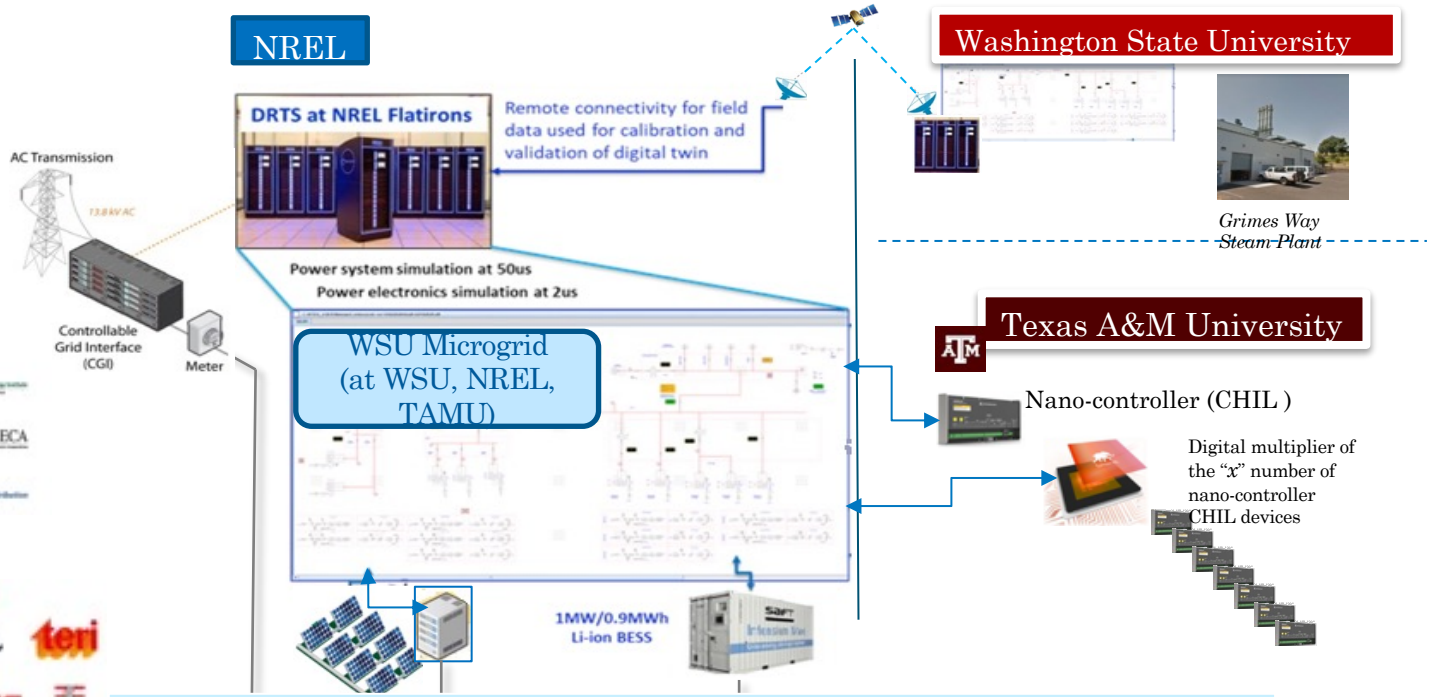
ETIPP - Sitka AK Utility analysis – DRTS Multi-rate Simulation Model



Notional One-Line Diagram



NREL – UI-ASSIST Microgrid Environment

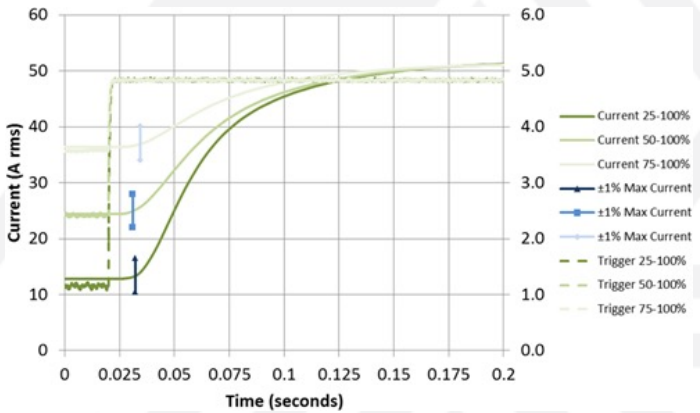


UI-ASSIST

The U.S.-India collAborative for smart diStribution System wIth Storage, is a six-year collaboration between several partners in the United States and India. Led by Washington State University in the US and IIT Kanpur in India, UI-ASSIST aims to increase accessibility to renewable energy in both countries.

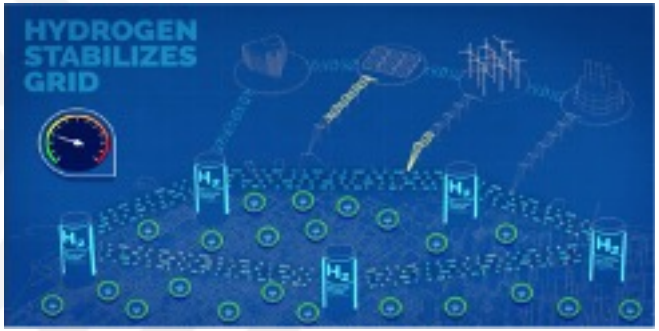
Hydrogen - Potential Grid Service Capabilities

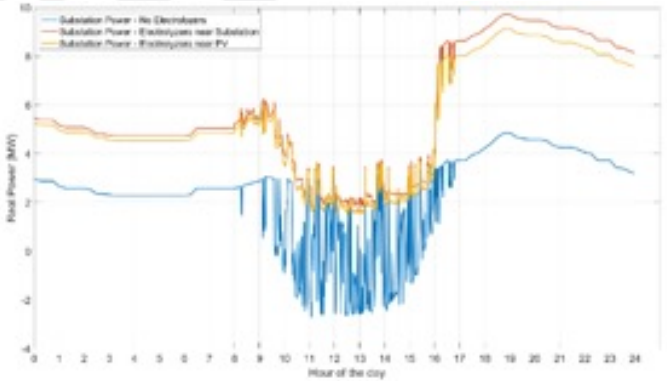
- Electrolyzer can be used as **controllable load** and provide **fast sub-second response**.



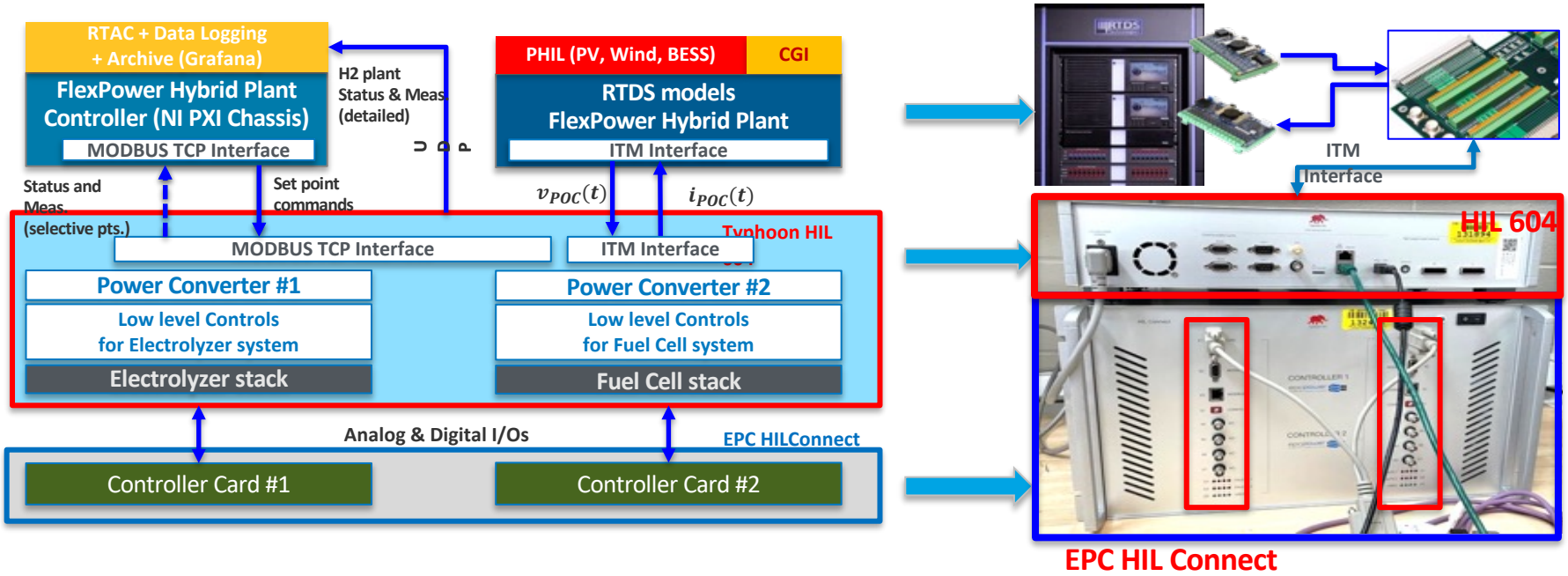
- Electrolyzers can enable **higher penetration** of renewable energy with hydrogen production and reduce **transients**.

- Electrolyzer can provide **wide-area frequency** and **voltage regulation.**





Enabling Utilities to collaborate with lab-scale facilities to evaluate hardware innovations and their impact on the power grid: ELECTROLYZER EXAMPLE



Hydrogen Electrolyzer Standardization

Real-time Simulation
SunSpec MODBUS Interface in Typhoon for Hydrogen Electrolyzer, includes low-level control integration with H2SCADA.

Model Validation
SunSpec MODBUS Standard and Vendor Model in Typhoon HIL with EPC Power's power converter controller.

CHIL Validation
SunSpec System Validation Platform with Typhoon CHIL.

CHIL-based Validation in Typhoon HIL Real-time Test Suite.

Industry Engagement
Electrolyzer Information Model and Interface Standardization with SunSpec, Electrolyzer, Power Electronics industry.

Industry Adoption
Industry acceptance, adoption, and harmonization with Grid Codes (CA Rule-21, HI Rule-14) and Standards such as IEEE 1547.

Current work → **Future work**

Industry collaboration

Typhoon HIL

nel

epcpower excellence in power conversion

SUNSPEC ALLIANCE

Additional industry collaboration:

SEMIKRON DANFOSS

Hitachi Energy

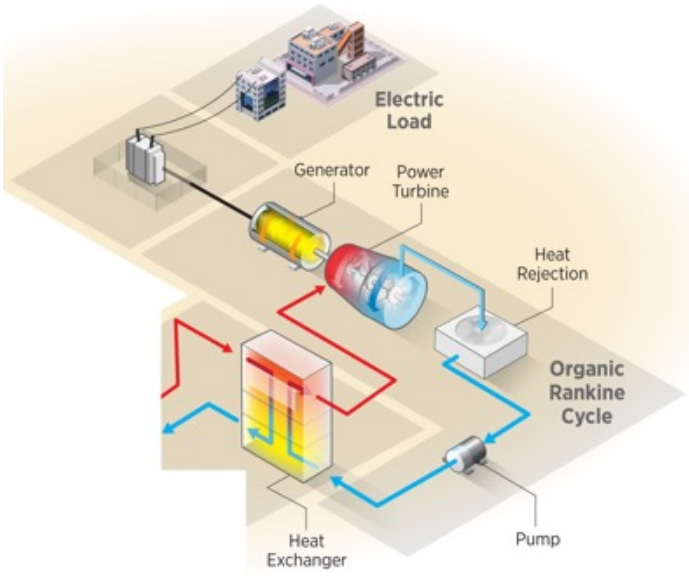
TECO Westinghouse

OPAL-RT TECHNOLOGIES

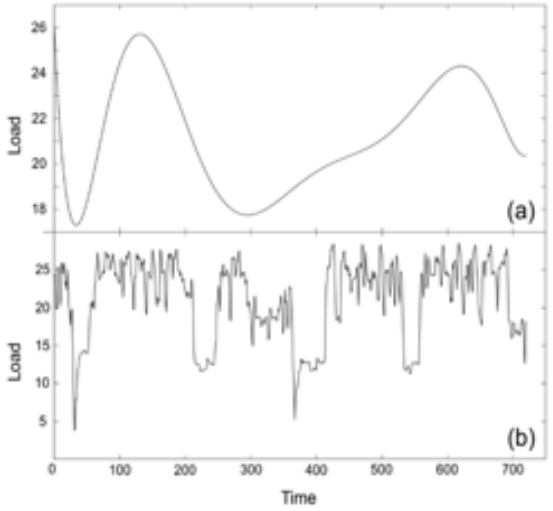
DOE- AMO Megwatt - Integration into Real Time Simulation Environment

Megawatt Scale, Multi-Source Heat Recovery System with a Flexible Grid Interconnect

ORC integration into real time simulation



Digital Real Time Simulation



CLEMSON UNIVERSITY

TECO Westinghouse

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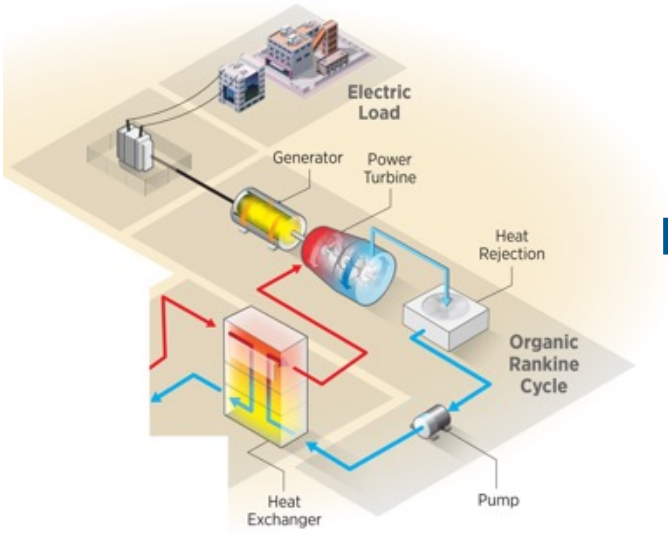
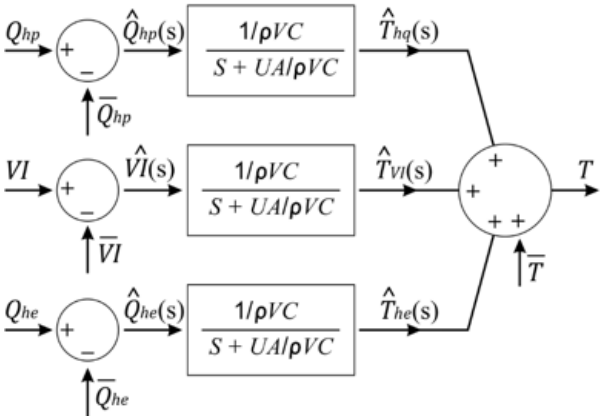
Megawatt - Integration into Real Time Simulation Environment

ORC integration into real time simulation



Physics based model



$$\Delta P_{ORC}(s) = \frac{n_{\omega 1}s + n_{\omega 0}}{s^2 + d_{\omega 1}s + d_{\omega 0}}\Delta\omega(s)$$

Transfer function

Digital Real Time Simulation

To be replaced for the current system from TECO

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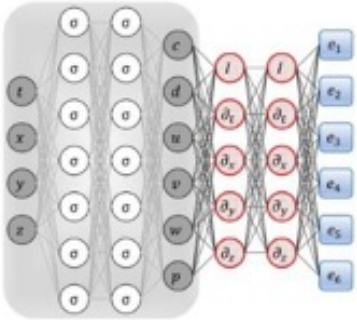
Megawatt - Machine learning approach for scalability

Input

Heat input: *Qin(t)*
Ambient temp.: Tinf(t)
Load: L(t)

Transient physics-based model
$(t_0 \le t \le t_0+\Delta t = t_2)$

Training



DeepONet Neural network

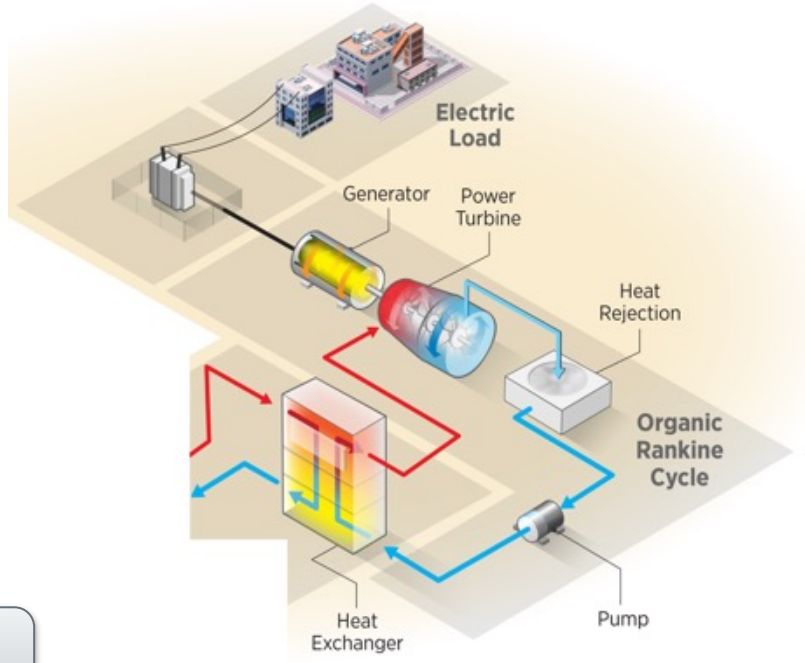
Output

Efficiency.: eta(t)
State of charge: SoC(t)
Heat losses: Qloss(t)

Testing

Physics-based model calculation
$(t_0 \le t \le t_0+\Delta t = t_2)$

Machine learning model prediction
$(t_2 \le t \le t_2+\Delta t = t_3)$



Analysis, comparison, and Validation

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Thank You

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