American Modelica Conference 2022

Modeling and Control of Nuclear-Renewable Integrated Energy Systems for Electricity and Hydrogen Production




Authors: Roshni Anna Jacob and Jie Zhang

The University of Texas at Dallas

Presenter: Roshni Anna Jacob

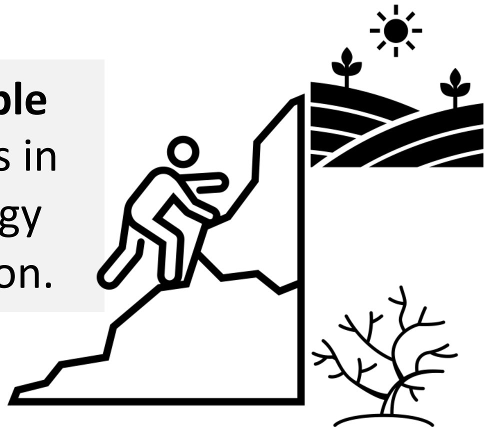
Introduction

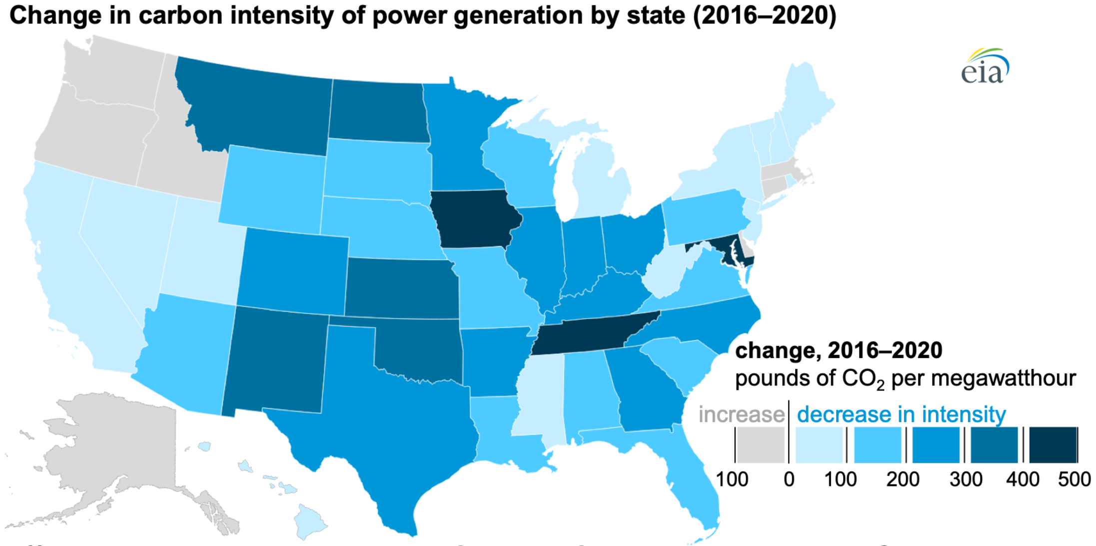
MOTIVATION:

- ❑ Rapid depletion of fossil fuel resources.
- ❑ Extreme weather events attributed to climate change.
- ❑ Need for energy security and resilience.

Diversification of energy resources along with decarbonization is the future of sustainable energy.

Increase in **nuclear- renewable mix** in power generation aids in the shift towards green energy resources and decarbonization.





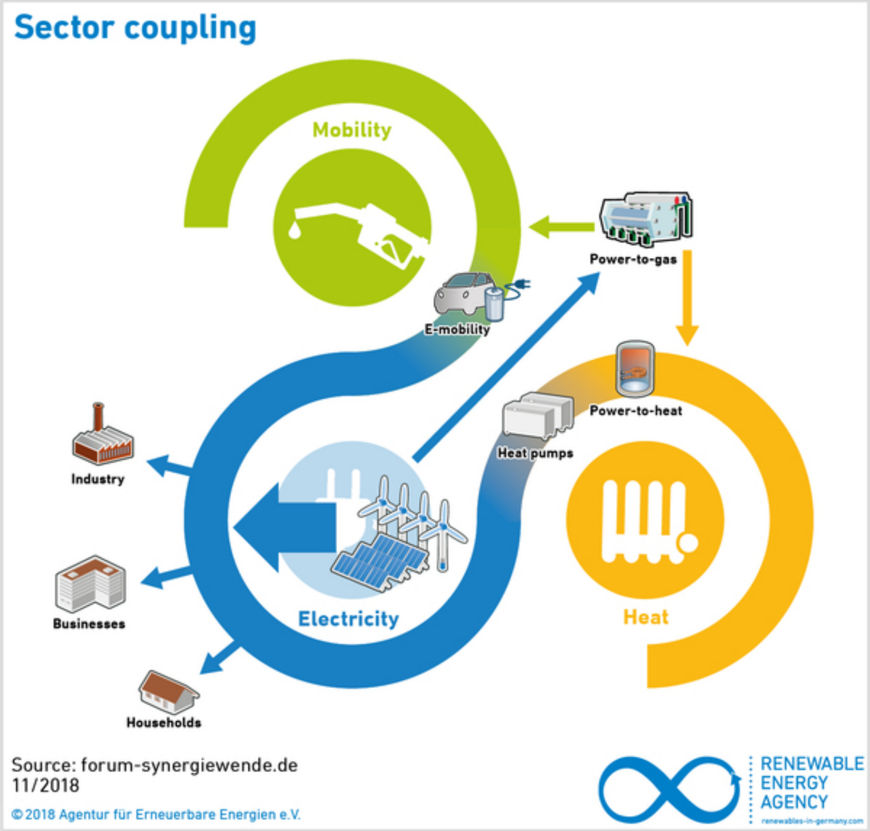
“From 2016 to 2020, the carbon intensity of U.S. power generation fell 18%.” – U.S. Energy Information Administration, *[Power Plant Operations Report]*

Nuclear power can generate enormous amounts of reliable, carbon free electricity. They contribute to the stability of electricity grids by backing up the intermittent output of renewable sources through flexible operation or load following.

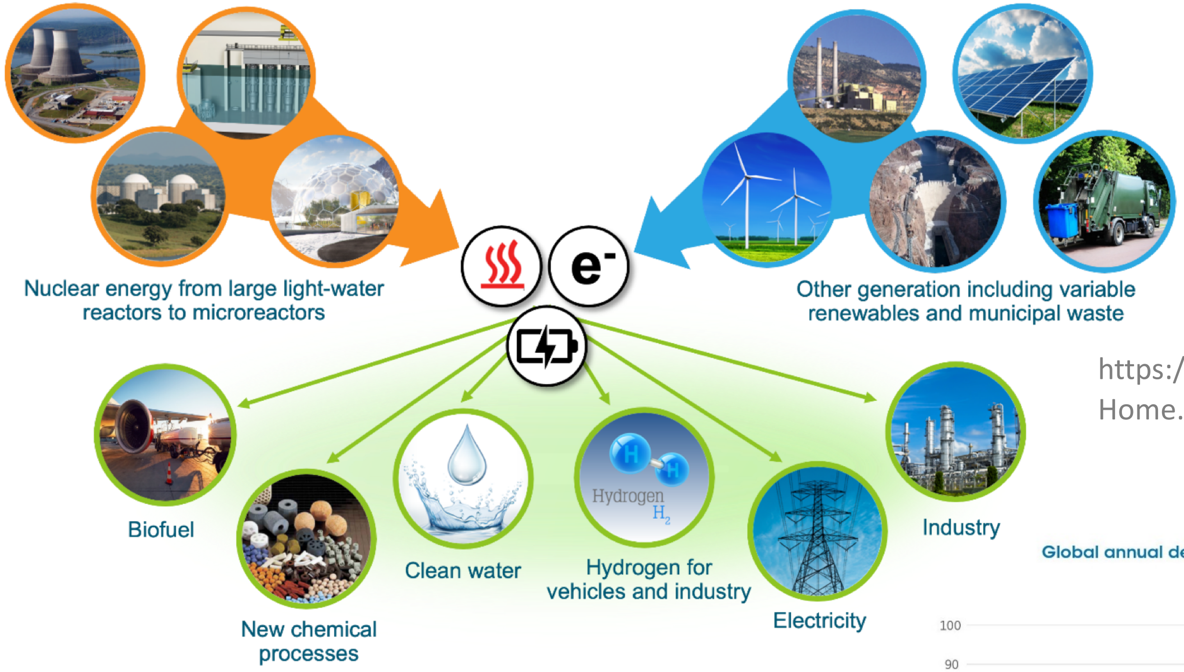
https://www.iaea.org/newscenter/news/nuclear-and-renewables-playing-complementary-roles-in-hybrid-energy-systems

Background

- ❑ Improve energy utilization by employing the same generation resources to supply multiple end uses such as electricity, heat, transportation, etc.

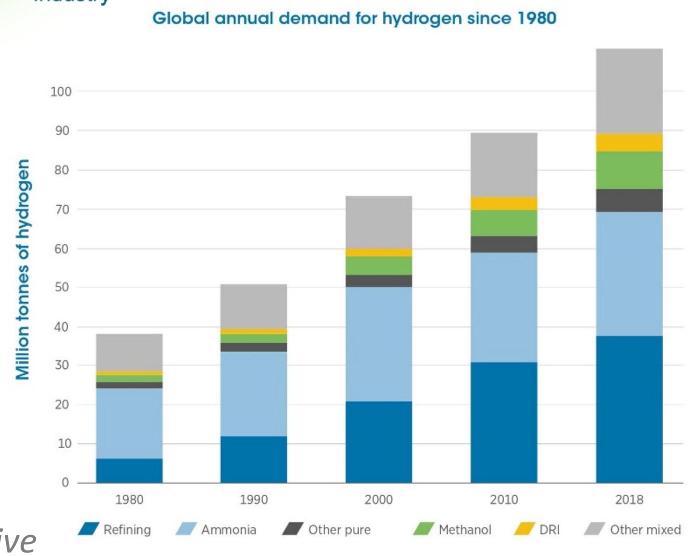


Integrated Energy Systems (IES) is an approach of considering multi-energy systems holistically.



https://ies.inl.gov/SitePages/Home.aspx

- ❑ Green hydrogen production has gained unprecedented momentum
- ❑ Hydrogen is also now a commodity in the electricity/thermal energy sector.



Irena 2019 report, Hydrogen: a renewable energy perspective

Background

- **Small Modular Reactors (SMRs)** are advanced nuclear reactors with size from tens of megawatts up to hundreds of megawatts .

- SMRs are **modular**, **scalable**, and a **clean energy** resource, which can provide reliable energy for power generation, process heat, desalination, and/or other industrial uses.

The U.S. DOE has partnered with NuScale Power and Utah Associated Municipal Power Systems (UAMPS) to demonstrate a first-of-a-kind reactor technology at the Idaho National Laboratory this decade.

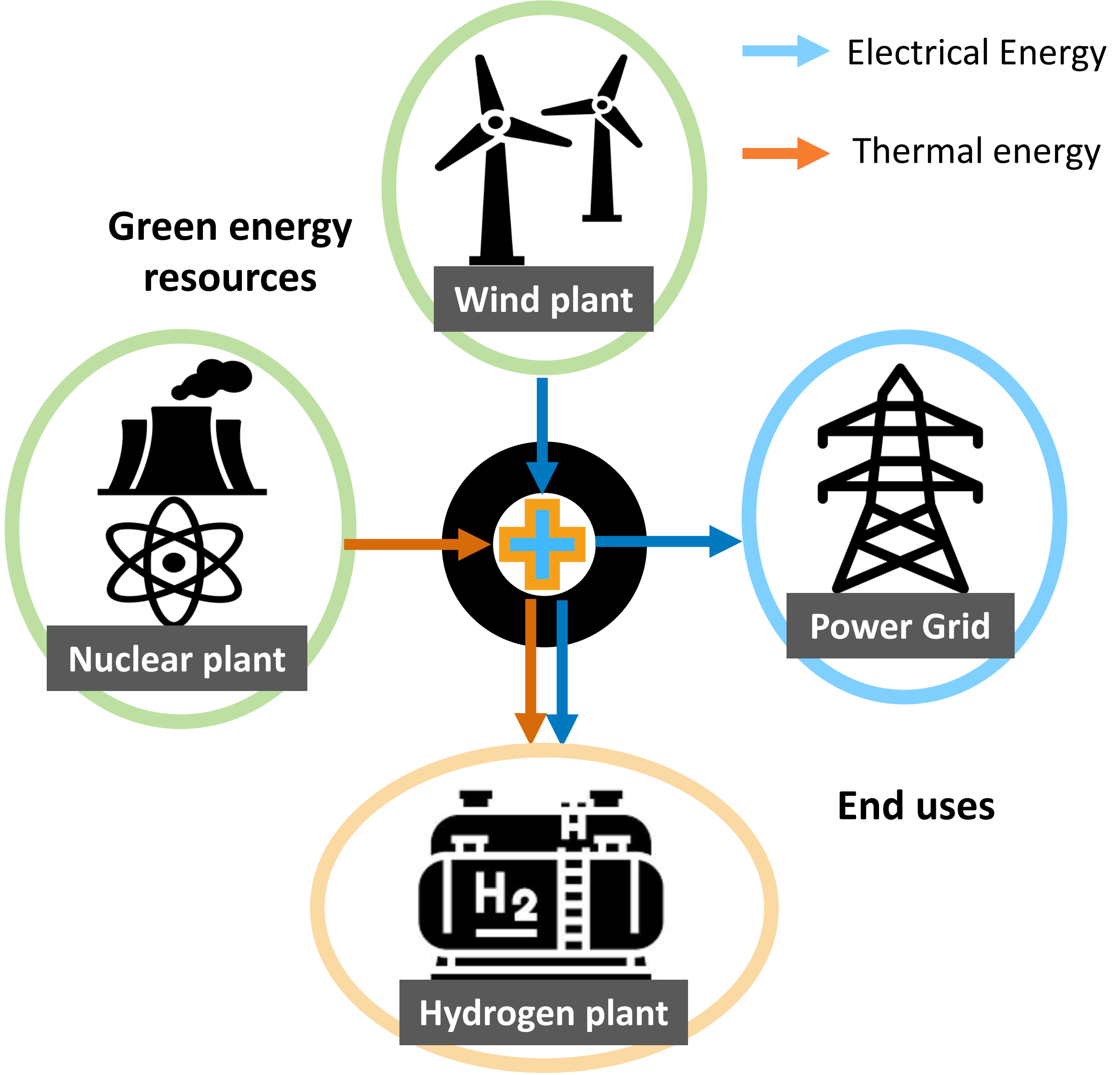
https://inl.gov/trending-topic/small-modular-reactors/

Goal

- **Design and model** an IES with **nuclear plant (i.e., SMR)** as the primary source along with **wind energy,** supplying **electricity to the grid** and utilizing **thermal energy and electricity to produce hydrogen**.

- Design a control system to ensure coordinated control between different subsystems while responding to the optimal dispatch signals.

- Evaluate the IES performance and inspect load following capability.



Choice of Modeling and Simulation Platform

Modelica

- **Multi-domain modeling**.
- Ease of modeling hybrid, non-linear, simultaneous, differential-algebraic equations.
- **Physical interaction between components possible using connectors**.
- Modeling is based on equations as opposed to assignment statements.
- Flow directionality can be modeled.
- **Object oriented language: reusable, extensible and exchangeable**.

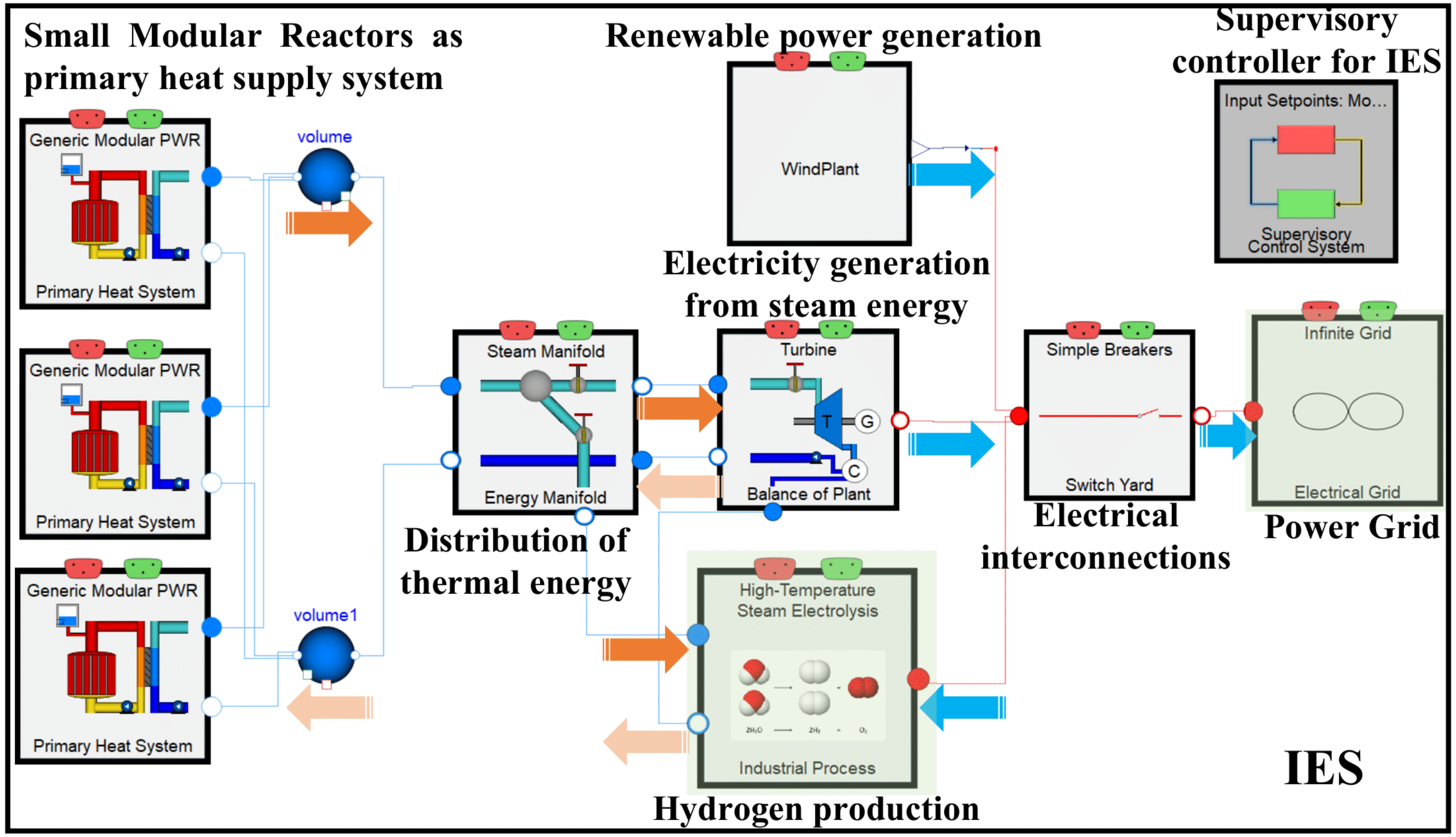
Dymola

IES modeling requirements:

- A **"system of systems".**
- Multi-domain modeling tool: different forms of energy and material transfer within the IES. **Thermal, fluid, mechanical and electrical component models in our case**.
- **Physics based modeling** and simulation to evaluate the behavior and response of components and system to dispatch signals.

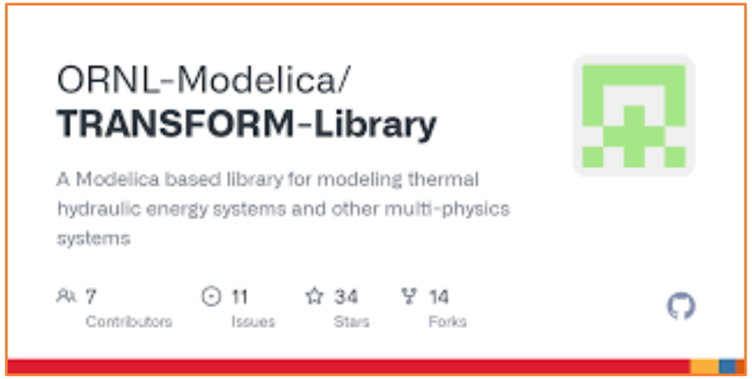
Model Development

Top level view of IES model in Dymola

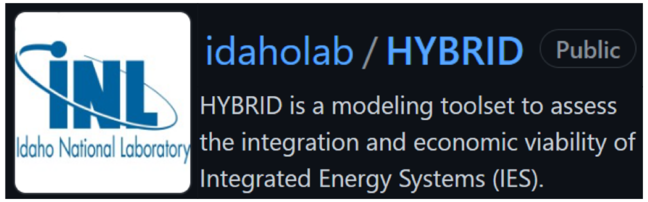


Thermal-hydraulic domain Electricity domain End services

Dependencies



https://github.com/ORNL-Modelica/TRANSFORM-Library



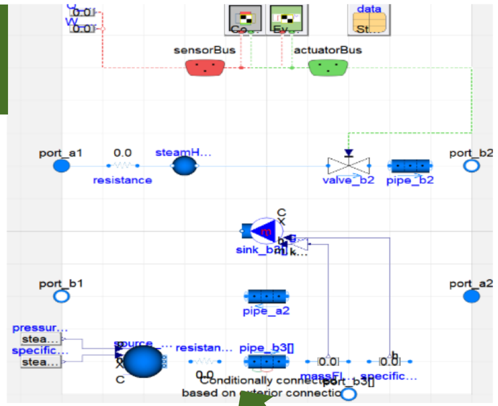
https://github.com/idaholab/HYBRID

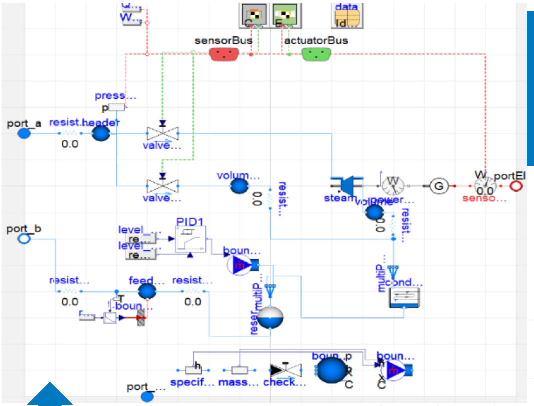
https://github.com/christiankral/WindPowerPlants

The IES park uses the template provided by ORNL in the TRANSFORM library. These sandbox models have also been adopted by INL in the HYBRID-NHES package.

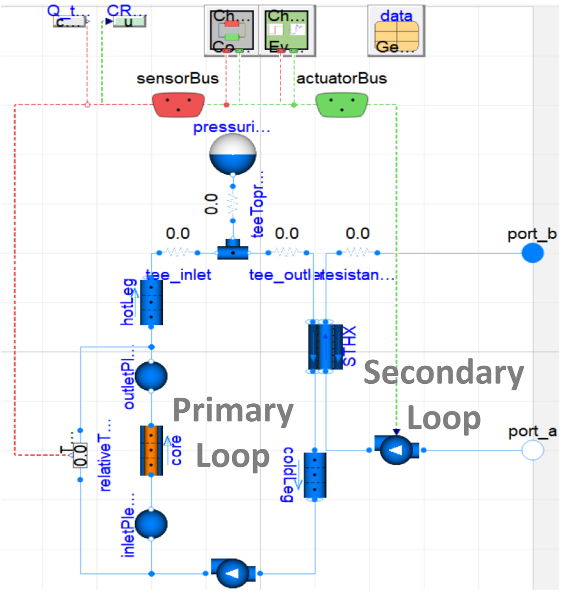
Model Development

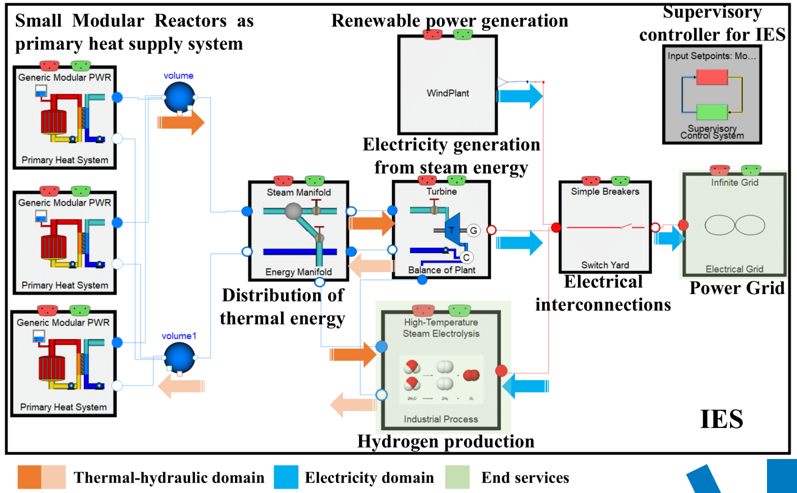
Steam Manifold: Diverts steam to different subsystems using valves



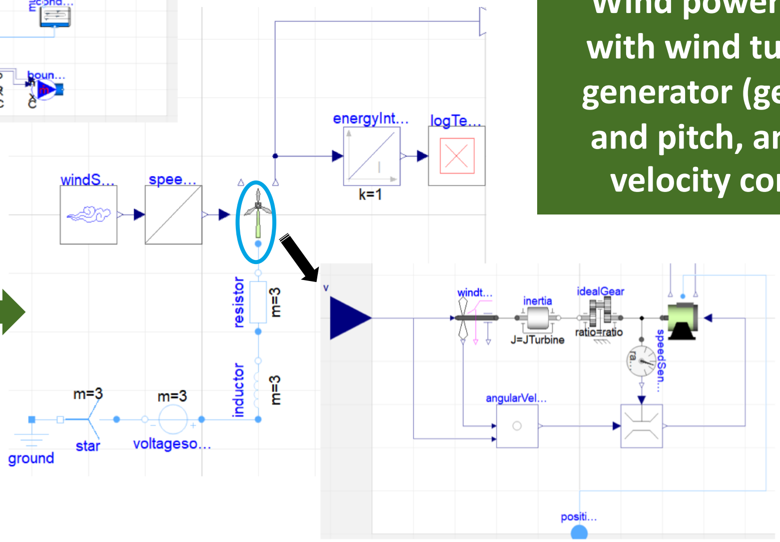


Balance of Plant: Generates electrical power from thermal energy (Valves for load following)

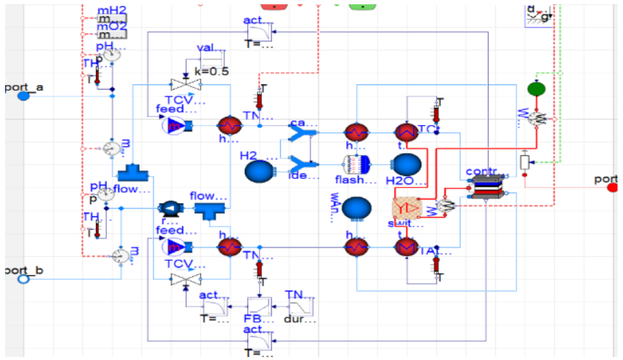




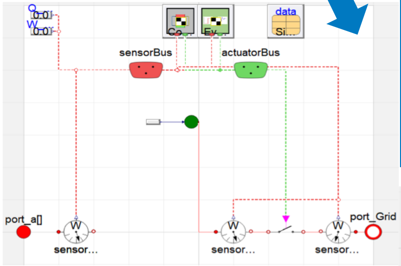
Wind power plant with wind turbine, generator (generic) and pitch, angular velocity control



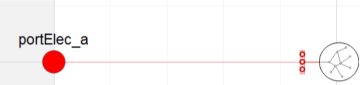
Nuclear plant: Primary heat supply system of three modular reactors of 160MWt each



Hydrogen production using high temperature steam electrolysis



Switch yard with interconnections to the power grid (infinite sink/source)



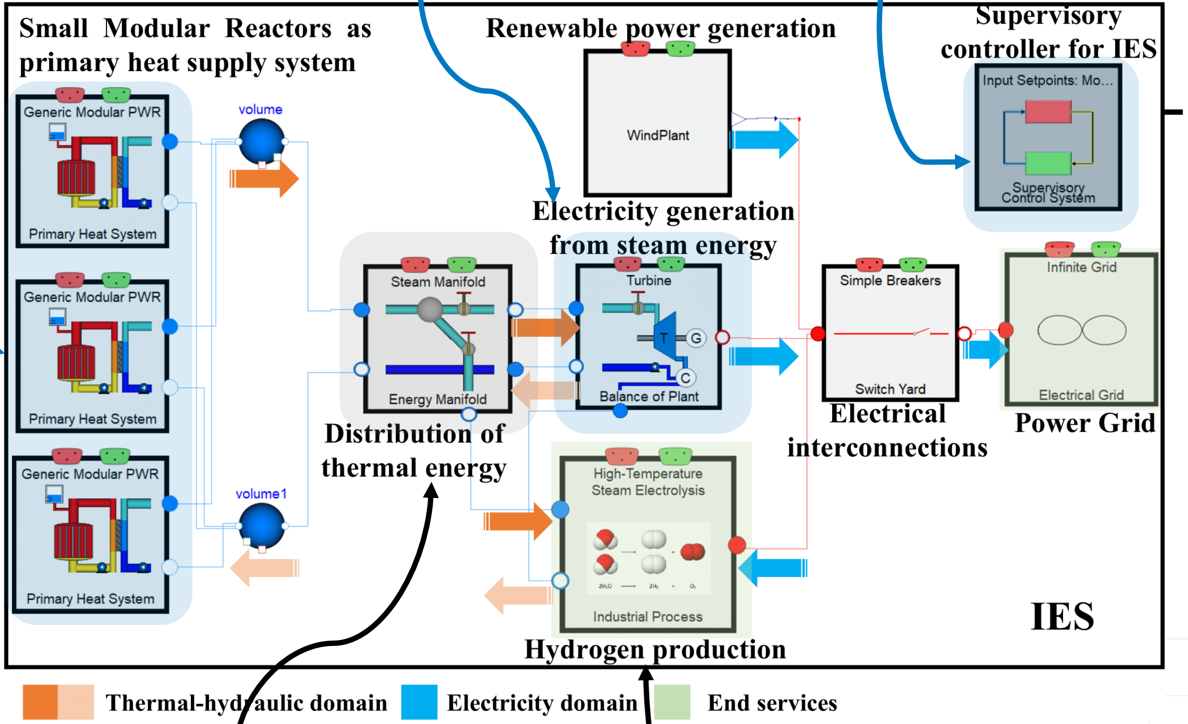
Supervisory control is responsible for overall system control and coordination. Accepts dispatch signals and sends control signals to lower-level control modules

Control and Co-ordination

Steady state control

Power and pressure control

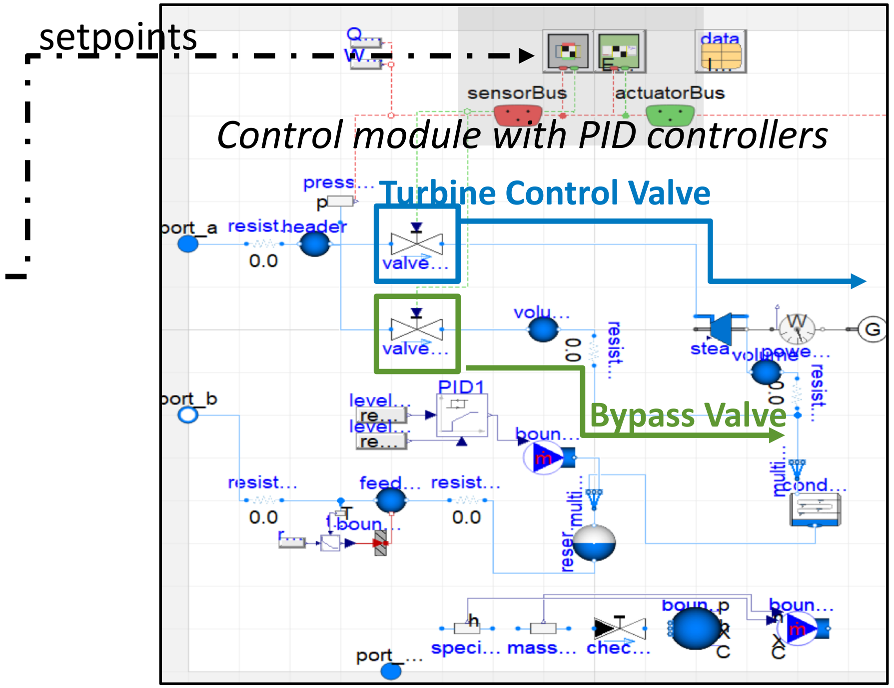
Overall control architecture



Valve control

Steam or power control mode

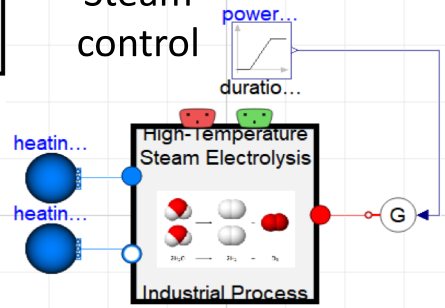
Electrical Load Following in IES

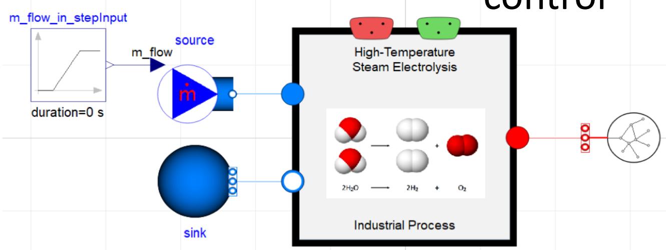


Hydrogen Plant Modes

Steam control

Power control



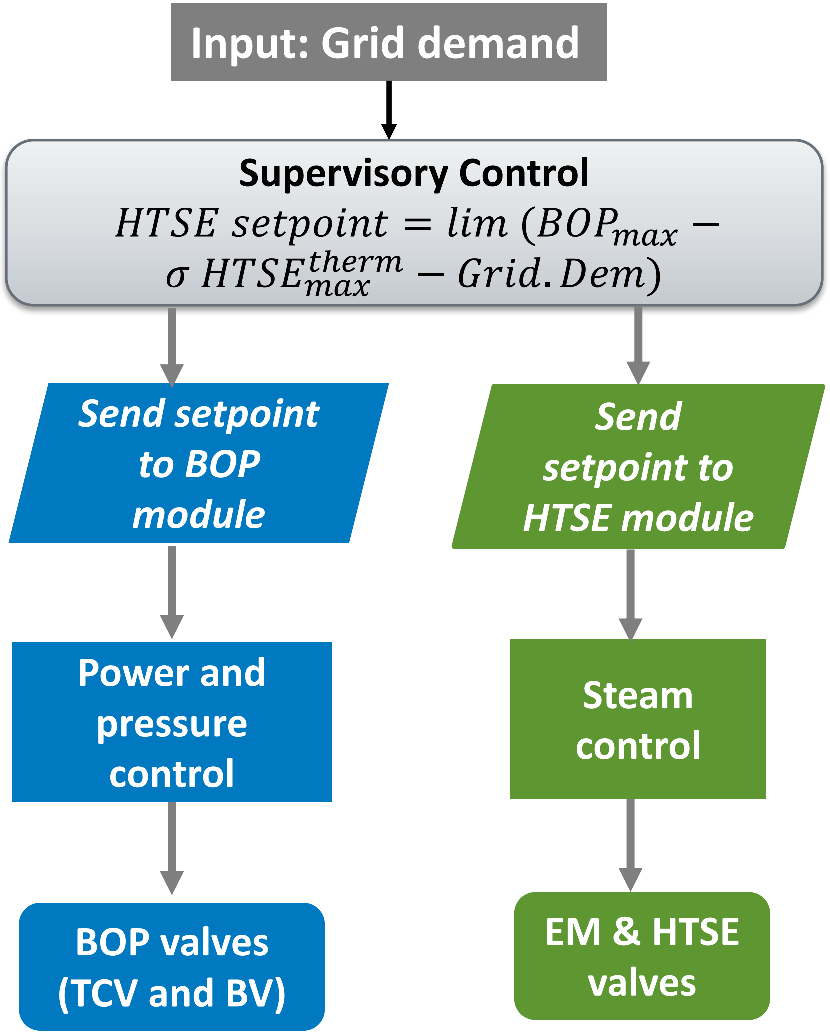


Power required is defined; steam is controlled

Steam required is defined; power is controlled

Control Architecture

IES with nuclear generation supplying electricity to grid and hydrogen as byproduct



$\boldsymbol{BOP_{max}}$: Maximum operating point of BOP

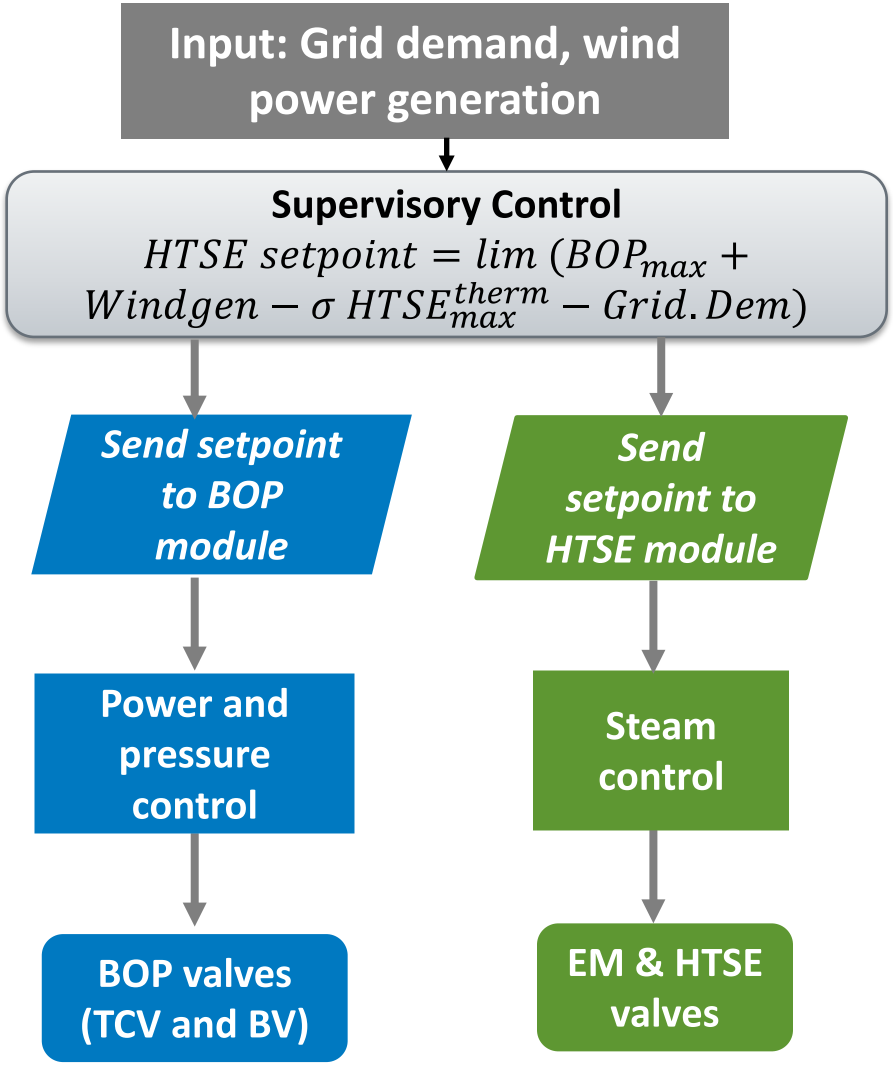
$\boldsymbol{HTSE_{max}^{therm}}$: Maximum thermal energy consumed

$\boldsymbol{\sigma}$: Thermal-electrical energy conversion factor

$\boldsymbol{Grid.Dem}$: Power demand of grid

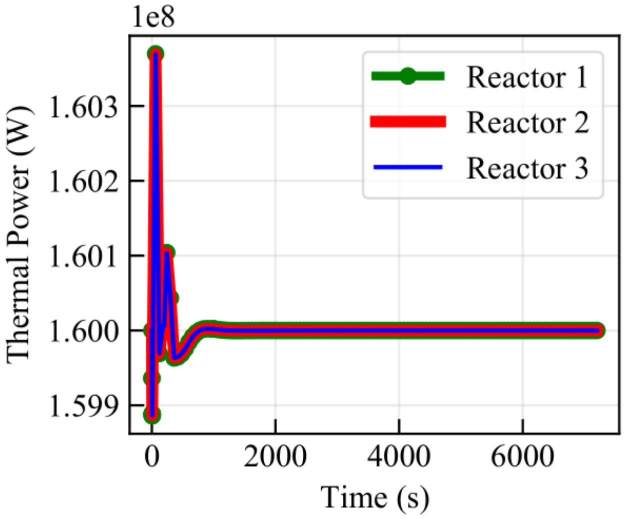
$\boldsymbol{Windgen}$: Power generated by the wind plant

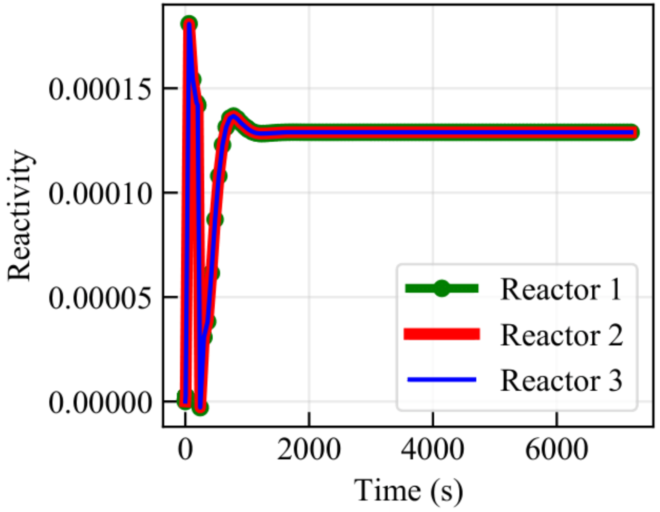
IES with nuclear and wind generation supplying electricity to grid and hydrogen as byproduct

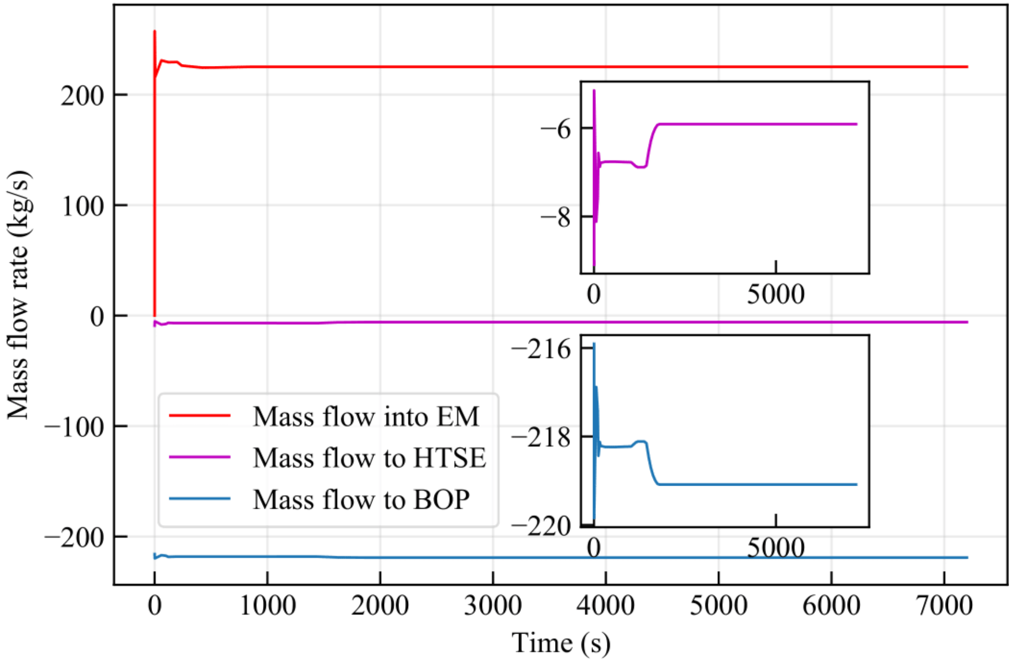


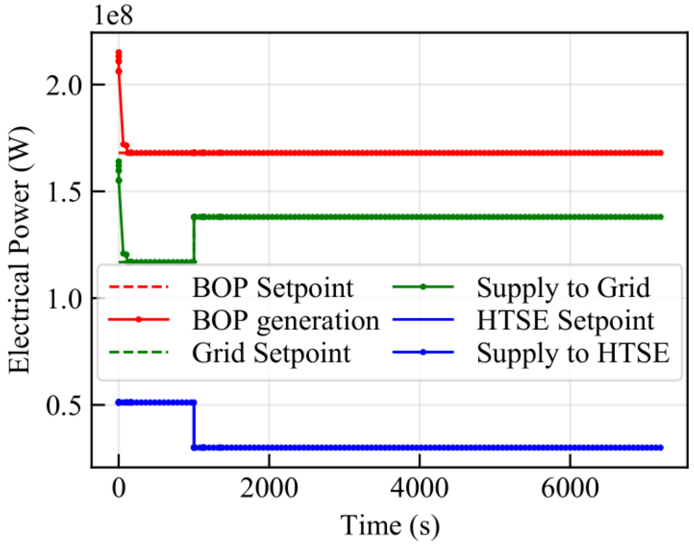
Simulation Results

IES with nuclear generation supplying electricity to grid and hydrogen as byproduct





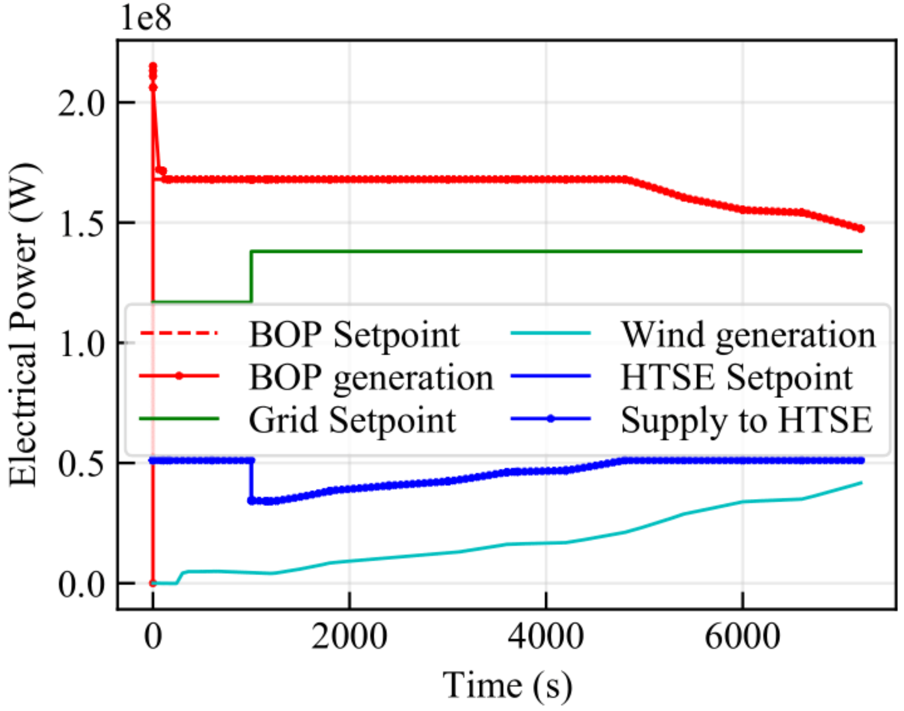


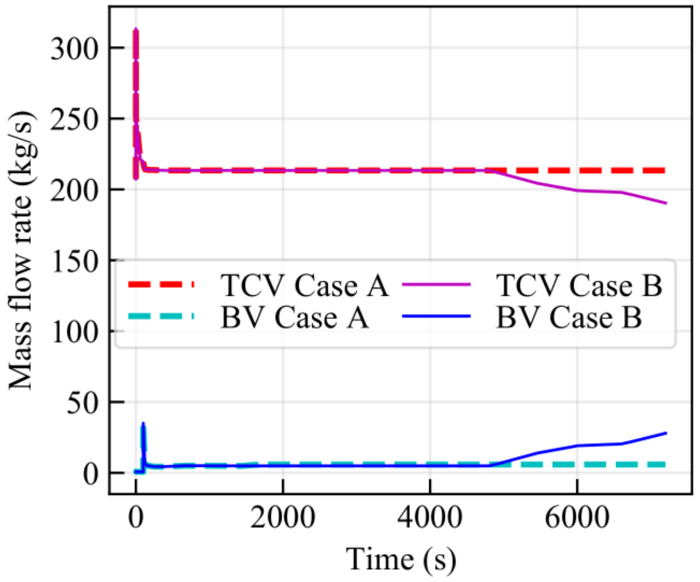


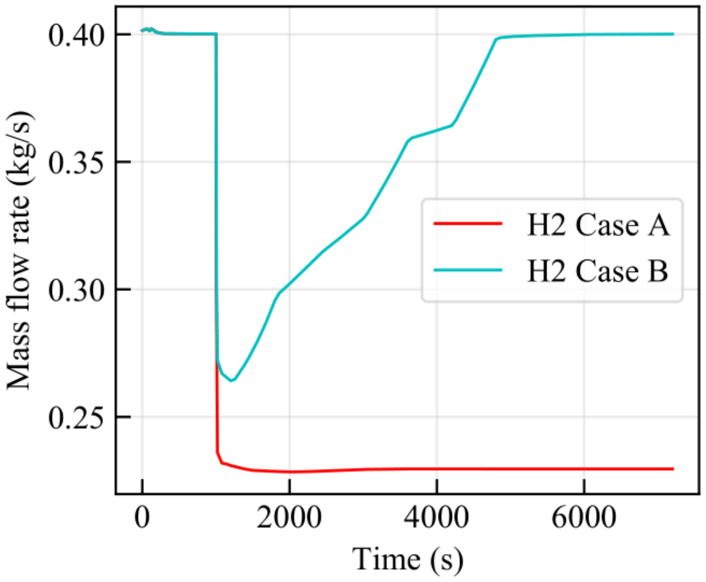
The mass flow into HTSE and BOP corresponds to the electrical power profiles of BOP and HTSE

Simulation Results

IES with nuclear and wind generation supplying electricity to grid and hydrogen as byproduct





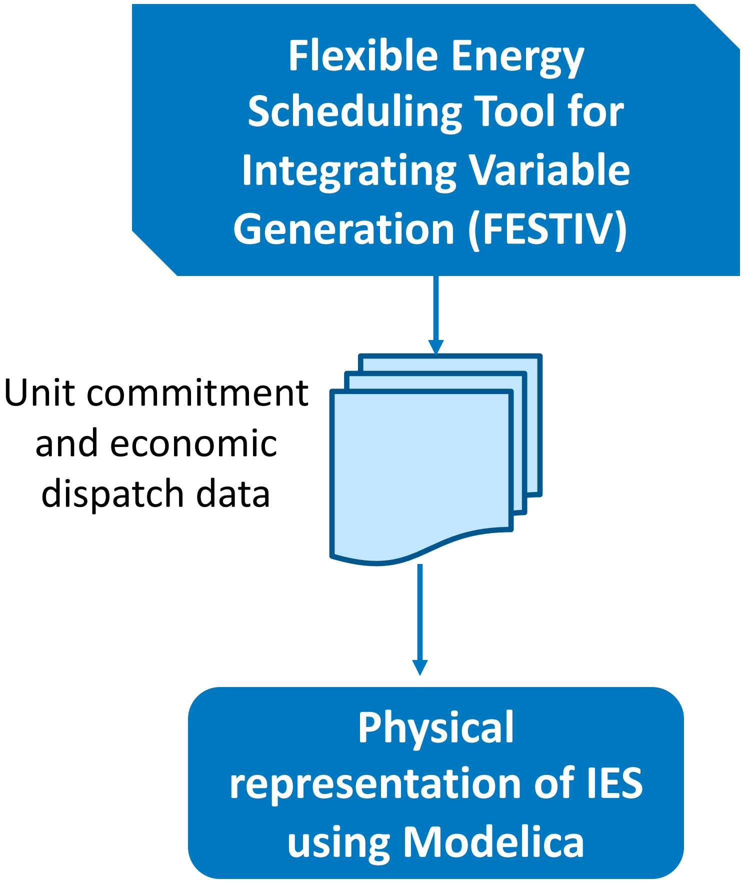


Conclusion

- An **integrated energy system** comprising of **nuclear and wind** power plants as generating resources, **grid** as electrical load, and **hydrogen production** plant as industrial plant, was designed and developed in the **Modelica**-based **Dymola** platform.
- The **control architecture** and **load-following** capability of the IES were evaluated.
- It was observed that the various **components and associated controllers** in the IES faithfully follow the **setpoints** generated by the **supervisory control** during load following conditions.

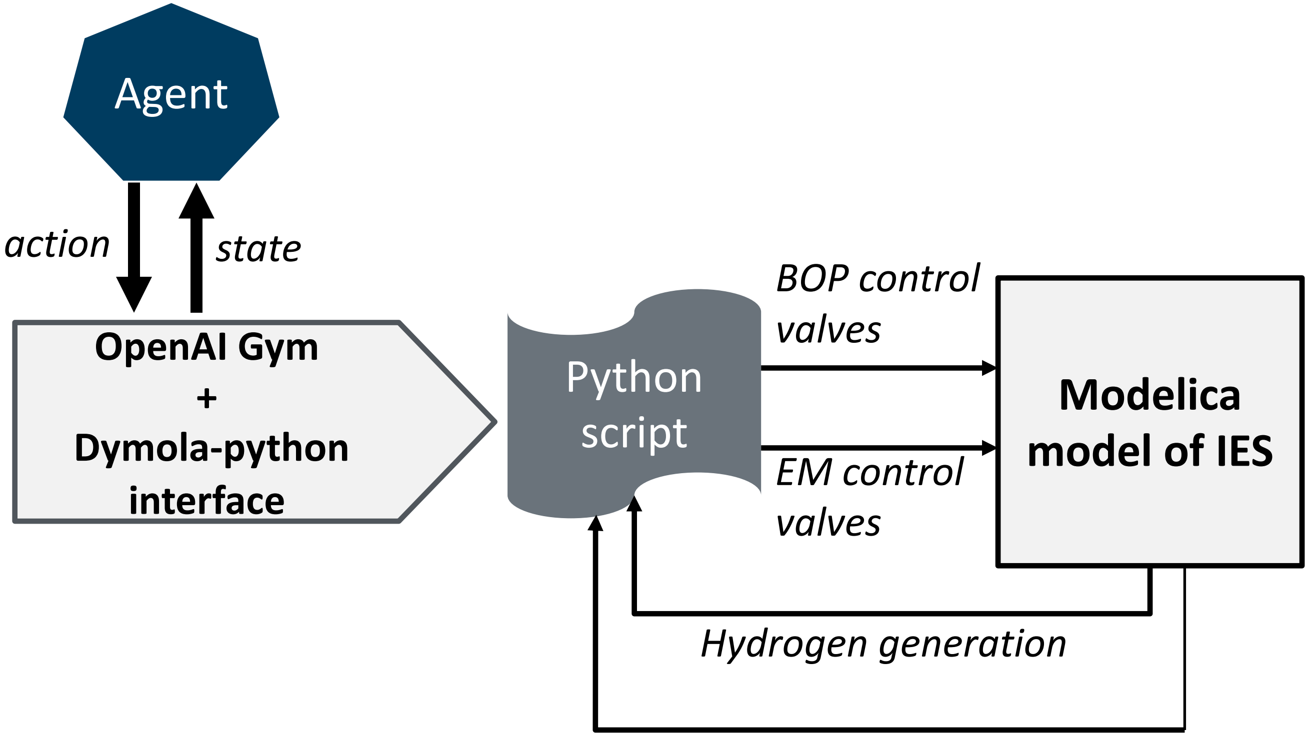
Ongoing and Future Work

Integration with optimal scheduling tool



Perform dynamic simulation using dispatch signals to evaluate feasibility and determine actual hydrogen and electricity production

Reinforcement learning control on physics-based models



Thank You


multidisciplinary
design
optimization
fidelity
linear
system
failure
solar
data
cost
engineering
deformation
statistical
battery
energy
experiments
optimum
surrogate
learning
evaluation
reliability
renewable
mathematical
stochastic
algorithm
decomposition
methodology
displacement
probabilistic
bounds
illustration
exploration
minimization
approximation
objective
criteria
complex
equivalence
uncertainty
computing
metamodeling
wind
nonlinear
inequality
integer
mining
bayesian
gradient
heuristic
storage
discrete
machine
power
recursive
structural
loads
value