Smart Energy Systems Lab

Joint IAEA-ICTP Workshop on Reactor Physics, Thermal Hydraulics and Plant Design Engineering of Small Modular Reactors (SMR4212)
Trieste, Italy, 13 – 17 April 2026

Nuclear-Renewable Hybrid Energy Systems
Small Modular Reactors for Non-Power Applications and Integrated Energy Systems

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Acknowledgement: SESL Team Members, Ontario Tech University, Canada

Energy Transition Roadmap

Task-1: Analysis of Energy Grids for a Given Region or Application

Task-2: Low-Carbon Energy Transition Scenario Assessment

Task-3: Integrated Hybrid Energy Modeling and Simulation

Task-4: Supply Side Design and Control Strategies for Smart Energy Grids

Track-5: Smart Energy for Water Networks

Track-4: Smart Energy for Transportation Infrastructures

Track-3: Thermal Grids and Storage Technologies

Track-2: Gas and Hydrogen Grids and Storage Technologies

Track-1: Electricity Grids and Storage Technologies

Module-6: Energy Transitioning Projects for Communities

Module-5: Transactive Energy, Performance, and LCC

Module-4: Smart Sensors, Monitoring, Diagnosis, Data Centers

Module-3: AI, Optimization, Data Analytics

Module-2: Energy Computational Modeling and Simulation

Module-1: Energy Transitioning Scenario Modeling

Task-8: Energy Transition Planning, Technology Deployment and Business Modeling

Task-7: Data Analytics of Smart Energy Grids Operation with Co-Simulation

Task-6: Optimization of Smart Energy Grids Design and Control

Task-5: Demand Side Design and Control Strategies for Smart Energy Grids

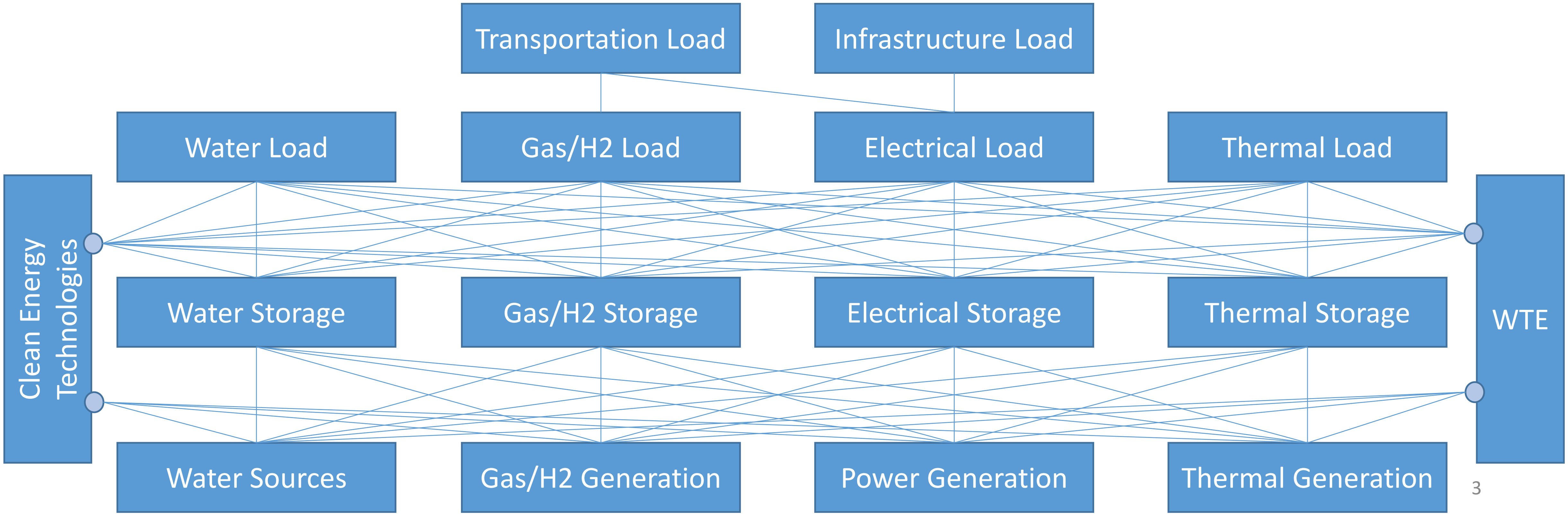
Energy Transition

Policies, Procedures, and Regulations

Region, Application, and Integration

Business Models and Management Scheme Strategies

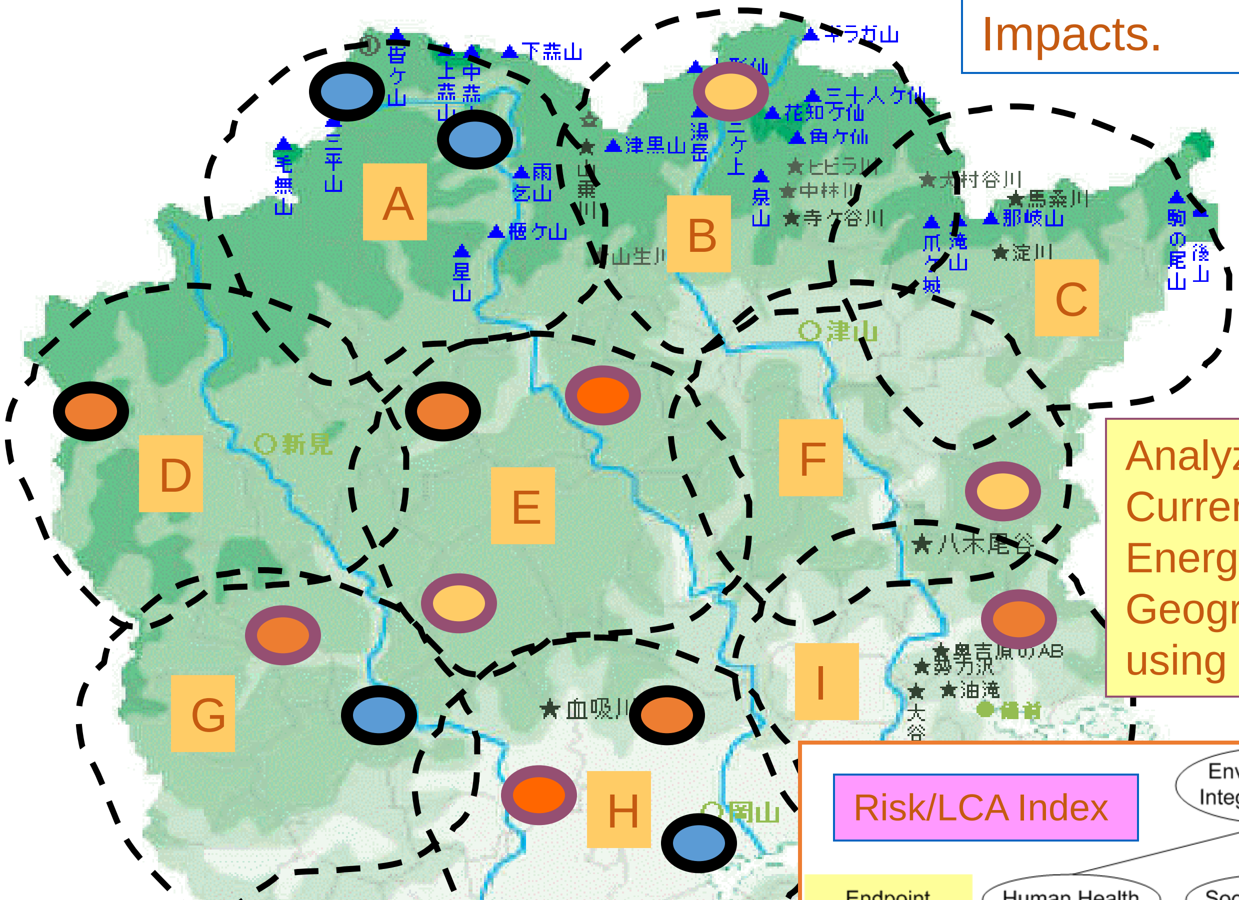
Control Strategies



Hybrid Energy Infrastructures

Classify Energy Use & Supply as per Amounts / Risks / Environmental Impacts.

- Hydro Power Plants
- Wind Mill
- Solar
- Thermal Power Plants
- Nuclear Power Plants

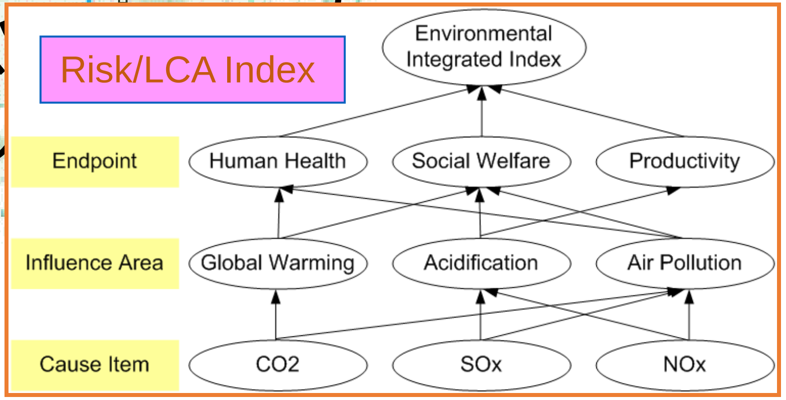


Fuel Cells

Ocean/Tide Plants

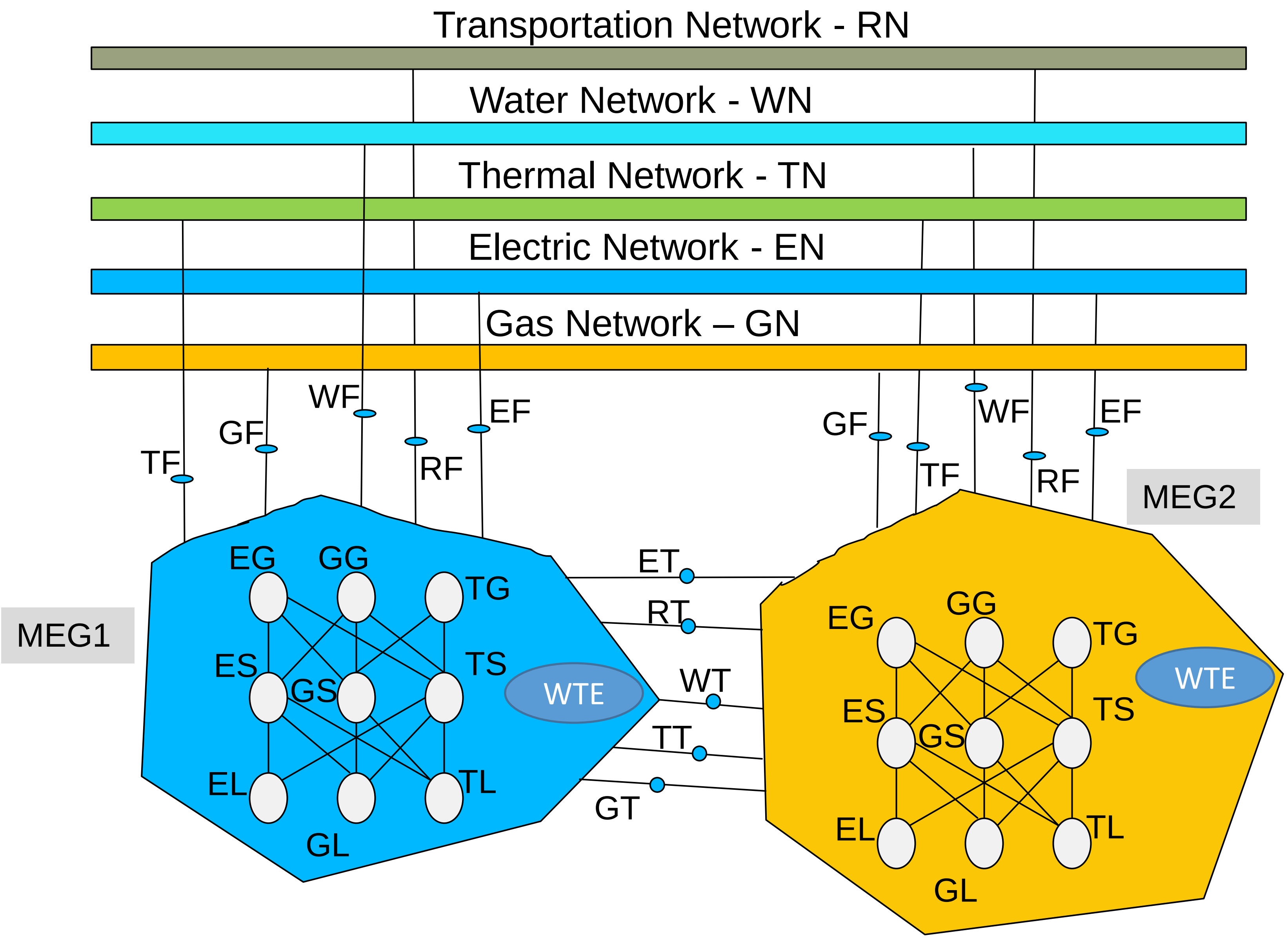
…

Analyze and Evaluate Current & Future Energy Needs in each Geographical Area using LCA/LCC Index

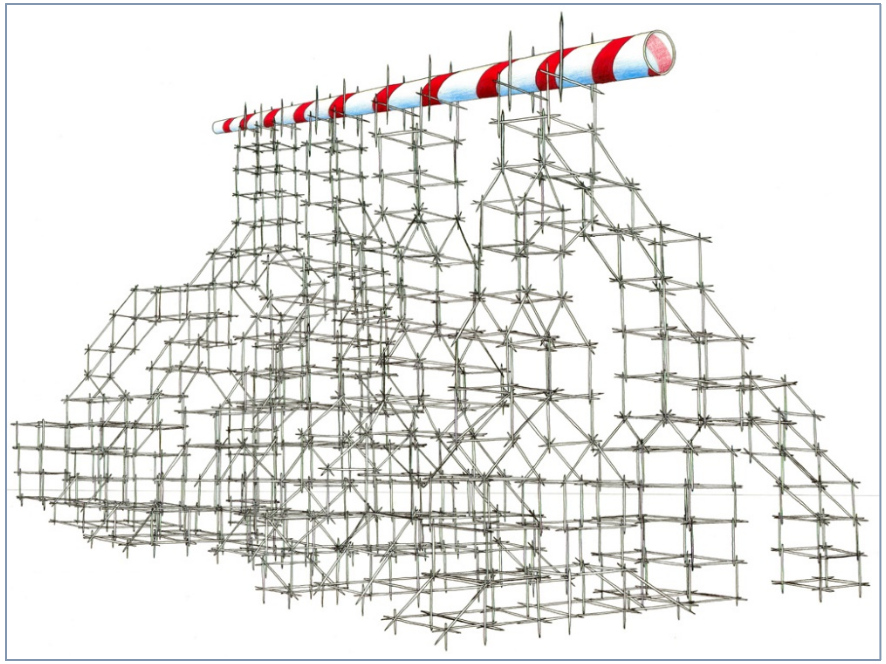


Clustering, Data Mining for Optimized Energy Production/Supply Chain

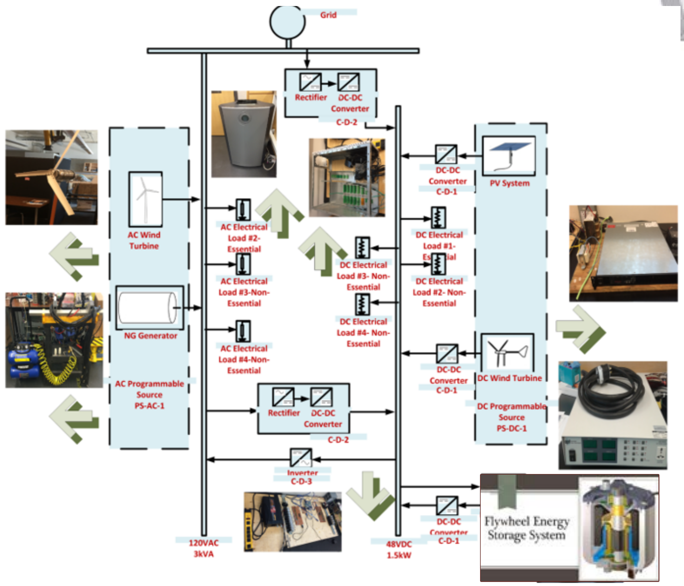
Interconnected Micro Energy Grids



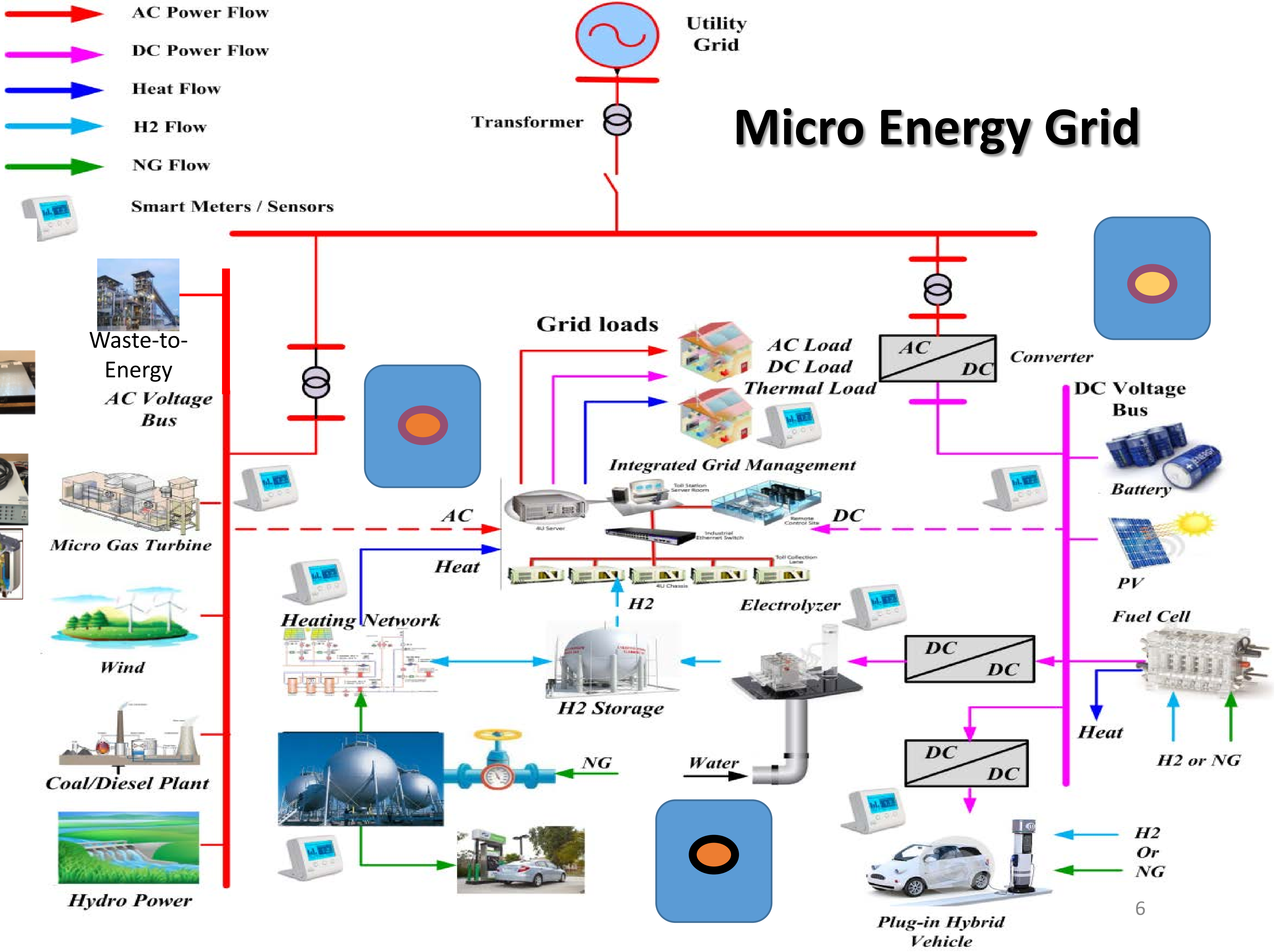
Adaptive Interconnected Micro Energy Grid Superstructure



MEG Demonstration at UOIT

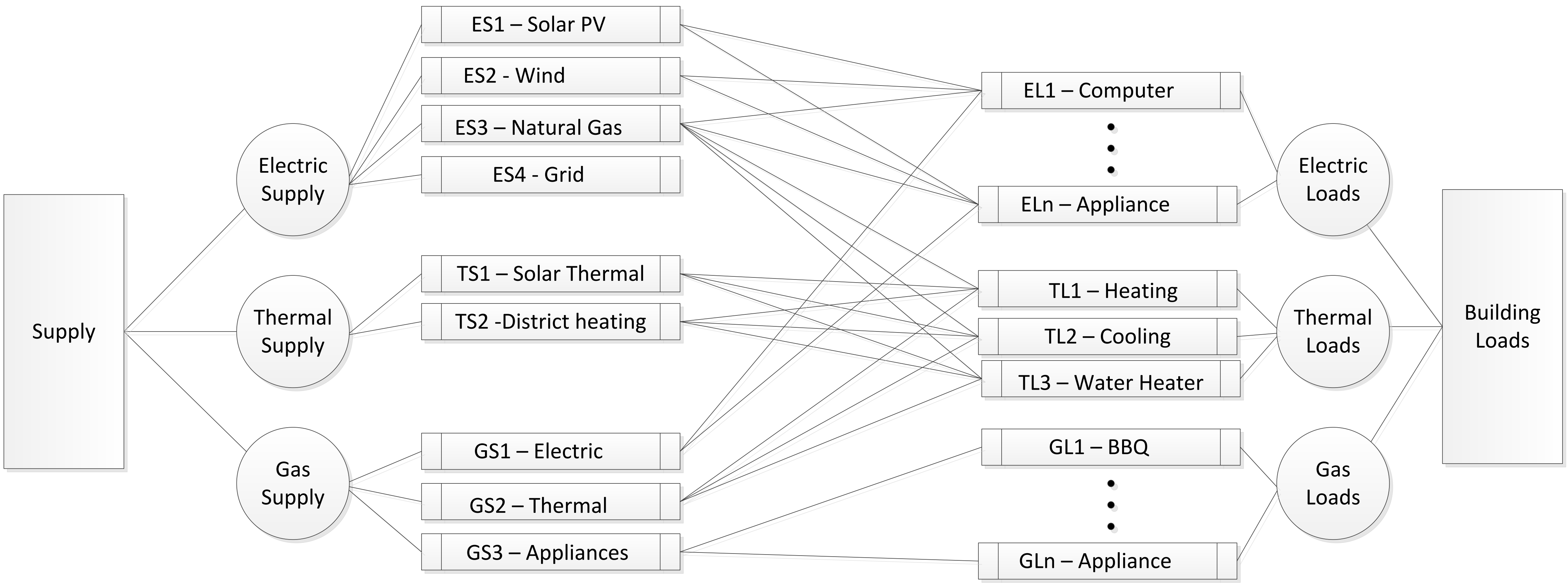


Micro Energy Grid



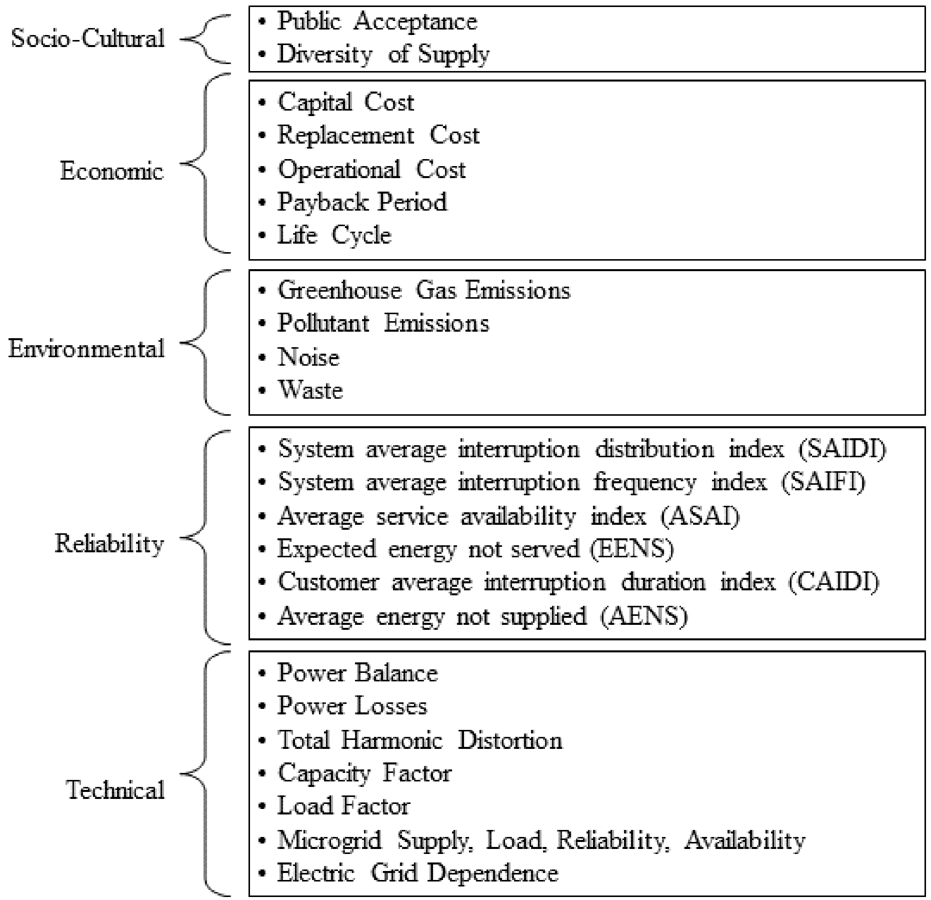
- Energy Supply
- Food Supply
- Health Supply
- Water Supply
- Transportation Network

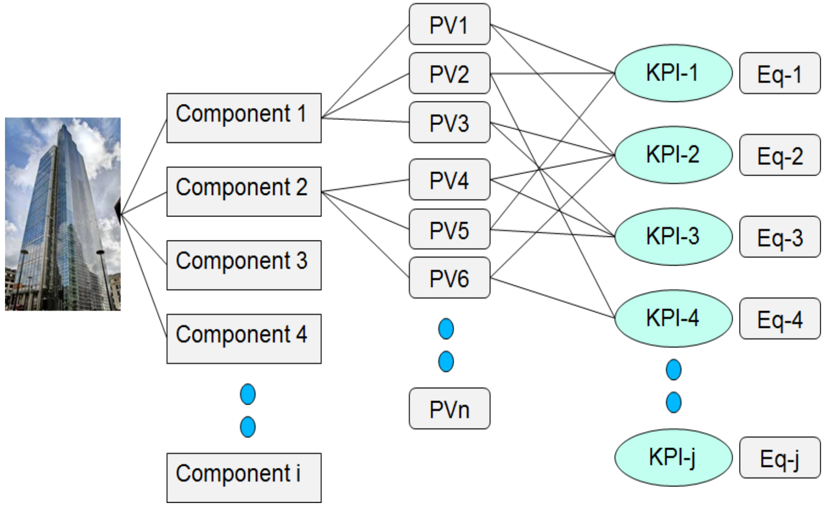
Energy Semantic Networks - ESN



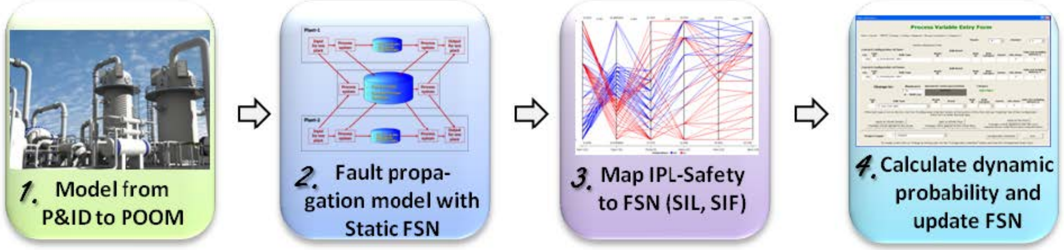
KPI Modeling

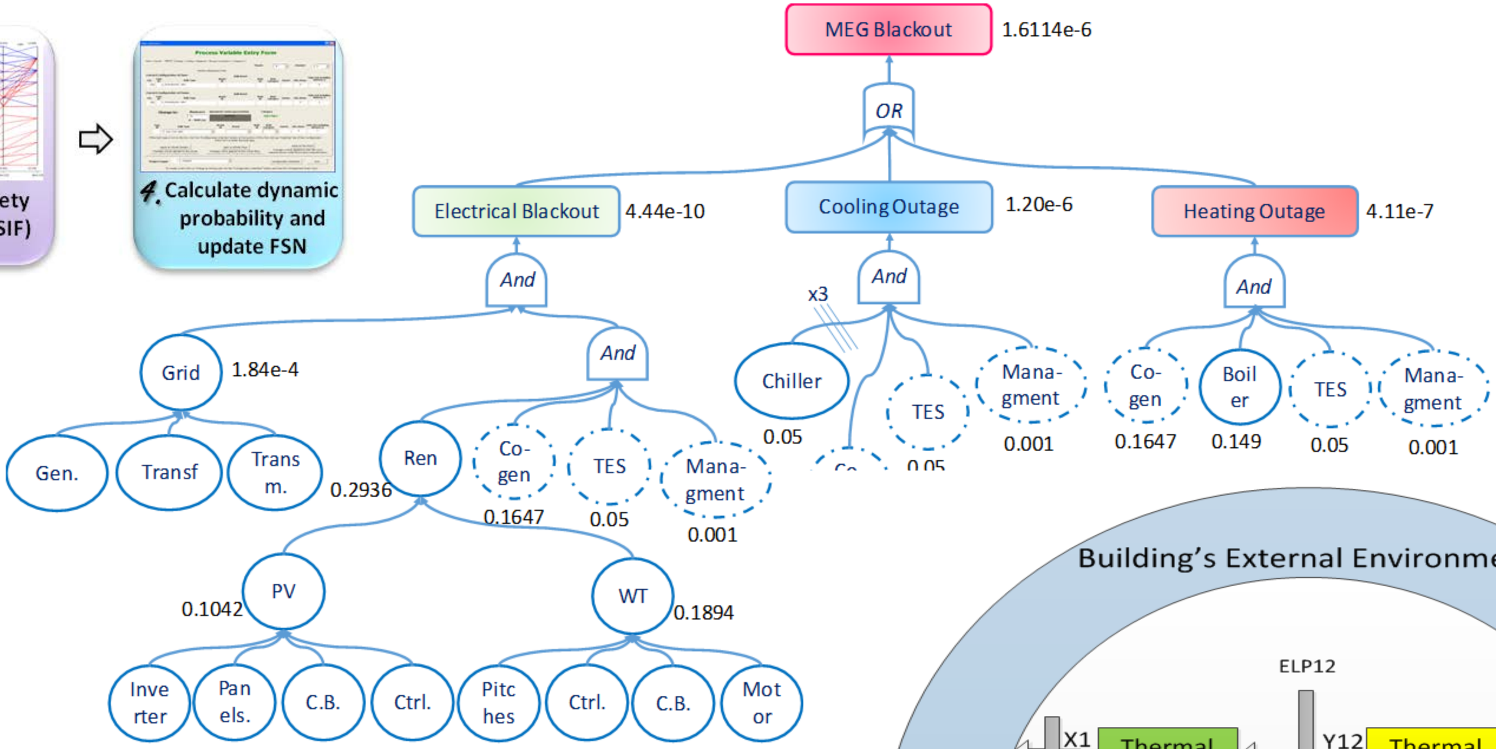
- EWFHT (Generation / Storage / Loads)
- KPI Modeling
  - Resiliency
  - Socio-cultural
  - Economic
  - Environmental
  - Reliability / Safety / Security
  - Technical

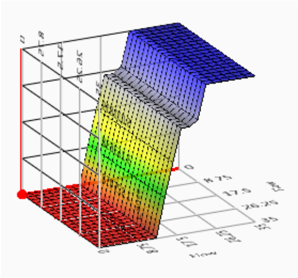


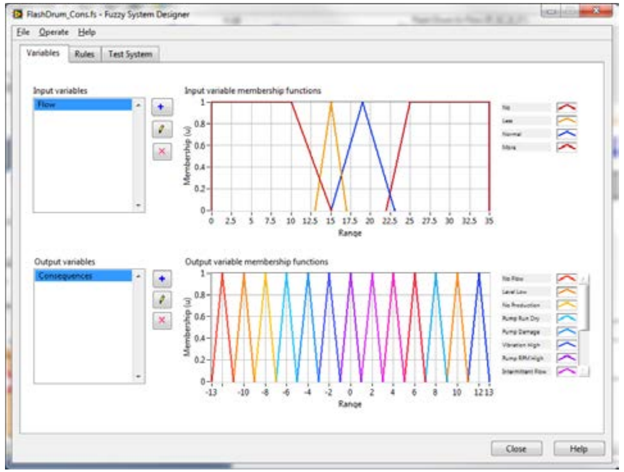


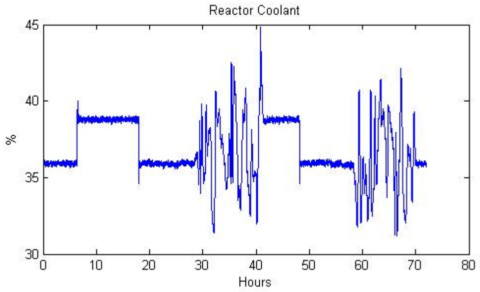
Risk-based Energy Systems

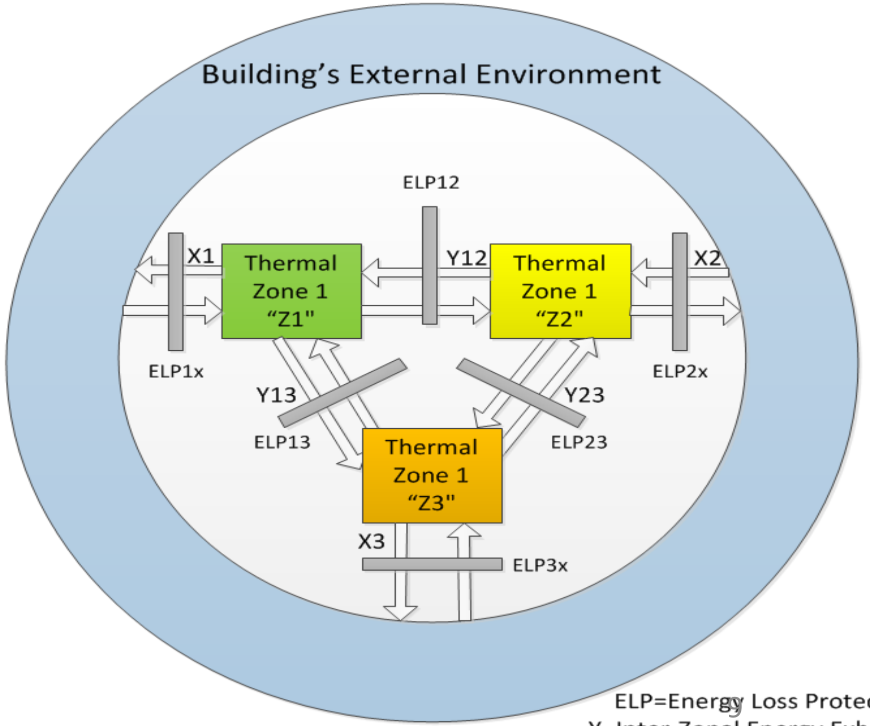








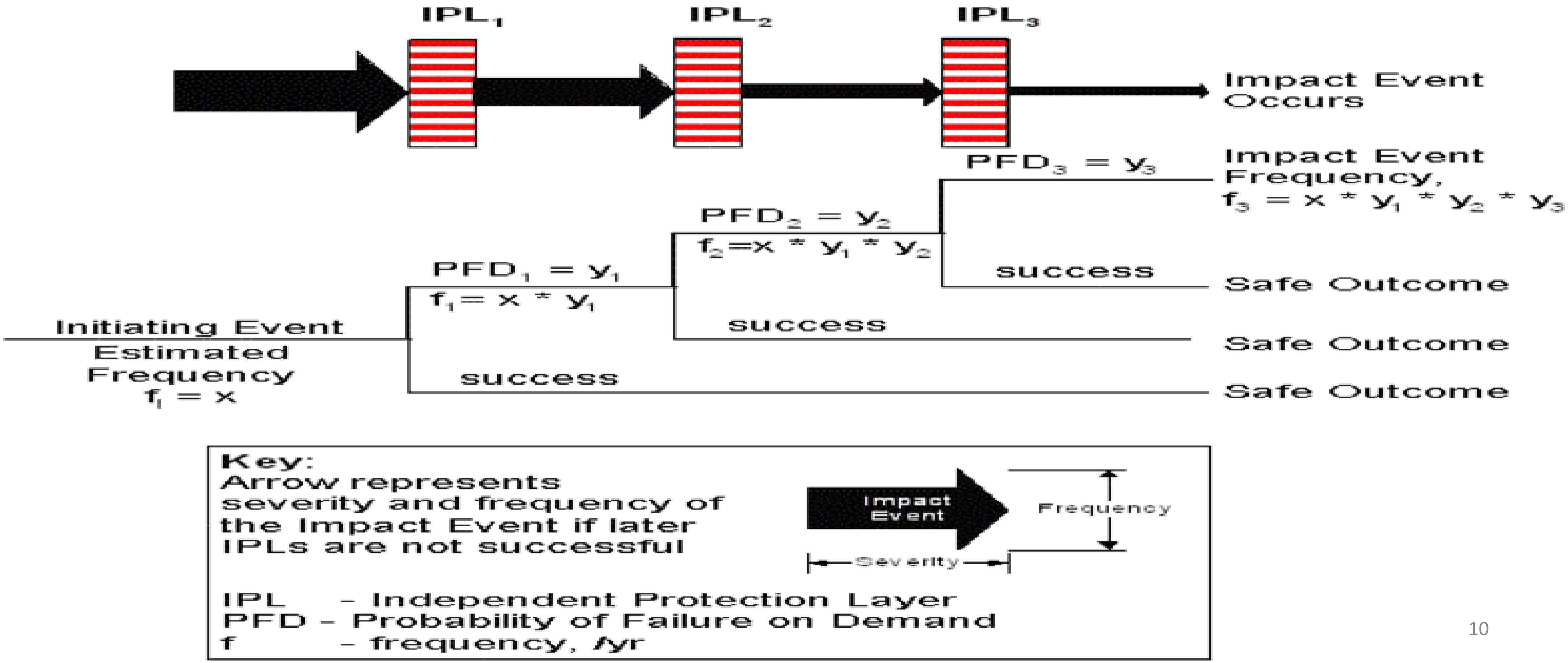




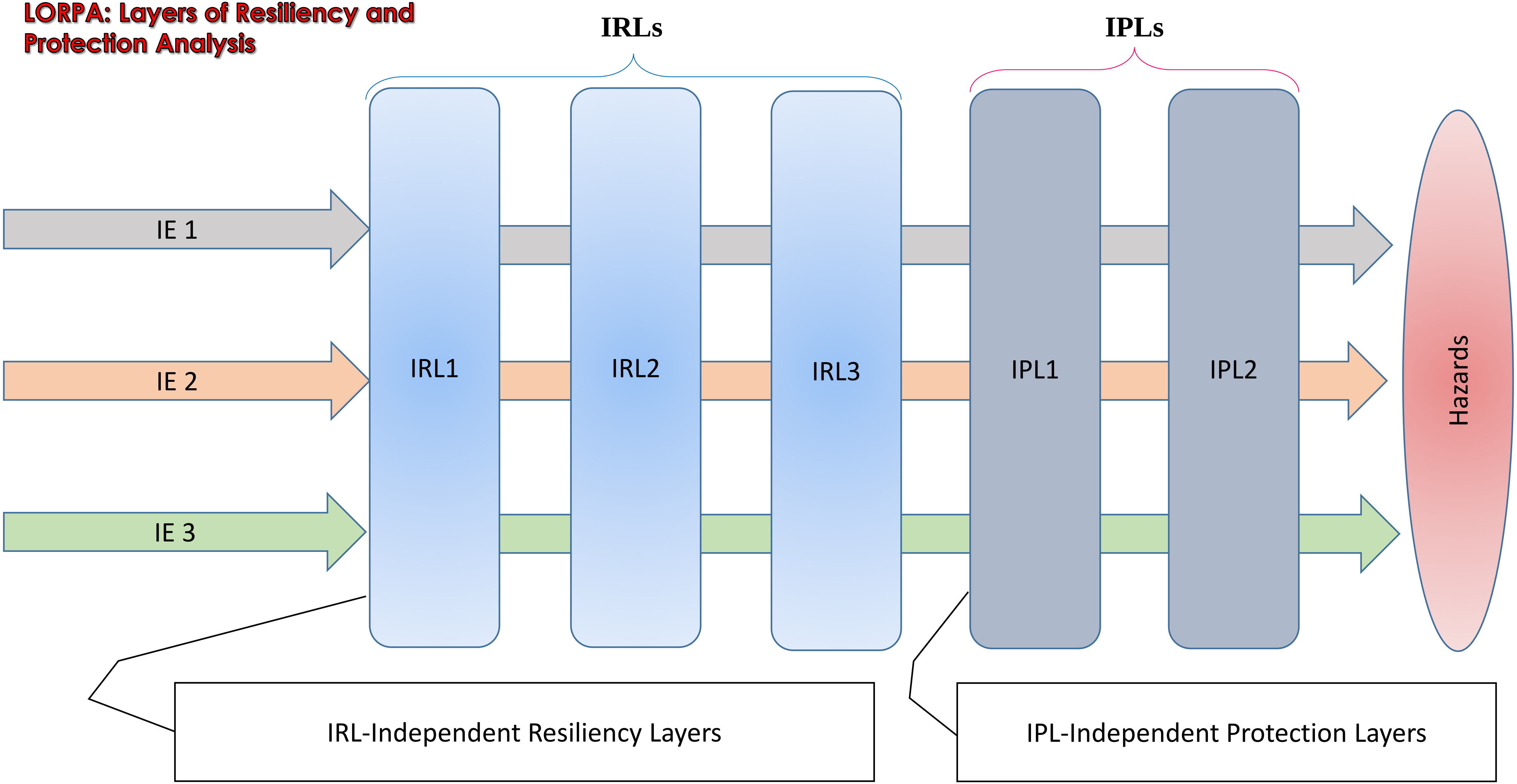
ELP=Energy Loss Protection
Y=Inter-Zonal Energy Exhcnge
X=Energy Exchange with external Environment

LOPA (Layer of Protection Analysis)

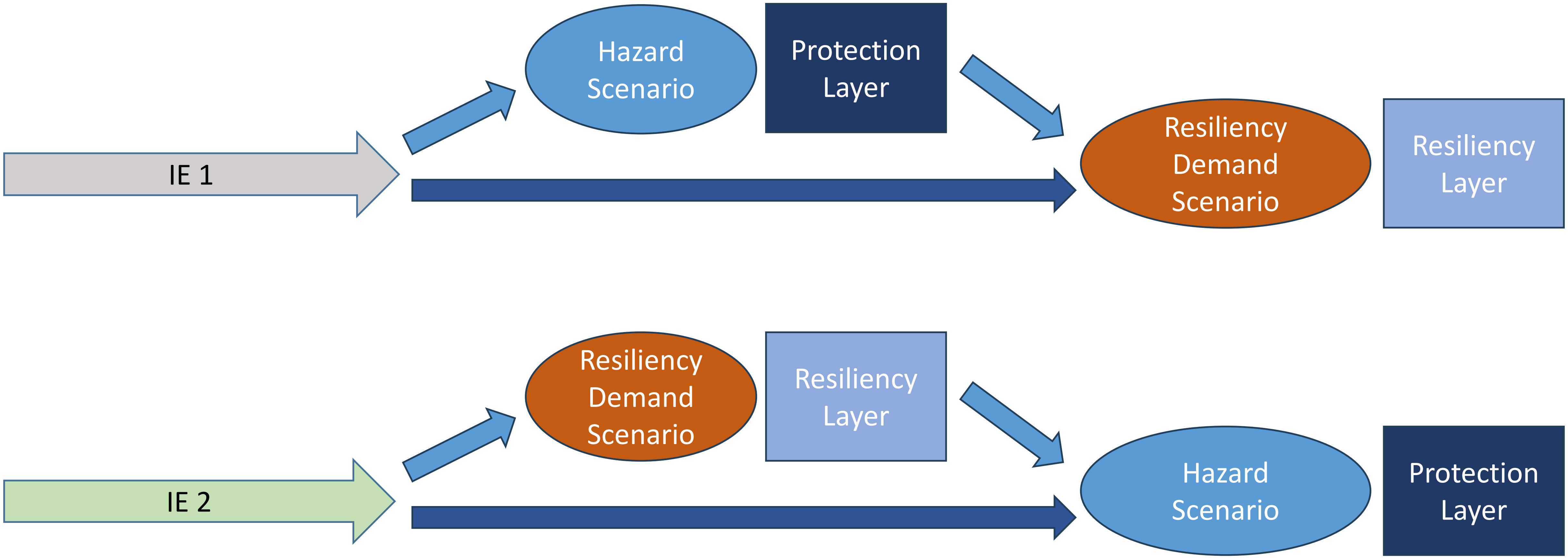
- **<u>LOPA Definition:</u>** is to determine if there are sufficient layers of protection against the consequences of an accident scenario (can the risk be tolerated?).



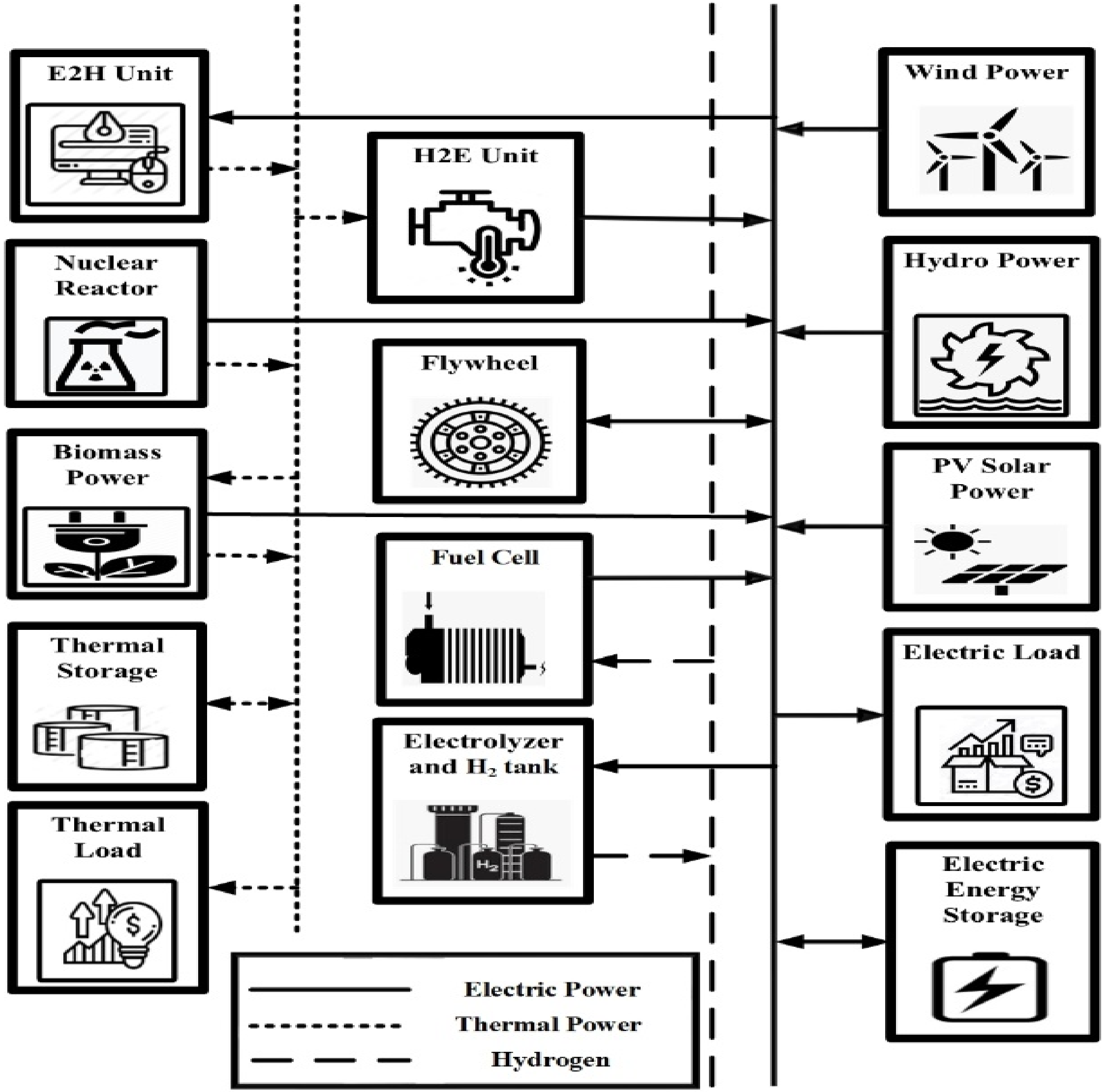
LORPA: Layers of Resiliency and Protection Analysis



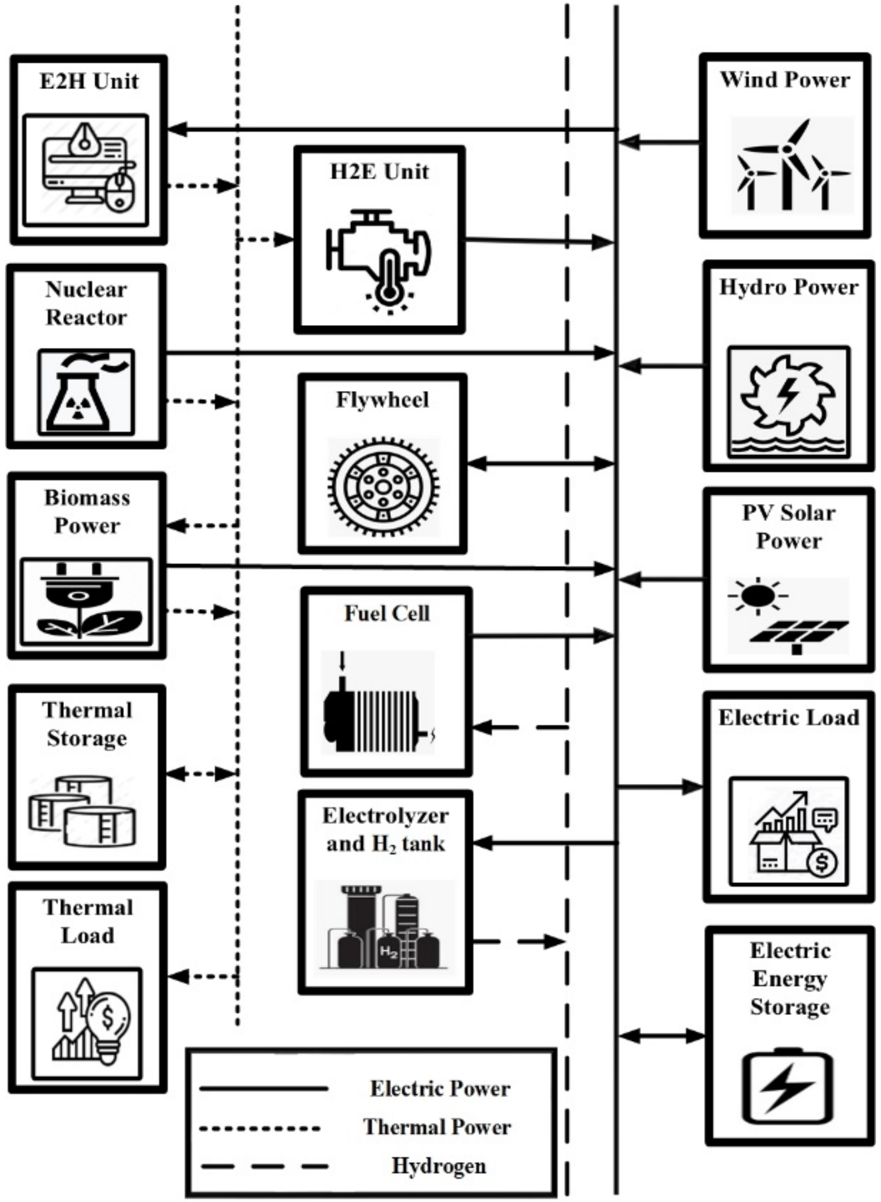
LORPA: Layers of Resiliency and Protection Analysis



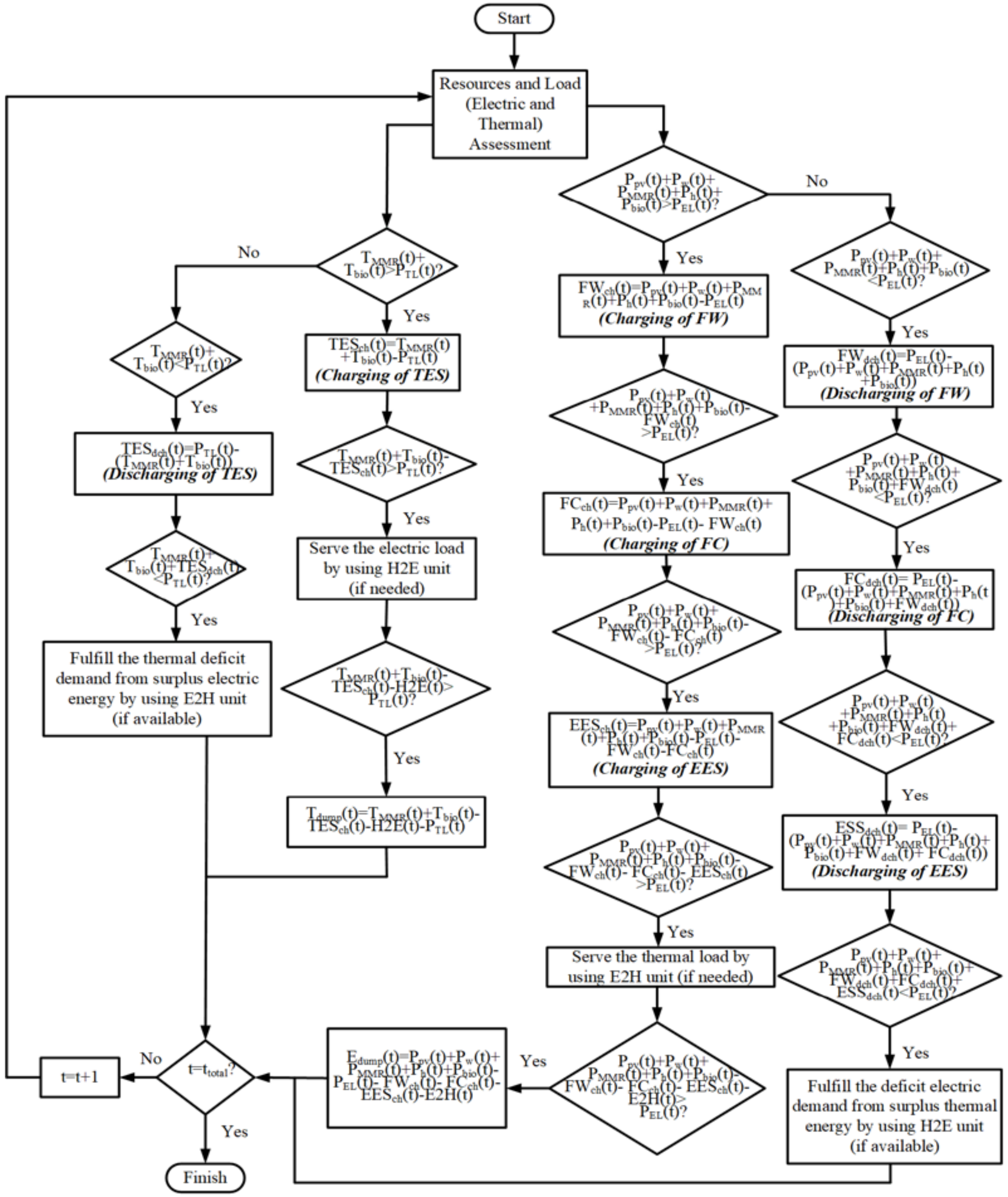
Nuclear-Renewable Integration Strategies



iii)



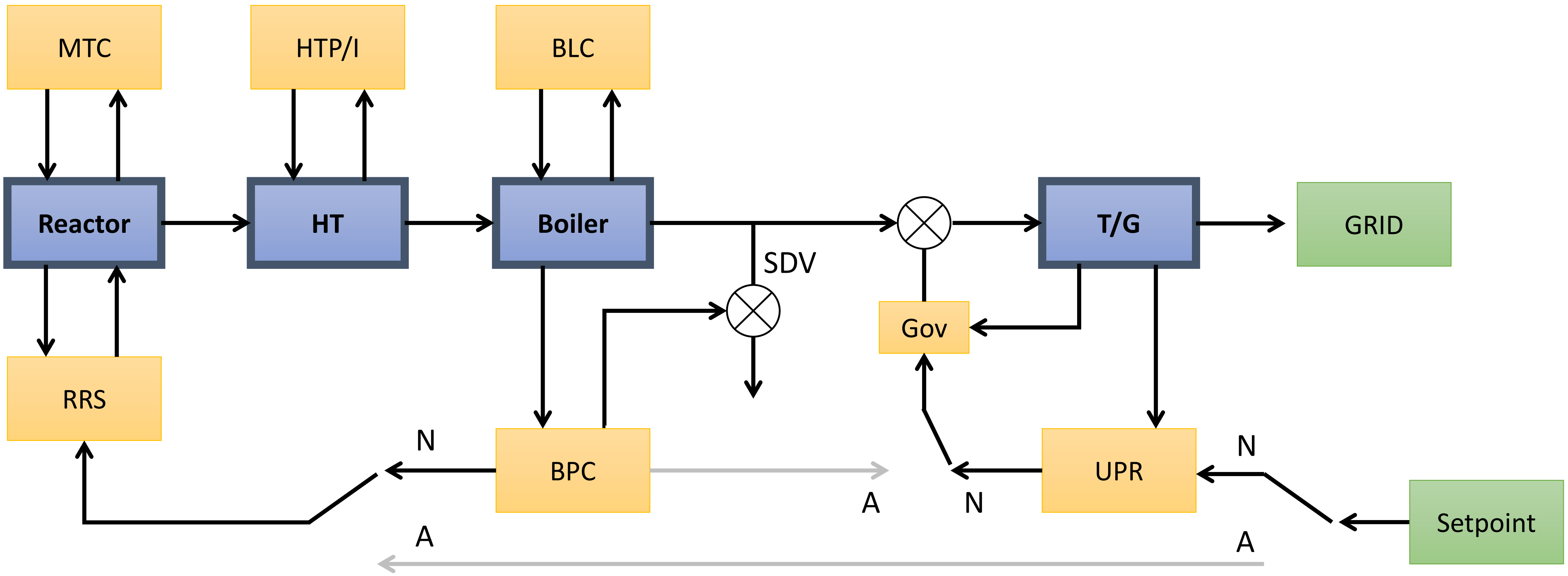
Multiple Resources and Multiple Products-based Coupling



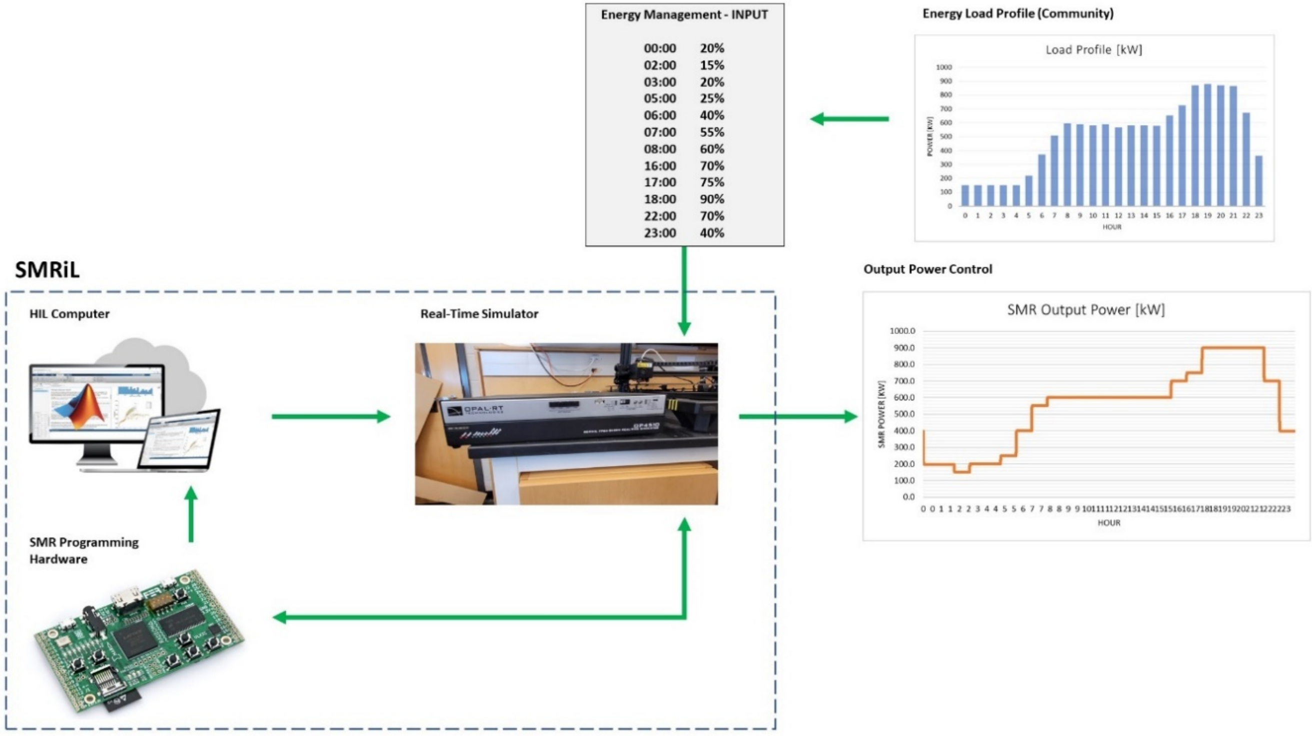
Energy Management Algorithm

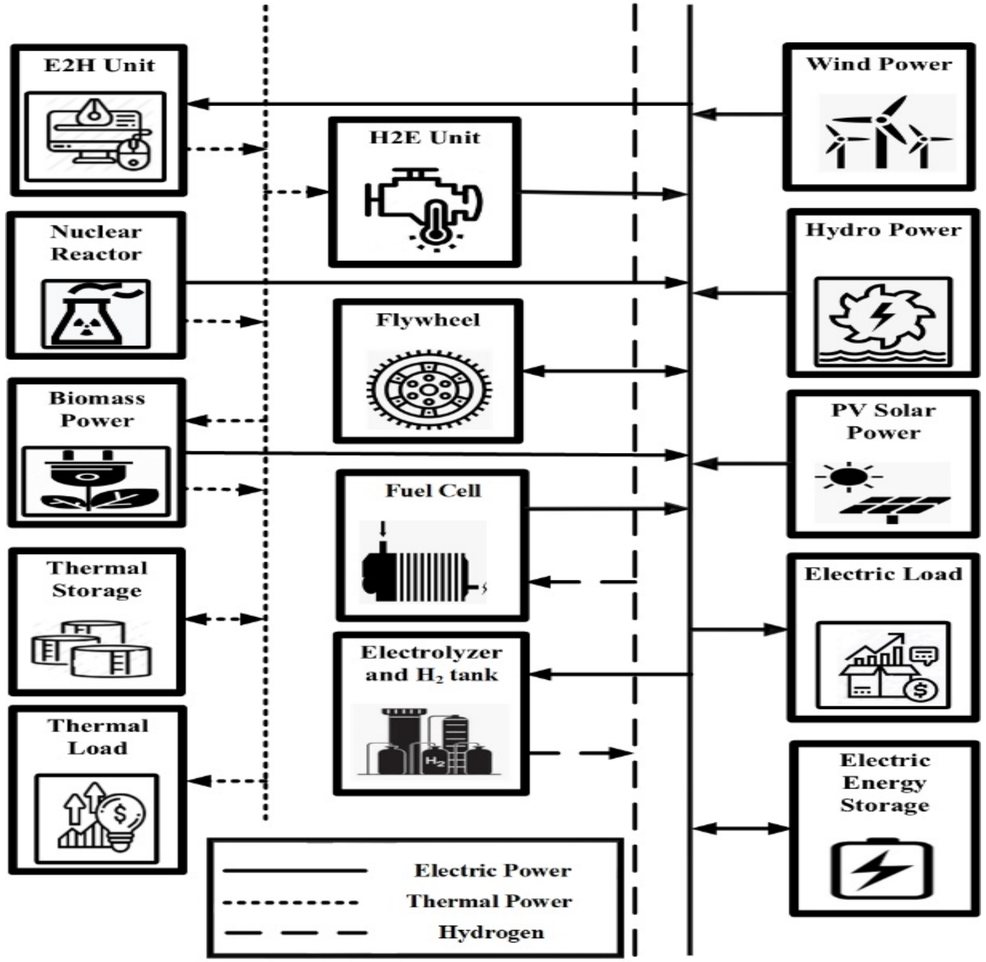
Load Following in Nuclear Power Plants (NPP)

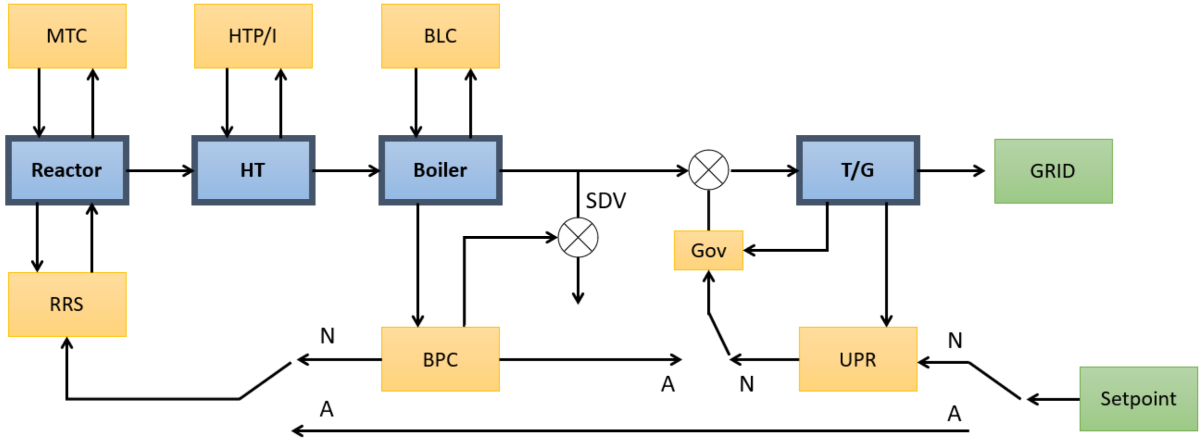
- Power control in NPPs can be simply divided into two modes: Normal Mode or Alternate Mode



NR HESS: Nuclear-Renewable Hybrid Energy Systems Simulator with SMR-in-the-Loop





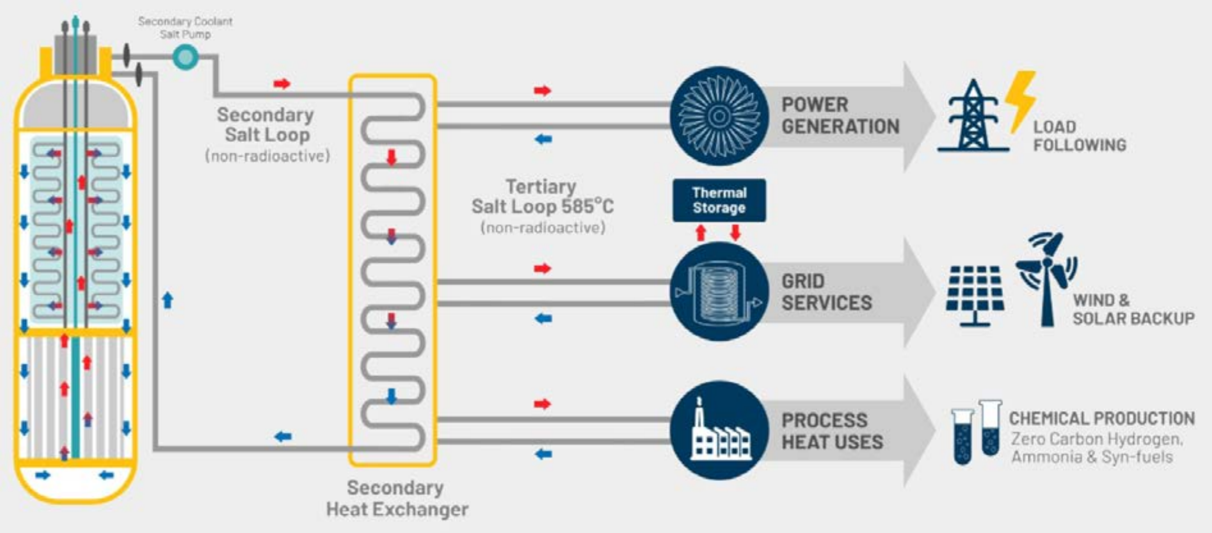


Nuclear Power Analysis

- **Nuclear Reactor Limitations:**
  - New designs (Generation III+ and IV) have load-following capabilities but were not originally designed for it.
  - Each design has its own operational limitations for load-following.
- **Evaluation Challenges:**
  - Existing models and simulators help understand physical effects but are insufficient for real-life conditions.
  - Difficulty in evaluating systems considering grid demand and flexibility for integrating renewable hybrid energy systems.
- **Need for Comprehensive Evaluation:**
  - Assessing the performance of individual components is not enough.
  - Understanding cooperative interactions between different energy sources and load demand is essential.

Acronym	Type	MWe	Load Following (%pm)
BWRX-300	BWR	300	0.50%
NuScale	PWR	710 (6x12)	0.67%
IMSR-400	MSR	194	5.00%
ACR-1000	HWR	1200	0.40%

Source: International Atomic Energy Agency. "Advanced Reactors Information System (ARIS)."



Source: Terrestrial Energy. "Versatile." Terrestrial Energy

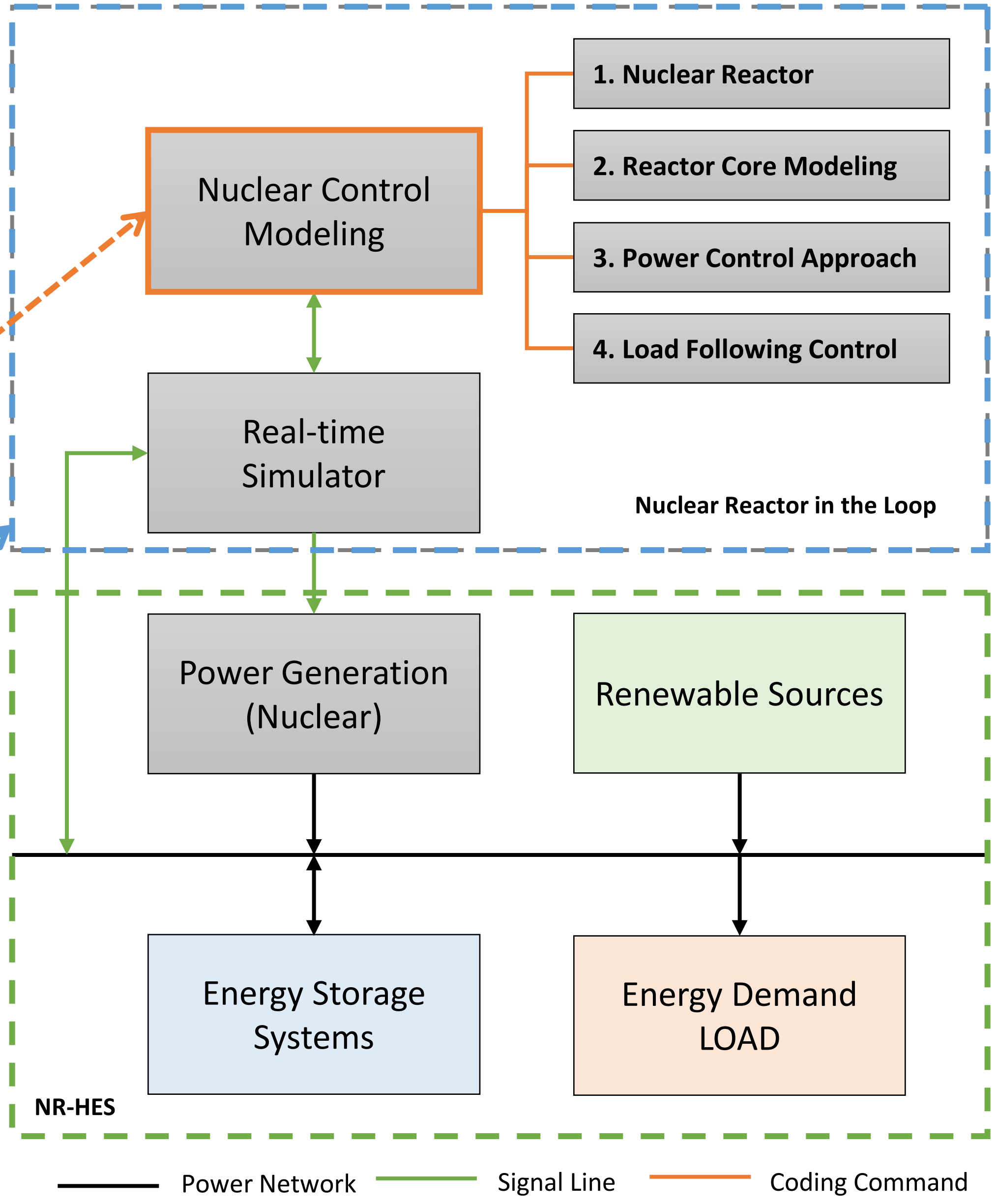
Proposed Approach

- Contribute to the development and evaluation of Nuclear-Renewable Hybrid Energy Systems (N-RHES) with Load Following capabilities.
- Address the complexities of transitioning to a zero-carbon future by integrating nuclear and renewable energy.
- Employ a three-fold approach:

1. Development of Adaptive Control Model

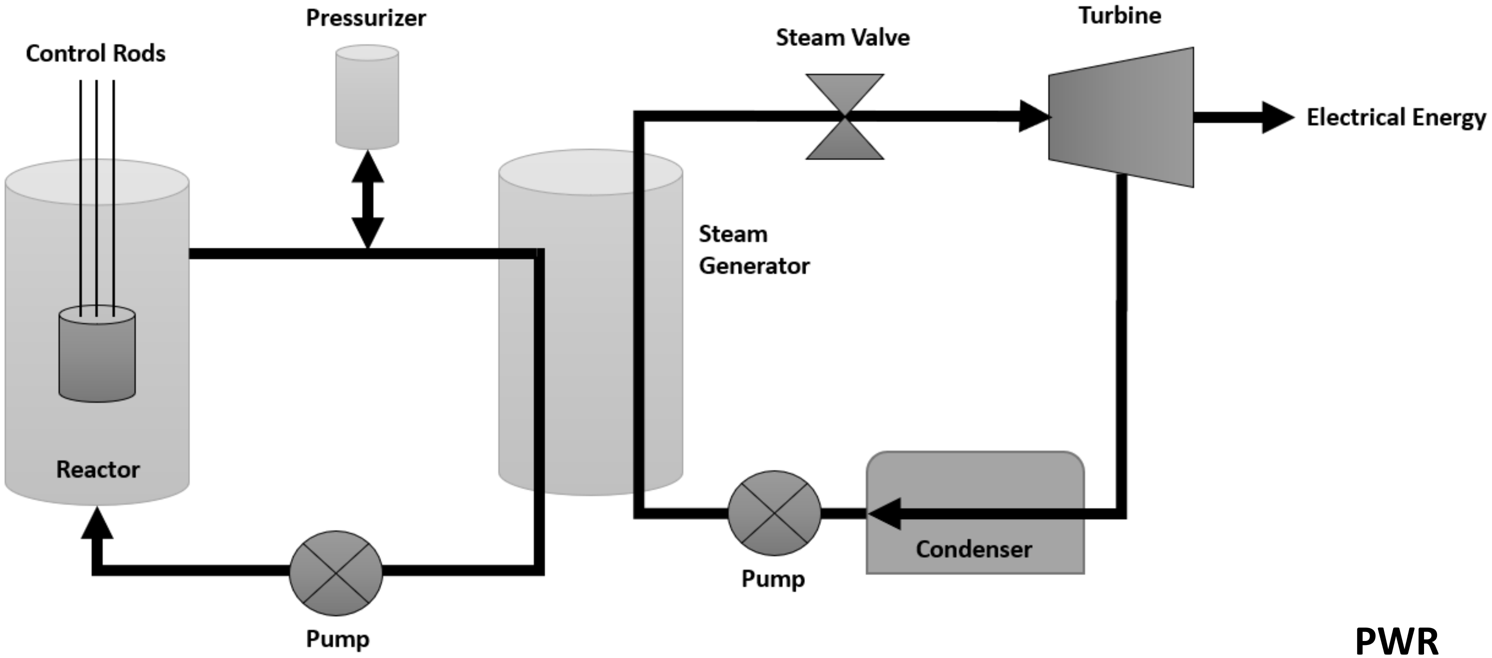
2. Integration with NRiL for Real-Time Validation

3. Evaluate LF performance with NR-HES Simulator



Development of Adaptive Control Model

- A nuclear power plant relies on the controlled fission of heavy nuclei to produce heat, which is then used to generate steam. This steam drives turbines connected to generators, producing electricity. The interrelation of the following physical phenomena ensures the efficient and safe production of nuclear power:
- **Fission and Heat Generation**
- **Moderation and Control**
- **Heat Transfer and Steam Production**
- **Mechanical to Electrical Energy Conversion**
- **Cooling and Safety Systems**



PWR

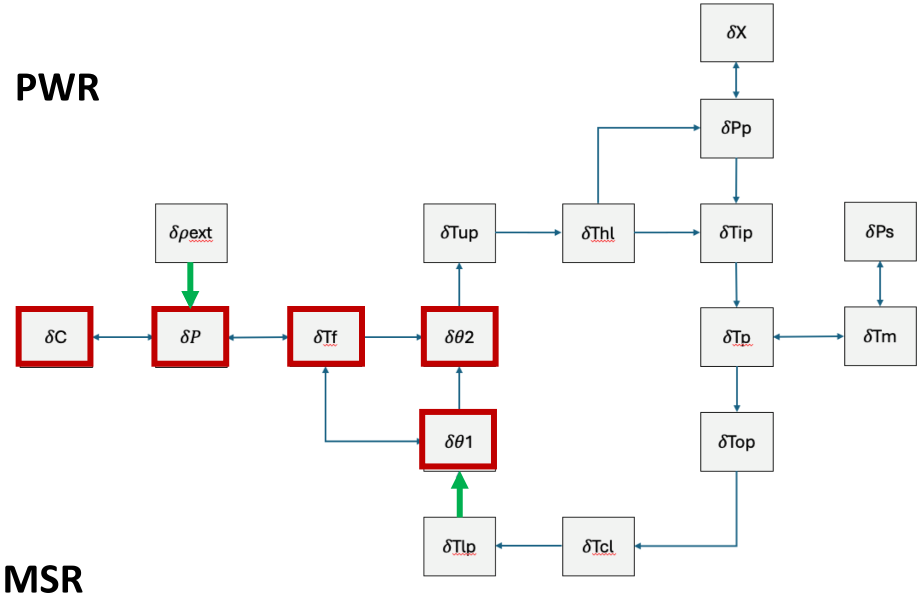
Development of Adaptive Control Model

- **Models Utilized:**
  - **Pressurized Water Reactor:** Kerlin, T. W., Katz, E. M., Thakkar, J. G., & Strange, J. E. (1976). Theoretical and Experimental Dynamic Analysis of the H. B. Robinson Nuclear Plant. *Nuclear Technology*, 30(3), 299-316.
  - **Molten-Salt Reactor:** Kerlin, T. W., Ball, S. J., & Steffy, R. C. (1972). Theoretical Dynamics Analysis of the Molten-Salt Reactor Experiment. Oak Ridge National Laboratory.
- **Key Points:**
  - **Proven Methodologies:** Both models have been rigorously validated, ensuring the reliability and accuracy of the dynamic analyses conducted.
  - **Versatile Application:** These models are adaptable to various nuclear technologies, making them suitable for studying different reactor types within hybrid energy systems.
  - **Historical Significance:** As foundational models in nuclear reactor development, they provide a robust framework and valuable insights into reactor behavior.
  - **Transient and Frequency Response Analysis:** The detailed analysis of transient responses and frequency behavior ensures a comprehensive understanding of the reactors' dynamic performance, which is crucial for optimizing load-following capabilities within N-RHES.

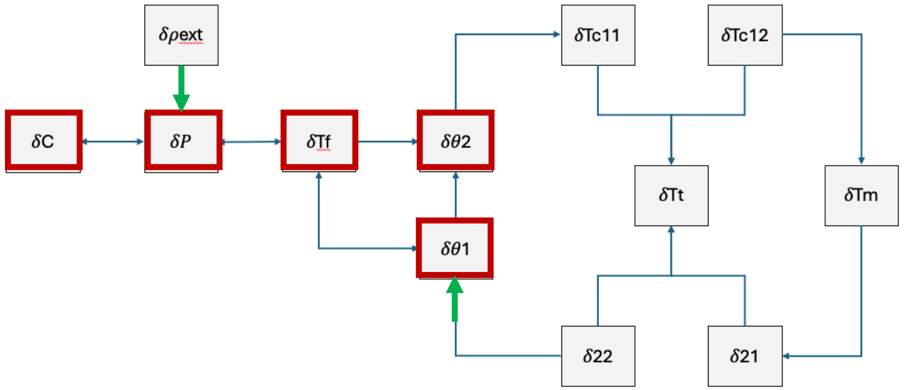
Development of Adaptive Control Model

- The behavior of a nuclear power plant can be described by a set of equations that represent the physical and thermal processes occurring within the plant.

PWR



MSR



- **Example of a model: PWR**

Reactor Power:

$$\frac{d}{dt}\left(\frac{\delta P}{P_o}\right) = \frac{-\beta}{\Lambda}.\left(\frac{\delta P}{P_o}\right) + \frac{\alpha_c}{2\Lambda}.\delta\theta_1 + \frac{\alpha_c}{2\Lambda}.\delta\theta_2 + \frac{\alpha_f}{\Lambda}.\delta T_f + \lambda.\delta C + \frac{\delta\rho_{ext}}{\Lambda}$$

Precursor concentration:

$$\frac{d}{dt}(\delta C) = \frac{\beta}{\Lambda}.\left(\frac{\delta P}{P_o}\right) - \lambda.\delta C$$

Fuel temperature equation:

$$\frac{d}{dt}(\delta T_f) = \frac{f.P_o}{m_f.C_{Pf}}.\left(\frac{\delta P}{P_o}\right) - \frac{U_{fc}.A_{fc}}{m_f.C_{Pf}}.(\delta T_f - \delta\theta_1)$$

Heat transfer (first coolant node):

$$\frac{d}{dt}(\delta\theta_1) = \frac{(1-f).P_o}{2.m_{c1}.C_{Pc}}.\left(\frac{\delta P}{P_o}\right) + \frac{U_{fc}.A_{fc1}}{m_{c1}.C_{Pc}}.(\delta T_f - \delta\theta_1) + \frac{\dot{m}_c}{m_{c1}}(\delta T_{CL} - \delta\theta_1)$$

Heat transfer (second coolant node):

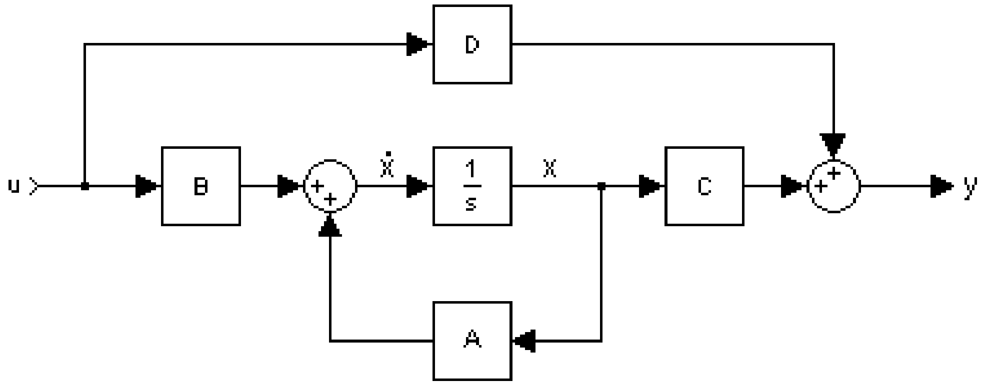
$$\frac{d}{dt}(\delta\theta_2) = \frac{(1-f).P_o}{2.m_{c2}.C_{Pc}}.\left(\frac{\delta P}{P_o}\right) + \frac{U_{fc}.A_{fc2}}{m_{c2}.C_{Pc}}.(\delta T_f - \delta\theta_1) + \frac{\dot{m}_c}{m_{c2}}(\delta\theta_1 - \delta\theta_2)$$

Development of Adaptive Control Model

- **Space State Representation in Reactor Dynamics**
  - State-space representation is a mathematical framework used to model and analyze systems represented by a set of input, output, and state variables related by first-order differential equations.
  - Numerical Method: Finite Element Analysis and Finite Difference Methods
- **Key components:**
  - State Variables [$\dot{x}$]: Represent the system's status at any given time. In reactor dynamics, state variables can include neutron density, precursor concentrations, and temperatures
  - Input Variables [u]: External influences or control actions applied to the system, such as reactivity changes or control rod movements.
  - Output Variables [y]: Measurable quantities of interest, like reactor power output or coolant temperature.
- **Equations:**

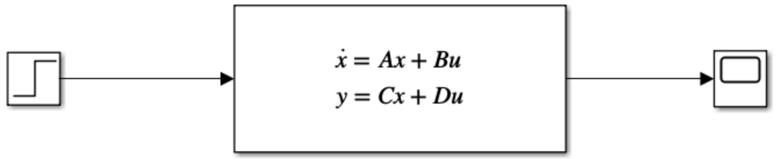
$$\dot{x} = Ax + Bu$$

$$y = Cx + Du$$



Development of Adaptive Control Model

- **State Space Representation**

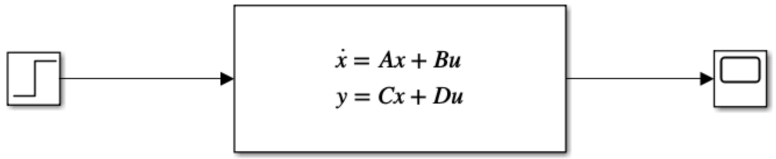


$$\begin{bmatrix} \delta P/Po \\ \delta C \\ \delta Tf \\ \delta\theta 1 \\ \delta\theta 2 \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} & A_{14} & A_{15} \\ A_{21} & A_{22} & A_{23} & A_{24} & A_{25} \\ A_{31} & A_{32} & A_{33} & A_{34} & A_{35} \\ A_{41} & A_{42} & A_{43} & A_{44} & A_{45} \\ A_{51} & A_{52} & A_{53} & A_{54} & A_{55} \end{bmatrix} * \begin{bmatrix} \delta P/Po \\ \delta C \\ \delta T_f \\ \delta\theta 1 \\ \delta\theta 2 \end{bmatrix} + \begin{bmatrix} B_{11} \\ B_{21} \\ B_{31} \\ B_{41} \\ B_{51} \end{bmatrix} * u(t)$$

Matrix A (system matrix)	$\left(\frac{\delta P}{P_o}\right)$	δC	δT_f	$\delta\theta_1$	$\delta\theta_2$
$\frac{d}{dt}\left(\frac{\delta P}{P_o}\right) = \frac{-\beta}{\Lambda}.\left(\frac{\delta P}{P_o}\right) + \frac{\alpha_c}{2\Lambda}.\delta\theta_1 + \frac{\alpha_c}{2\Lambda}.\delta\theta_2 + \frac{\alpha_f}{\Lambda}.\delta T_f + \lambda.\delta C + \frac{\delta\rho_{ext}}{\Lambda}$	$A11 = \frac{-\beta}{\Lambda}$	$A12 = \lambda$	$A13 = \frac{\alpha_f}{\Lambda}$	$A14 = \frac{\alpha_c}{2\Lambda}$	$A15 = \frac{\alpha_c}{2\Lambda}$
$\frac{d}{dt}(\delta C) = \frac{\beta}{\Lambda}.\left(\frac{\delta P}{P_o}\right) - \lambda.\delta C$	$A21 = \frac{\beta}{\Lambda}$	$A22 = -\lambda$	$A23 = 0$	$A24 = 0$	$A25 = 0$
$\frac{d}{dt}(\delta T_f) = \frac{f.P_o}{m_f.C_{Pf}}.\left(\frac{\delta P}{P_o}\right) - \frac{U_{fc}.A_{fc}}{m_f.C_{Pf}}.(\delta T_f - \delta\theta_1)$	$A31 = \frac{f.P_o}{m_f.C_{Pf}}$	$A32 = 0$	$A33 = -\frac{U_{fc}.A_{fc}}{m_f.C_{Pf}}$	$A34 = \frac{U_{fc}.A_{fc}}{m_f.C_{Pf}}$	$A35 = 0$
$\frac{d}{dt}(\delta\theta_1) = \frac{(1-f).P_o}{2.m_{c1}.C_{Pc}}.\left(\frac{\delta P}{P_o}\right) + \frac{U_{fc}.A_{fc1}}{m_{c1}.C_{Pc}}.(\delta T_f - \delta\theta_1) + \frac{\dot{m}_c}{m_{c1}}(\delta T_{CL} - \delta\theta_1)$	$A41 = \frac{(1-f).P_o}{2.m_{c1}.C_{Pc}}$	$A42 = 0$	$A43 = \frac{U_{fc}.A_{fc1}}{m_{c1}.C_{Pc}}$	$A44 = -\frac{U_{fc}.A_{fc1}}{m_{c1}.C_{Pc}} - \frac{\dot{m}_c}{m_{c1}}$	$A45 = 0$
$\frac{d}{dt}(\delta\theta_2) = \frac{(1-f).P_o}{2.m_{c2}.C_{Pc}}.\left(\frac{\delta P}{P_o}\right) + \frac{U_{fc}.A_{fc2}}{m_{c2}.C_{Pc}}.(\delta T_f - \delta\theta_1) + \frac{\dot{m}_c}{m_{c2}}(\delta\theta_1 - \delta\theta_2)$	$A51 = \frac{(1-f).P_o}{2.m_{c2}.C_{Pc}}$	$A52 = 0$	$A53 = \frac{U_{fc}.A_{fc2}}{m_{c2}.C_{Pc}}$	$A54 = -\frac{U_{fc}.A_{fc2}}{m_{c2}.C_{Pc}} + \frac{\dot{m}_c}{m_{c2}}$	$A55 = -\frac{\dot{m}_c}{m_{c2}}$

Development of Adaptive Control Model

- **State Space Representation**



$$\begin{bmatrix} \delta P/Po \\ \delta C \\ \delta Tf \\ \delta\theta 1 \\ \delta\theta 2 \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} & A_{14} & A_{15} \\ A_{21} & A_{22} & A_{23} & A_{24} & A_{25} \\ A_{31} & A_{32} & A_{33} & A_{34} & A_{35} \\ A_{41} & A_{42} & A_{43} & A_{44} & A_{45} \\ A_{51} & A_{52} & A_{53} & A_{54} & A_{55} \end{bmatrix} * \begin{bmatrix} \delta P/Po \\ \delta C \\ \delta T_f \\ \delta\theta 1 \\ \delta\theta 2 \end{bmatrix} + \begin{bmatrix} \boldsymbol{B_{11}} \\ \boldsymbol{B_{21}} \\ \boldsymbol{B_{31}} \\ \boldsymbol{B_{41}} \\ \boldsymbol{B_{51}} \end{bmatrix} * u(t)$$

Matrix B (input matrix)	Step Reactivity	Temperature Feedback
$\frac{d}{dt}\left(\frac{\delta P}{P_o}\right) = \frac{-\beta}{\Lambda}.\left(\frac{\delta P}{P_o}\right) + \frac{\alpha_c}{2\Lambda}.\delta\theta_1 + \frac{\alpha_c}{2\Lambda}.\delta\theta_2 + \frac{\alpha_f}{\Lambda}.\delta T_f + \lambda.\delta C + \frac{\delta\rho_{ext}}{\Lambda}$	$B11 = \frac{1}{\Lambda}$	$B11 = 0$
$\frac{d}{dt}(\delta C) = \frac{\beta}{\Lambda}.\left(\frac{\delta P}{P_o}\right) - \lambda.\delta C$	$B21 = 0$	$B21 = 0$
$\frac{d}{dt}(\delta T_f) = \frac{f.P_o}{m_f.C_{Pf}}.\left(\frac{\delta P}{P_o}\right) - \frac{U_{fc}.A_{fc}}{m_f.C_{Pf}}.(\delta T_f - \delta\theta_1)$	$B31 = 0$	$B31 = 0$
$\frac{d}{dt}(\delta\theta_1) = \frac{(1-f).P_o}{2.m_{c1}.C_{Pc}}.\left(\frac{\delta P}{P_o}\right) + \frac{U_{fc}.A_{fc1}}{m_{c1}.C_{Pc}}.(\delta T_f - \delta\theta_1) + \frac{\dot{m}_c}{m_{c1}}(\delta T_{CL} - \delta\theta_1)$	$B41 = 0$	$B41 = \frac{\dot{m}_c}{m_{c1}}$
$\frac{d}{dt}(\delta\theta_2) = \frac{(1-f).P_o}{2.m_{c2}.C_{Pc}}.\left(\frac{\delta P}{P_o}\right) + \frac{U_{fc}.A_{fc2}}{m_{c2}.C_{Pc}}.(\delta T_f - \delta\theta_1) + \frac{\dot{m}_c}{m_{c2}}(\delta\theta_1 - \delta\theta_2)$	$B51 = 0$	$B51 = 0$

Development of Adaptive Control Model

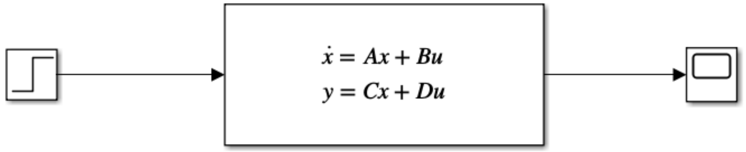
- **PWR Response – Matlab (Simulink)**

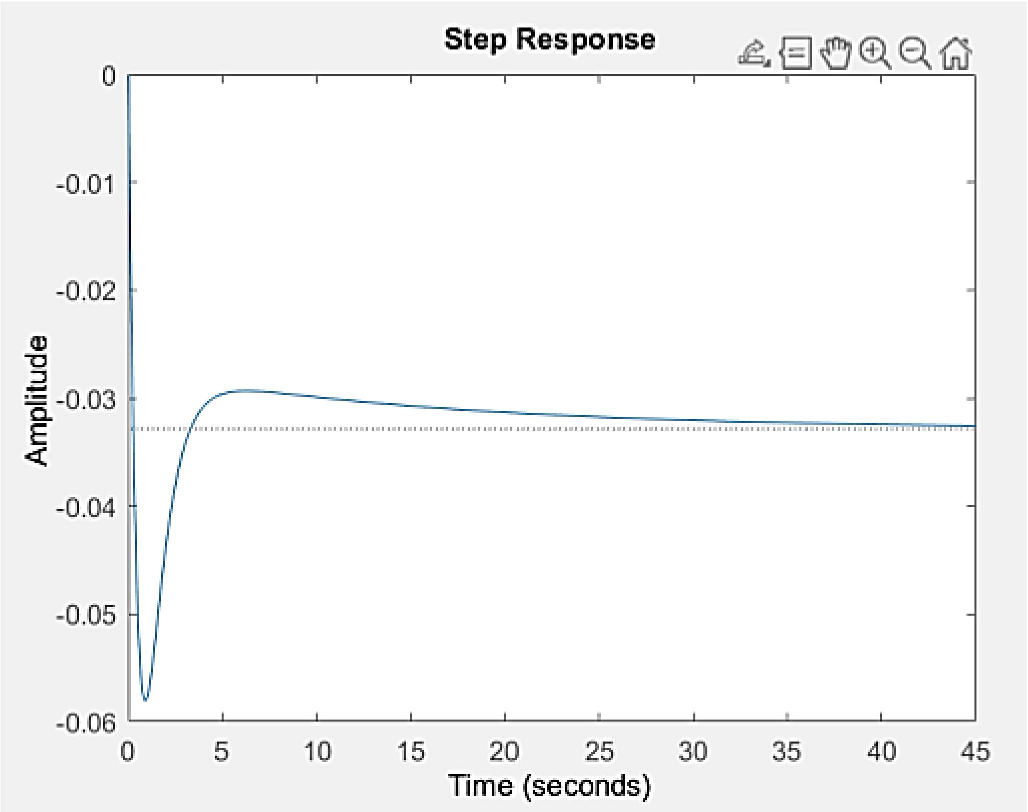
```
A =

 -385.3631    0.0822   -0.6145   -5.5866   -5.5866
  385.3631   -0.0822         0         0         0
  241.8700         0   -0.2532    0.2532         0
    2.4731         0    0.0970   -3.4733         0
    2.4731         0    0.0970    3.2793   -3.3763
```

```
Bt =

         0
         0
         0
    3.3763
         0
```

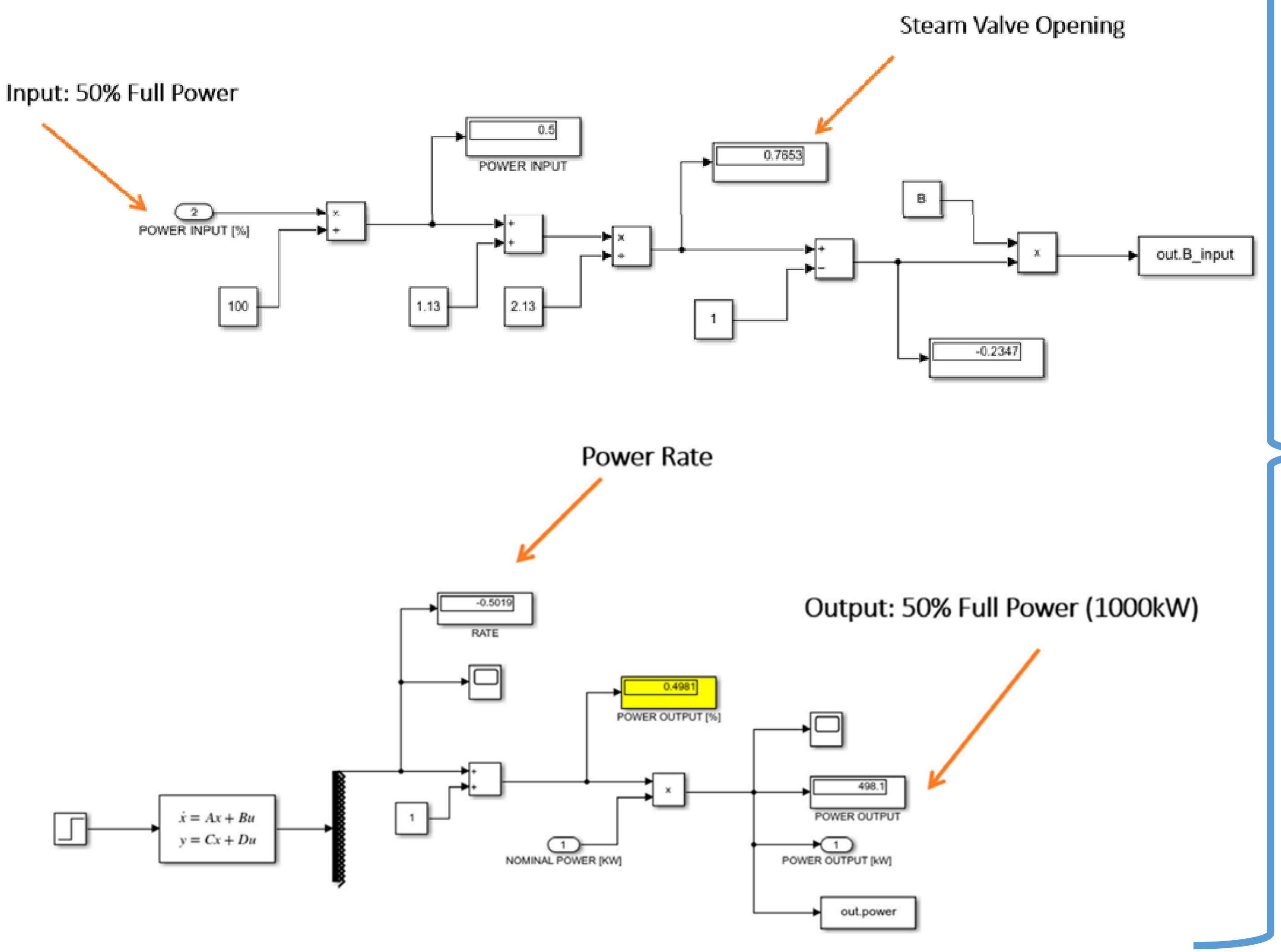


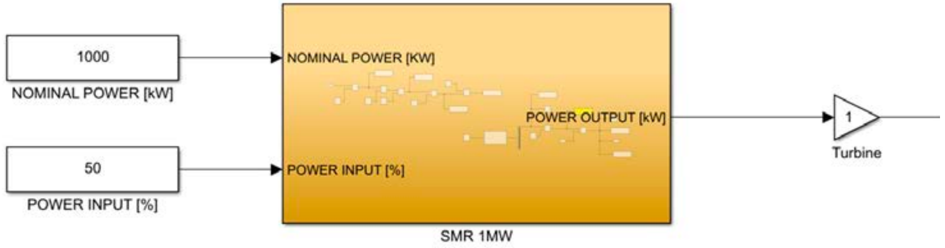


- **Reactor Thermal Power**
- Input: Change in the feedback temperature (+3 ^{o}F) - Doppler Effect
- Output: Prompt power decrease -5.7%, after 45s maintain stable in -3.2% PR

Development of Adaptive Control Model

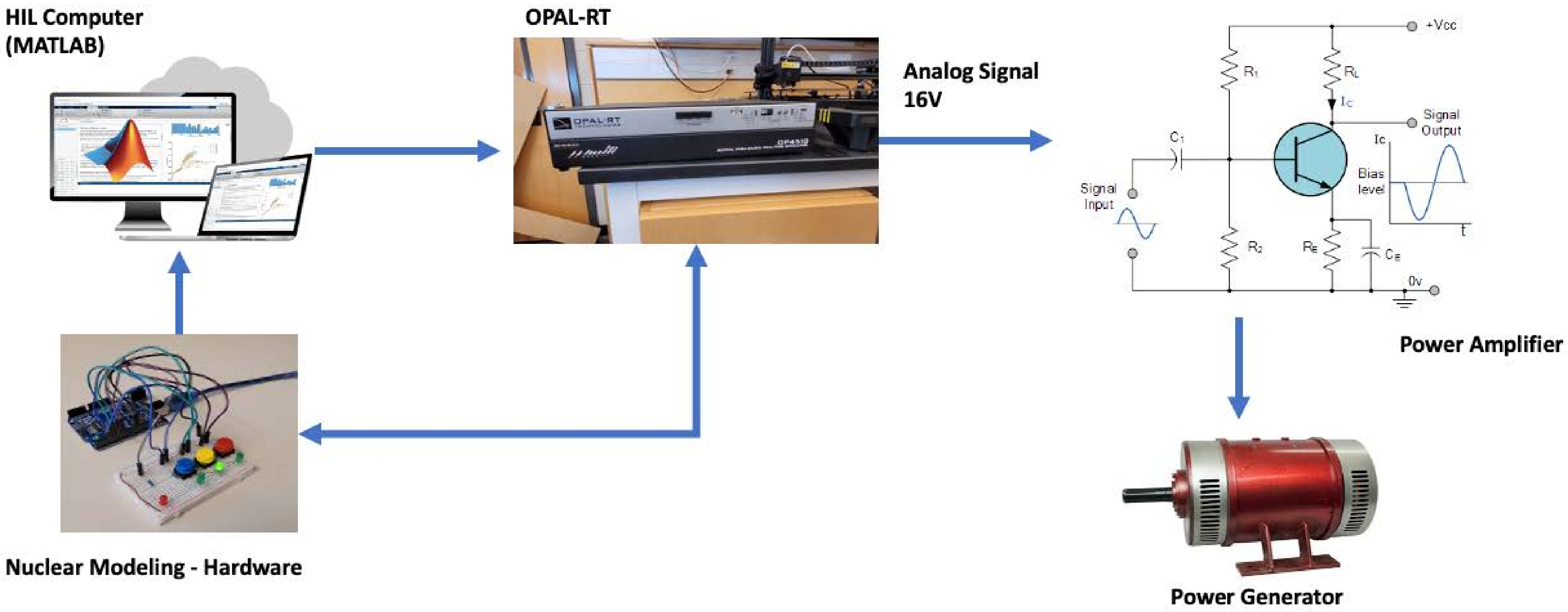
- **Matlab (Simulink)**





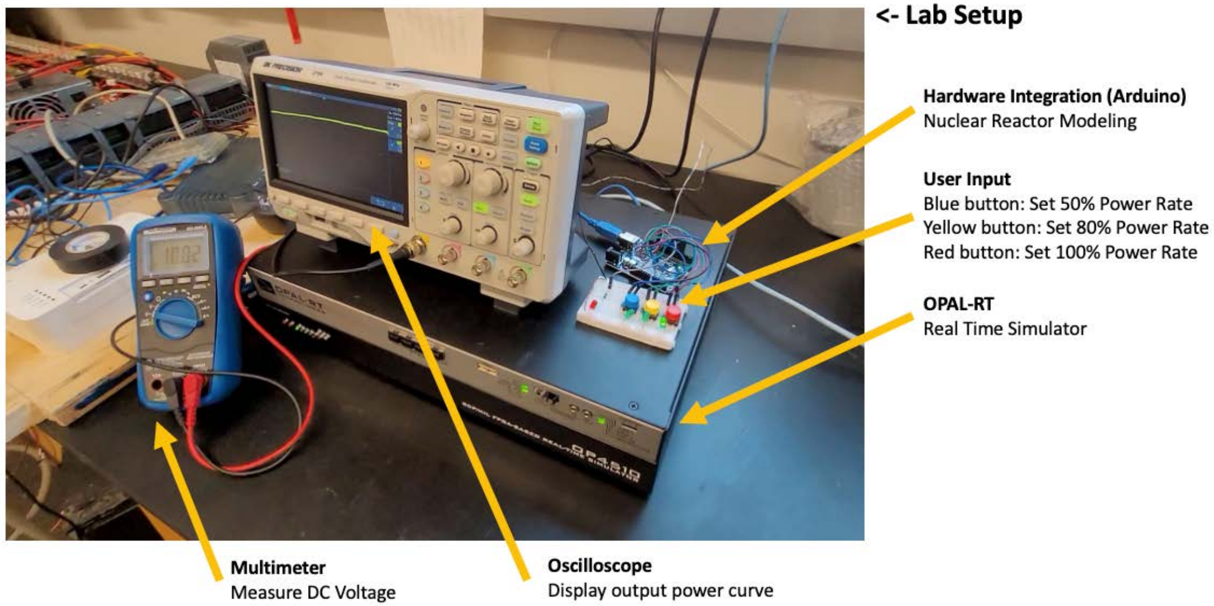
Integration with NRiL for Real-Time Validation

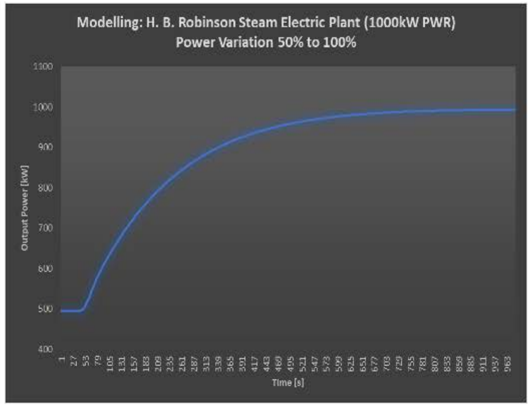
- **Real Time Simulation Schematic**

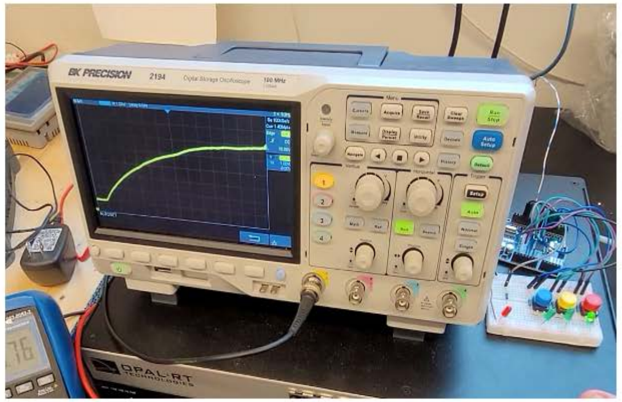


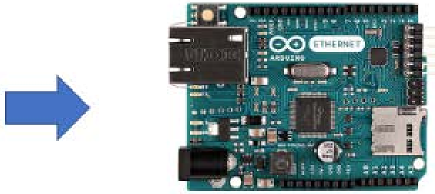
Integration with NRiL for Real-Time Validation

- **Lab Setup**

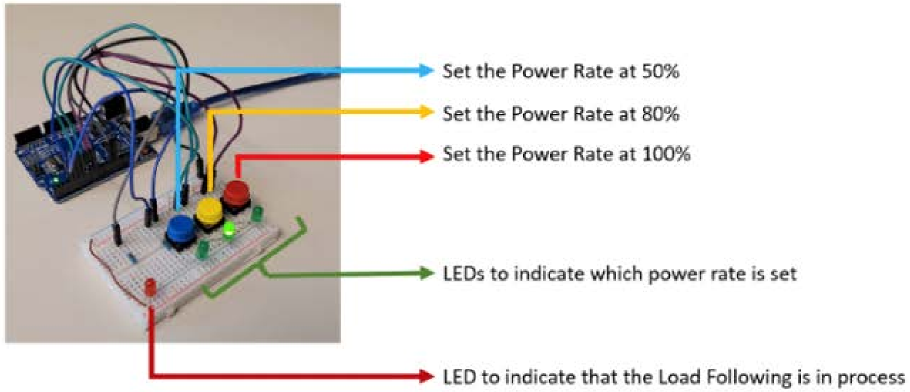


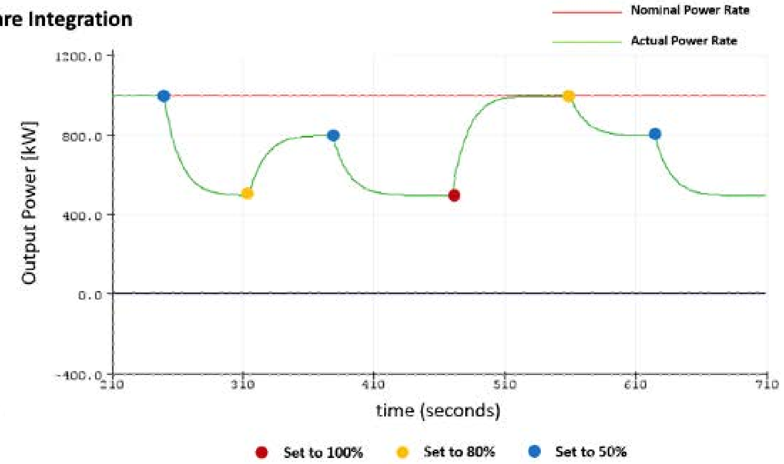






Hardware Integration

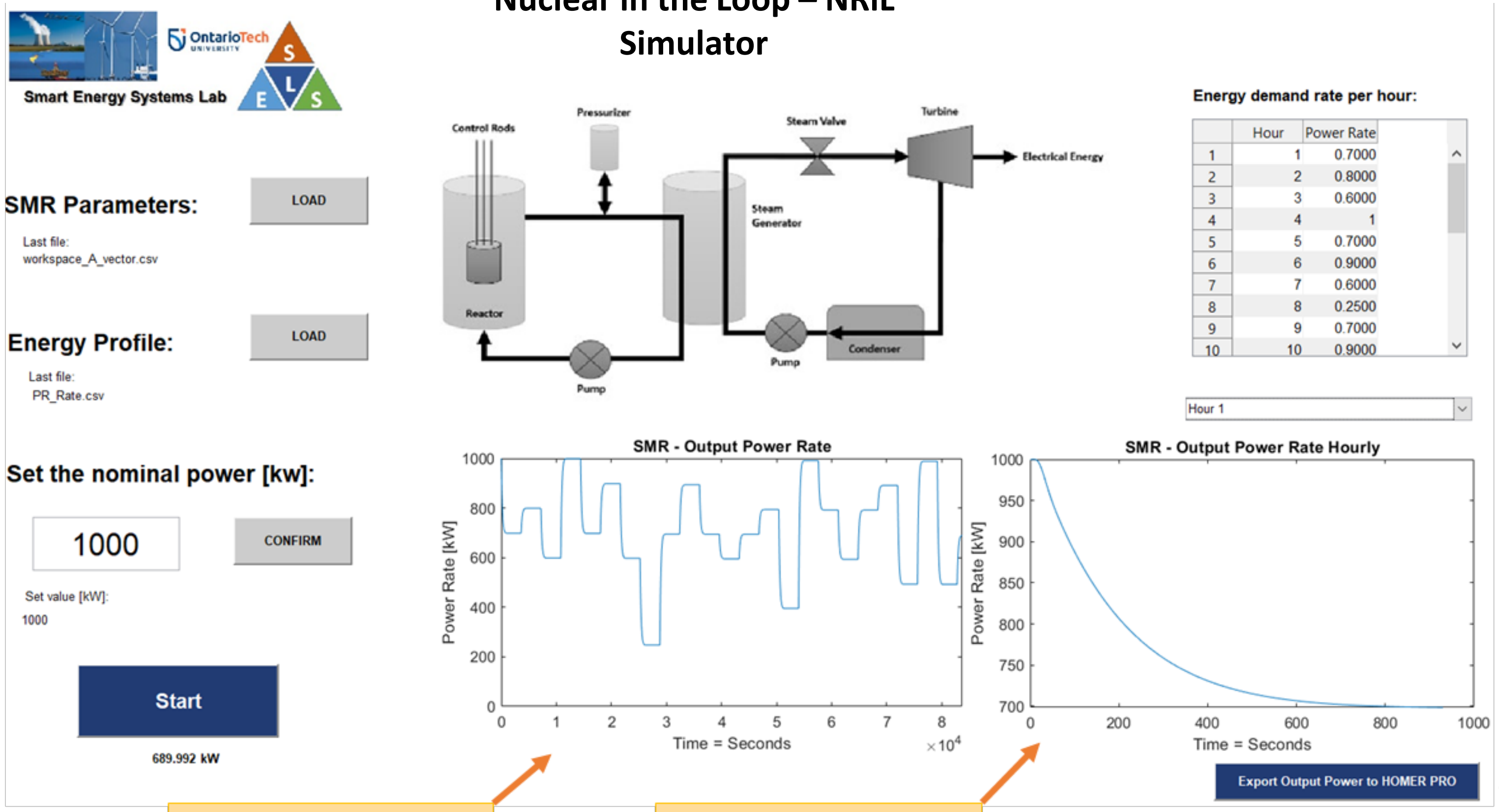




Evaluate LF performance for NR-HES Simulator

- **User Interface**

Nuclear in the Loop – NRiL Simulator



Nuclear reactor parameters

Load Following profile

Nominal Power [kW]

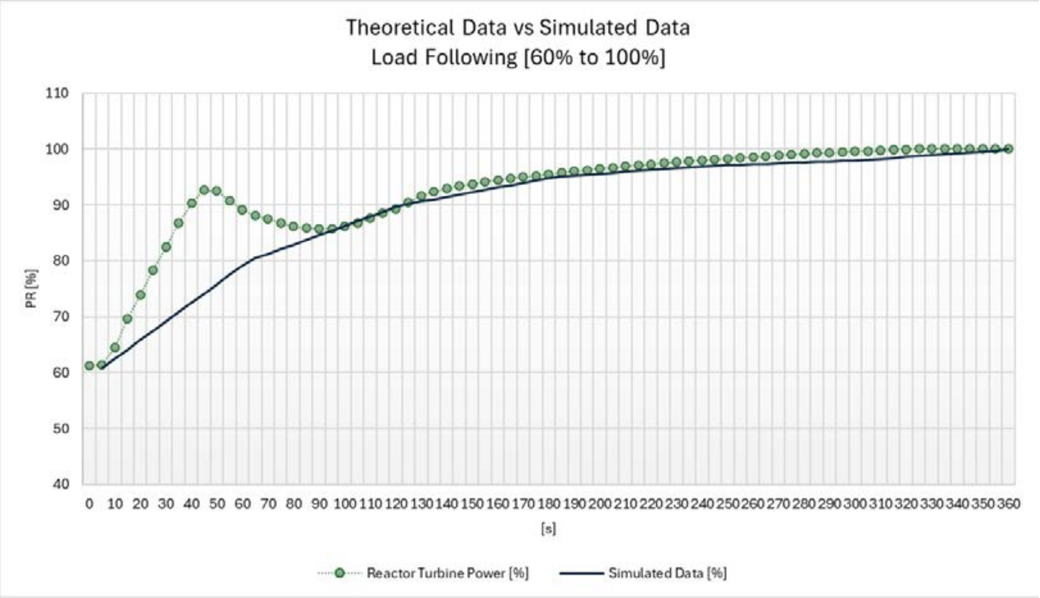
Output Power Rate

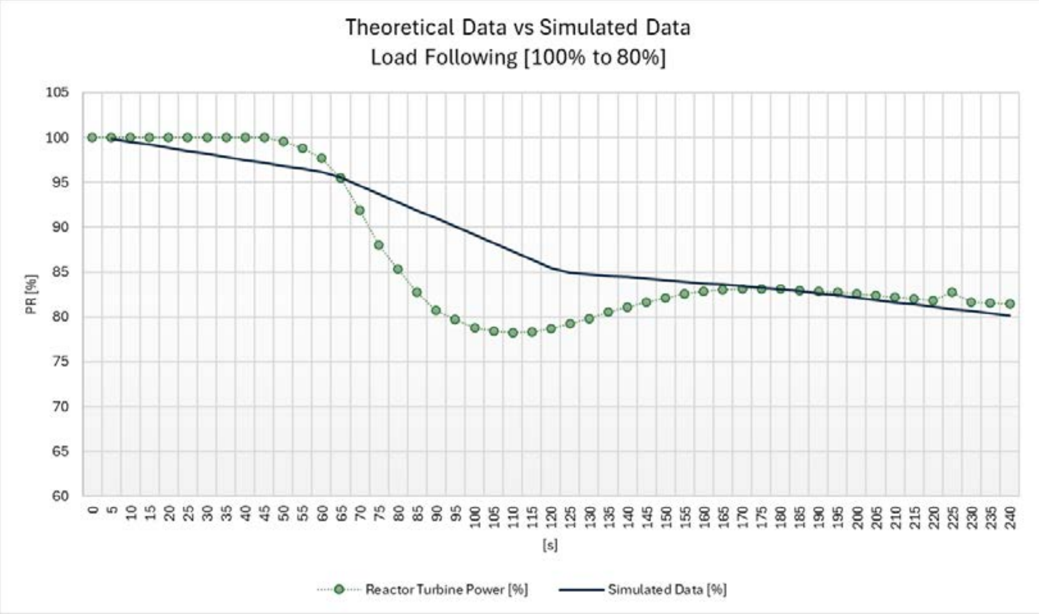
Generation curve

Simulation HOMER

Application in the NRHESS

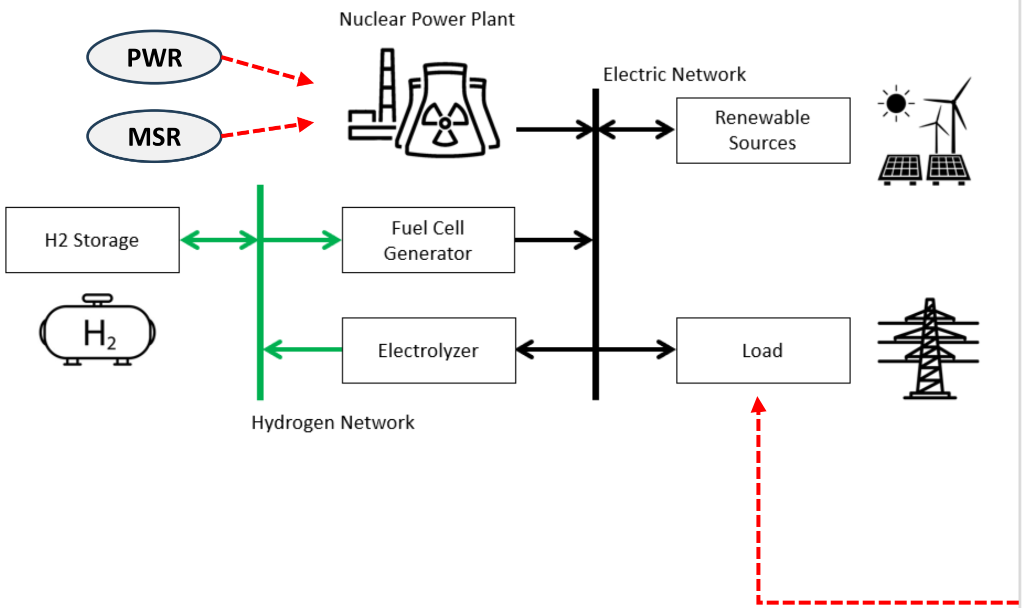
- **Validation Highlights:**
  - Simulated data captures dynamic behavior in both ramp-up and ramp-down scenarios.
  - Close correspondence confirms model reliability.
- **Main Constraints**
  - Longer simulation timeframes (minutes) can miss transient effects and power spikes.
  - Need for shorter timeframes (seconds or milliseconds) to capture rapid dynamics accurately.
  - Refinement needed in interpolation techniques and control algorithms.
- **Real Time Simulation show significance in this part.**



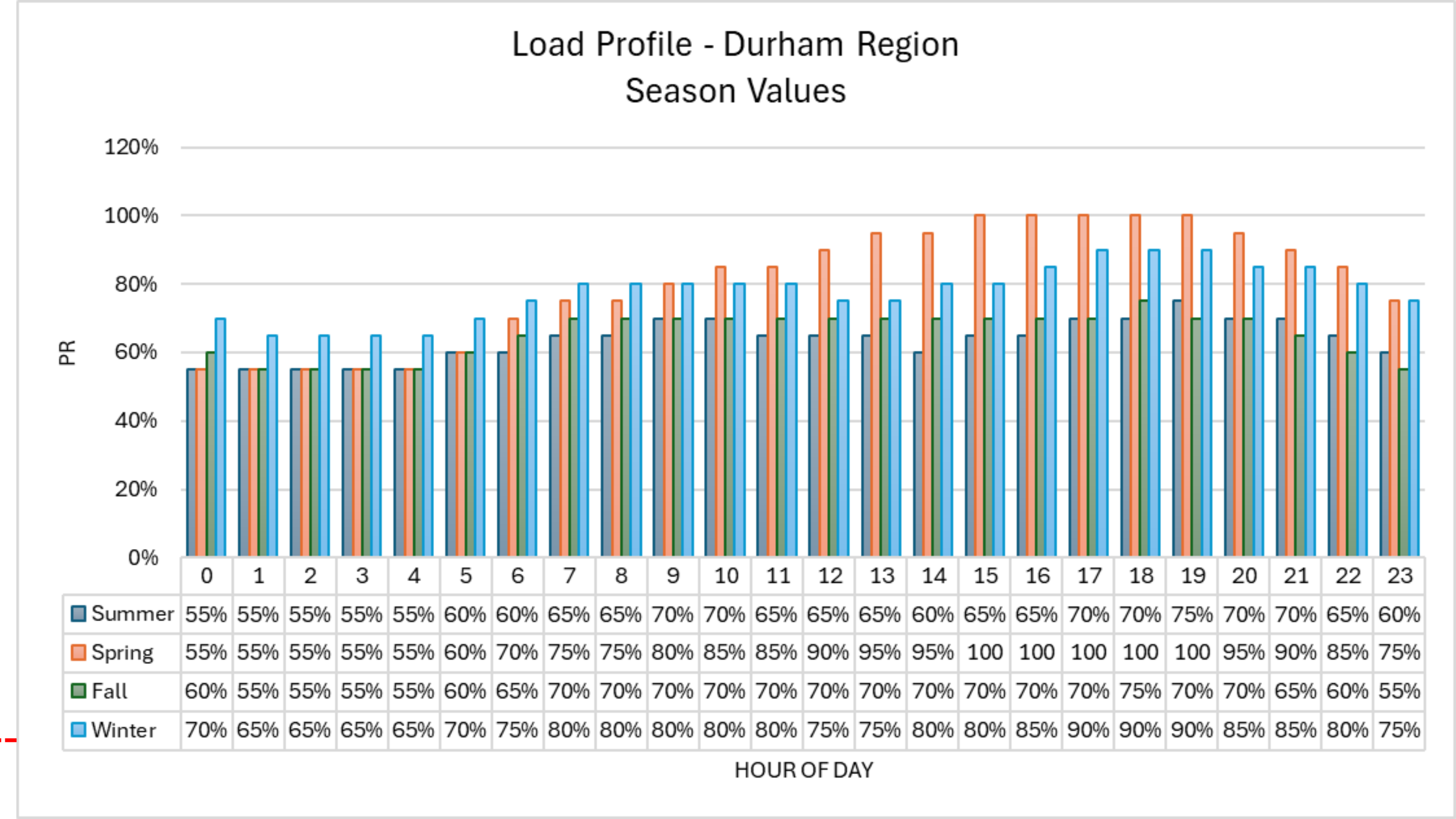


Application in the NRHESS

- **Schematic:**



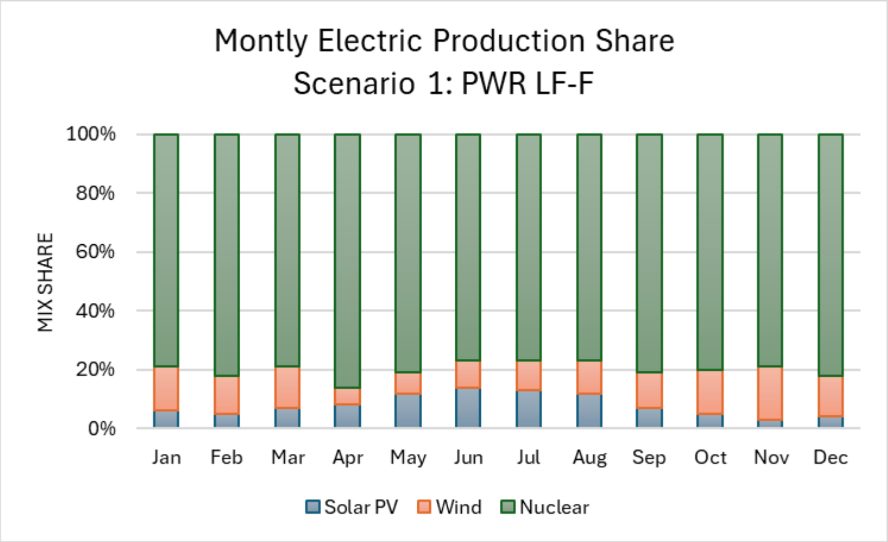
Load Following Profile:



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Summer	55%	55%	55%	55%	55%	60%	60%	65%	65%	70%	70%	65%	65%	65%	60%	65%	65%	70%	70%	75%	70%	70%	65%	60%
Spring	55%	55%	55%	55%	55%	60%	70%	75%	75%	80%	85%	85%	90%	95%	95%	100	100	100	100	100	95%	90%	85%	75%
Fall	60%	55%	55%	55%	55%	60%	65%	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%	75%	70%	70%	65%	60%	55%
Winter	70%	65%	65%	65%	65%	70%	75%	80%	80%	80%	80%	80%	75%	75%	80%	80%	85%	90%	90%	90%	85%	85%	80%	75%

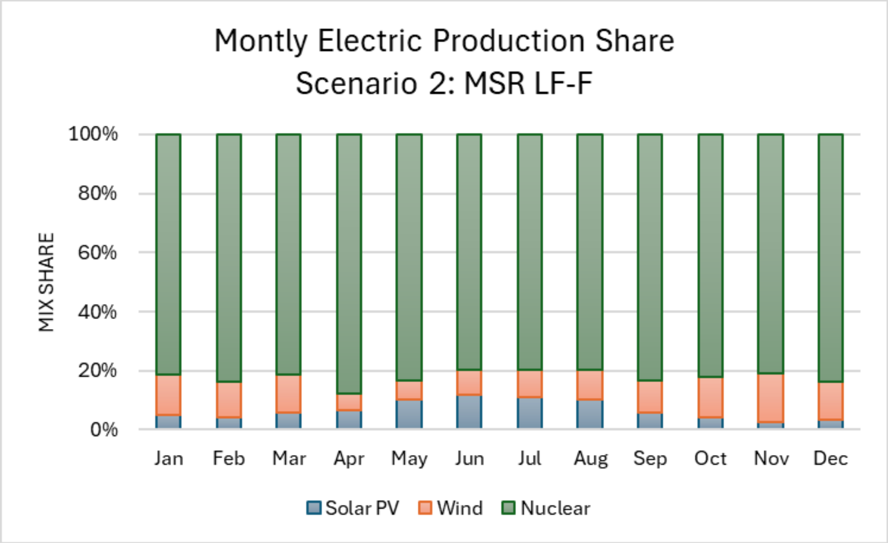
Application in the NRHESS

- Outcomes:
- **PWR Model:**



Component	kWh/year	Share
Solar PV	1,082,112,350.37	7.998%
Wind Turbine	1,623,168,525.55	11.997%
Nuclear	10,824,316,488.68	80.005%
Total	13,529,597,364.60	100%
Surplus	7,462,513,344.60	23%
COE	$ 0.152	

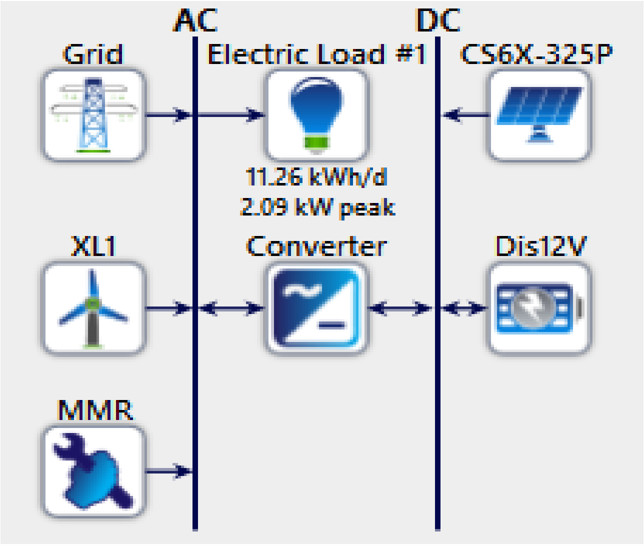
- **MSR Model:**



Component	kWh/year	Share
Solar PV	913,906,707.44	6.816%
Wind Turbine	1,464,181,520.71	10.920%
Nuclear	11,030,167,456.05	82.264%
Total	13,408,255,684.20	100%
Surplus	7,341,171,664.20	21%
COE	$ 0.134	

Design and Model of the N-H MHES

The diagram below shows the schematic of a Nuclear-Renewable Micro Hybrid Energy System for an Electric vehicle charging station. The lifetime of this hybrid system is assumed to be 25 years. The Electric load is synonymous to an Electric Vehicle in this model. For the design and planning of the microgrid model, the location that was used in the HOMER pro software is 141 Kennedy Ave, Toronto, ON M6R 2L2, Canada (43°39.2’N, 79°23.0’W).The N-H MHES consists of the following components:



Nuclear-Renewable Micro Hybrid Energy System

System Components

Micro Modular Reactor (MMR)

MMR is a small-scale fourth-generation nuclear reactor, and it is in the process of development. It can produce thermal energy and electricity in parallel by combined heat and power CHP. The MMR is basically a nuclear reactor that can generate electricity between 1 MWe and 20 MWe. The reactor is manufactured in the factory and then transported to the site for assembling. It takes less time and investment to construct, and it has basically no operation and maintenance cost. Recently, the Ultra Safe Nuclear Corporation designed a MMR Energy System which is a zero-carbon nuclear power plant, integrating one or several standardized micro module reactors. The electrical and thermal power rating of the MMR is 5 MWe and 15 MWt.

Nuclear Power Plant (NPP)

The NPP, having a MMR rated 20 MWt, is considered. The NPP can supply 8 MWe from 20 MWt energy. The capital cost and maintenance cost is $80 M and $160,000 respectively.

System Component

Nuclear Reactor

- Fourth-generation nuclear reactor, ranging from 1-10 MW_e, and has CHP capability.
- Modularity, easy to transport, fast to build, sealed core, excellent safety margin, and simple operation.
- Assembled in a factory and delivered to a designated place as a package.
- Does not need any refuelling in its' entire lifetime, and the fuel module is sealed at the site.

Table: Specification of MMR unit

Parameters	Value	Parameters	Value
Reactor size (MW_e)	5	**Fixed O & M cost ($\$/kW_e$)**	350
Plant lifetime (Years)	40	**Fuel cost ($\$/MWh$)**	10
Core lifetime (Years)	10	**Decommissioning cost ($\$/MWh$)**	5
Capacity factor (%)	95	**Refueling cost of fuel module ($\$$)**	20 million
Overnight capital cost ($\$/kW_e$)	15,000	**Plant efficiency (%)**	40

$$MMR_{cap} = \sum_{i=1}^{N_{MMR}} MMR_{cap(1st)} \times (N_{MMR})^R$$

MMR_{cap} = Total capital cost of the MMR ($)

$MMR_{cap(1st)}$ = first unit deployment cost of the MMR unit ($)

R = Rate of cost reduction (%) = 15%

Solar PV Panel

Solar power generation by PV panels largely depends on solar irradiance, ambient temperature, and PV panel surface area. Explicit modeling of PV panel to extract solar power from UOIT location can be represented:

$$P_{PV}(t) = N_{PV} \times \eta_{PV}(t) \times PV_{area} \times G_t(t)$$

$$\eta_{PV}(t) = \eta_{ref} \times \eta_{MPPT} \times [1 + \beta(T_c(t) - T_{cref})]$$

$$T_c(t) = T_a(t) + \left(\frac{NOCT - 20}{800}\right) \times G_t(t)$$

$N_{PV} = Number\ of\ PV\ panel$

$\eta_{PV}(t)$ = Instantaneous PV panel efficiency (%)

PV_{area} = Area occupied by unit PV panel (m^2)

$G_t(t)$ = Solar irradiance (kW/m^2)

η_{ref} = Reference efficiency of the PV panel (17.3%)

η_{MPPT} = Efficiency of the Maximum Power Point Tracking (MPPT) unit (95%)

β = Temperature coefficient ($-0.41\ °C^{-1}$)

T_{cref} = PV panel reference temperature (25 °C)

$NOCT$ = Nominal operating cell temperature (45 °C).

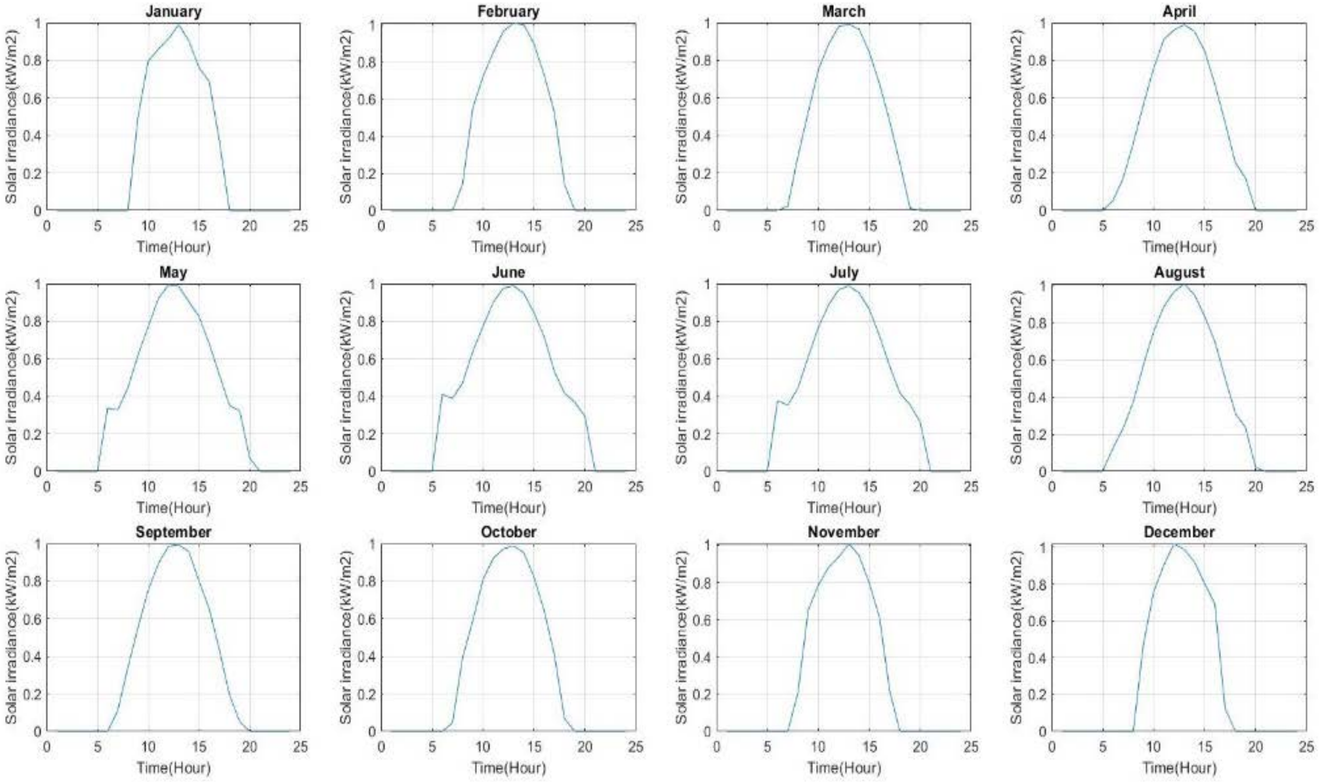


Fig: Solar irradiance data of the project location

Wind Turbine

Hub height of wind turbine and power generated from wind turbine can be determined from below equations:

$$V = \left(\frac{h_{hub}}{h_{ref}}\right)^{a}$$

$$P_W(t) = \begin{cases} 0, & V < V_{min}, V > V_{max} \\ a \times V^3(t) - b \times P_r & V_{min} \leq V \leq V_r \\ P_r, & V_r \leq V \leq V_{max} \end{cases}$$

$$a = \frac{P_r}{V_r^3 - V_{min}^3} \qquad b = \frac{V_{min}^3}{V_r^3 - V_{min}^3}$$

h_{hub} = Hub height (16 m)

h_{ref} = Anemometer height (50 m)

a = Power law exponent (1/7)

V_{min} = Minimum wind speed (2.75 m/s)

V_{max} = Maximum wind speed (20 m/s)

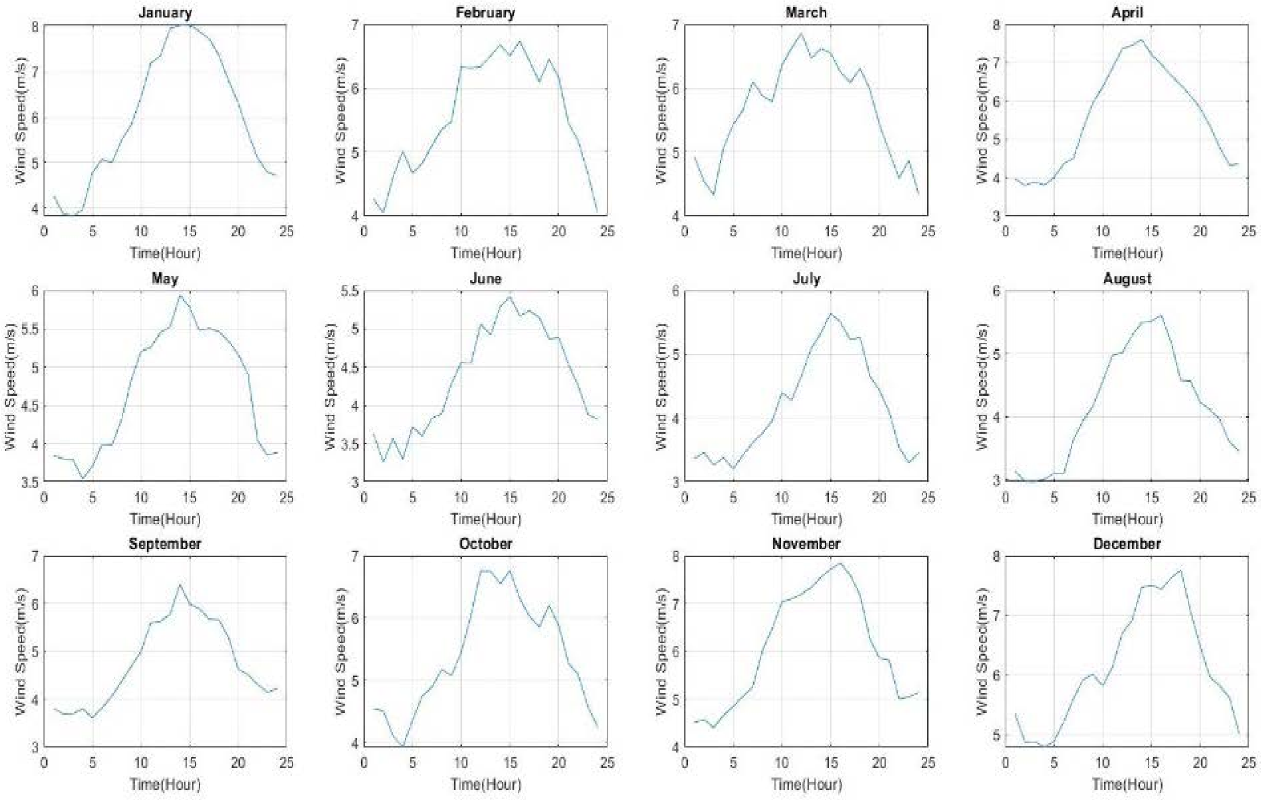


Fig: Wind speed data of the project location

Hydro Turbine

The annual mass flow rate of Lake Ontario, located near the UOIT campus, is collected and synthesized for the simulation. The following equations are used to calculate hydropower generation.

$$P_h(t) = H_{eff} \times \rho_w \times g \times Q_{turbine}(t) \times \eta_{HT}$$

$$H_{eff} = H_a(1 - H_{loss})$$

$$Q_{turbine}(t) = \begin{cases} 0, & Q_{available} < Q_{min} \\ Q_a, & Q_{min} \leq Q_{available} \leq Q_{max} \\ Q_{max}, & Q_{available} > Q_{max} \end{cases}$$

H_{eff} = effective water head (m)

ρ_w = Water density $(\frac{kg}{m^3})$

$g =$ Gravitational constant $(\frac{m}{s^2})$

$Q_{turbine}(t)$ = Mass discharge rate $(\frac{m^3}{s})$

η_{HT} = HT efficiency (80%)

H_a = usable water head (m)

H_{loss} = Pipe head loss (15%)

Biogas Generator

A dairy farm containing 150 cows, is considered to produce biogas from cow manure. The nominal capacity of the BG is 153 kW. The waste heat recovery ratio of the BG is regarded as 40% in this study

$$P_{bio}(t) = \frac{\sum_{n=1}^{i} N_i . m_i . k_{DSi} . k_{OSi} . v_{Bi} . e_{Bi}}{K_e . T_c}$$

n = Number of group of animals

N_i = Number of animals in a specific group

m_i = Manure produced per animal (37 kg/day)

k_{DSi} = Dry substance content in the manure of particular animal (0.18)

k_{OSi} = Organic substance content in dry substance (0.86)

v_{Bi} = Specific biogas output from the organic substance (204 $m^3/tons$)

e_{Bi} = Specific heat energy obtained from manure (kWh/m^3),

K_e = Electric efficiency of the plant (40%)

T_c = Number of operational hours of the plant during the year (4380 hours/year).

Flywheel

FW energy storage utilizes kinetic energy in its rotor to store energy. FW stores mechanical energy and converts it to electrical energy when needed. It has a fast response to energy demand. The rating of a single unit FW, considered in this study, is 57 kWh (1000 kW). Stored energy of flywheel can be calculated by below equation

$$E_c(\mathrm{t}) = \frac{1}{2} I \omega(t)^2$$

I = Moment of inertia of FW ($kg.m^2$)

$\omega(t)$ = Rotational speed of the FW (rev/s)

Charging and discharging of the FW within N-R MHES can be calculated by the following equations

$$E_{FW,charging}(t) = E_{FW}(t-1) + E_{available}(t)$$

$$E_{FW,discharging}(t) = E_{FW}(t-1) - E_{demand}(t)$$

Fuel Cell, Electrolyzer, and Hydrogen tank

Amount of hydrogen produced by electrolyzer is given by below equation

$$H_{production}(t) = \{H_{tank}(t) - H_{tank}(t-1)\} = \eta_{elec} \times E_{elec}(t) \times \frac{H_2\ density\ (kg/m^3)}{H_2\ heating\ value(kWh/m^3)}$$

$H_{tank}(t)$ = Amount of hydrogen (kg) at time t

η_{elec} = Electrolyzer efficiency (40%)

$E_{elec}(t)$ = input energy to the electrolyzer (kWh

H_2 heating value is 3.4 kWh/m^3

H_2 density is 0.09 kg/m^3

The electric energy produced by the FC is determined

$$E_{FC}(t) = \{H_{tank}(t-1) - H_{tank}(t)\} \times \eta_{FC} \times \frac{H_2\ heating\ value(kW\ h/m^3)}{H_2\ density\ (k\ g/m^3)}$$

η_{FC} = Efficiency of the FC (50%).

Electric and Thermal Energy Storage

The selection of the battery capacity of the system depends on the demand and the days of autonomy. The following equation can measure the EES (battery) capacity (kWh).

$$EES_{capacity} = \frac{P_{EL,avg} \times AD}{DOD \times \eta_{inv} \times \eta_{ESS}}$$

$P_{EL,avg}$ *is the* Average electric demand (kW) AD is the Autonomy days (typically 3 to 5 days), DOD is the depth of discharge of the battery (80%), η_{inv} is the efficiency of the inverter (95%), and η_{ESS} is the battery efficiency (85%)

The EES charging and discharging scenario can be characterized:

$$E_{EES}(t) = E_{EES}(t-1) + E_{EES,in}(t)\eta_{EES} \qquad E_{EES}(t) = E_{EES}(t-1) - \frac{E_{EES,out}(t)}{\eta_{EES}}$$

where $E_{EES,in}(t)$ is the available battery charging energy (kWh) and $E_{EES,out}(t)$ is the possible battery discharging energy (kWh).

The TES charging and discharging scheme can be expressed as:

$$E_{TES}(t) = E_{TES}(t-1) + E_{TES,in}(t)\eta_{TES} \qquad E_{TES}(t) = E_{TES}(t-1) - \frac{E_{TES,out}(t)}{\eta_{TES}}$$

where $E_{TES,in}(t)$ is the available charging energy of the TES (kWh), η_{TES} is the efficiency of the TES (80%), and $E_{TES,out}(t)$ is the output energy of the TES (kWh).

H2E and E2H Unit

An H2E unit is considered to generate electricity from excess thermal power if required by the electric load. The H2E unit consists of steam generator, steam turbine, and electric generator.

$$H2E(t) = \eta_{H2E} \times P_{excess}(t) \qquad \eta_{H2E} = \eta_{SG} \times \eta_{ST} \times \eta_{EG}$$

η_{SG} is the steam generator efficiency (40%), η_{ST} is the steam turbine efficiency (40%), η_{EG} is the electric generator efficiency (95%), and $P_{excess}(t)$ is the surplus thermal power at time step t.

An E2H is also regarded in this research to produce thermal energy from surplus electric energy.

$$E2H(t) = \eta_{E2H} \times T_{excess}(t)$$

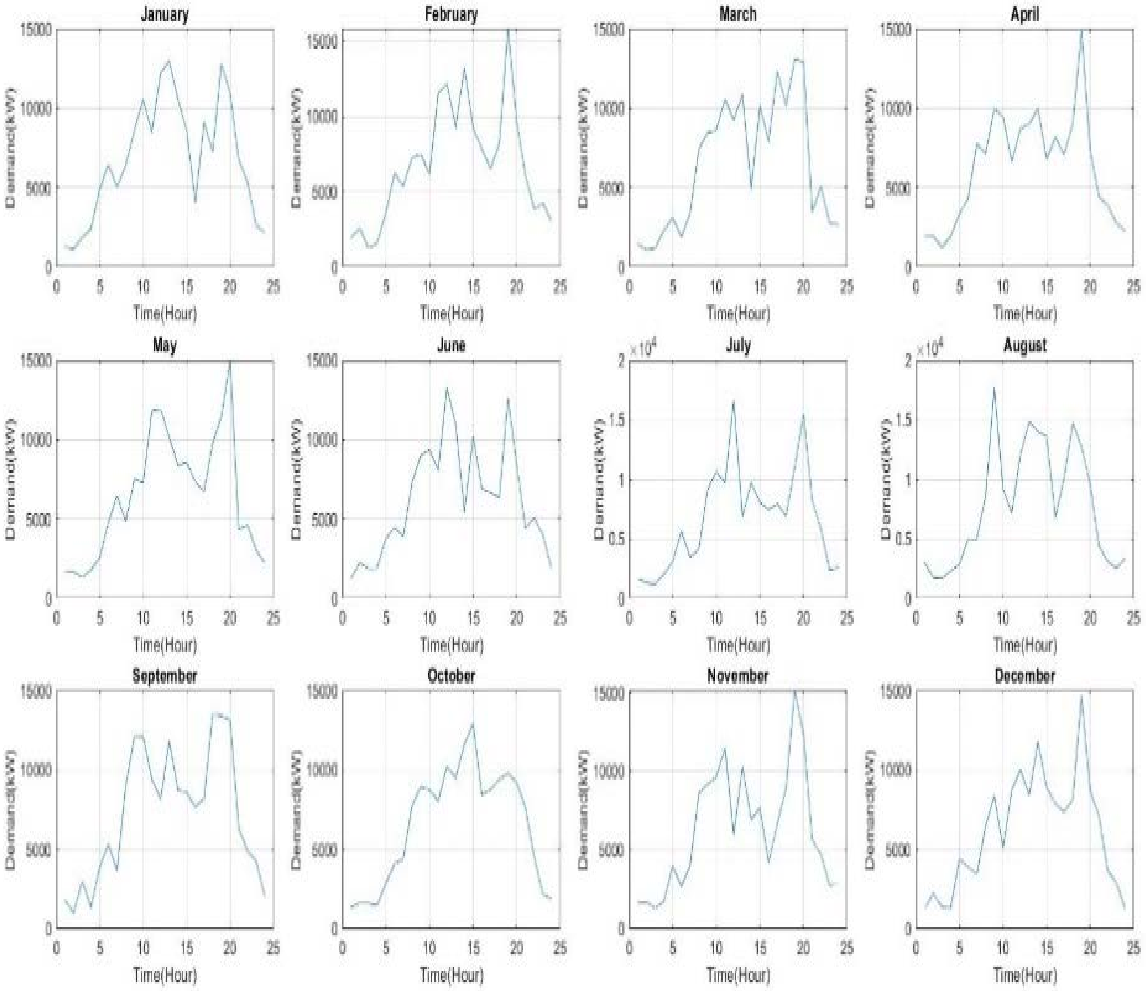
η_{E2H} is the efficiency of E2H unit (98%) and $T_{excess}(t)$ is the surplus electric power at time step t.

Input parameters

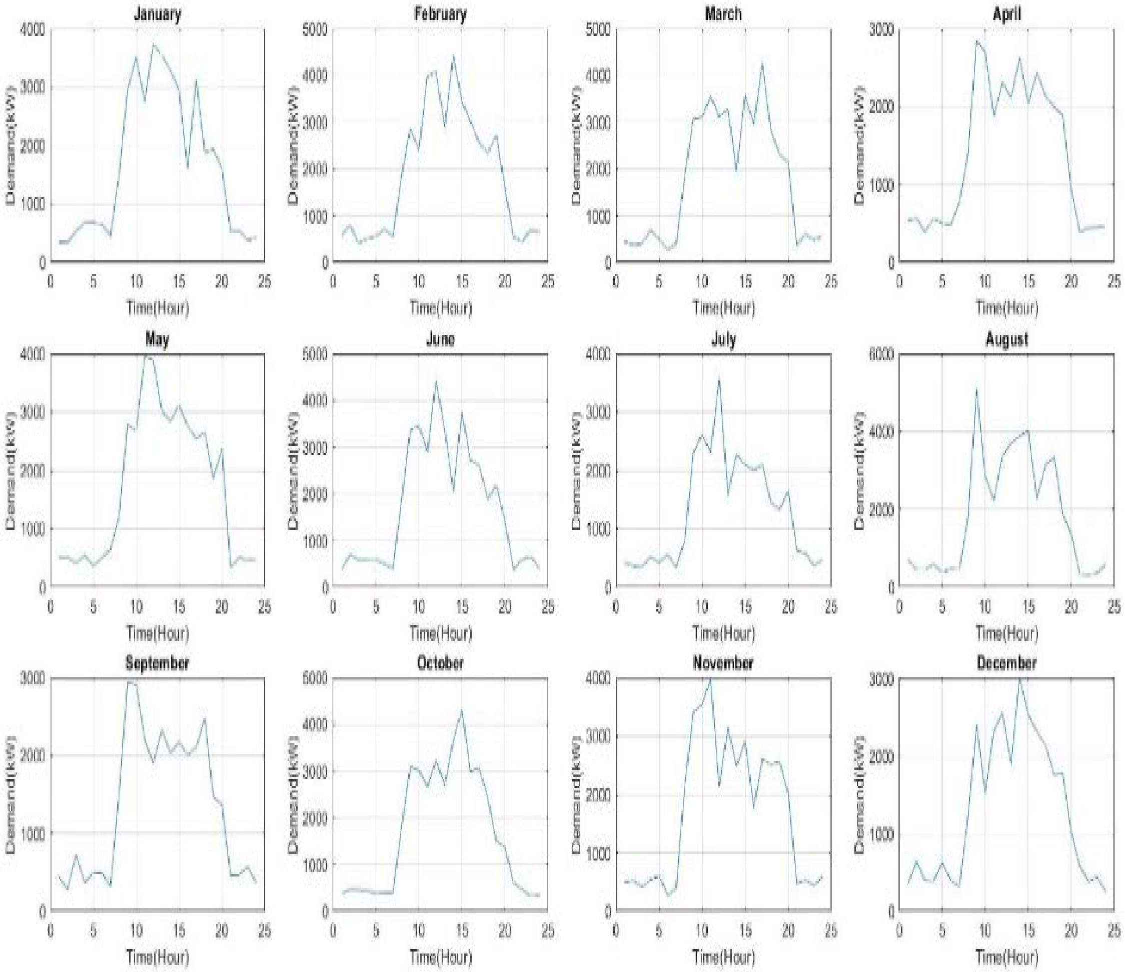
Table: Input Parameters

Component	Capital cost ($\$/kW_e$)	Replacement cost ($\$/kW_e$)	O & M cost ($\frac{\$}{kW_e}/year$)	Lifetime ($year$)
PV panel	2800	2500	12	25
WT	1521	1521	48	25
HT	2500	250	100	40
BG	4000	2500	300	25
FW	300	300	20	20
FC	600	500	0.0153	4.5
Electrolyzer	1500	1000	20	15
Hydrogen tank	1200 ($/kg)	800 ($/kg)	15 ($/kg/year)	25
EES	398	398	0	4.5
TES	5	5	0	30
H2E unit	1932	1932	0.9	15
E2H unit	54	54	0	20
Inverter	210	210	0	15

Electric and Thermal Load Profile



Electric Load Profile



Thermal Load Profile

Simulation and Results

The objective function of the minimization problem can be defined as follows.

$$\min f_{NPC} = \sum_{i=1}^{n} NPC_i$$

The energy management constraints are presented by following equations.

$$\sum P_{gen}(t) \geq \sum_{t=1}^{t_{total}} P_{EL}(t)\,, \qquad \sum T_{gen}(t) \geq \sum_{t=1}^{t_{total}} P_{TL}(t)$$

$$\sum P_{gen}(t) = \sum_{t=1}^{t_{total}} P_{PV}(t) + \sum_{t=1}^{t_{total}} P_{W}(t) + \sum_{t=1}^{t_{total}} P_{MMR}(t) + \sum_{t=1}^{t_{total}} P_{HT}(t) + \sum_{t=1}^{t_{total}} P_{BG}(t)$$

$$\sum T_{gen}(t) = \sum_{t=1}^{t_{total}} T_{MMR}(t) + \sum_{t=1}^{t_{total}} T_{BG}(t)$$

Loss of Power Supply Probability (LPSP) is inserted as an optimization constraint in the problem formulation to confirm the reliability and resiliency of the energy system.

$$LPSP_{elec} \leq LPSP_{elec,max}, \qquad LPSP_{elec} = \frac{\sum_{t=1}^{t_{total}} \left(P_{EL}(t) - P_{gen}(t)\right)}{\sum_{t=1}^{t_{total}} P_{EL}(t)}$$

$$LPSP_{ther} \leq LPSP_{ther,max}\ , \qquad LPSP_{ther} = \frac{\sum_{t=1}^{t_{total}} \left(P_{TL}(t) - T_{gen}(t)\right)}{\sum_{t=1}^{t_{total}} P_{TL}(t)}$$

The decision variable constraints of the problem can be written as follows.

$$0 \leq N_{PV} \leq N_{PV,max}$$

$$0 \leq N_{WT} \leq N_{WT,max}$$

$$0 \leq N_{MMR} \leq N_{MMR,max}$$

$$0 \leq N_{FW} \leq N_{FW,max}$$

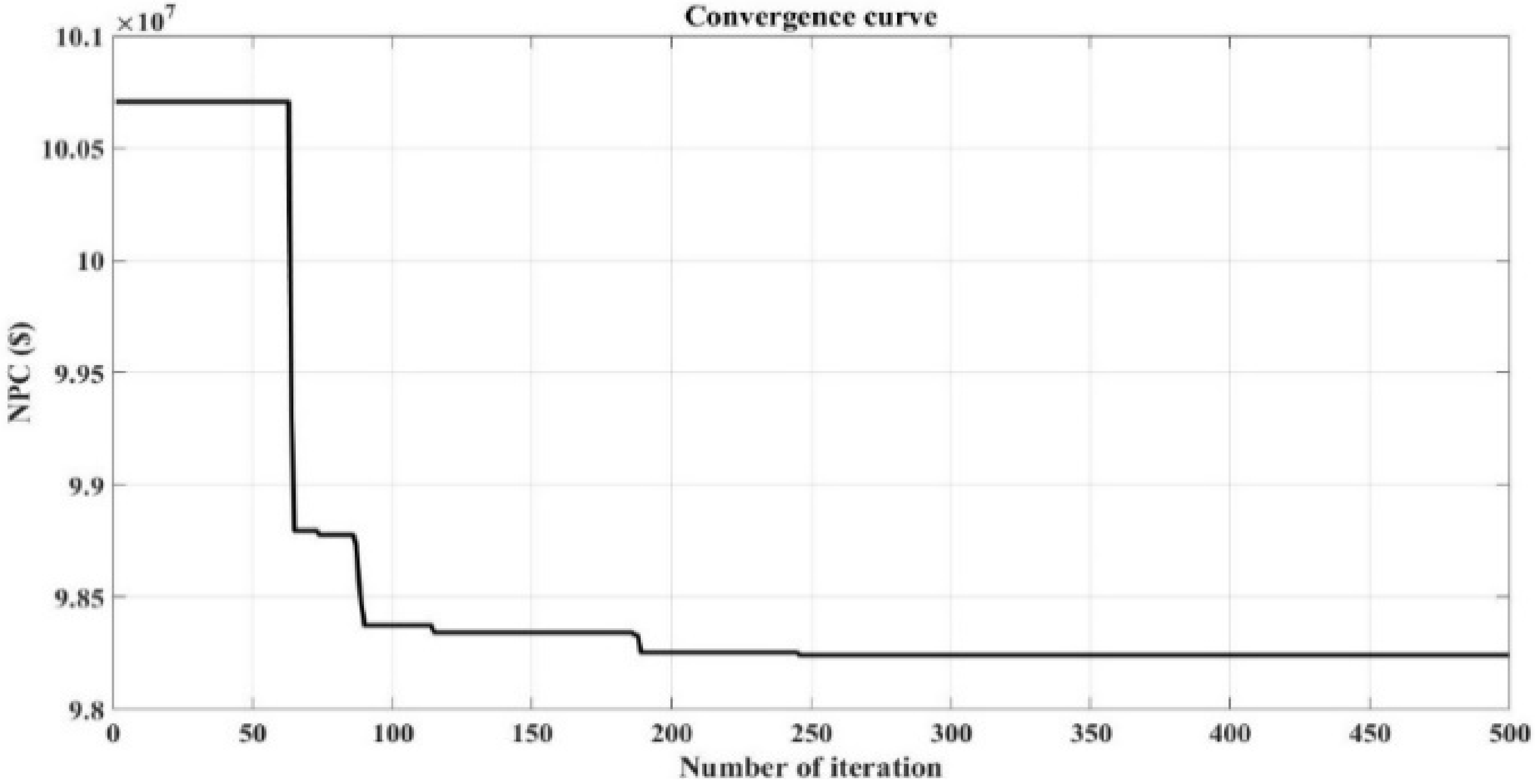
$$0 \leq N_{Htank} \leq N_{Htank,max}$$

$$0 \leq Capacity_{HT} \leq Capacity_{HT,max}$$

$$0 \leq HRR_{MMR} \leq HRR_{MMR,max}\ , \quad N_{PV}, N_{WT}, N_{MMR}, N_{FW}, N_{FC} \in \mathbb{Z}$$

Table: Simulation Results

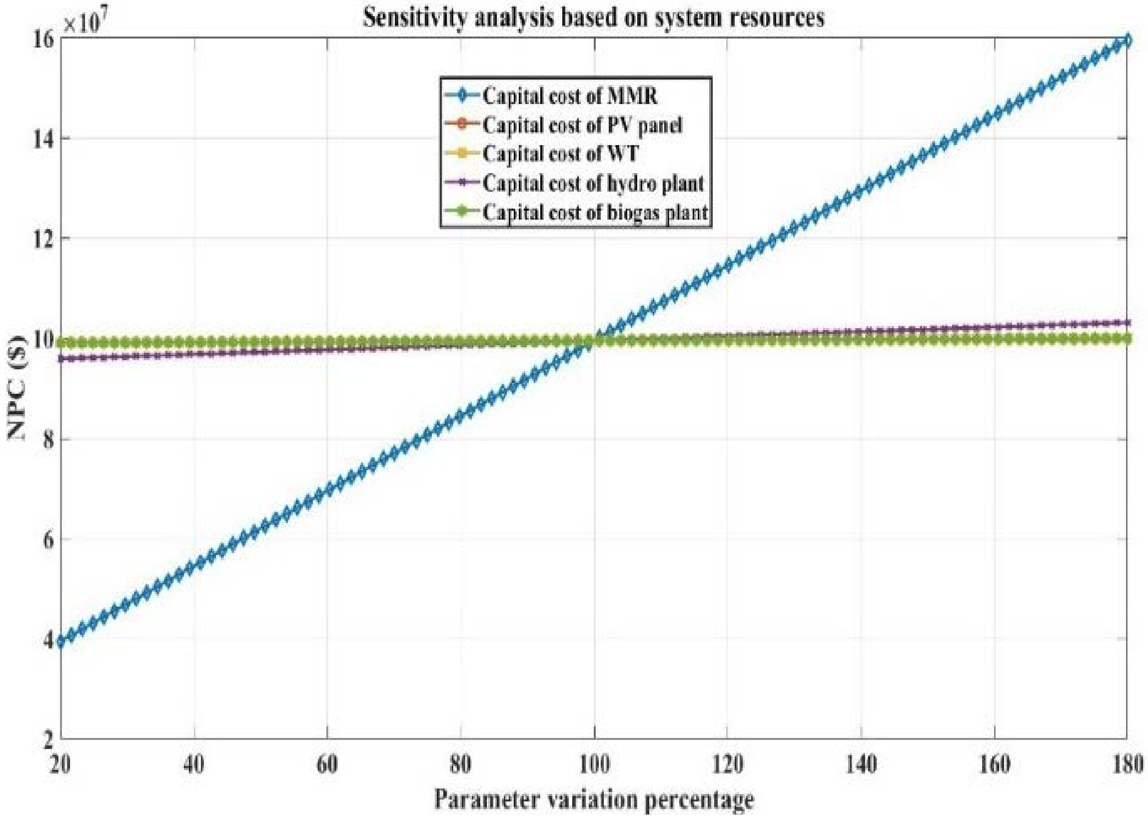
Cases	Direct coupling (Case-01)	Single resource and multiple products-based coupling (Case-02)	Multiple resources and multiple products-based coupling (Case-03)
Number of particles	100	100	100
Number of iterations	500	500	500
Number of MMR	2	2	1
Number of PV panels	6	N/A	36
Number of WT	8	N/A	56
Hydro turbine capacity (kW)	22.85	N/A	1797.15
Waste HRR of MMR (%)	N/A	20	40
Number of FW	5	7	3
Number of Hydrogen tank	3	1	10
BG capacity (kW)	152.95	152.95	152.95
NPC (million $)	165.00	161.02	98.3
$LPSP_{elec}$ (%)	4.95 (LPSP)	0	7.68
$LPSP_{ther}$ (%)		0	1.17



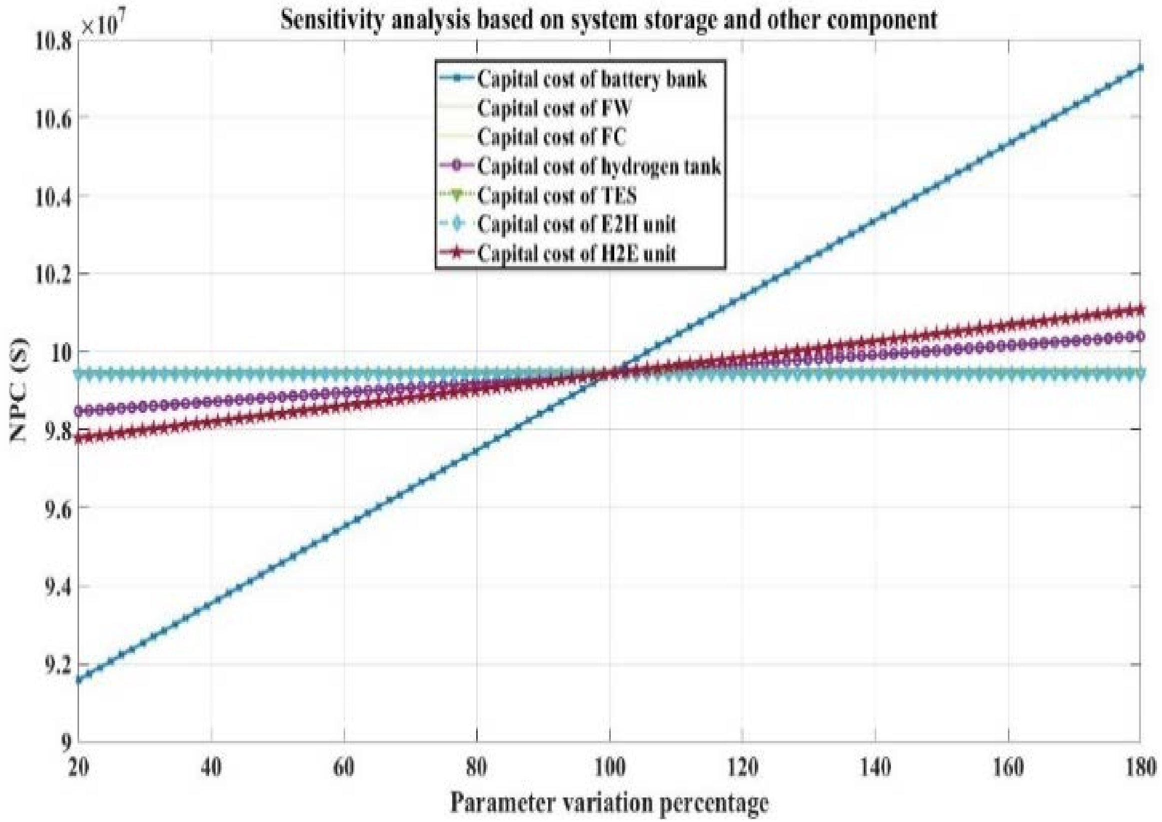
Convergence Curve of the Lowest NPC system (Multiple resource and multiple products-based coupling)

Sensitivity Analysis

A sensitivity assessment has also been conducted to realize the effect of various parameters on NPC.



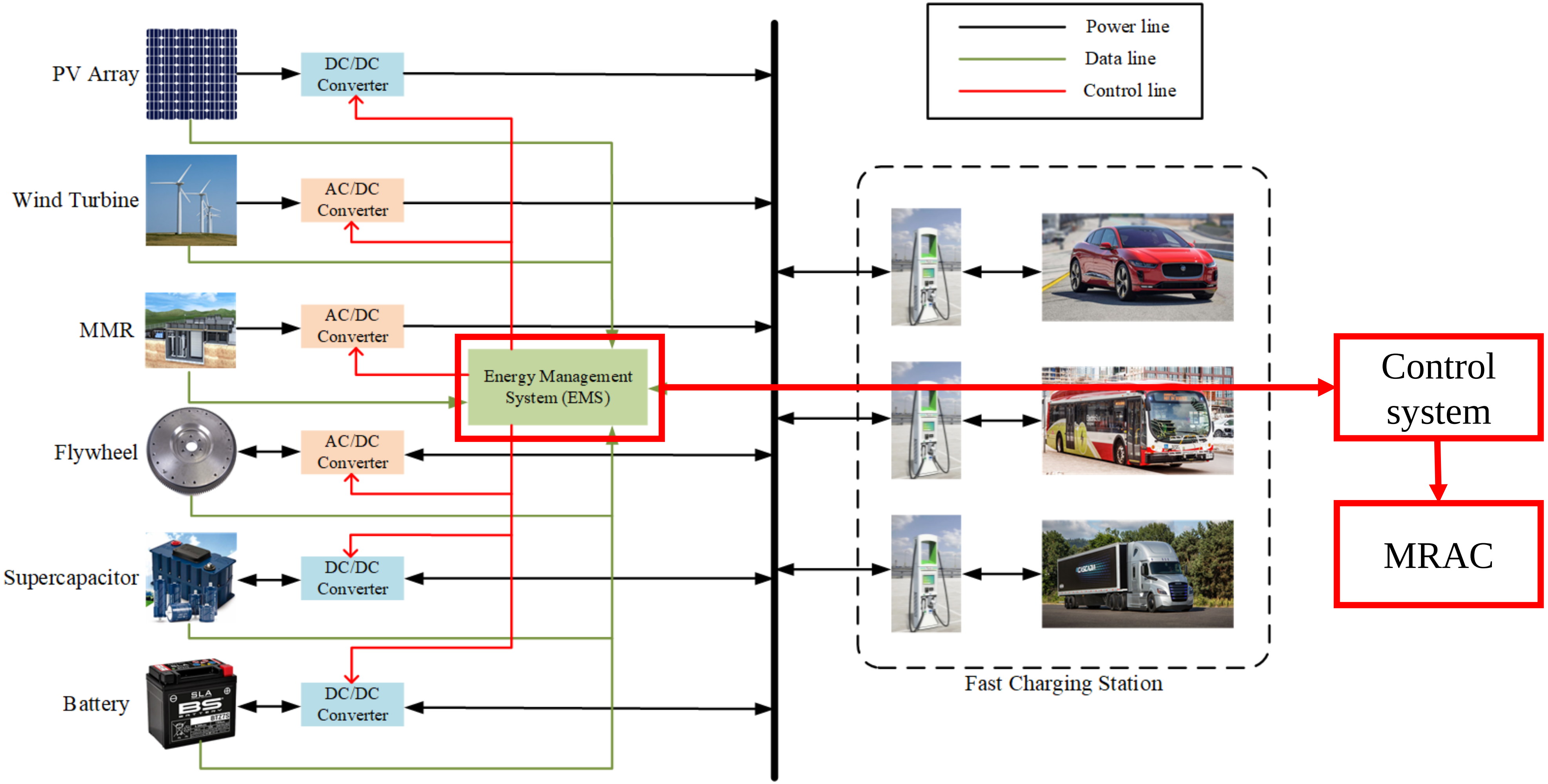
Sensitivity of NPC to variation of energy resources parameters



Sensitivity of NPC to variation of energy storages and other parameters

Design and Simulation of a Nuclear-Renewable Micro Hybrid Energy System for Electric Vehicle Charging Stations

Energy Management System of NR-HES



Model Reference Adaptive Control (MRAC) with Mixed-Integer Linear Programming

Optimization Problem Formulation

The entire optimization issue may be stated as follows, taking into account the constraints and objective function established in the preceding sections:

minimize	R
subject to	binary variables
	storage model
	storage constraints
	power balance

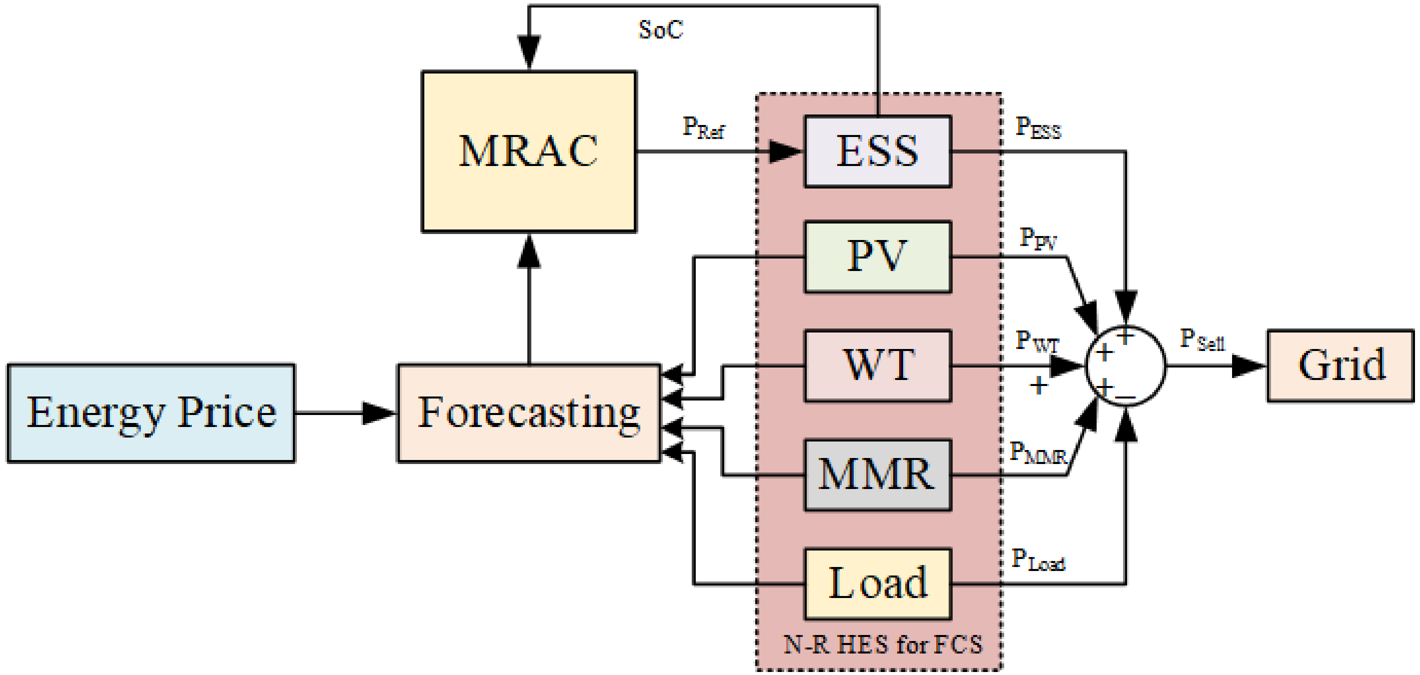
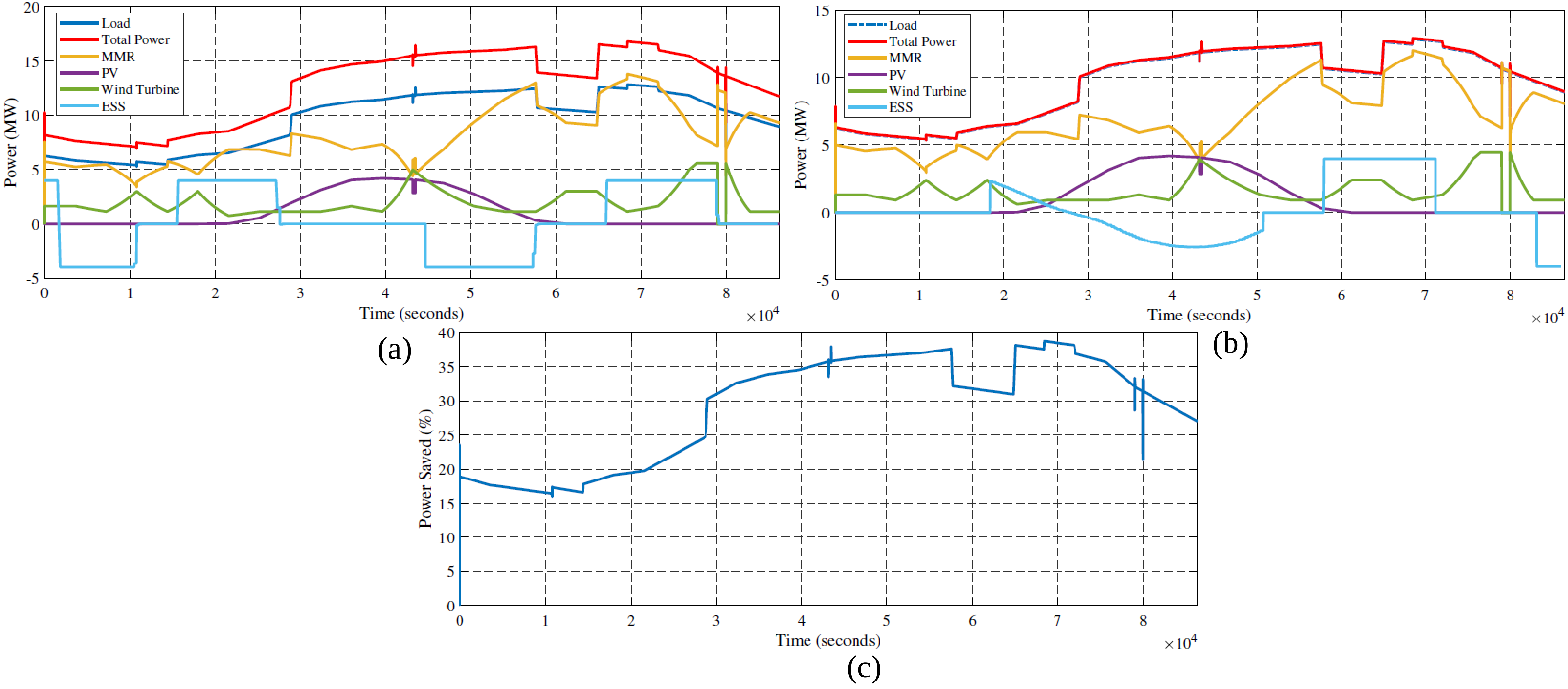


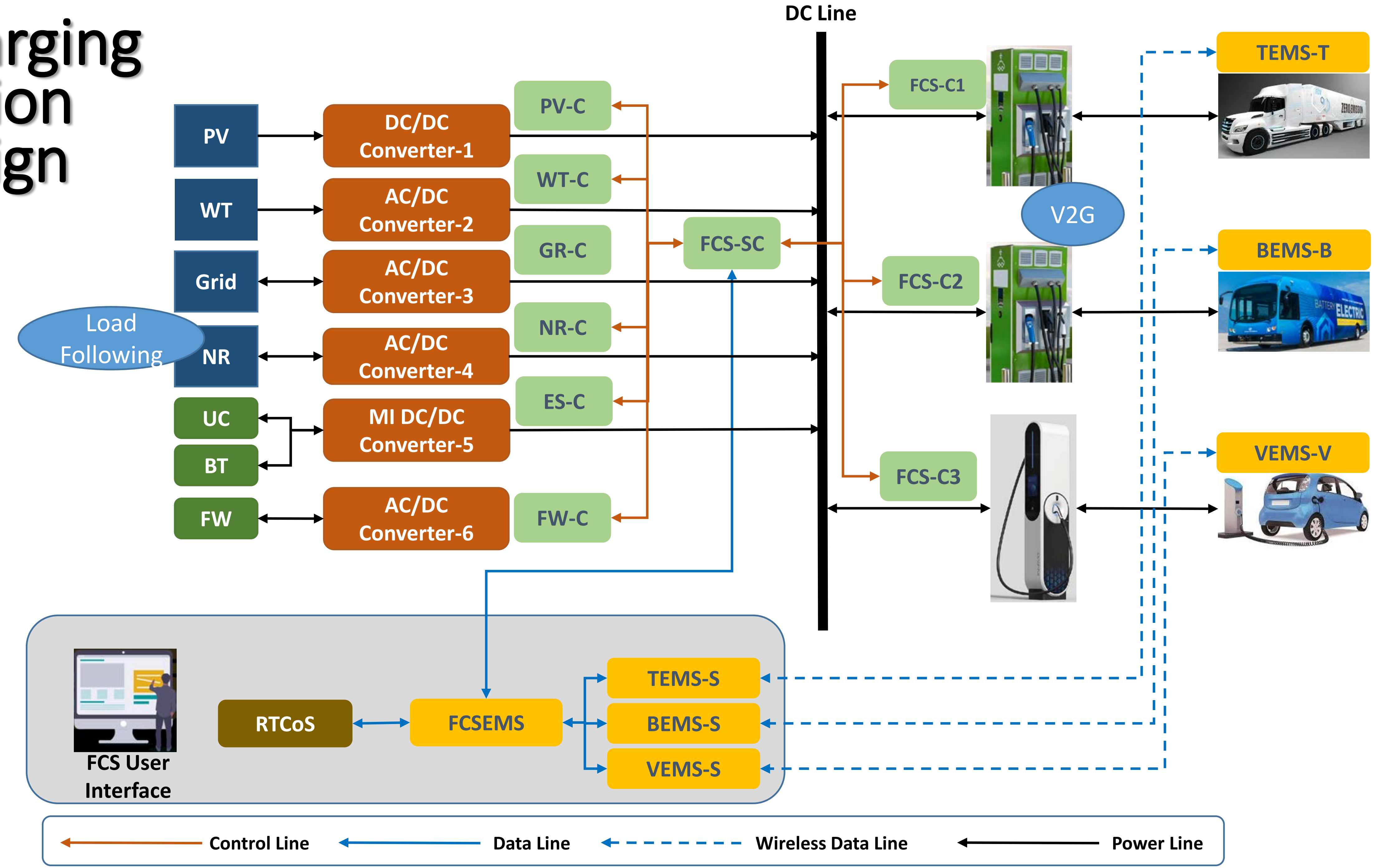
Illustration of MRAC system with optimization strategy

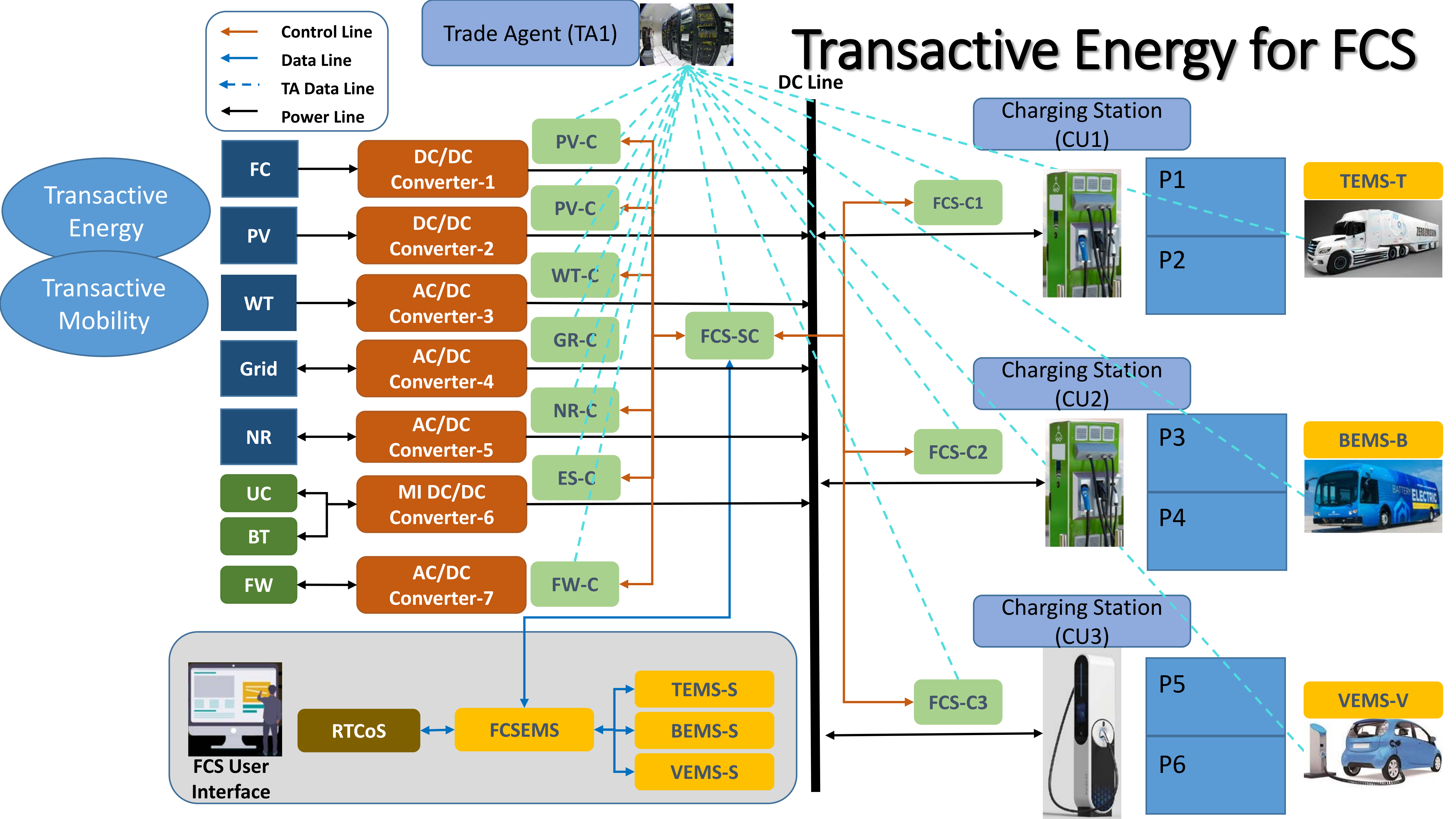
Performance Analysis



Performance of the system with (a) conventional EMS (b) Proposed EMS (c) Power saving by the proposed EMS

EV Charging Station Design





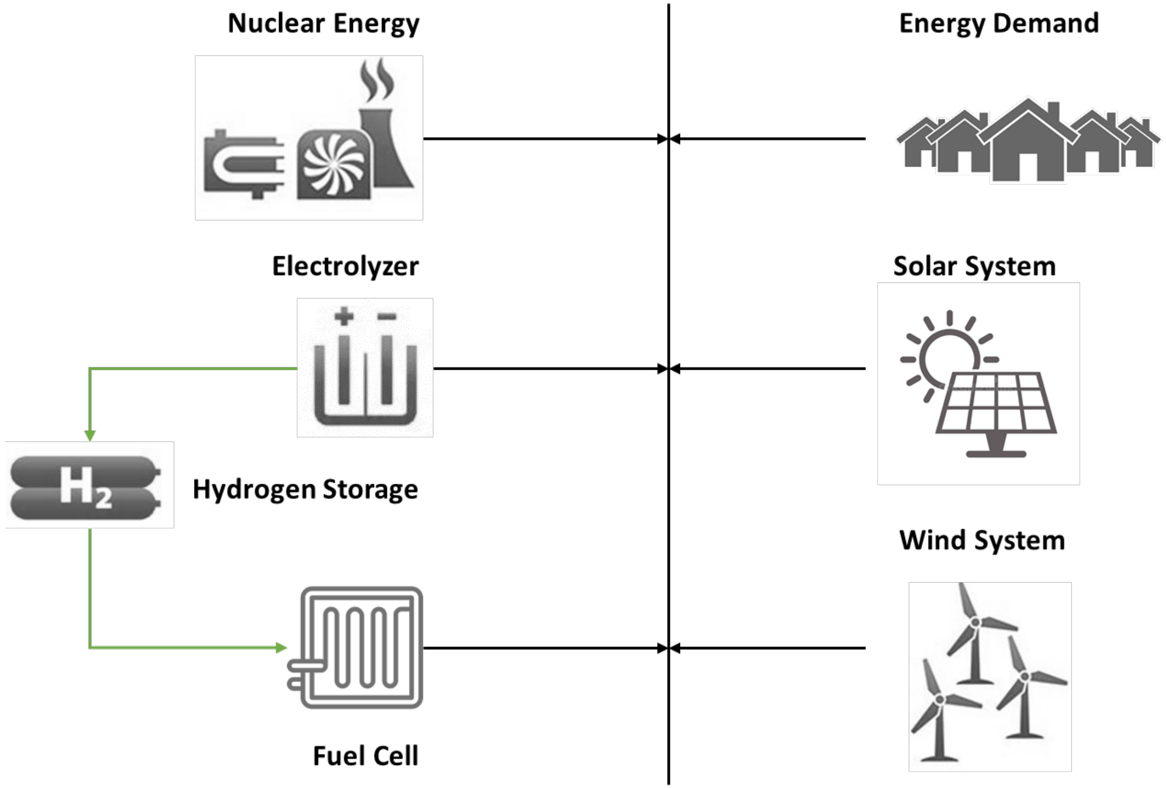
Transactive Energy for FCS
Control Line
Data Line
TA Data Line
Power Line
Trade Agent (TA1)
DC Line
Transactive Energy
Transactive Mobility
FC
PV
WT
Grid
NR
UC
BT
FW
DC/DC Converter-1
DC/DC Converter-2
AC/DC Converter-3
AC/DC Converter-4
AC/DC Converter-5
MI DC/DC Converter-6
AC/DC Converter-7
PV-C
PV-C
WT-C
GR-C
NR-C
ES-C
FW-C
FCS-SC
FCS-C1
FCS-C2
FCS-C3
Charging Station (CU1)
Charging Station (CU2)
Charging Station (CU3)
P1
P2
P3
P4
P5
P6
TEMS-T
BEMS-B
VEMS-V
FCS User Interface
RTCoS
FCSEMS
TEMS-S
BEMS-S
VEMS-S

Optimal Ratio of Nuclear-Renewable Energy Systems

System Schematic

- Base Case

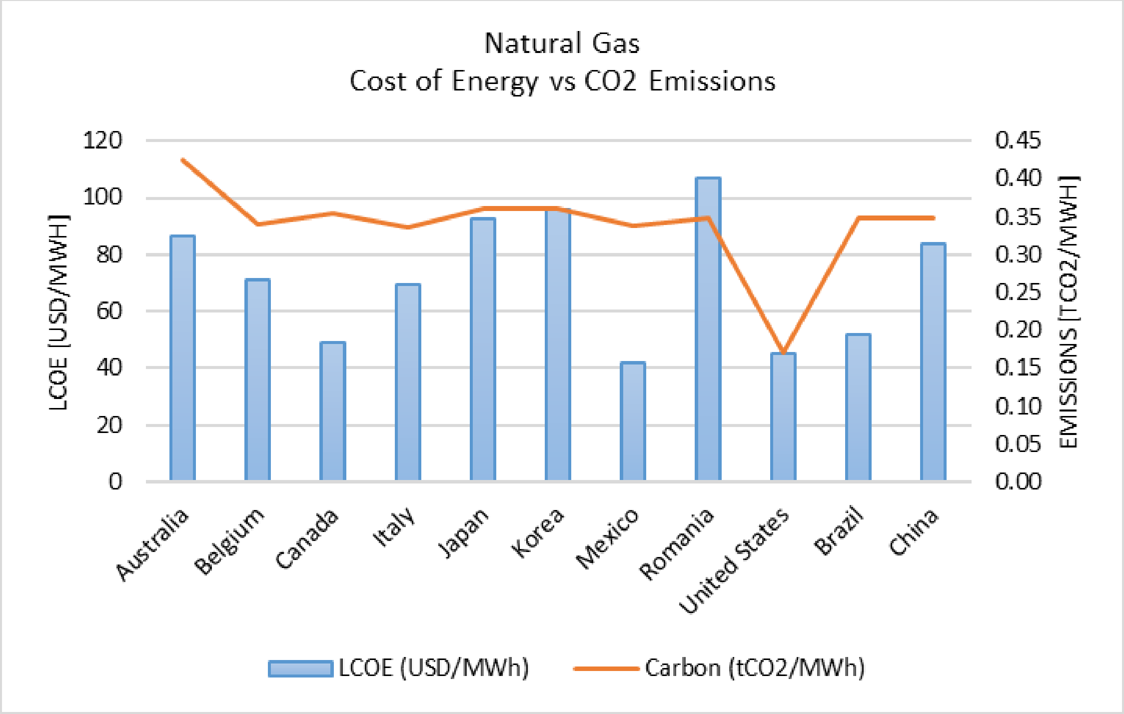
- Proposed System

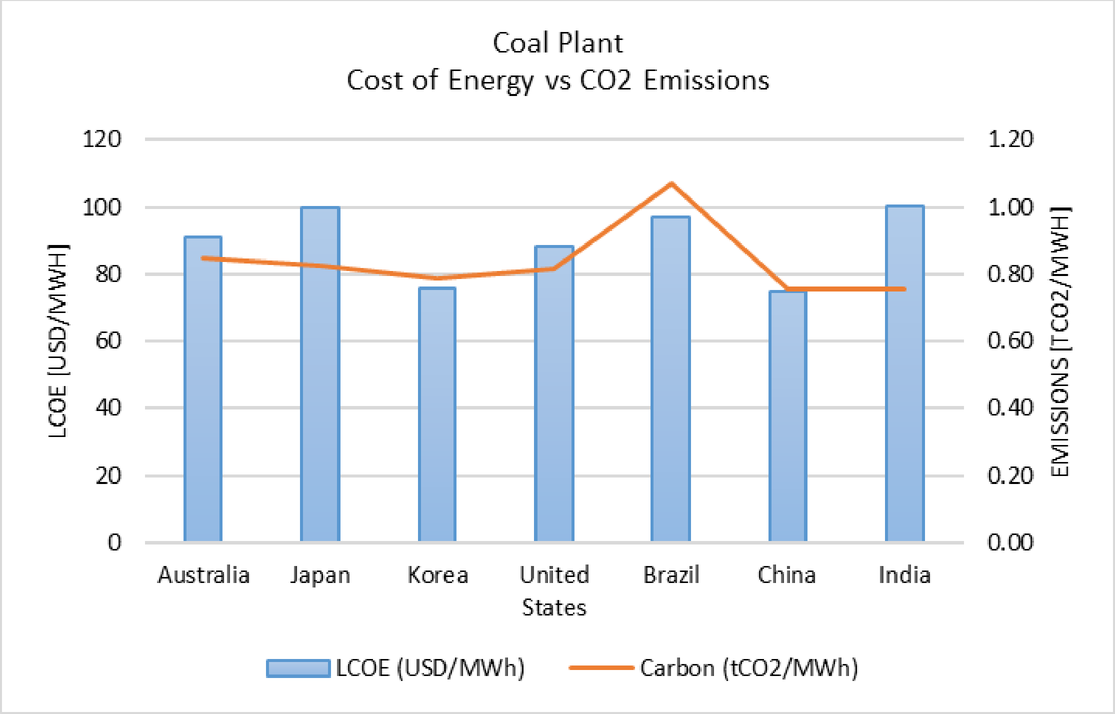


Base Case: Cost of Generating Electricity

Gas and Coal Fired Power Plant

- Reference:
  - Projected Costs of Generation Electricity
  - 2020 Edition
  - International Energy Agency (IEA) and Nuclear Energy Agency (NEA)





Proposed System

Assumptions

- In order to evaluate the optimal ratio of nuclear and renewable is important to consider the following inputs and constrains:
- Inputs:
  - Investment / Fuel / O&M Costs
  - Renewable Resources
  - Energy Profile Load
- Constrains:
  - Minimum Nuclear Load Ratio
  - Size limit for solar and wind farms
  - Cost of Energy
  - Energy Load Variation

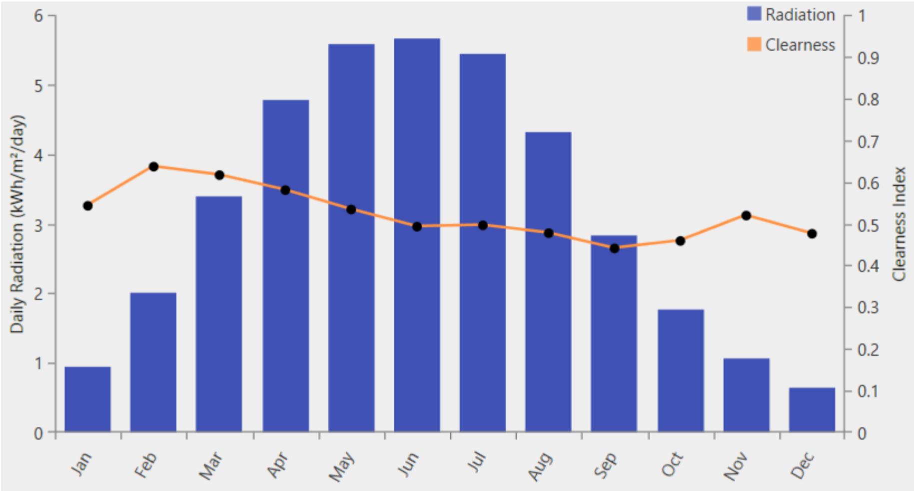
Input

Renewable Resources

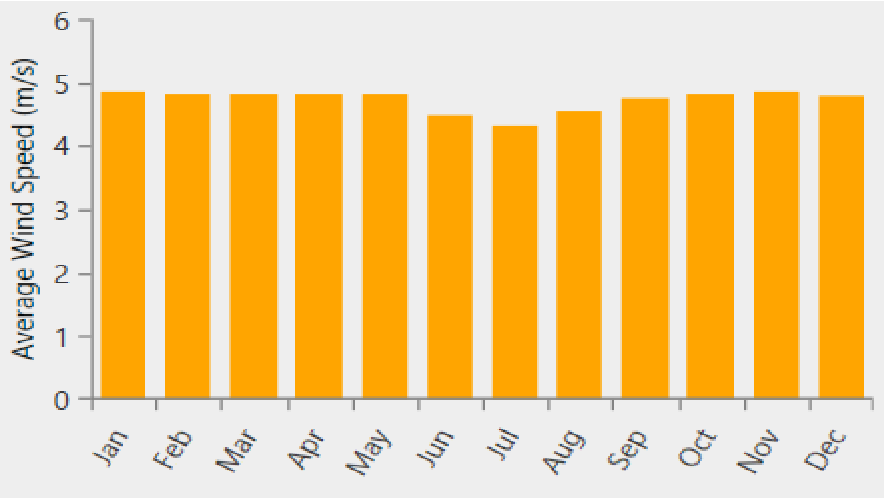
- Location: Remote Community
  - Northern Ontario, Canada

- Database:
  - NASA Prediction of Worldwide Energy Resource (POWER)

- Solar Resource: 3.2 kWh/m2/day



- Wind Resource: 4.73 m/s

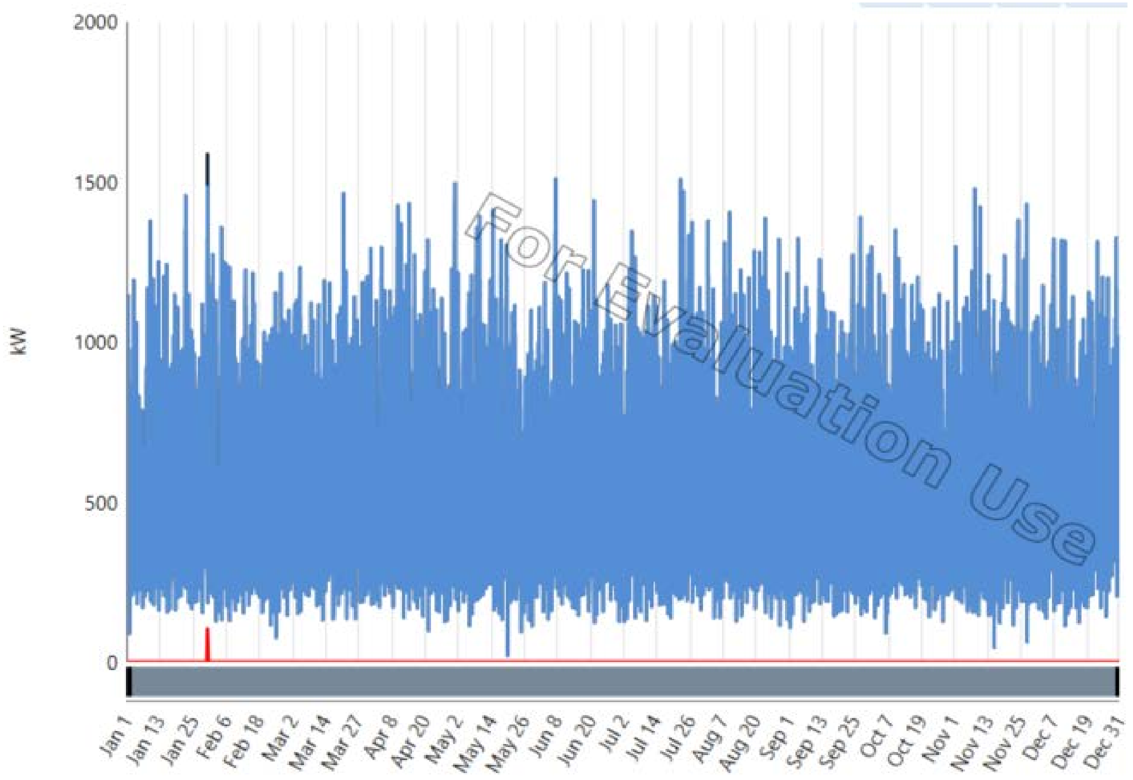


Input

Energy Profile

- Generic energy profile for a remote community

Metric	Value	Unit
Average Consumption	14,000	kWh/day
Average Power	583.33	kW
Power Peak	1,586.4	kW
Load Factor	0.37	-



Components

Small Modular Reactor

Description	Value	Unit
Fuel Type	Uranium	
Capacity	1000	kW
Capital Cost*	4000	$/kWe
Refurbishment Cost*	2500	$/kWe
O&M Cost*	16	$/MWh
Fuel Cost*	1390	$/kg
Lifetime*	60	Years
Minimum Load Ratio	50	%

*Data based on the SMR BWRX-300 Project

Components

Solar System

Description	Value	Unit
Upper Limit Size	500	kW
Investment Cost	550.00	$/kW
Replacement	550.00	$/kW
O&M Cost	9.00	$/kW/year
Lifetime	30	Years

Wind System

Description	Value	Unit
Upper Limit Size	500	kW
Investment*	1,130.00	$/kW
Replacement	1,130.00	$/kW
O&M Cost*	48	$/kW/year
Lifetime*	30	Years

Components

Generator – Fuel Cell

Description	Value	Unit
Upper Limit Size	500	kW
Investment	2,500.00	$/kW
Replacement	2,500.00	$/kW
O&M Cost*	3.65	$/kW/year
Lifetime	6	Years

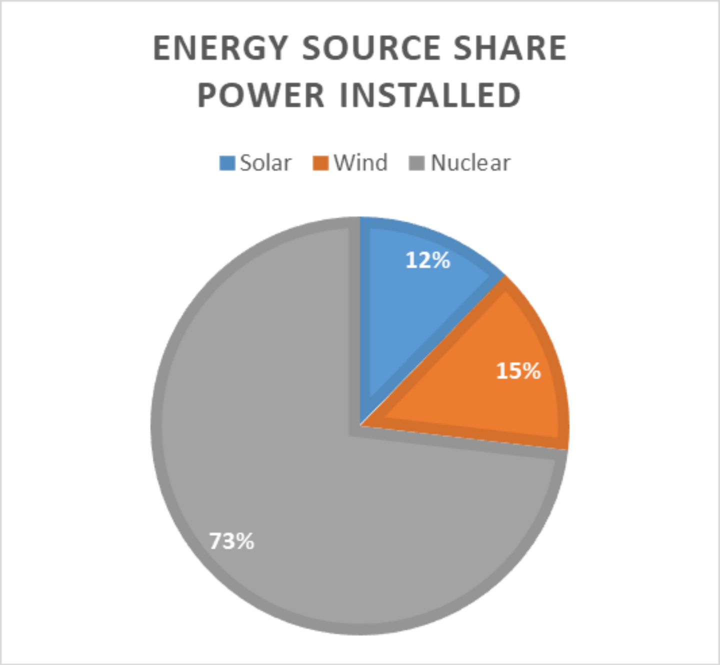
Converter DC/AC

Description	Value	Unit
Upper Limit Size	1600	kW
Investment	300.00	$/kW
Replacement	300.00	$/kW
Efficiency	95	%
Lifetime	15	Years

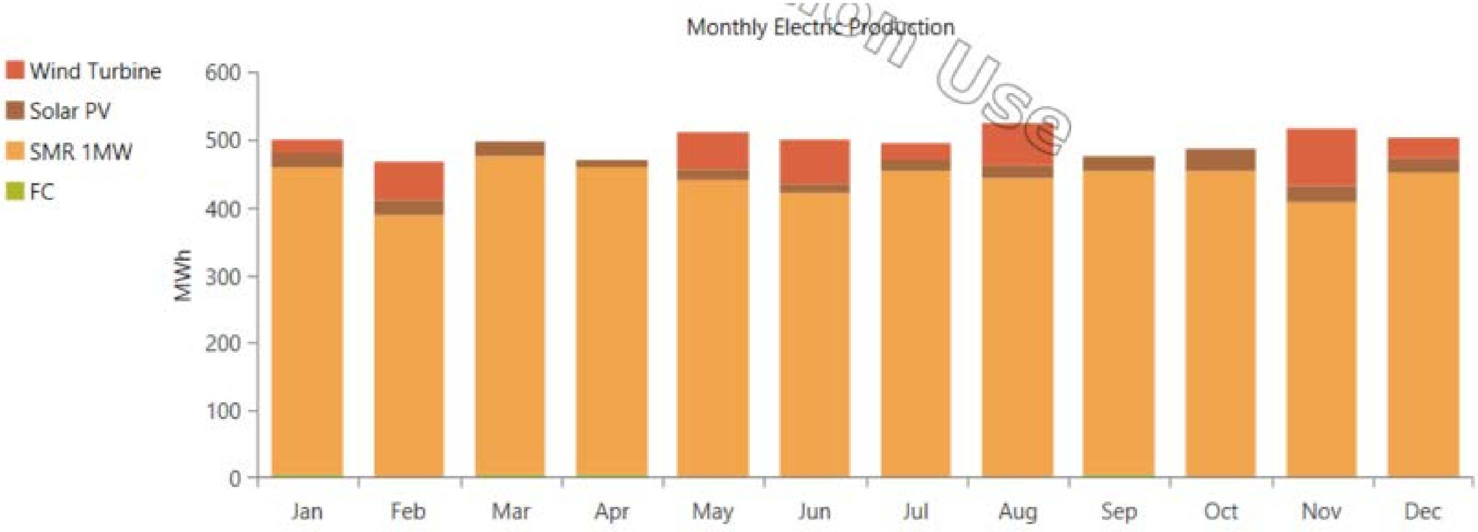
Case Study - Results

Electrical Analysis – Ratio Nuclear vs Renewable

- Simulation: HOMER Pro
  - System configuration that provided lowest Cost of Electricity: ***Levelized COE $0.5148***



Energy Generation	kWh/yr	%
Solar Energy	233,793	3.94
Wind Energy	403,680	6.8
Nuclear Energy	5,257,640	88.5
Generator – Fuel Cell	44,025	0.74

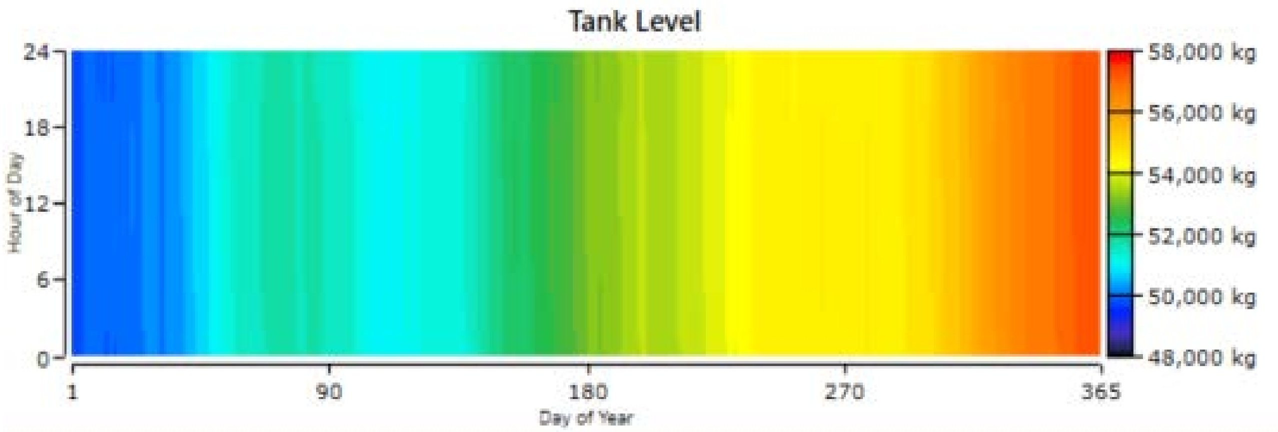


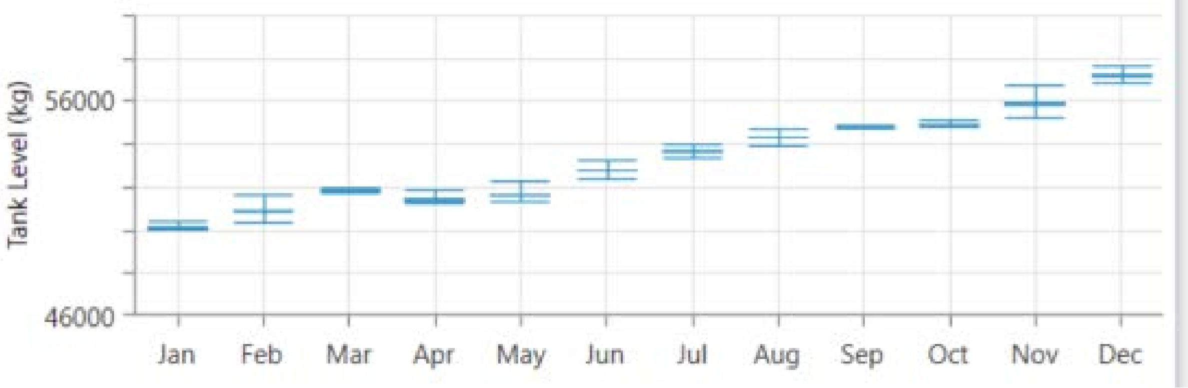
Power Installed	kW	%
Solar Energy	167	12
Wind Energy	200	15
Nuclear Energy	1000	73

Case Study - Results

Energy Storage – Hydrogen Tank

Metric	Value	Unit
Hydrogen Storage Capacity	100,000	kg
Energy Storage Capacity	3,334	MWh
Autonomy	5,714	hr





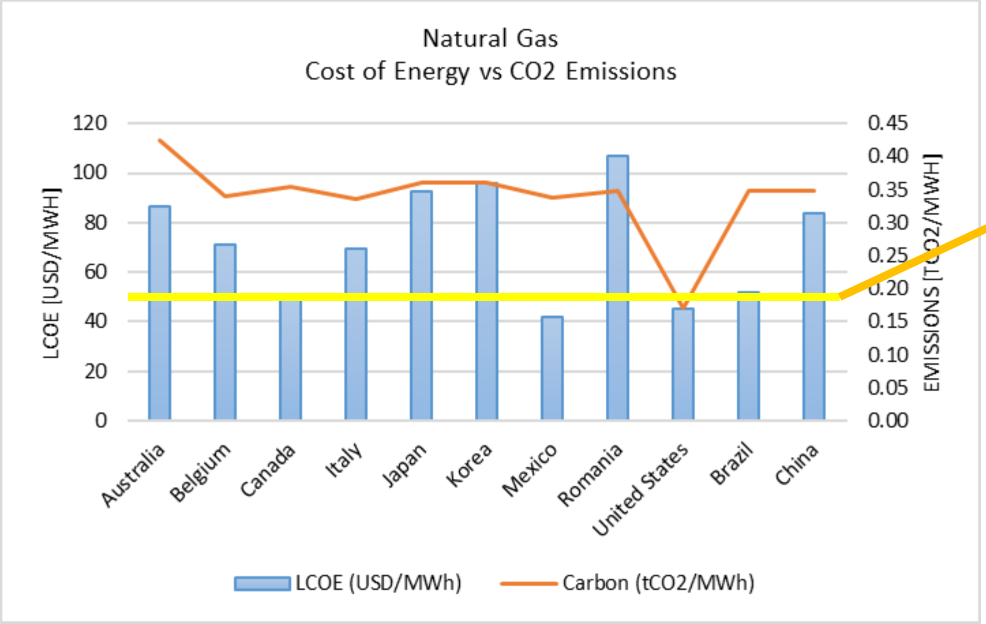
Case Study - Results

Economic Analysis

- Proposed System:

Metric	Value
NPC – Net Present Cost	$40,175,660
Levelized Cost of Energy	$0.5148
Operating Cost	$2,239,157.00

- Base Case:



Case Study:
Levelized Cost of Energy: **$0.5148**

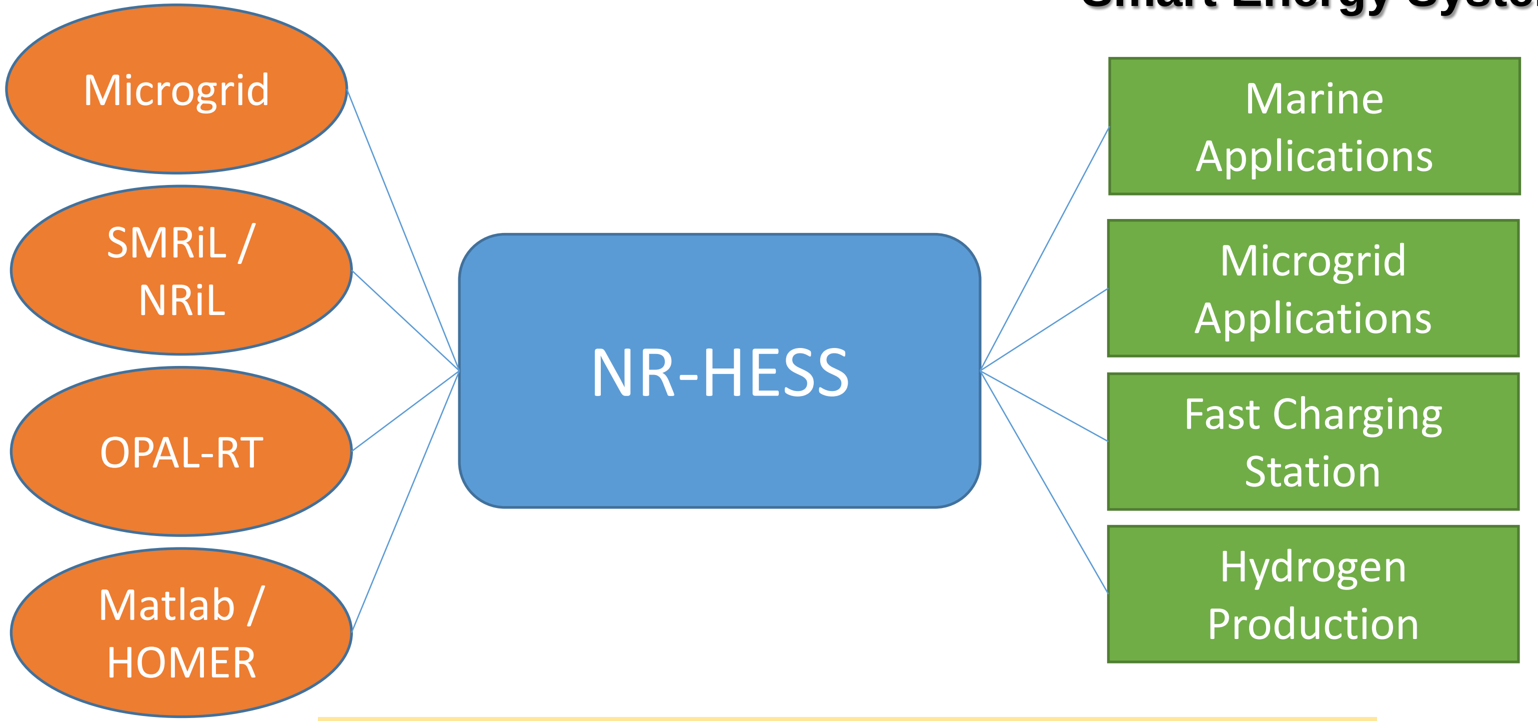
CO2 Emission:
Natural Gas - Canada: **0.36 tCO2/MWh**

Considering energy consumption:
5,110 MWh/year

Total emission using Natural Gas:
1,840 tonnes of CO2 per year

Nuclear-Renewable Hybrid Energy Systems Simulator (NR-HESS)

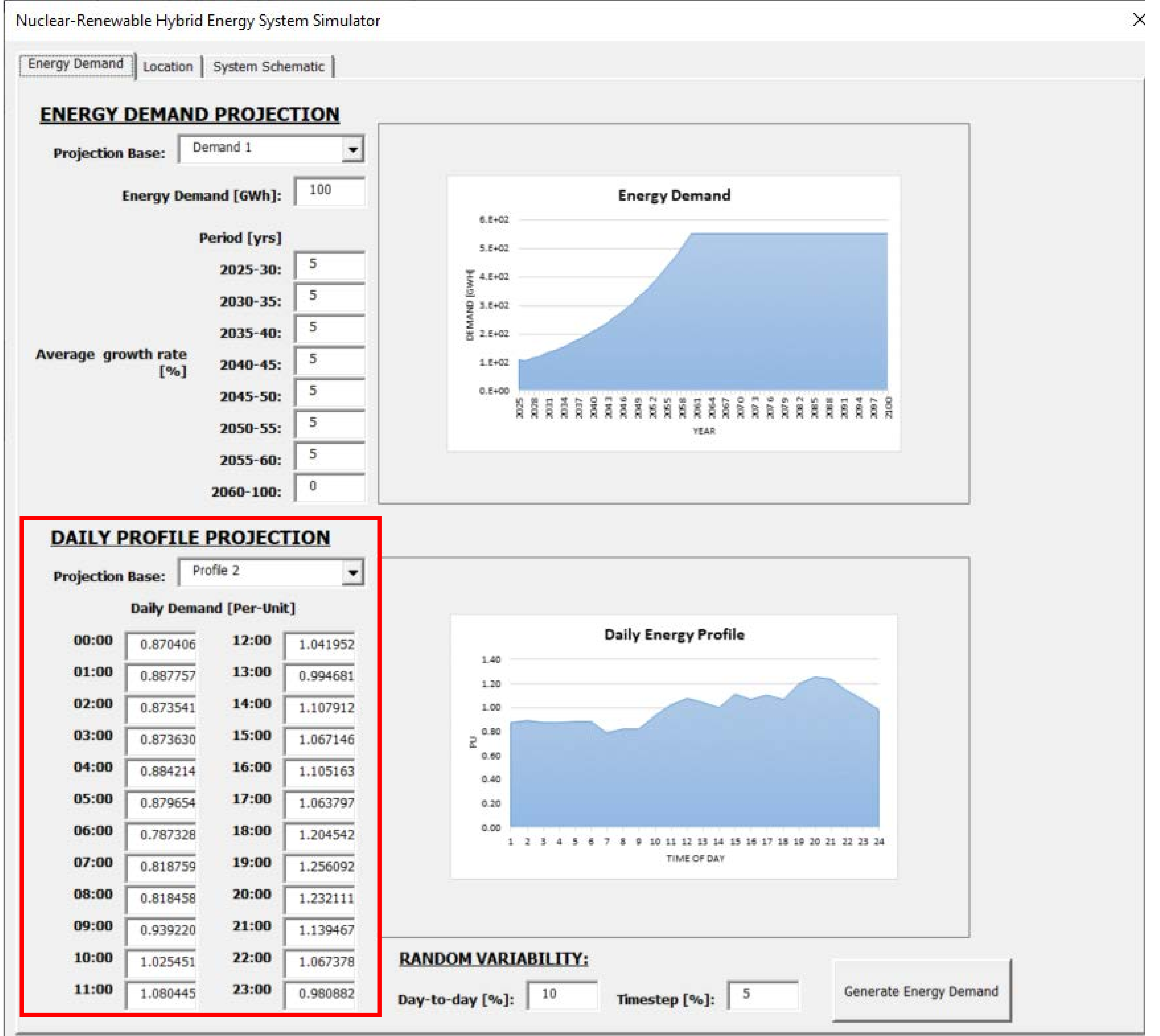
Smart Energy Systems Lab



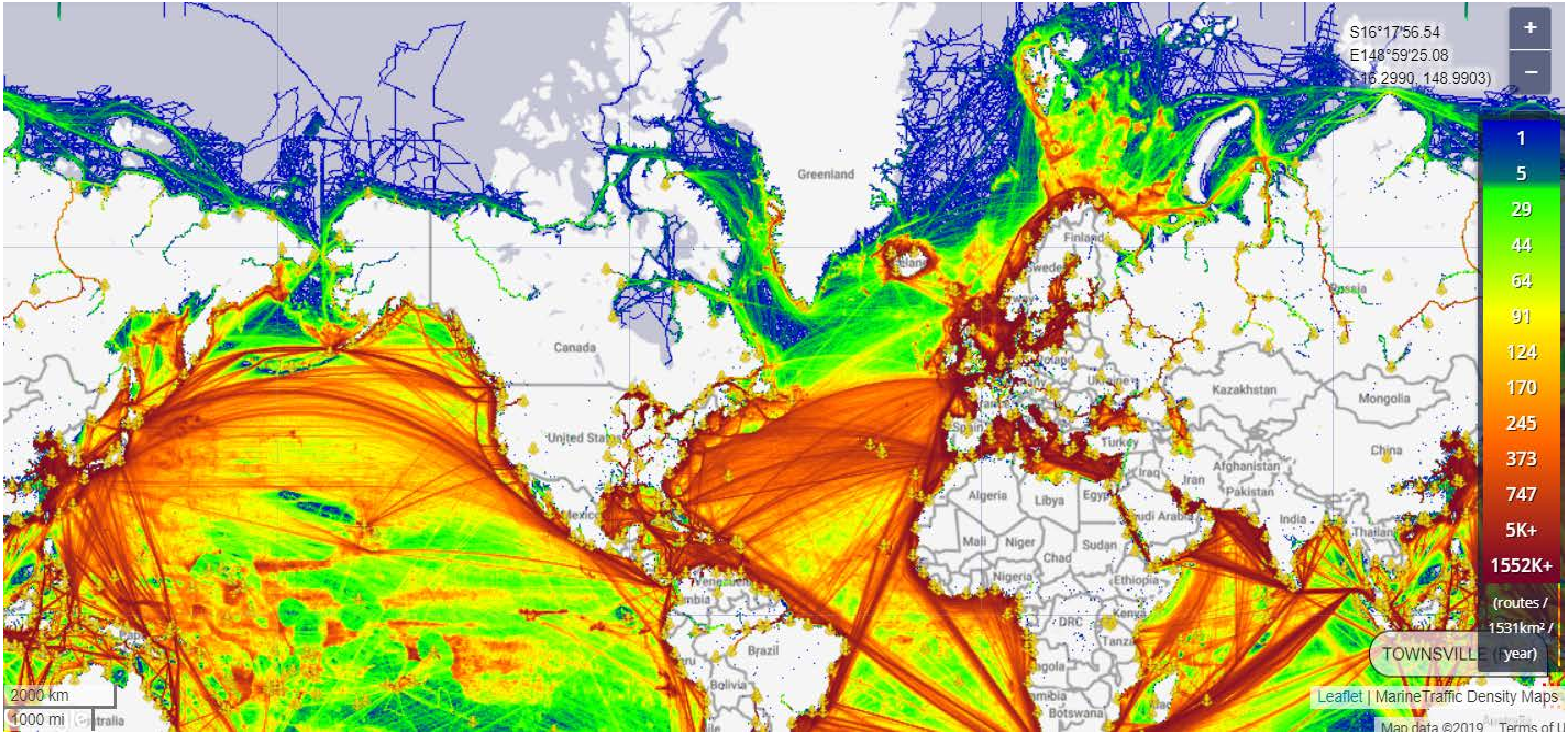
- Renewable Energy and Energy Storage Systems
- Nuclear Power Technologies
- Nuclear-Renewable Hybrid Energy Systems
- Demand Side Management
- Micro Hybrid Energy Systems
- Techno-Economic Analysis
- Group Discussions and Individual Work

SIMULATOR INPUT

- **Energy Demand**
- **Daily Profile Projection:**
  - Projection Base: Library of daily demand profiles.
  - Daily Demand (Per-Unit): Hourly values set by the user, representing the energy demand at different times of the day. The "per-unit" concept normalizes demand to a base value, allowing for easier comparison and analysis of different profiles.
- Key Features:
  - This section is essential as it influences how energy sources will operate throughout the day.
  - Similar to the yearly projection, users can save up to 10 different daily profiles.

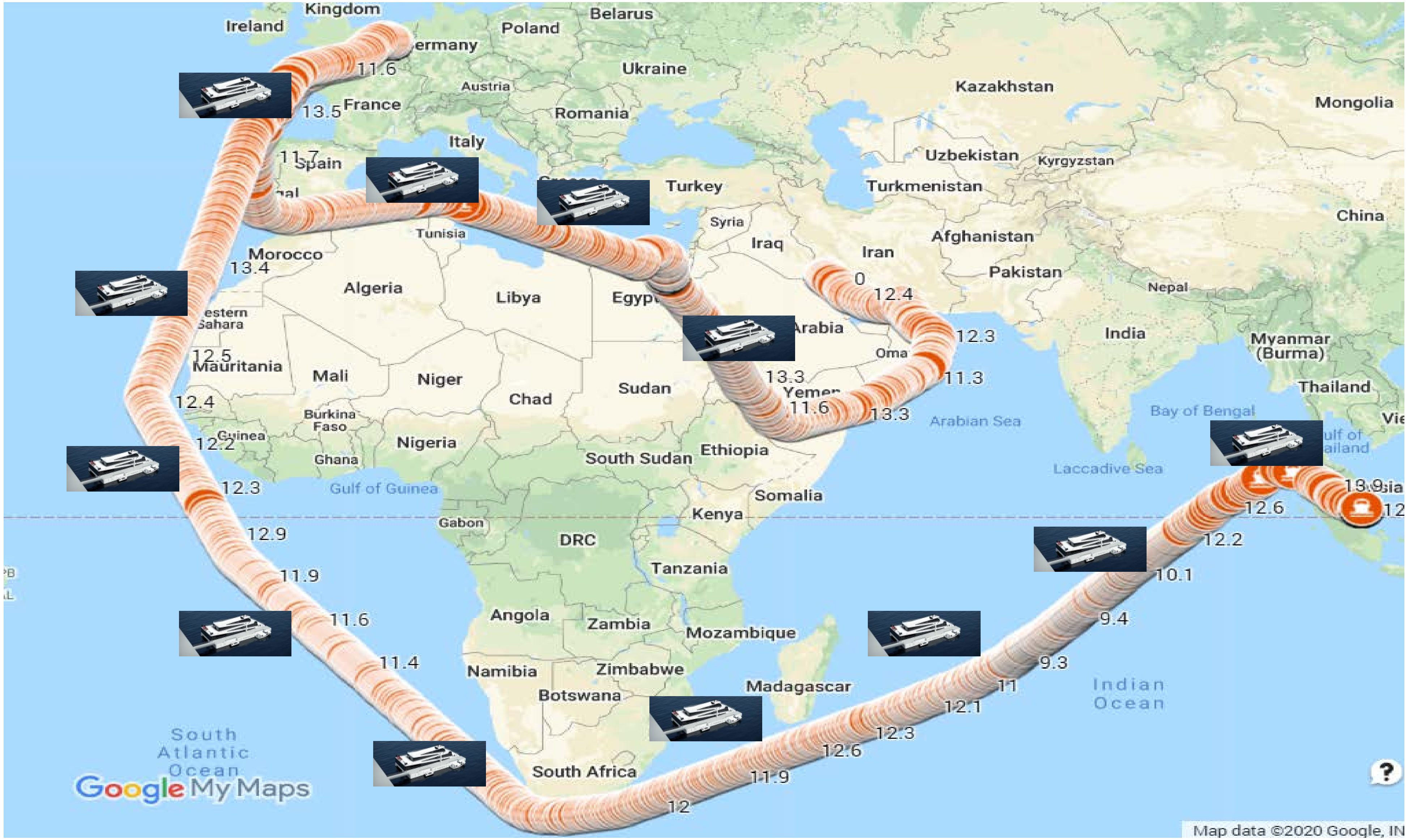


Implementation in Marine Ships



https://www.marinetraffic.com/en/ais/home/centerx:-12.0/centery:24.8/zoom:2

Charging Stations for Ships



Ship Parameters and Voyage Route

SL. NO	SHIP DESCRIPTION	
1	Ship's name (IMO number)	Baltic Sunrise (9307633)
2	Date delivered / Builder (where built)	Nov 08, 2005 / Hyundai Heavy Industries Co. Ltd., Ulsan Shipyard, Korea
3	Flag / Port of Registry	Marshall Islands / Majuro
4	Call sign	V7NP2 / 538006485
5	Type of ship	Oil Tanker
6	Length overall (LOA)	333.12 m
7	Length between perpendiculars (LBP)	324.00 m
8	Extreme breadth (Beam)	60.04 m
9	Deadweight	309373 MT
10	Displacement	352410 MT

Parameters of 'Baltic Sunrise'

Route of 'Baltic Sunrise'

Data Collection and Calculation

SL. No	Parameter/ Assumption	Category	Notation	Value
1	Beam of the ship	Parameter	B	60 m
2	Volume displacement of the ship	Parameter	v	344649.08 m^3
3	Draught of the ship	Parameter	D	21.6 m
4	Extreme breadth (Beam)	Parameter	Bex	60.04 m
5	Average draught of the ship	Parameter	D_avg	16.15 m
6	Length between perpendiculars	Parameter	LBP	324 m
7	Gravitational acceleration	Parameter	g	9.81 m/s^2
8	Seawater density at 30^0C temperature	Parameter	ρ_w	1021.7 kg/m^3
9	Seawater viscosity at 30^0C temperature	Parameter	γ_w	0.84931×10^{-6} m^3s^{-1}
10	Average speed of the ship	Parameter	Vs_avg	11.94 kn or 6.1424 ms^{-1}
11	Incremental resistance coefficient due to surface roughness of ship	Assumption	C_A	0.0004
12	Maximum speed of the ship	Parameter	Vs_max	17.9 kn or 9.2185 ms^{-1}

Parameters / Assumption of 'Baltic Sunrise

$$P_{ship\,(x,y)} = R_{THR} \cdot V_{s(x,y)}$$

$$R_{THR} = C_{THR} \cdot \frac{1}{2}\rho_w \cdot s_s \cdot V_{s\_avg}{}^2$$

$$C_{THR} = C_{Fs} + C_{Rs} + C_A$$

$$S_s = 1 \cdot 7L_{wl} \cdot B + \frac{v}{D} = 55410.6 \text{ m}^2$$

$$C_{Fs} = \frac{0.075}{(\log R_{ns} - 2)^2} = 1.37 \times 10^{-3}$$

$$R_{ns} = \frac{Vs\_avg \times L_{wl}}{\gamma_w} = 2.42 \times 10^9$$

$$L_{wl} = \frac{LBP}{0 \cdot 97} = 334.02\ m$$

$$\frac{B}{D} \cong 3.00$$

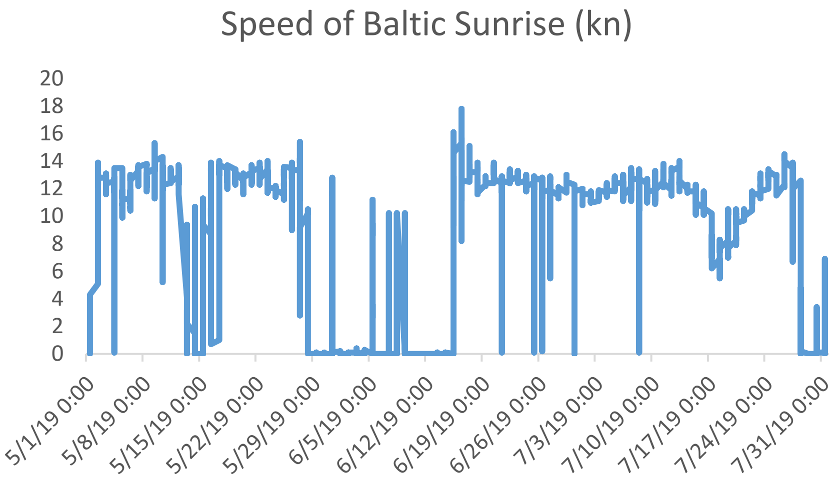
$$C_p = \frac{v}{A_m L_{w_l}} \cong 0.6$$

$$A_m = B_{ex} \times D = 1296.864 \text{ m}^2$$

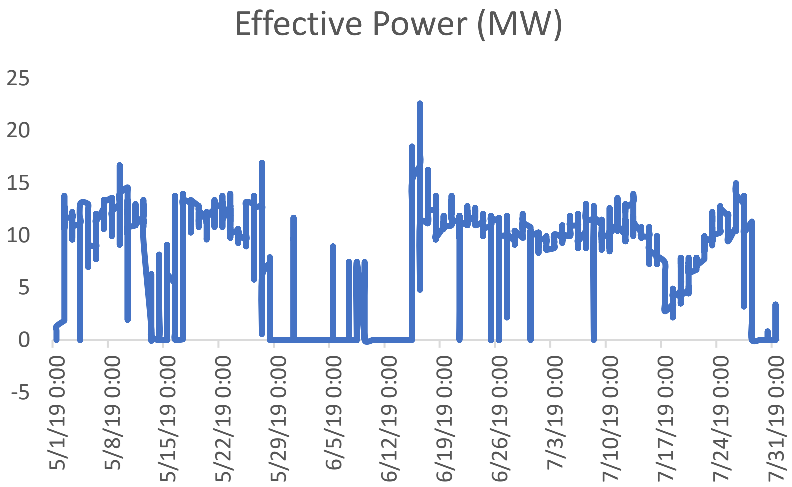
$$\frac{v}{L_{w_l}^3} = 9.2 \times 10^{-3}$$

$$F_{ns} = \frac{Vs\_max}{\sqrt{g \times L_{w_l}}} = 0.16$$

Estimation of Energy Demand of Marine Ship for a Given Route

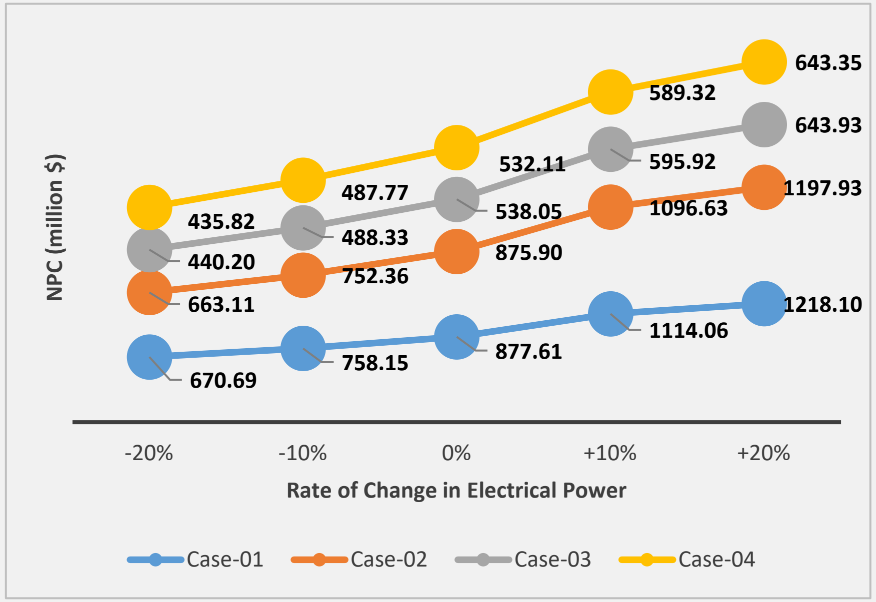


Speed of Baltic Sunrise (1st May’19 to 31st July’19)

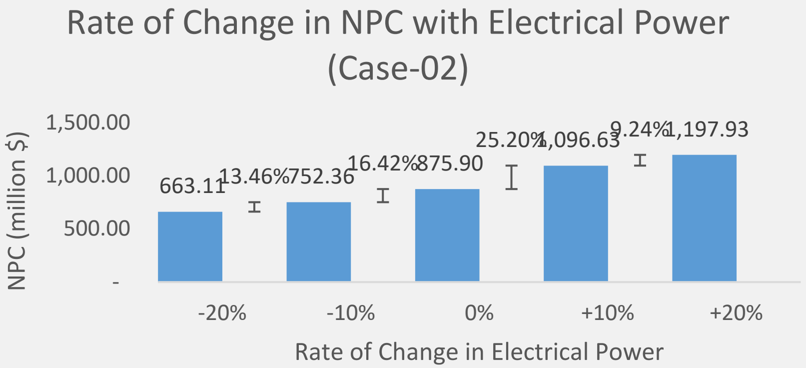


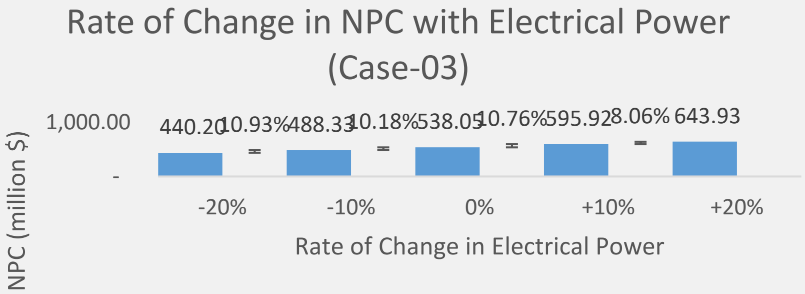
Estimation of Effective Power (MW) Requirement of Baltic Sunrise (1st May’19 to 31st July’19)

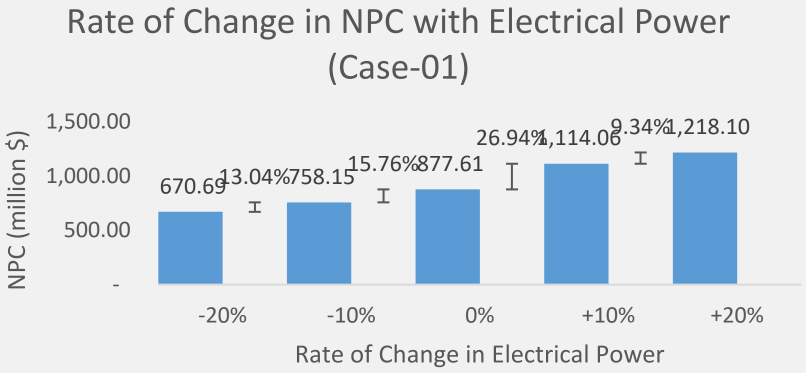
Sensitivity Analysis - Electrical Power Requirement

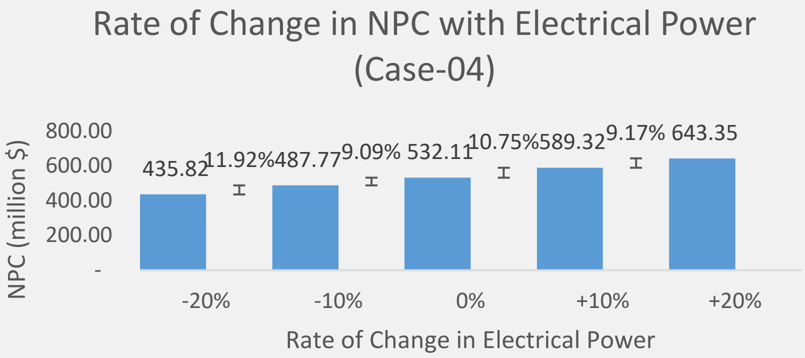


Sensitivity Assessment of Electrical Power on NPC

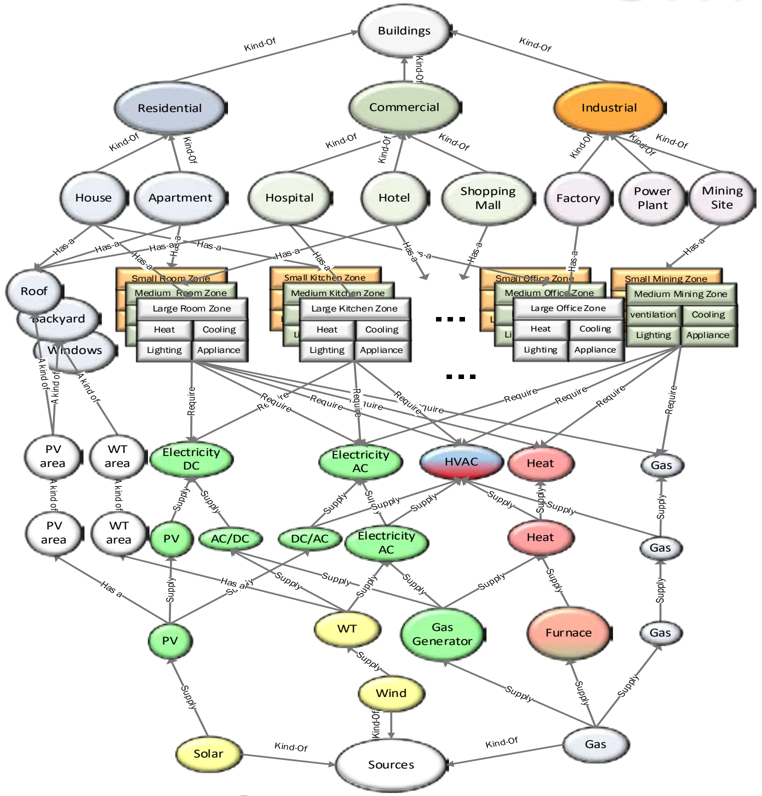


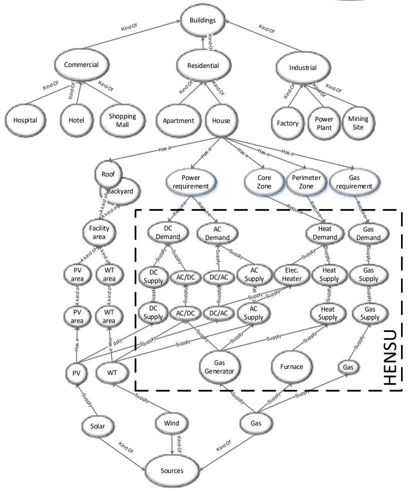




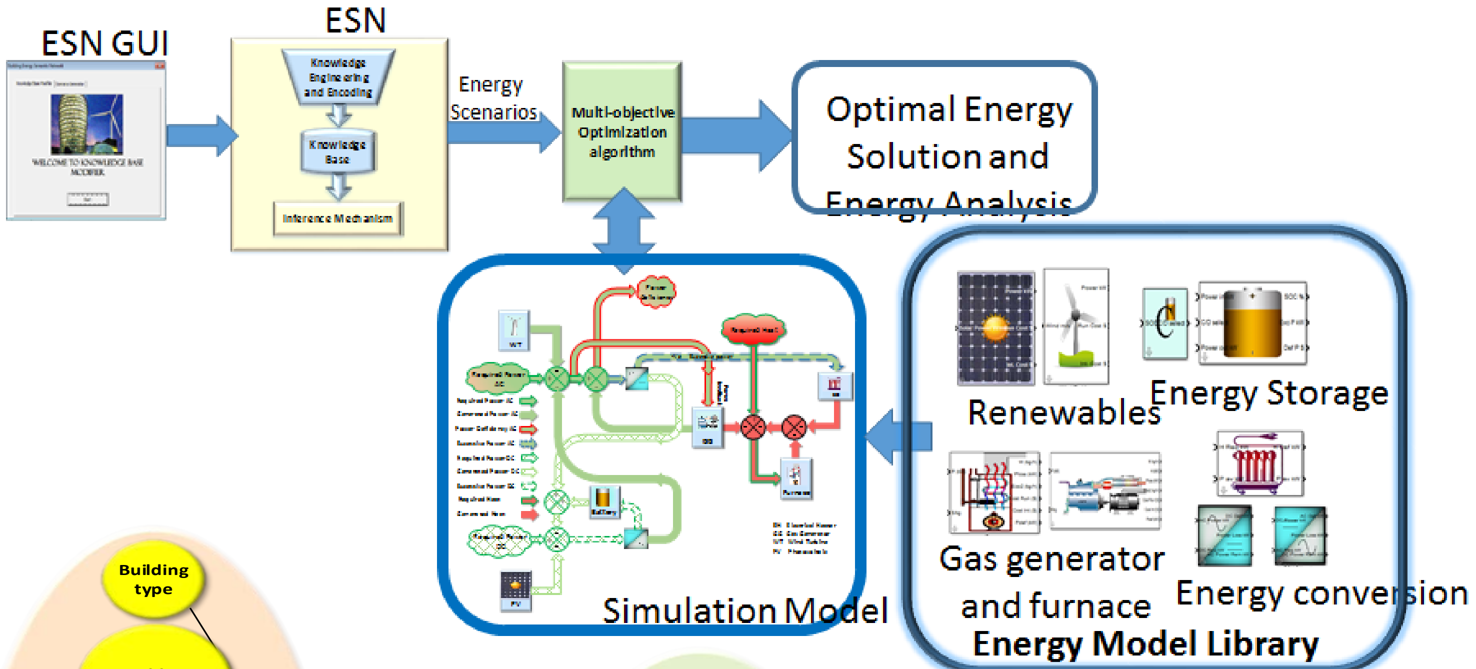


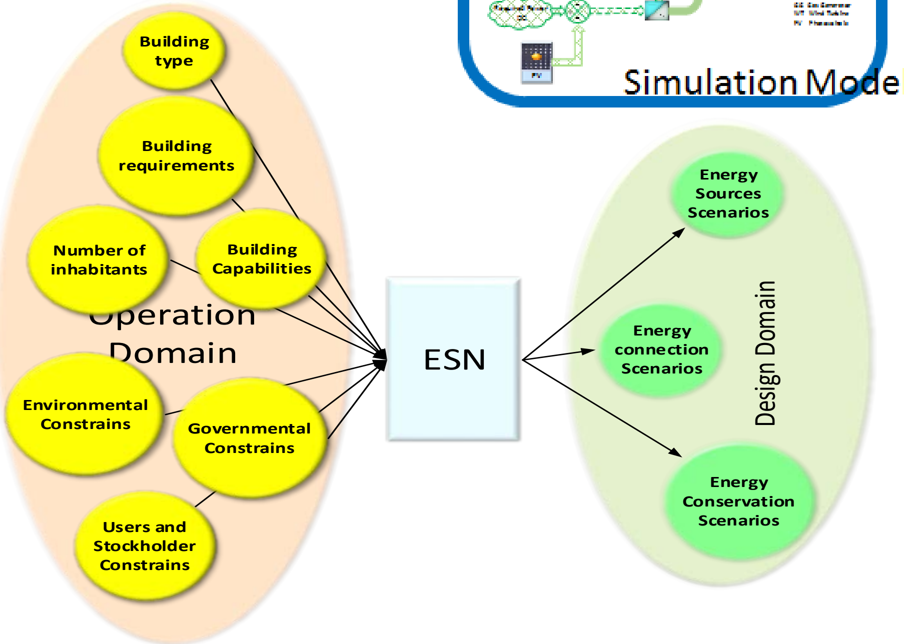
Smart Energy Infrastructures





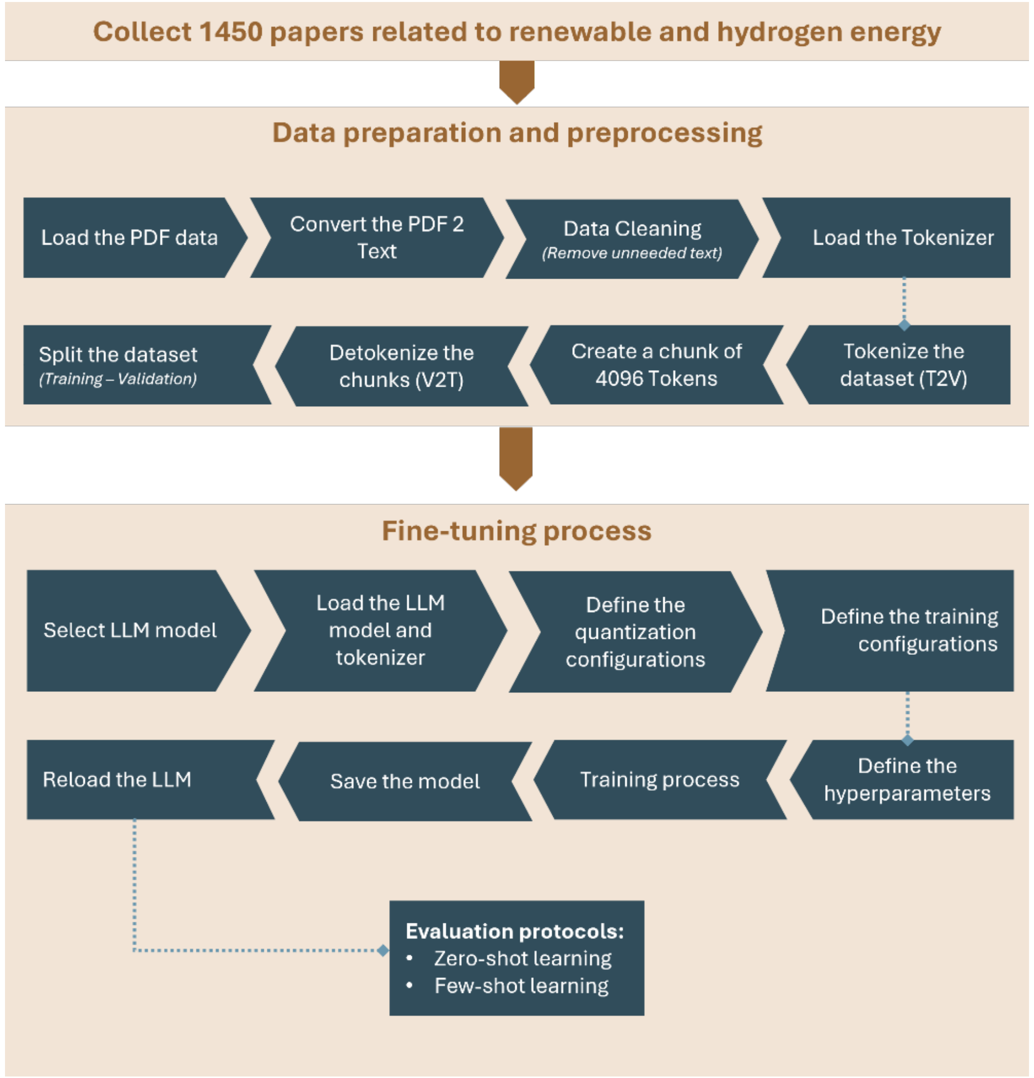
$$C^i = \begin{bmatrix} c^i_{1,1} & \cdots & c^i_{1,J_{i-1}} \\ \vdots & c^i_{j,k} & \vdots \\ c^i_{J_i,1} & \cdots & c^i_{J_i,J_{i-1}} \end{bmatrix}_{J_{i-1}\times J_i}$$





RE-LLaMA, Domain-Specific Large Language Models for Renewable Energy Planning

- Data Preparation: Created a comprehensive dataset of 1450 renewable energy papers that underwent rigorous cleaning
- Model Adaptation: Leveraged LLaMA 3.1 8B as the foundation and employed domain-adaptive pretraining with autoregressive next-token prediction to enhance the model's renewable energy domain expertise.



MG-OPT Multi-Objective Optimization Framework for Hybrid Renewable Energy Systems with Hydrogen Integration

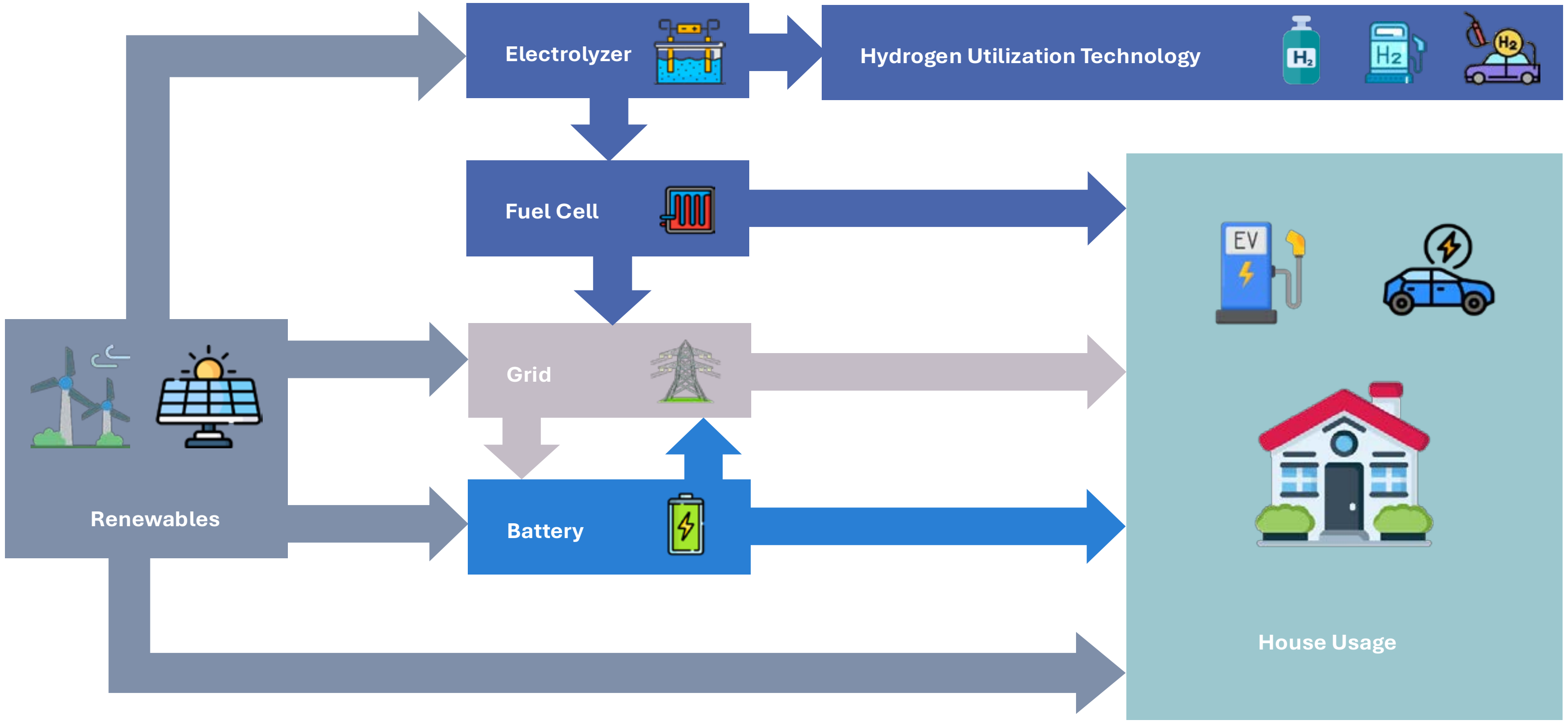
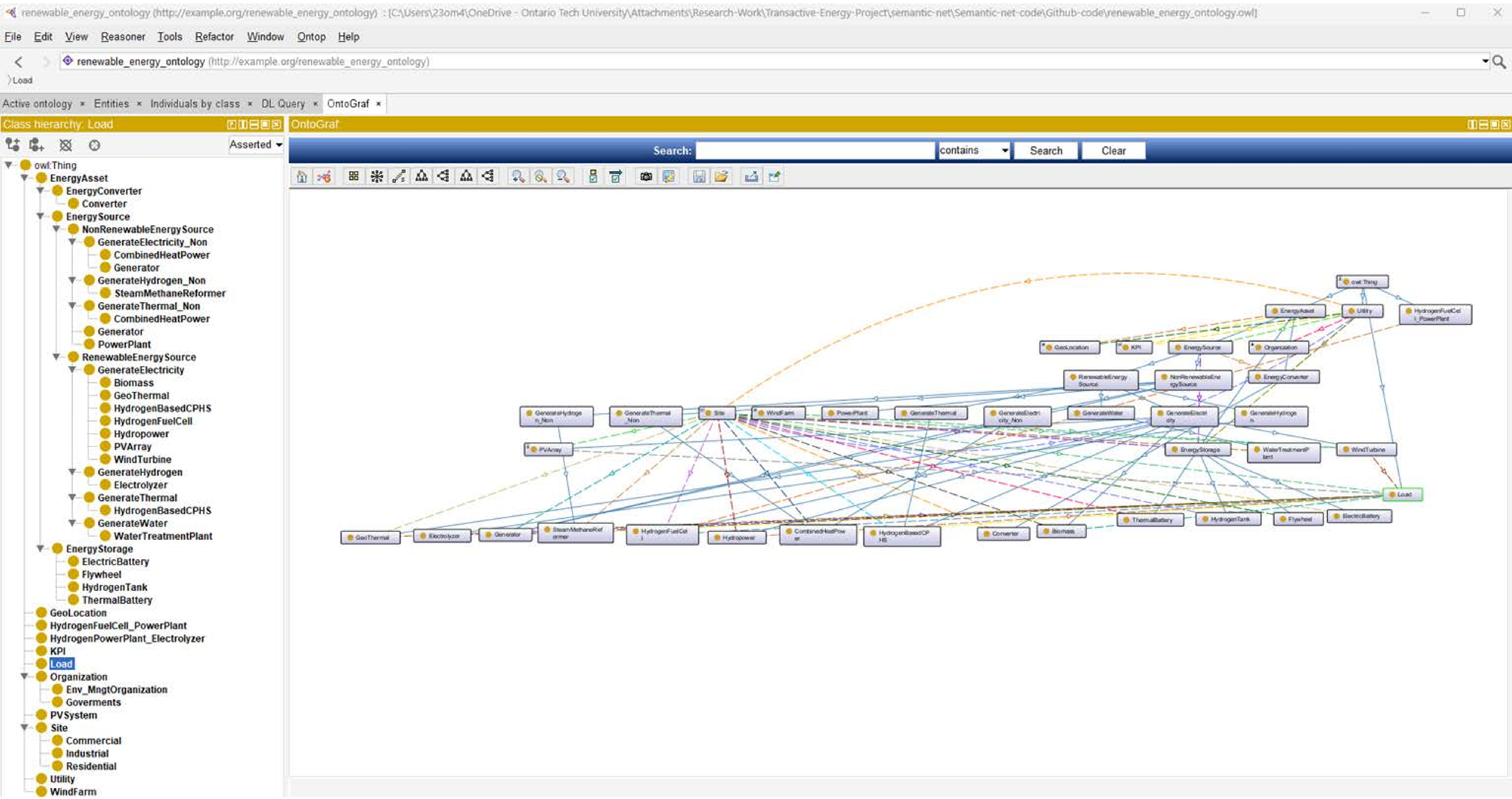
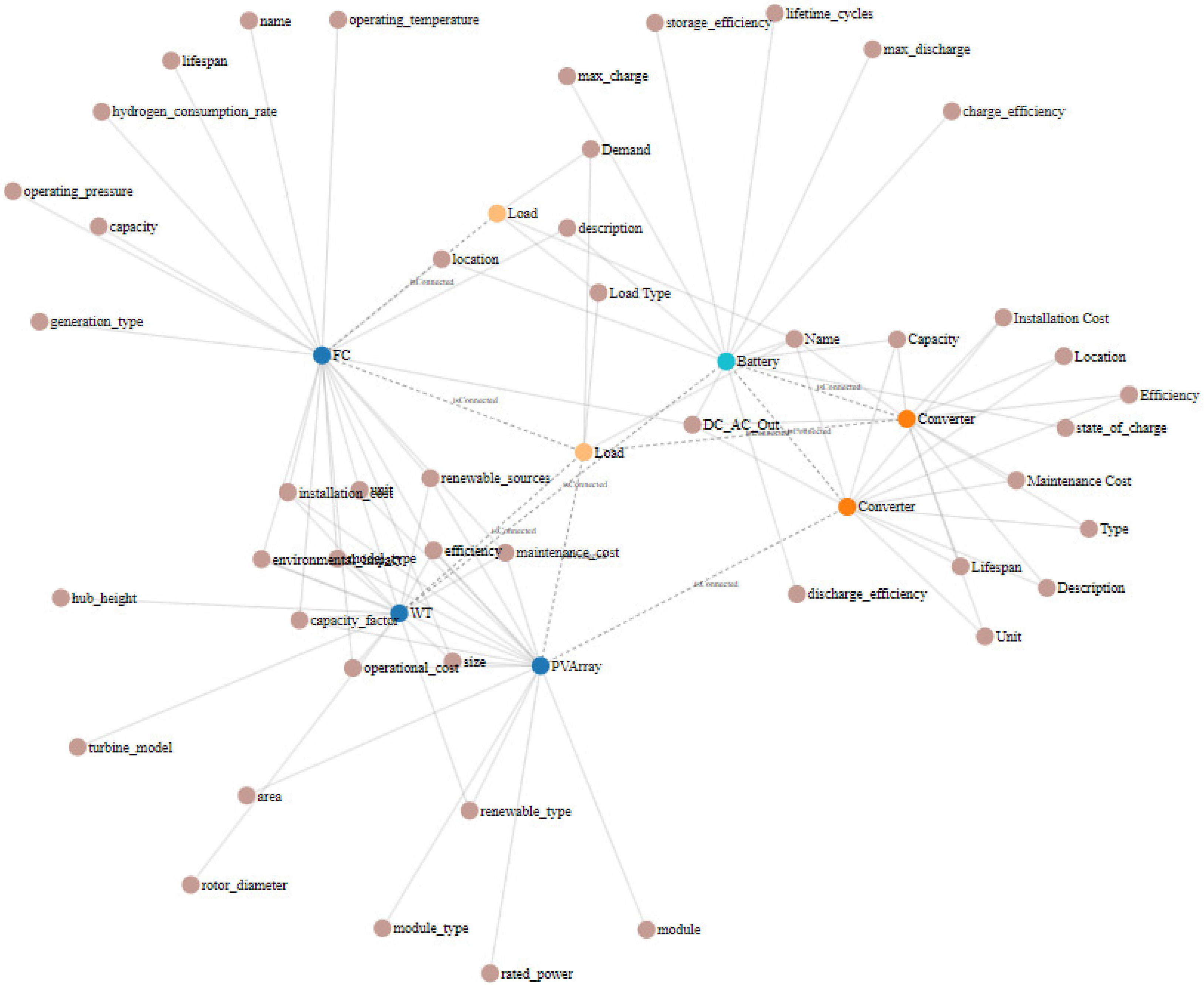
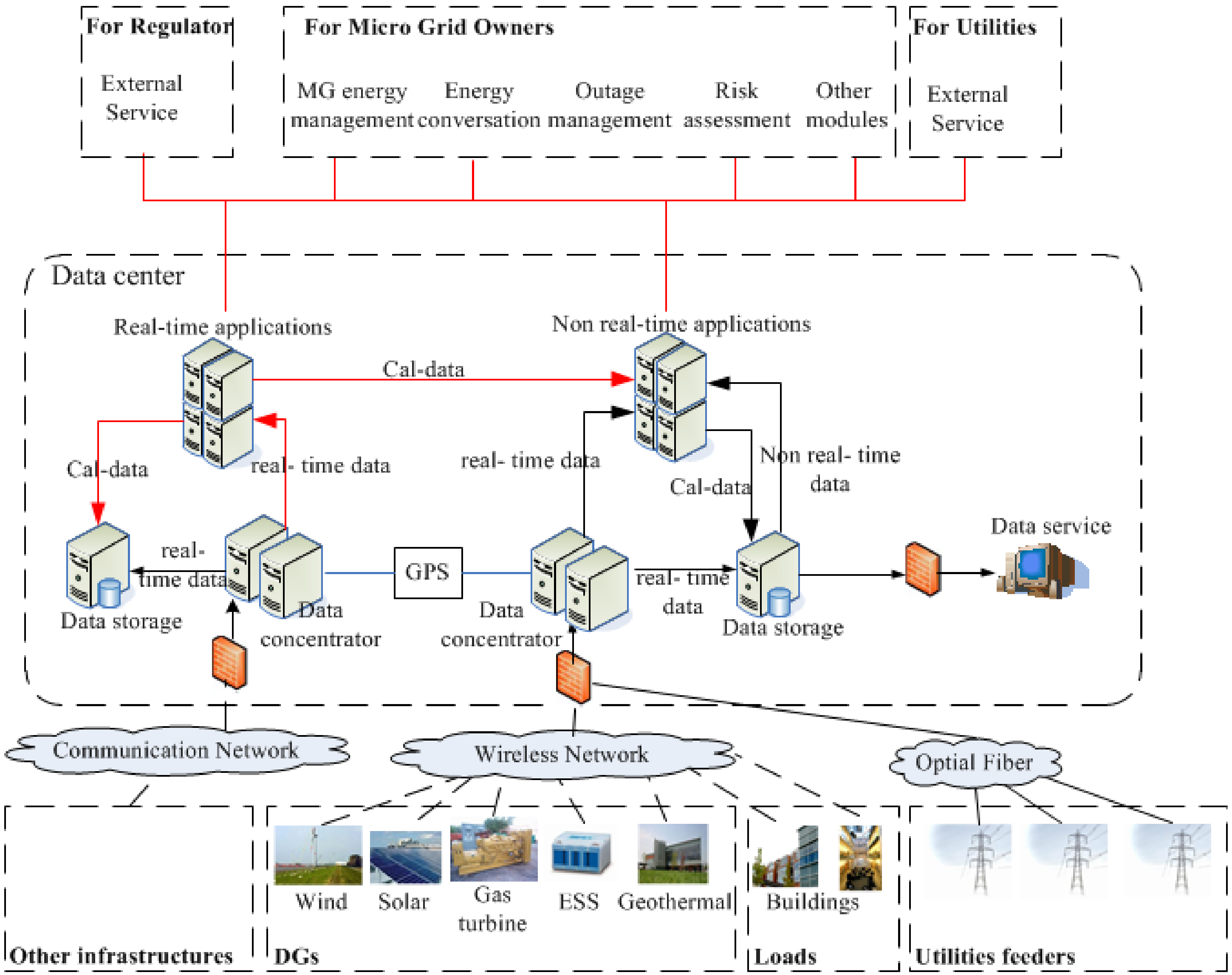


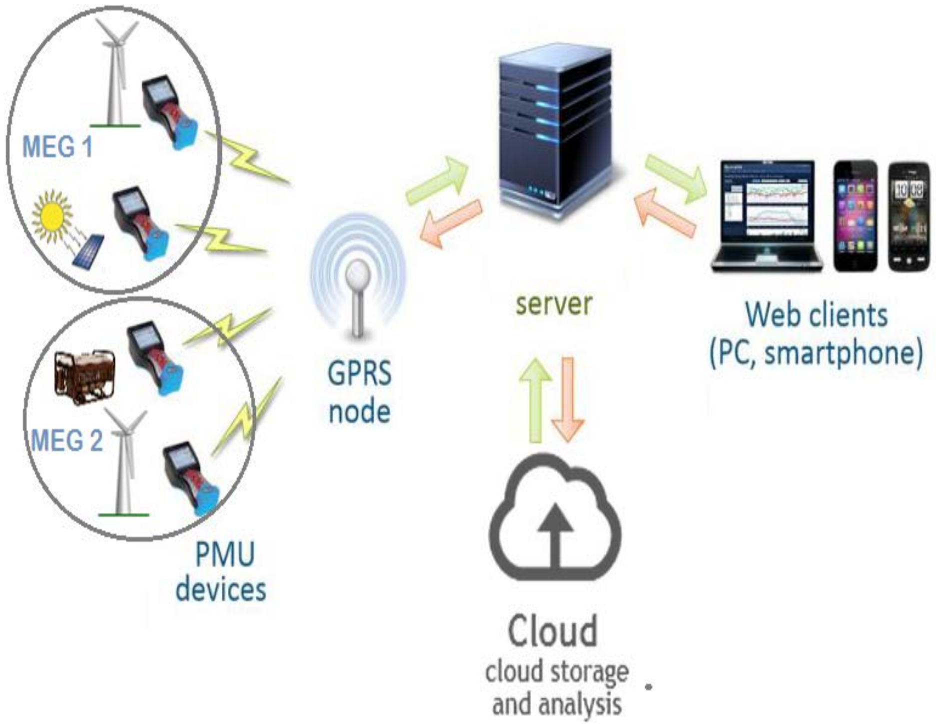
Figure 6: illustrates the architectural framework of a Hydrogen Renewable Energy System (HRES), showing the integration of renewable energy sources (solar and wind) with hydrogen infrastructure and energy storage systems connected to a charging station that serves both vehicles and various facilities including residential, commercial, industrial, and healthcare buildings.

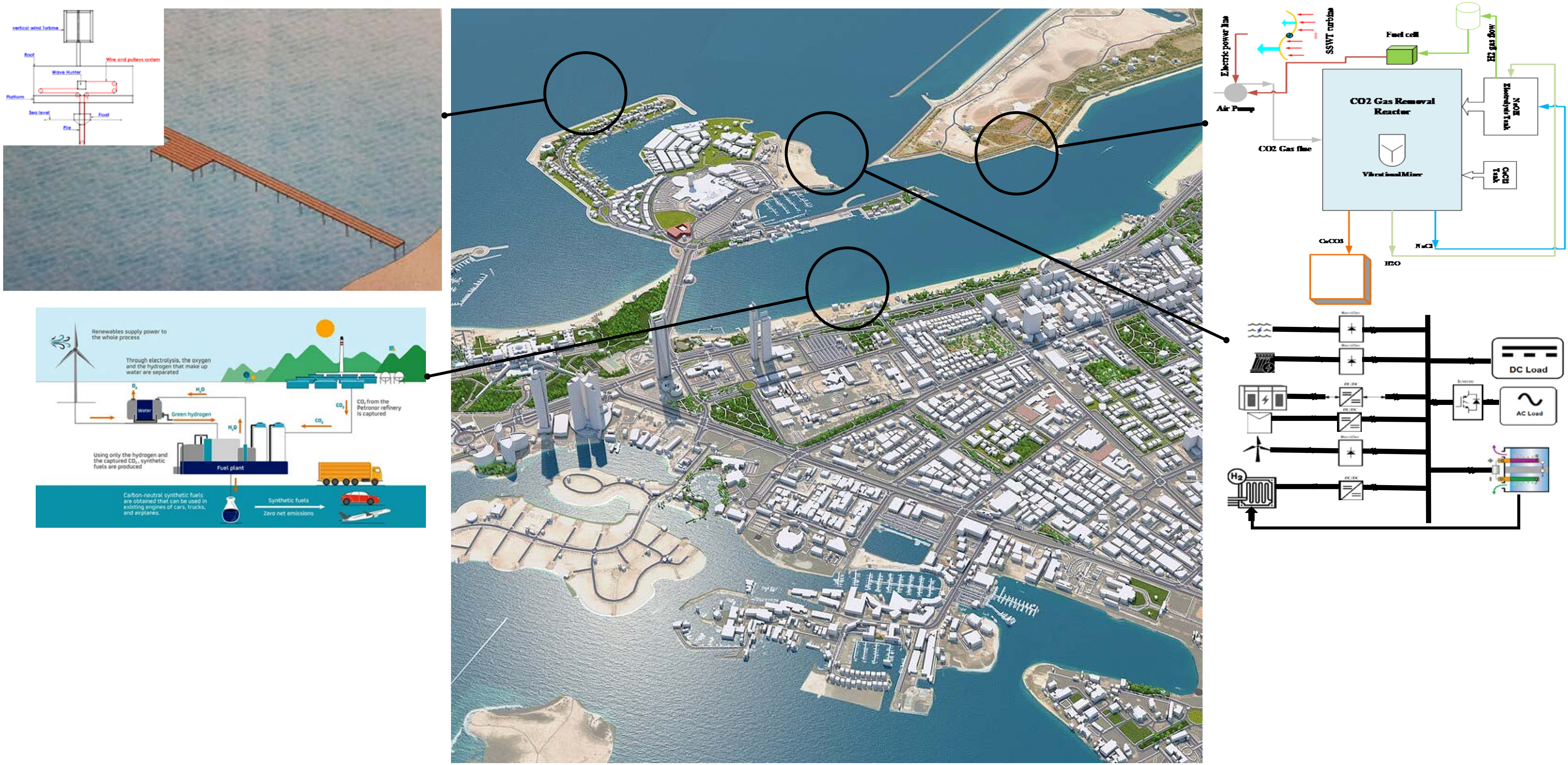

renewable_energy_ontology (http://example.org/renewable_energy_ontology) : [C:\Users\23om4\OneDrive - Ontario Tech University\Attachments\Research-Work\Transactive-Energy-Project\semantic-net\Semantic-net-code\Github-code\renewable_energy_ontology.owl]
File Edit View Reasoner Tools Refactor Window Ontop Help
renewable_energy_ontology (http://example.org/renewable_energy_ontology)
Load
Active ontology Entities Individuals by class DL Query OntoGraf
Class hierarchy: Load
Asserted
OntoGraf
Search: contains Search Clear
owl:Thing
EnergyAsset
EnergyConverter
Converter
EnergySource
NonRenewableEnergySource
GenerateElectricity_Non
CombinedHeatPower
Generator
GenerateHydrogen_Non
SteamMethaneReformer
GenerateThermal_Non
CombinedHeatPower
Generator
PowerPlant
RenewableEnergySource
GenerateElectricity
Biomass
GeoThermal
HydrogenBasedCPHS
HydrogenFuelCell
Hydropower
PVArray
WindTurbine
GenerateHydrogen
Electrolyzer
GenerateThermal
HydrogenBasedCPHS
GenerateWater
WaterTreatmentPlant
EnergyStorage
ElectricBattery
Flywheel
HydrogenTank
ThermalBattery
GeoLocation
HydrogenFuelCell_PowerPlant
HydrogenPowerPlant_Electrolyzer
KPI
Load
Organization
Env_MngtOrganization
Goverments
PVSystem
Site
Commercial
Industrial
Residential
Utility
WindFarm


name
operating_temperature
storage_efficiency
lifetime_cycles
lifespan
max_discharge
max_charge
hydrogen_consumption_rate
charge_efficiency
Demand
operating_pressure
Load
description
capacity
location
Load Type
generation_type
Installation Cost
Name
Capacity
FC
Battery
Location
Efficiency
Converter
DC_AC_Out
state_of_charge
Load
renewable_sources
installation_cost
unit
Maintenance Cost
Converter
Type
efficiency
maintenance_cost
environmental_impact
model_type
Lifespan
Description
discharge_efficiency
hub_height
WT
capacity_factor
Unit
operational_cost
size
PVArray
turbine_model
area
renewable_type
rotor_diameter
module_type
module
rated_power

Integrated Energy-Water-Food-Health-Transportation Data Center (Efficiency, Conservation, Safety, Reliability)







vertical wind Turbine
Roof
Wire and pulleys system
Wave Hunter
Platform
Sea level
Float
Pile
Renewables supply power to the whole process
Through electrolysis, the oxygen and the hydrogen that make up water are separated
Water
Green hydrogen
CO2 from the Petronor refinery is captured
Using only the hydrogen and the captured CO2, synthetic fuels are produced
Fuel plant
Carbon-neutral synthetic fuels are obtained that can be used in existing engines of cars, trucks, and airplanes.
Synthetic fuels
Zero net emissions
Electric power line
SSWT turbine
Fuel cell
H2 gas flow
Air Pump
CO2 Gas Removal Reactor
NaOH Electrolyte Tank
CO2 Gas flue
Vibrational Mixer
CaCl2 Tank
CaCO3
H2O
NaCl
DC Load
AC Load

Hossam A. Gabbar

Fast Charging and Resilient Transportation Infrastructures in Smart Cities

This book provides readers with expert knowledge on the design of fast charging infrastructures and their planning in smart cities and communities to support autonomous transportation. The recent development of fast charging infrastructures using hybrid energy systems is examined, along with aspects of connected and autonomous vehicles (CAV) and their integration within transportation networks and city infrastructures. The book looks at challenges and opportunities for autonomous transportation, including connected and autonomous vehicles, shuttles, and their technology development and deployment within smart communities. Intelligent control strategies, architectures, and systems are also covered, along with intelligent data centers that ensure effective transportation networks during normal and emergency situations. Planning strategies are presented to demonstrate the resilient transportation infrastructures, and optimized performance is discussed in view of performance indicators and requirements specifications, as well as regulations and standards.

- Provides practical examples of designing fast charging infrastructures for smart cities;
- Examines all aspects of connected and autonomous vehicle (CAV) integration within transportation networks and city infrastructures;
- Discusses future challenges and opportunities for autonomous transportation.

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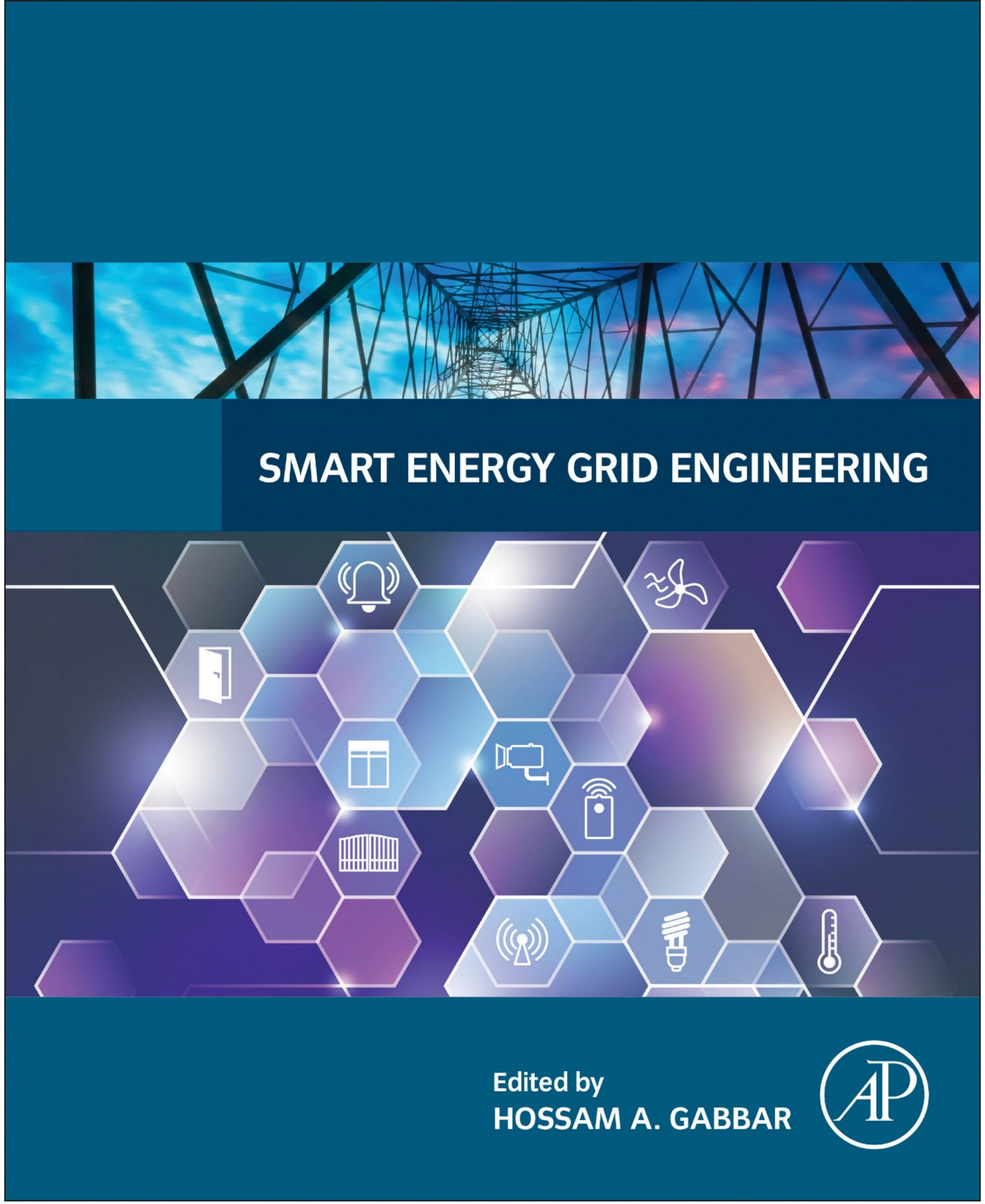

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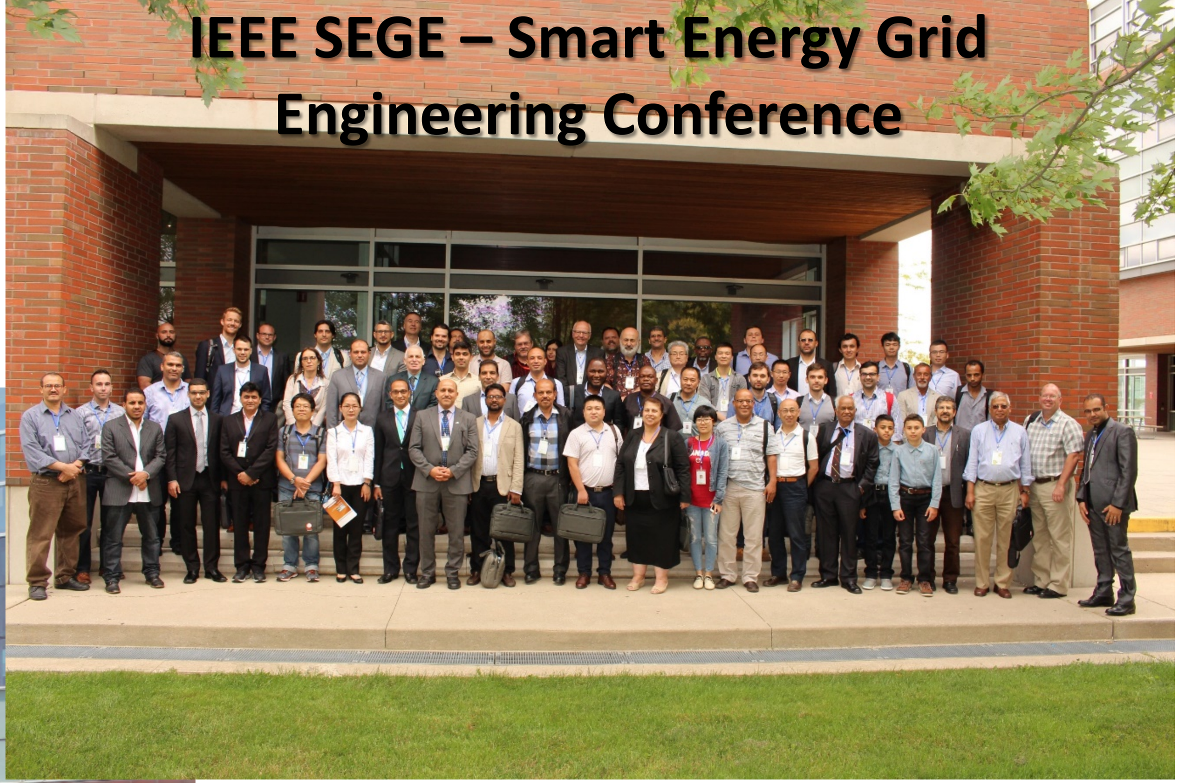

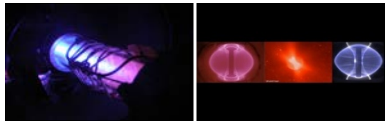

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