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Integrated Energy Systems

Resilience for IES

FORCE Overview and Training

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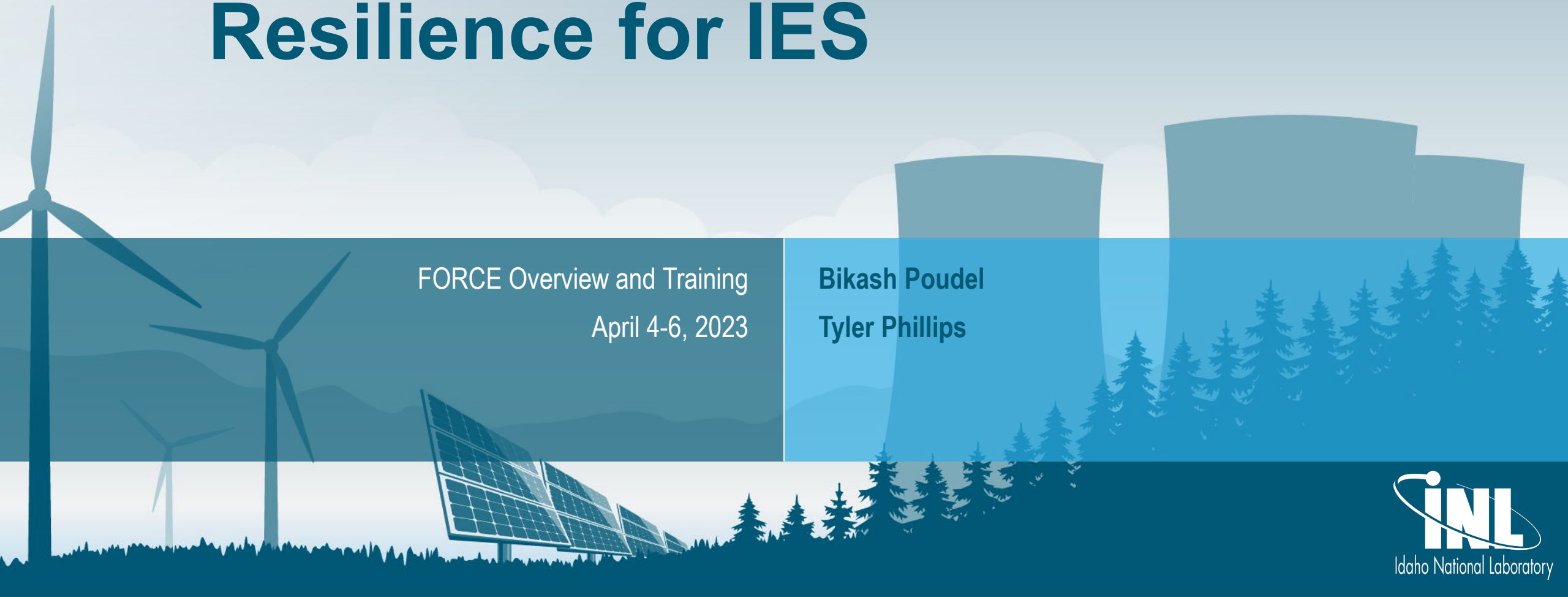

INL

Idaho National Laboratory

Overview

- What is resilience?
- Introduce resilience metric
  - Power system specific
- Metric results visualization
  - Hydro assets, solar & storage
- Resilience of integrated energy system
- Resilience metric calculation for IES assets
- Resilience-informed planning and operation

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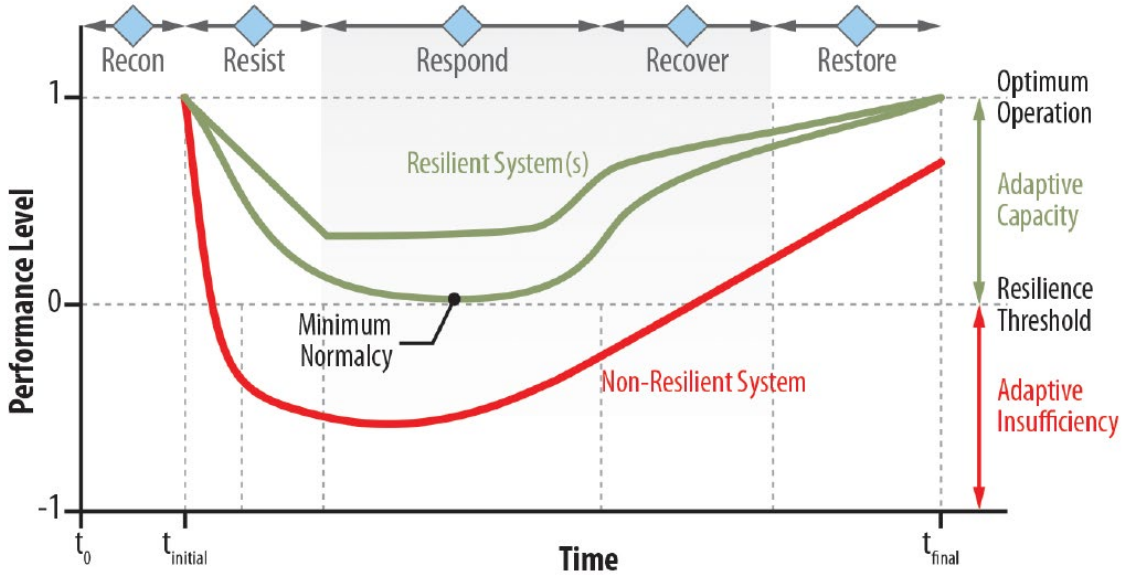
What is Resilience?

- There is no accepted definition of resilience
- General commonality among all definitions
  - Ability to anticipate a possible disaster
  - Adopt effective measures to reduce losses or failures
  - Restore quickly
  - 5 Rs of resilience



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Resilience Metric Introduction

- Reliability metrics often consider number and/or length of outages
  - Looking back in time
  - Want a metric looking forward in time
- Measure of the ability of a system to maintain frequency and voltage stability during a disturbance
- Frequency stability
  - Balance of real power
  - Unbalance leads to frequency change
- Voltage stability
  - Balance of reactive power
- Metric based on assets adaptive capacity
  - Control flexibility of the system in terms of real and reactive power
    - Operating point and nameplate capacity
  - Temporal constraints
    - Control latency and ramp rates

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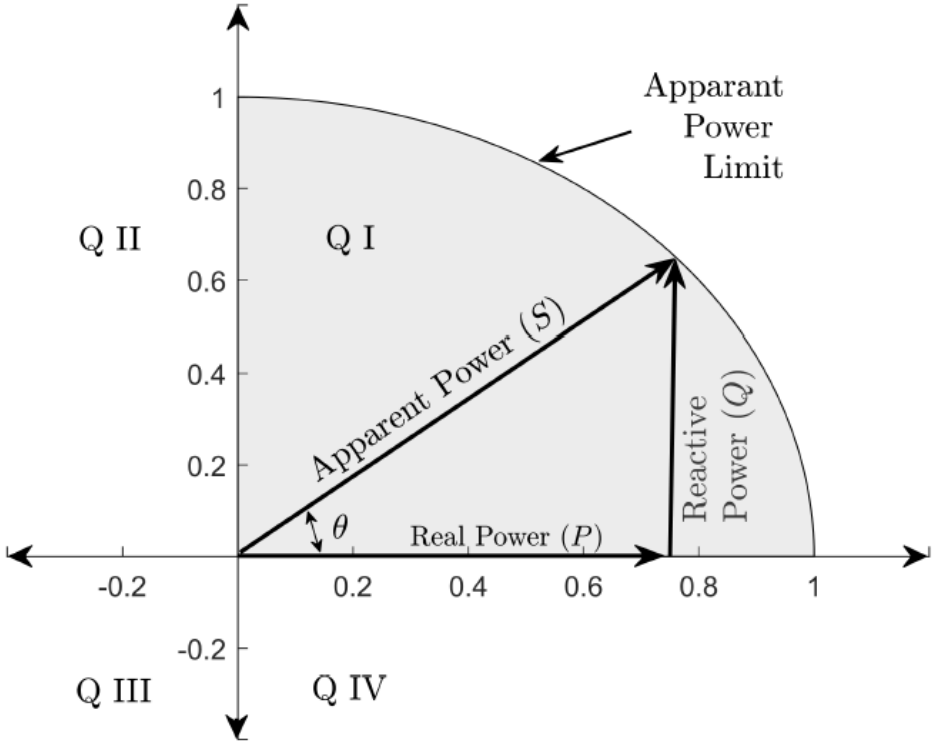
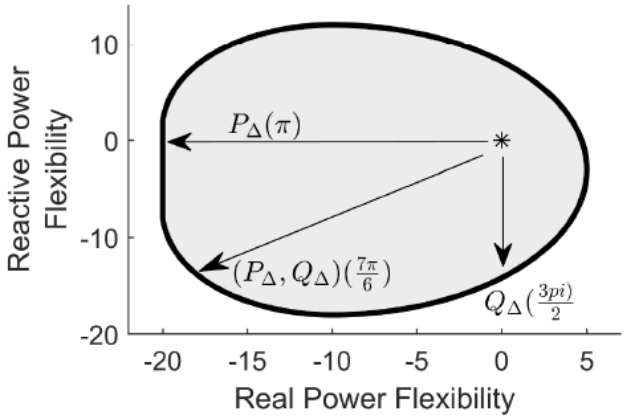
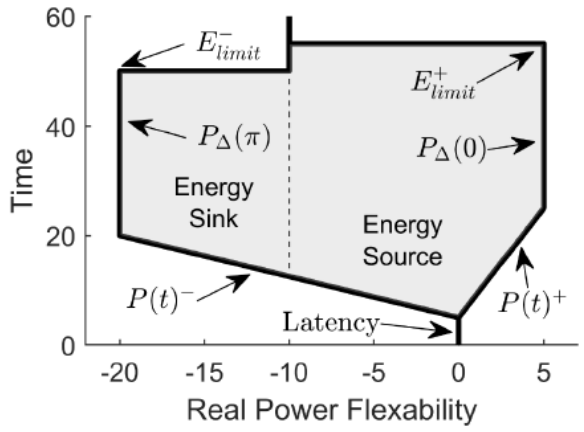
Resilience Metric Calculation

- Apparent power limit
  - $S(\theta) = \sqrt{P^2 + Q^2}$

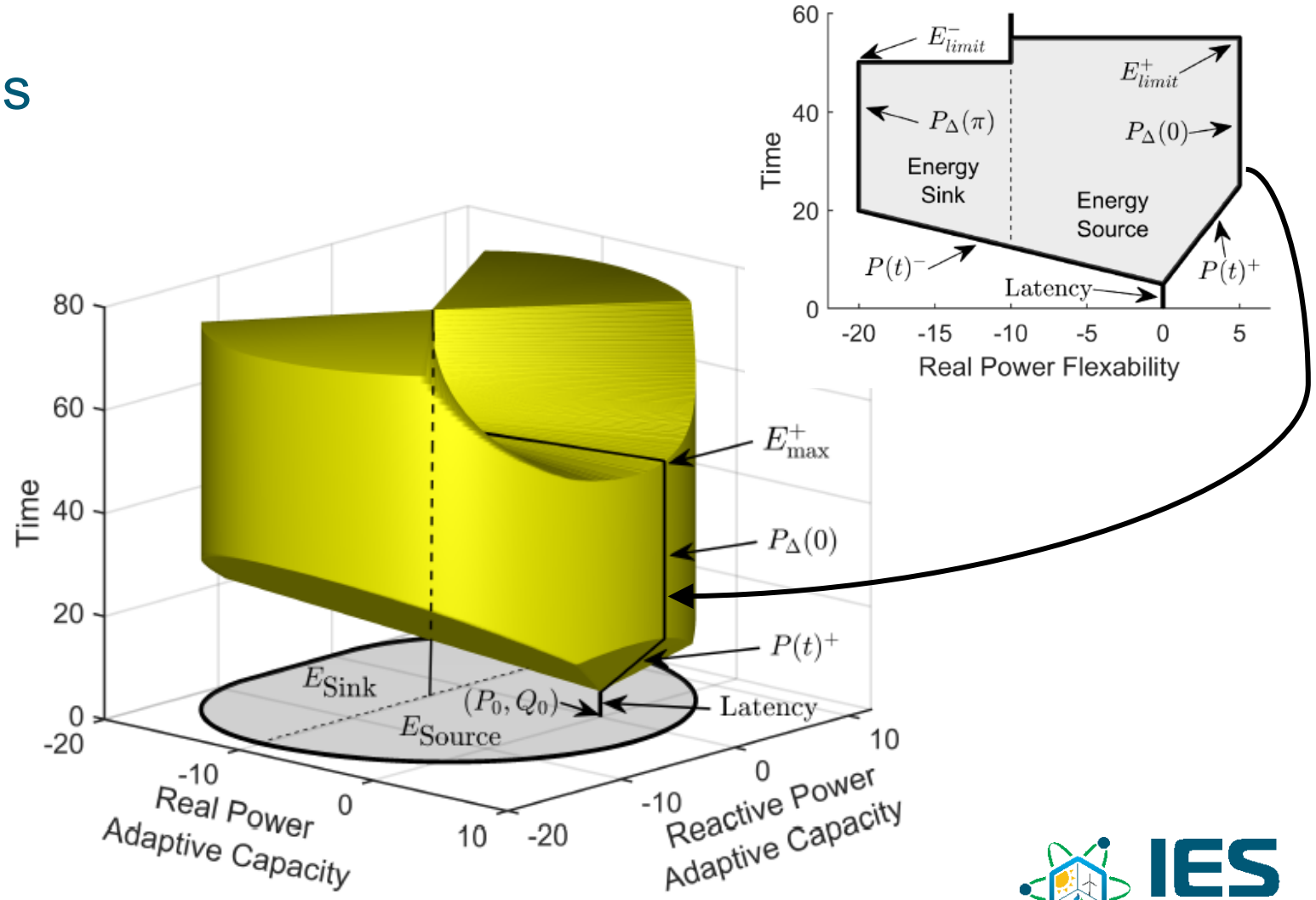






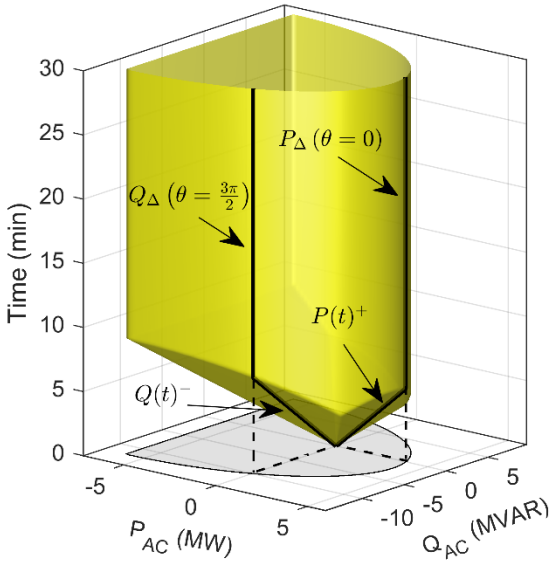
Adaptive Capacity Result

- Adaptive capacity at all power factor angles
  - Assets can be aggregated to define the system
- Surface represents the maximum extent the system can be controlled
  - From its current operation point
- Size of disturbance that can be withstood

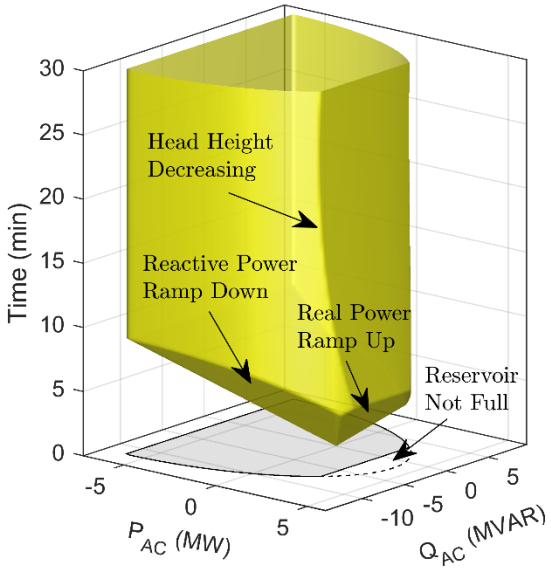


Hydro Power Adaptive Capacity

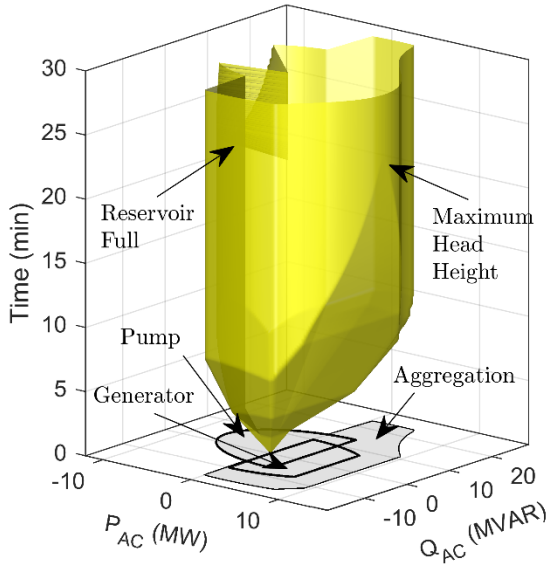
Run of River

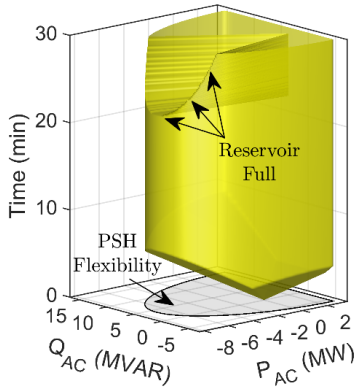


Hydro with Reservoir

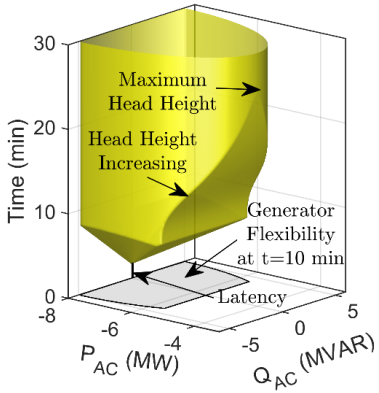


Pumped Storage Hydro (PSH)





Pump



Generate

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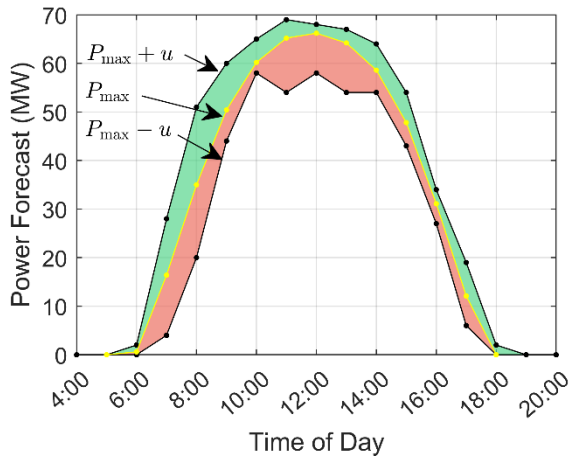
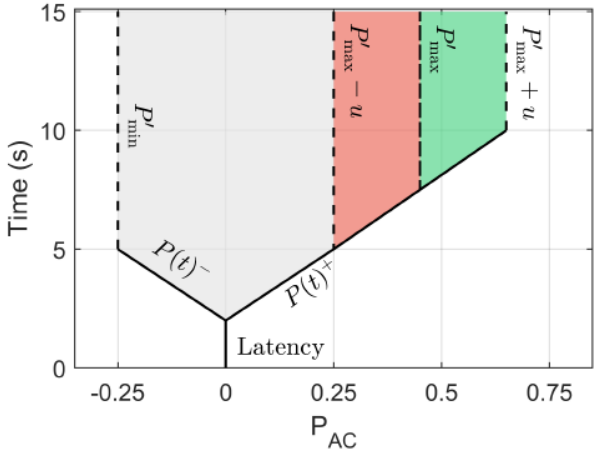
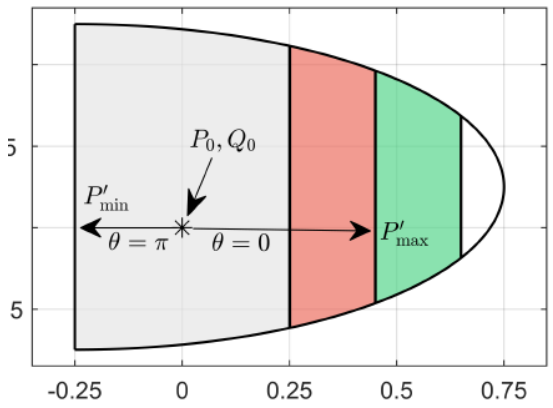
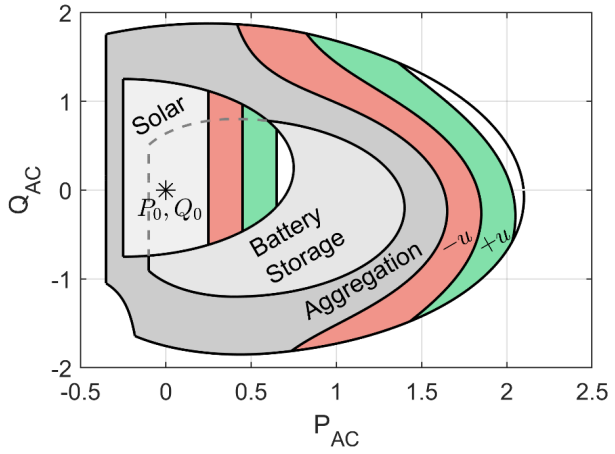
Solar PV and Battery Storage with Uncertainty

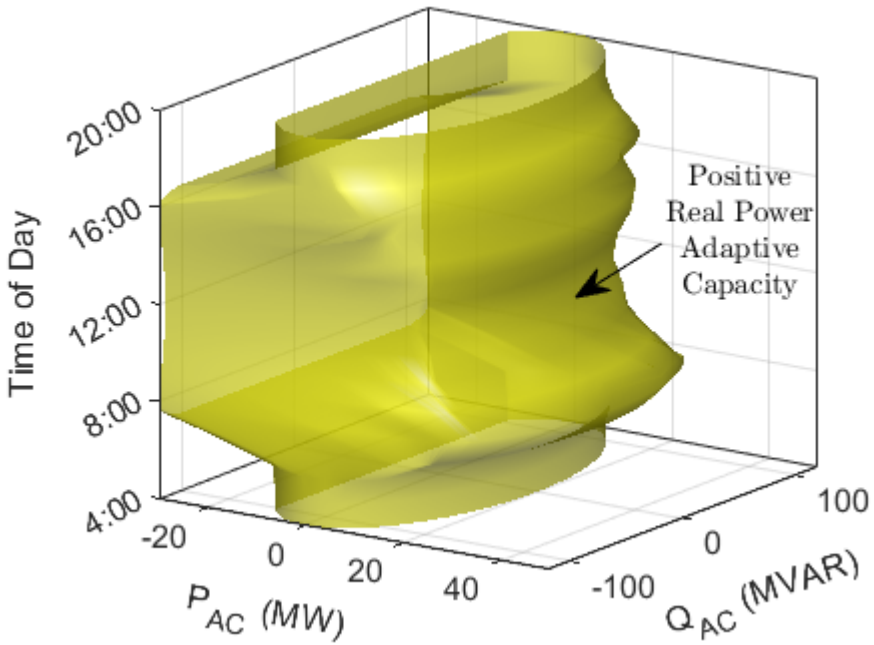
- Solar forecast with uncertainty





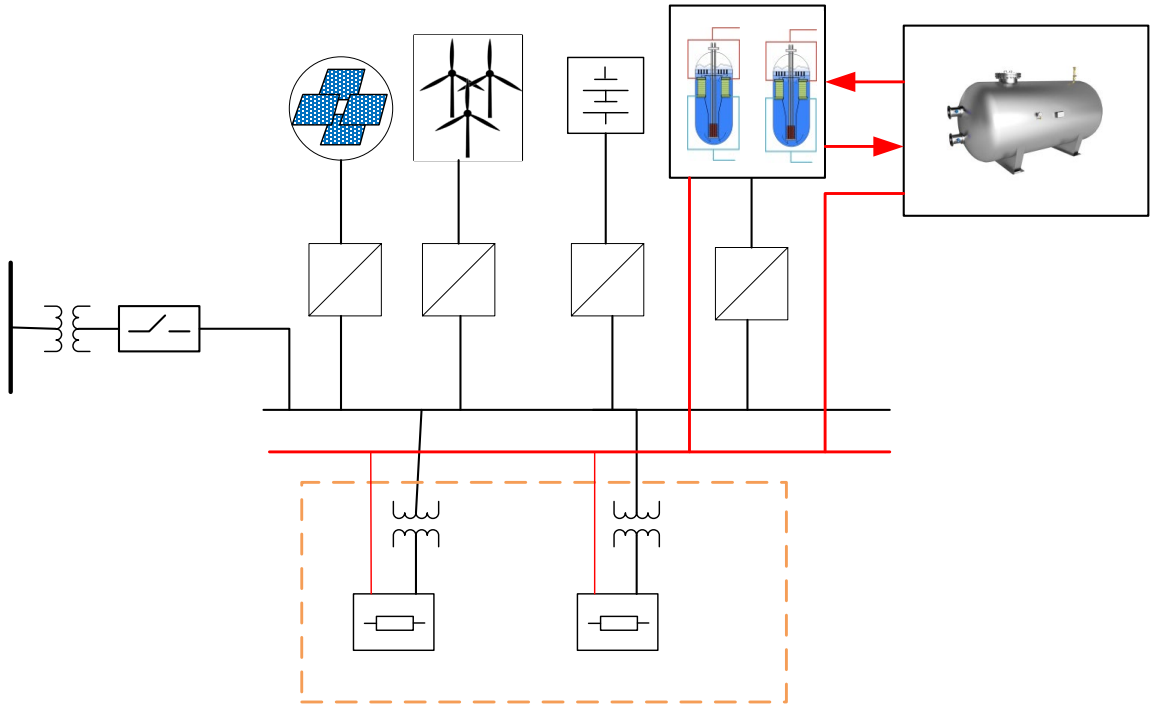






Resilience of Integrated Energy Systems

- IES components and resources with diverse flexibility profiles
  - Nuclear resources (Small Modular Reactors or Microreactors)
  - Flexible Heating/ Industrial process
  - Critical and non-critical loads
  - Thermal energy storage (TES)
  - Battery energy storage (BES)
  - Wind and PVs (source of disturbance)



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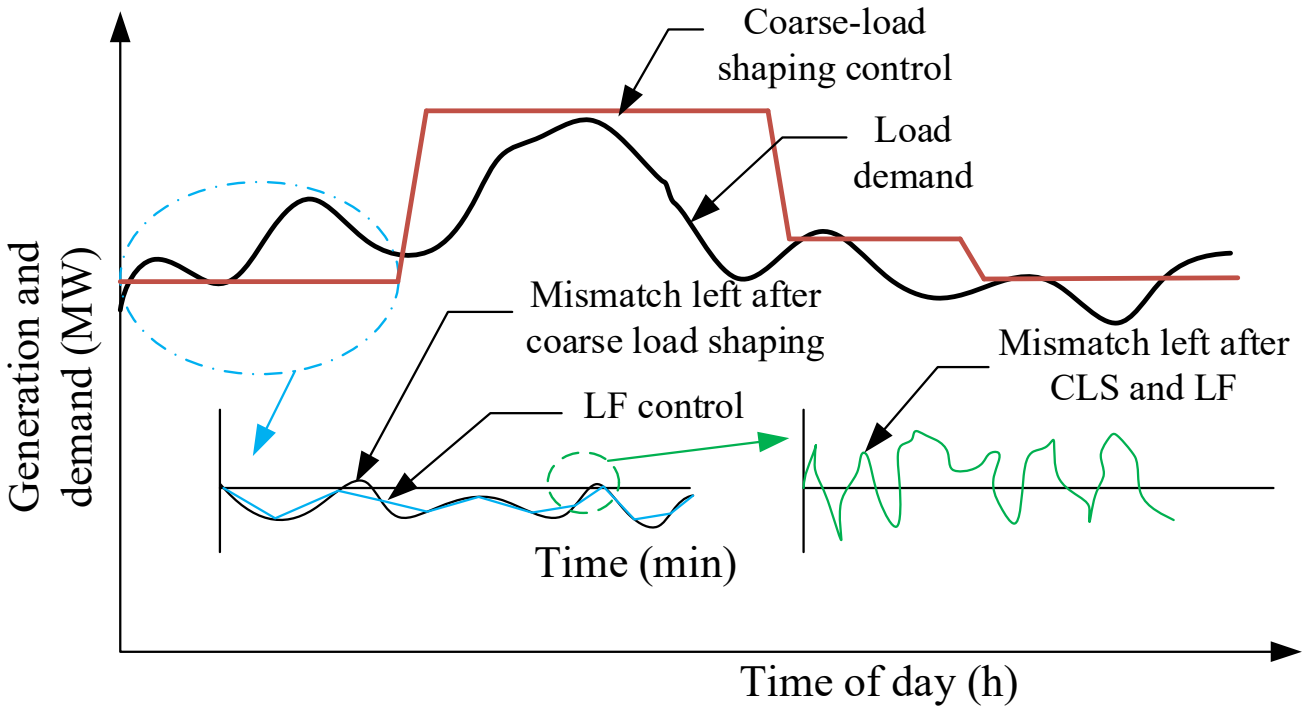
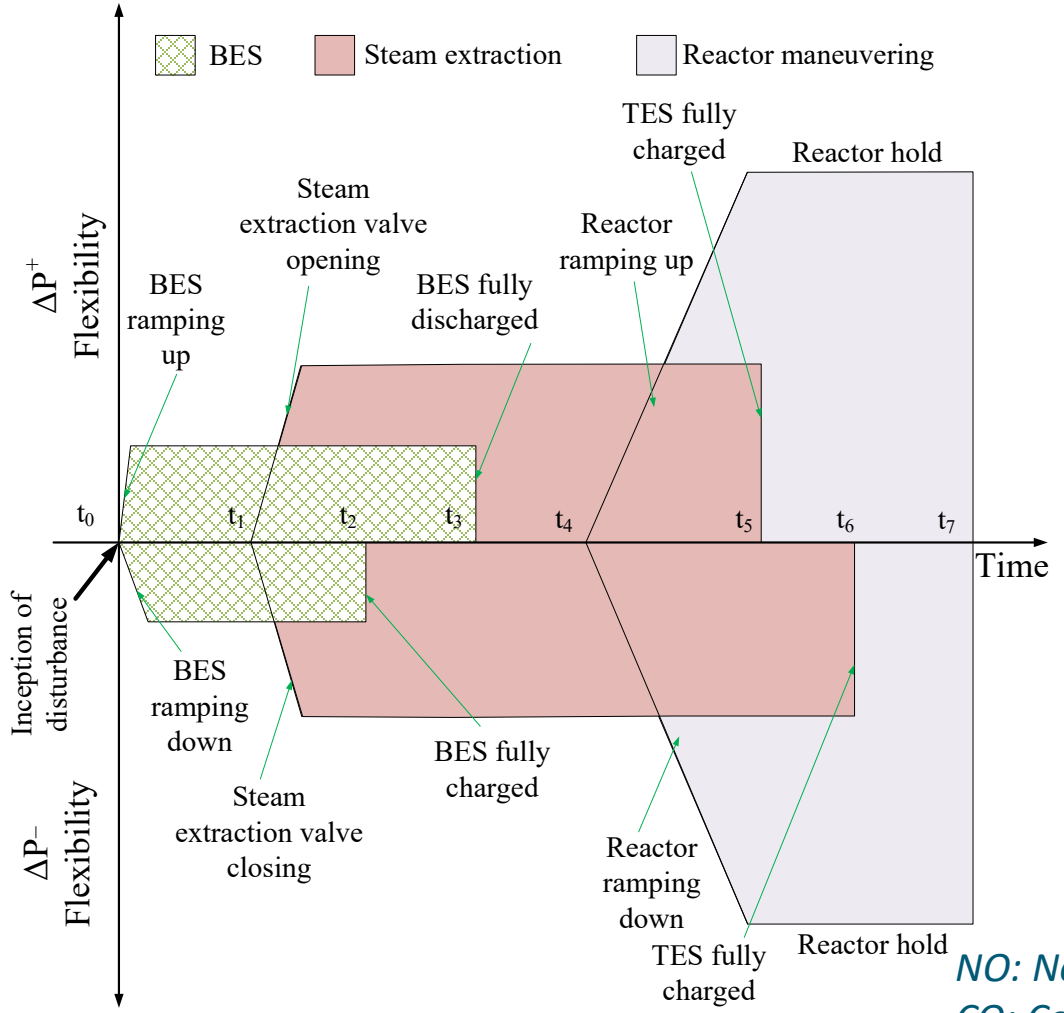
Hierarchical Control for Resilient Operation

- Hierarchical distributed control of flexible assets.
- Coarse-load shaping (CLS)
  - Reactor power maneuvering to provide coarse-load shaping.
  - Limited to 2-3 times a day.
- Load-following (LF) control
  - Flexible steam extraction to provide load following
  - More frequently than reactor control.
- Frequency control
  - Battery energy storage (BES) to provide frequency control
  - Steam bypass support battery energy storage, if the disturbance is too large.

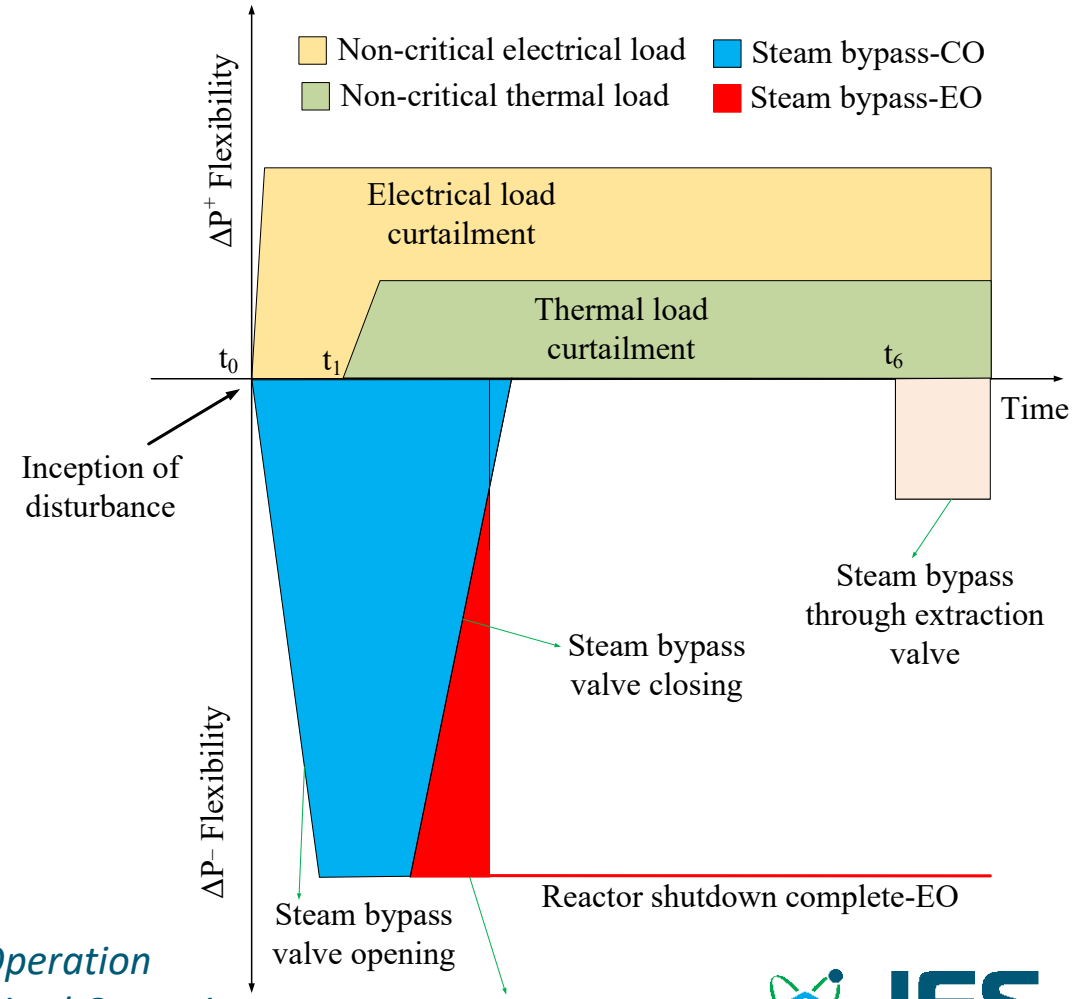


Adaptive Capacity Calculation of IES Assets

Normal Operation



Compromised and Emergency Operations



NO: Normal Operation
CO: Compromised Operation
EO: Emergency Operation

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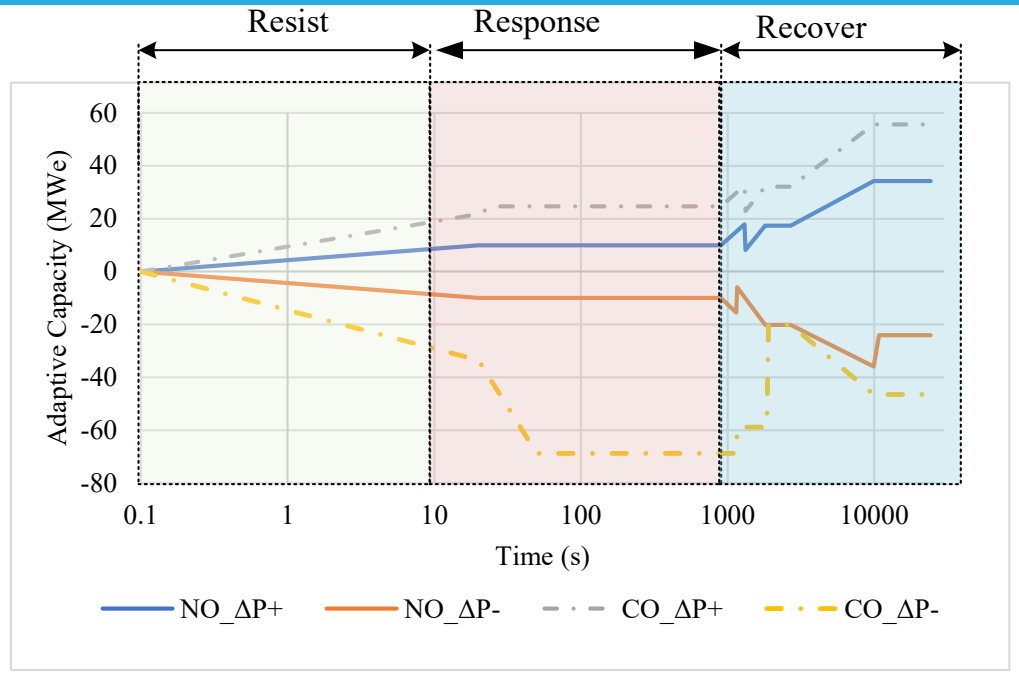
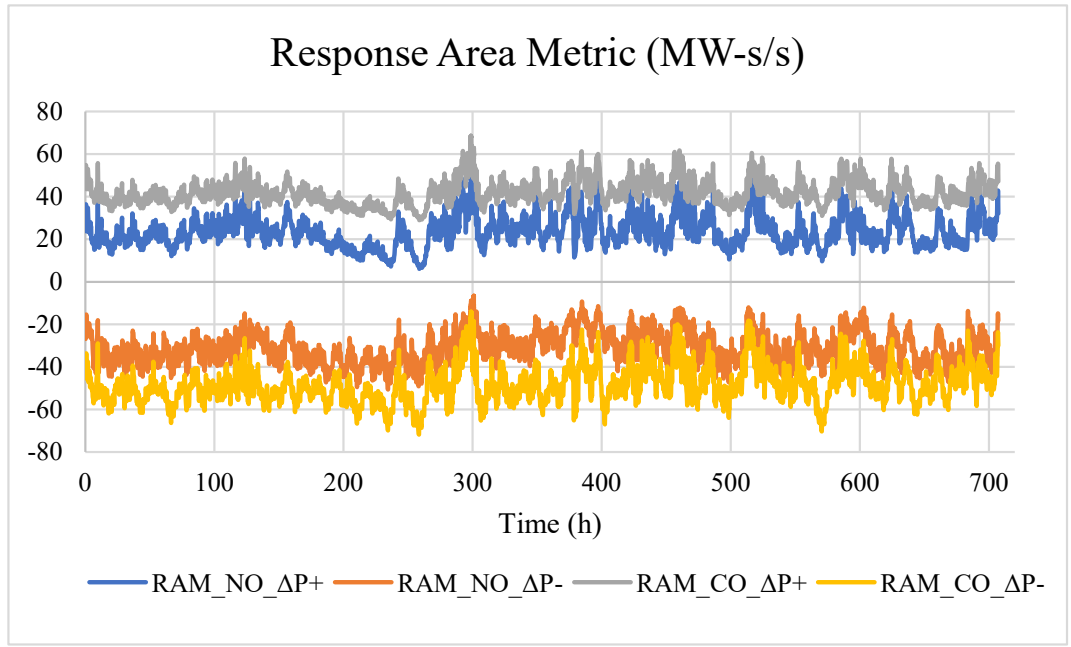
Case Study: Evaluating Resilience Metric



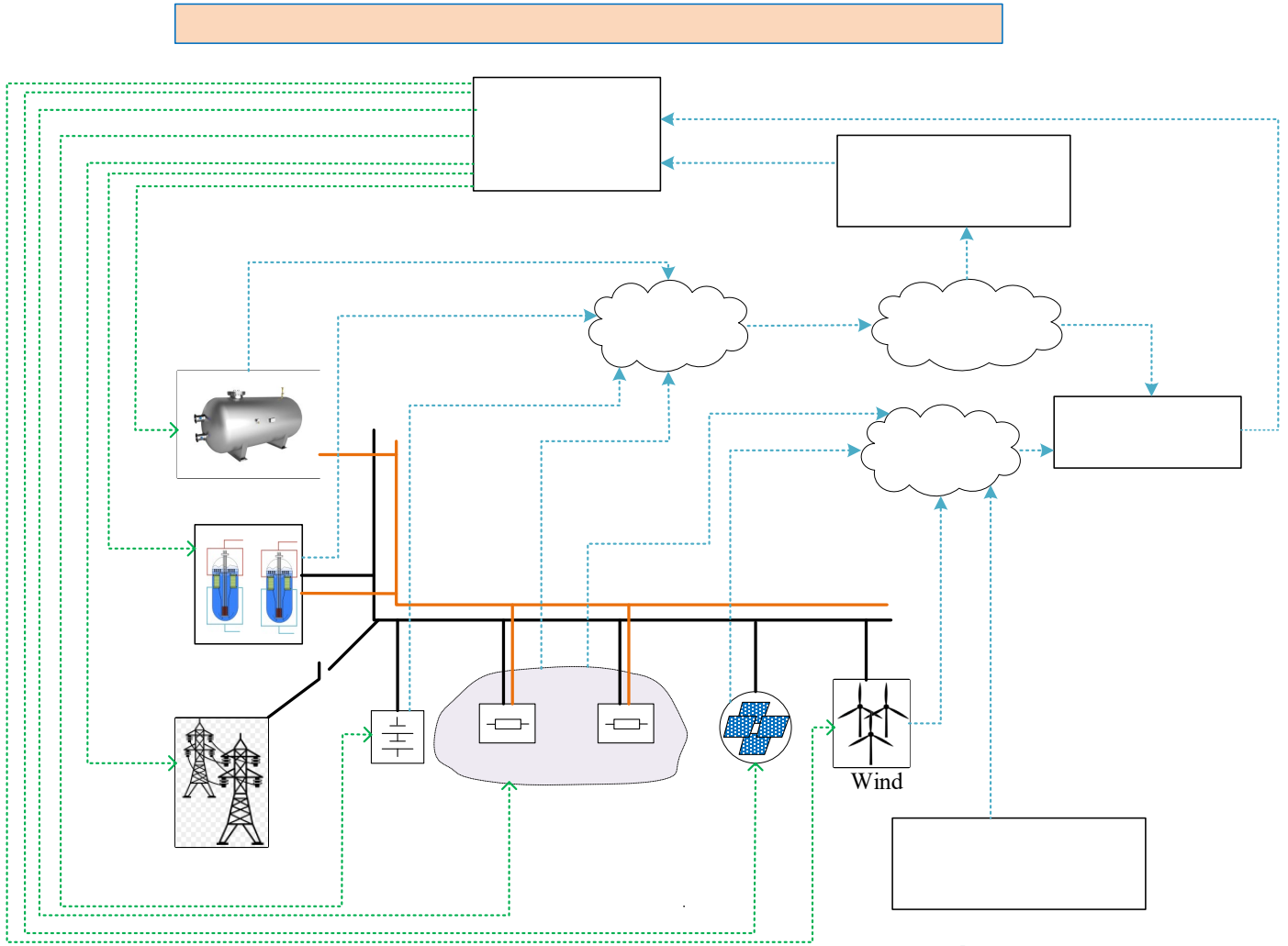


- The adaptive capacity of individual assets are aggregated to evaluate the net system adaptive capacity plotted in a logarithmic time scale.
- The response area metric (*RAM*) is calculated as:

$$RAM = \frac{Area\ under\ the\ adaptive\ capacity\ curve}{Total\ duration} = \frac{\int_0^{t_{FF}} P\_ad\_MW\ dt}{t_{FF}}\ \text{MWe-s/s}$$

Implementation for Resilience-Informed Planning and Operation

- Phase 1: Implementing resilience into FORCE
  - Resilience-informed sizing and dispatch optimization in HERON
  - Resilience-informed control in HYBRID
- Phase 2: Integrating grid components to IES Resilience
- Phase 3: Extending the resilience framework for thermal and industrial resources



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Discussion and Questions??

Thank You!!

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