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Power Grid Resilience: Cascading Failure Simulation and Black-Start Optimization

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Wednesday, July 28, 2021: Virtual Intern Symposium

Tuesday, August 3, 2021: Resilient Energy Systems Intern Institute

Wednesday, August 4, 2021: FORCEE Intern Institute

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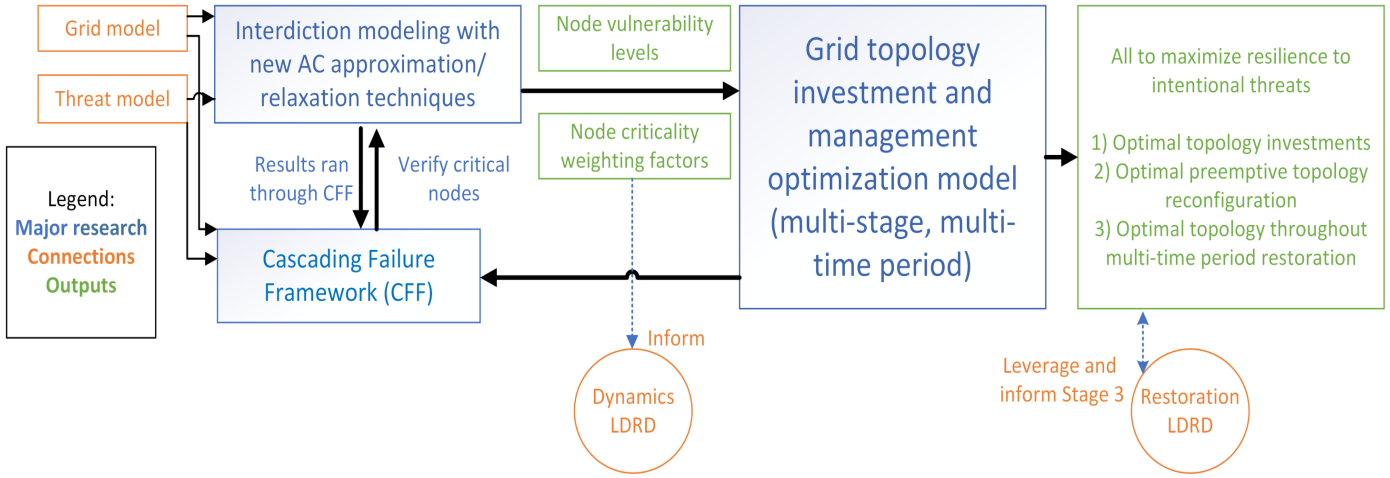
Overview

- Motivation of work
- Modeling of cascading failures with PSS CAPE TS Link
- Formulation for black-start assisted by energy storage
- Acknowledgments and closing

Relevance to Resilient Energy Systems Intern Institute

- Critical Nodes Laboratory Directed Research & Development (LDRD) collaboration, part of Thrust 3 of Resilient Energy Systems Intern Institute (RESII)
  - **Cascading failure simulation**
  - Interdiction analysis
  - Topology optimization
- To inform hardening investments, identify critical nodes/components in power system for resilience (particularly to cascading failures)
- Another stream of effort during internship: black-start optimization

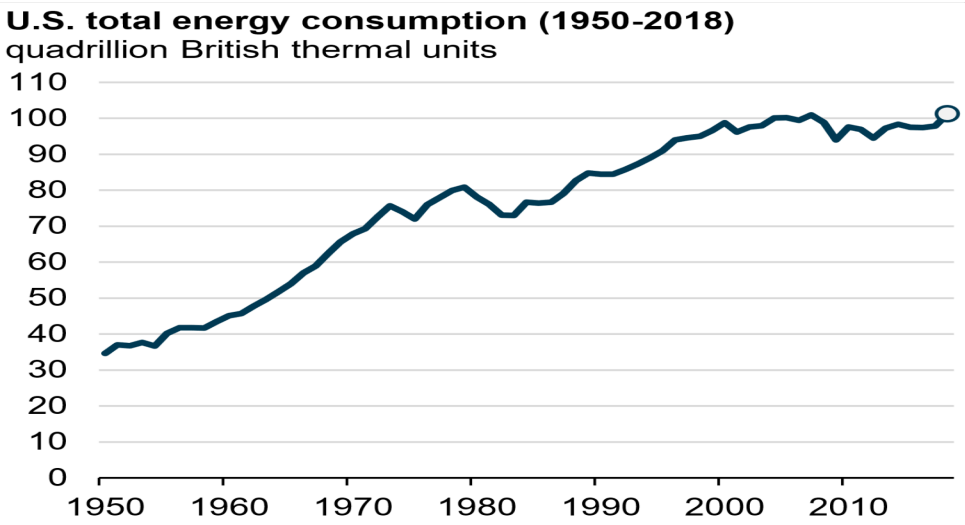


Organization of LDRD into subprojects, and its relation to other projects

Laboratory Directed Research and Development

Motivation of work

- Historical blackout events
  - Northeast blackout of 2003: 55 million people without power
  - 2001 blackout in India: 226 million people
- Cascading failure: “a sequence of dependent failures of individual components that successively weaken the power system” [1]
- Black-start: “the process of restoring an electric power station or a part of an electric grid to operation without relying on the external electric power transmission network to recover from a total or partial shutdown” [2]



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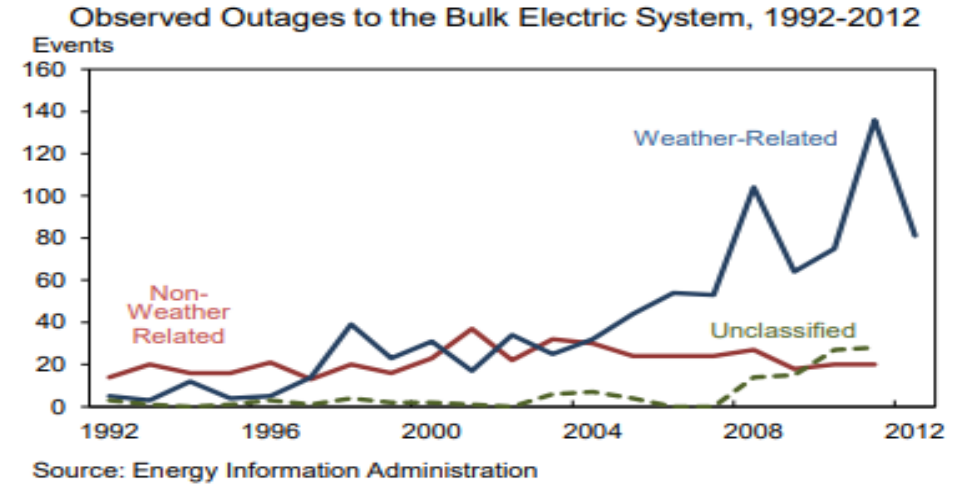

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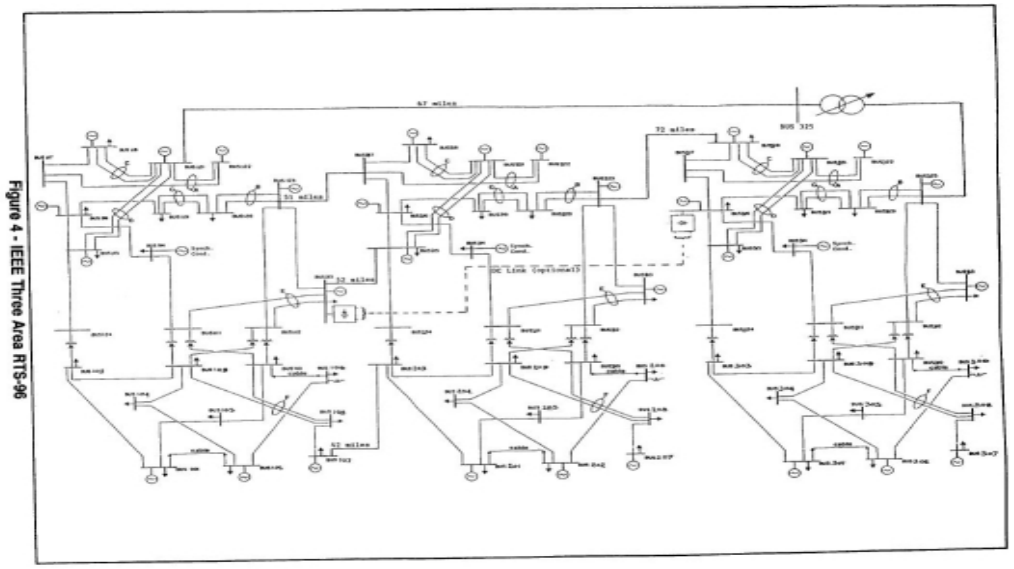
[2] Other causes of power outages include: operational failures, equipment malfunctions, circuit overloads, vehicle accidents, fuel supply deficiencies and load shedding – which occurs when the grid is intentionally shut down to contain the spread of an ongoing power outage (U.S. DOE, Form OE-417).

Testbed for modeling of cascading failures

- PSS®CAPE TS Link
  - PSS®CAPE: protective devices (relays and breakers)
  - PSS®E: electrical machine dynamics
- IEEE RTS-96 system
  - Total real load of 8550 MW
  - 36 generation buses, 120 branches, 51 loads (459 after splitting for underfrequency load shedding)
- Protective relays
  - For branches: overcurrent
  - For generators: over- and under-frequency, over- and under-voltage
  - For loads: underfrequency



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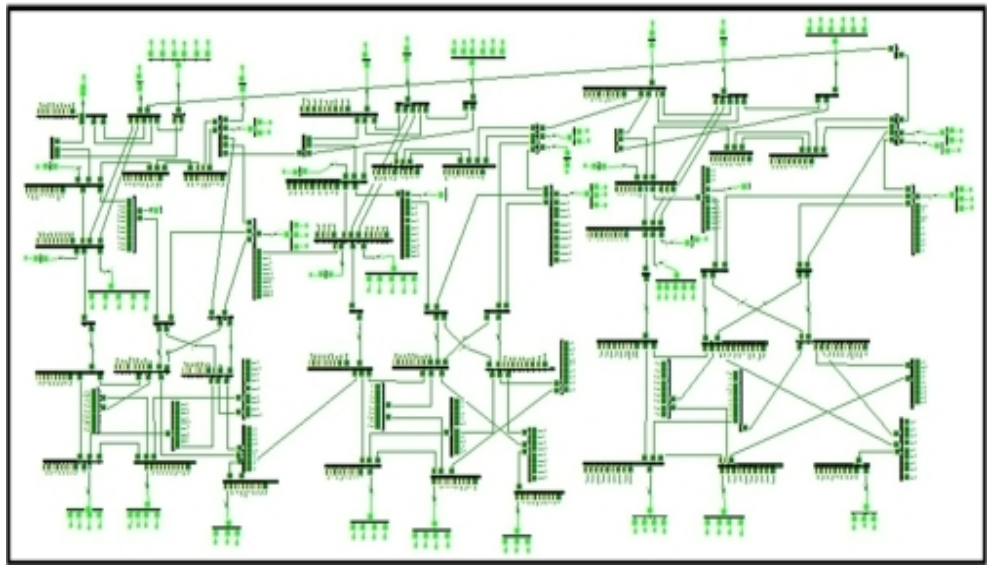
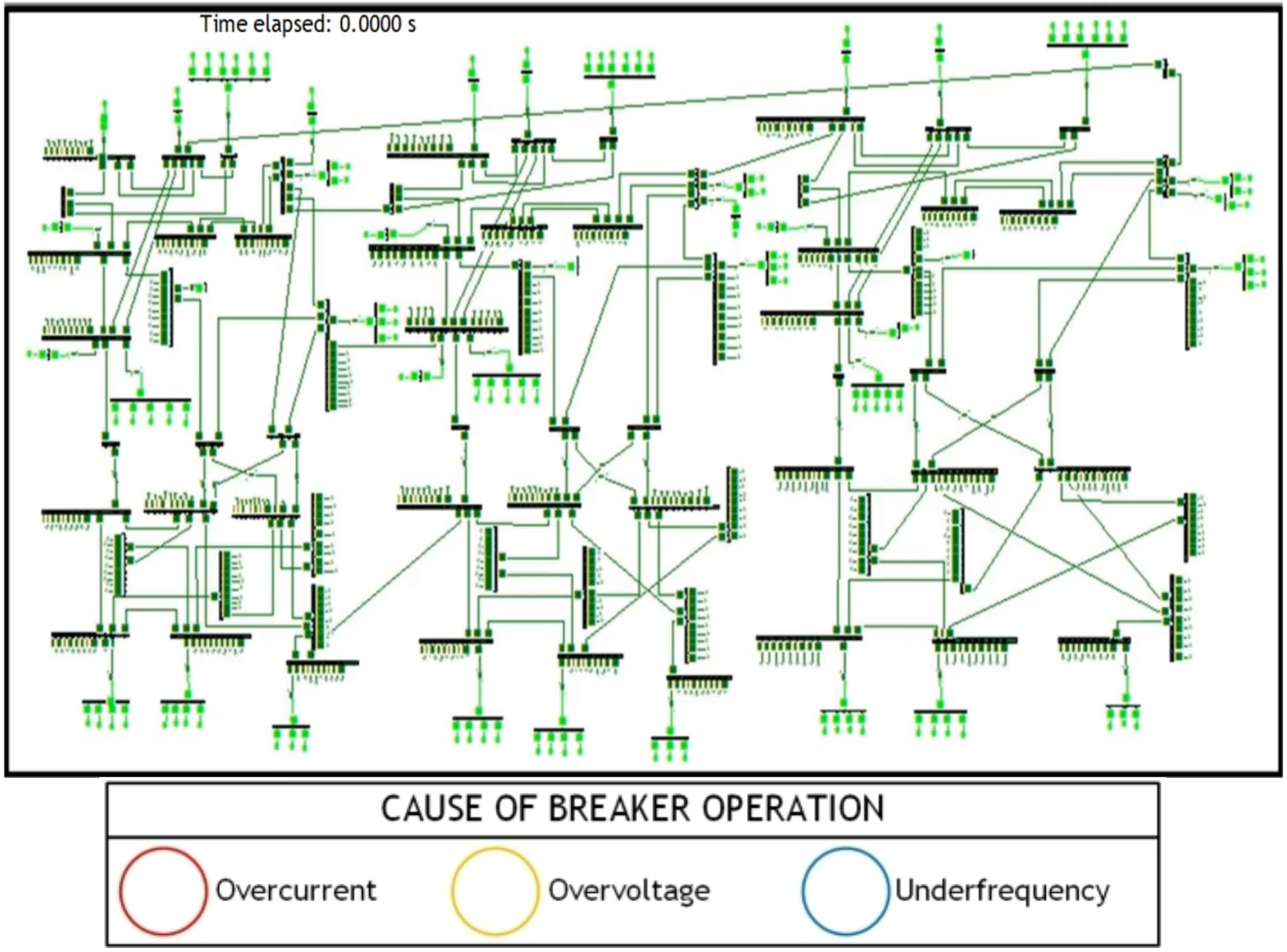


One-line diagram of RTS-96 model as seen in PSS®CAPE

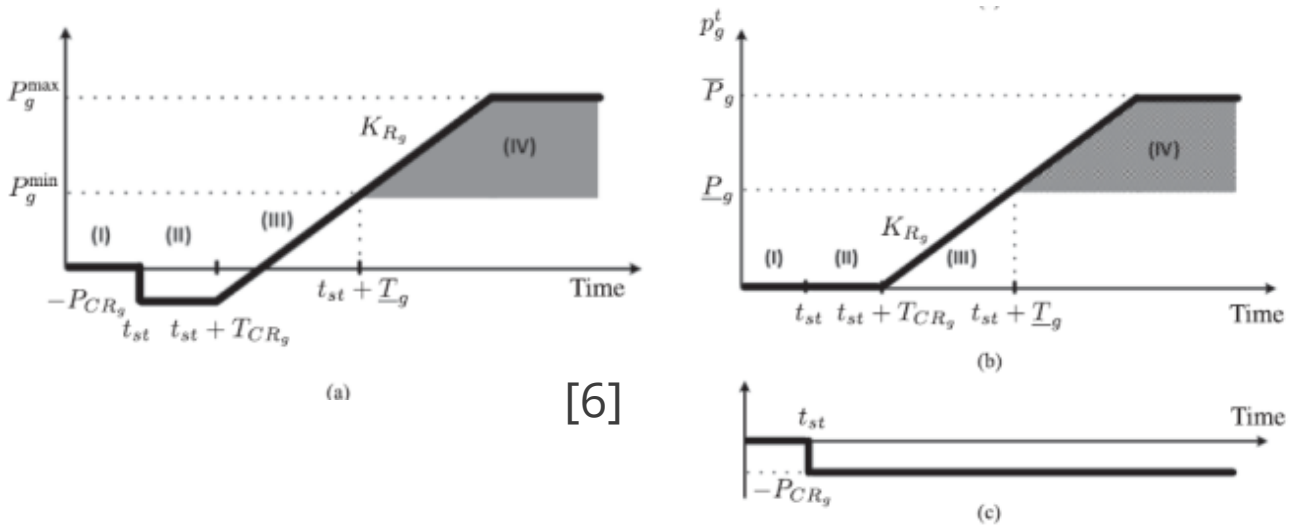
Demonstration of modeling capabilities

- Contingency: symmetrical midline faults on three branches
- Overall relay trip sequence:
  - Faulted branches (overcurrent)
  - Generators (overvoltage)
  - Generators (underfrequency)
  - Load (underfrequency)
- Simulation may inform (optimal) investment decisions
- Potential next steps:
  - IEEE 39-bus model for easier cascading without faults
  - Modeling in PSS®E alone



Features of initial formulation for mobile energy storage assisted black-start

- Techniques from prior art:
  - Modeling of generator output sequence for black-start (BS)
  - Modeling of time-space network
- Objective of formulation:
  - Total weighted load shed energy (e.g., VoLL)
  - Optionally, upgrading and operational costs
- Actions available:
  - Upgrading within budgets: select generators to gain BS capability, stationary energy storage systems (ESSs) to become mobile, buses to support ESS connections
  - Staging of mobile energy storage systems (MESSs) before blackout and routing/operation after blackout
  - Creating cranking paths from BS generators



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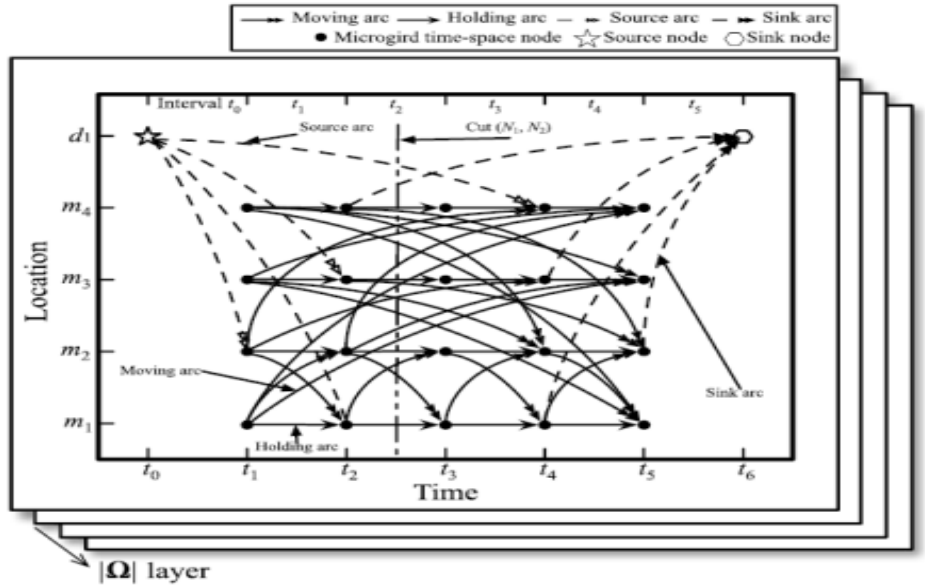

Fig. 1. A multi-layer time-space network for modeling temporal-spatial behavior of MESSs over the transportation network.

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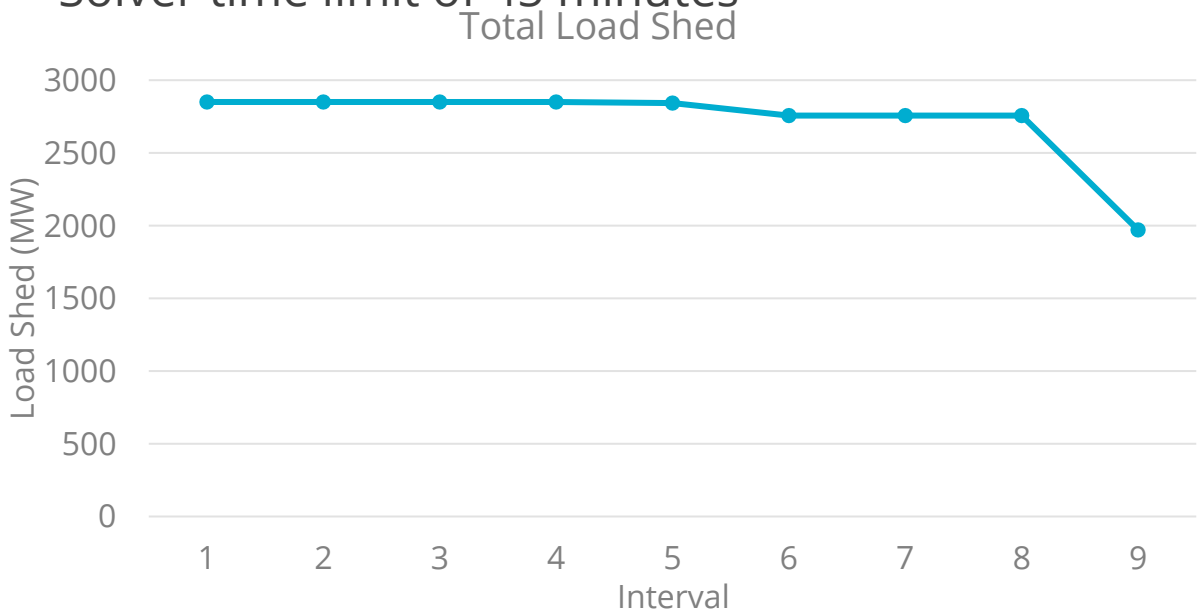
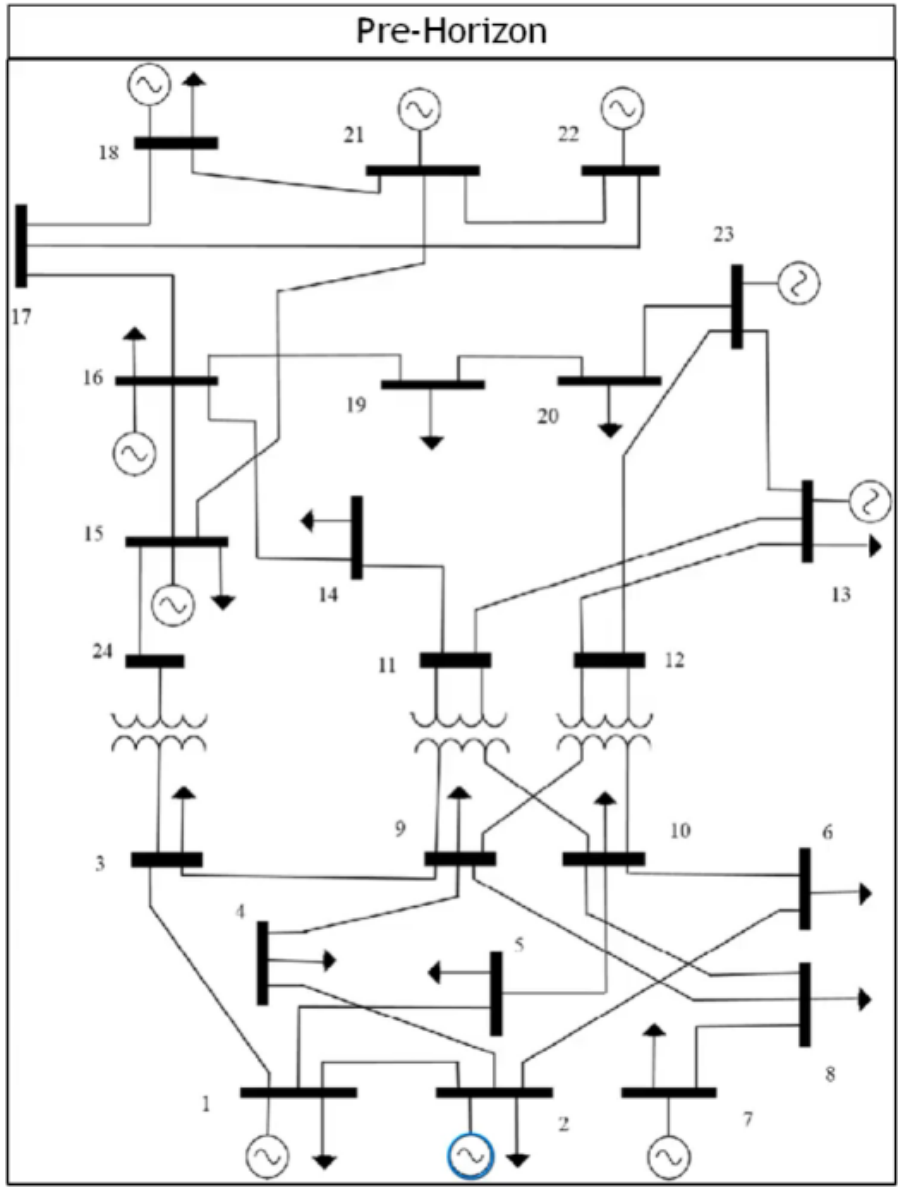
Sample results without energy storage systems

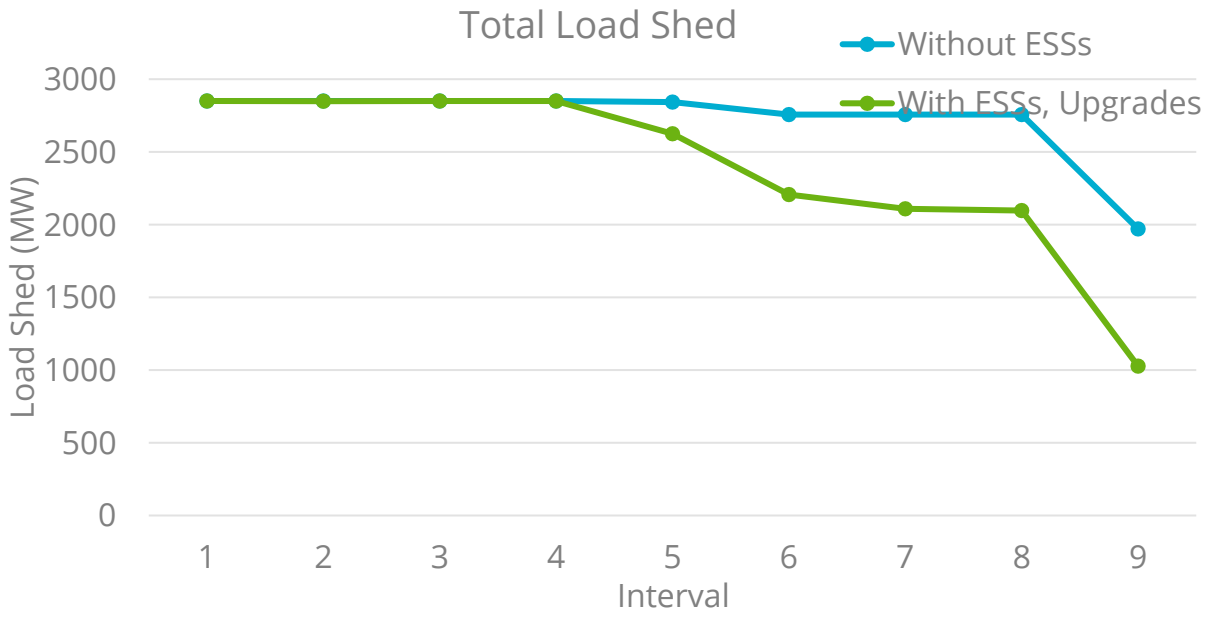
- IEEE 24-bus system (a third of IEEE RTS-96):
  - Total real load of 2850 MW, generation of 3000 MW
- Formulation instance settings (base case):
  - Horizon of nine 10-minute intervals, cranking duration of 30 minutes (i.e., 3 intervals)
  - Black-start (BS) capability on generators (172 MW total) at Bus 2
  - No energy storage systems (ESSs), no upgrades
  - Solver time limit of 45 minutes

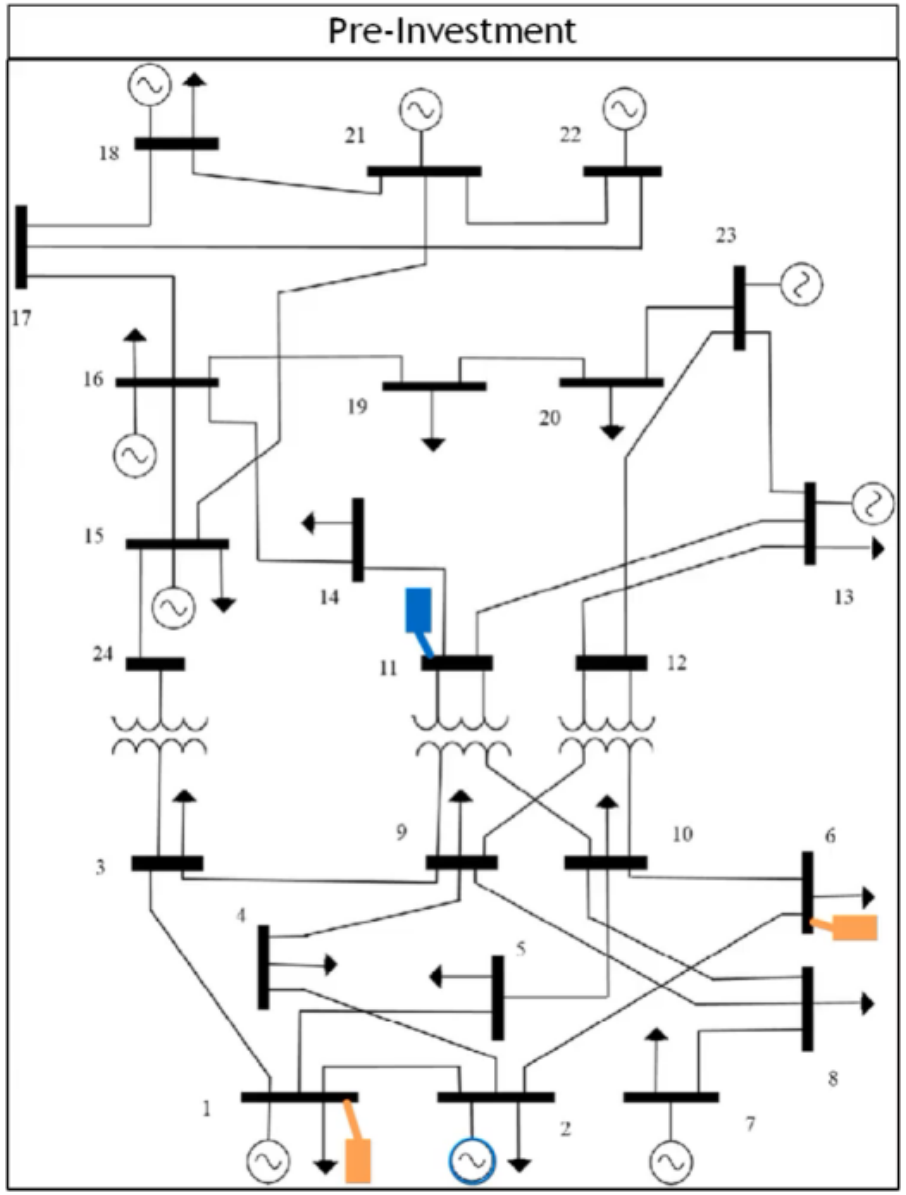




Sample results with energy storage systems and investments

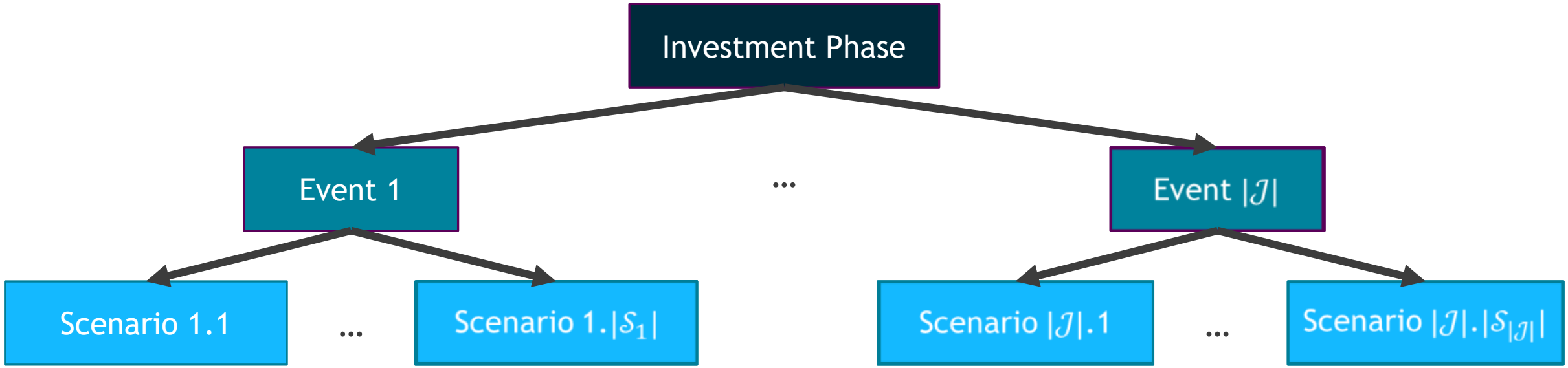
- Pre-upgrade resources:
  - Three energy storage systems (ESSs) (each rated 15 MVA, 10 MW, 50 MWh @ 50%): one mobile, two stationary
  - Black-start (BS) capability on generators (172 MW total) at Bus 2
- Upgrades permitted:
  - One stationary ESS can become mobile
  - 100 MW of generation capacity can gain BS capability
  - Solver time limit of 150 minutes





Possible paths forward for formulation

- Building on prior work to devise novel optimization modeling for black-start (BS) and mobile energy storage systems (MESS)
- Deciding on multi-stage structure:
  - First stage: investment phase
  - Second stage: pre-event preparation
  - Third stage: scenario-specific recourse
- Improving realism of BS optimization modeling
- Developing methods for improving solution time
- Accounting for BS of photovoltaic and wind generation, not just synchronous generators



Acknowledgments and closing

I would like to thank...

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Questions?

Thank you!

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