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Laboratory Scale FACTS Controller Development

Mariesa Crow
University of Missouri-Rolla

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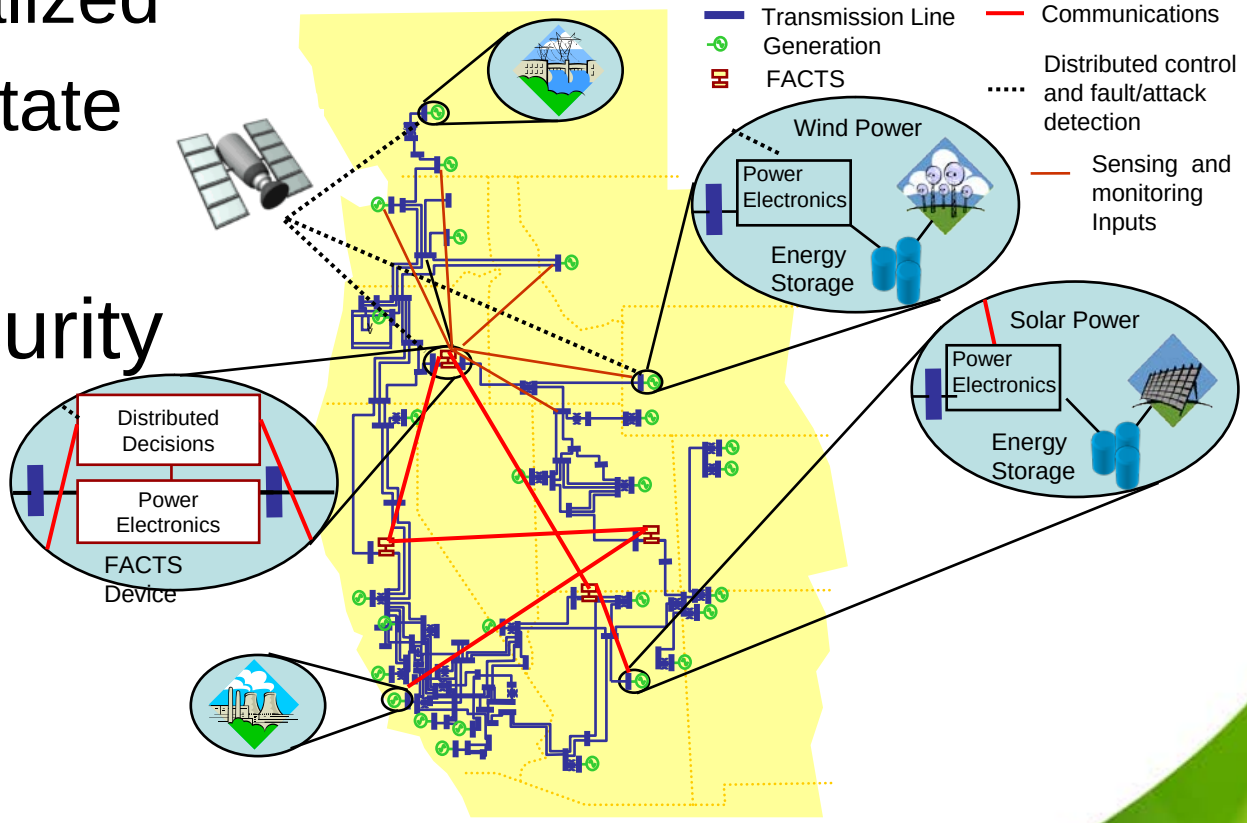
Issues

- Hardware-software co-design
- Device placement and control
  - Decentralized
  - Steady-state
  - Dynamic
- Cyber security
- Reliability



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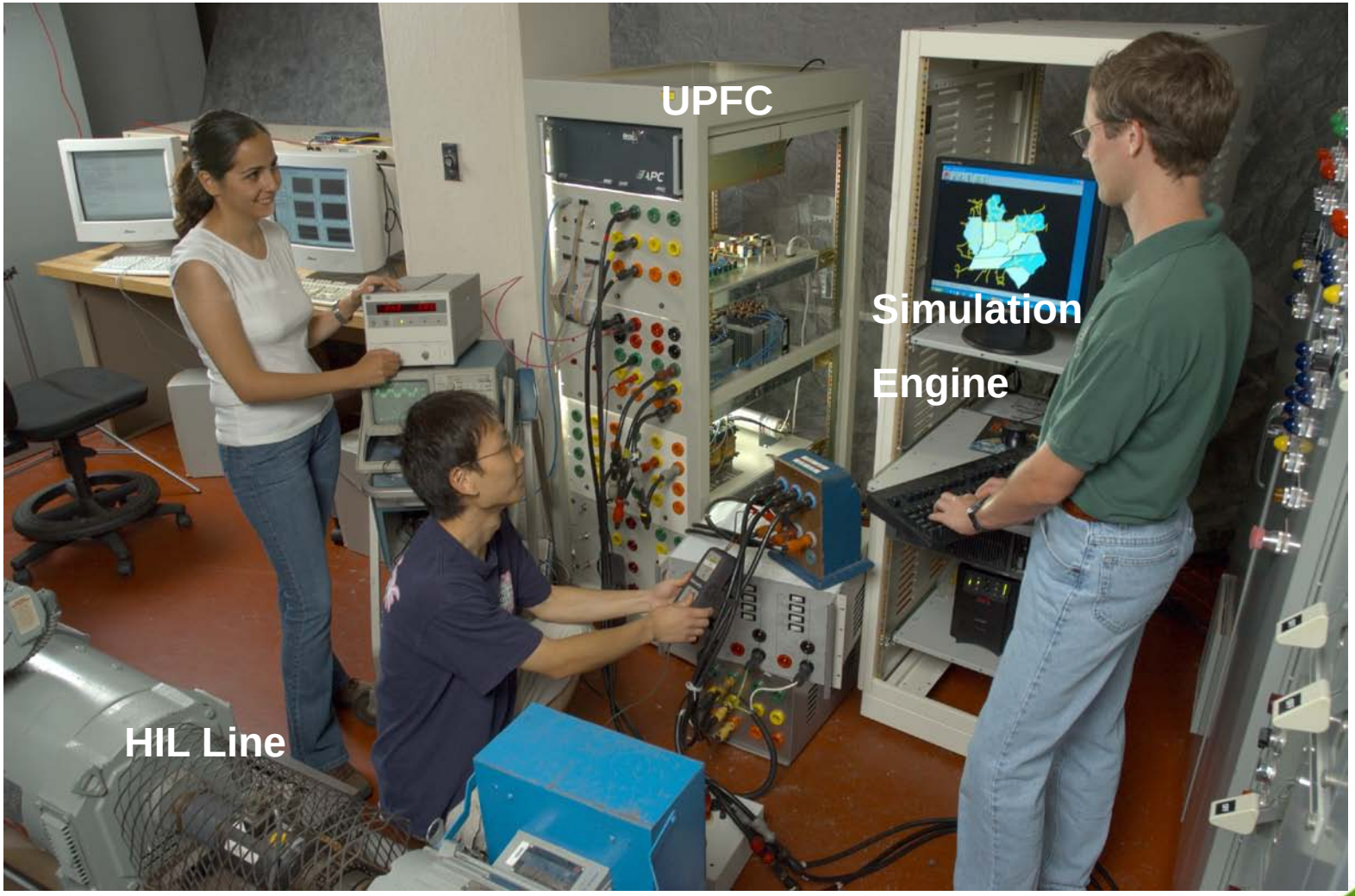
FACTS Interaction Laboratory



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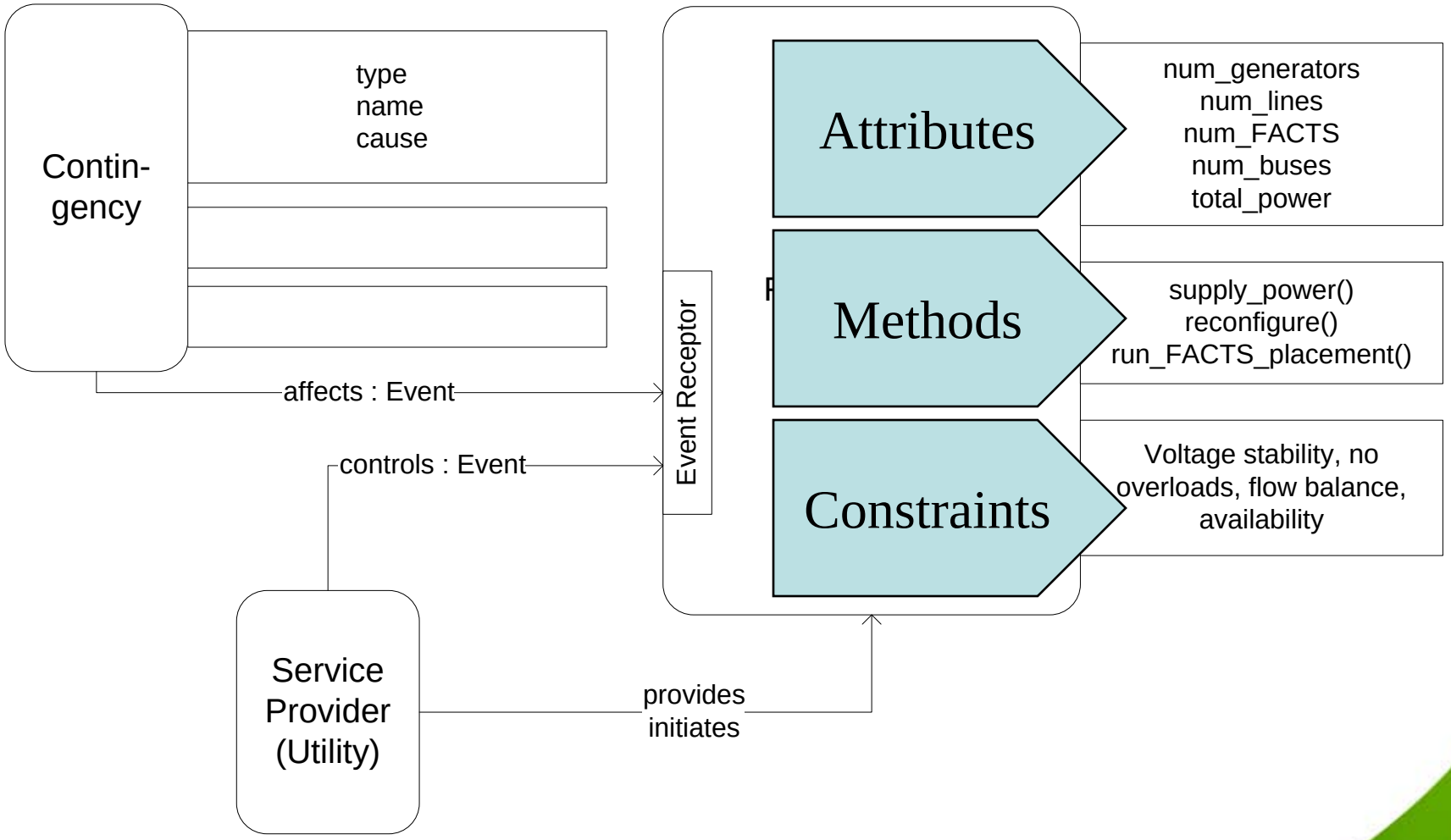
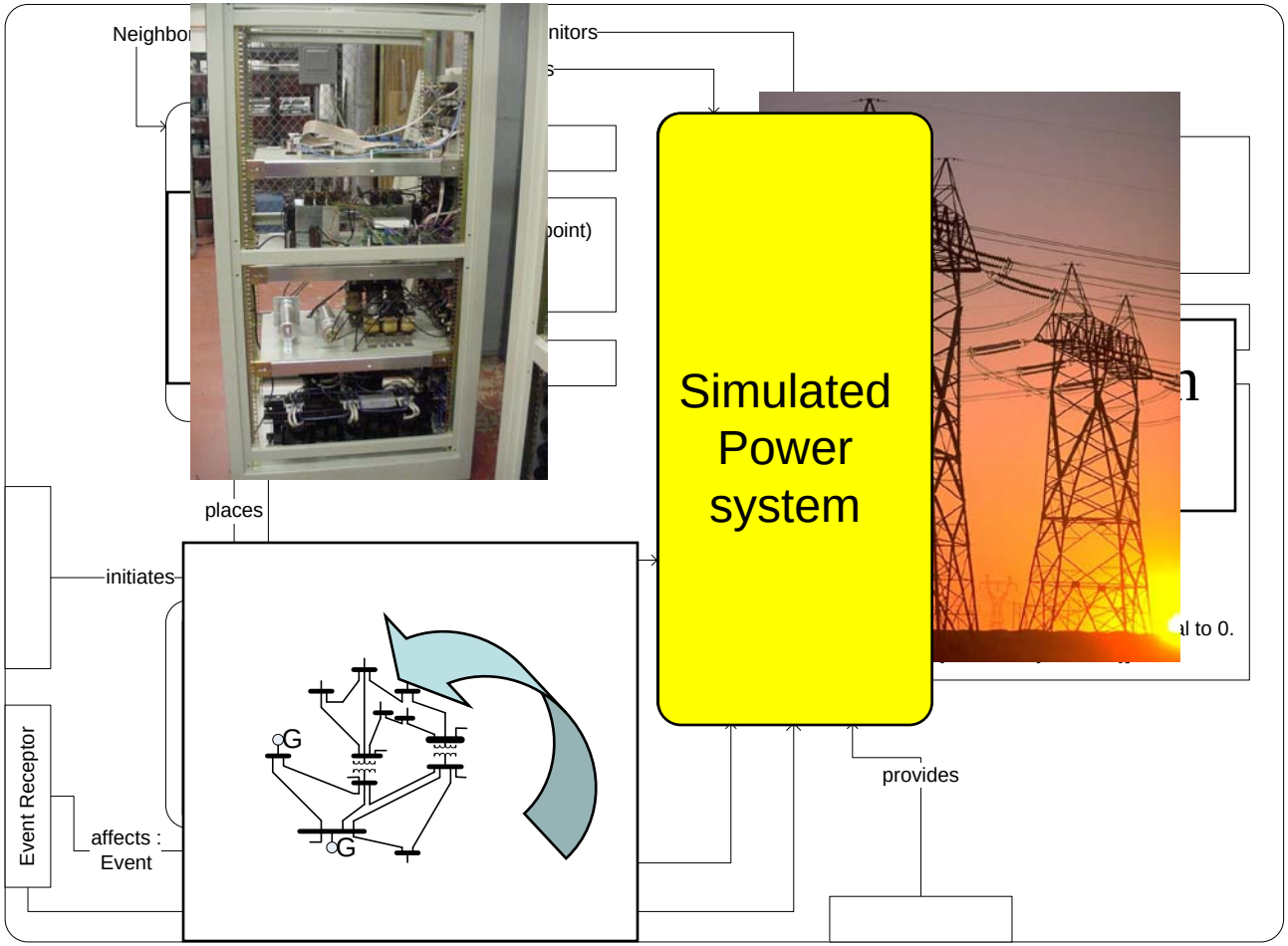
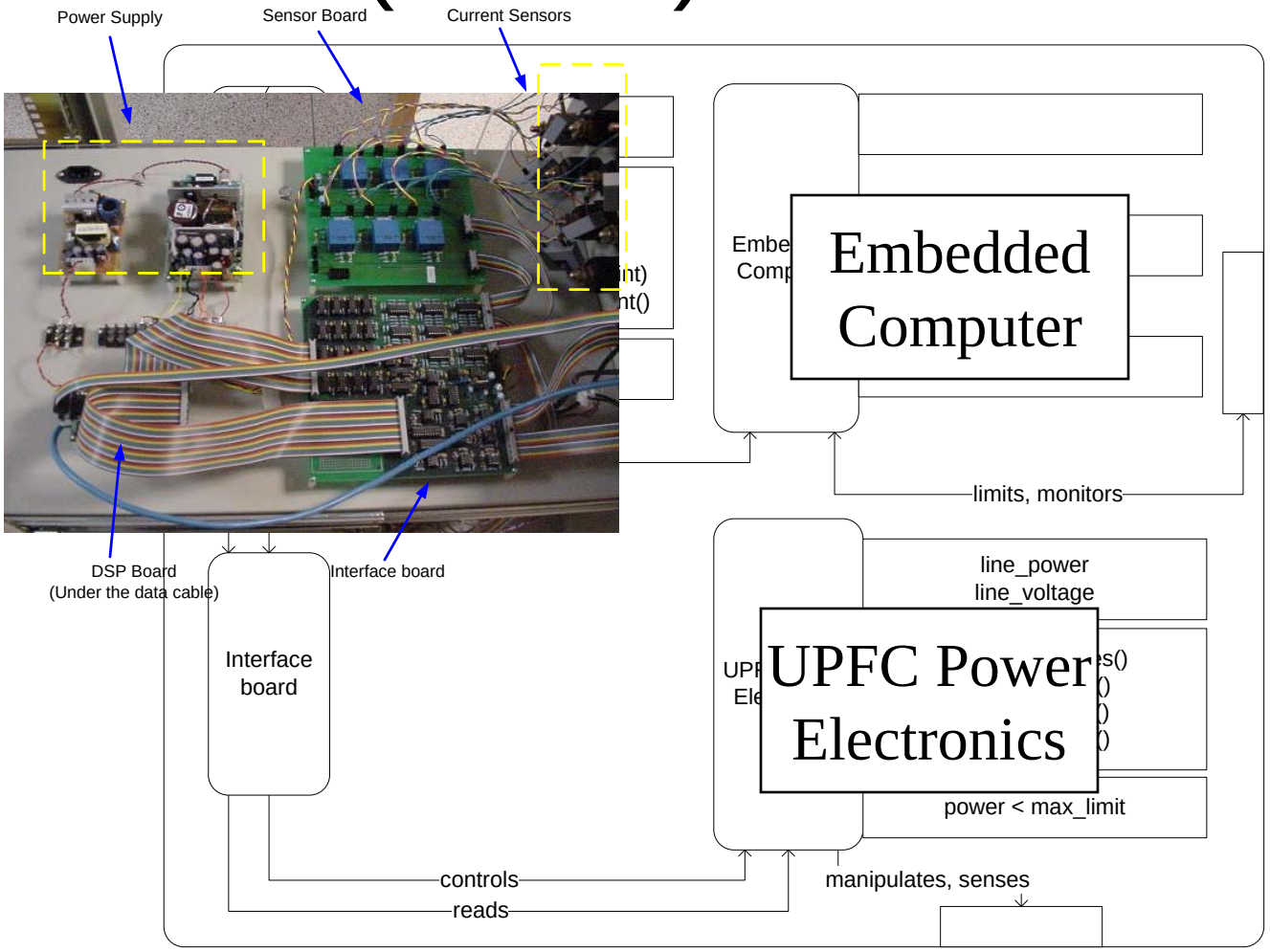
FACTS Power System Model



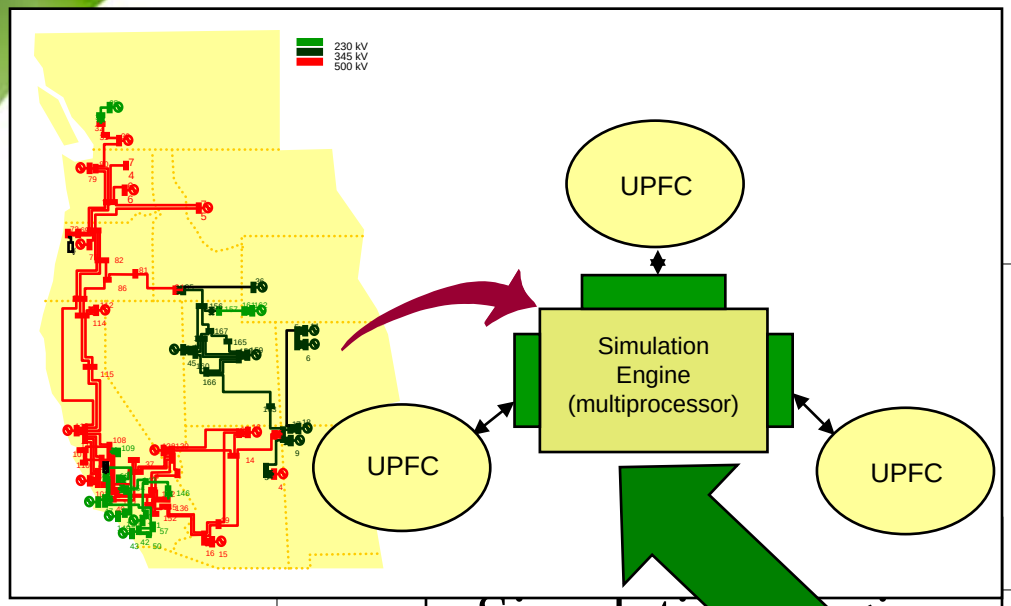
First Decomposition



Unified Power Flow Controller (UPFC) FACTS



Simulated Power Transmission System



UPFC

Simulation Engine (multiprocessor)

UPFC

UPFC

senses

generation_setpoint

Hardware in the Loop Line

Simulation Engine

limits, monitors

Machine 1

D/A output

A/D input

UPFC 1

Programmable load

Machine 2

D/A output

A/D input

UPFC 2

Programmable load

Machine 3

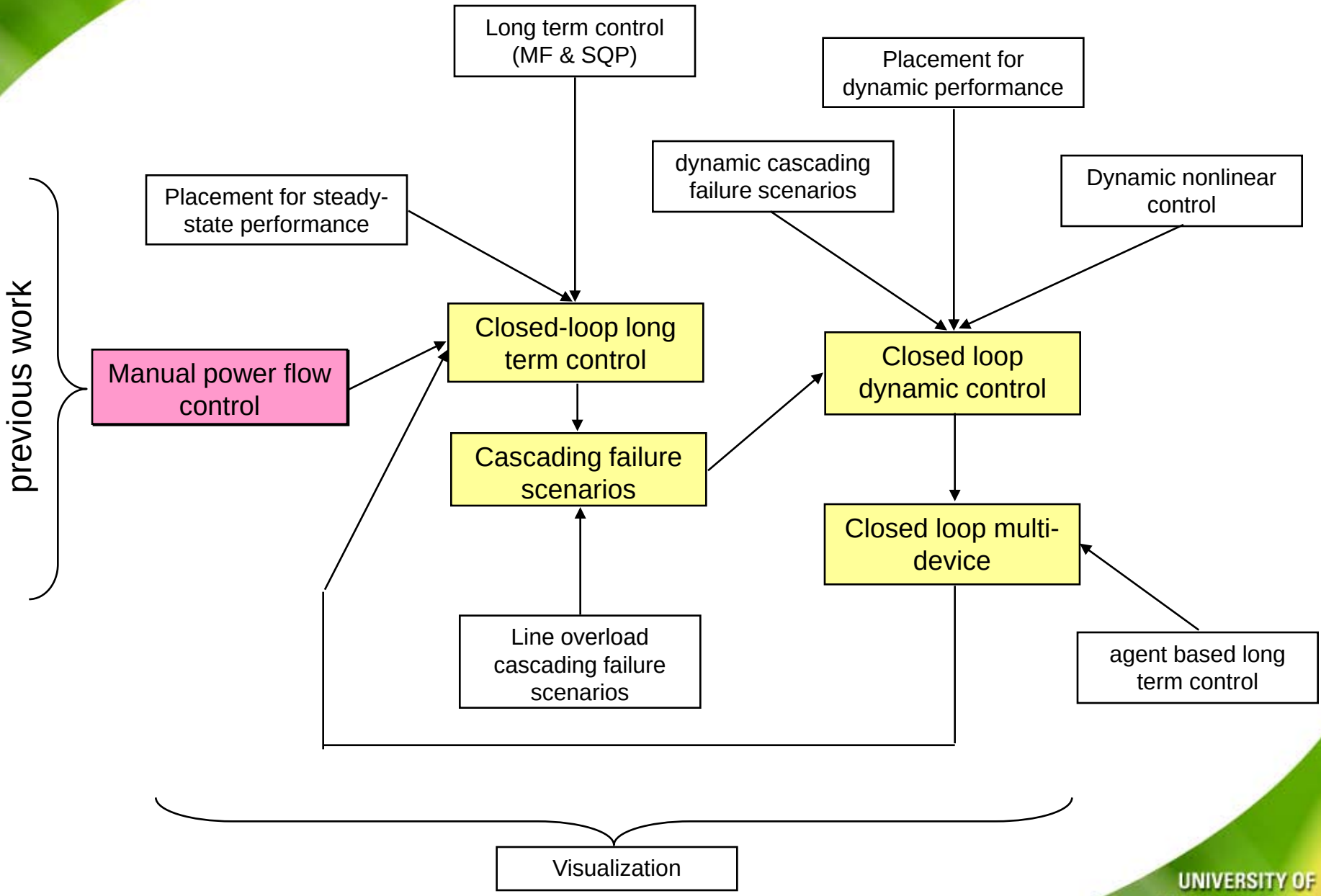
D/A output

A/D input

UPFC 3

Programmable load

Power System Simulation Engine


Long term control (MF & SQP)
Placement for dynamic performance
dynamic cascading failure scenarios
Dynamic nonlinear control
Placement for steady-state performance
previous work
Manual power flow control
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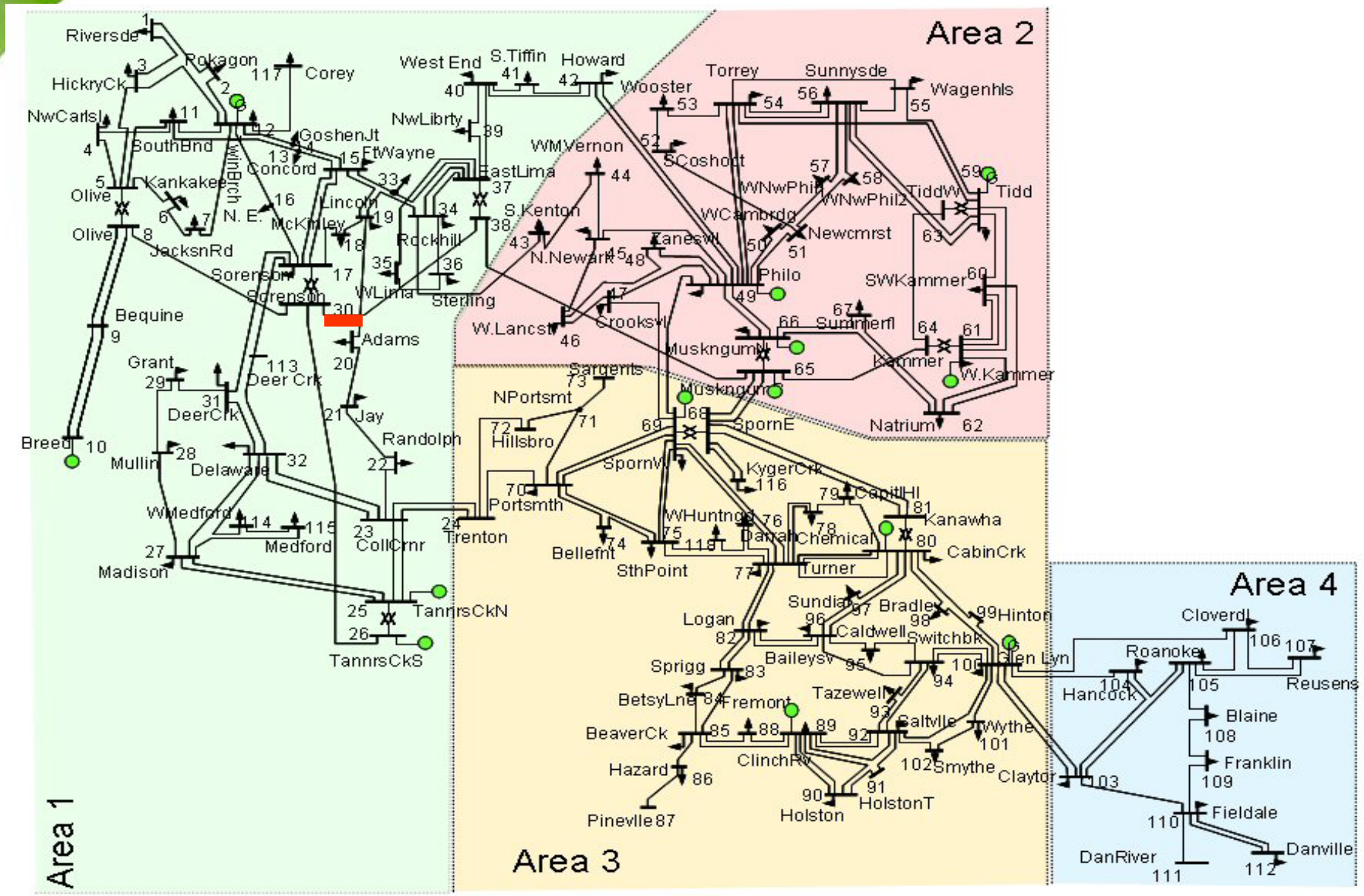
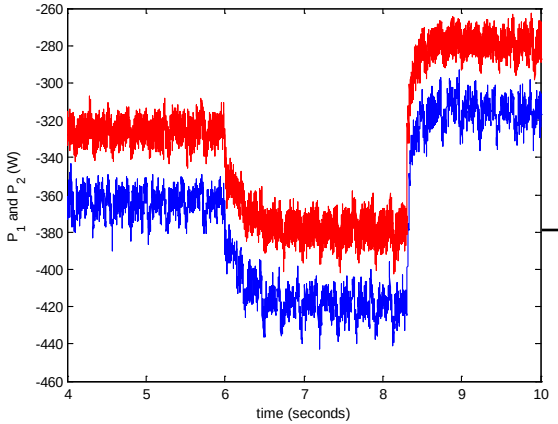
Visualization

IEEE 118 Bus Test System

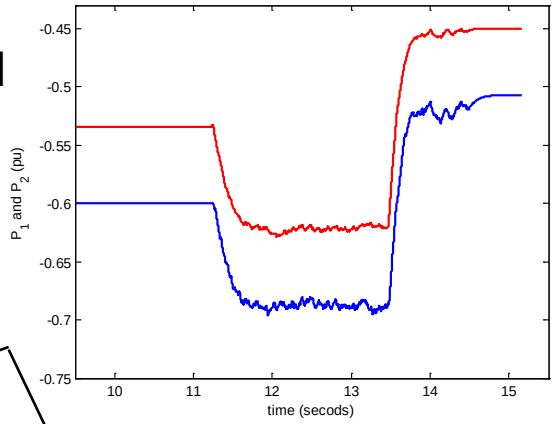


Manual Power Flow Control

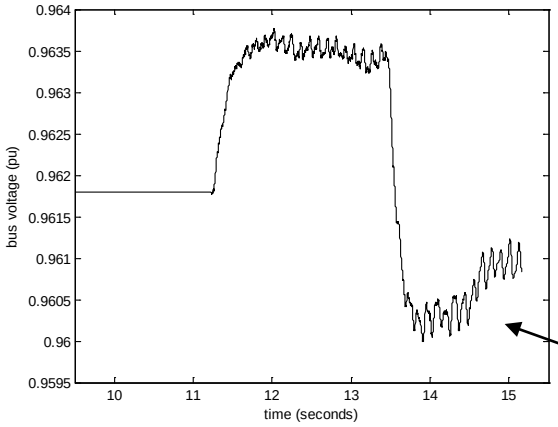
actual UPFC power flows

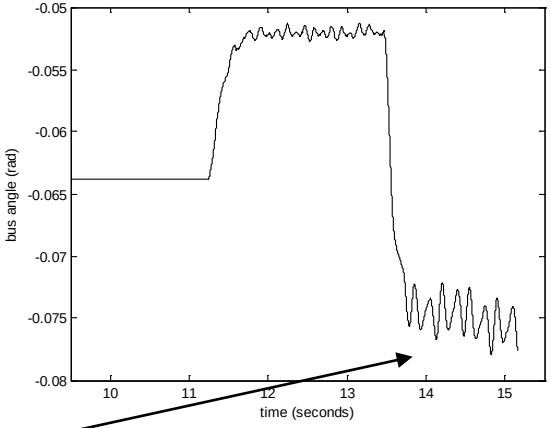


measured and filtered into simulation

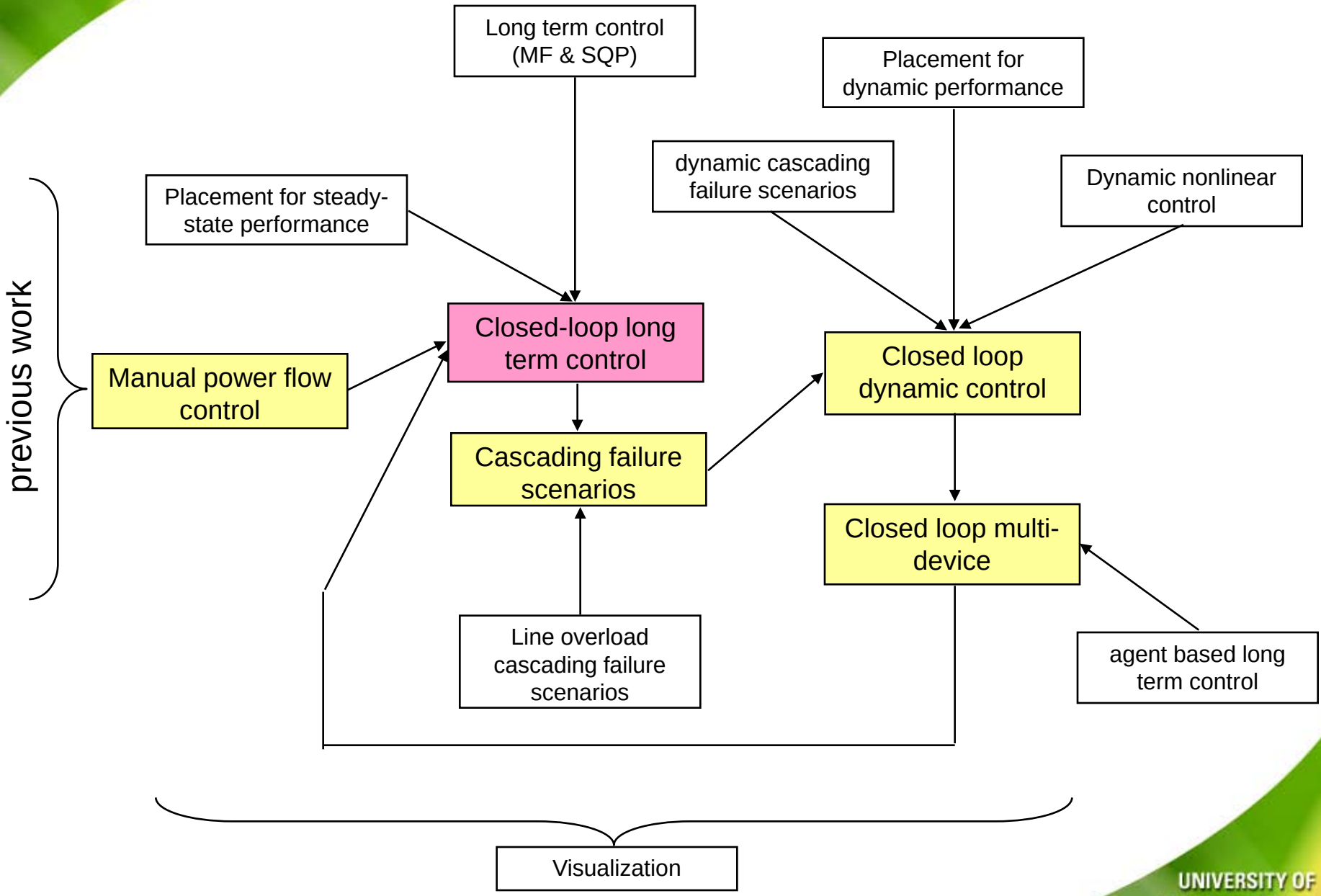


simulated bus voltages & angles





Note induced low frequency oscillations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Closed-loop long term control

- Which placements and settings yield the lowest PI over all possible contingencies?

Performance Index

$$PI = \sum_{SLC} \sum_{all\ Lines} \left(\frac{S_i}{S_i^{\max}} \right)^2$$

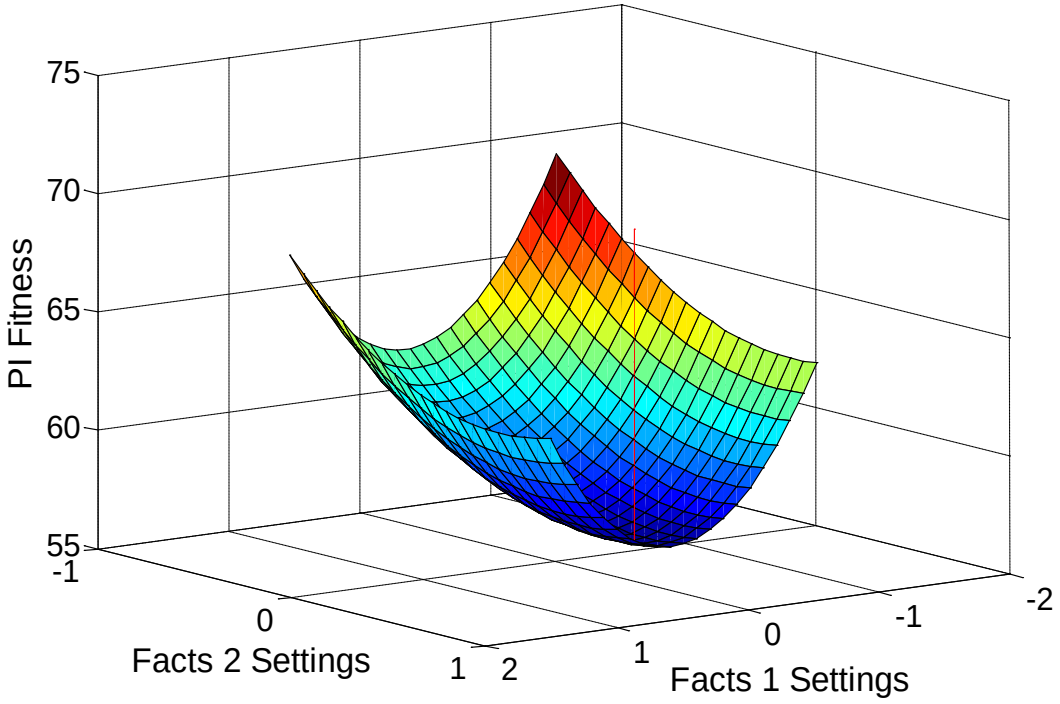
S_i – Power flow on line (MVA)

S^i_{max} – Rating of the line

SLC – Single Line Contingency

PI distributes line loadings as higher loadings incur heavier penalties than lower loadings

Optimal Setting for a Single Contingency

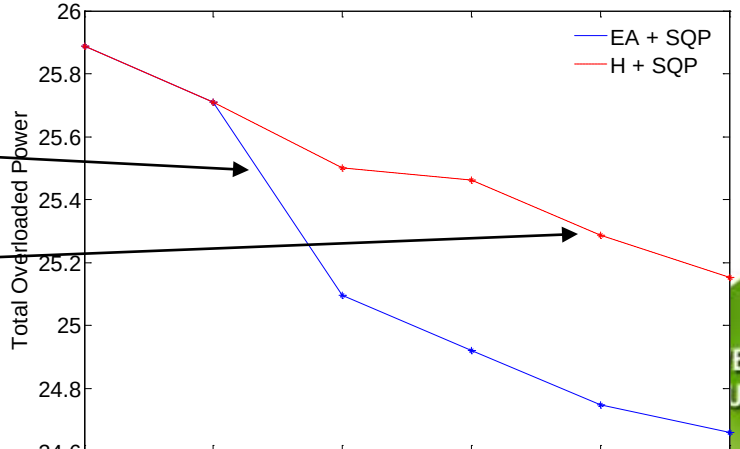


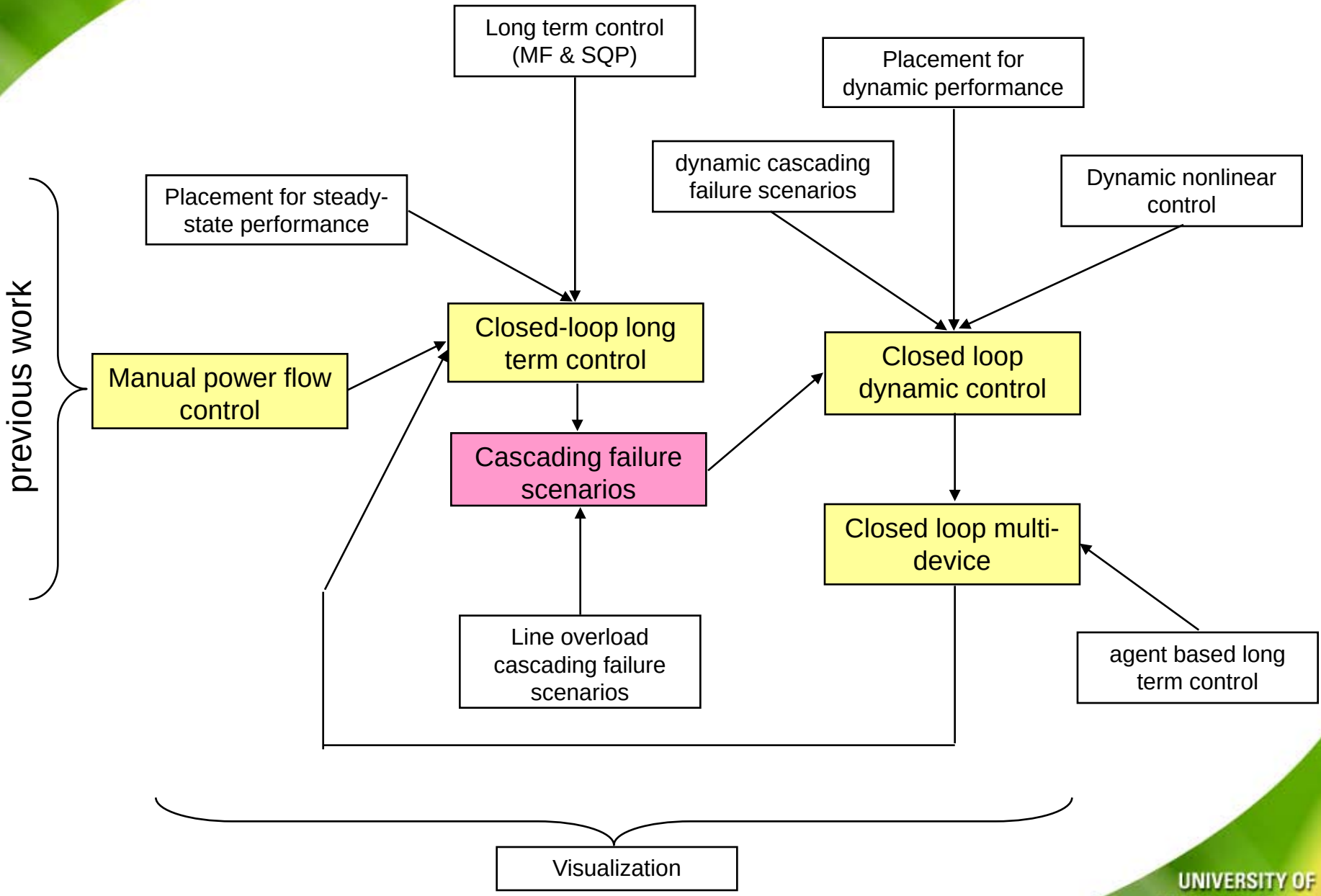
Degrees of Freedom:

- Number of FACTS devices
- Settings
- Placements

across the set of all contingencies

Evolutionary Algorithm
vs.
Pruned Brute Force (Heuristic)

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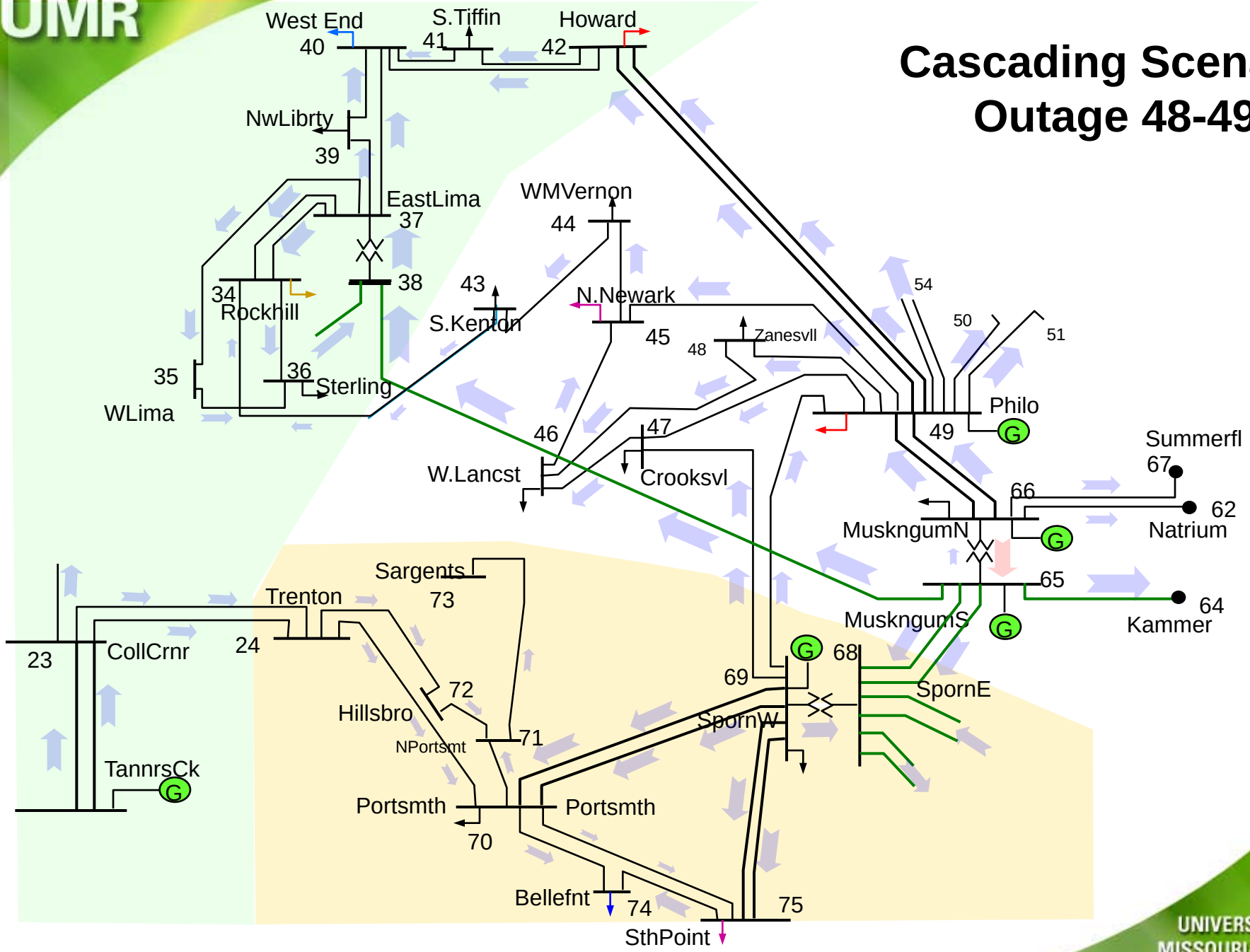
Cascading Scenario
Outage 48-49



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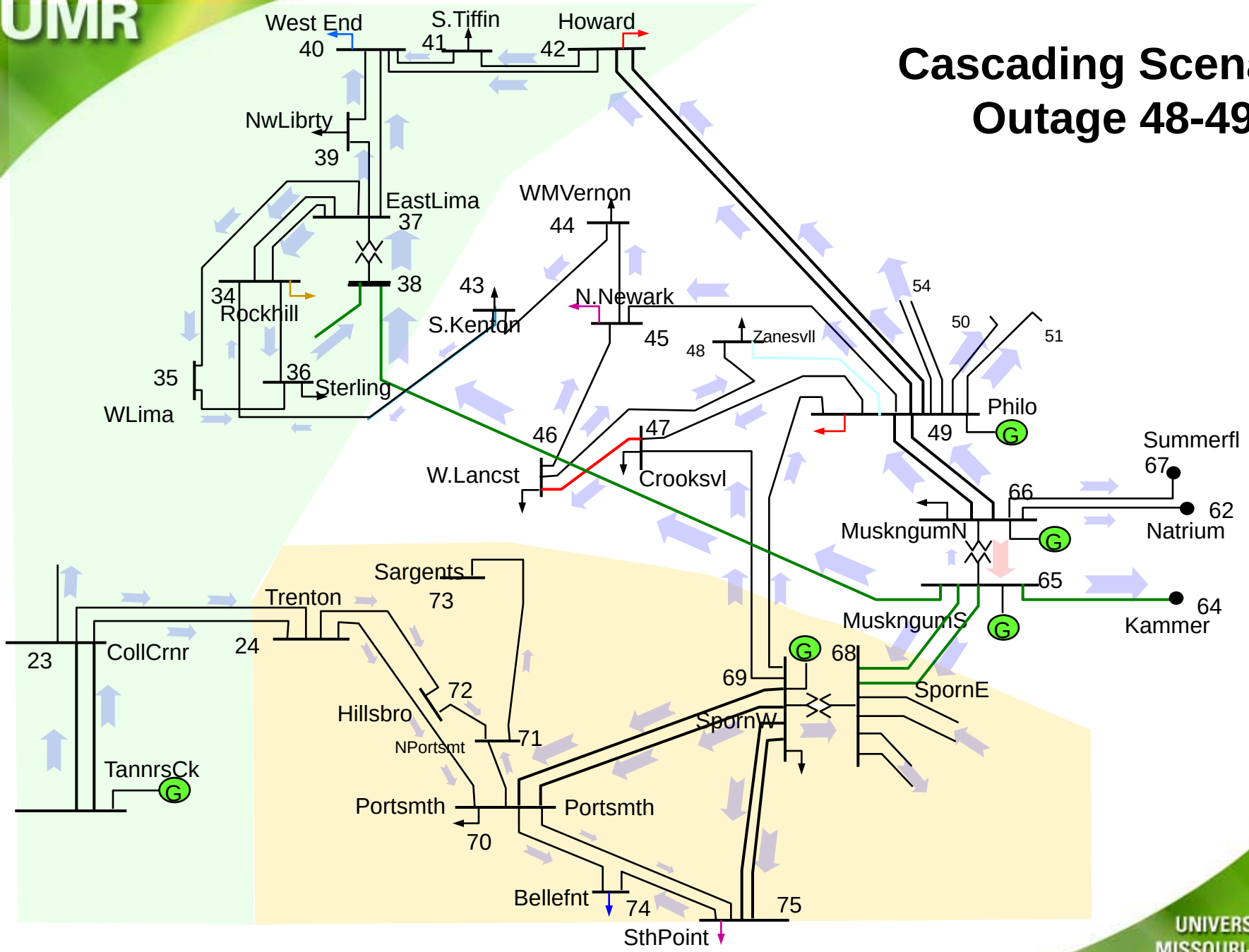

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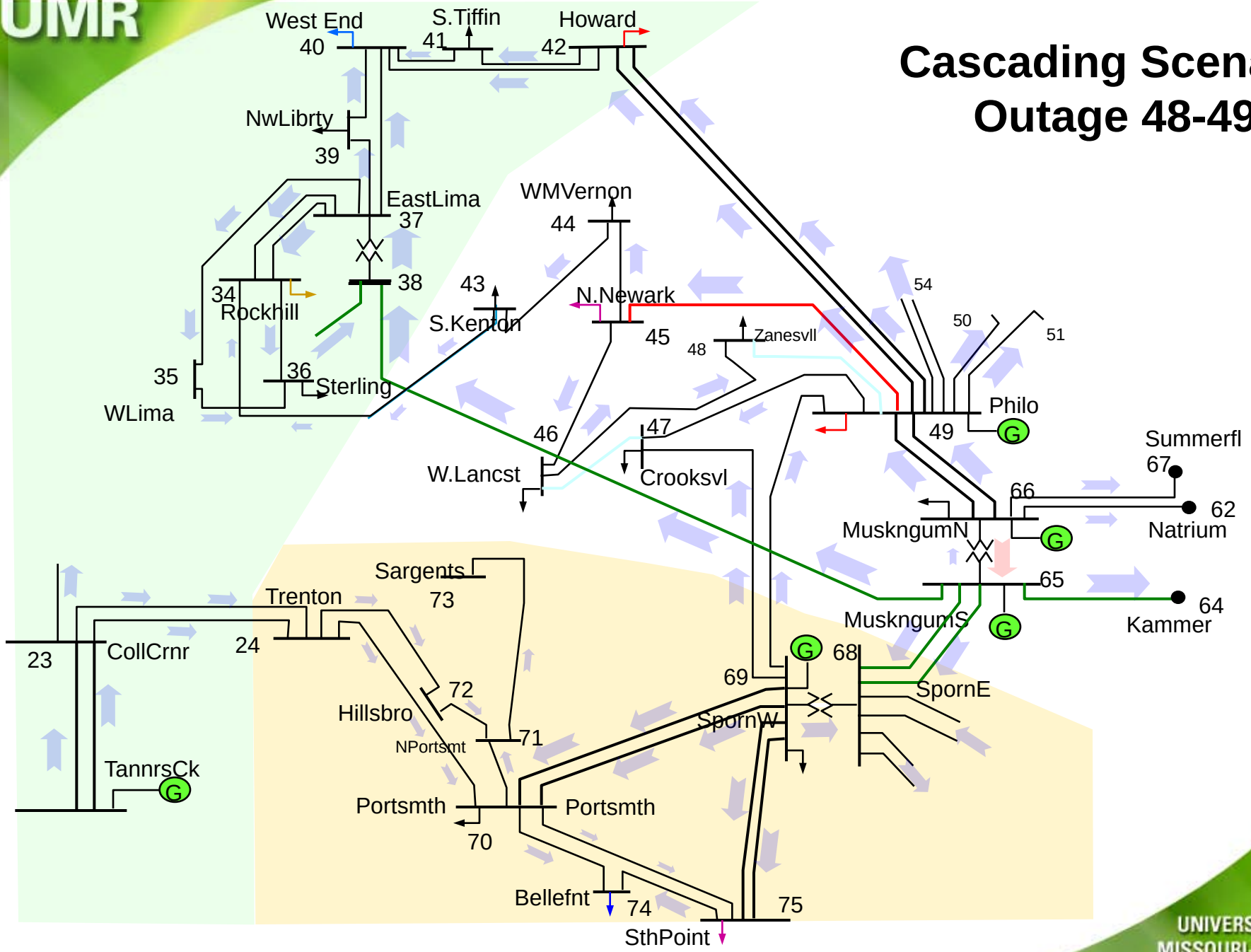

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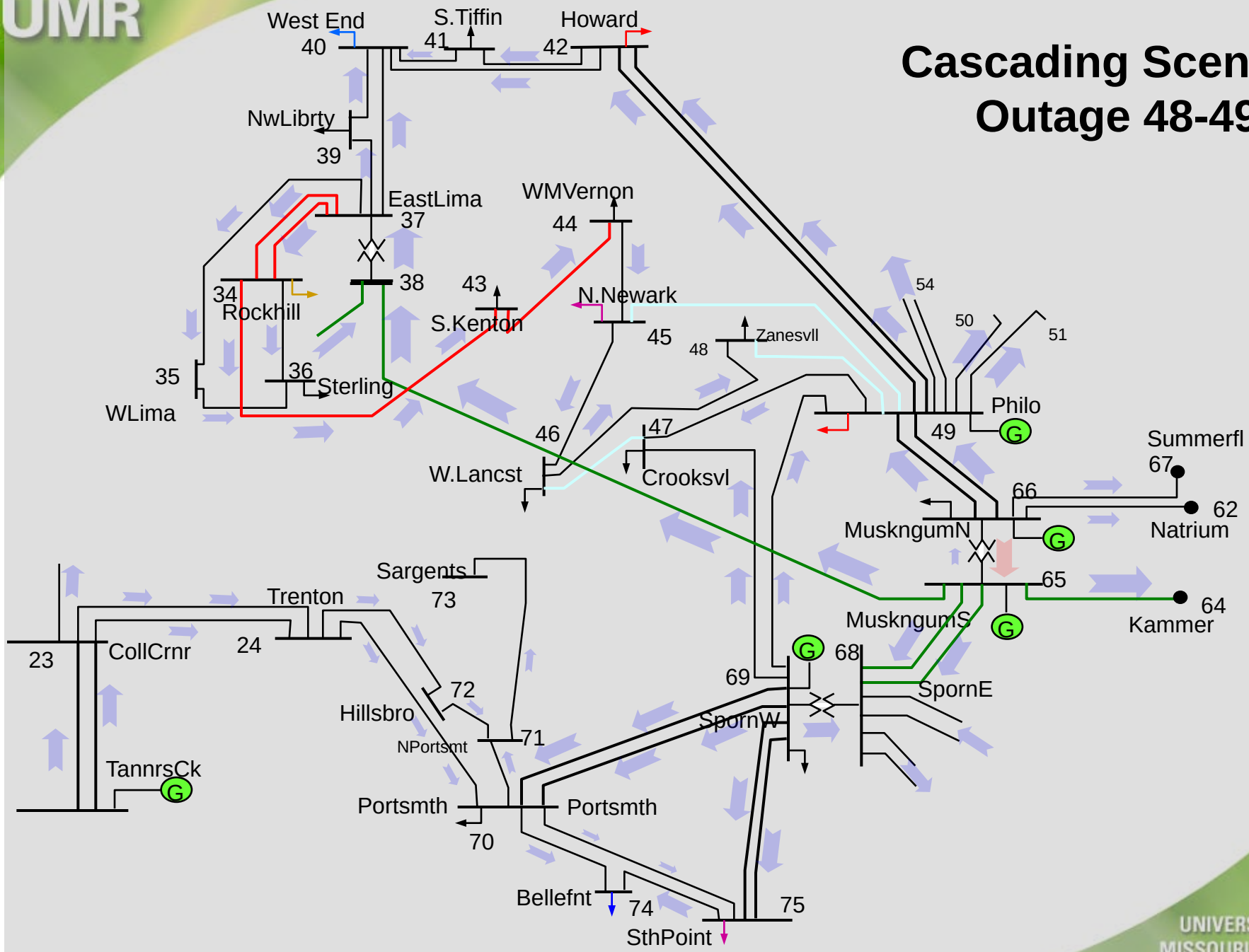

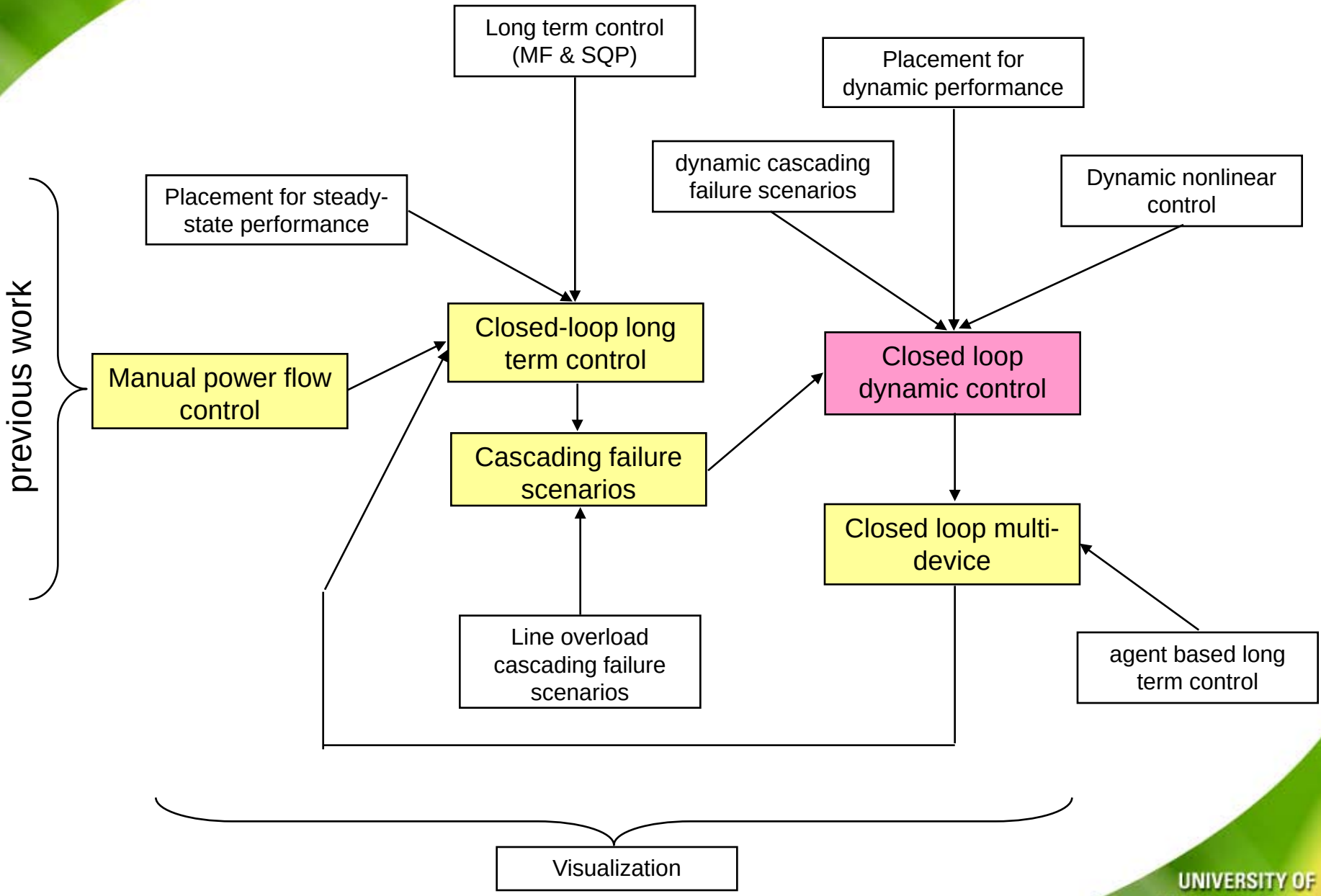
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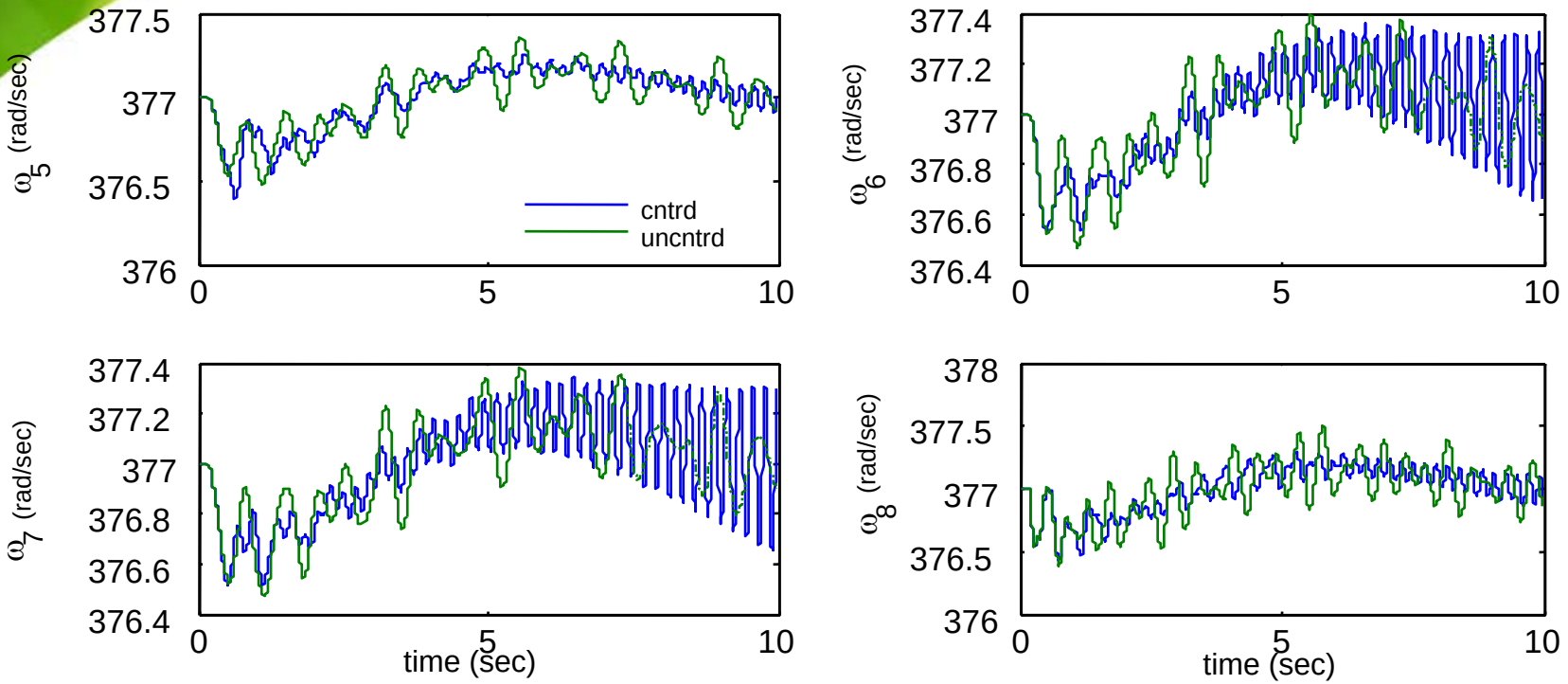
Two devices – uncoordinated control design – local information only



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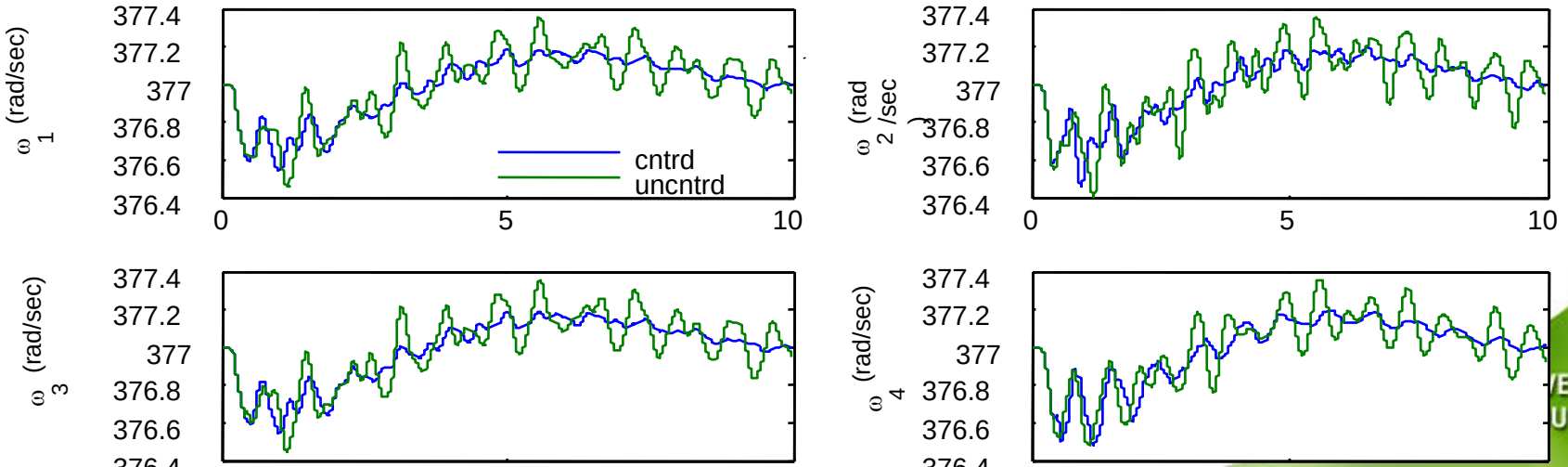
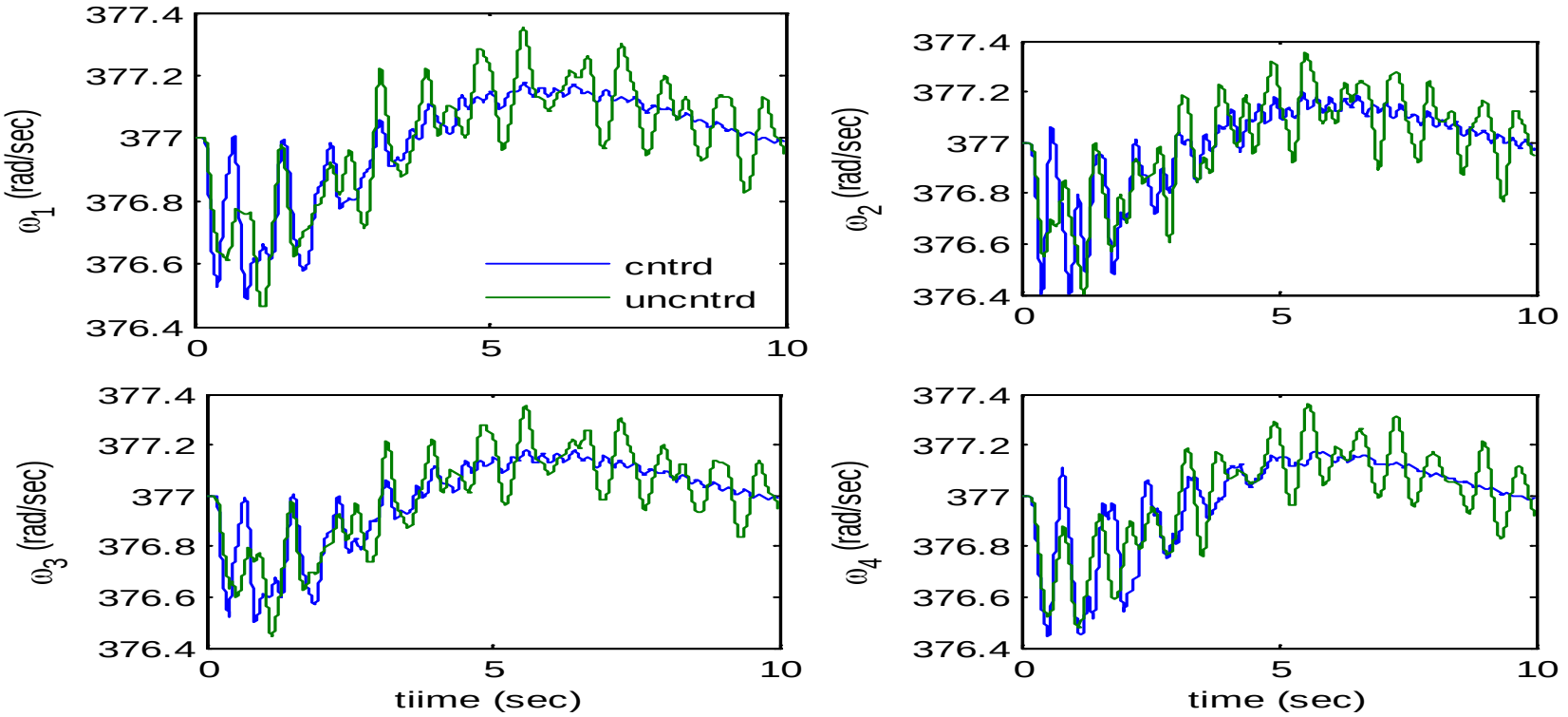
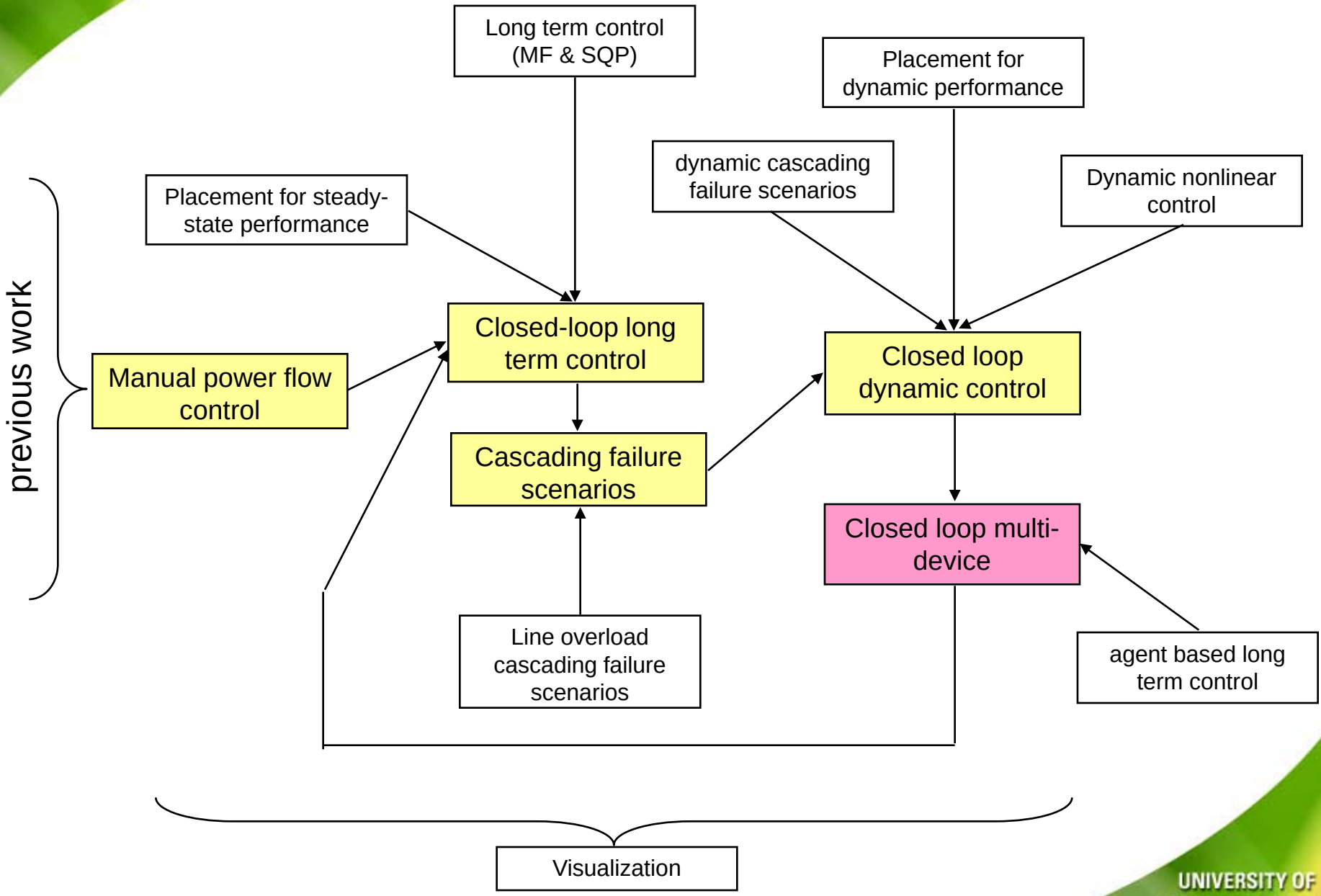


Two devices – H_∞ uncoordinated control design – tie line information only

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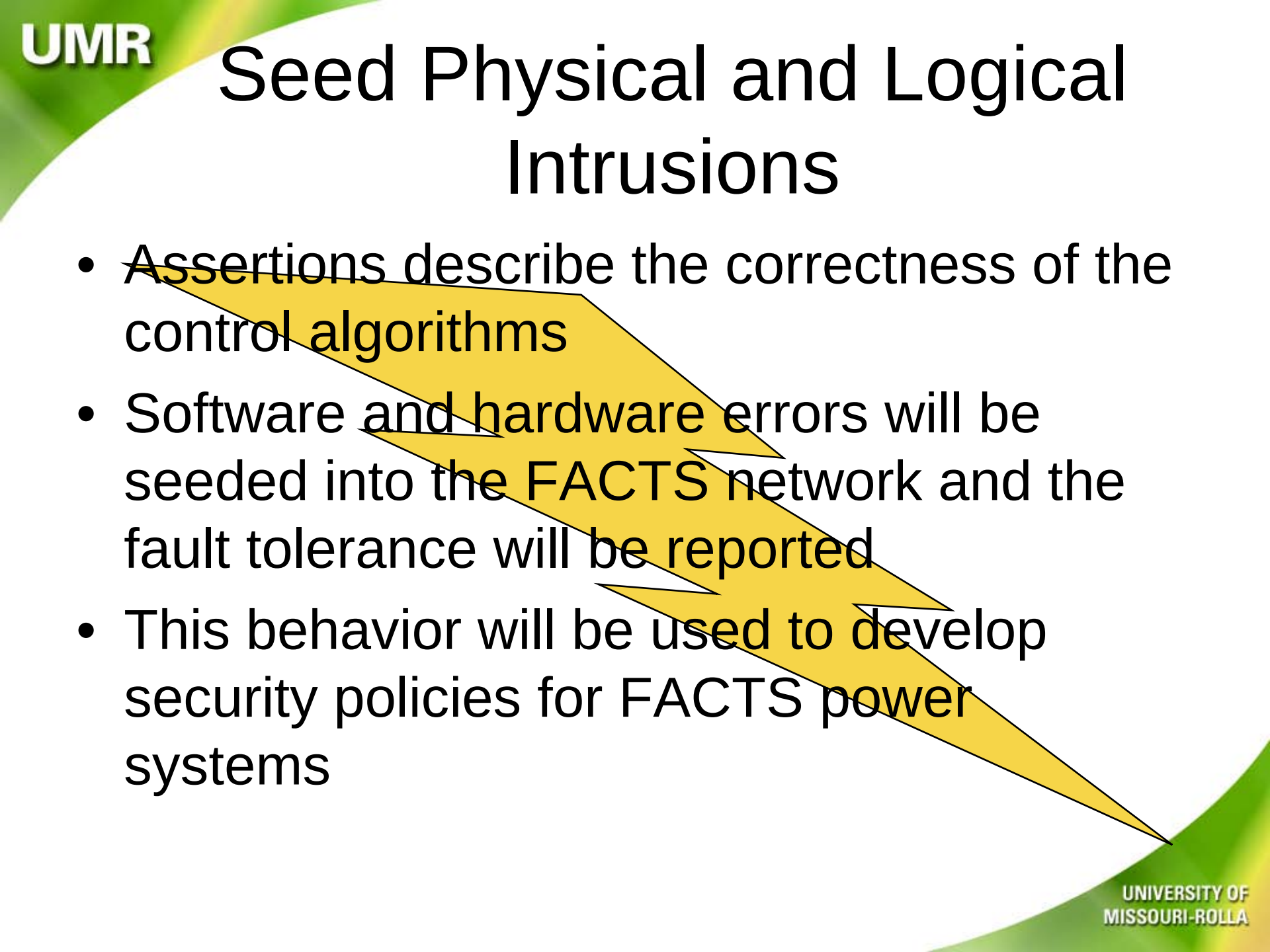
Seed Physical and Logical Intrusions

- Assertions describe the correctness of the control algorithms
- Software and hardware errors will be seeded into the FACTS network and the fault tolerance will be reported
- This behavior will be used to develop security policies for FACTS power systems



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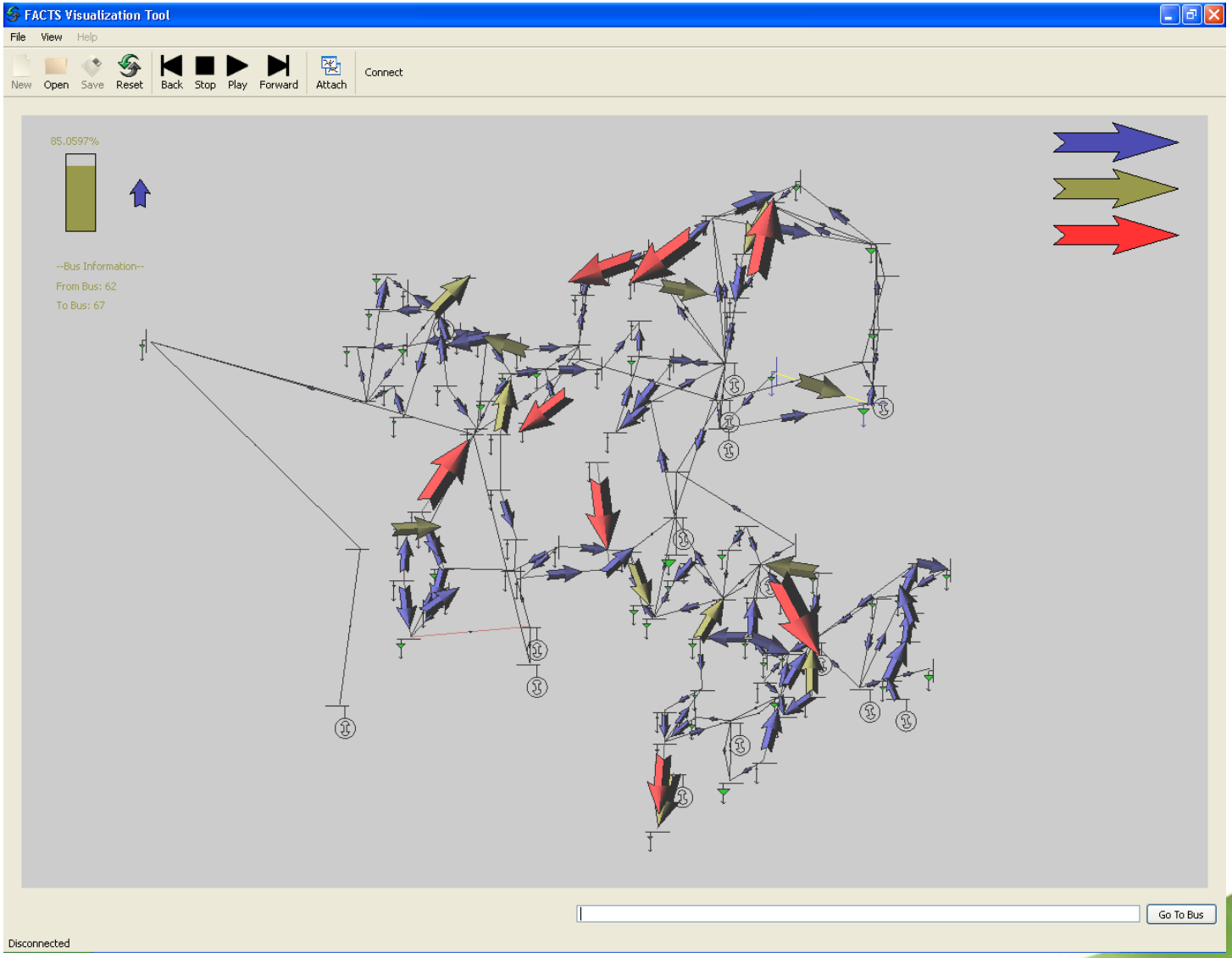
Visualization



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- John Boyes - Sandia National Laboratories