Resilient and Sustainable Interdependent Electric Power and Communications Systems

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Project Objectives

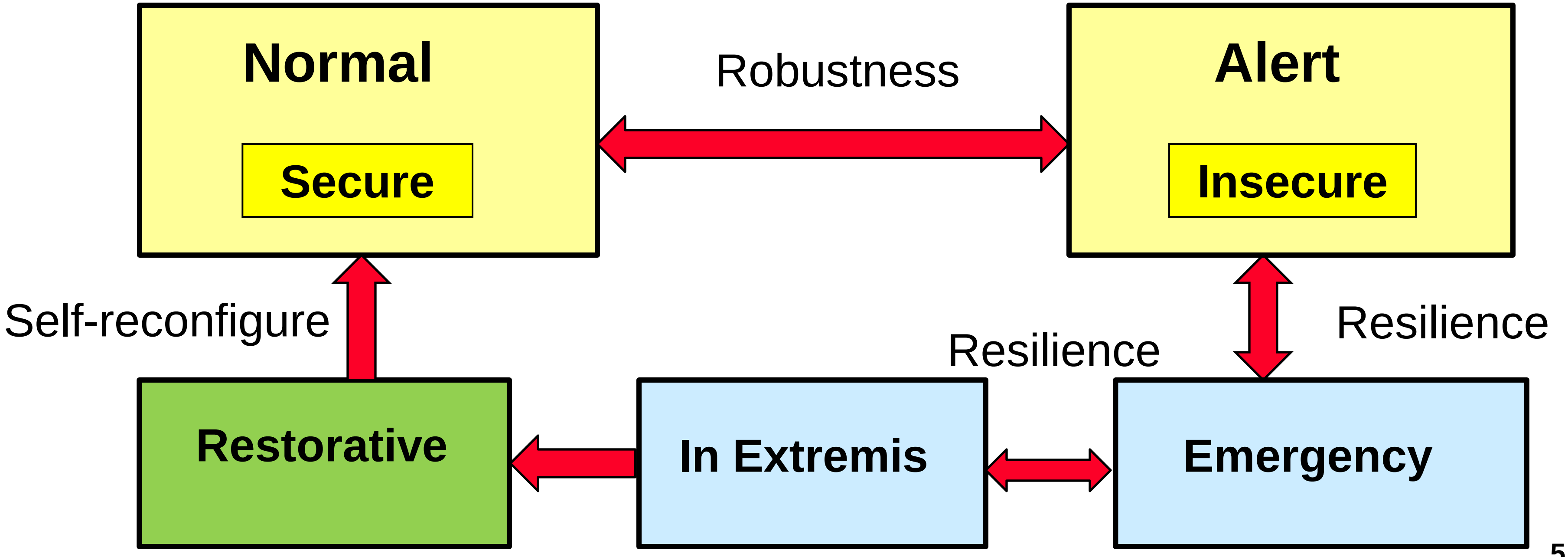
- Develop a risk management approach to optimally placing resources across interdependent electric power and communications infrastructures to mitigate cascading failures.

- Develop distributed multi-agent schemes to control a host of microgrids that are operated by businesses interacting in vibrant retail markets providing incentives for energy savings and survivability.

- Develop the theoretical foundations of a two-level Sustainability Assessment Framework (SAF) that makes use of indicators based on resilience, sustainability, social and economical indicators.

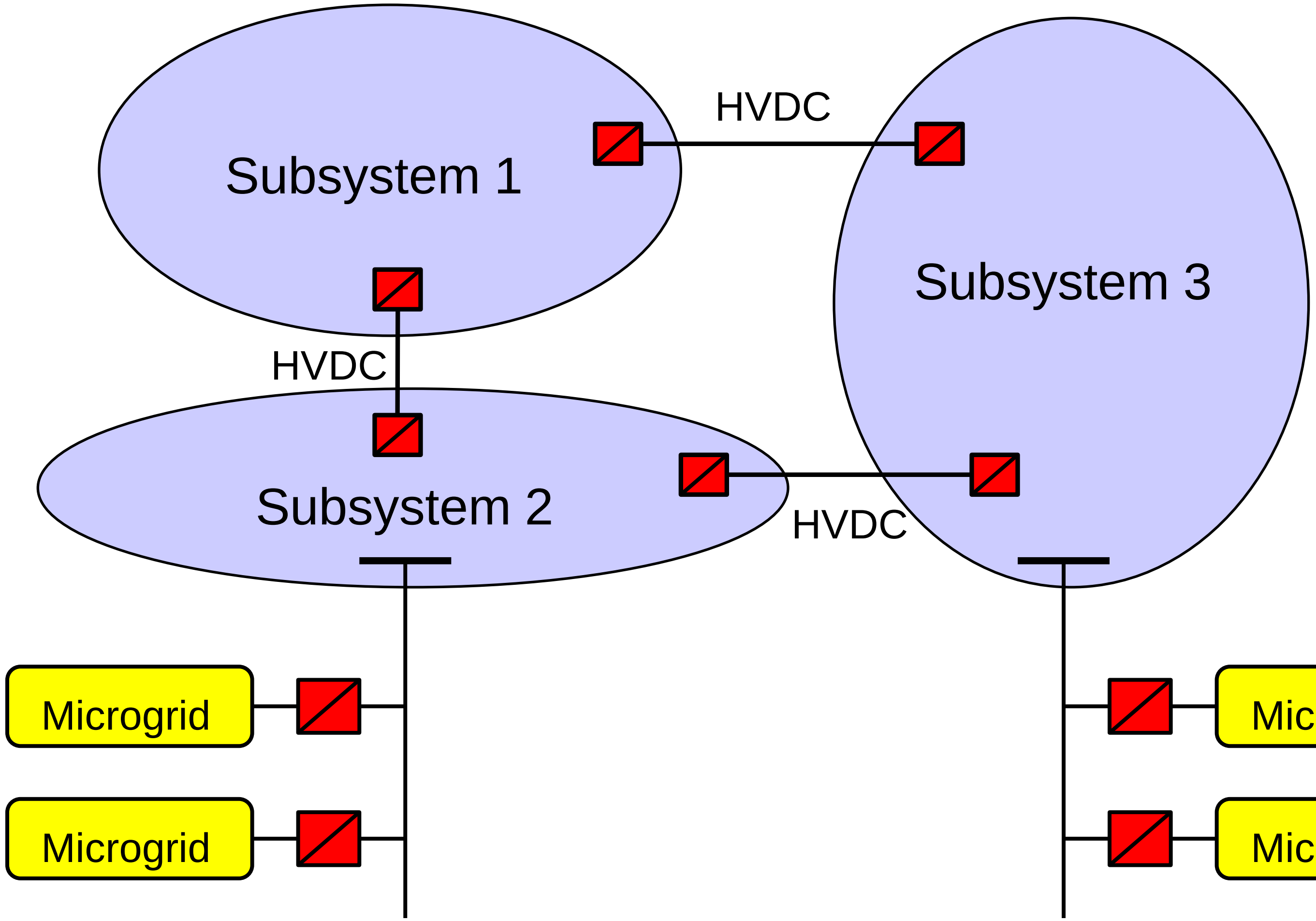
Definition of Robustness and Resilience

- **Robustness** to a class of disturbances is defined as the ability of a system to maintain its function (normal state) when it is subject to disturbances of this class.
- **Resilience** to a class of **unexpected** failures is defined as the ability of a system to gracefully degrade and to quickly **self-recover** to a normal state.



Power System Segmentation (EPRI)

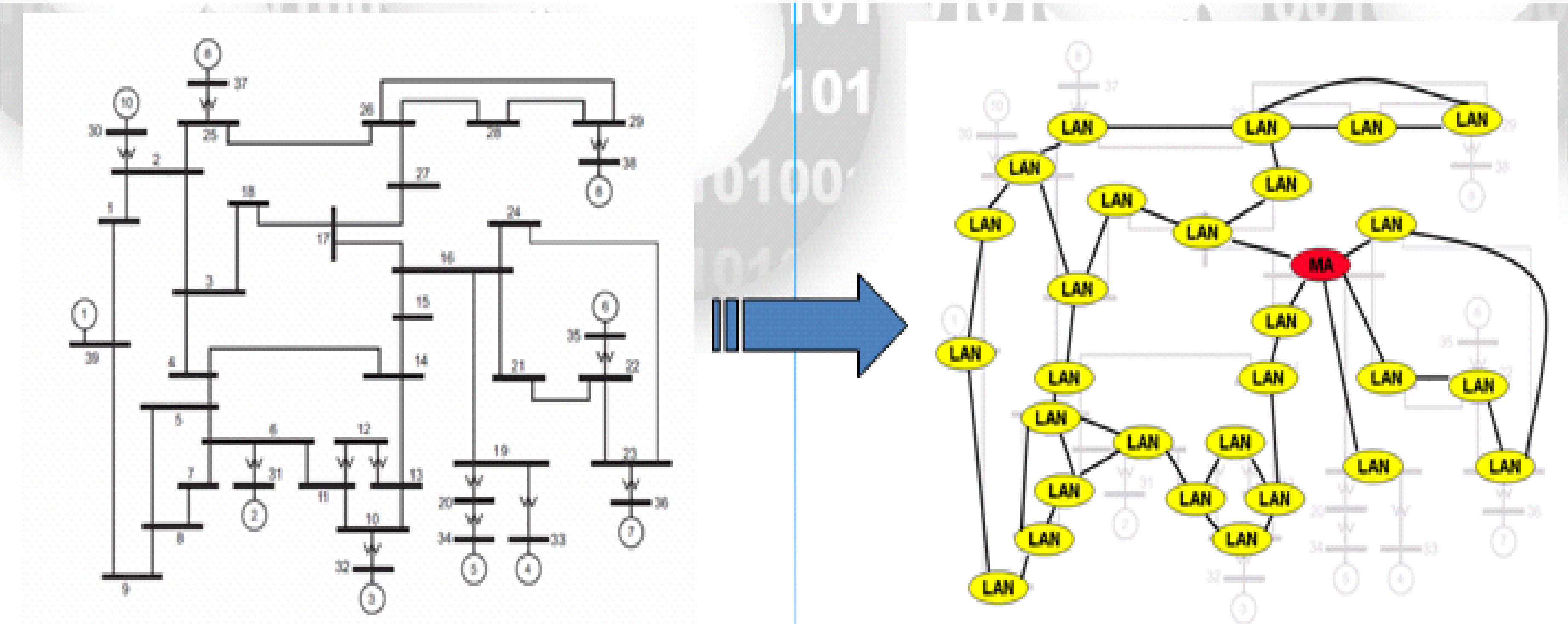
Resilience is achieved via system segmentation, distributed control actions, and demand response to frequency .



Resilience Metrics

- **Utility Grid's Resilience Metrics**
  - Fraction of power that responds to frequency changes and that contributes to the stabilization of a system
  - Fraction of load and storage devices that can be used as dynamic breaks.
  - Ratio of the recovery times (or costs) of a system with and without microgrids or HVDC links.
- **End Users' Resilience Metrics**
  - Fraction of energy supplied by local generation and storage during a utility outage at the end users.
  - Ratio of outage costs at the end user with and without microgrids.
  - Ratio of outage time at the end user with and without microgrids.

Co-Simulation of Power and Computer Systems



IEEE 39-Bus System and Communication Infrastructure

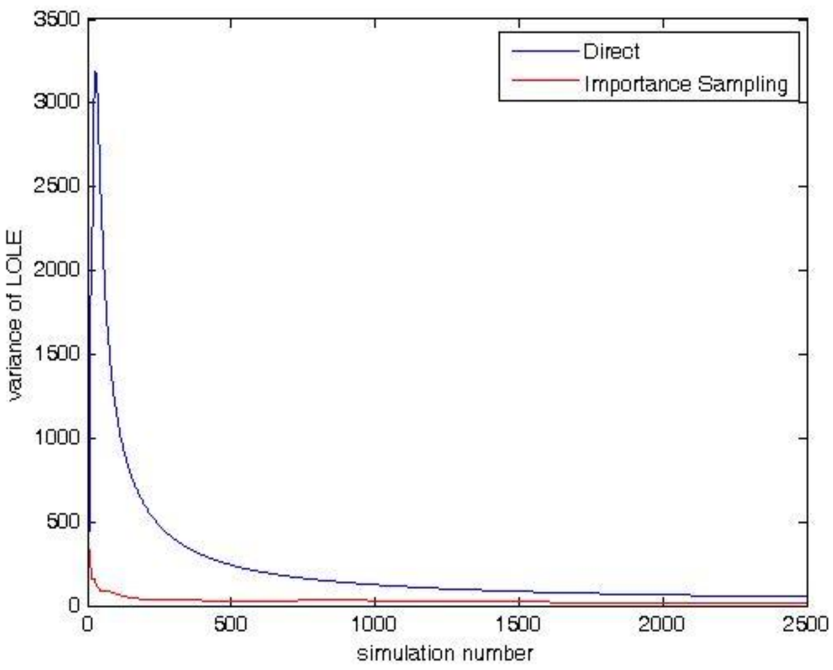
Two communications methods:

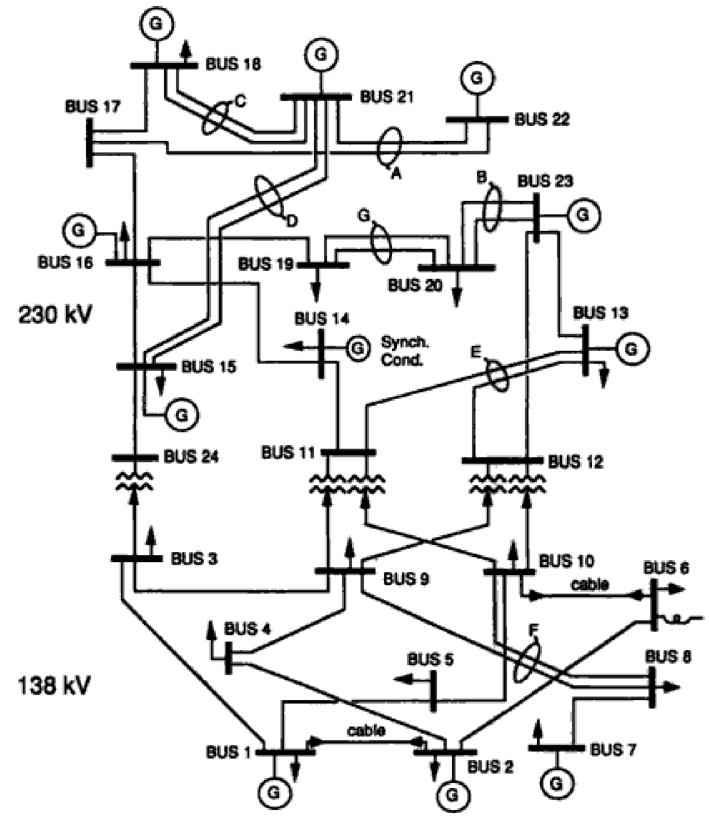
- Supervisory (master-slave)

- Ad-hoc (peer to peer)

Risk of Cascading Failure in Power Systems

The IEEE reliability test system has 9 different types of 32 generating units ranging from 12MW to 400MW.



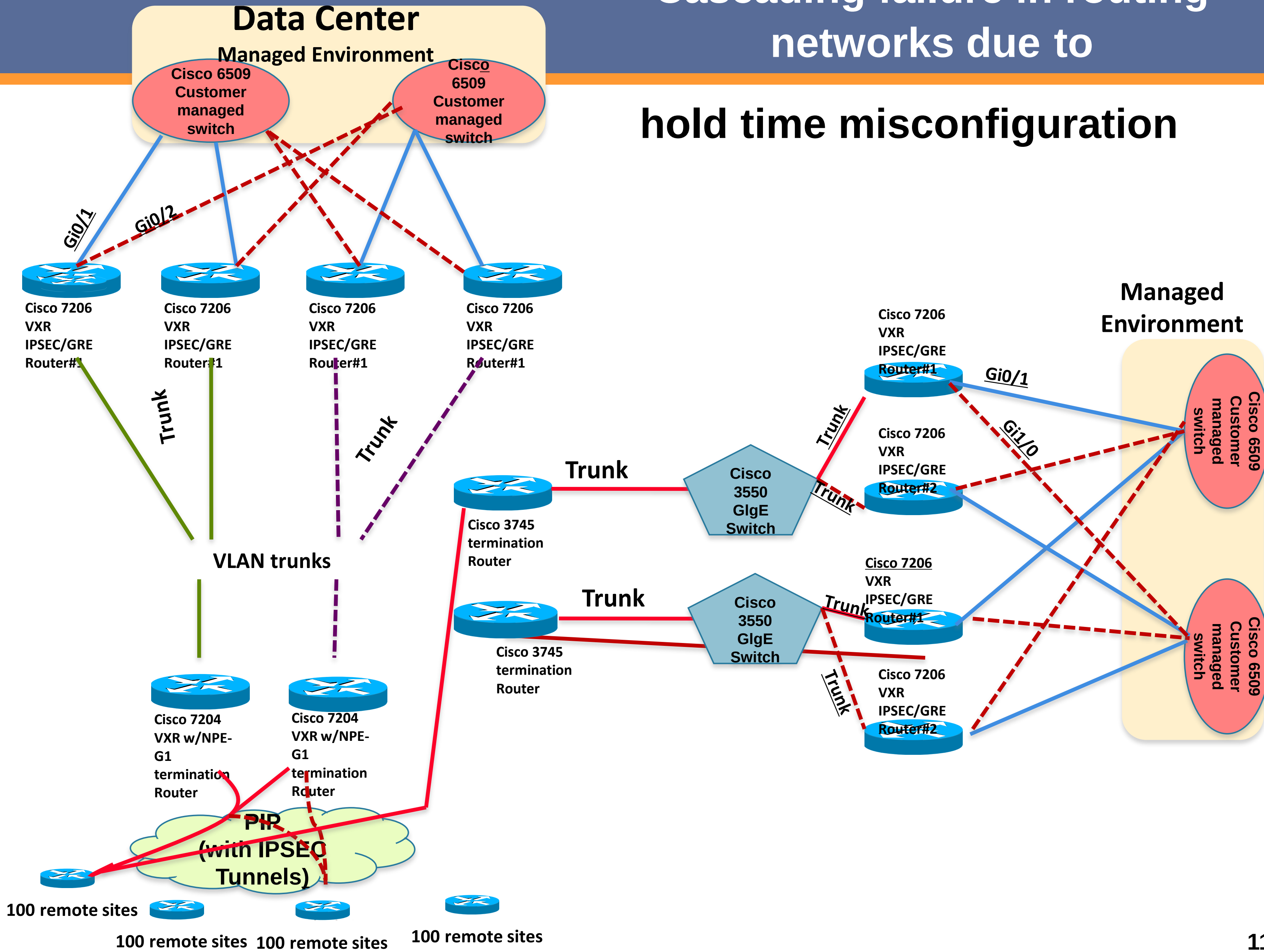


Importance sampling halves the computing time while maintaining the same accuracy obtained with the conventional reliability method.

Roy Billinton Test System

	Conventional System	Microgrid-embedded System
Expected Energy-Not-Served (MWh)	88.97	52.93
Energy input from system (MWh/y)	53673.95	11674.49
Reserve energy to system (MWh/y)	33686.05	78105.25
Number of cascading failures over 100 simulation years	3	0

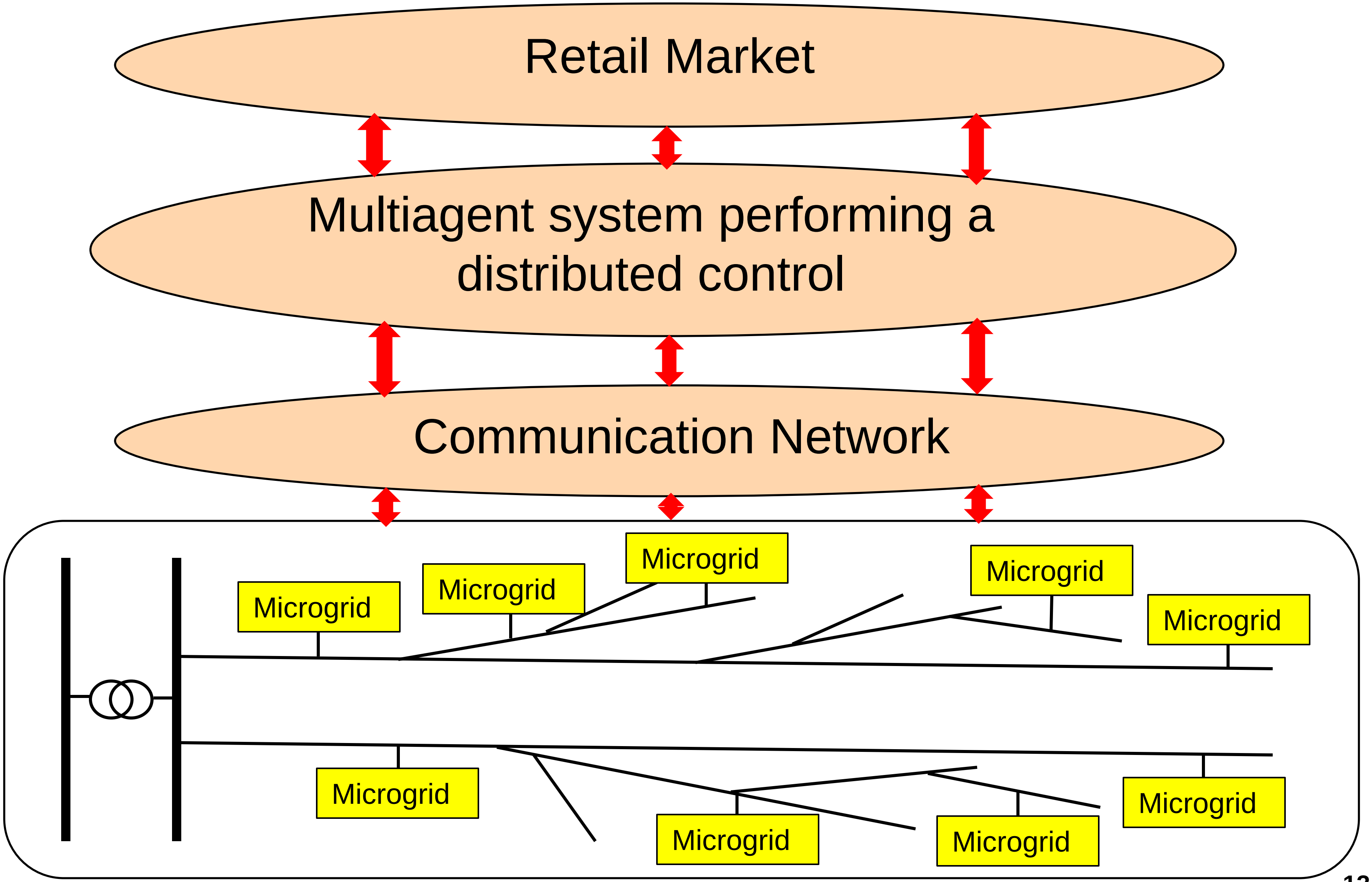
Cascading failure in routing networks due to hold time misconfiguration



Research in Risk Management

- Improve the computational efficiency and scalability of the co-simulation package, GECO, to large-scale systems.
- Investigate various modes of cascading failures in computer networks.
- Develop methods that evaluate the risk of catastrophic failure of large-scale interdependent power and computer networks.

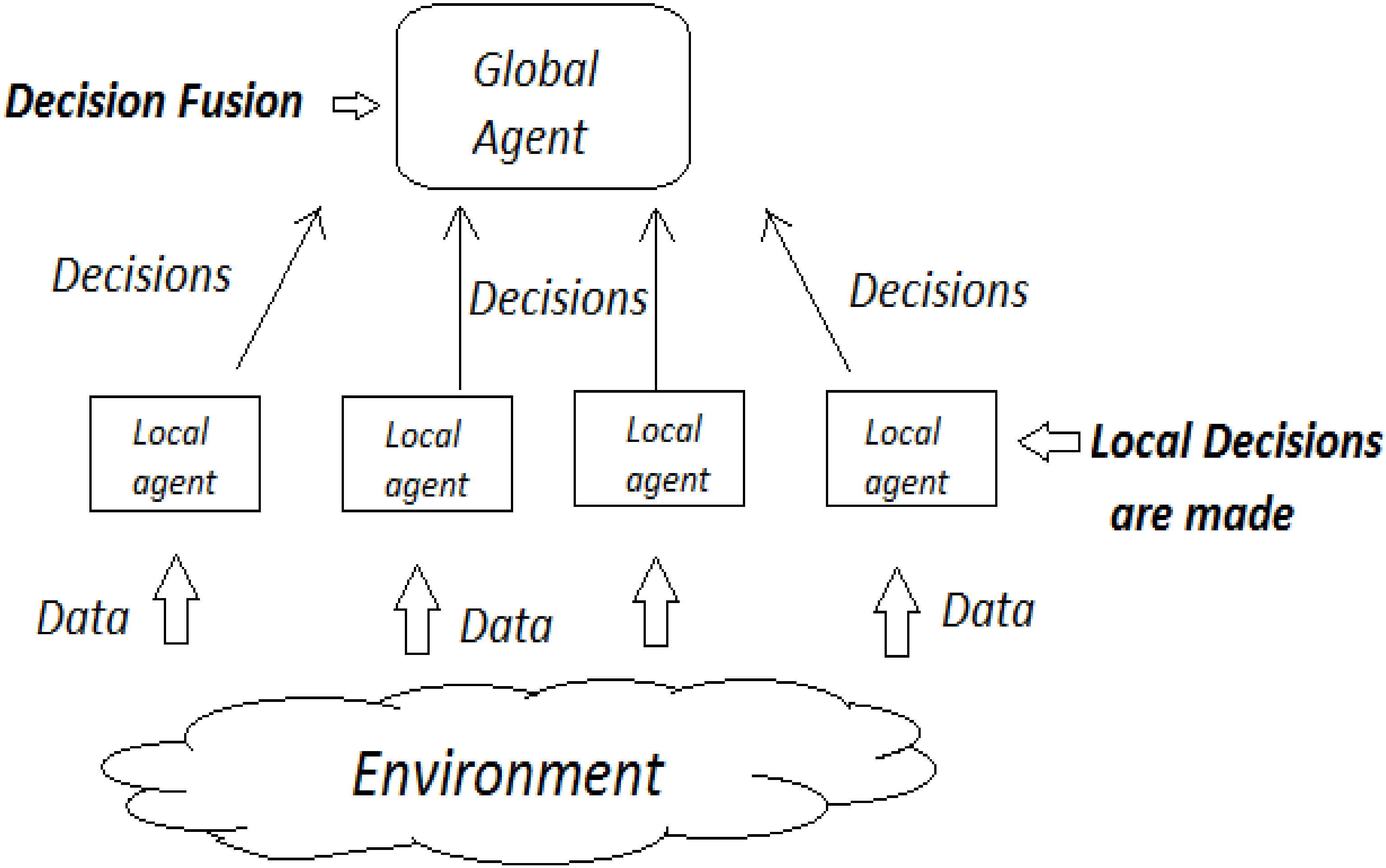
Multiagent System for Microgrid Control



Decentralized and Sequential Decision

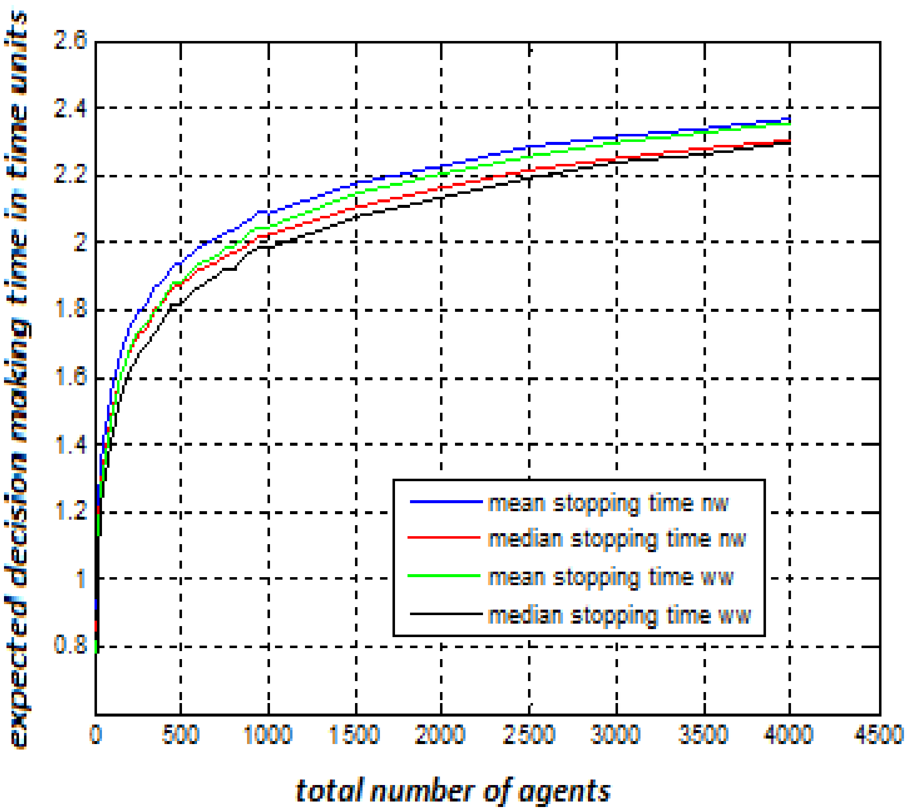
by Srivats Shukla, A. Urken, L. Mili

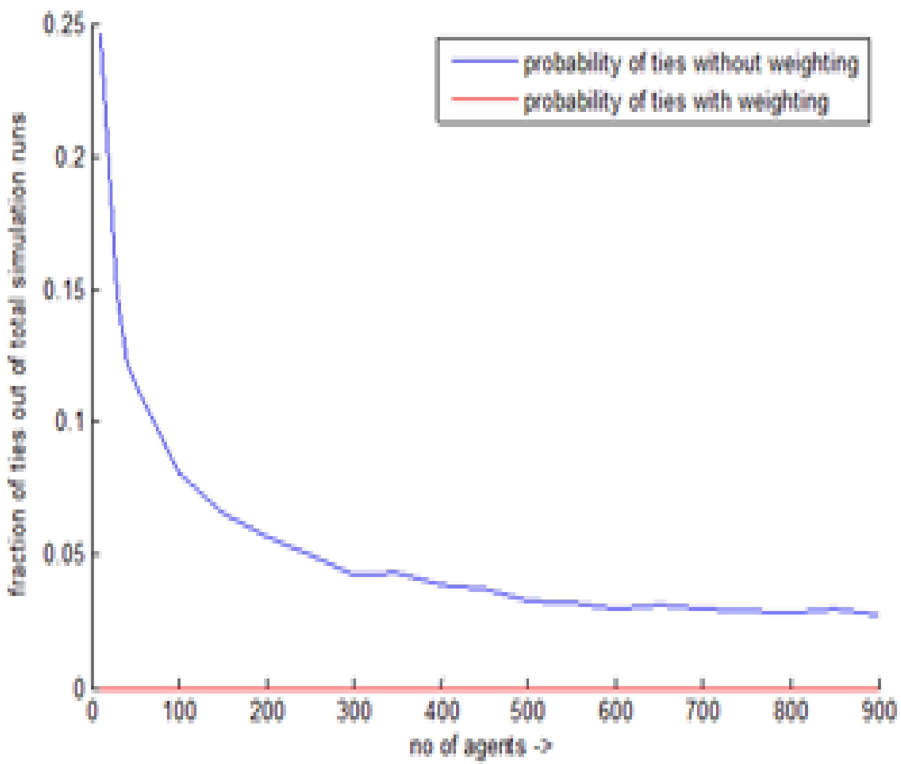
- Data arrives asynchronously in multiple steps.
- At every step, the decision is updated.



Reliable Decision in Minimum Time

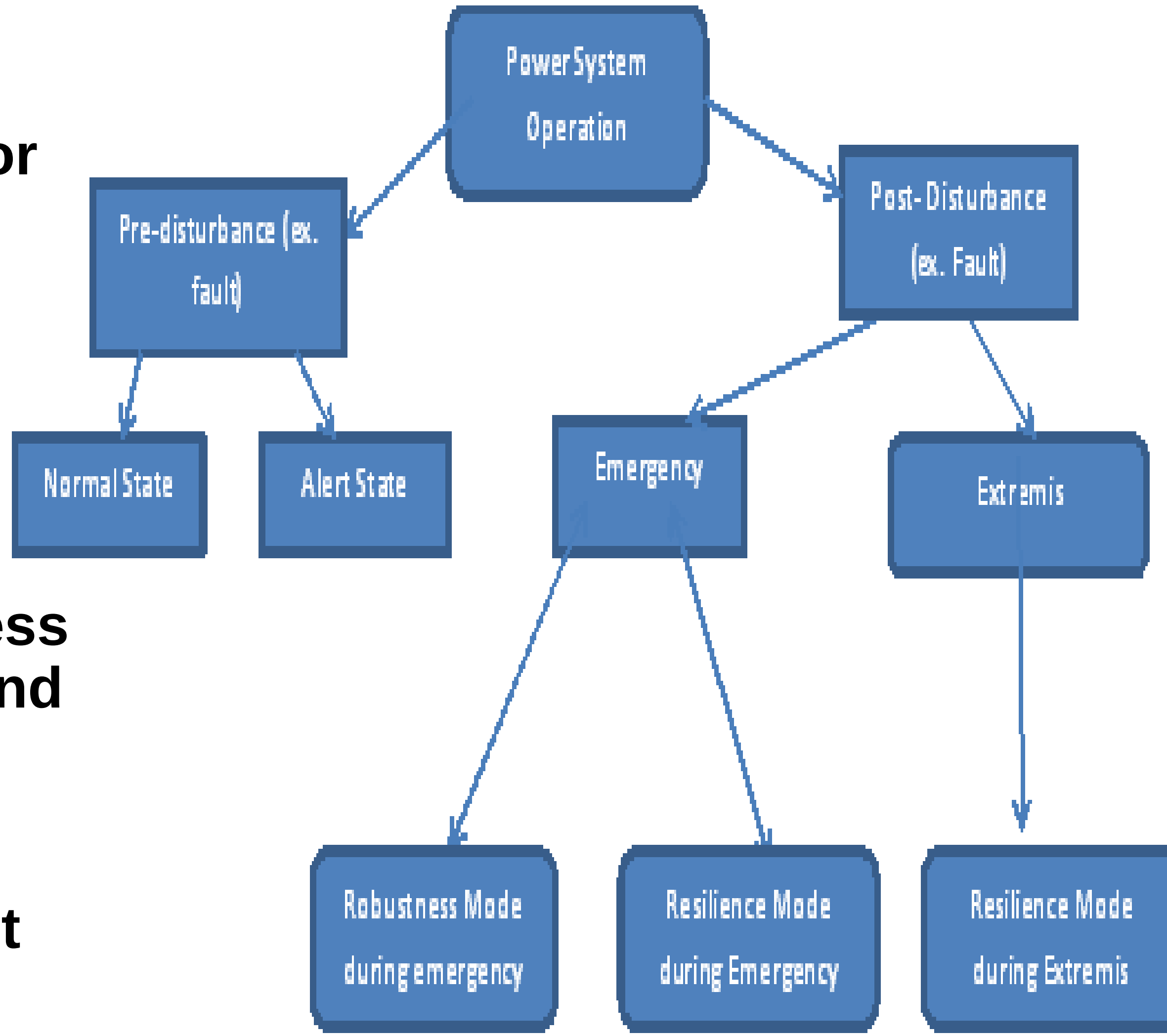
- **As compared to simple majority, weighted decision fusion provides**
  - **reduced expected decision making time**
  - **reduced probability of ties**





Research in Control of Microgrids

- Application of multi-hypothesis testing for power system state identification



- Analysis of robustness of tests to missing and contaminated data
- Multi-hypothesis testing for Condorcet and Borda Decision Fusion

Mitigating Hurricanes’ Impacts

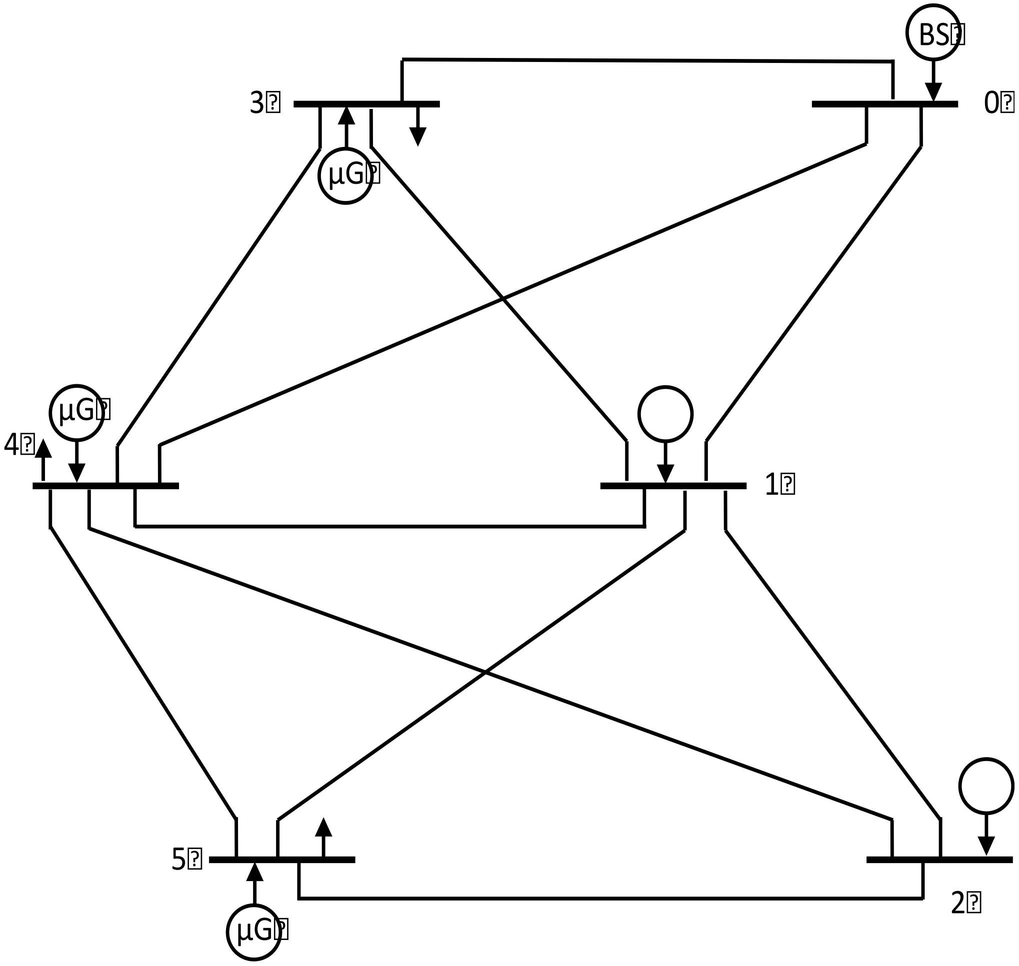
- **Following hurricanes, microgrids can provide electric energy to customers in an islanding mode for several weeks.**
- **A cost-benefit analysis is being carried out in a case study in Florida that integrates energy, transportation, water, and communications infrastructures**

MG Support for Post-Disaster Regional Power Restoration
Anya Castillo (JHU, FERC)

- ***Opportunity:*** **MGs may be able to provide black-start, voltage support, and energy locally to support restoration during regional outages due to hurricanes.**

- ***Research Goal:*** **Determine if MGs can yield:**
  - **Restoration time improvement both to its consumers and the grid;**
  - **economic benefits from MG to non-MG energy suppliers and consumers within a RTO.**

Test System Specifications



- **Characteristics of generating units, critical loads, black-start units, system load profile, islanding configurations.**
- **Flexibility to incorporating alternative MG configurations.**
- **Generic MG components:**
  1. **low-voltage network**
  2. **controllable & non-controllable sources**
  3. **storage**
  4. **communication & monitoring infrastructure;**
  5. **control sources, loads, interconnected modes**

w=1

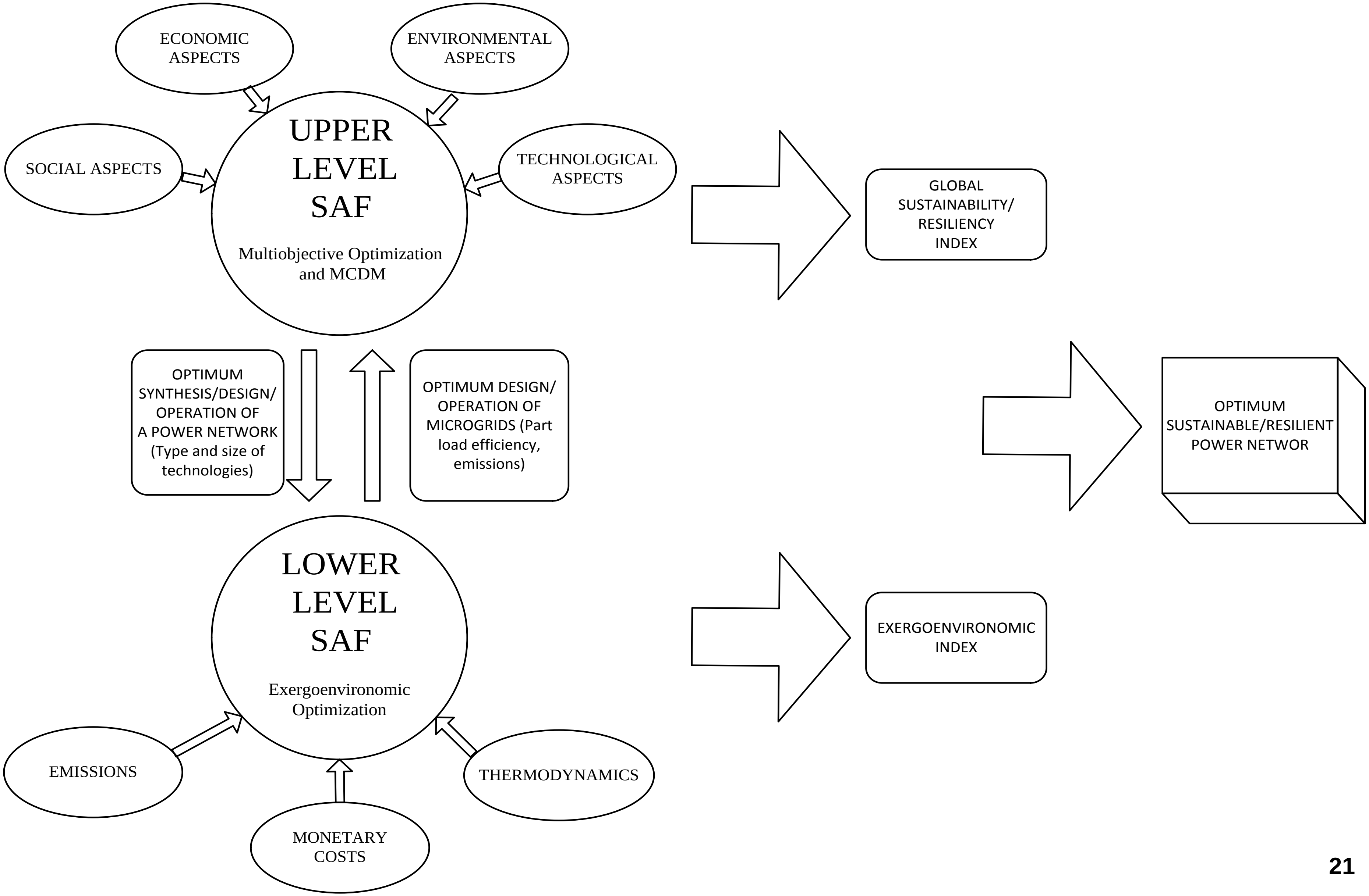
Simulation Outcomes

Scenarios	Damaged Units	Damaged Lines
Event A	Black Start at Node 0	(0,1), (0,3), (0,4)
Event B	Non Black Start at Node 1	(0,1), (1,2), (1,3), (1,4), (1,5)
Event C	Non Black Start at Node 2	(1,2), (2,4), (2,5)

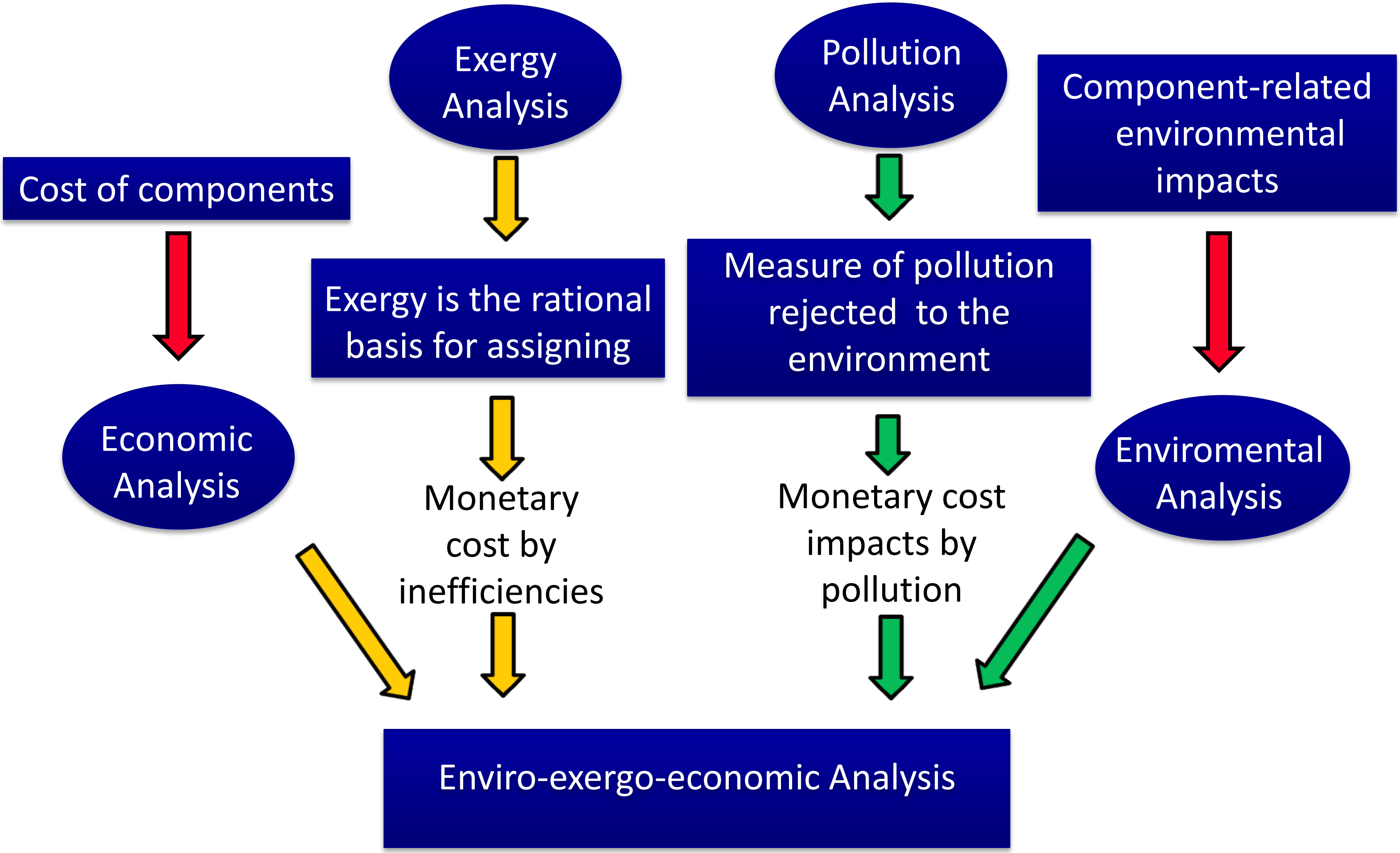
Assume: 20 minute restoration time for individual generators and lines
Total capacity = 210 MW

Scenario	MG Fraction of Capacity: 0% (baseline). Minutes until full restoration:	5% MG	15% MG	25% MG	35% MG
Event A	31	-37%	-45%	-51%	-57%
Event B	15	-55%	-61%	-67%	-72%
Event C	13	-63%	-68%	-72%	-76%
Overall	20	-52%	-58%	-63%	-68%

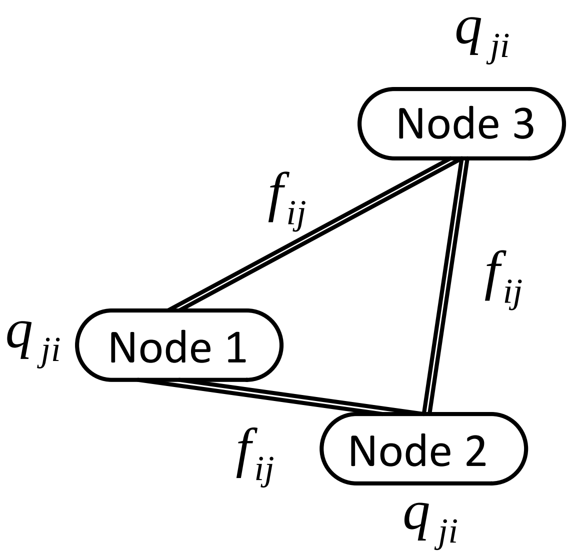
Sustainable Assessment Framework (SAF)



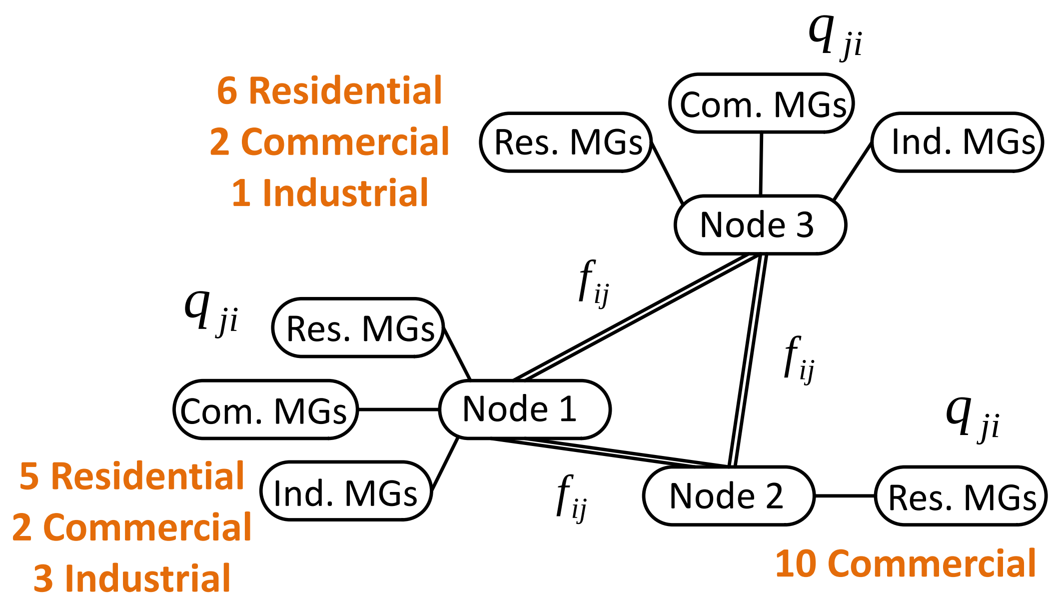
Lower Level: Exergo-economic-environmental Analysis



Upper Level SAF: Model of The Netherlands

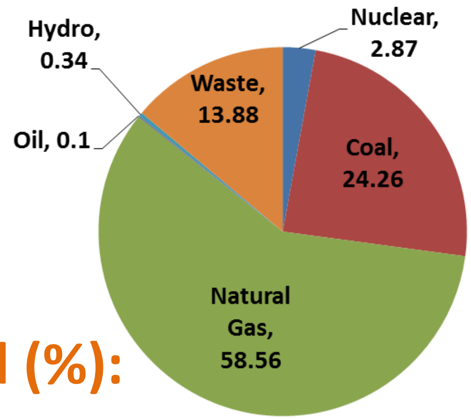


Scenario 1

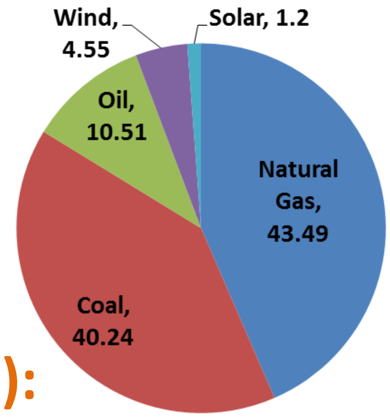


Scenario 2

Grid (%):



MGs (%):



MG Capacities:

20 MW Residential

110 MW Commercial

200 MW Industrial

Upper Level SAF: Some Conclusions

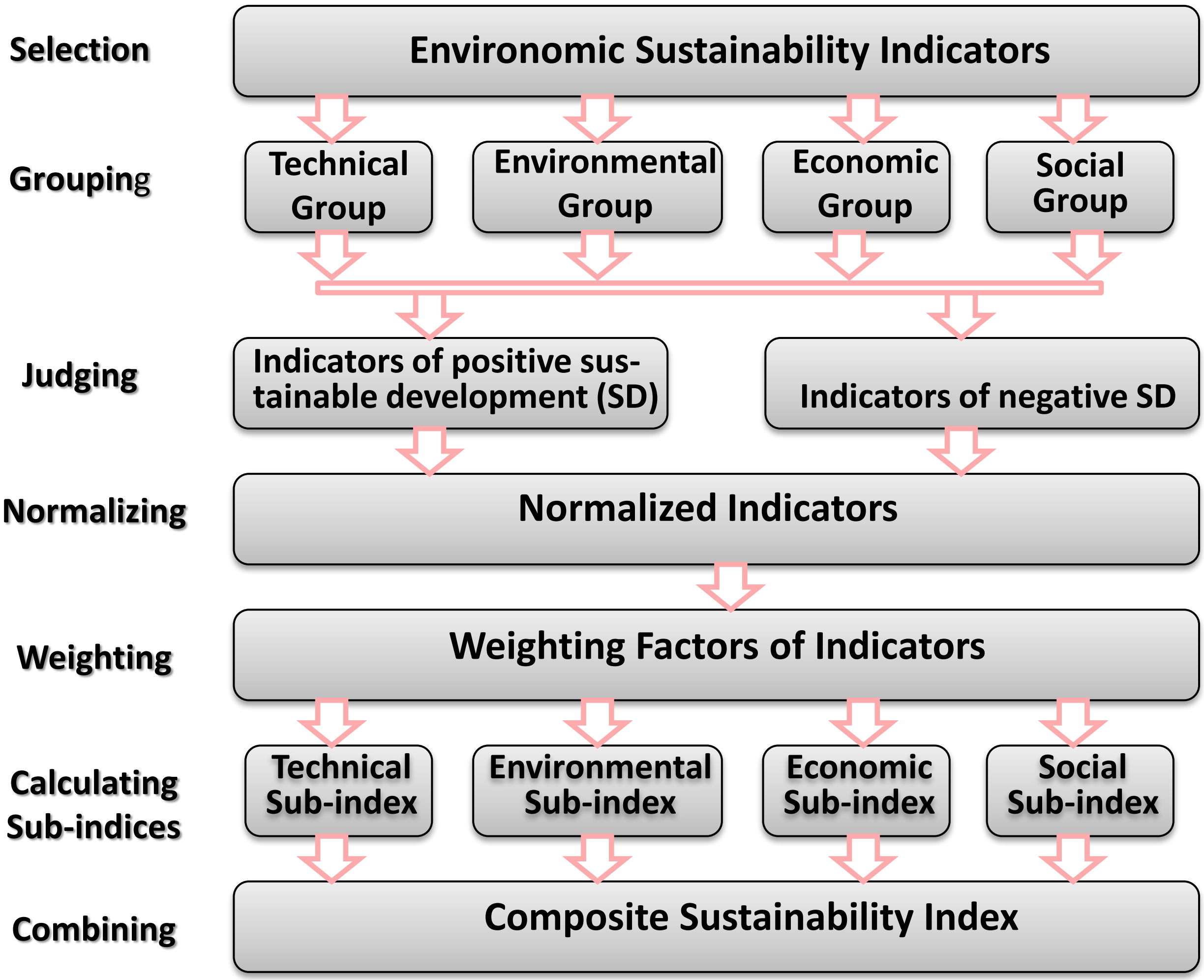
- Fuzzy Logic and Decision-Maker Weighting techniques point to the same optimum power network configuration for both the system with and without MGs

- Coal, nuclear, hydro, and waste fueled generating units are base and intermediate units, while natural gas units are peaking units.

- Main conclusions:
  - MGs leads to a better overall efficiency, a reduction in monetary costs, and an improved network resiliency.
  - Total life SO_2 emissions may not be improved with the inclusion of MGs.

Socio-Environomic-sustainability indicators

Proposed by Frangopoulos et al., 2010



$$\bar{I}_{ij} = \begin{cases} 0 & I_{ij} \leq a_{ij} \\ \dfrac{I_{ij} - a_{ij}}{b_{ij} - a_{ij}} & a_{ij} < I_{ij} < b_{ij} \\ 1 & I_{ij} \geq b_{ij} \end{cases}$$

Indicators of positive SD

$$\bar{I}_{ij} = \begin{cases} 1 & I_{ij} \leq a_{ij} \\ \dfrac{b_{ij} - I_{ij}}{b_{ij} - a_{ij}} & a_{ij} < I_{ij} < b_{ij} \\ 0 & I_{ij} \geq b_{ij} \end{cases}$$

Indicators of negative SD

Weighting factors

$$\bar{I}_{Sj} = \sum_i w_i \bar{I}_{ij} \qquad \sum_i w_{ij} = 1, \quad w_{ij} \geq 0$$

Sustainability Sub-index of group j, and relative weight of indicator i in group j

$$I_{CS} = \sum_i w_j \bar{I}_{Sj} \qquad \sum_j w_j = 1, \quad w_j \geq 0$$

Composite sustainability index and relative weight of the indicator in group j.

Research in Social Sciences

What We Need to Know ?

- **Combining data from various sources**
  - Survey/opinion data from households
  - grid data from energy providers
- **Understanding environmental concerns, which are multifaceted:**
  - energy use
  - pollution of water and air

Challenges: The Road Ahead

- **Analyzing heterogeneity**
  - Variation within neighborhoods and households
- **Understanding the importance of social organization**
  - policy creation and implementation

Consumer Behavior Patterns

- Collect Smart Grid information from social media (Twitter, Facebook).
- Develop methods that will provide rapid data desaggregation with good accuracy.
- Conduct correlation analysis between consumption patterns, customer preferences, and weather patterns.
- Develop visualization methods that reveal patterns of customer energy consumption.
- Extract patterns revealing customers’ choices.

Regulatory Barriers to Microgrid Deployment

- **Public utility commission (PUC) regulations may prohibit microgrids from crossing public rights-of-ways. Approval from local municipalities may be imposed.**
- **Utilities may impose onerous interconnection requirements under the pretext of protecting the reliability of the utility grid.**
- **Microgrids are not mentioned in net metering provision and therefore, are not eligible for such service.**
- **PUCs can play a key role in facilitating microgrid development. This will require an engineering expertise from PUC to address the reliability issue.**