2011 RESIN Workshop

Making the Concepts of Robustness, Resilience and Sustainability Useful Tools for Power System Planning, Operation and Control

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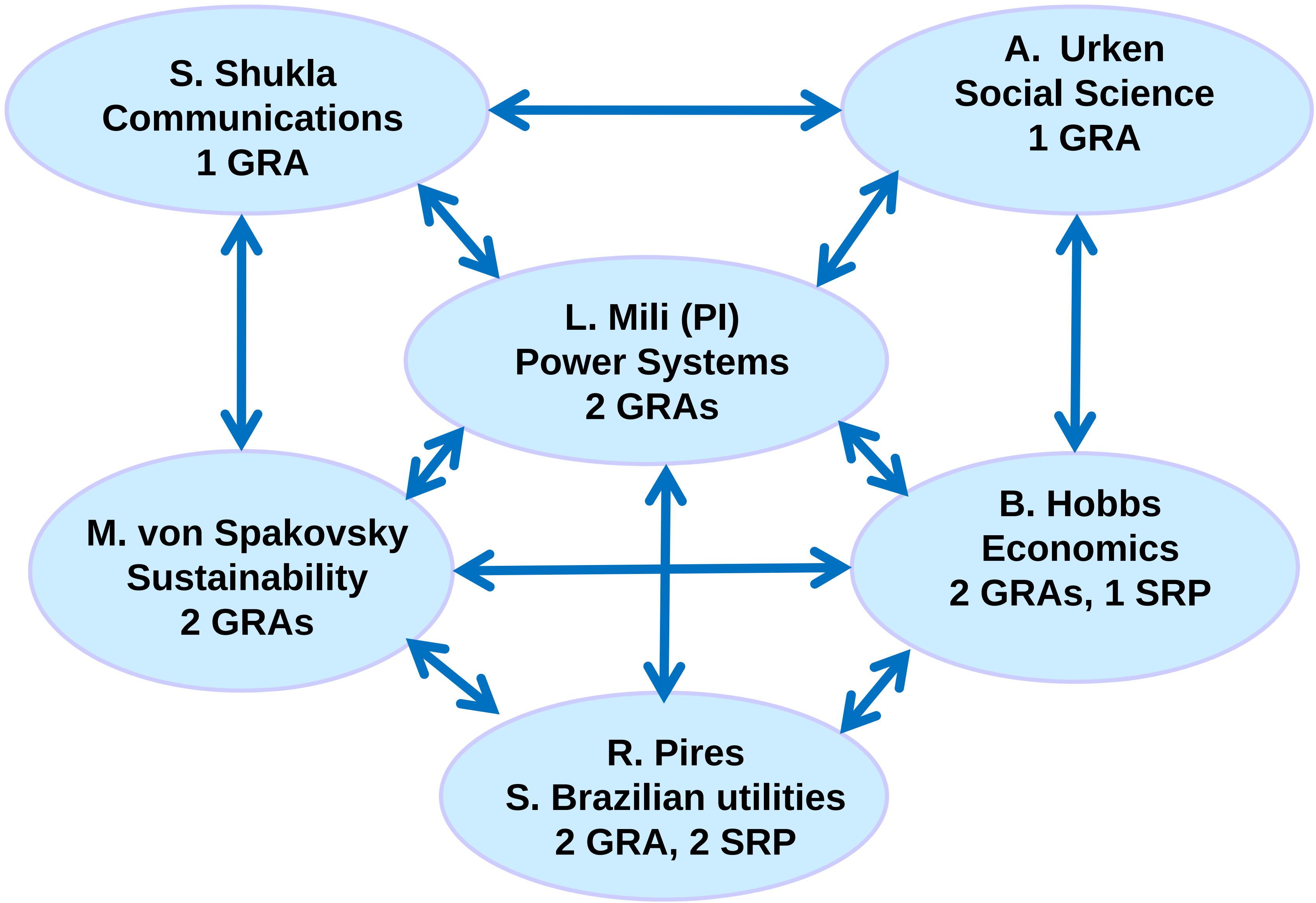
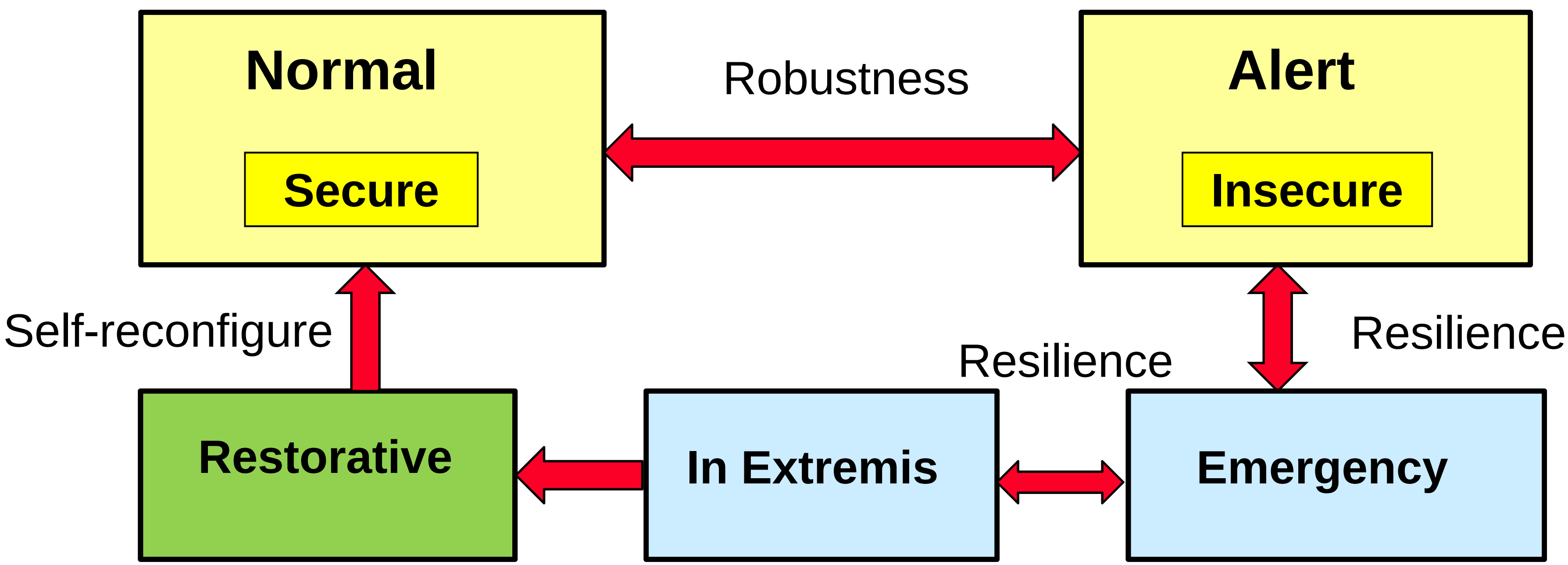


Definition of Robustness and Resilience

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

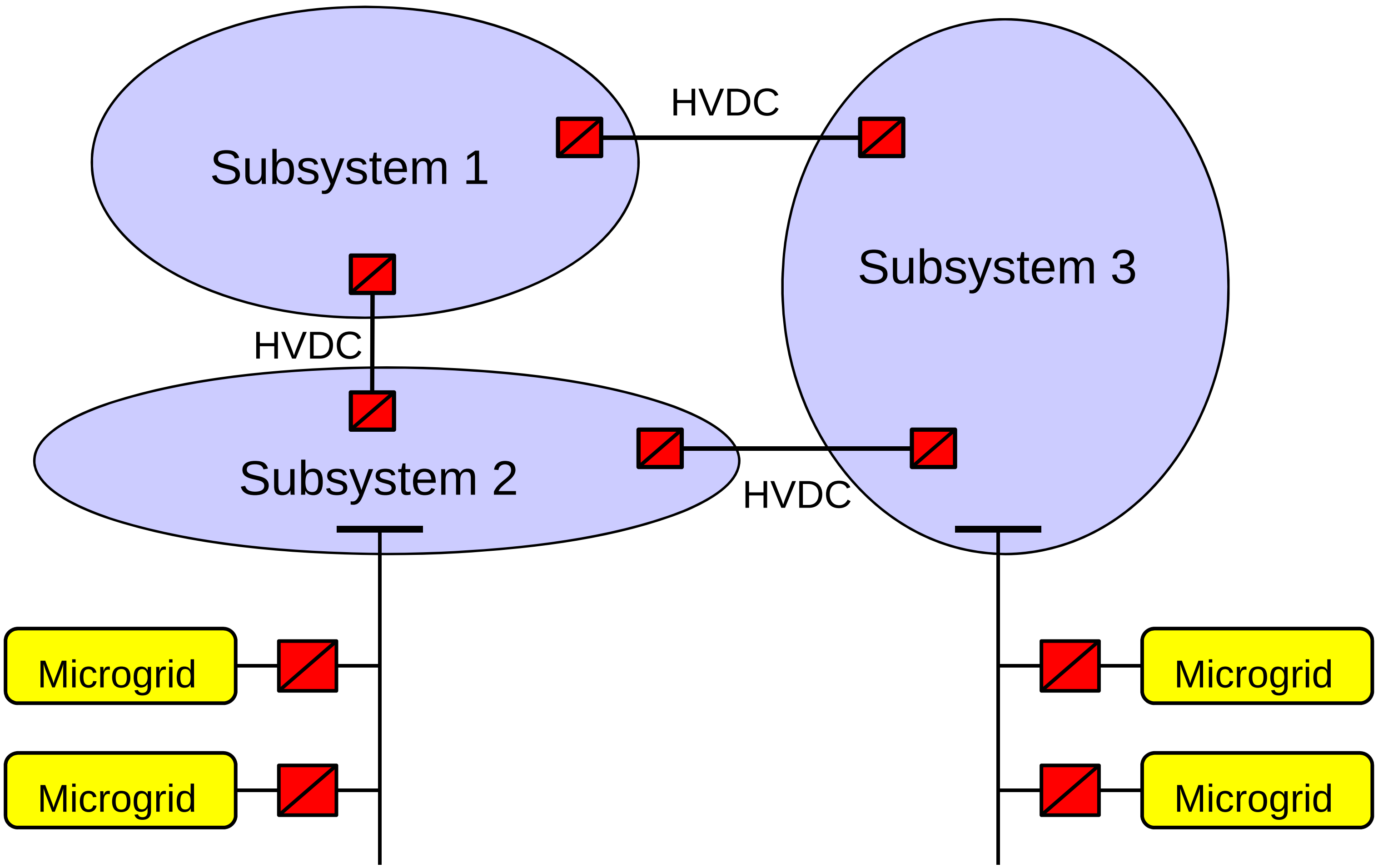


Achieving Resilience via Modularity

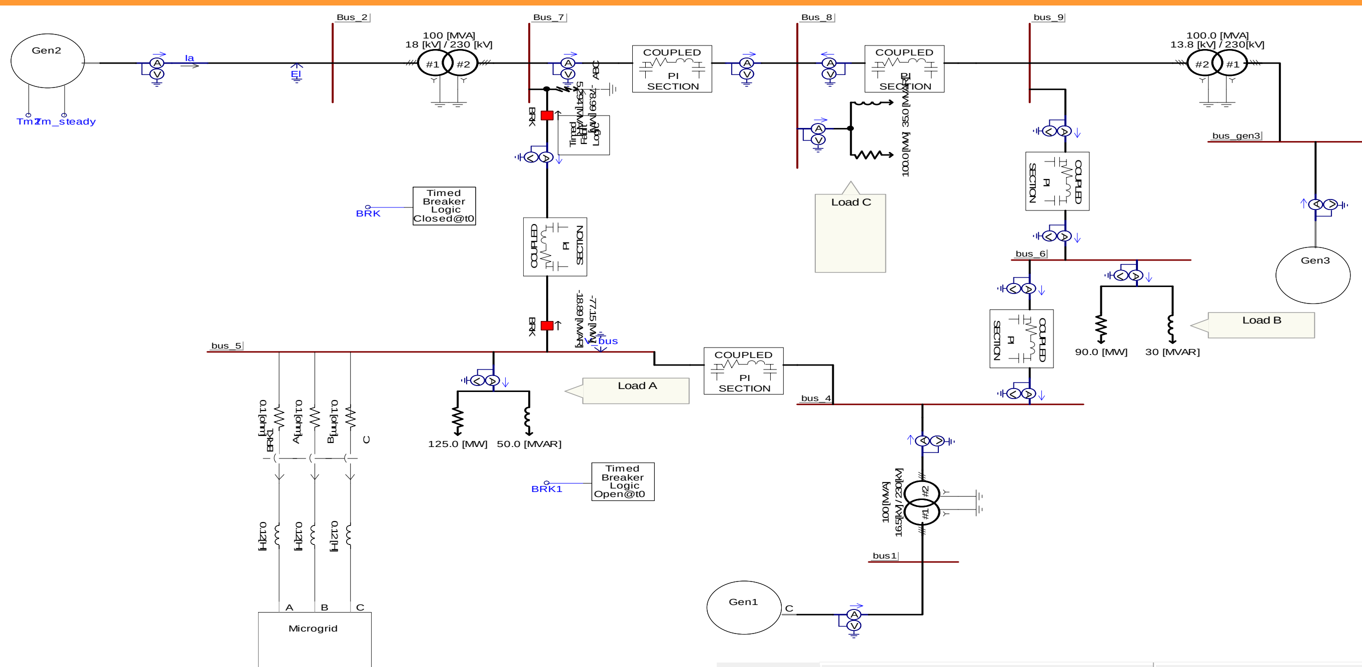
- **Resilience is achieved**
  - **via a segmentation of the system into weakly coupled subsystems to prevent the propagation of local failures to large areas via cascading events;**
  - **and via distributed and coordinated control actions**
- **A trade-off between robustness and resilience can be formulated as an optimization problem subject to a bound on the cost.**
- **This optimization will indicate where to segment the transmission system via HVDC links and will give us the desired level of penetration of microgrids.**

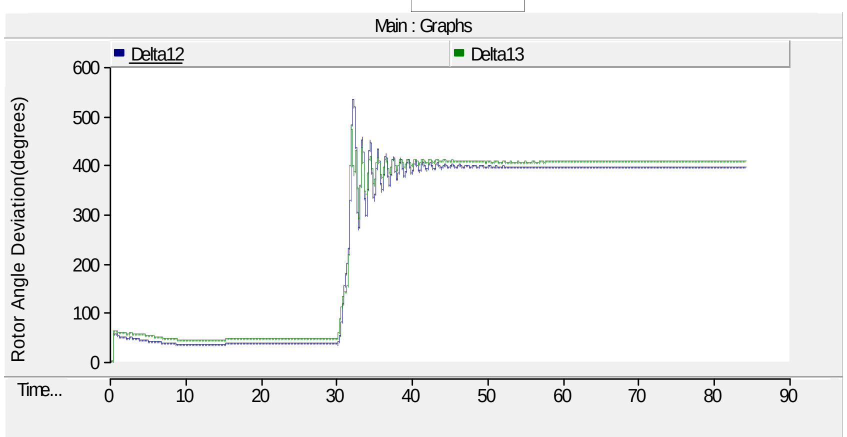
Power System Segmentation (EPRI)

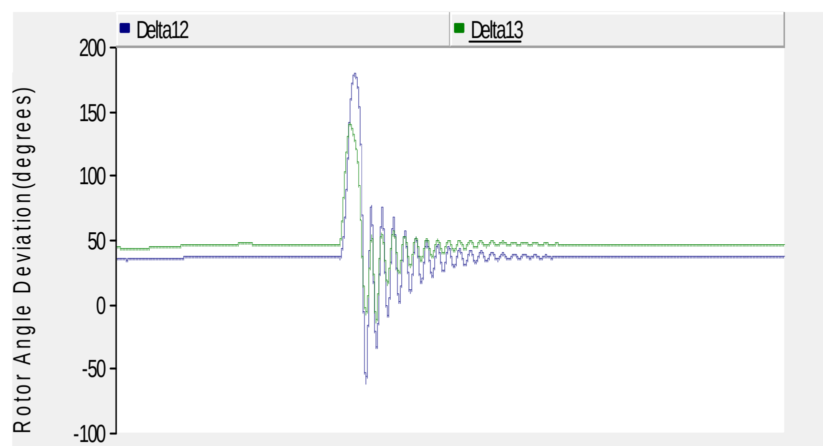
A metric of system flexibility is being developed using the potential energy function.



Enhancement of the Stability Margin







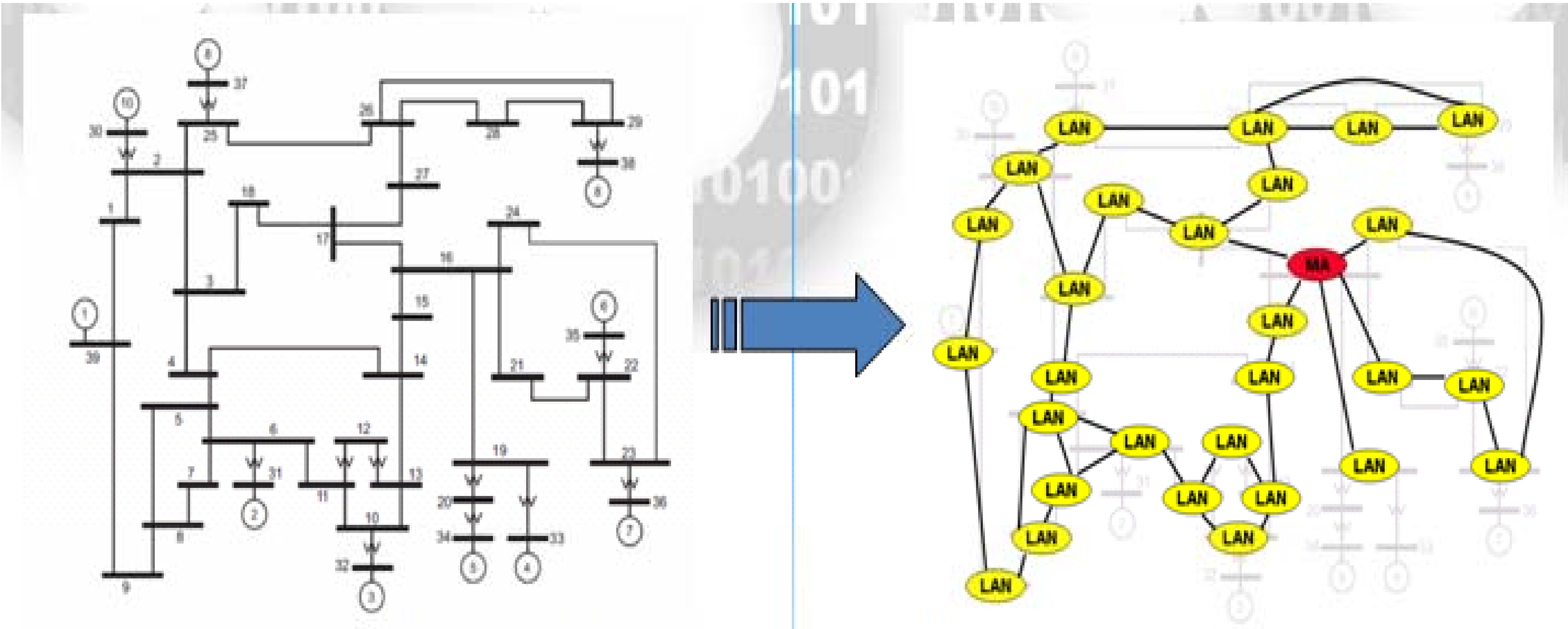
System without microgrid: critically unstable; Critical clearing time is 833 ms

The microgrid increases the stability margins. Critical clearing time is 1.3 s

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**

Agent Based Supervision of Zone 3 Relays



IEEE 39-Bus System and Communication Infrastructure

- Master agents co-ordinate with slaves in a peer-to-peer manner
- Monitor and control power system through interconnected network

Maximum Delays in the Network

Maximum delays in the network sharing same topology with the power lines

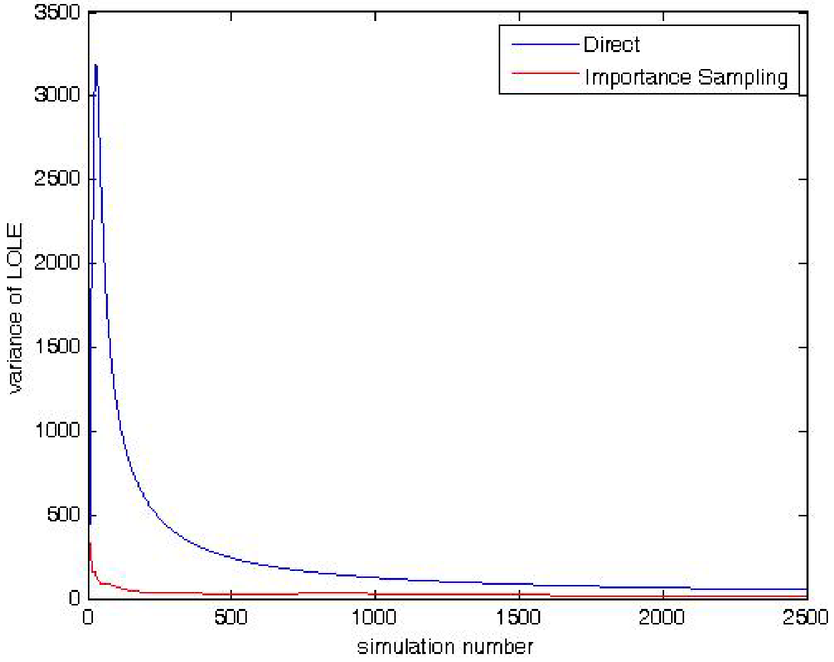
	PLC	Copper	Fiber
UDP without Traffic	160.4ms	2ms	0.416ms
TCP without outTraffic	640.4ms	4.8ms	0.464ms
UDP with Traffic	N/A	3.6ms	0.432ms
TCP with Traffic	N/A	5.2ms	0.448ms

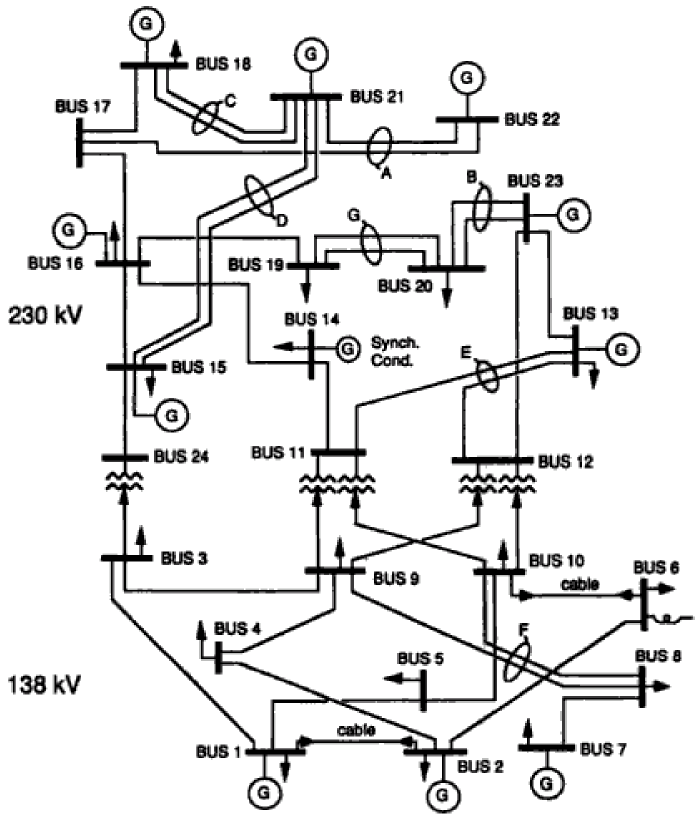
Maximum delay in the hierarchical network with LANs in the substation

	PLC	Copper	Fiber
UDP without Traffic	1082.588ms	12.188ms	2.684ms
TCP without outTraffic	2002.748ms	22.748ms	3.024ms
UDP with Traffic	N/A	48.4ms	3.014ms
TCP with Traffic	N/A	50.8ms	3.104ms

Modeling of Cascading Failure in Power Systems

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

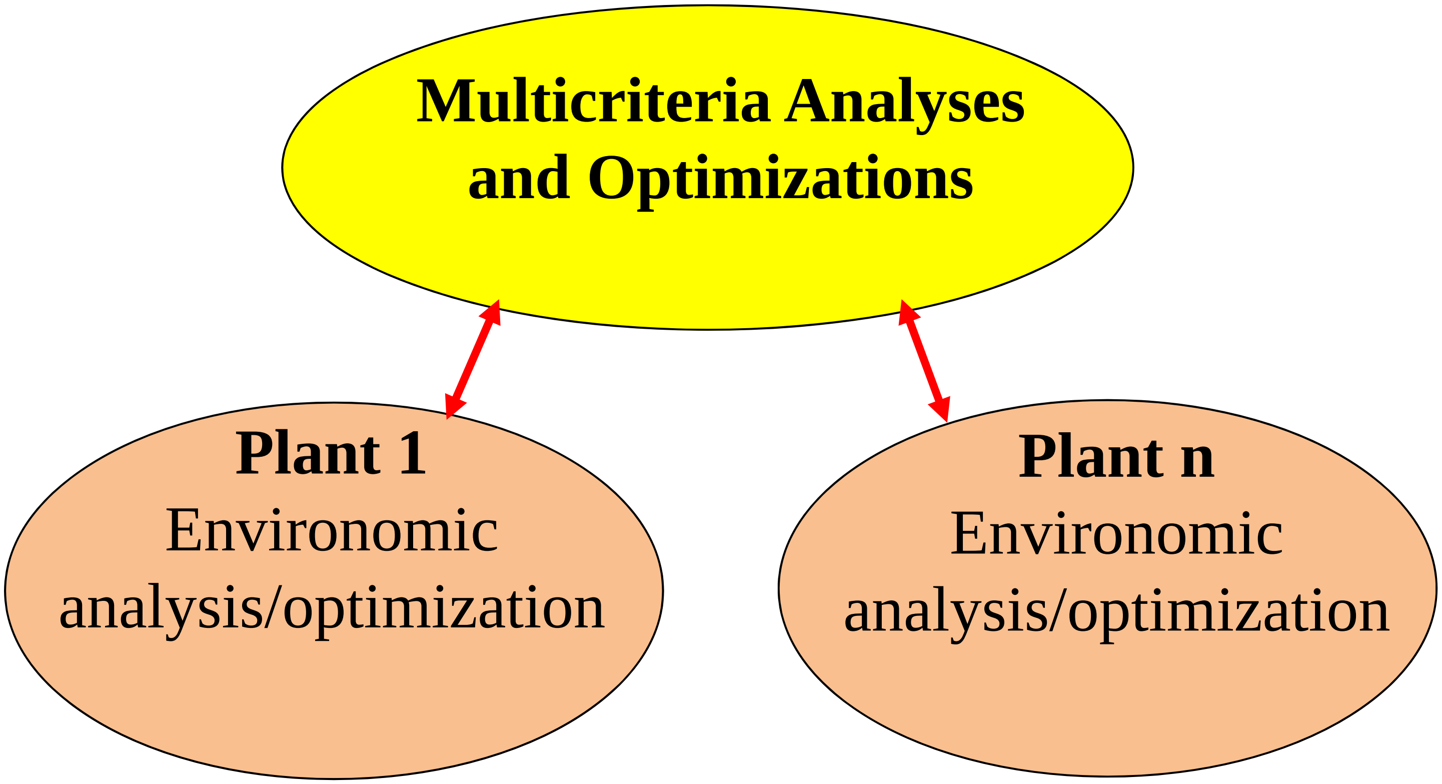




The variance of the Loss of Load Expectation (LOLE) for the direct method and the importance sampling algorithm

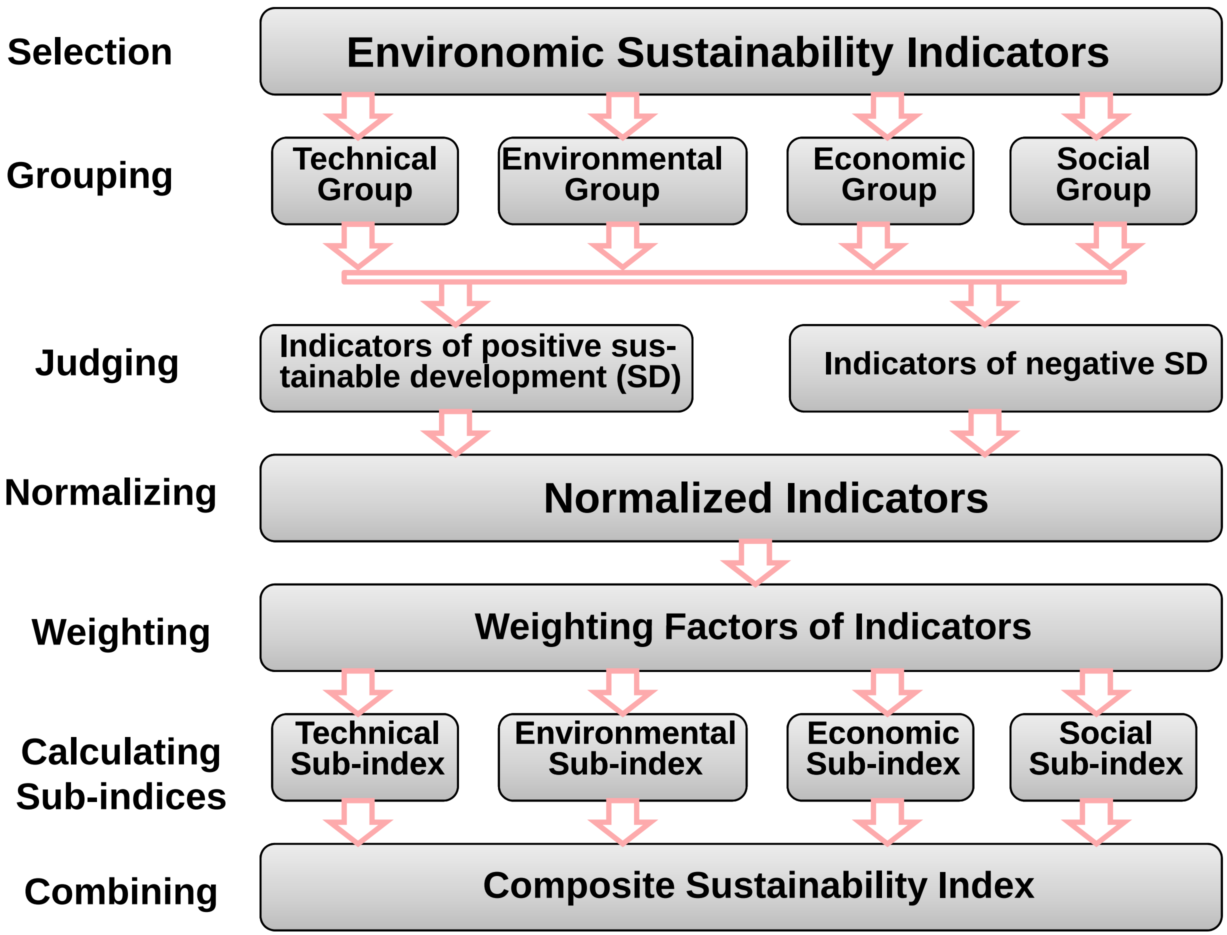
Sustainability of Power and Communications Systems

- **Development of theoretical foundations of a two-level sustainability assessment framework (SAF)**



Sustainable Power System

- **Selection of environomic sustainability indicators to assess the sustainability of the *NW European regional transmission/distribution grid interacting with a set of micro-grids* (*Frangopoulos et al., 2010*).**



$$\bar{I}_{ij} = \begin{cases} 0 & \text{if } I_{ij} \le a_{ij} \\ \dfrac{I_{ij} - a_{ij}}{b_{ij} - a_{ij}} & \text{if } a_{ij} < I_{ij} < b_{ij} \\ 1 & \text{if } I_{ij} \ge b_{ij} \end{cases}$$

Indicators of positive SD

$$\bar{I}_{ij} = \begin{cases} 1 & \text{if } I_{ij} \le a_{ij} \\ \dfrac{b_{ij} - I_{ij}}{b_{ij} - a_{ij}} & \text{if } a_{ij} < I_{ij} < b_{ij} \\ 0 & \text{if } I_{ij} \ge b_{ij} \end{cases}$$

Indicators of negative SD

Weighting factors

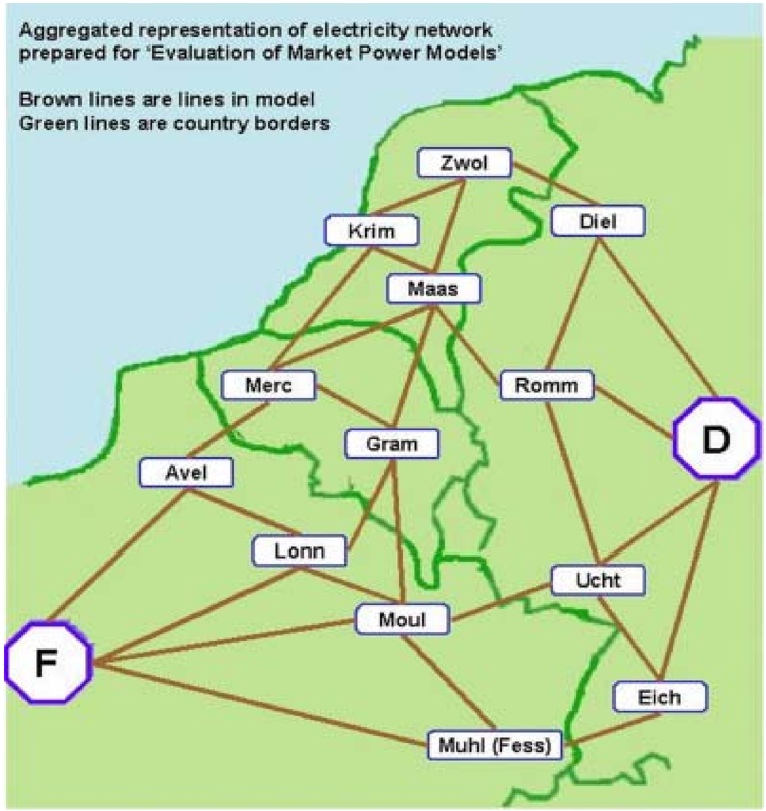
$$\bar{I}_{Sj} = \sum_i w_{ij} \bar{I}_{ij} \qquad \sum_i w_{ij} = 1, \qquad w_{ij} \ge 0$$

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

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

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

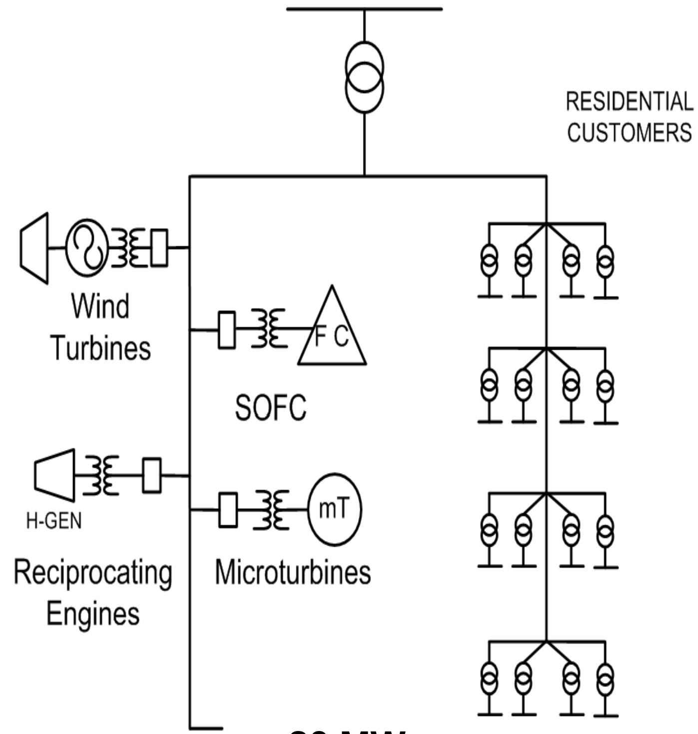
Sustainability of Microgrids in the NW European Market



- **Goal: Assess the sustainability of microgrids in the NW European market that consists of 15 nodes.**
- **Market Simulator: COMPETES (COmprehensive Market Power in Electricity Transmission and Energy Simulator) www.ecn.nl/ps/tools/modelling-systems/competes/**
- **This Model was enhanced to quantify emissions and thermodynamic efficiency**
- **Collaborators: O. Ozdemir and S. Hers, ECN (The Netherlands)**

Sustainable Power System

- **Development of a 20 MW residential micro-grid configuration including renewable and non-renewable technologies with cogeneration tied to a NW European power network and used in *an upper-level SAF*.**
- **50 Residential MGs are aggregated at the node Krim in the Netherlands**
- **The daily load demand is divided into base load, intermediate load, and peak load.**



20 MWe

Emission rates in the MG by technology (ton/MWh)

Technology	CO_2	NO_x	SO_x
SOFC	0.402	0.000007	-
Gas MT	0.778	0.000238	-
Diesel RE	0.826	0.00095	0.00163
Boiler	0.234	0.00038	-

Characteristics of MG technologies

MG technology	Capital cost ($/kW)	Useful life (years)	Unitary size (kW)	Energetic efficiency
Wind turbines	1,467	20	1,800	18%
SOFC	4,700	10	1,000	50%
Microturbine	2,500	20	60	26%
Diesel RE	350	20	180	34%

Impacts of Microgrids

- **Microgrids (MGs) lead to an improvement in the energetic and exergetic efficiency.**
- **MGs enhance the sustainability of a power system because they yield a reduction in both CO_2 and NO_x emissions.**
- **MG scenarios are *less economically sustainable* due to the high capital costs of the MG technologies, especially fuel cells.**

Application of an Upper-level SAF to the NW European Power Network

Indicator	S1	S2	S3	S4
1	0	0.46	0.54	1
2	0	0.62	0.39	1
3	0.03	0	1	0.94
Environmental sub-index	*0.01*	*0.36*	*0.65*	*0.98*
4	1	0.49	0.51	0
5	0	0.28	0.73	1
Economic sub-index	*0.50*	*0.38*	*0.62*	*0.50*
6	0.5608	0.5608	0.5635	0.5635
7	0.4561	0.4645	0.4582	0.4667
8	0.4111	0.4111	0.4132	0.4132
9	0.4453	0.4538	0.4474	0.4560
Technical sub-index	*0.4683*	*0.4726*	*0.4706*	*0.4749*
Composite sustainability index	***0.3260***	***0.4052***	***0.5776***	***0.6517***

S1 – no MG, no CO2 price **S2 – MG, no CO2 price**
S3 – no MG, CO2=25 €/ton **S4 – MG, CO2=25 €/ton**

Conclusions

- **Microgrids will allow a host of small-scale renewable energy resources to be interconnected with a power system.**
- **Microgrids will provide a power system with enhanced flexibility and agility during emergency conditions.**
- **Microgrids will represent a paradigm shift in power system operation and control. They are one of the key components of a smart grid.**