Carnegie Mellon

# Bridging Gap between Modern Grid Design, Operations and Software


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Disclaimer: Highly personal take at the state of the field;


Acknowledgment to EESG Ilic group http://www.eesg.ece.cmu.edu/

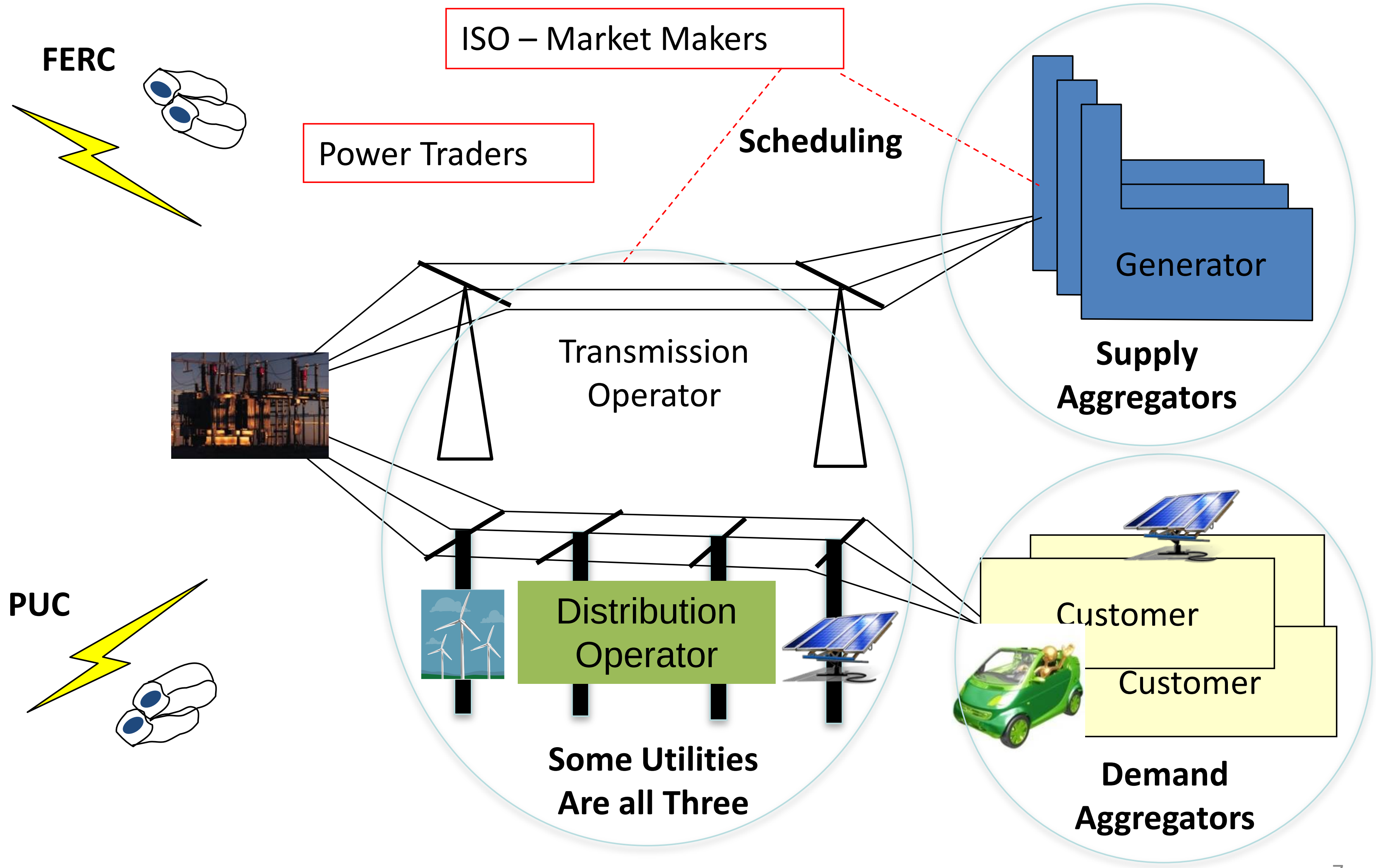
# The big picture

- (Electric) energy systems—the industry in evolution
- Driven by technology, changing societal goals and industry restructuring ("wicked", ill-conditioned complex problems)
- Smart grids design, operations and software-- the case of IT enabling sustainable industry evolution?
- Motivating example – Azores Islands (Flores and Sao Miguel)
- The main challenge/idea –from constraining to enabling in a multi-stakeholders environment
- A possible unifying approach?--next generation SCADA with well-defined protocols (Dynamic Monitoring and Decision Systems (DyMonDS))
- Key relevance of simulation-based scalable test beds. Smart Grid in a Room Simulator (SGRS) –NIST collaboration with CMU/EESG approach to moving forward http://www.eesg.ece.cmu.edu/

# The system works today, but…

- Increased frequency and duration of service interruption (effects measured in billions)
- Major hidden inefficiencies in today's system (estimated 25% economic inefficiency by FERC)
- Deploying high penetration renewable resources is not sustainable if the system is operated and planned as in the past (``For each 1MW of renewable power one would need .9MW of flexible storage in systems with high wind penetration" –clearly not sustainable)
- Long-term resource mix must serve long-term demand needs well

# Contextual complexity facing design and operations



# Broader role of information technology (IT) in transforming ill-conditioned into well-structured design problems [3]

- **Observations relevant for smart grid R&D agenda**

--Real gap between the needs and innovation methods

http://energy.gov/epsa/quadrennial-energy-review-qer; http://www.energy.gov/epsa/initiatives/revolution-now

--Particularly striking lack of viewing the problem as system design problem with many stakeholders and with an eye on potential for software-enabled novel architectures (new SCADA)

--The main challenge: Making the case for systems R&D&D

--Our belief: The main opportunity to modernize by al stakeholders (including utilities—major role); next generation SCADA as the main enabler (utility role)

# Broad role of smart grids--Making the most out of the naturally available resources given socio environment?

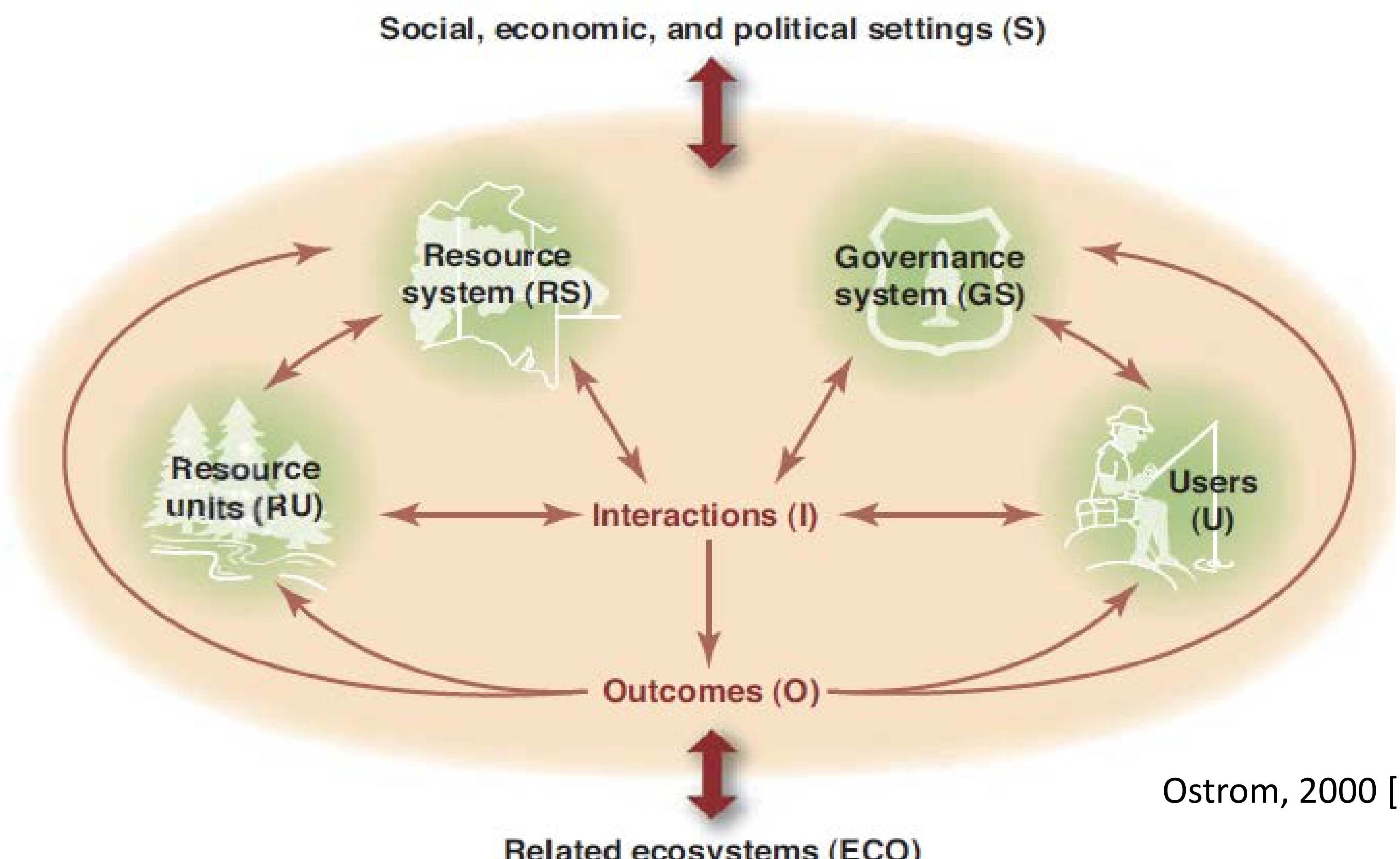



**Fig. 1.** The core subsystems in a framework for analyzing social-ecological systems.

Ostrom, 2000 [3]

# "Smart Grid" ←→ electric power grid and IT for enabling sustainable energy SES

| Energy SES | Man-made Grid | Man-made ICT |
|---|---|---|
| • Resource system (RS)<br>• Generation (RUs)<br>• Electric Energy Users (Us) | • Physical network connecting energy generation and consumers<br>• Needed to implement interactions | • Sensors<br>• Communications<br>• Operations<br>• Decisions and control<br>• Protection |

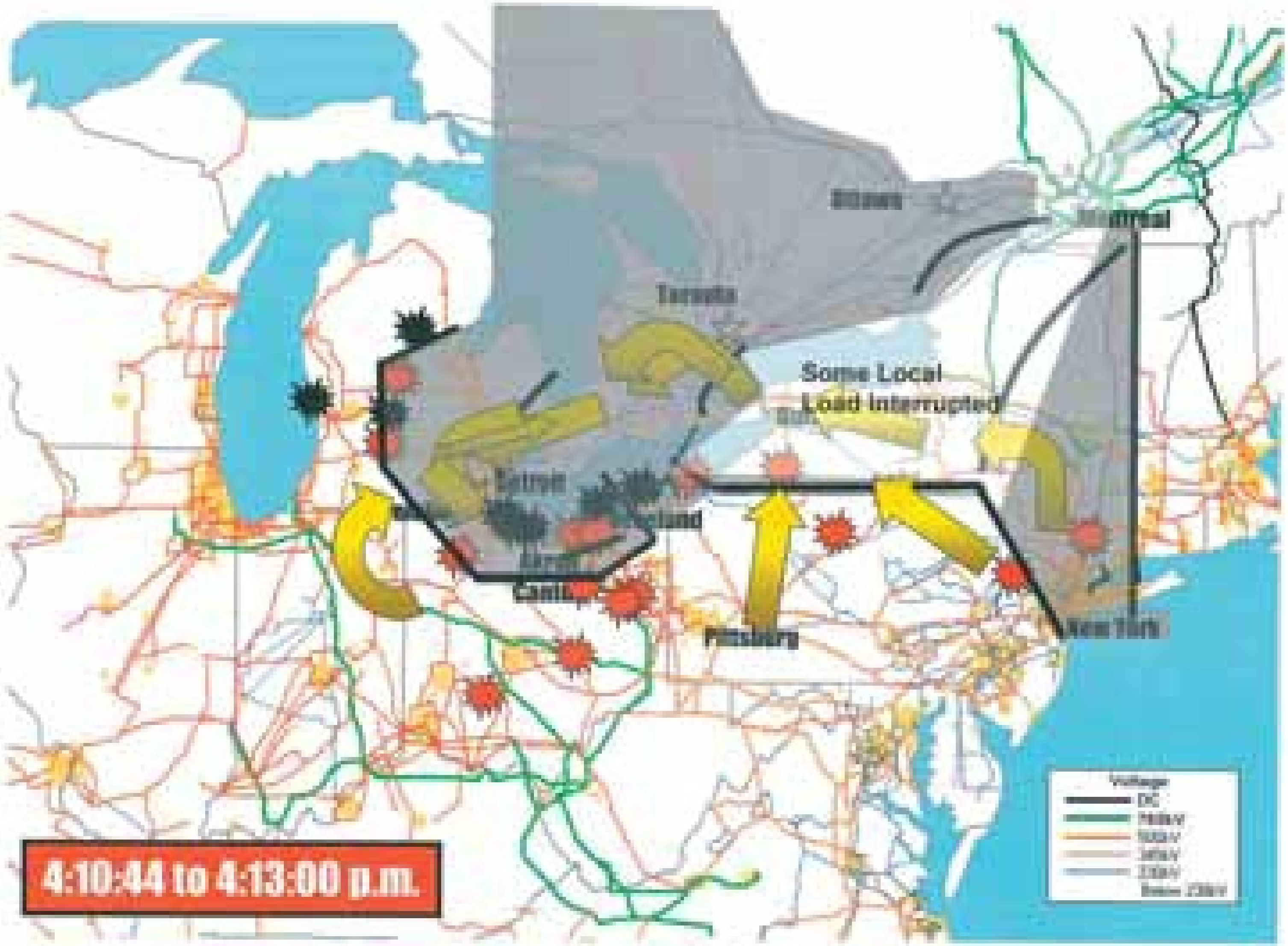
References: [7], [8], [17]

# Integrating combination of technologies at value?

- Value is a system-dependent concept (time over which decision is made; spatial; contextual)
- Cannot apply capacity-based thinking; cannot apply short-run marginal cost thinking
- Reconciling economies of scope and economies of scale
- Value of flexibility (JIT,JIP, JIC)
- Hardware, information, decision-making software; distributed, coordinated –all have their place and value

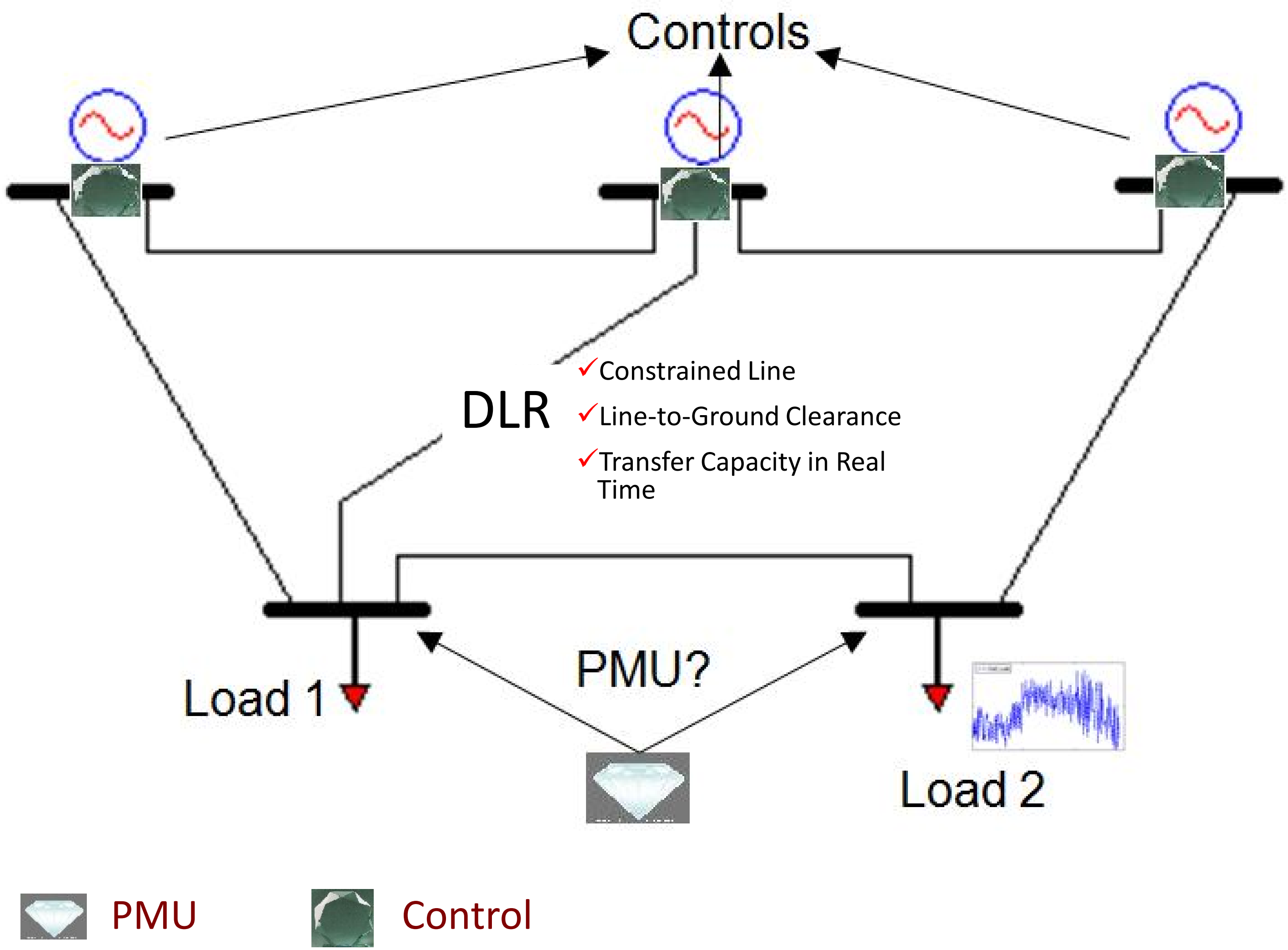
# Low hanging fruits and longer term goals

- Higher utilization of available physical capacity by embedding IT into various system components, multi-directional information exchange and IT-enabled decision making by all
- Minimal coordination could go a very long way to ensuring sustainable services (potential for avoiding blackouts)




Minimal IT coordination could have avoided  2003 blackout…[5]

# Value of real-time data driven automation (PMUs,WAMS)?





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# Motivating example--Azores Island, Flores


Figure 1: Satellite image of Flores Island.

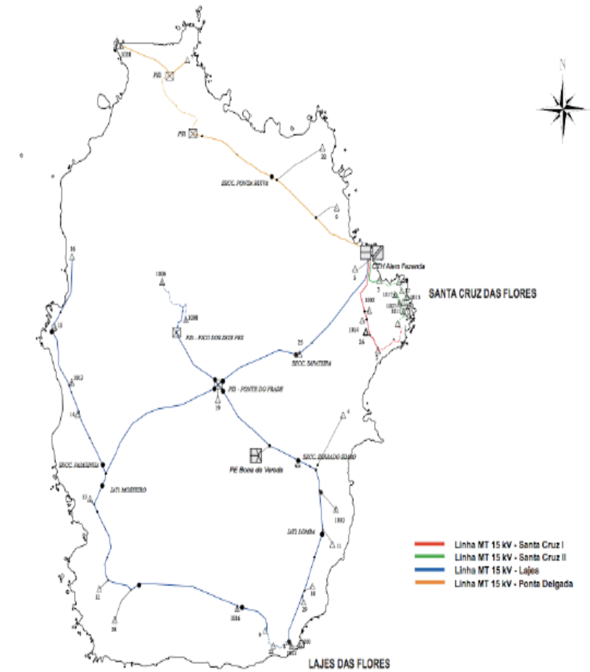
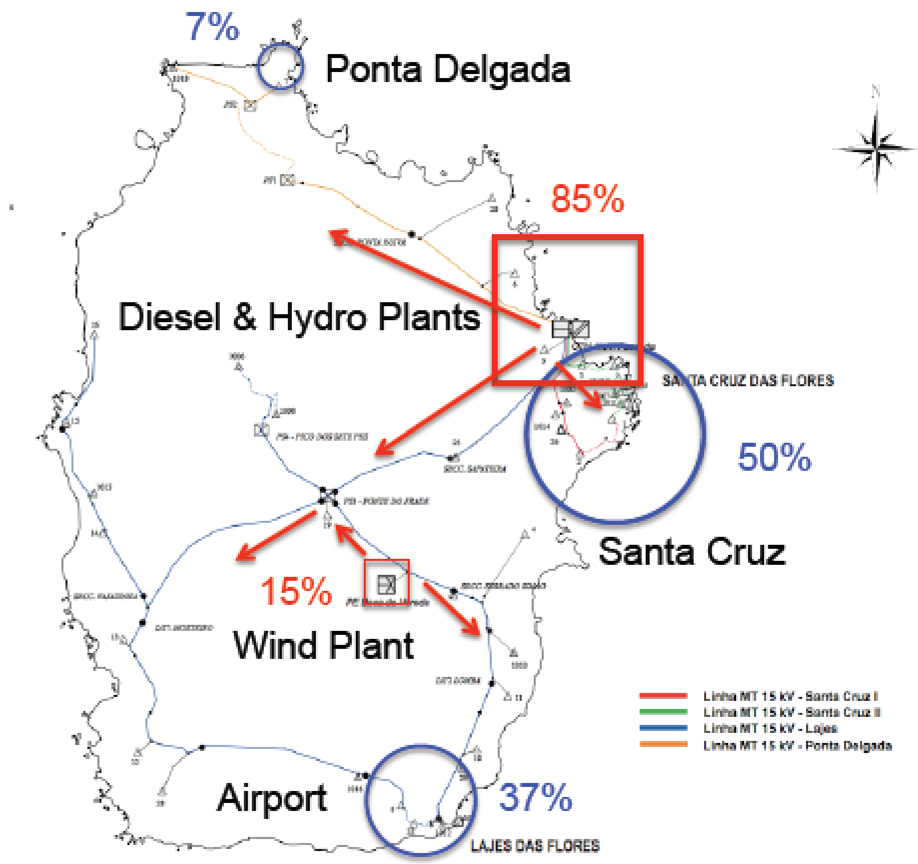


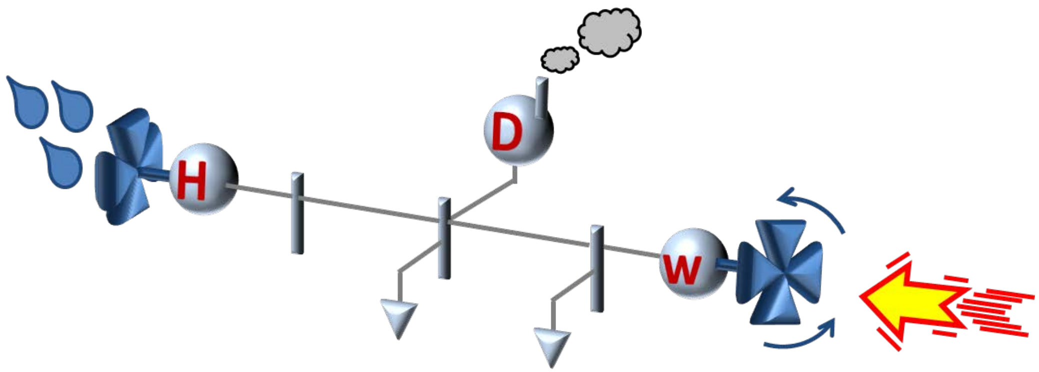

Figure 2: Electrical Network of Flores Island.

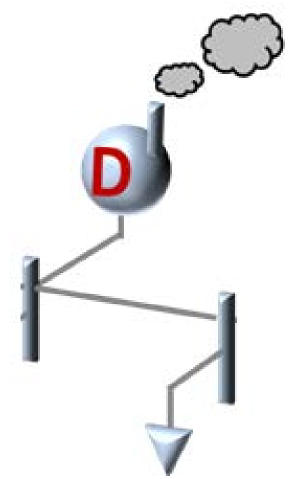
Ilic et al, 2013 [7,8]

# Motivating example---From old to new paradigm—Flores Island Power System, Portugal



# Controllable components—today's operations (very little dynamic control, sensing)

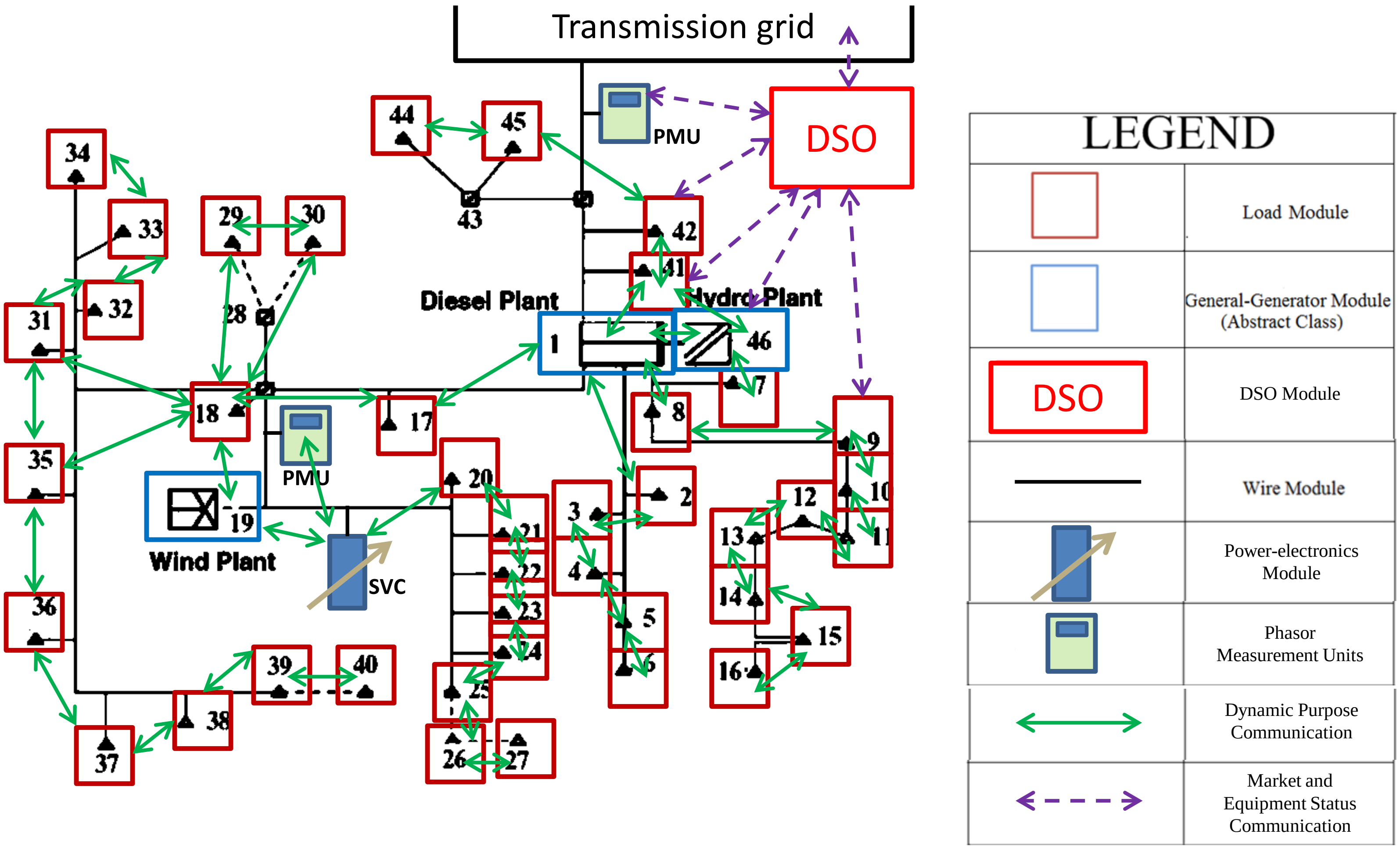



**H** – Hydro
**D** – Diesel
**W** – Wind

*Sketch by Milos Cvetkovic

# Information exchange in the case of Flores---new (lots of dynamic control and sensing)



# Opportunities/incentives for value-based innovation by all?

- Proof-of-concept-low-cost clean Azores islands
- Enable integration/use of clean energy (wind, PVs) at value
- Different stakeholders bring different value
- Utilities are key to designing enabling delivery at value

- new software/SCADA to gather binding info about who needs what and willingness to pay/be paid; minimal secure info to enable exchange to invest/operate at well-defined value; minimal coordination to optimize system performance and ensure reliability given info from grid users

-possible to give incentives for voltage optimization of T&D equipment; reconfiguration; deployment of remote switching/control/monitoring;

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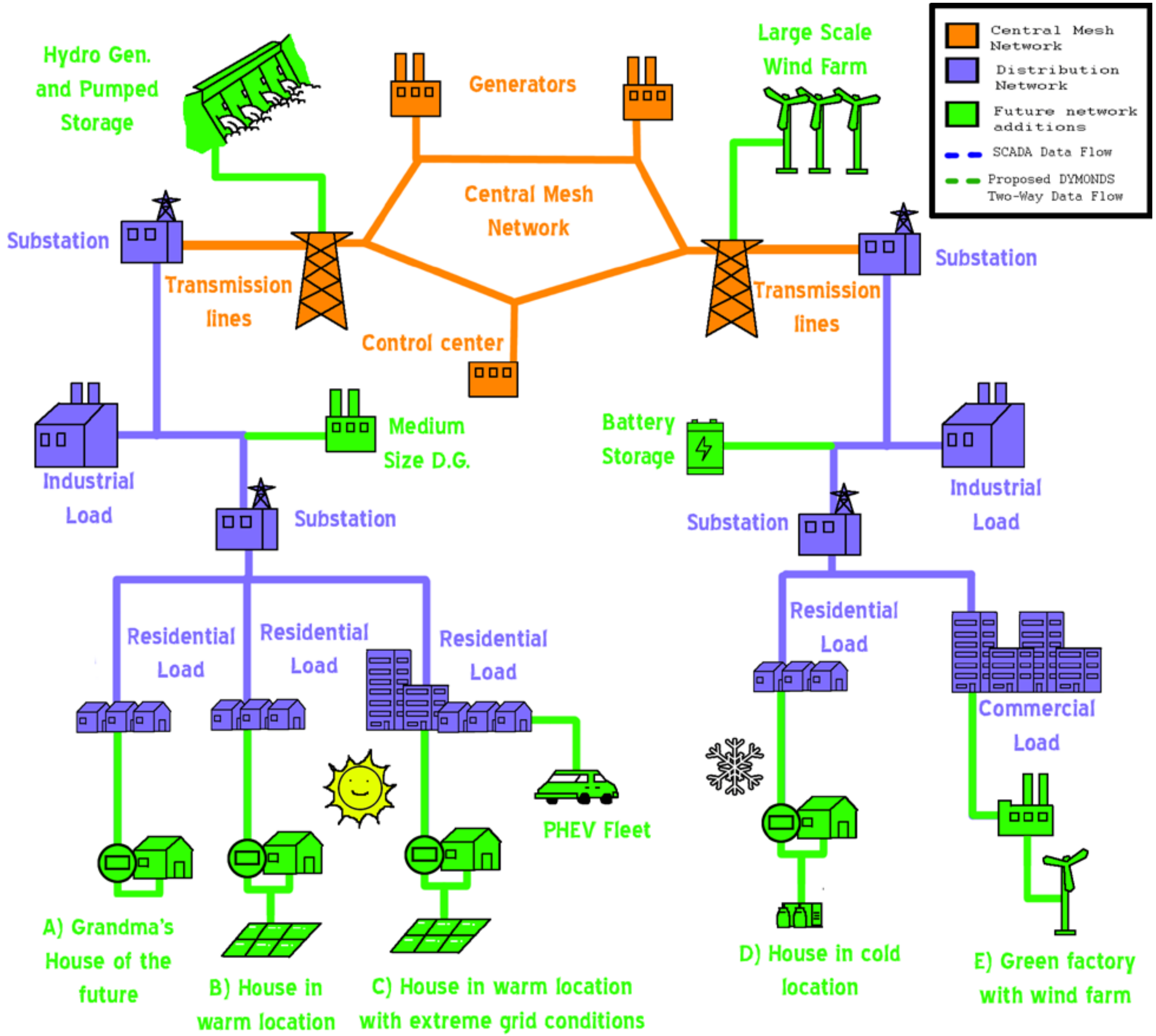
# The need for qualitatively new paradigm

- The old ways of looking at problems no longer work.
- To understand the wicked problems requires much more sophisticated perspectives that include what previously was ignored.
- Without this understanding there will be no sustainable innovation.
- Individual actors concerned with their own objectives sub-optimize.
- Evolution of the system is/should be of interest.
- Potential for system evolution from rigid hierarchically controlled entity (dominated by (N-1) preventive approach) to a more dynamic real-time optimized and information-driven entity of greater long-term robustness and efficiency.

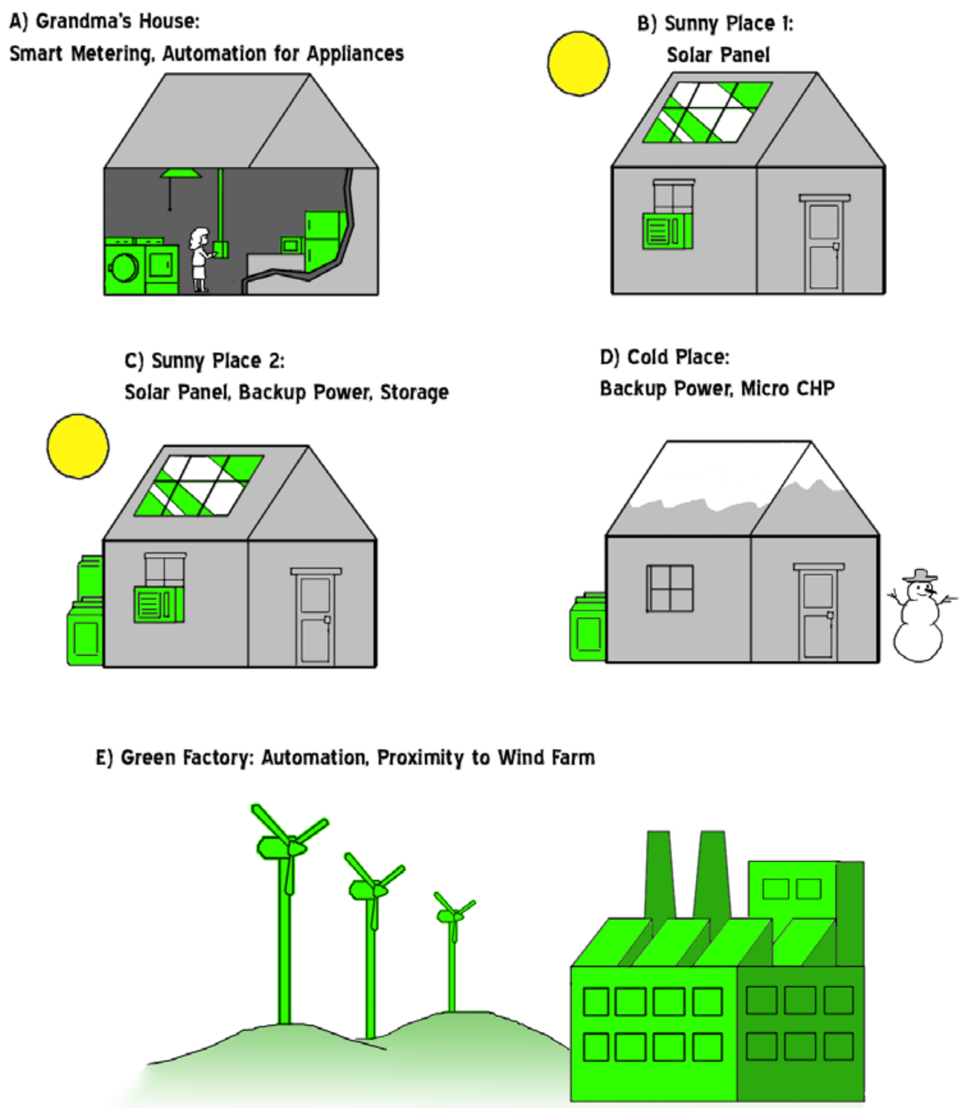
# The main challenge/idea –from constraining to enabling in a multi-stakeholders environment

| Single optimization subject to constraints | Enabling (reconciling) tradeoffs |
|---|---|
| Schedule supply to meet given demand | Schedule supply to meet demand (both supply and demand have costs assigned) |
| Provide electricity at a predefined tariff | Provide electricity at QoS determined by the customers willingness to pay |
| Produce energy subject to a predefined $CO_2$ constraint | Produce amount of energy determined by the willingness to pay for $CO_2$ effects |
| Schedule supply and demand subject to transmission congestion | Schedule supply, demand and transmission capacity (supply, demand and transmission costs assigned) |
| Build storage to balance supply and demand | Build storage according to customers willingness to pay for being connected to a stable grid |
| Build specific type of primary energy source to meet long-term customer needs | Build specific type of energy source for well-defined long-term customer needs, including their willingness to pay for long-term service, and its attributes |
| Build new transmission lines for forecast demand | Build new transmission lines to serve customers according to their ex ante (longer-term) contracts for service |

# A possible unifying approach?--next generation SCADA with well-defined protocols



# Diverse users



# System paradigm change

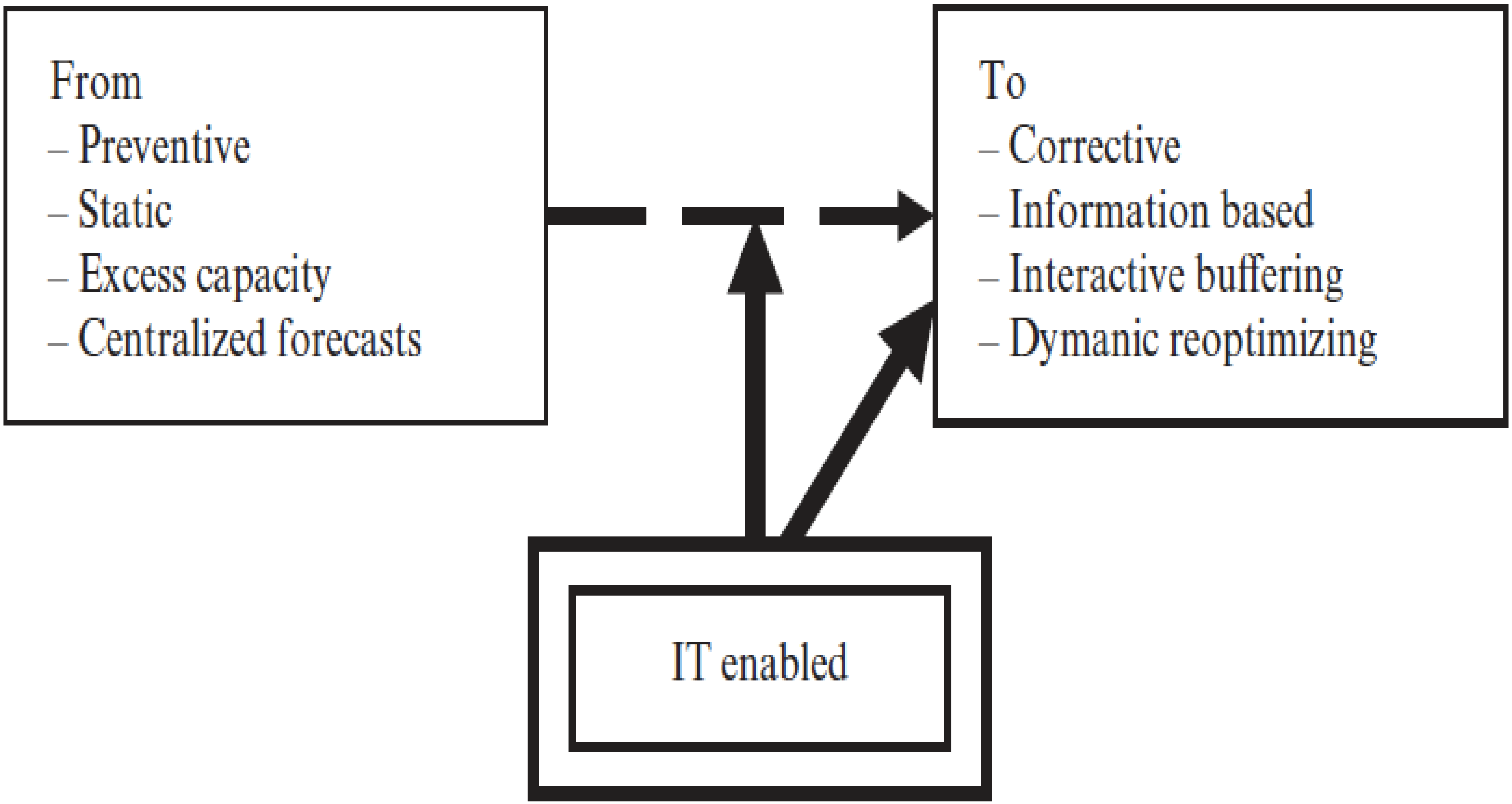



*Figure 7.7 System paradigm change in the electricity sector*

# Dynamic Monitoring and Decision Systems (DyMonDS)

- From single top-down coordinating management to the multi-directional multi-layered interactive IT exchange. [7,8,17]

- At CMU we call new transformed SCADA Dynamic Monitoring and Decision Systems (DYMONDS) and have formed a Center to work with industry and government on: (1) new models to define what is the type and rate of key IT exchange; (2) new decision tools for self-commitment and clearing such commitments. \http:www.eesg.ece.cmu.edu.

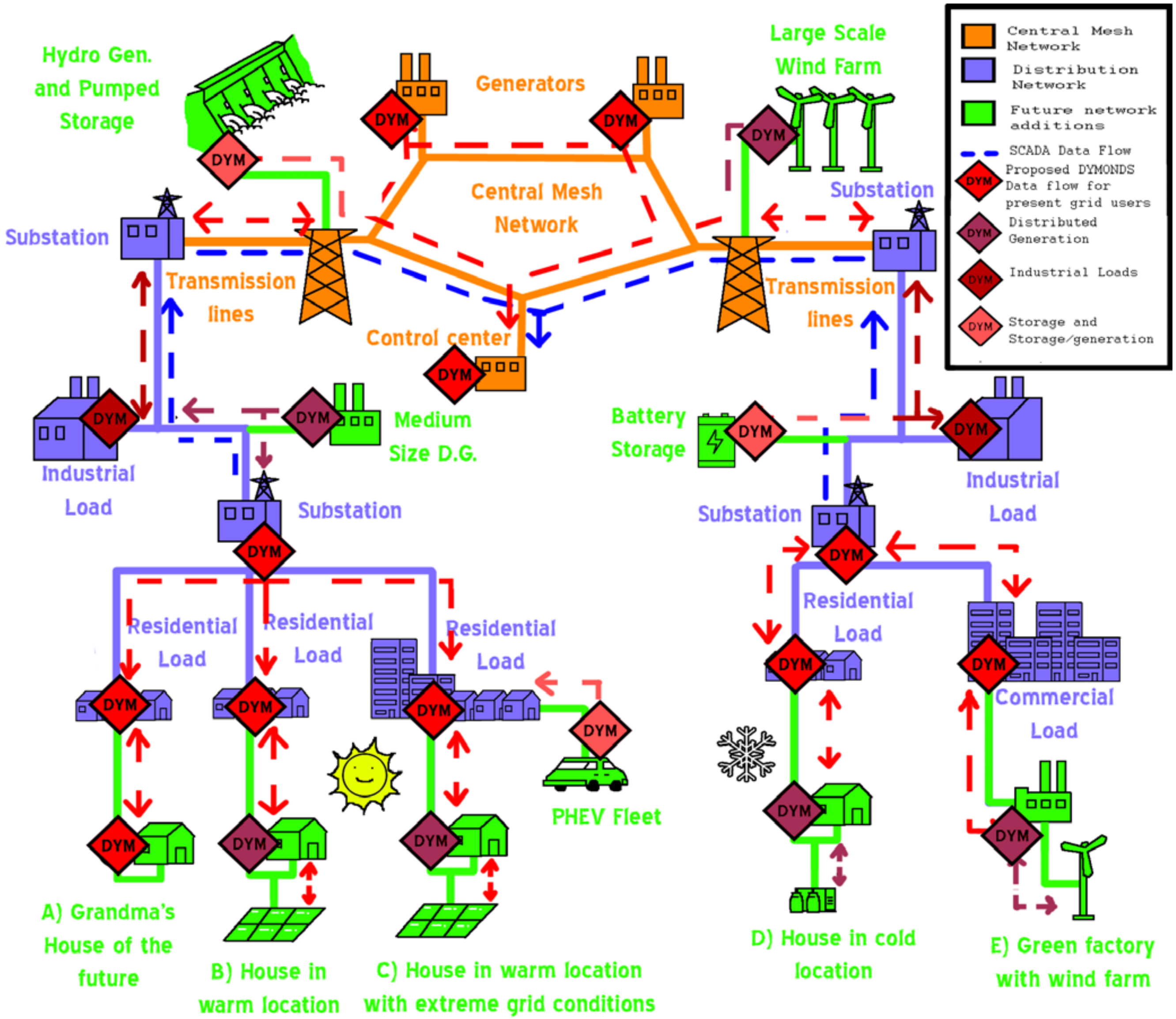
# T&D as an Enabler

- New dispatch of self-committed resources together with on-line power factor/voltage compensation will make it possible to fit different pieces of the puzzle together. [7,8,17]

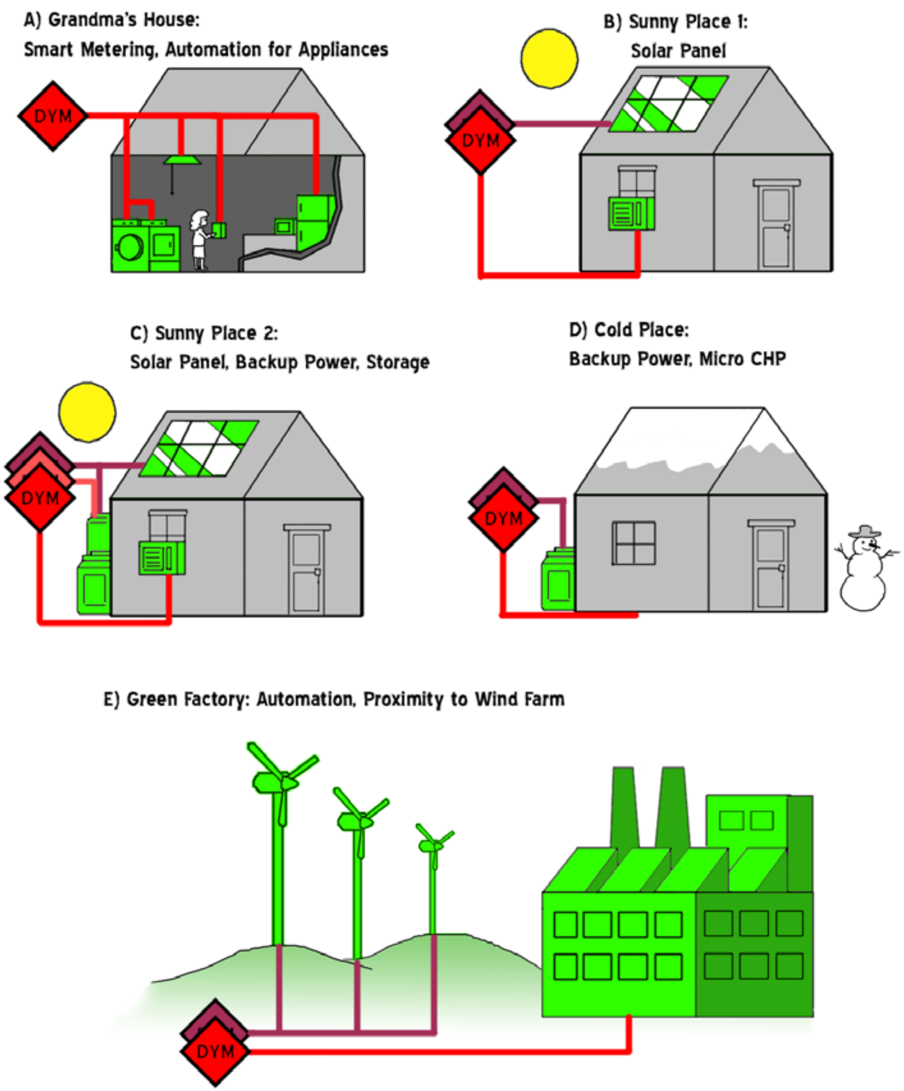
- Much more reliance on distributed sensing, actuation and coordinated management of these resources. Real time awareness of D flows.

- No models, no simulations, no decision tools. Without these, it will be much more costly to proceed. R&D ahead of us.

# DYMONDS-enabled Physical Grid

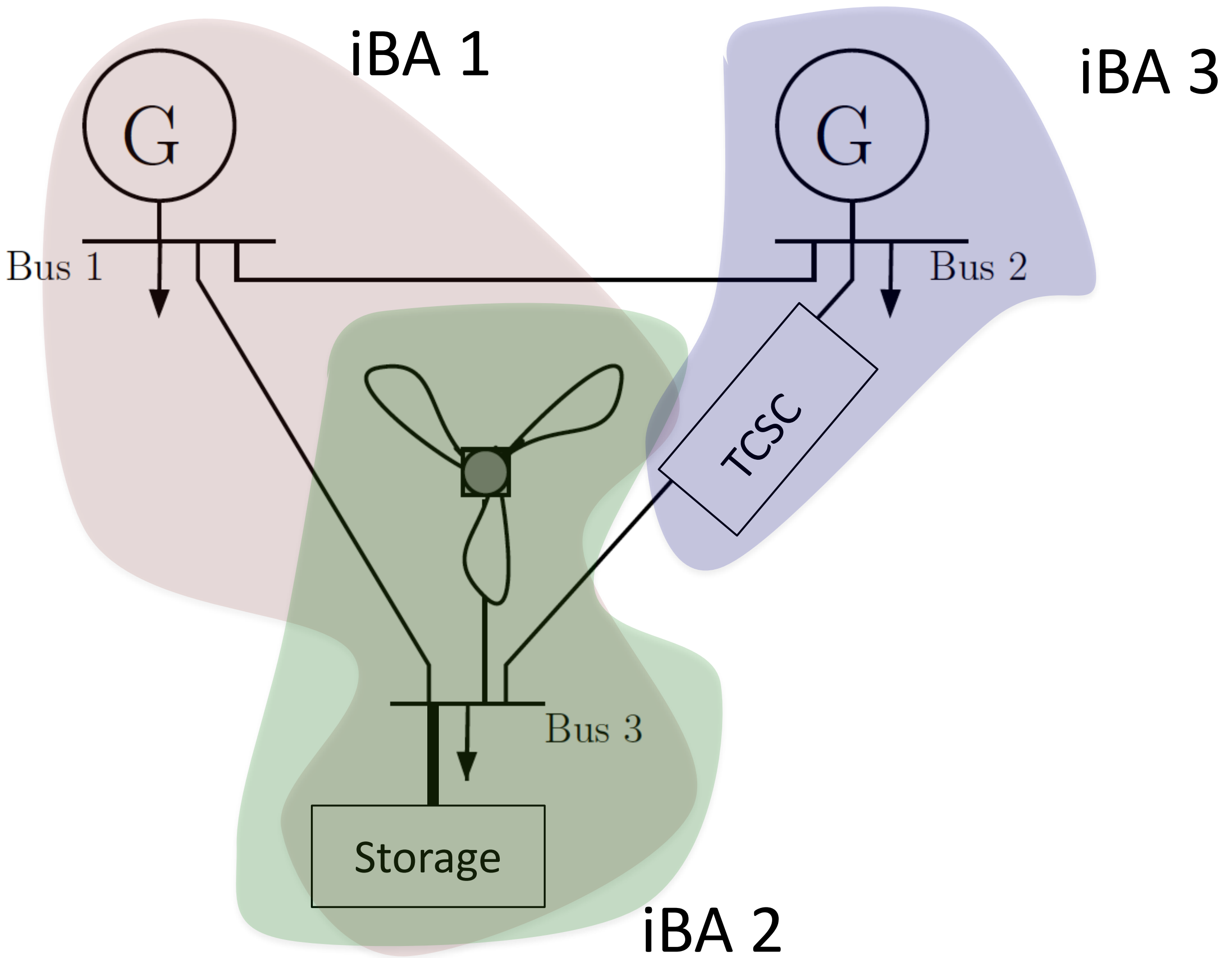


# Smart users



A) Grandma's House:
Smart Metering, Automation for Appliances
DYM
B) Sunny Place 1:
Solar Panel
DYM
C) Sunny Place 2:
Solar Panel, Backup Power, Storage
DYM
D) Cold Place:
Backup Power, Micro CHP
DYM
E) Green Factory: Automation, Proximity to Wind Farm
DYM

# Examples of iBAs—new ways of ensuring both reliable and efficient operations



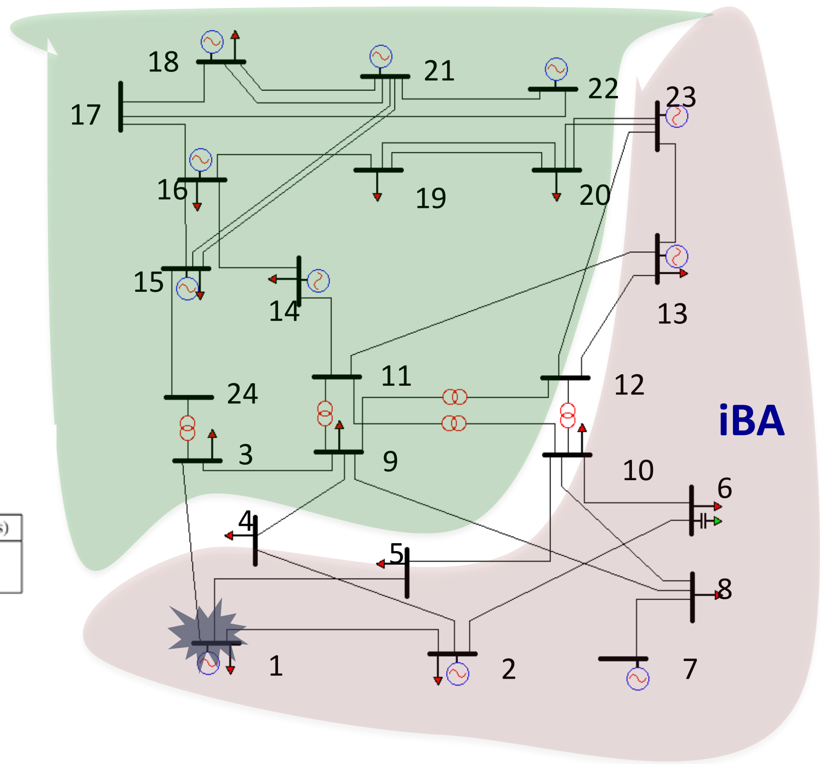
# Possible to create iBAs for meeting transient stability distributed standard

**Given disturbance**

Tripping of generator 1

TABLE I
CONTINGENCY CONSIDERED ON THE IEEE RTS 24 BUS SYSTEM

| CONTINGENCY (CATEGORY B) | DURATION (secs) |
|---|---|
| Tripping of generator 1 after 3-phase fault on its terminal bus | 0.17 |



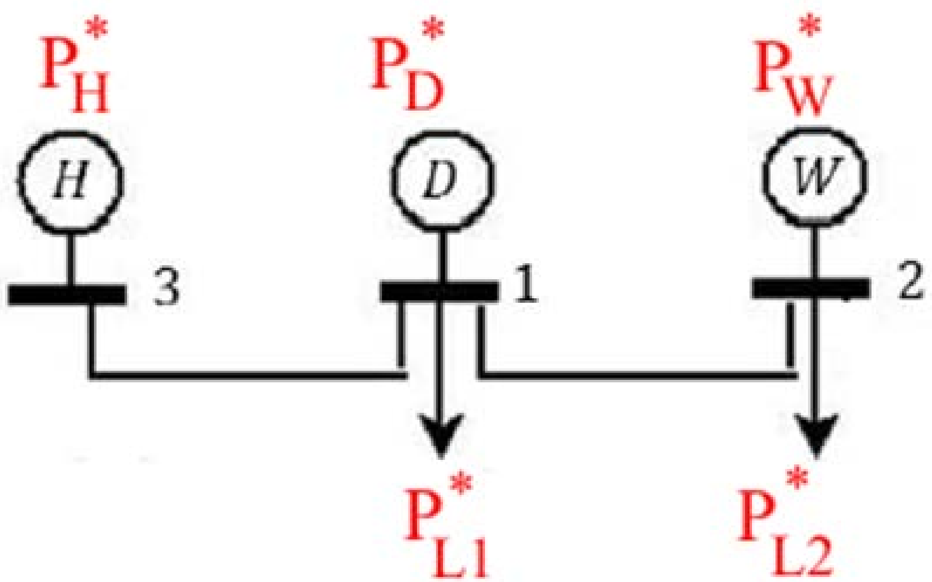

**S.Baros, M.Ilic** intelligent Balancing Authorities (iBAs) for Transient Stabilization of Large Power Systems IEEE PES General Meeting 2014

# Must simplify!

- Utilities are having  hard time adding all these new components and their smarts for simulating system-wide dynamics
- Is there a ``smarter" way to model and define modular functionalities so that the interconnected system meets  system-level performance? (university R&D role)
- Simulators to assess/demonstrate potential benefits from innovation before building
- Do not oversimplify!

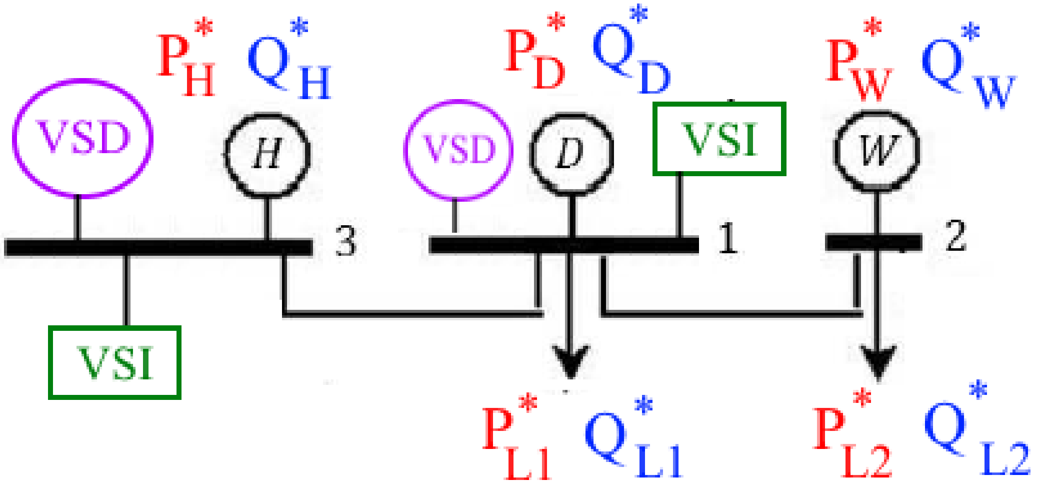
# Key relevance of simulation-based scalable test beds (Flores Island case) [18]

- Based on prices, market computes active power set points P* from each component



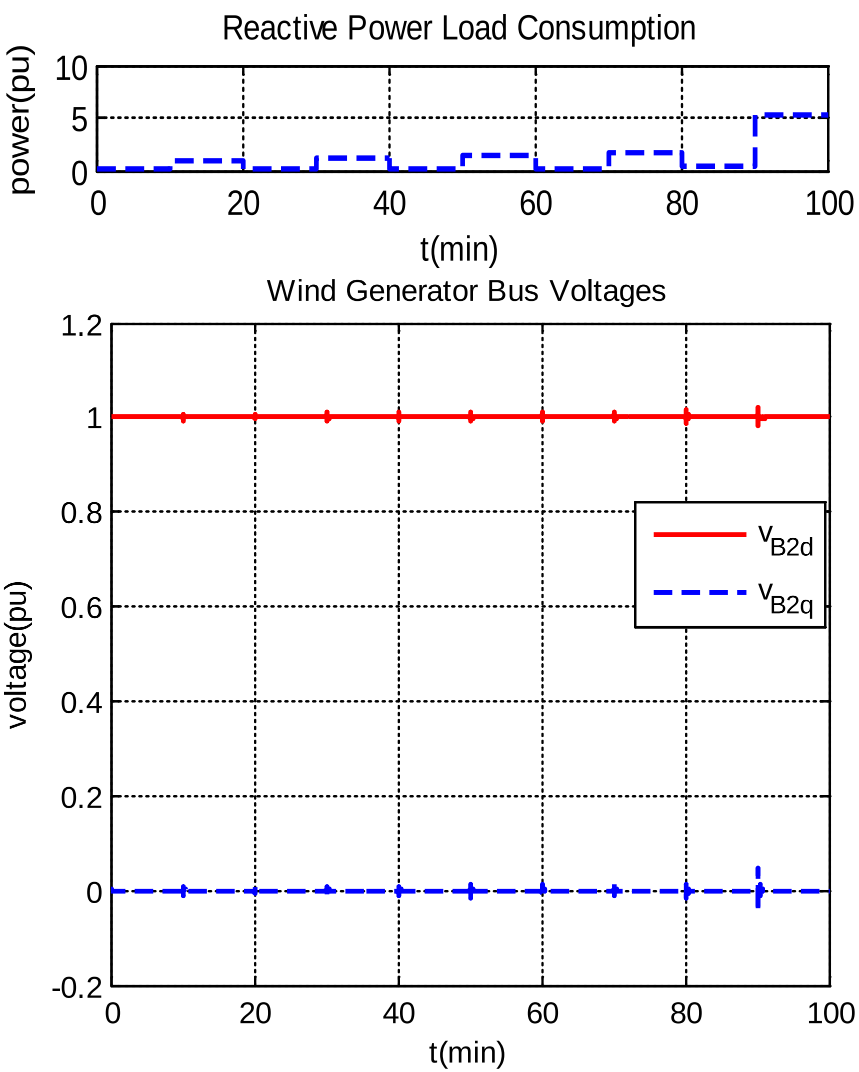
# Flores Island – Essential to exchange the right binding info

- Since currently the market does not specify reactive power set points Q*, data for Q* is randomly created
- Place a voltage source inverter and the variable speed drive on the hydro and diesel generator buses
- Control the sum of the power out of the hydro and diesel generators to match the active and reactive power set points

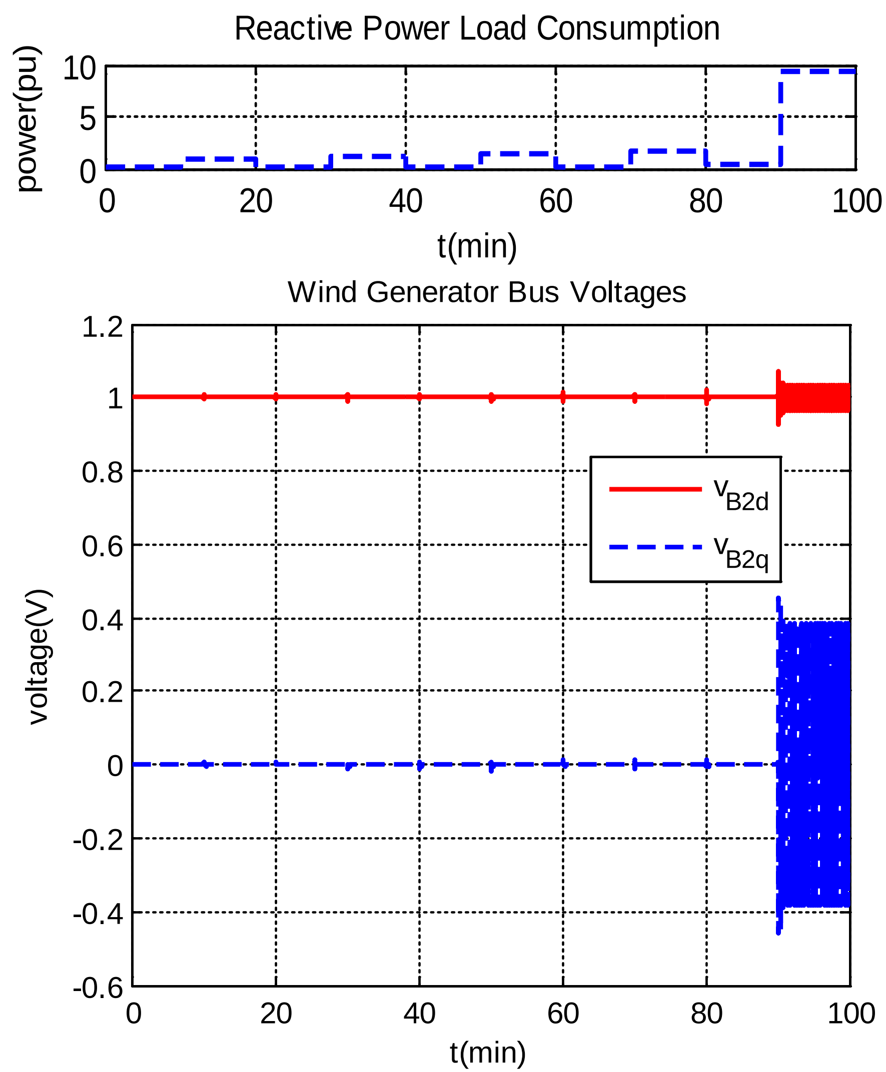


# Simulation Results – Combining Dynamics and ALM

## Stable Case:



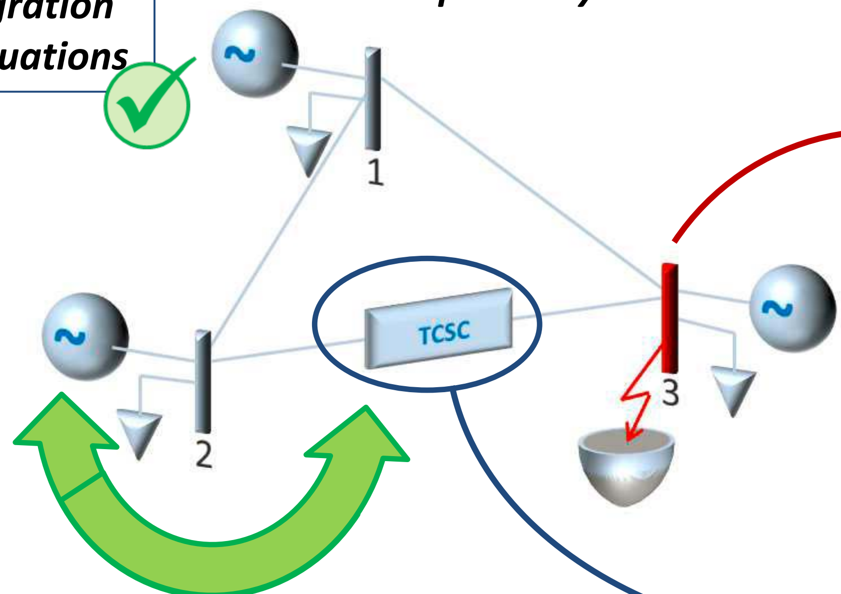

## Unstable Case:



# Transient Stabilization of Interactions Using PMUs/ FACTS [13]

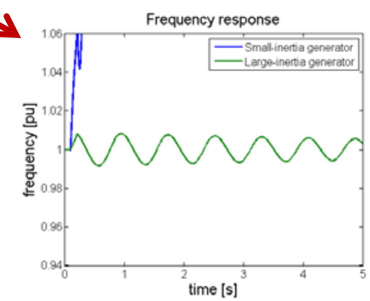
***Implications for SGRS distributed integration of differential equations***

***Large scale interconnected power system***

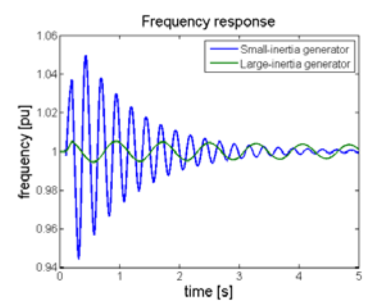



***Transient stability problem***

- ***Nonlinear dynamics***
- ***Multiple time scales***
- ***Large regions***




Unstable




Stable

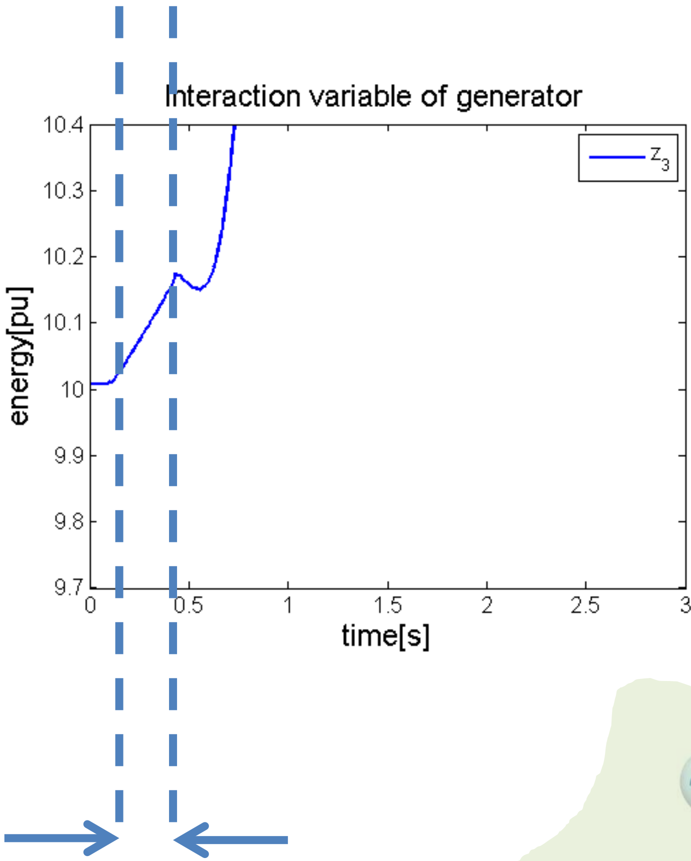
***Interactions are captured using an energy-based model***

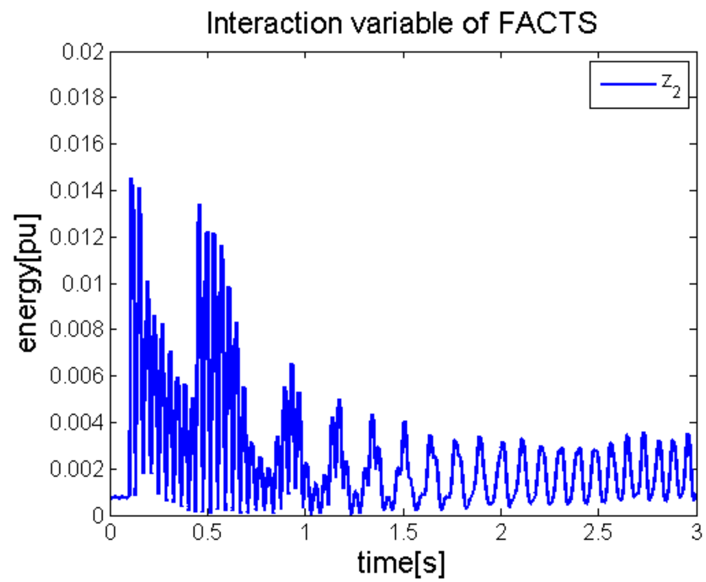
- ***Accumulated energy as a measure of stability***
- ***Managing energy to ensure stability***

***<u>Cooperative</u> power electronics (FACTS) control***

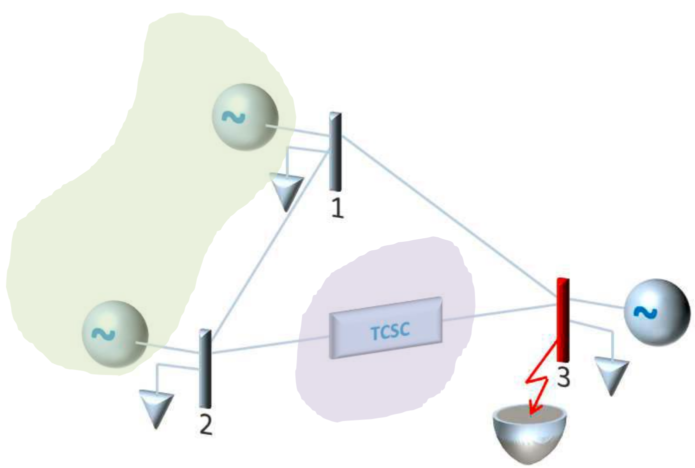
- ***Fast thyristor switching***
- ***Flow control***

# Response of Uncontrolled System



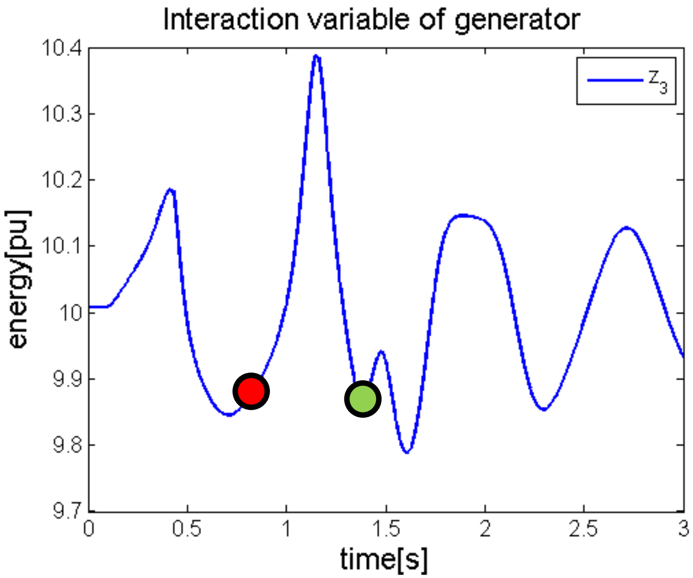



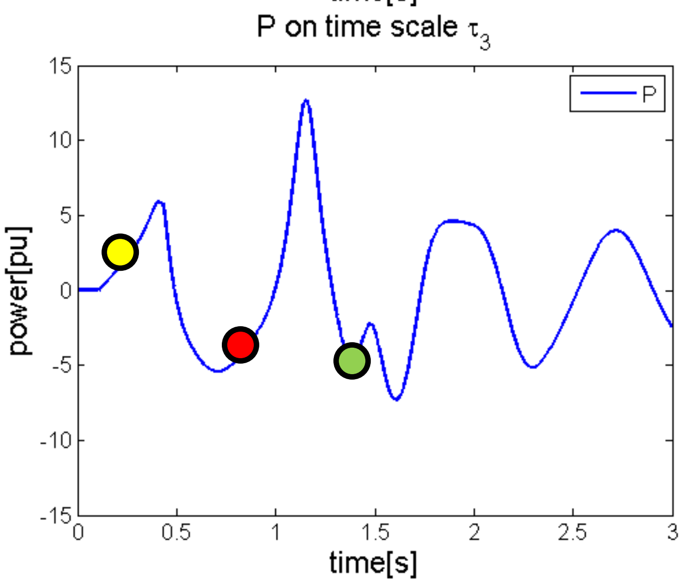

Short circuit at bus 3
in duration of 0.35 sec




M. Cvetkovic, M. Ilic, "*Cooperative Line-flow Power Electronics Control for Transient Stabilization*", IEEE Conference on Decision and Control, December 2014.

# Controlled System Response



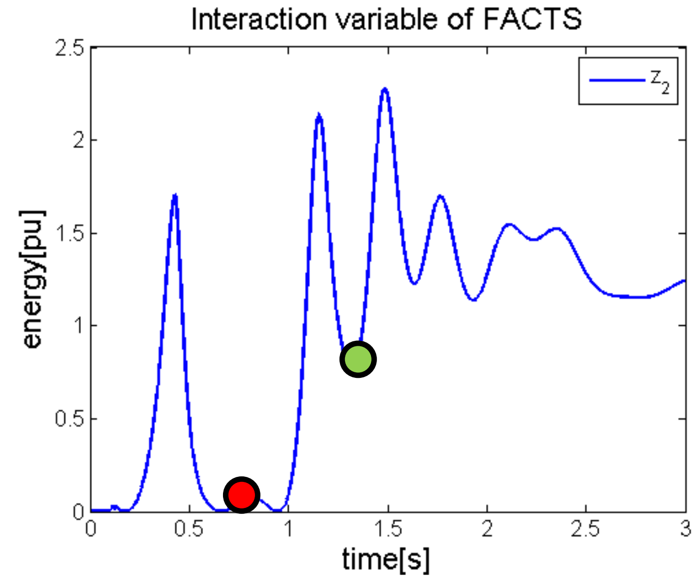



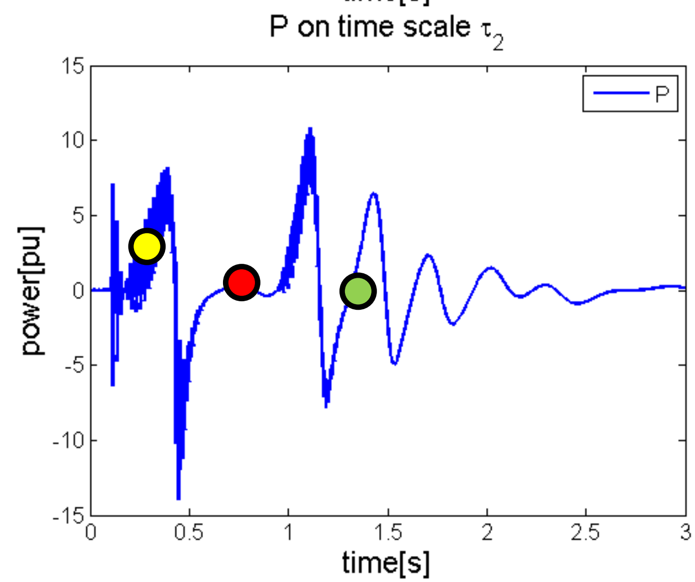

$$P_{\tau_3} = \frac{1}{\tau_3}\int_{\tau_2} P_{\tau_2}\,dt$$

$z_2 = 0$

FACTS energy has reached zero

States converge to a different equilibrium

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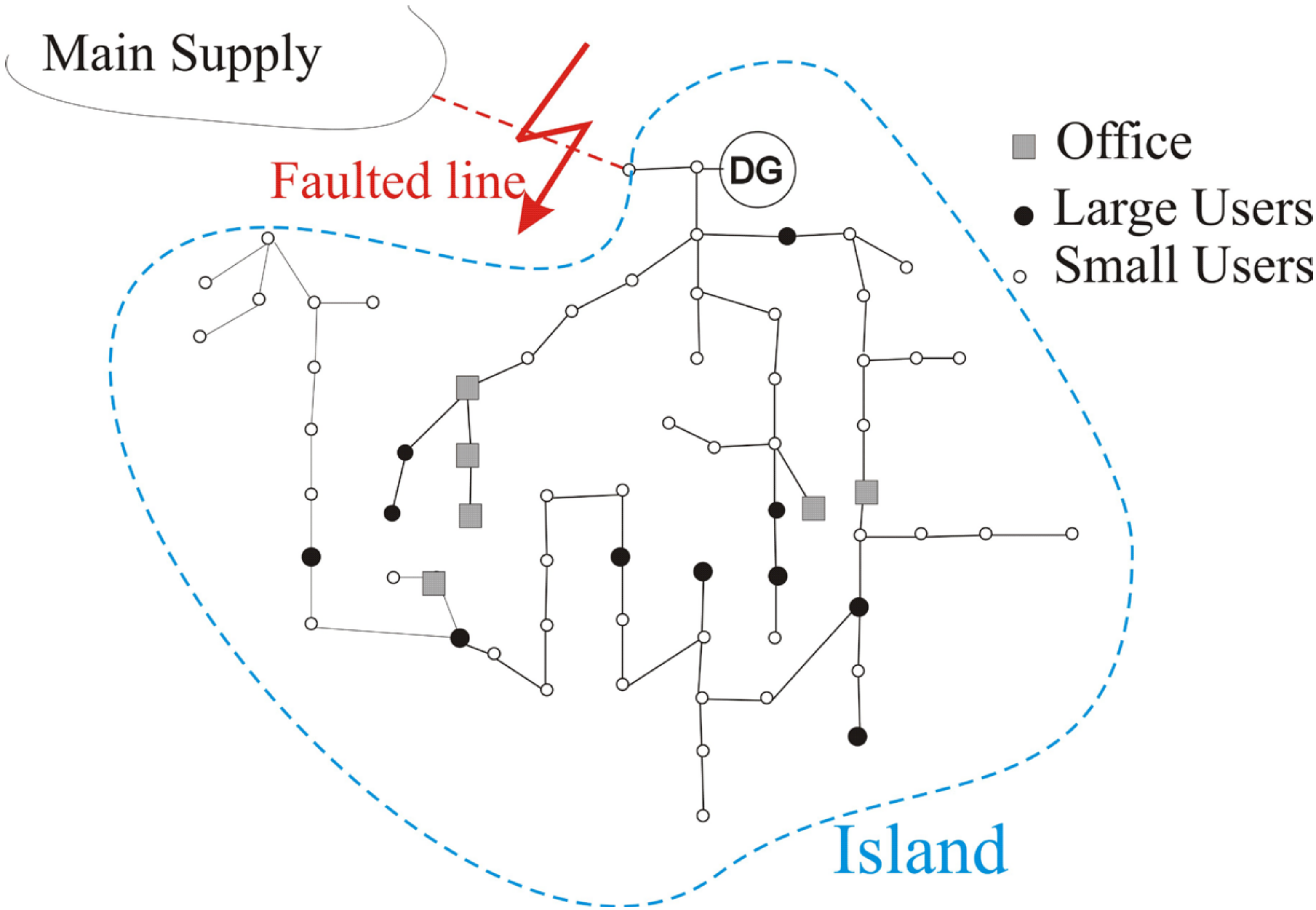
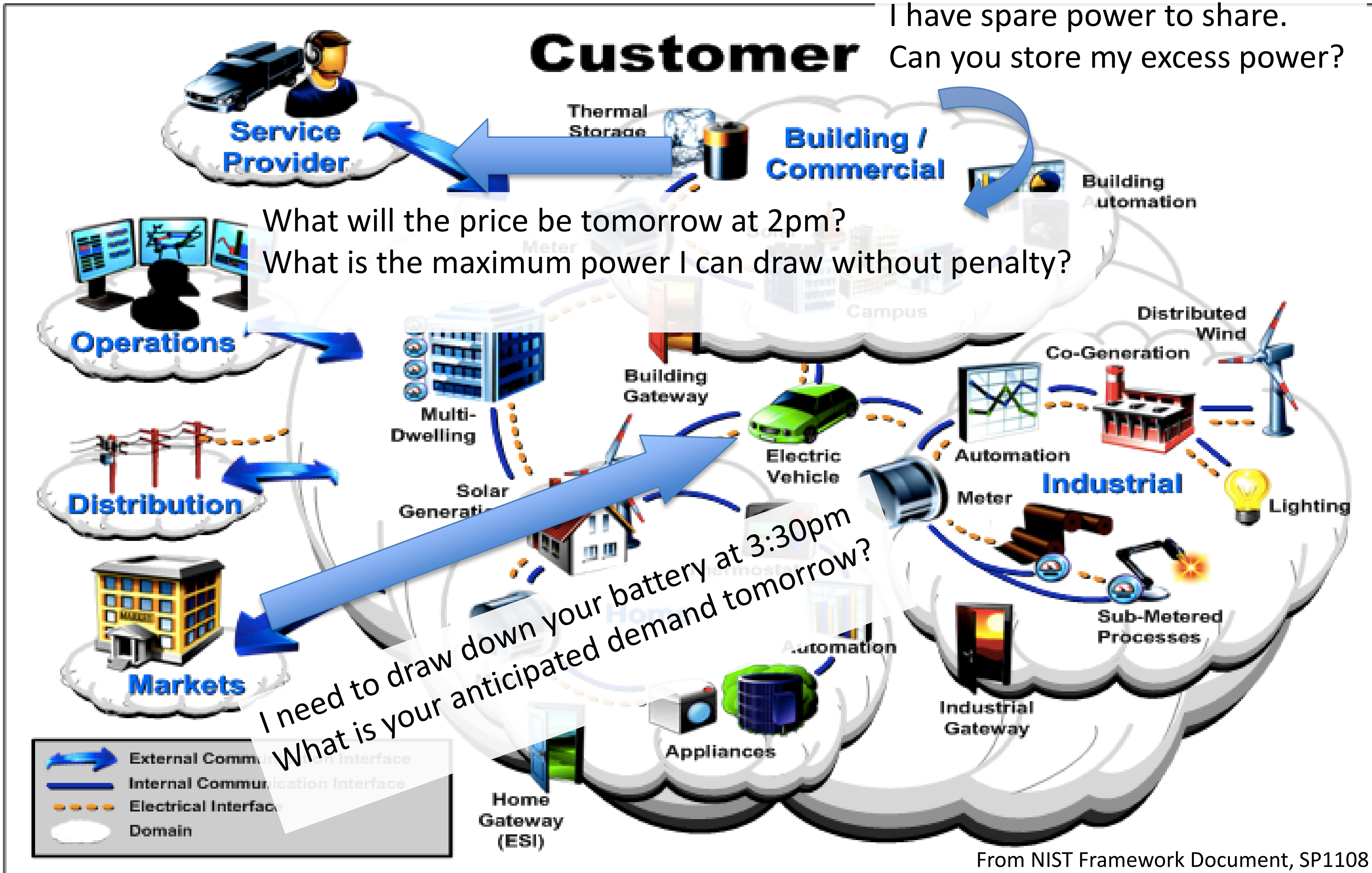
# Maximizing Reliable Service by Coordinated Islanding and Load Management



# CMU Smart Grid in a Room Simulator (SGRS)

Integration of Smart Consumers (DER) [14,18]




From NIST Framework Document, SP1108

# Concluding thoughts—hidden value of "smarts"- Enablers of….

- Significantly reduced spinning reserves (value of PMUs, closing the loop with FACTS; automation of storage control)
- Significant improvements in total fuel cost/customers bills while meeting (differentiated) service specifications (value of smart AC OPF software; good state estimator; smart switches)
- Customer choice/grid users choice or service
- Reduced service cost for given service specs
- Warning: It wont work without systematic physics-based modeling/software; new SCADA specifications.

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