Smart Grids as a Means of Implementing Sustainable Energy Services

The Key Role of Dynamic Monitoring and Decision Systems (DYMONDS)

Marija Ilic

milic@ece.cmu.edu

Talk Outline

- Some predictions of most likely architectures
- Three different architectures and the related R&D challenge
- Dynamic Monitoring and Decision Systems (DYMONDS) vision
- Demo of a rudimentary DYMONDS-based Smart Grid Simulator at CMU

Some predictions of (long-term) power network architectures

- Interstate EHV DC transmission connecting large nuclear power plants (backbone network)
- Closer to the end users a mix of

  -highly distributed micro-grids with their own back-up small power plants and/or connections to the backbone

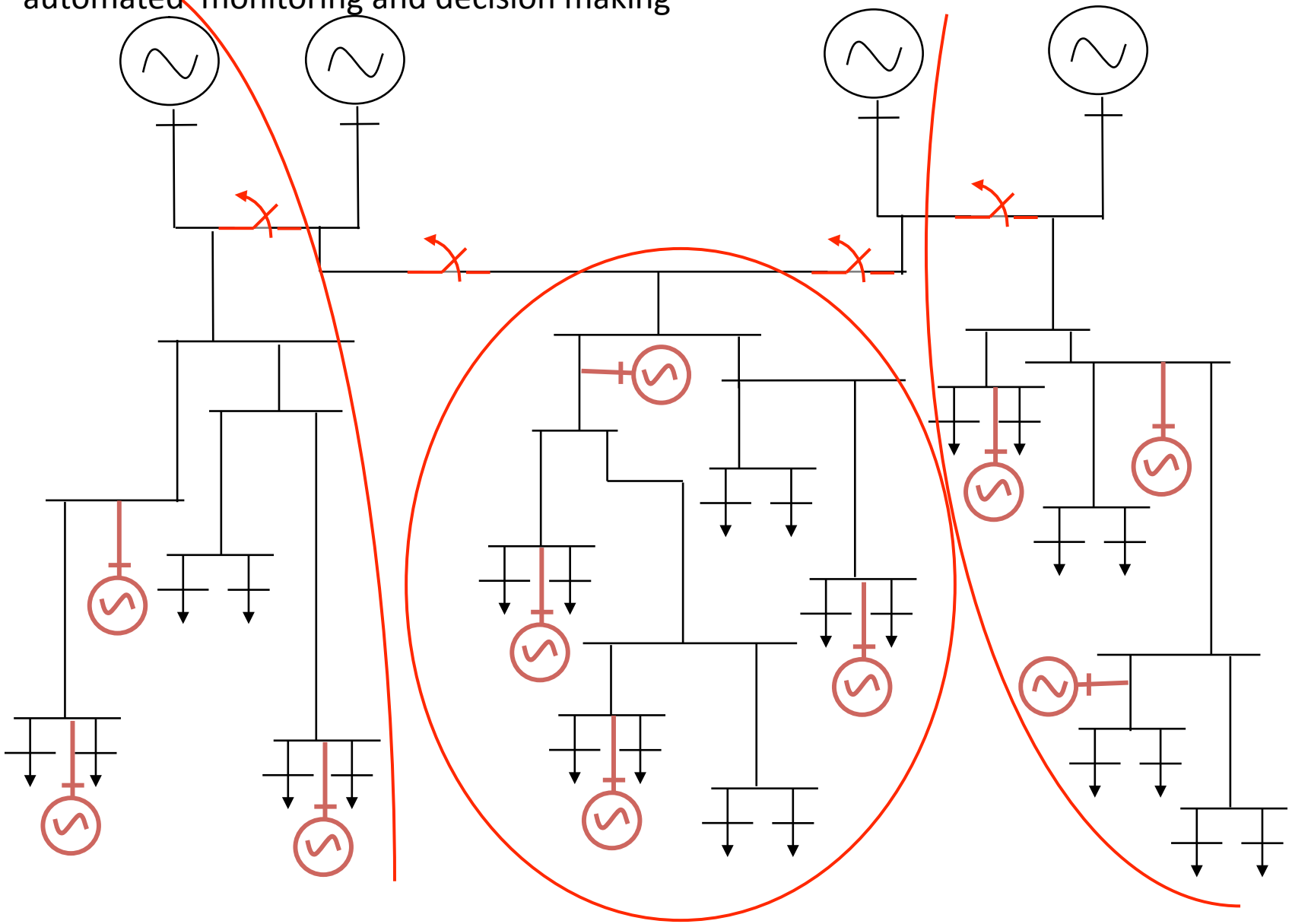
  -medium-sized fossil fuel/gas power plants
- Significant penetration of IT:

  -Making micro-grids highly flexible (BOTH reliable/secure and efficient!) with the end user actively participating;

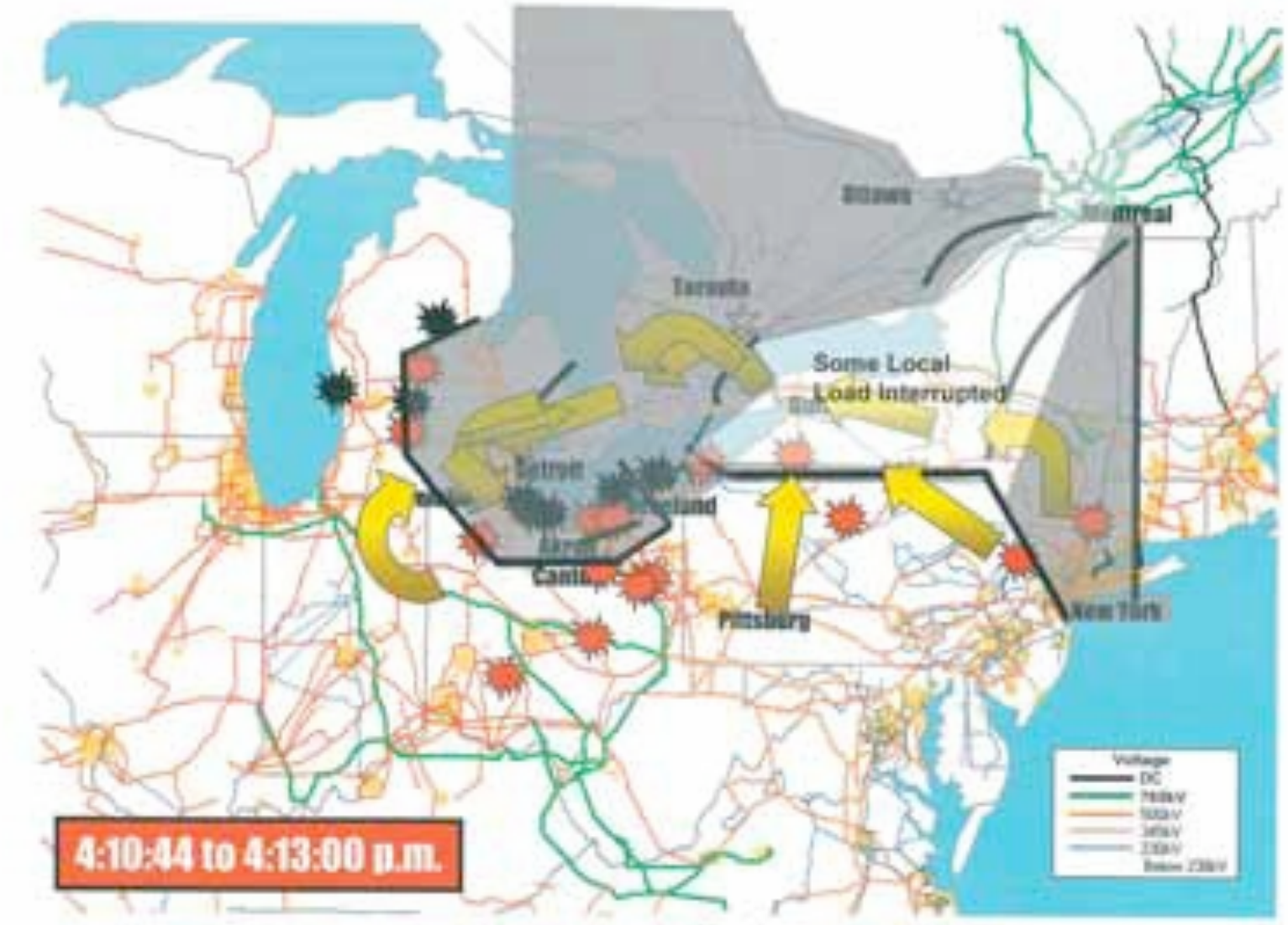
  -Facilitating on-line coordination of the backbone network and the micro-grids for reliability.

Today's Hierarchical Systems—Old Infrastructure

Complex large electric networks, operated in stationary ways; no near-real time automated monitoring and decision making



Often overstressed and prone to failures, yet sustained under-utilization

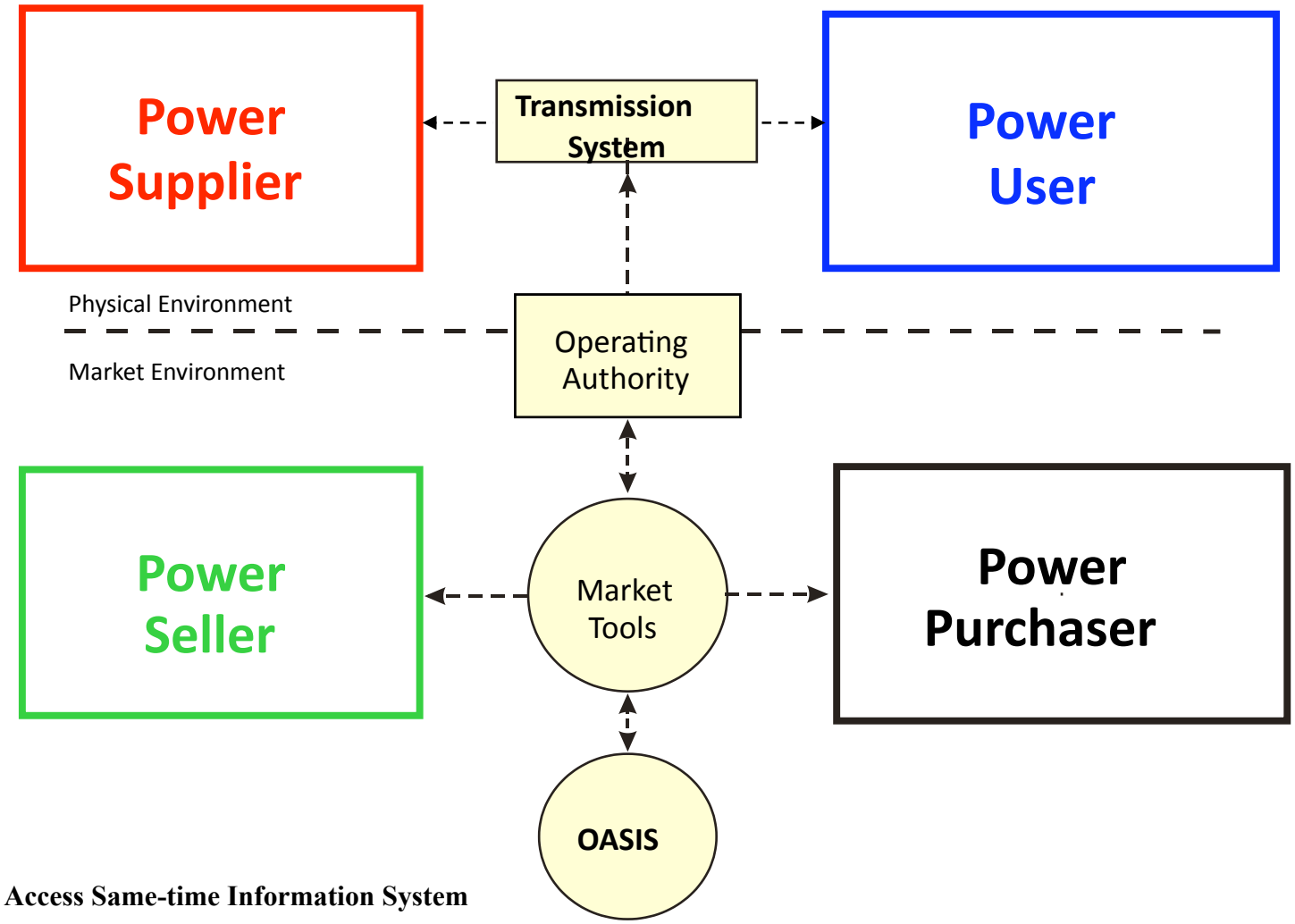


•Lots of equipment must be re-built (must understand engineering and policy to decide what is the right way to put it together);

• Need IT, and faster control and numerical algorithms to enable timely decisions.

Functional Unbundling of Regulated Utilities (Deregulation)

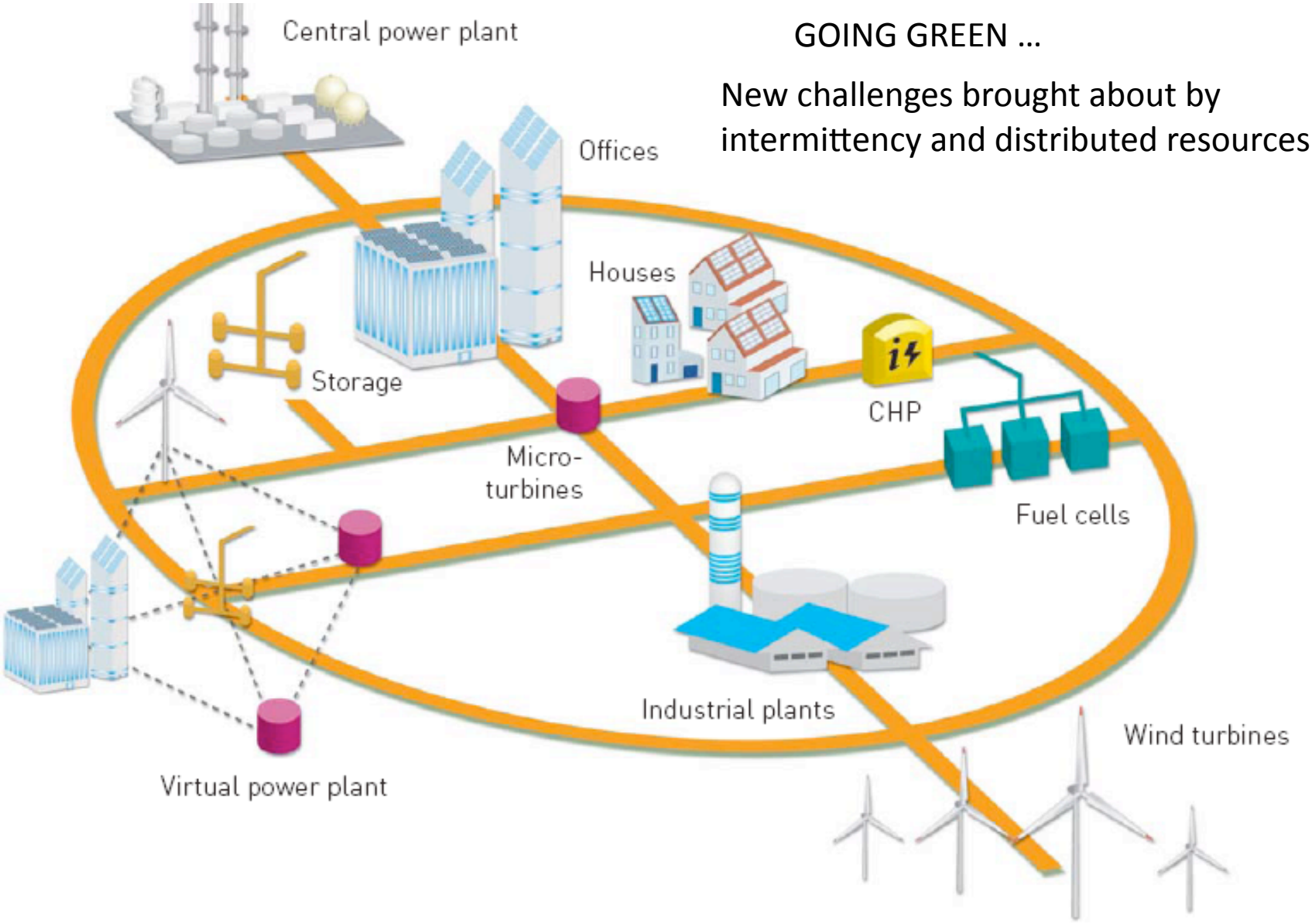
New challenges brought about by industry restructuring (need to operate real-time markets by means of IT; must know economics, policy, finance); not working well now—the markets never were designed properly



OASIS: Open Access Same-time Information System

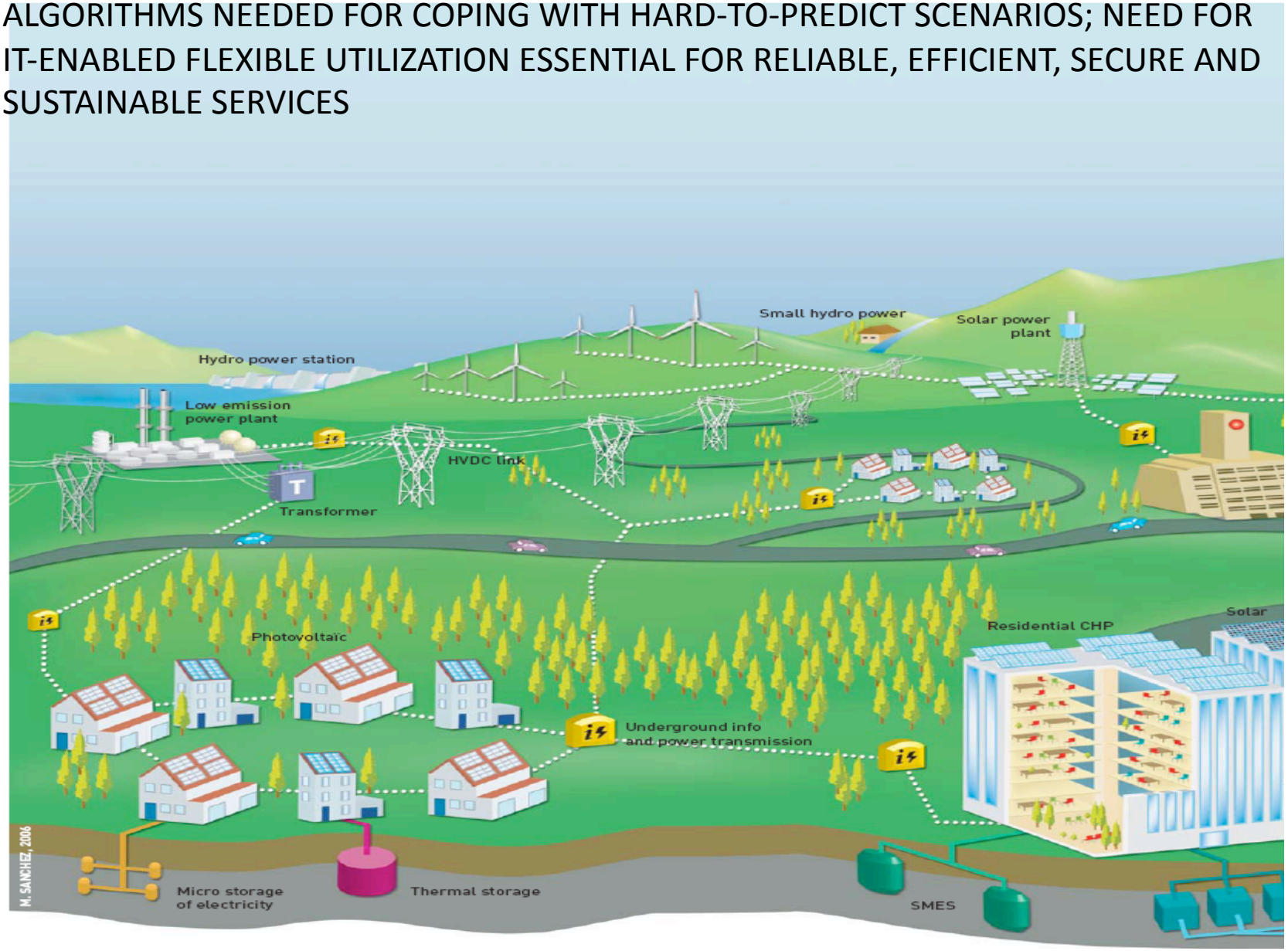
GOING GREEN …

New challenges brought about by intermittency and distributed resources

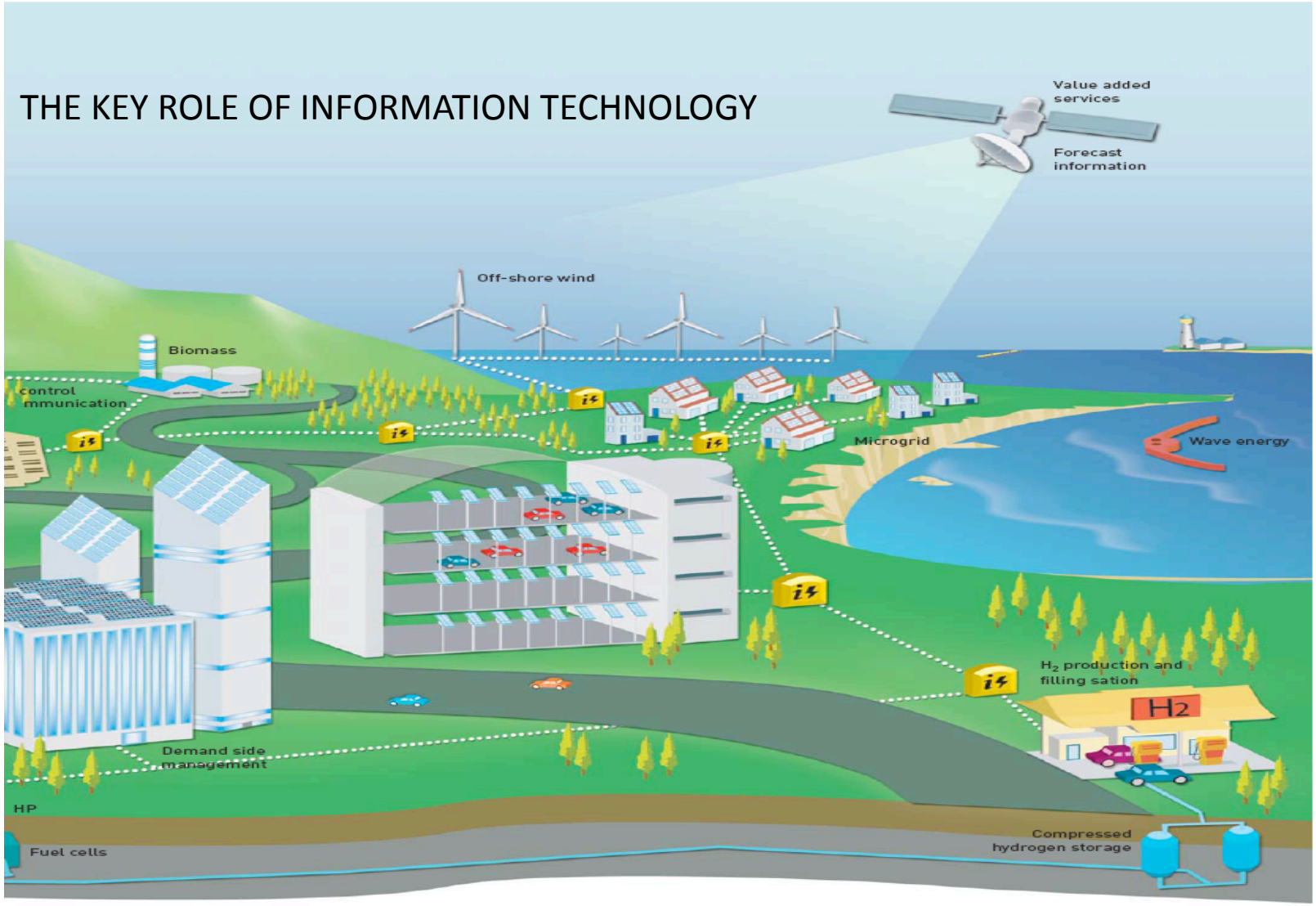


Future Network Vision

ALGORITHMS NEEDED FOR COPING WITH HARD-TO-PREDICT SCENARIOS; NEED FOR IT-ENABLED FLEXIBLE UTILIZATION ESSENTIAL FOR RELIABLE, EFFICIENT, SECURE AND SUSTAINABLE SERVICES



THE KEY ROLE OF INFORMATION TECHNOLOGY

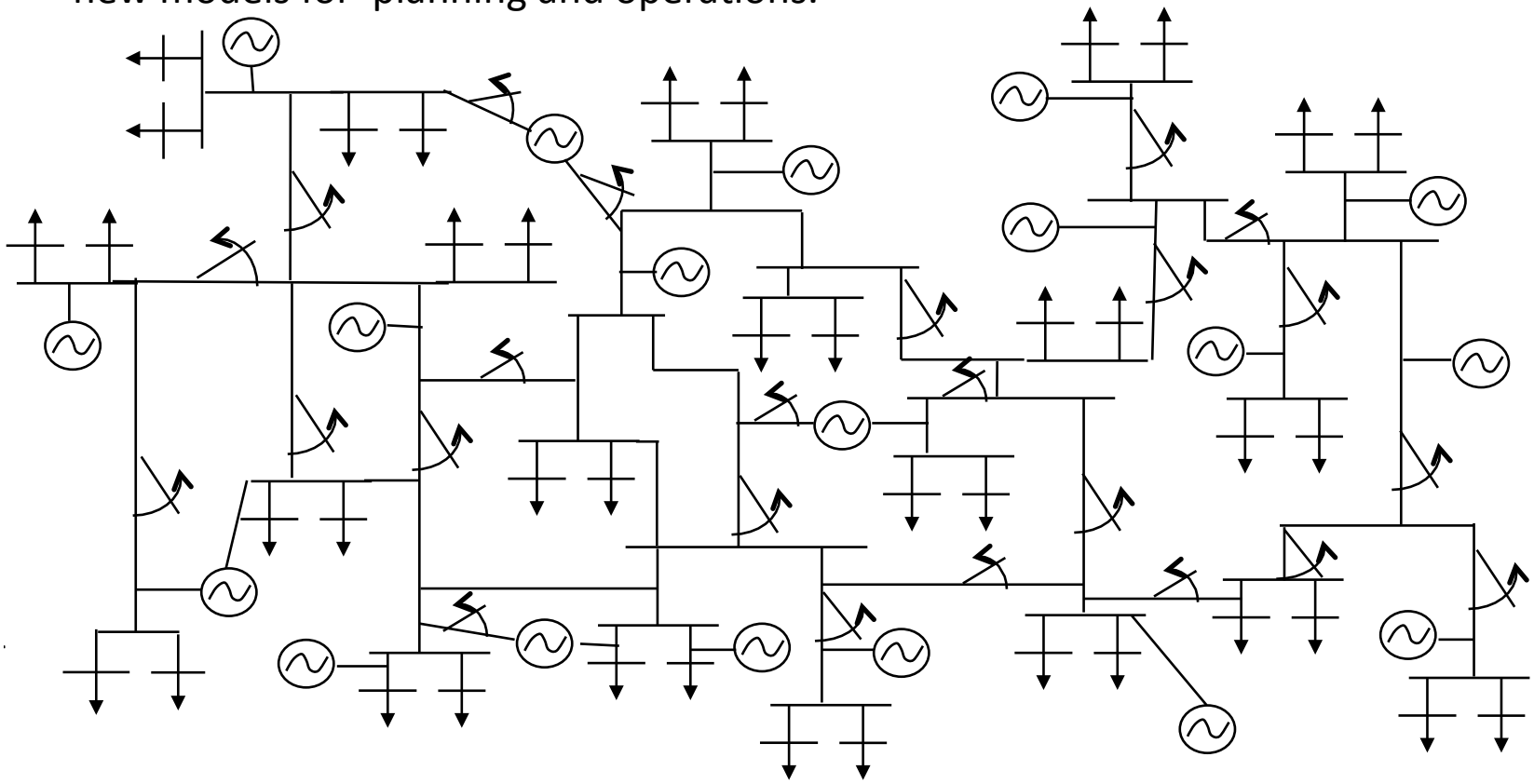


Smart Grid— A means of implementing sustainability (multiple tradeoffs)

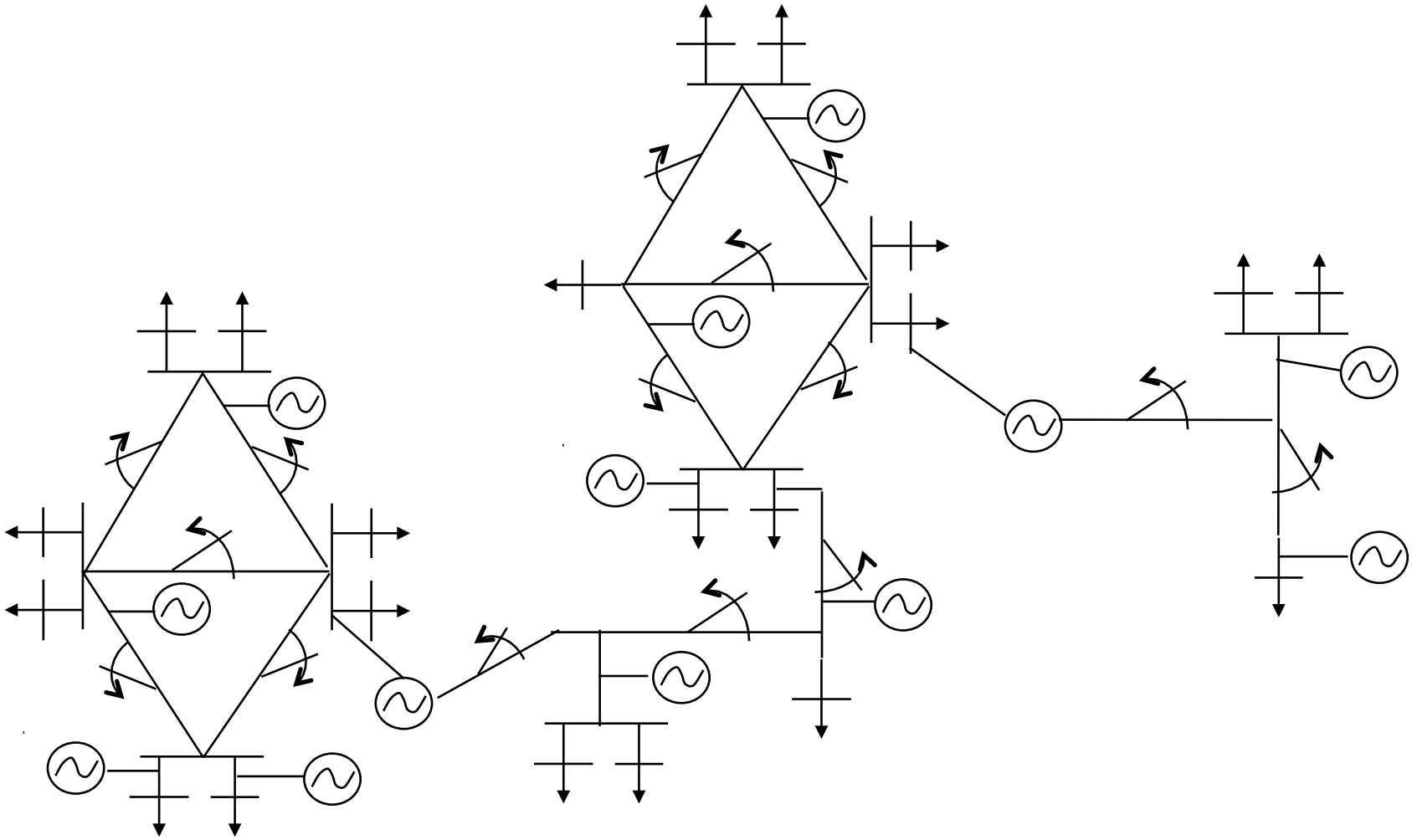
Single optimization subject to constraints (today)	Reconciling tradeoffs (new)
Schedule supply to meet given demand	Schedule supply to meet demand (both supply and demand have costs assigned)
Provide electricity at a predefined tariff	Provide electricity at QoS determined by the customers willingness 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

Distributed future energy systems – Qualitatively NEW NETWORK SYSTEM ARCHITECTURES

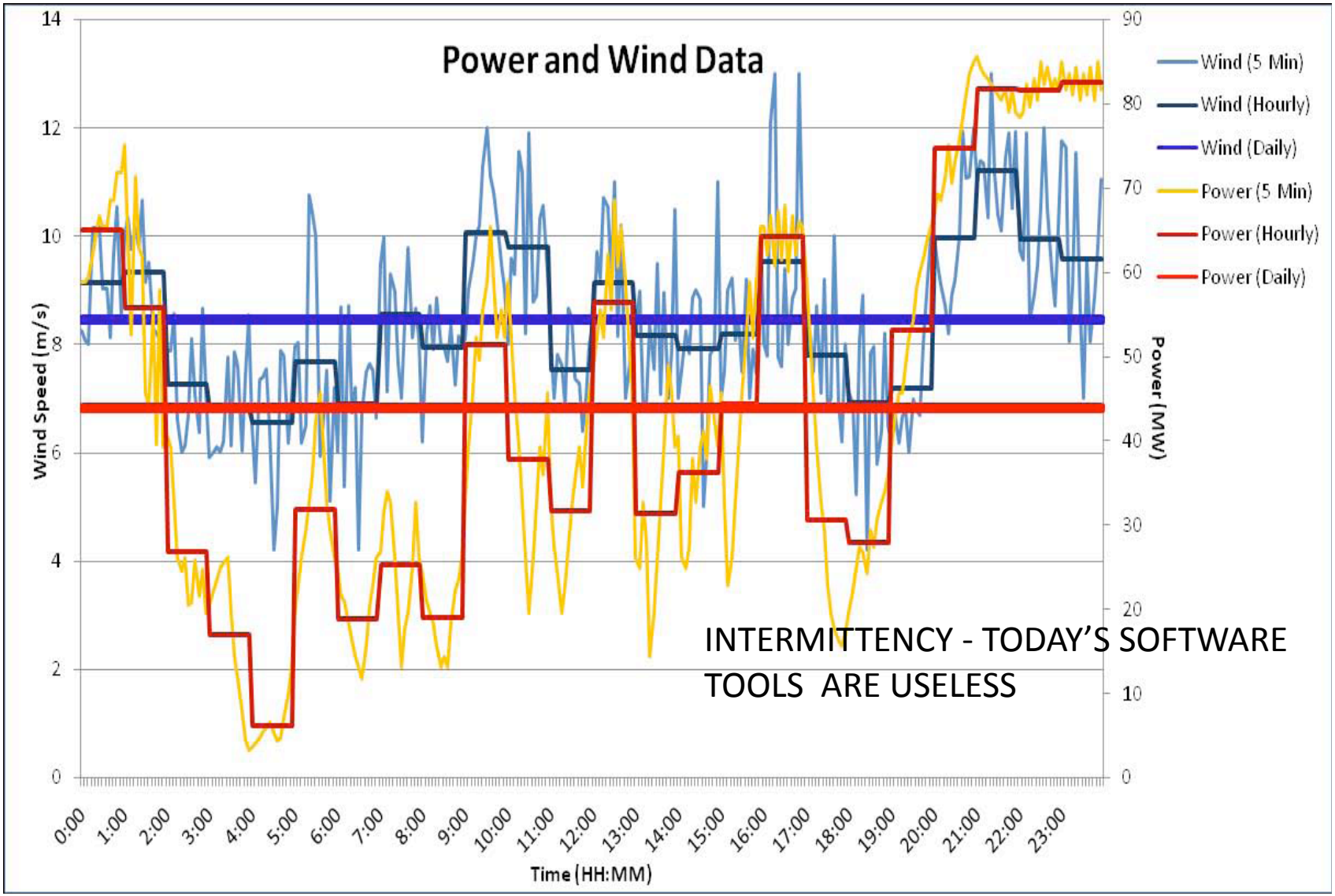
-distributed sensors and actuators, with their IT network;
new models for planning and operations.



Multi-layered interactive (dynamically aggregated) system —Need for IT-enabled regrouping to reconcile tradeoffs



Typical system input (load, wind, solar) –Need for prediction, look ahead decision making, sensing;
OTHERWISE BLACKOUTS AND INEFFICIENCY



Major R& D challenges:

- Understand the value of various technologies under specific paradigms

- Develop operating, maintenance and planning decision tools for all three paradigms and their transitions
- Value IT for all three paradigms—this is essential to catalyze innovation

The critical concept

- Flexible reliability-related risk management
- Closely related to the questions of back-up power at times of price spikes/interruptions
- From extensive interconnections for reliability to distributed reliability provision

Current efforts at CMU

- New SRC ERI/SGRC
- Based on the vision of Dynamic Monitoring and Decision Systems (DYMONDS)
- First proof-of-concept Smart Grid Simulator for systems with wind, demand side response, PHEVs and conventional generation

  -Possible to integrate high amounts of intermittent resources in a sustainable way and enable choice at value

Dynamic Monitoring and Decision System (DYMONDS) [1]

- Conventional system operation
  - Centralized decision making
    - ISO knows and decides all
  - Not proper for future electric energy systems
    - Too many heterogeneous decision making components : DGs, DRs, electric vehicles, LSEs, etc.

- Dynamic Monitoring Decision-making System (DYMONDS)
  - Distributed decision making system
    - Distributed optimization of multiple components → computationally feasible
  - Individual decisions submitted to ISO (as supply/demand bids)
    - Individual inter-temporal constraints **internalized**
    - Market clearance and overall system balanced by ISO

Modeling, Analysis and Decision Making--Change of Paradigm

- Current power systems simulators
  - Centralized optimization
  - Information concentrated on ISO

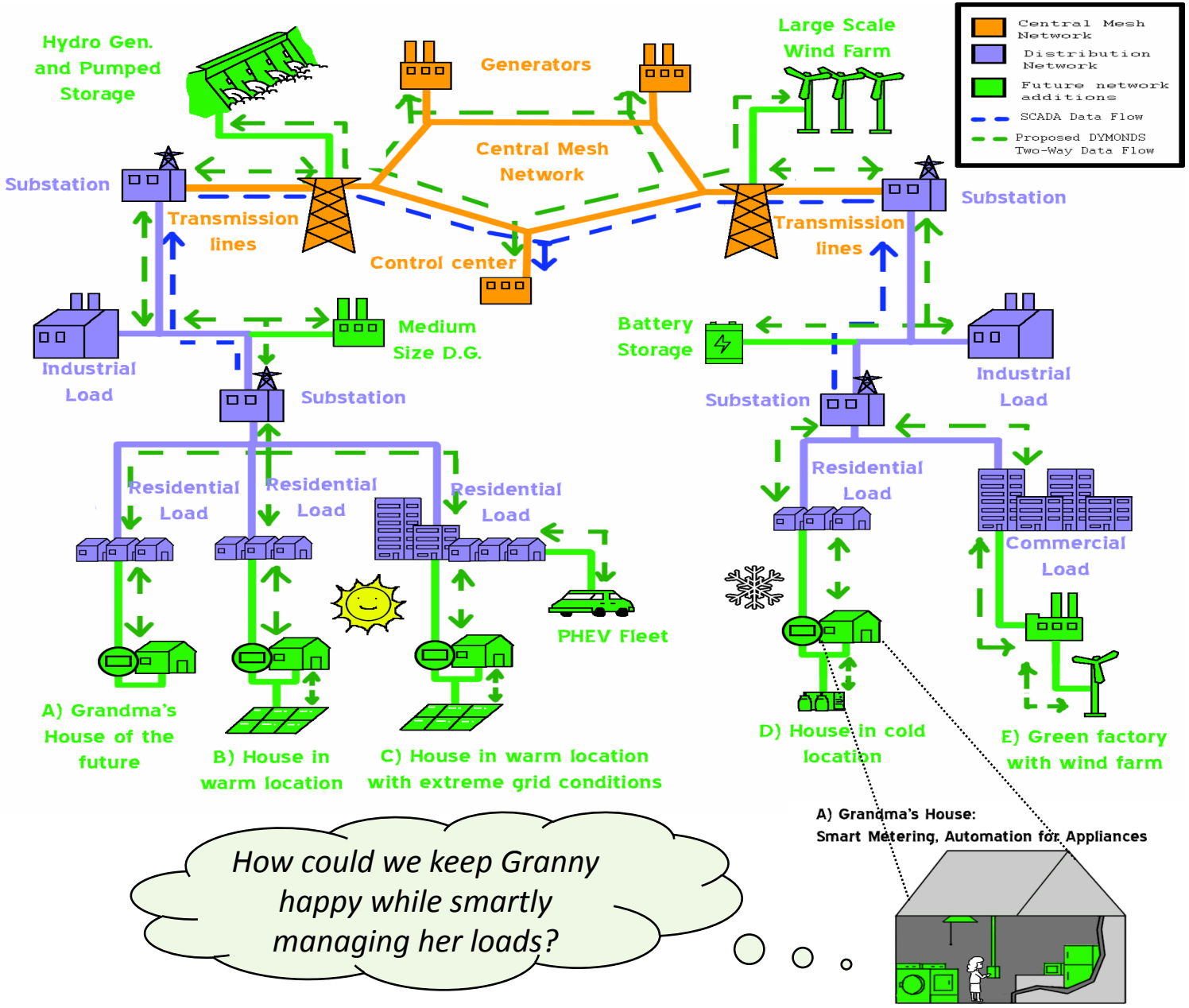
- Future energy systems simulator (DYMONDS)
  - Distributed optimization
    → modularized simulation
  - Appropriate **information exchange** between the components
  - Balance of the system by ISO

New DYMONDS Functionalities

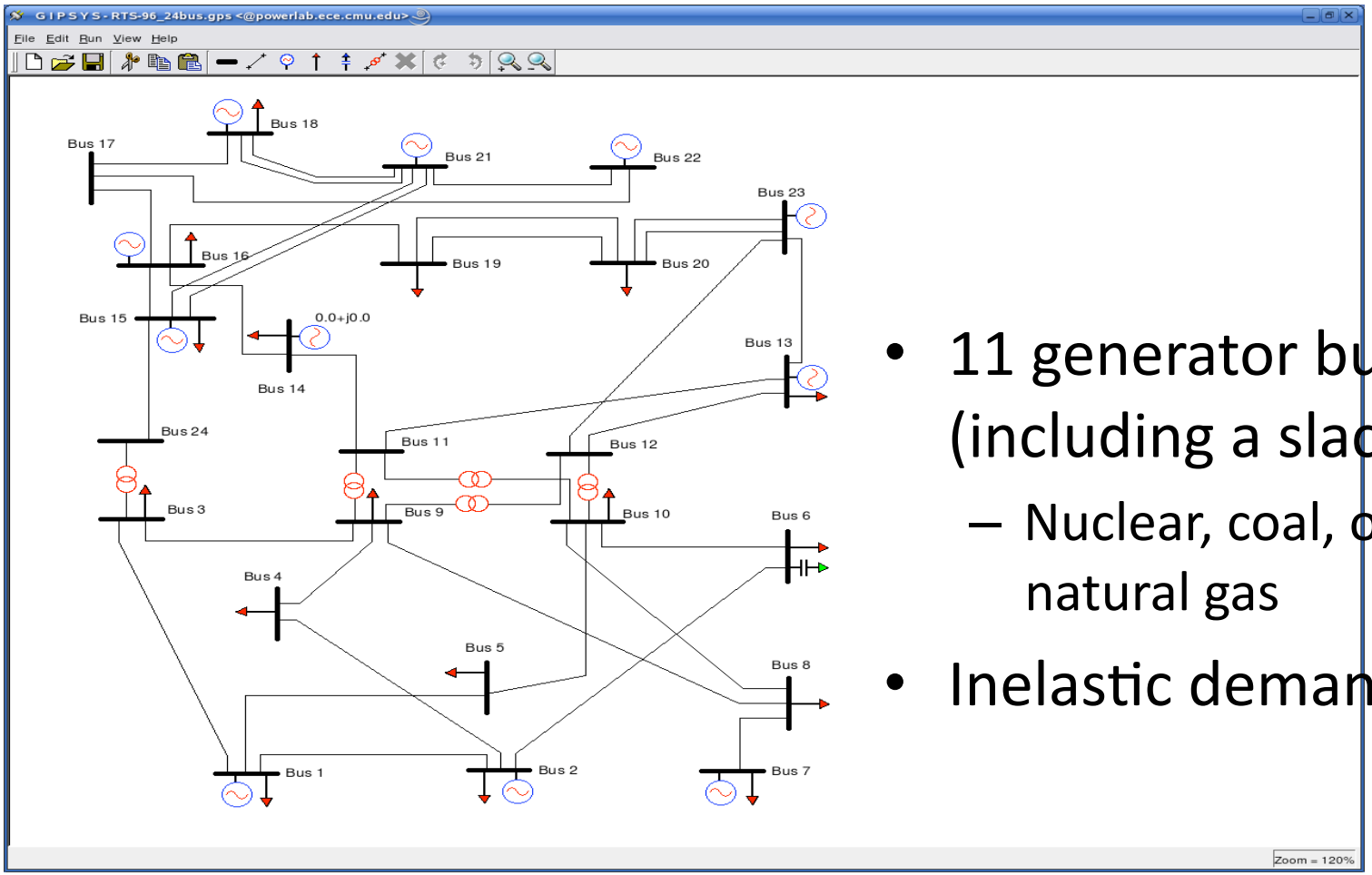
- Just-in-Time (JIT) --predictions; dynamic look-ahead decision making
- Just-in-Place (JIP) --distributed, interactive, multi-layered
- Just-in-Context (JIC) ---- performance objectives function of organizational rules, rights, and responsibilities (3Rs) and system conditions.
- Sample examples of improved performance—on-going work in EESG
  http://www.eesg.ece.cmu.edu

Demonstration of Dynamic Monitoring and Decision System (DYMONDS) for Sustainable Energy Systems

© Electric Energy Systems Group
http://www.eesg.ece.cmu.edu
Electrical and Computer Engineering
Carnegie Mellon University


Hydro Gen. and Pumped Storage
Generators
Large Scale Wind Farm
Central Mesh Network
Distribution Network
Future network additions
SCADA Data Flow
Proposed DYMONDS Two-Way Data Flow
Substation
Transmission lines
Control center
Substation
Transmission lines
Substation
Industrial Load
Medium Size D.G.
Battery Storage
Industrial Load
Substation
Substation
Residential Load
Residential Load
Residential Load
Residential Load
Commercial Load
PHEV Fleet
A) Grandma's House of the future
B) House in warm location
C) House in warm location with extreme grid conditions
D) House in cold location
E) Green factory with wind farm
How could we keep Granny happy while smartly managing her loads?
A) Grandma's House:
Smart Metering, Automation for Appliances

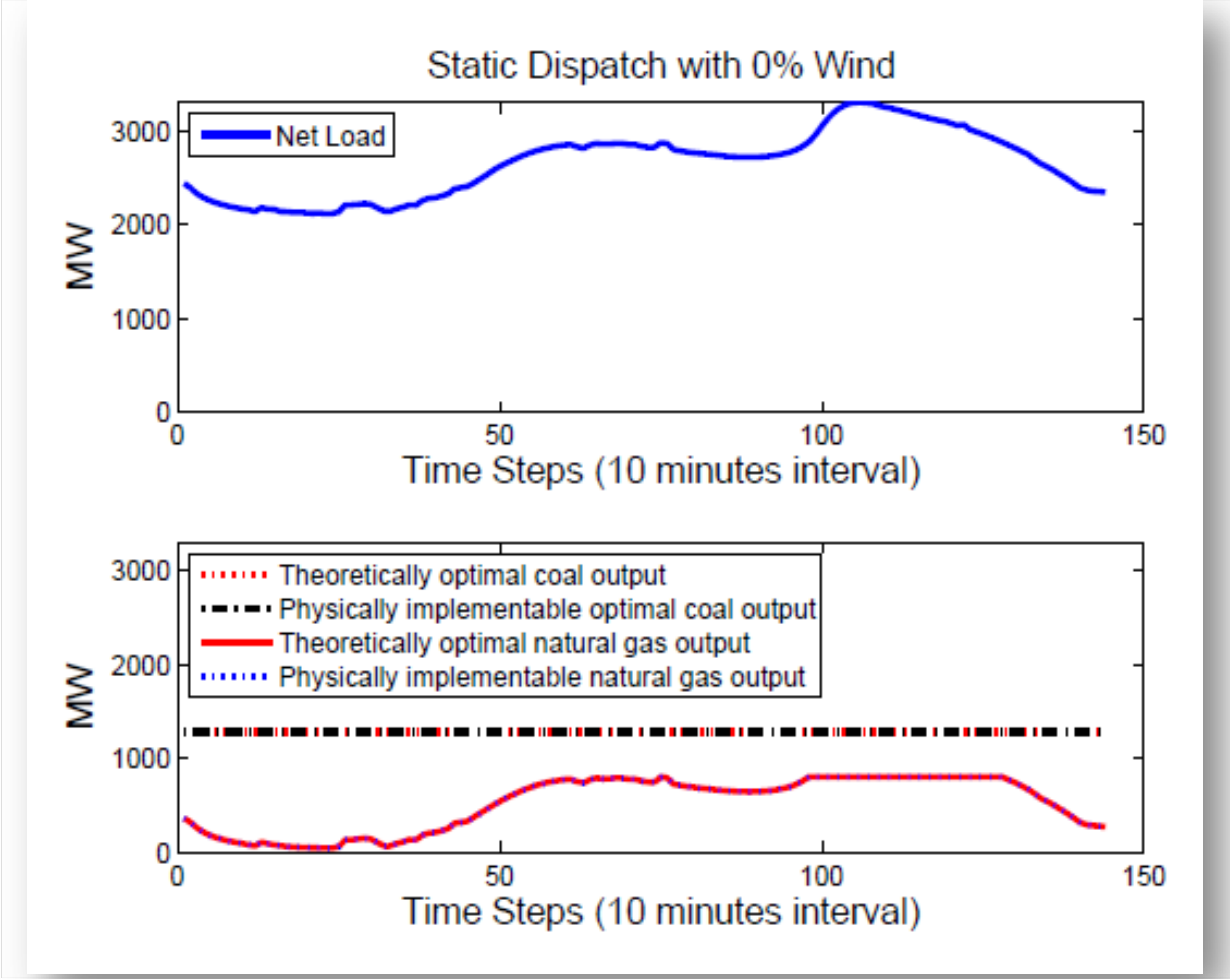
IEEE 24-bus Reliability Test System (RTS) in GIPSYS [2]



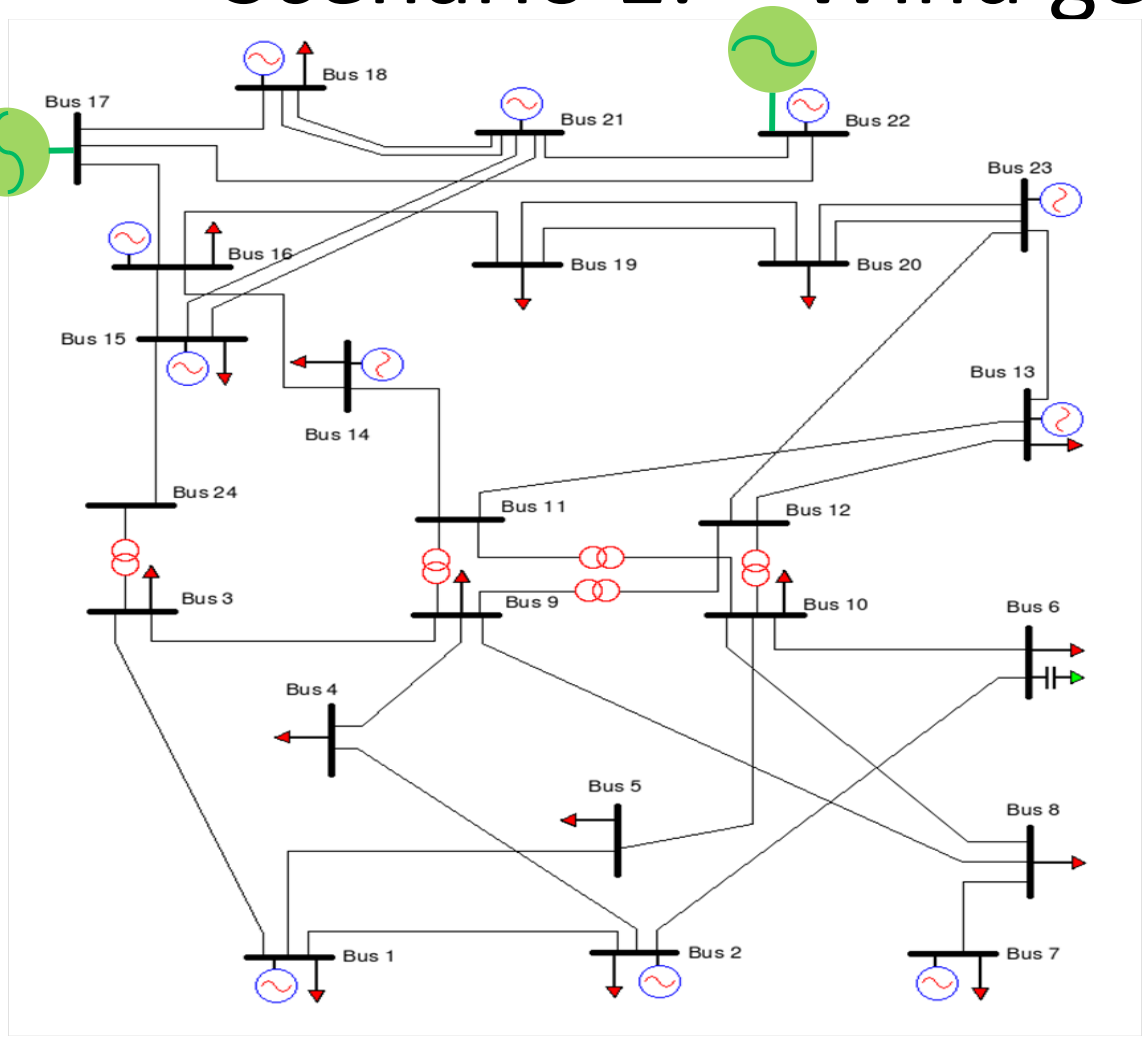
Jovan Ilić

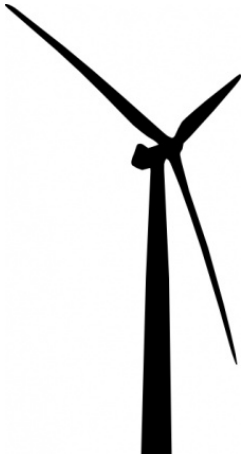
- 11 generator buses (including a slack bus)
  - Nuclear, coal, oil, natural gas
- Inelastic demand

Current electric power systems



DYMONDS Simulator
Scenario 1: + Wind generation [3,4]

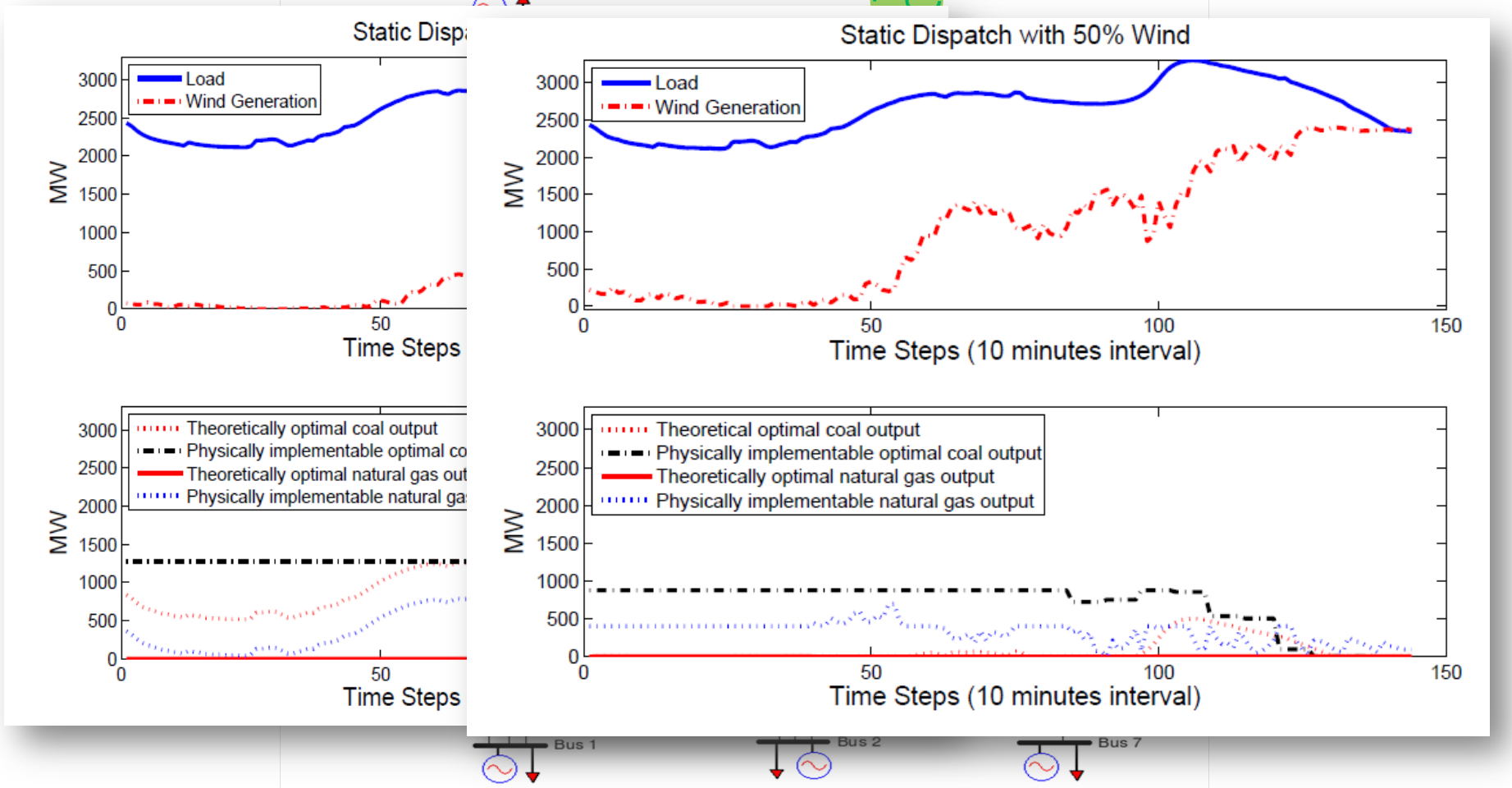




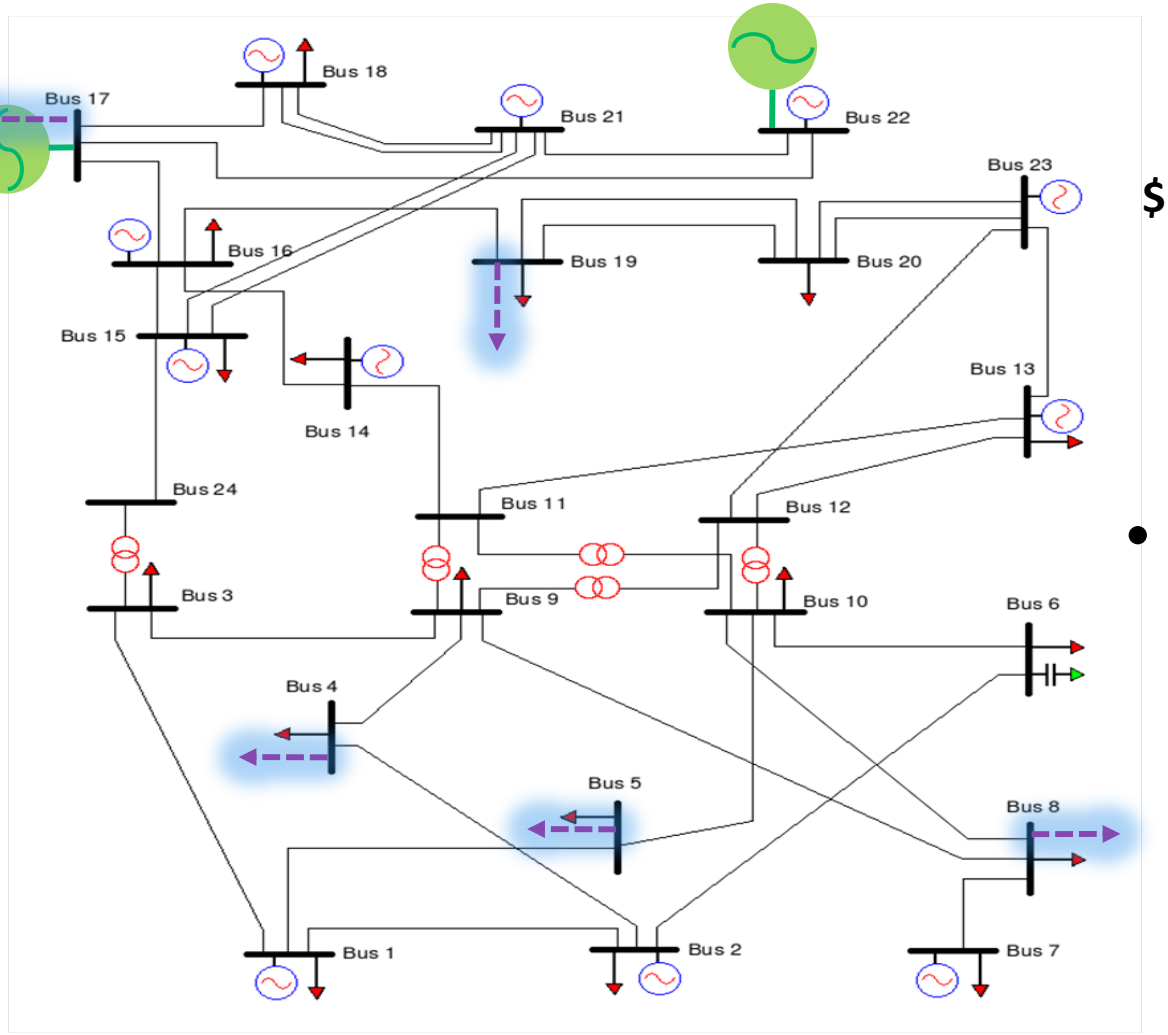
Le Xie

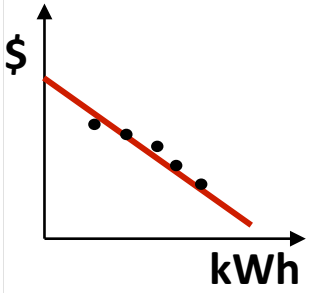
- 20% / 50% penetration to the system

DYMONDS Simulator
Scenario 1: + Wind generation



DYMONDS Simulator
Scenario 2: + Price-responsive demand [3-5]

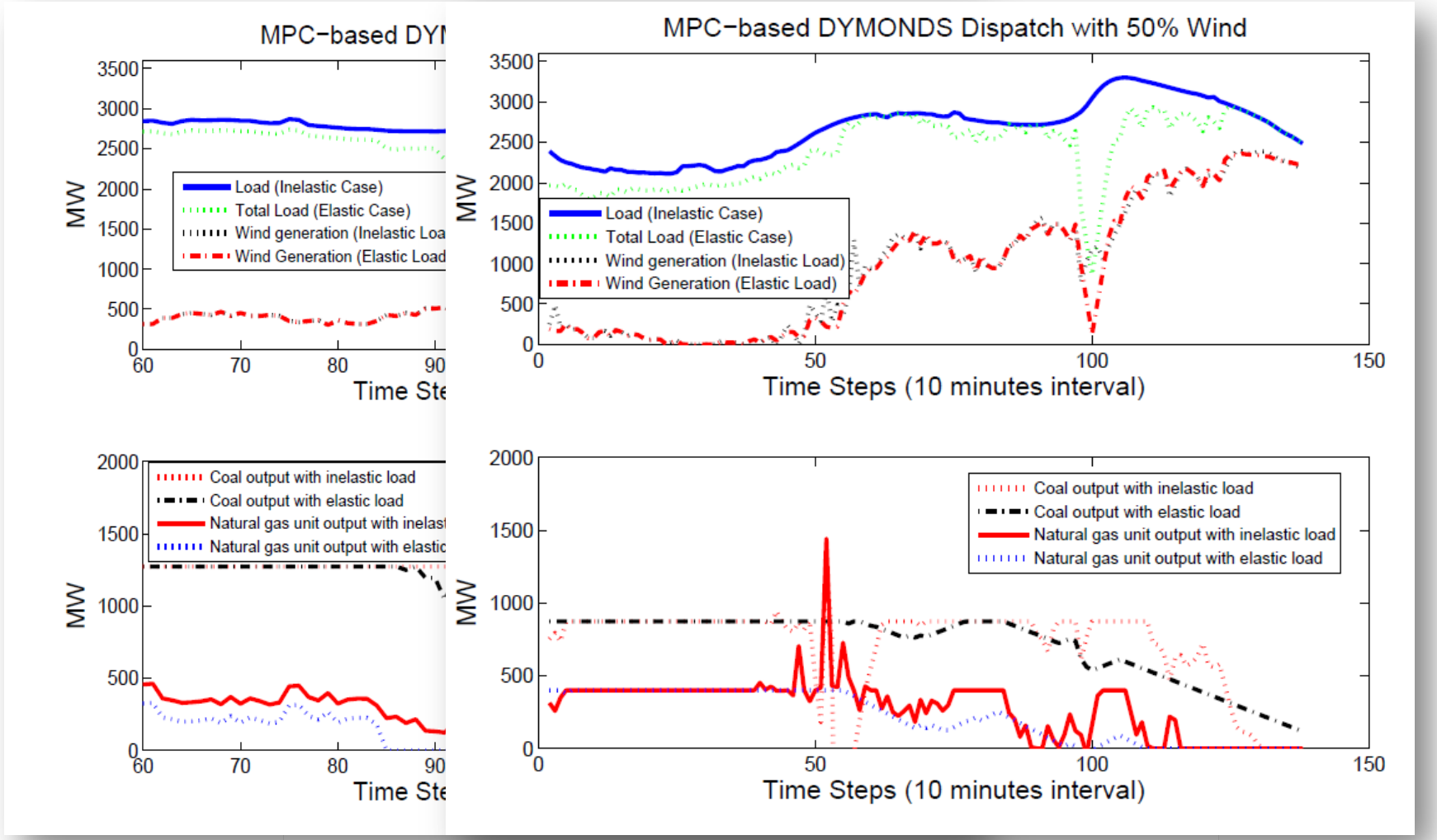




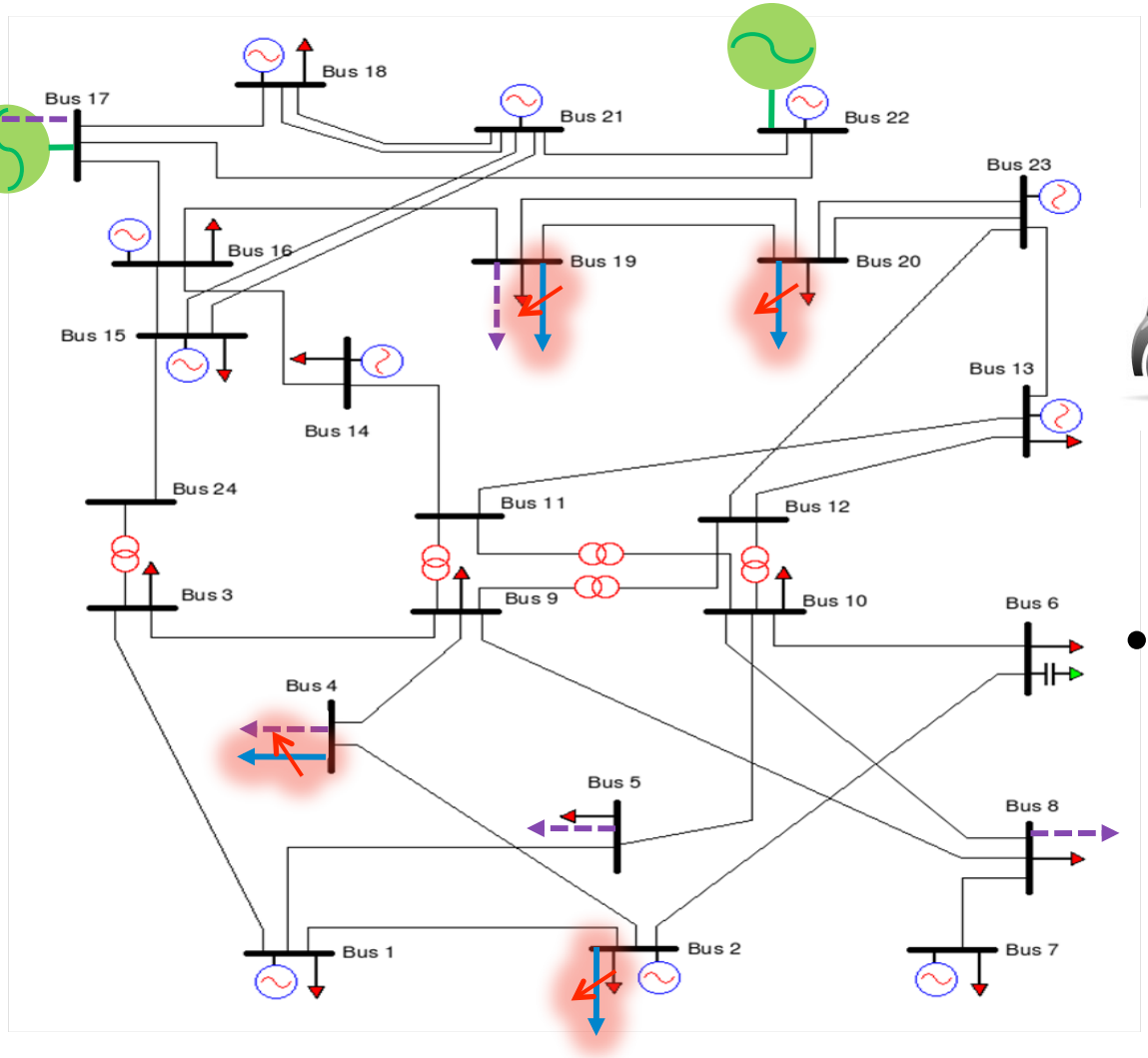
J.Y. Joo

- Elastic demand that responds to time-varying prices

DYMONDS Simulator
Scenario 2: + Price-responsive demand



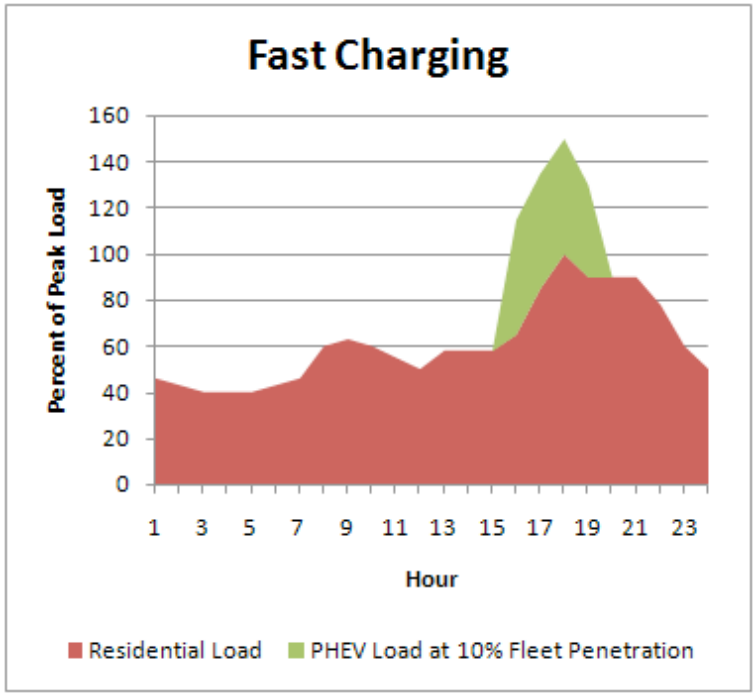
DYMONDS Simulator
Scenario 3: + Electric vehicles [6]

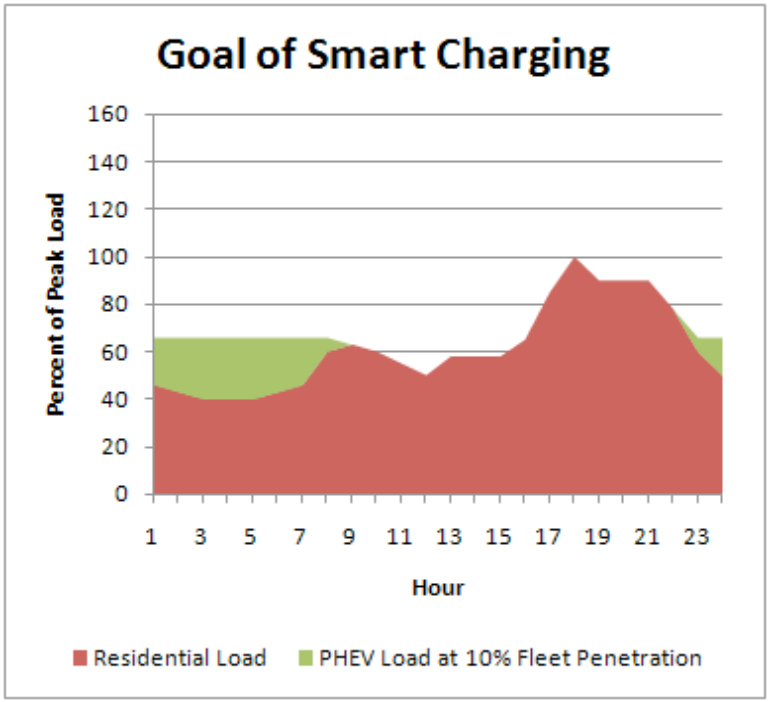


NiklasRotering

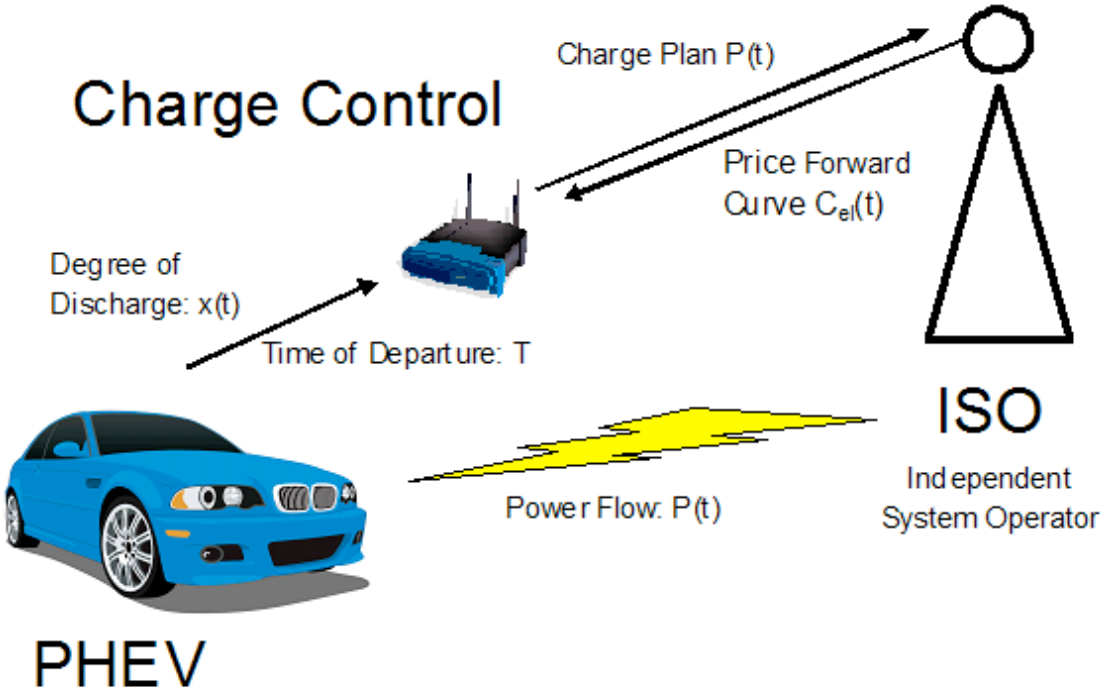
- Interchange supply / demand mode by time-varying prices

Optimal Control of Plug-in-Electric Vehicles: Fast vs. Smart (Rotering)

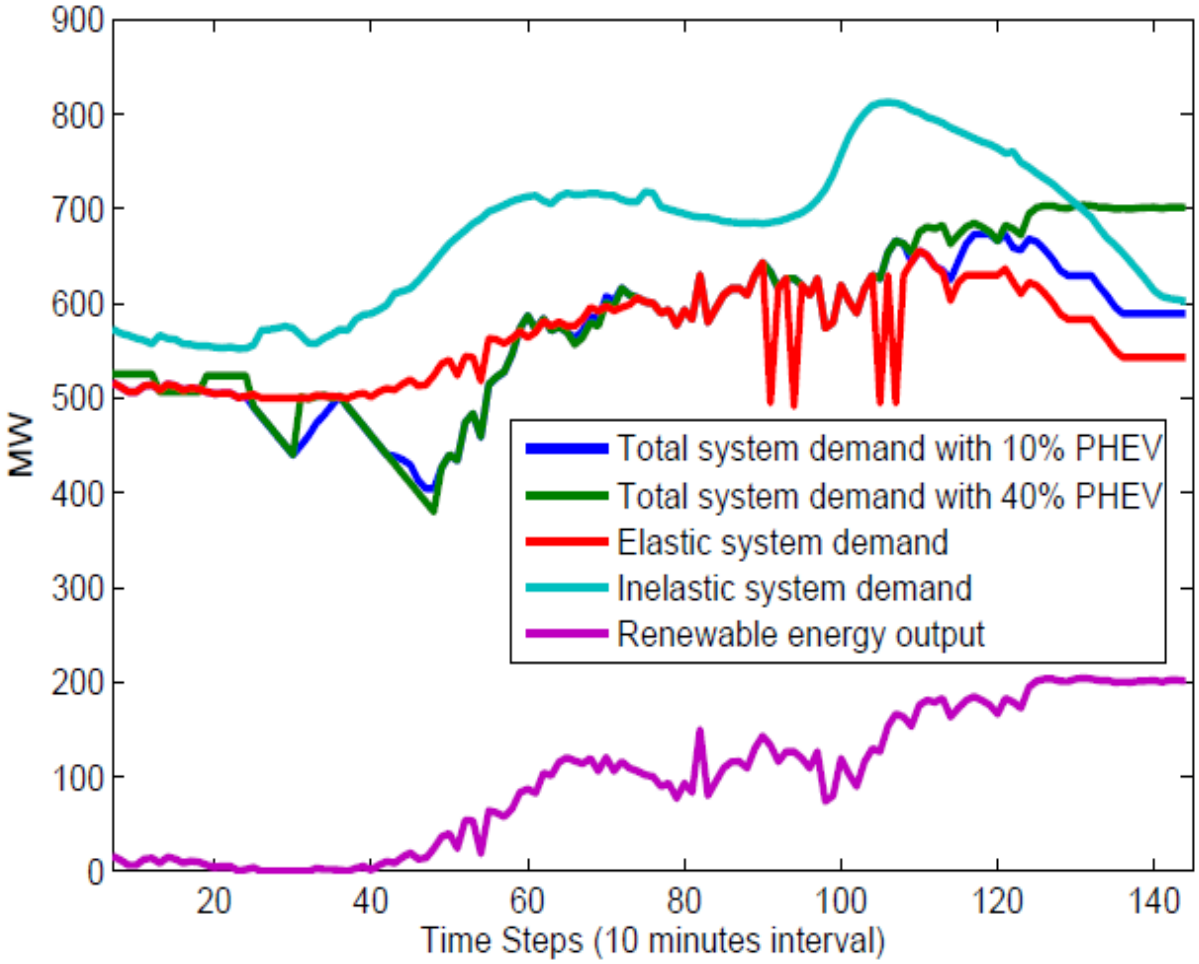




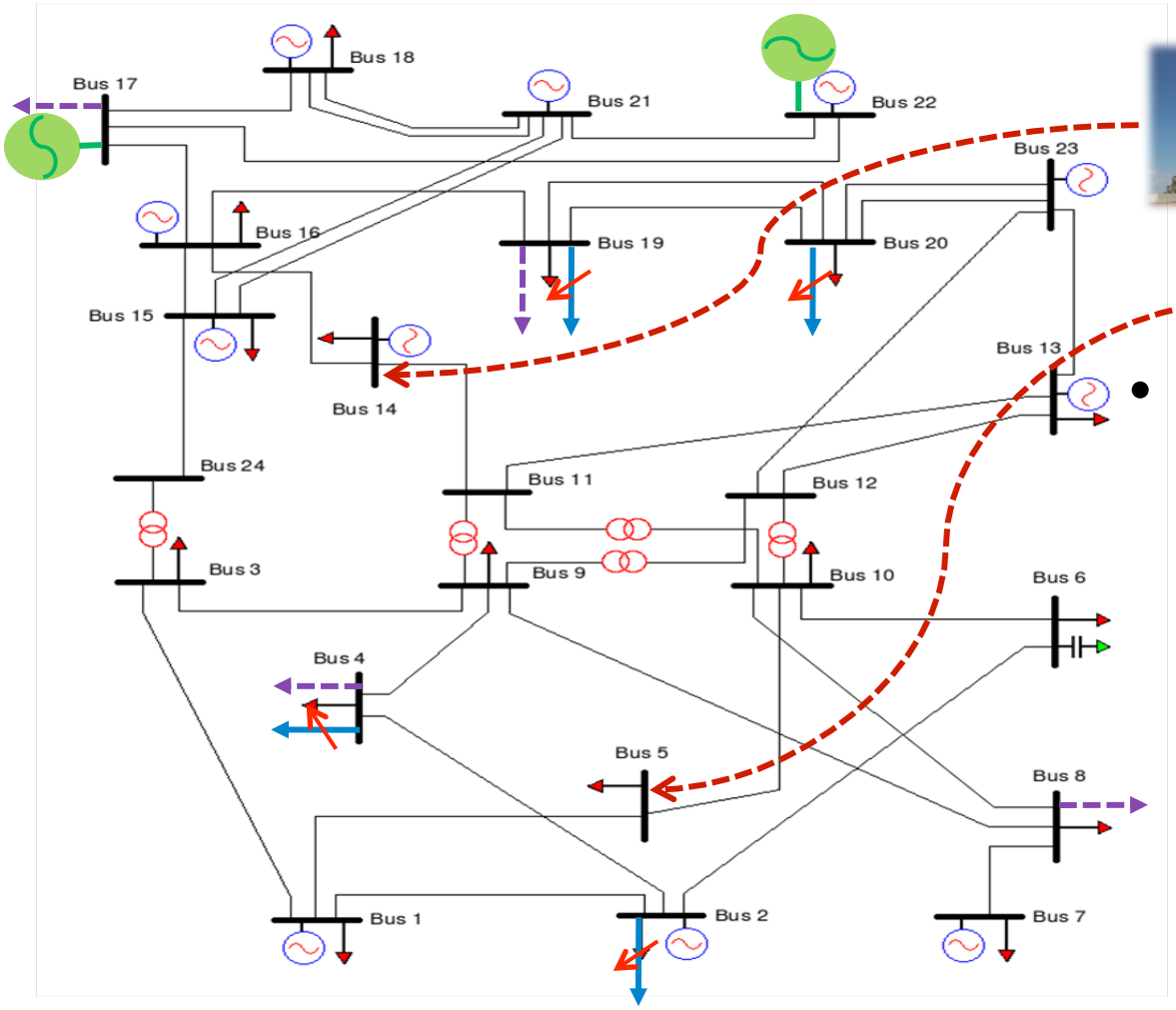
Information flow—Fantastic Use of Multi-layered Dynamic Programming



DYMONDS Simulator
Scenario 3: + Electric vehicles [4]



DYMONDS Simulator
Scenario 4: + long-run decision making [4]

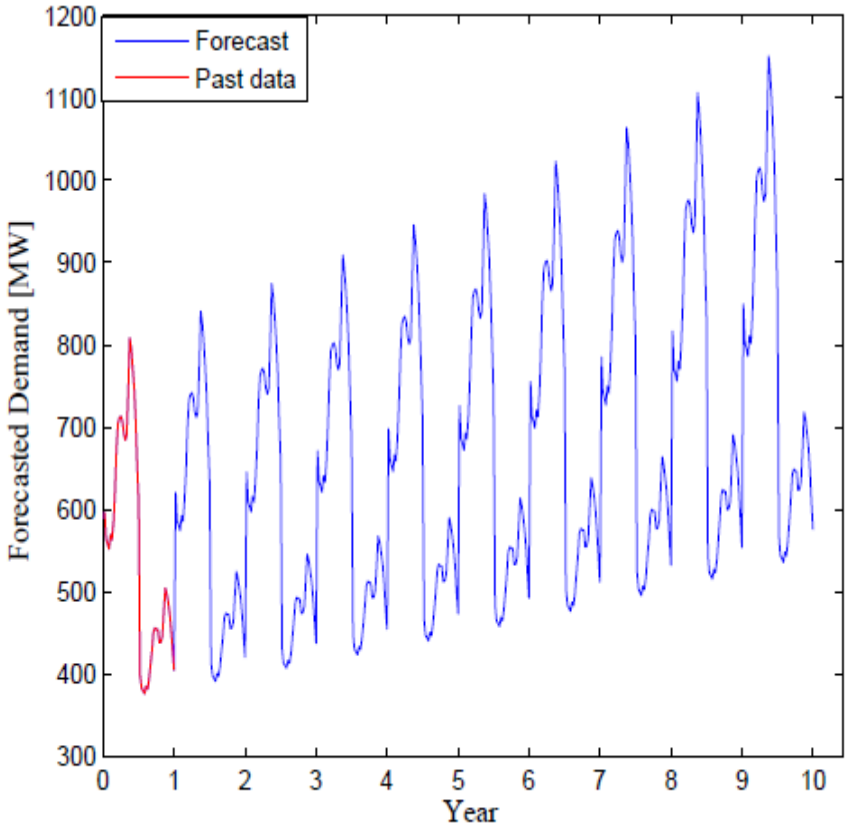


Marija Prica

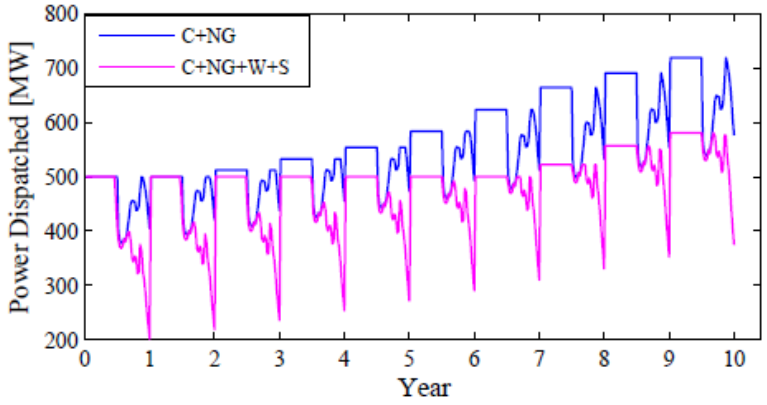
- Long-run planning of new generation capacity installation
  - Long-run marginal bids
  - For the next 10 years

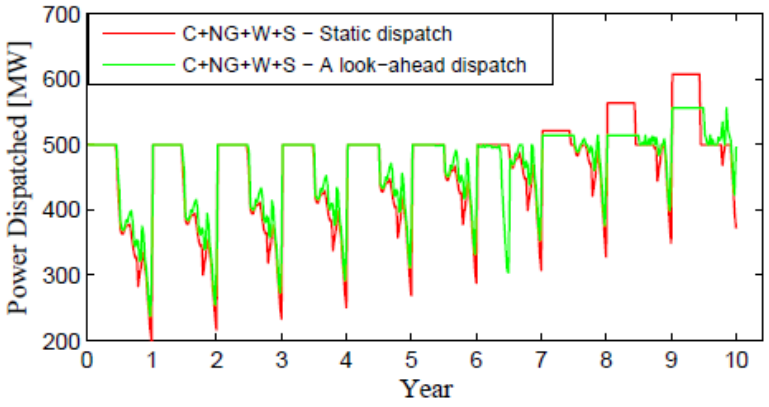
DYMONDS Simulator
Scenario 4: + long-run decision making

- Long-term load forecast



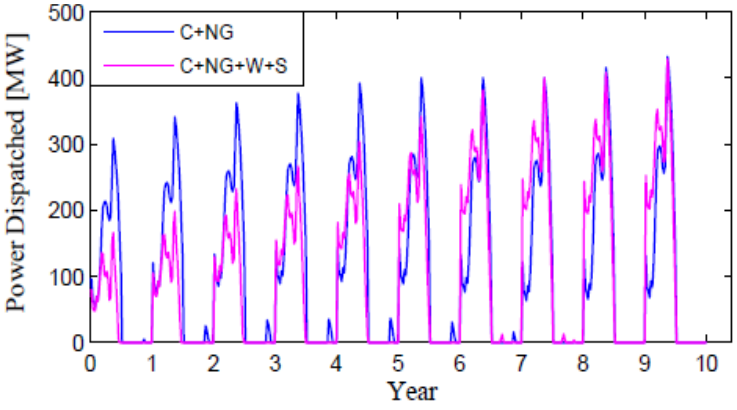
- Coal power plant

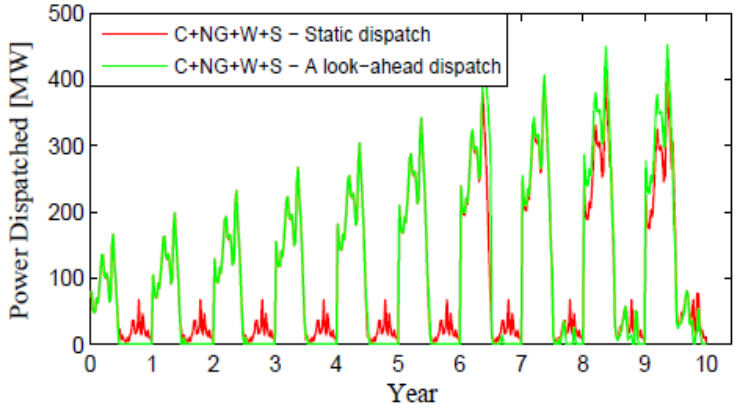




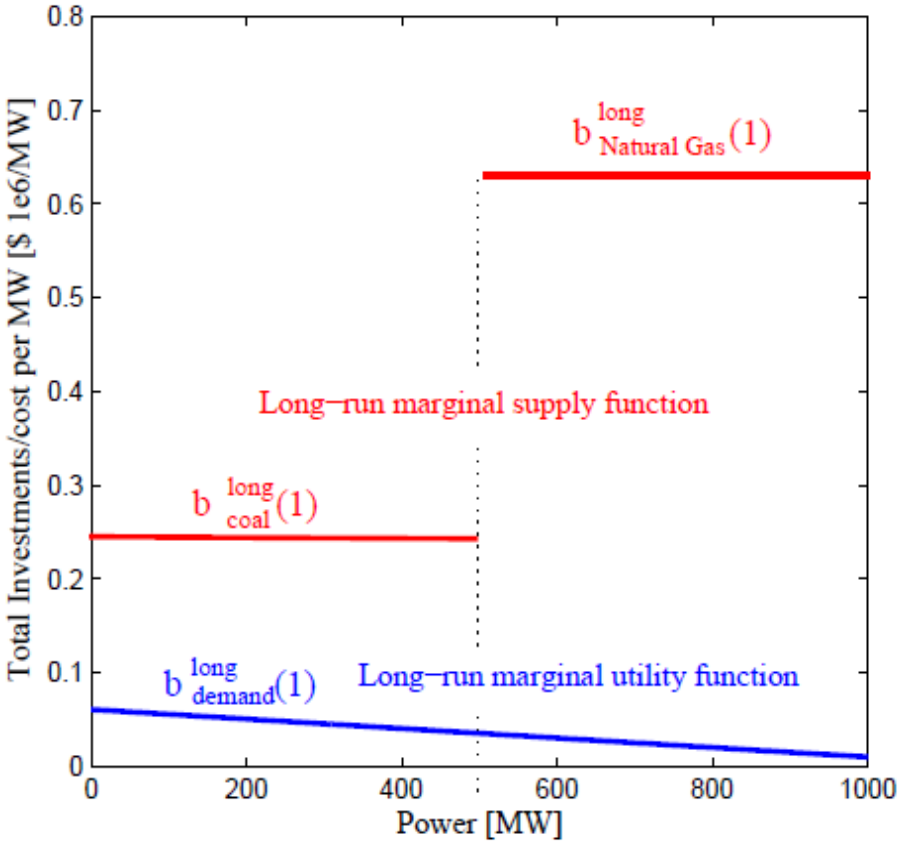
DYMONDS Simulator
Scenario 4: + long-run decision making

- Natural gas power plant

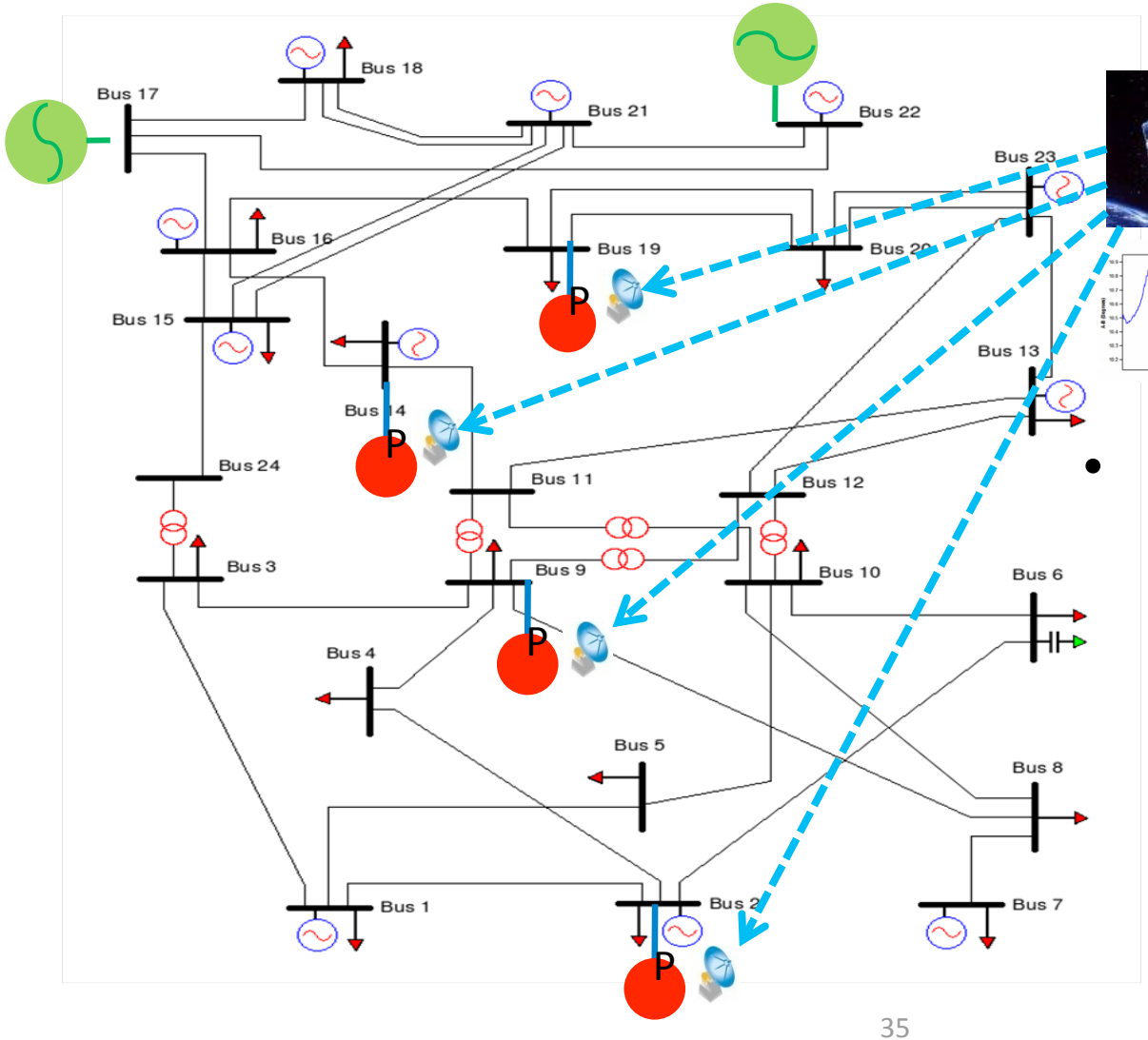


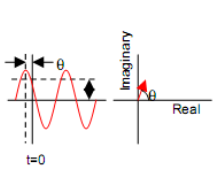


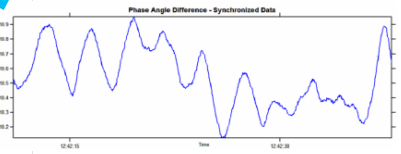
- Long-run bidding functions



DYMONDS Simulator
Scenario 5: + PMU-Based Robust Control [7]





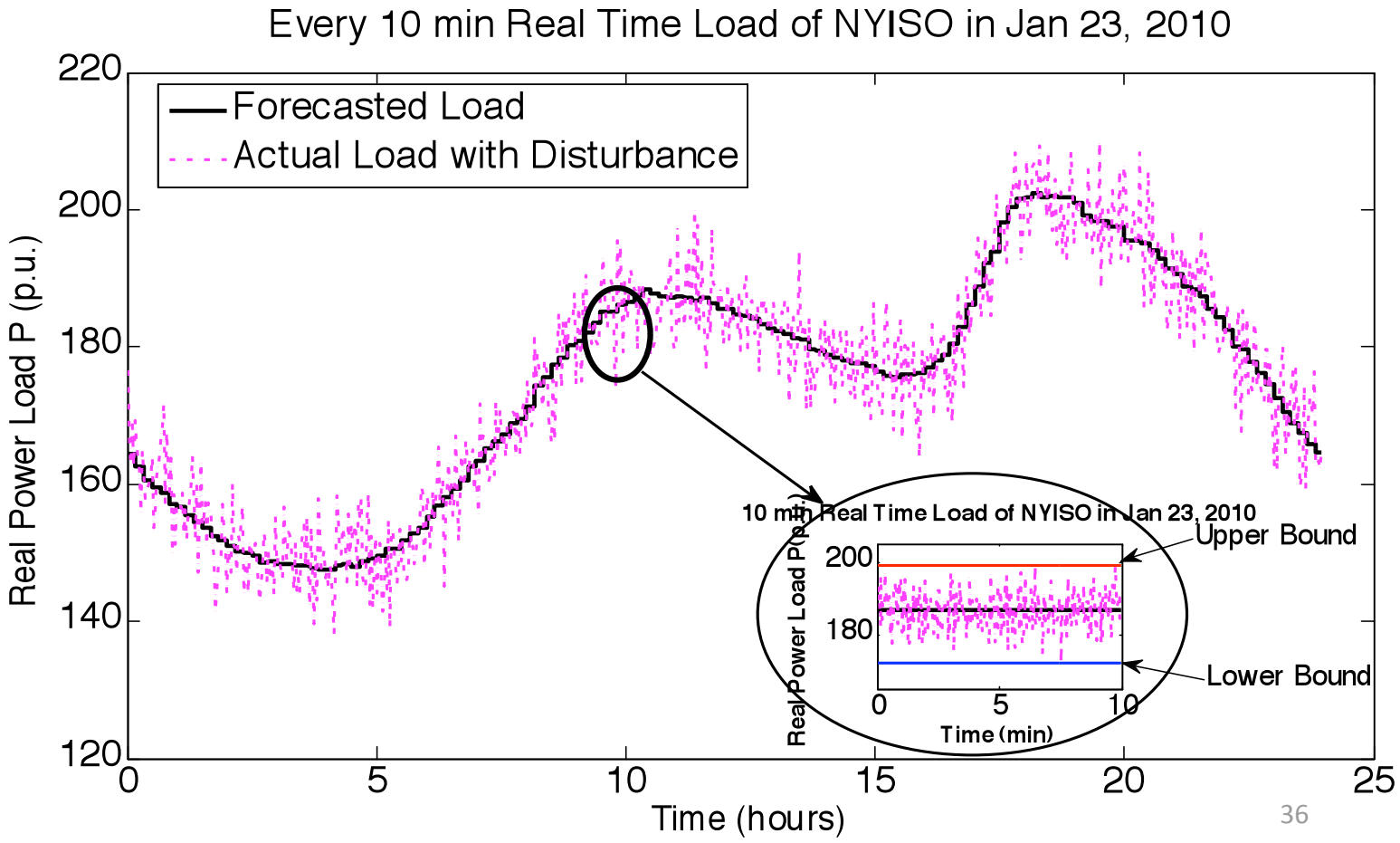


Zhijian Liu

- Automated Voltage Control (AVC) and Automated Flow Control (AFC)
  - Design Best Locations of PMUs
  - Design Feedback Control Gains

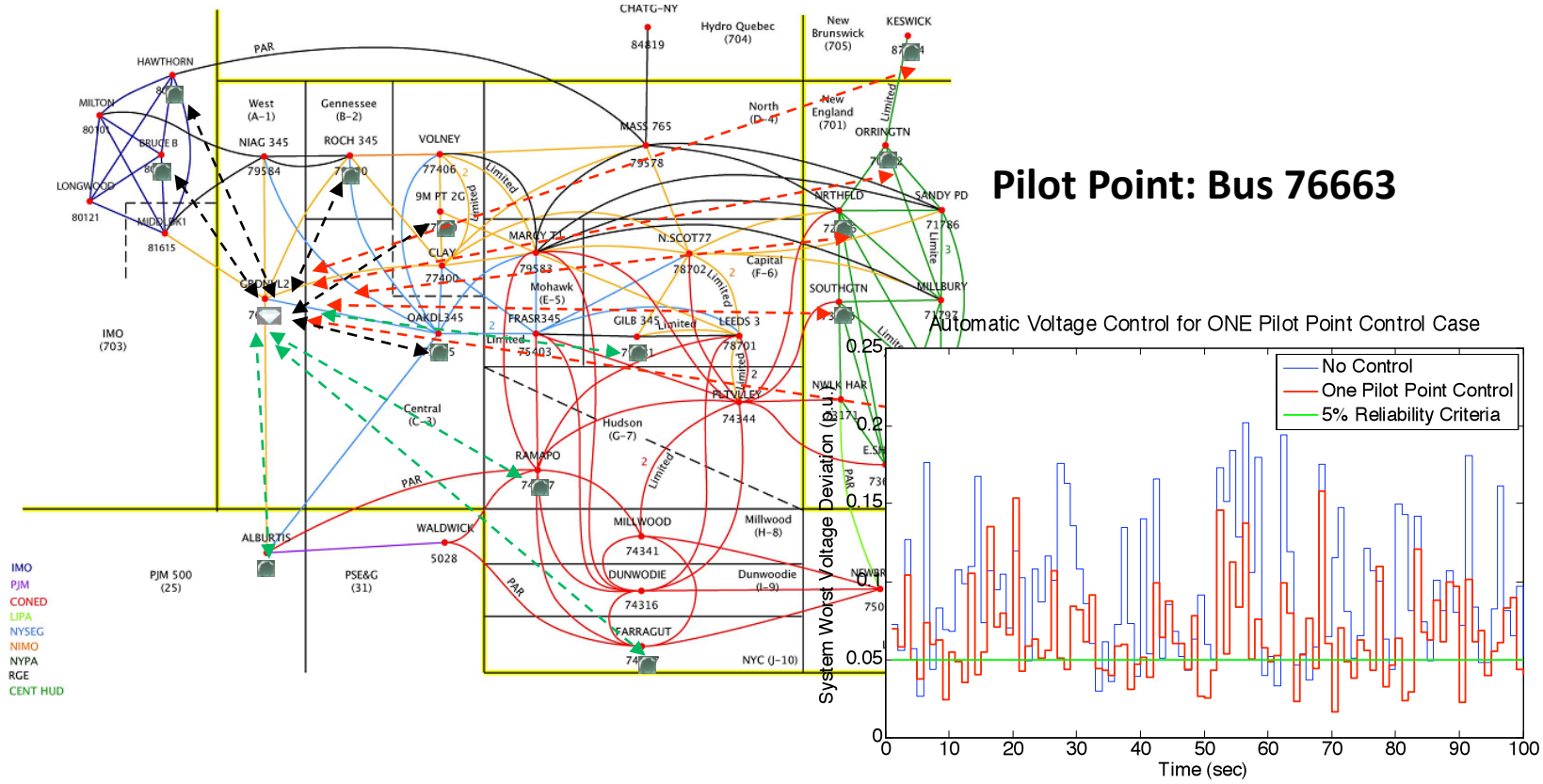
DYMONDS Simulator
Scenario 5: + PMU-Based Robust Control

- System Load Curve [8]



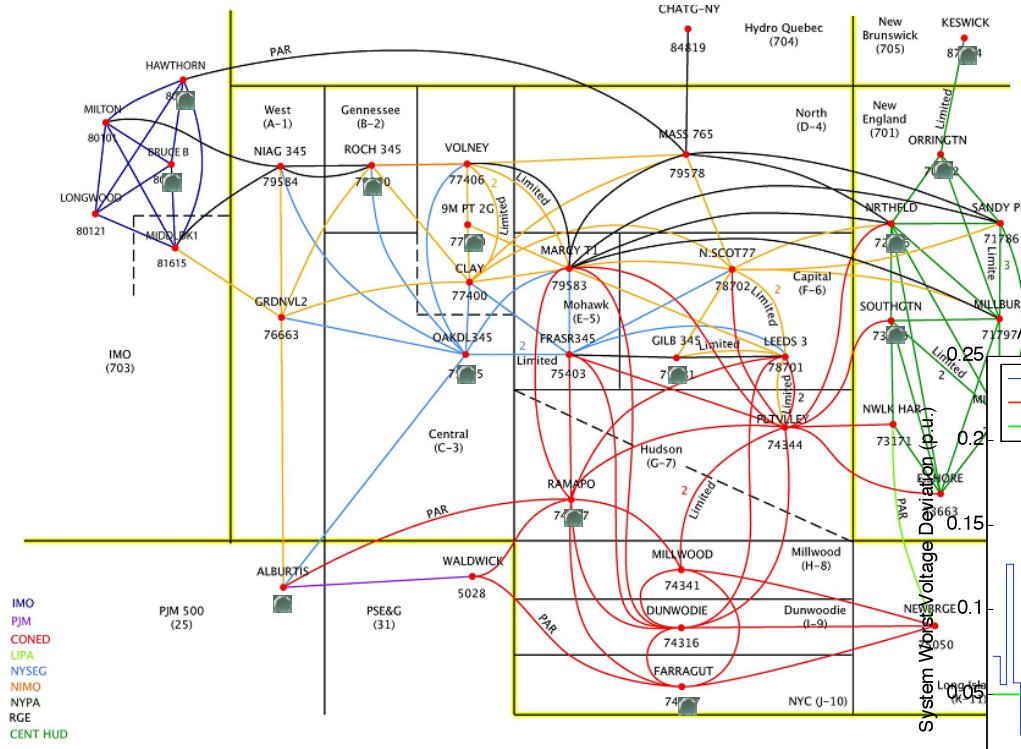
DYMONDS Simulator
Scenario 5: + PMU-Based Robust Control

- **Robust AVC Illustration in NPCC System [7, 9]**



DYMONDS Simulator
Scenario 5: + PMU-Based Robust Control

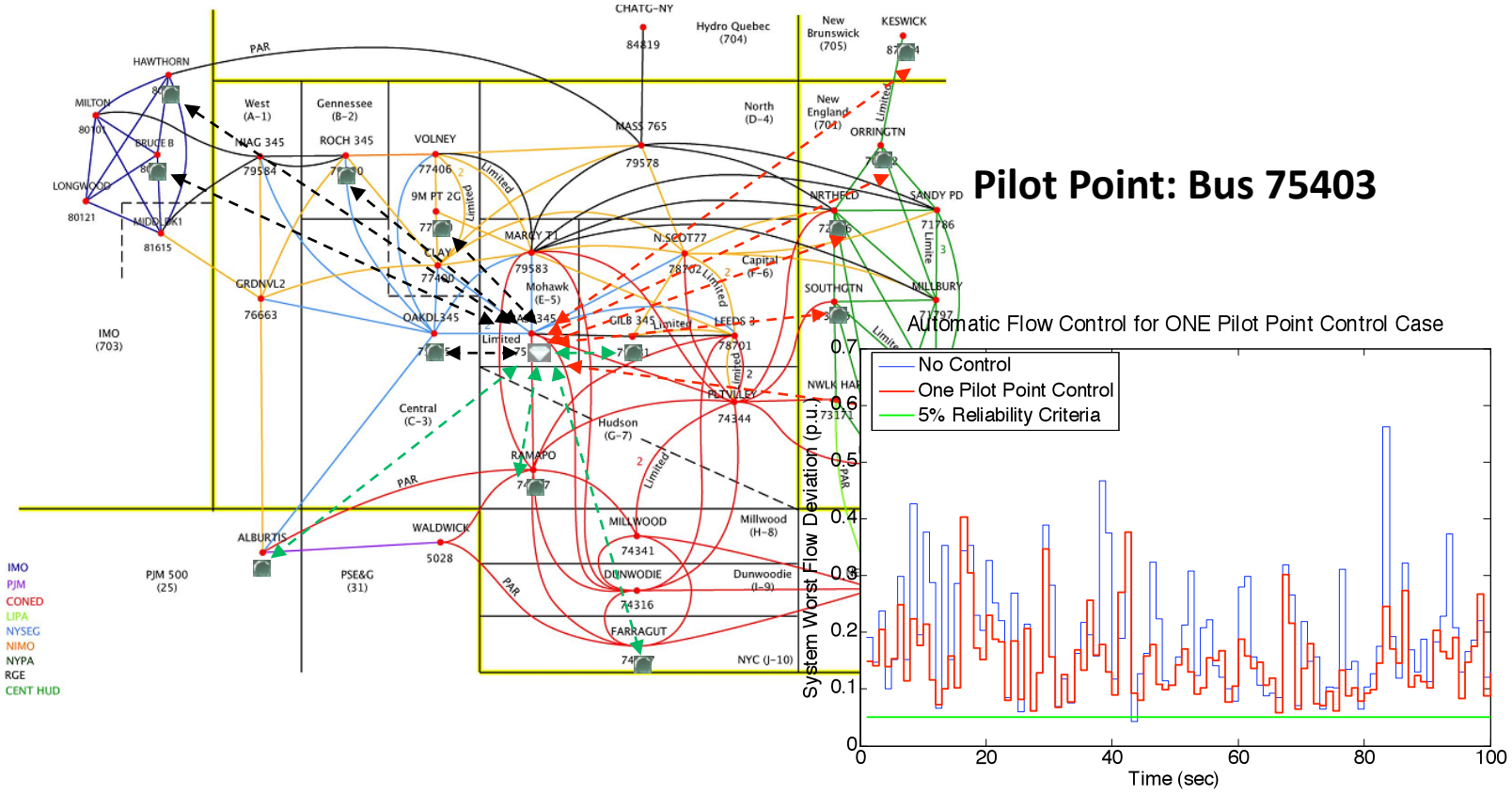
- **Robust AVC Illustration in NPCC System**



All load buses are Monitored

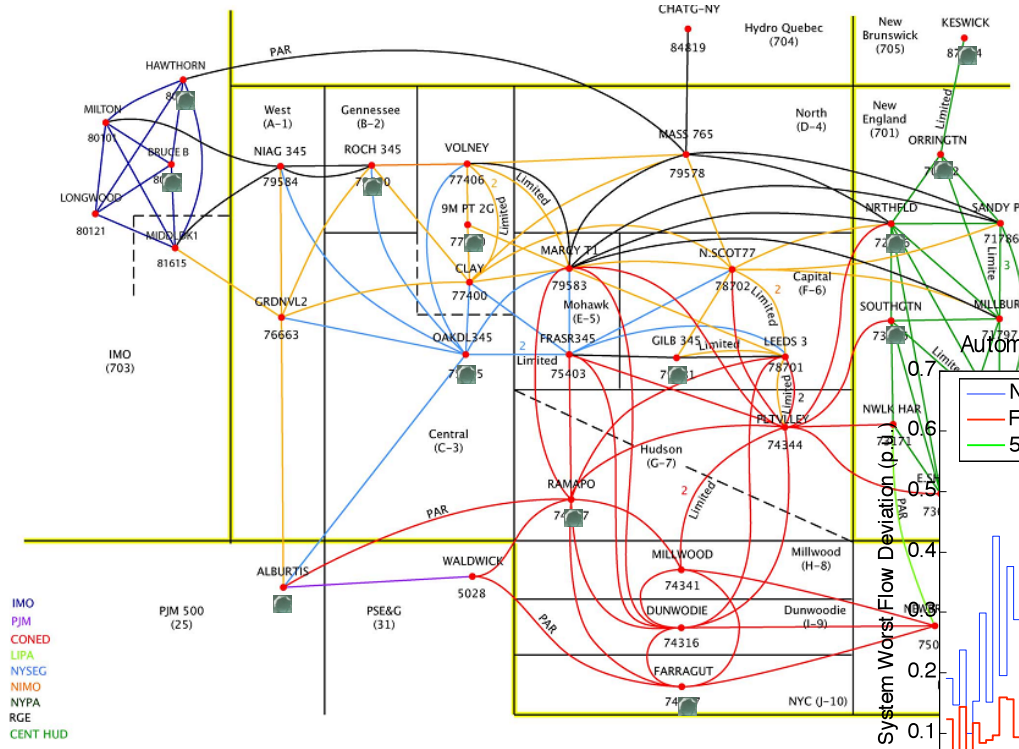
DYMONDS Simulator
Scenario 5: + PMU-Based Robust Control

- **Robust AFC Illustration in NPCC System [7, 9]**

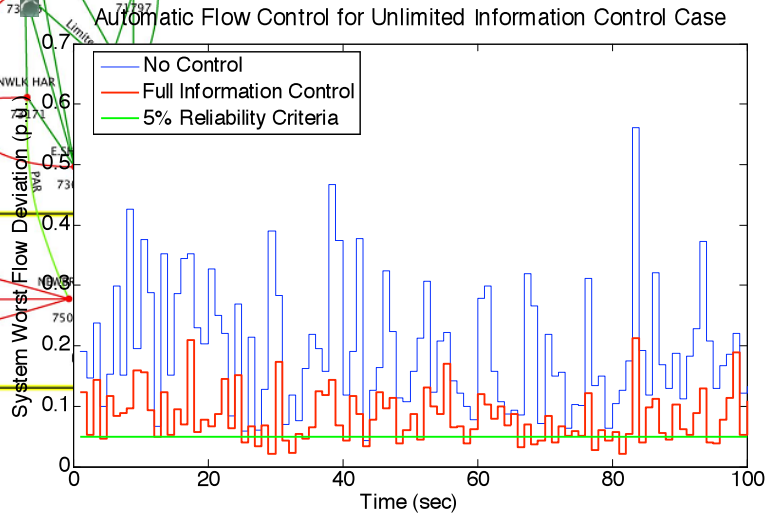


DYMONDS Simulator
Scenario 5: + PMU-Based Robust Control

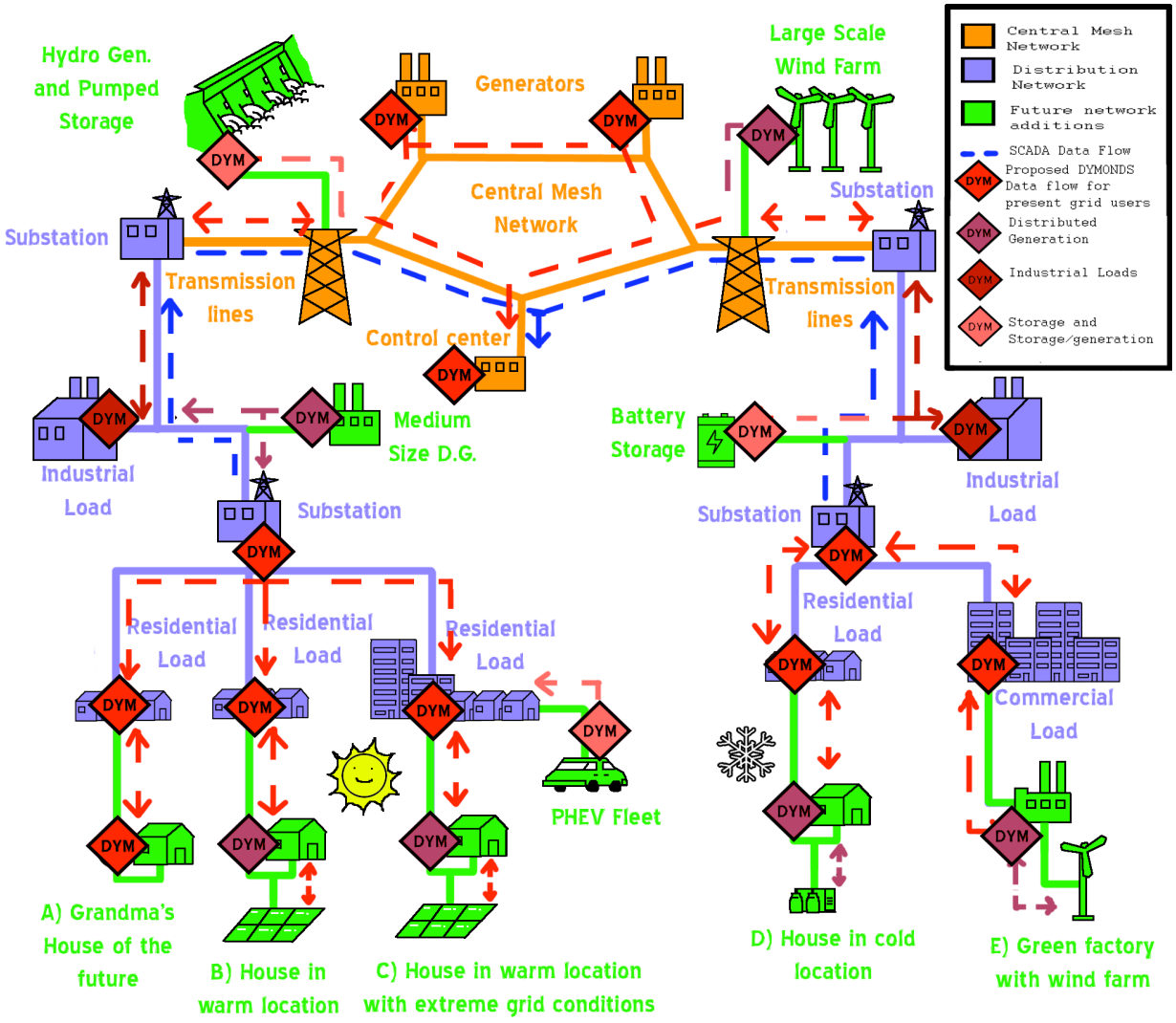
- **Robust AFC Illustration in NPCC System**



All load buses are Monitored



A Broad View of the Smart Grid



Long-term vision

- Build a serious momentum in defining next generation energy systems
- Work with industry, other universities and government to create a joint vision
- Build user friendly simulators of future systems in which quantifiable relations between the technology, policy and economics can be demonstrated
- Help catalyze innovation, particularly ICT for future energy systems
- Help define policy in support of innovation

References

1. Marija Ilić, Dynamic Monitoring and Decision Systems (DYMONDS) and Smart Grids: One and The Same, EESG Working Paper R-WP-21, 2009
2. Jovan Ilić, Interactive Power Systems Simulator, Carnegie Mellon University, https://www.ece.cmu.edu/~nsf-education/software.html
3. Marija Ilić, Le Xie and Jhi-Young Joo, Efficient Coordination of Wind Power and Price-Responsive Demand Part I: Theoretical Foundations, Part II: Case Studies, IEEE Transactions on Power Systems, under review, Jan 2010
4. Marija Ilić, Jhi-Young Joo, Le Xie, Marija Prica and Niklas Rotering, A Decision Making Framework and Simulator for Sustainable Electric Energy Systems, under review in Feb 2010
5. Jhi-Young Joo and Marija Ilić, A Multi-Layered Adaptive Load Management (ALM) System: Information exchange between market participants for efficient and reliable energy use, 2010 IEEE PES Transmission & Distribution Conference, April 2010, accepted
6. Niklas Rotering and Marija Ilić, Optimal Charge Control of Plug-In Hybrid Electric Vehicles In Deregulated Electricity Markets, IEEE Transactions on Power Systems, accepted in Aug 2009
7. Zhijian Liu and Marija Ilić, Toward PMU-Based Robust Automatic Voltage Control (AVC) and Automatic Flow Control (AFC), 2010 IEEE PES General Meeting, July 2010, accepted in Feb 2010 and to be presented
8. New England ISO Website Data available at http://www.iso-ne.com/
9. E. Allen, J. Lang, and M. Ilic, "A Combined Equivalenced-Electric, Economic, and Market Representation of the Northeastern Power Coordinating Council U.S. Electric Power System," IEEE Transactions On Power Systems, vol. 23, no. 3, pp. 896-907, Aug 2008.