SMART GRID AND THE DIGITAL ECONOMY FOR THE OPTIMAL OPERATION OF ELECTRICITY INFRASTRUCTURE

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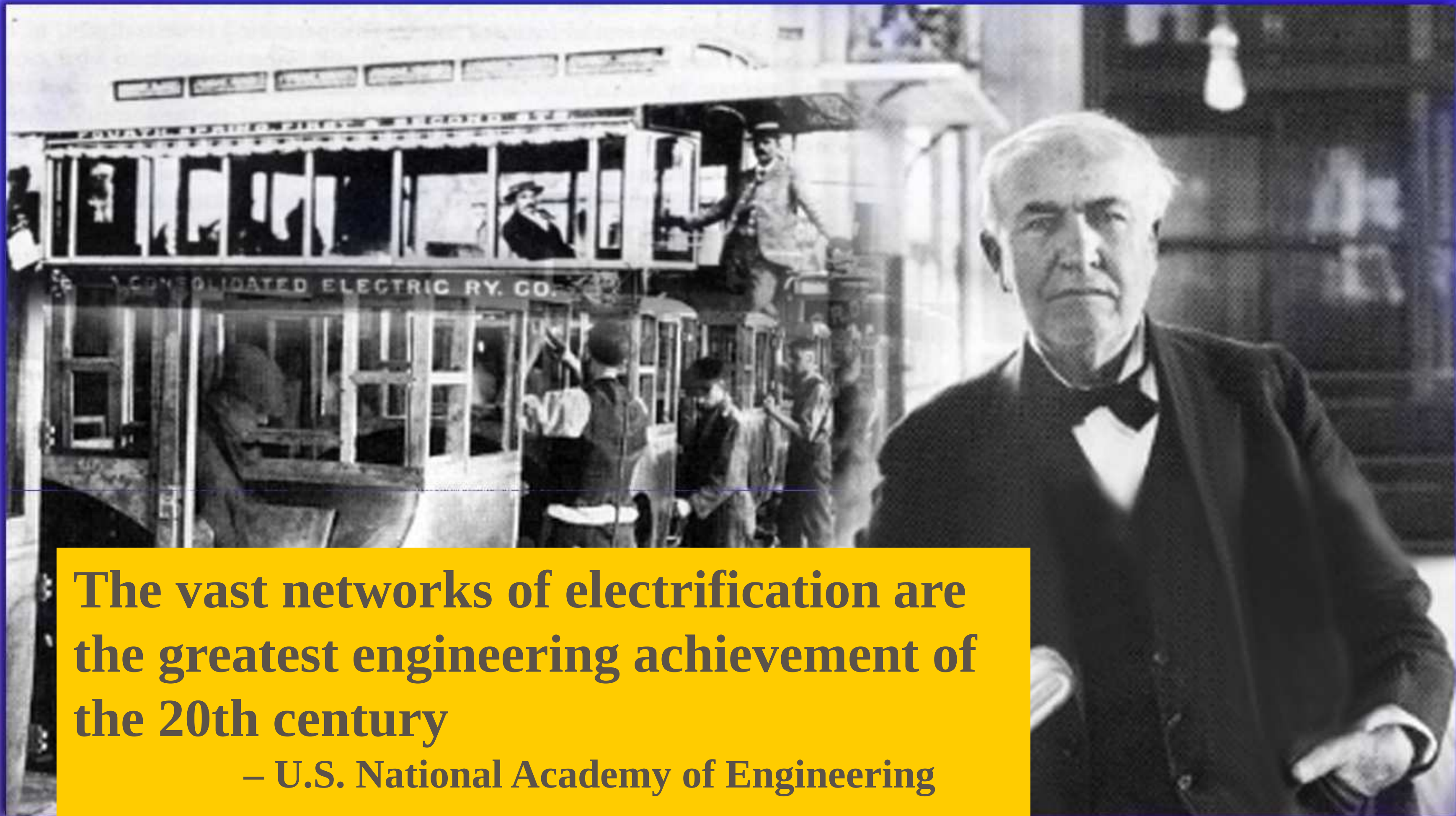
Outline

- Smart Grid Technology
  - Integration
- Microgrids
  - High Reliability Distribution System
  - Optimal Control of Microgrid
  - Reliability Evaluation
  - Islanding and Synchronization
- Perfect Power System
  - Robert W. Galvin Center at IIT

Transforming Society



The vast networks of electrification are the greatest engineering achievement of the 20th century

– U.S. National Academy of Engineering

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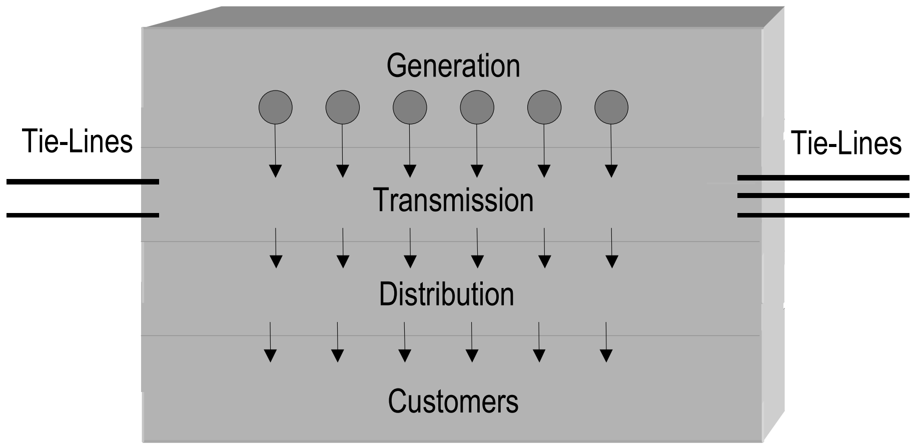
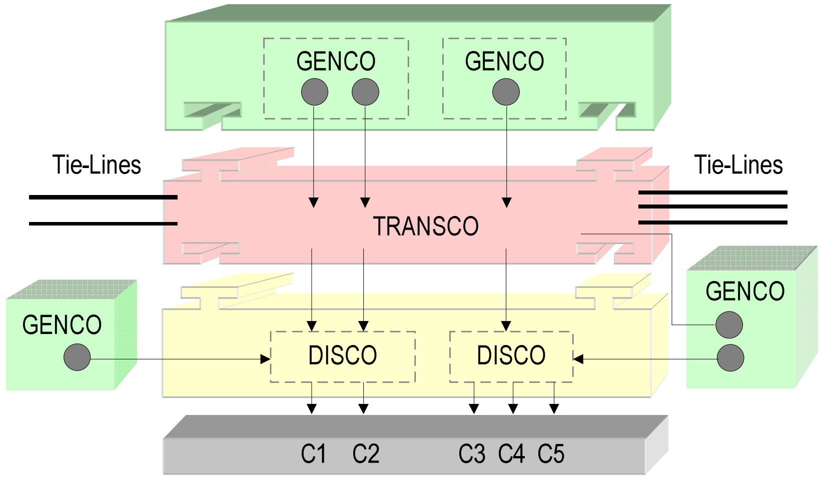
The Interconnection

- Edison designed the entire electrical system down to the wall outlet and in 1881 established the first power company
- In the 1930s, isolated power systems melded into interconnected systems
- In the 1950s and 1960s, isolated systems were converted to large regional pools
  - bulk delivery over long distances
  - originated at large generating plants
- With economies of scale, prices declined and demands increased

Power System Overview

- Market structure
  - Vertically integrated utilities
  - Competitive market



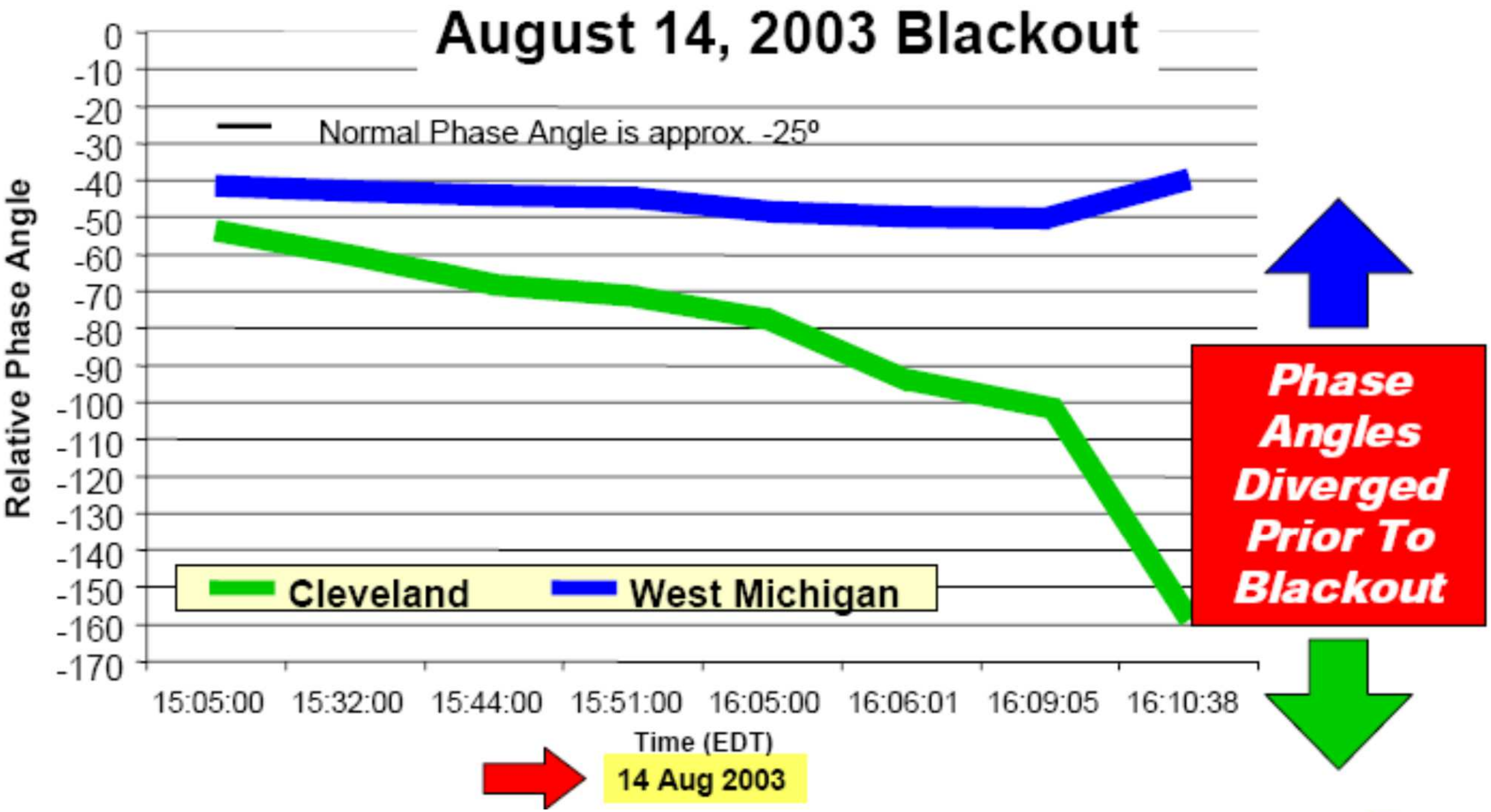


Power System Challenges

- Market competition increased the stress on power delivery system
  - The quest for the lowest cost power delivery led to an explosion of power transactions

- Power system was not designed for the fast pace of competition
  - Power system was largely based on the 1950s technology
  - Strain on the aging system began to show in digital era

Lack of situational awareness led to Blackout



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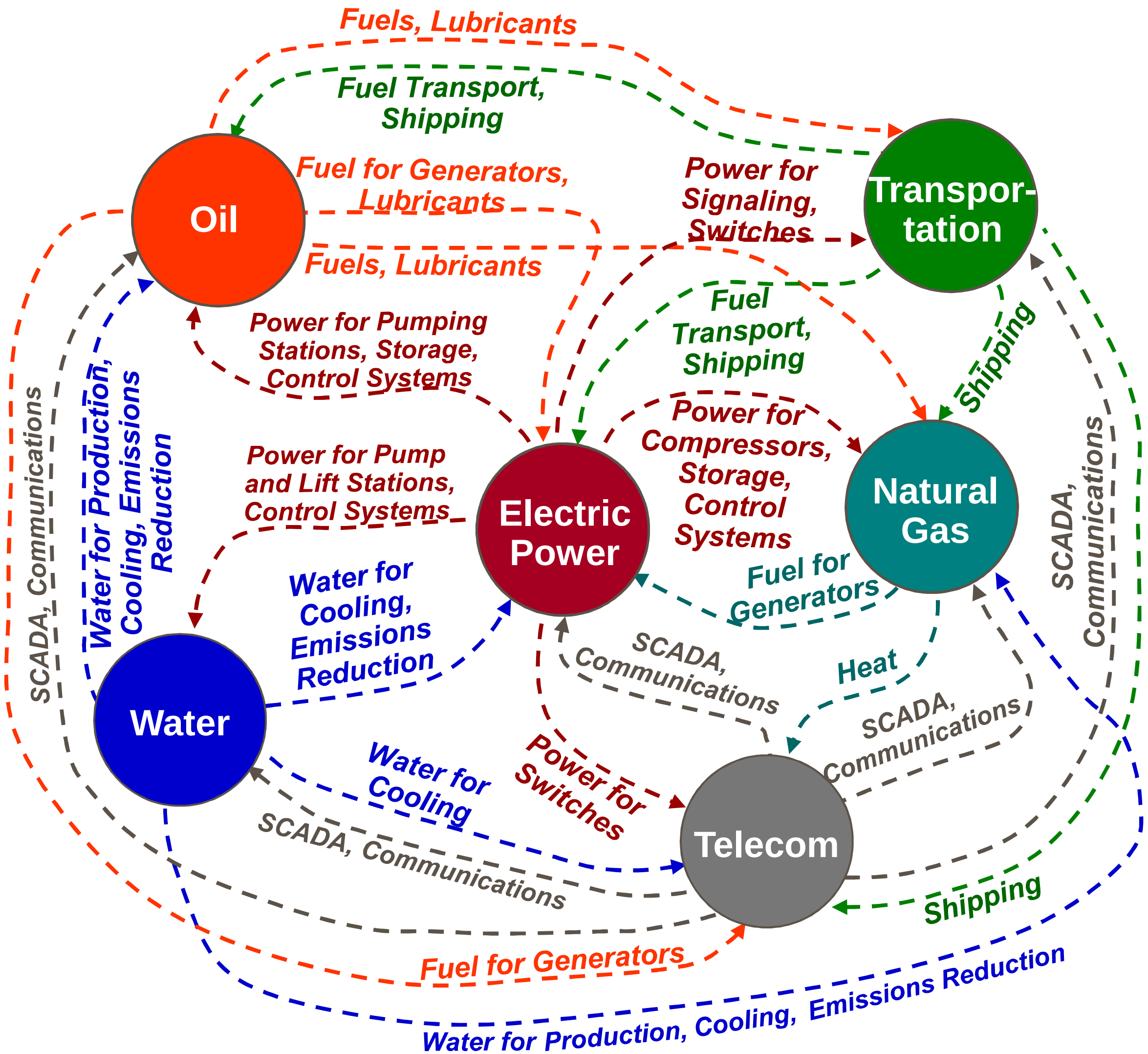
Interdependent Infrastructures



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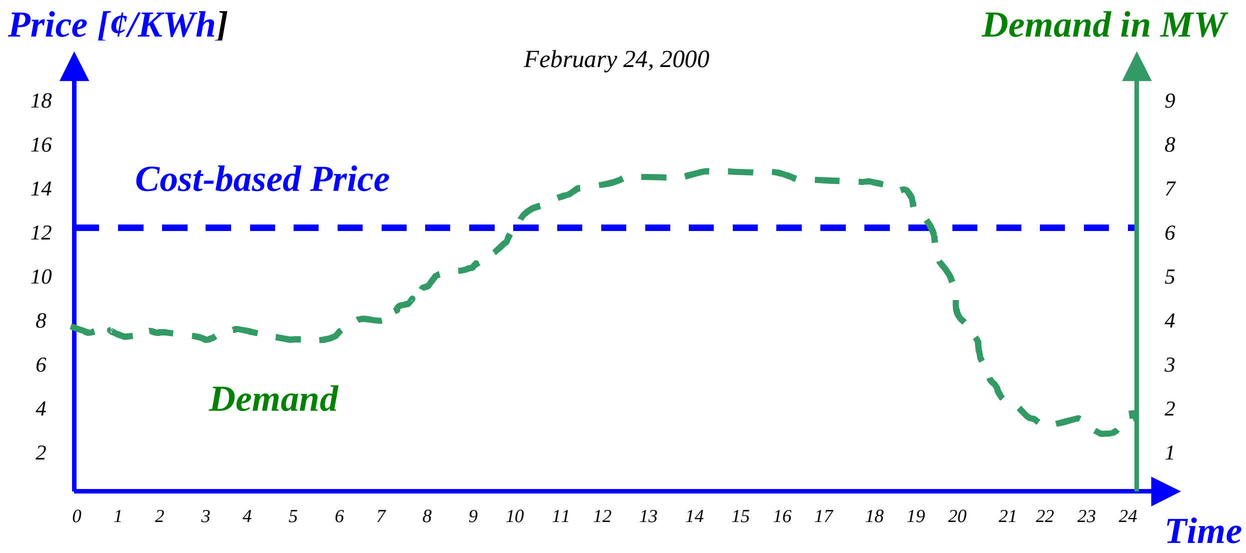
Electricity Infrastructure

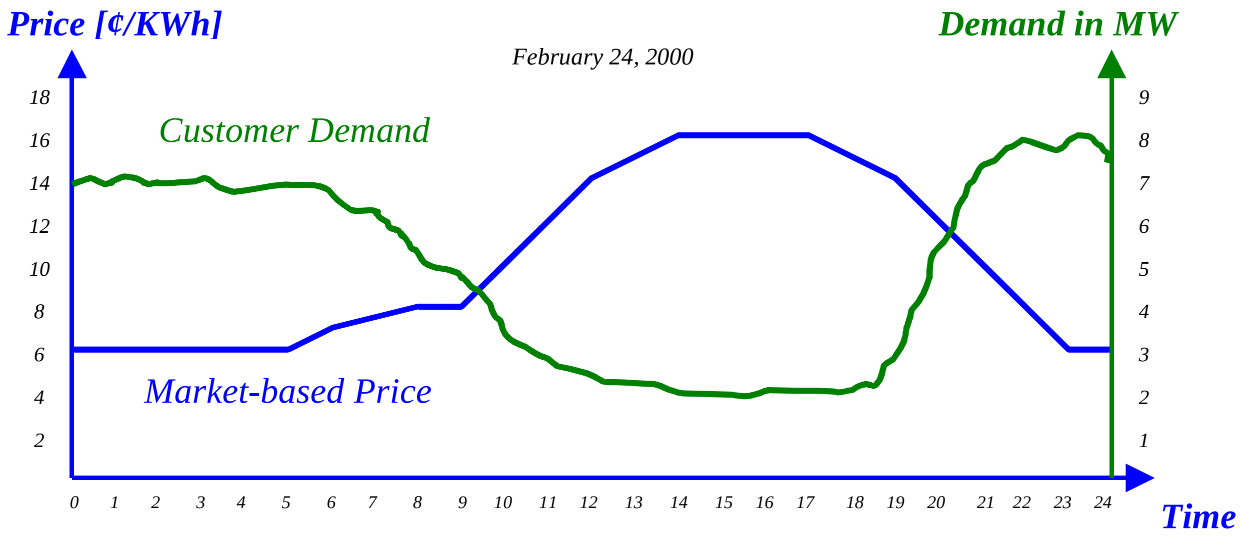
- **Supply Adequacy and Economics**: Applications of renewable energy, storage technologies for enhancing the security, coordination of renewable and storage supplies, carbon footprints
- **Transmission Expansion and Security**: Expansion planning of transmission facilities, coordination of energy infrastructures, superconductors, HVDC, physical and cyber security, wide area measurements, PMUs
- **Smart Grid**: Energy efficiency, price response, peak load reduction, distribution automation, new building technologies, smart metering, sensors, communication and control techniques

What is Smart Grid?

- Smart grid is a response to economic, security, and environmental mandates placed on energy supply and delivery
- Smart grid provides access points that can be identified, much like computer devices, with an IP address on the internet
- Smart grid uses the internet protocol to shuttle information back and forth between the utility and customers
- With two-way communications between consumers and suppliers, both parties can get far more control over the grid consumption, and physical and cyber security



Behavior of a Demand in a Vertically integrated Power Market



Response of a Demand to Price Signals

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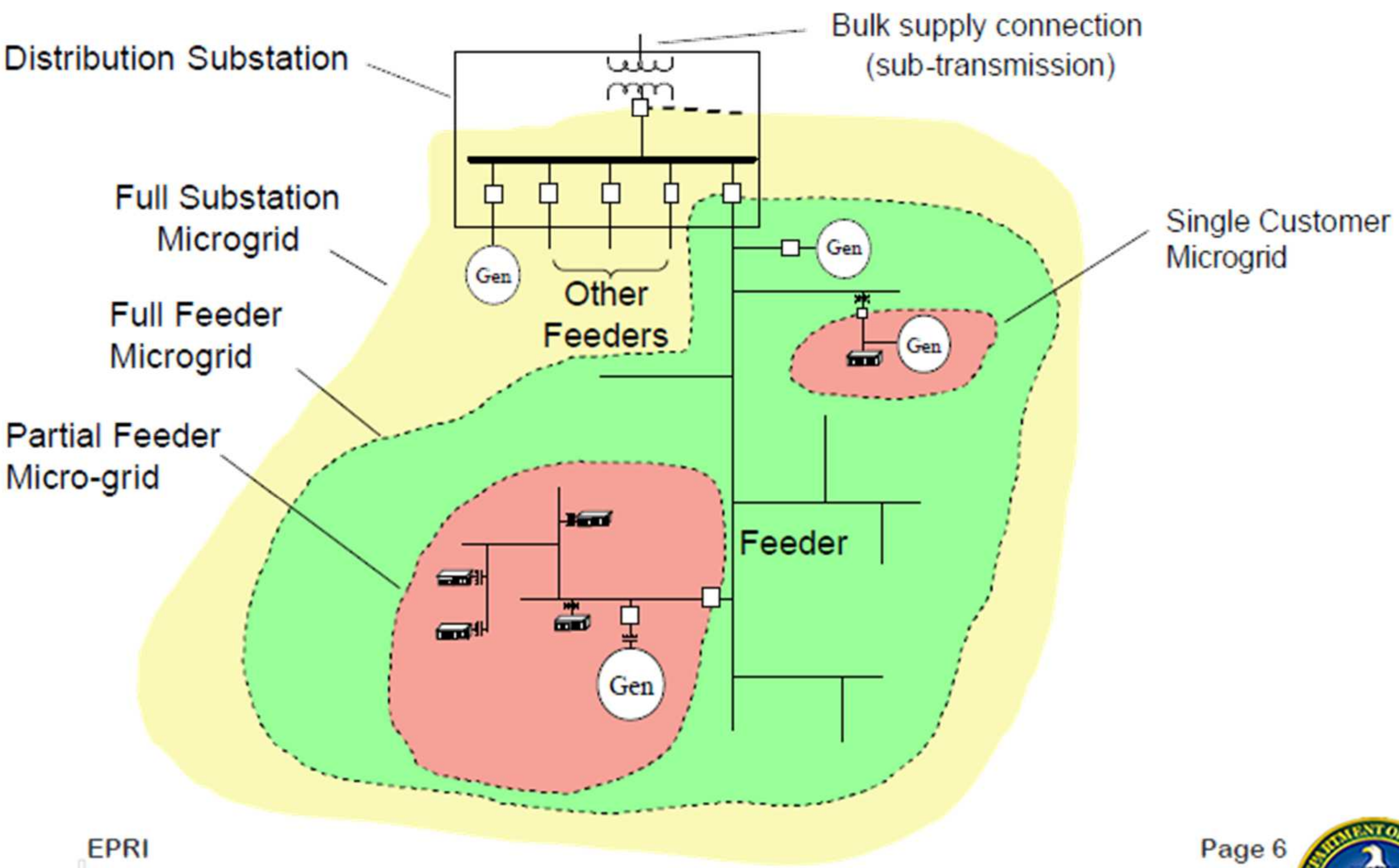
Various Size "Islands" on a Distribution System (All Could be Potential Microgrids)



Nominal System Voltage	Typical Maximum Loading Limits per Distribution Circuit with Commonly Used Conductors	Approximate Typical Area That Can Be Served per Circuit (km^2) *
480 V	0.1-0.5 MVA	< 0.1
4.8 kV	3-5 MVA	1-10
13.2 kV	7-13 MVA	5-30
25 kV	13-25 MVA	10-60
34.5 kV	18-35 MVA	15-90

*Service areas are illustrative of those found with load densities ranging from typical rural to typical suburban. Areas served will be less in high-density urban environments.

Peak Load Reduction Microgrid Projects

Chevron Energy Solutions

What: CERTS Microgrid Demonstration

Where: Santa Rita Jail, Alameda County, California

Technologies: Microgrid technology, large-scale battery storage, photovoltaics, fuel cell, wind turbines

ATK Space Systems

What: Powering a Defense Company with Renewables

Where: Promontory, Utah

Technologies: Hydro-turbines, compressed air storage, solar thermal, wind turbines, waste heat recovery system

City of Fort Collins

What: Mixed Distributed Resources

Where: Fort Collins, Colorado

Technologies: Photovoltaics, combined heat and power, thermal storage, fuel cell, microturbines, PHEV, demand response

Illinois Institute of Technology

What: The Never-Failing Perfect Power Prototype

Where: Illinois Institute of Technology, Chicago, Illinois

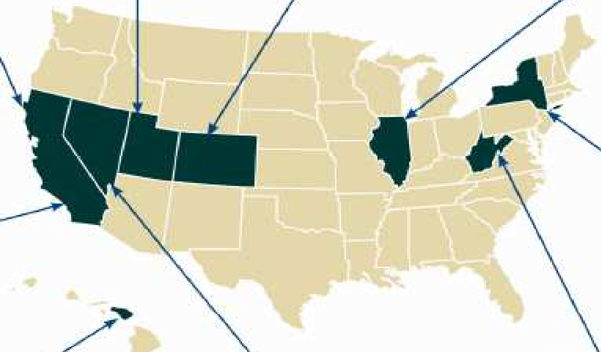
Technologies: Advanced meters, intelligent perfect power system controller, gas fired generators, demand response controller, uninterruptable power supply, energy storage

SDG&E

What: Beach Cities Microgrid

Where: San Diego, California

Technologies: Demand response, energy storage, outage management system, automated distribution control, advanced metering infrastructure



Consolidated Edison

What: Interoperability of Demand Response Resources

Where: New York City, New York

Technologies: Demand response, PHEVs, fuel cell, combustion engines, intelligent islanding, dynamic reconfiguration, fault isolation

University of Hawaii

What: Transmission Congestion Relief

Where: Maui, Hawaii

Technologies: Intermittency management system, demand response, wind turbines, dynamic simulations modeling

University of Nevada, Las Vegas

What: "Hybrid" Homes - Dramatic Residential Demand Reduction

Where: Las Vegas, Nevada

Technologies: Photovoltaics, advanced meters, in-home dashboard, automated demand response, energy storage

Allegheny Power

What: West Virginia Super Circuit - Dynamic Feeder Reconfiguration

Where: Morgantown, West Virginia

Technologies: Biodiesel combustion engine, microturbine, photovoltaics, energy storage, advanced wireless communications, dynamic feeder reconfiguration

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Goals of the DOE RDSI Project

- 50% peak demand reduction
- 20% permanent demand reduction
- Demonstrate the value of Perfect Power
  - Cost avoidance and savings in outage costs
  - Deferral of planned substations
- New products and commercialization
- Replicable to larger cities
- Promotion of energy efficiency and cleaner cities

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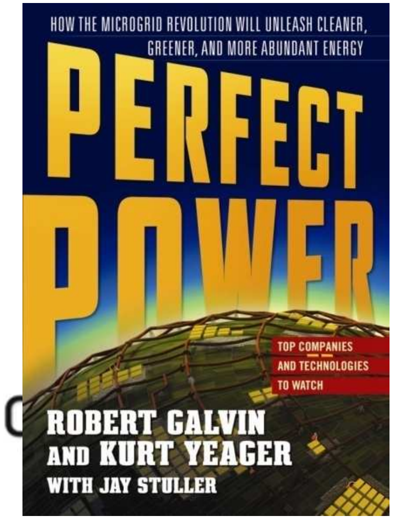
Perfect Power at Illinois Institute of Technology

- Funded by the U.S. Department of Energy
- Located at Illinois Institute of Technology (IIT)
- Involves the entire campus
- Partners: IIT, Exelon, S&C, Schweitzer, Siemens, Schneider, Eaton, GE, Invenergy, Intelligent Generation, ZBB, Viryd, I-GO, Smart Signal, Catch The wind



"The perfect power system will ensure absolute and universal availability of energy in the quantity and quality necessary to meet every consumer's needs. It is a system that never fails the consumer." Bob Galvin

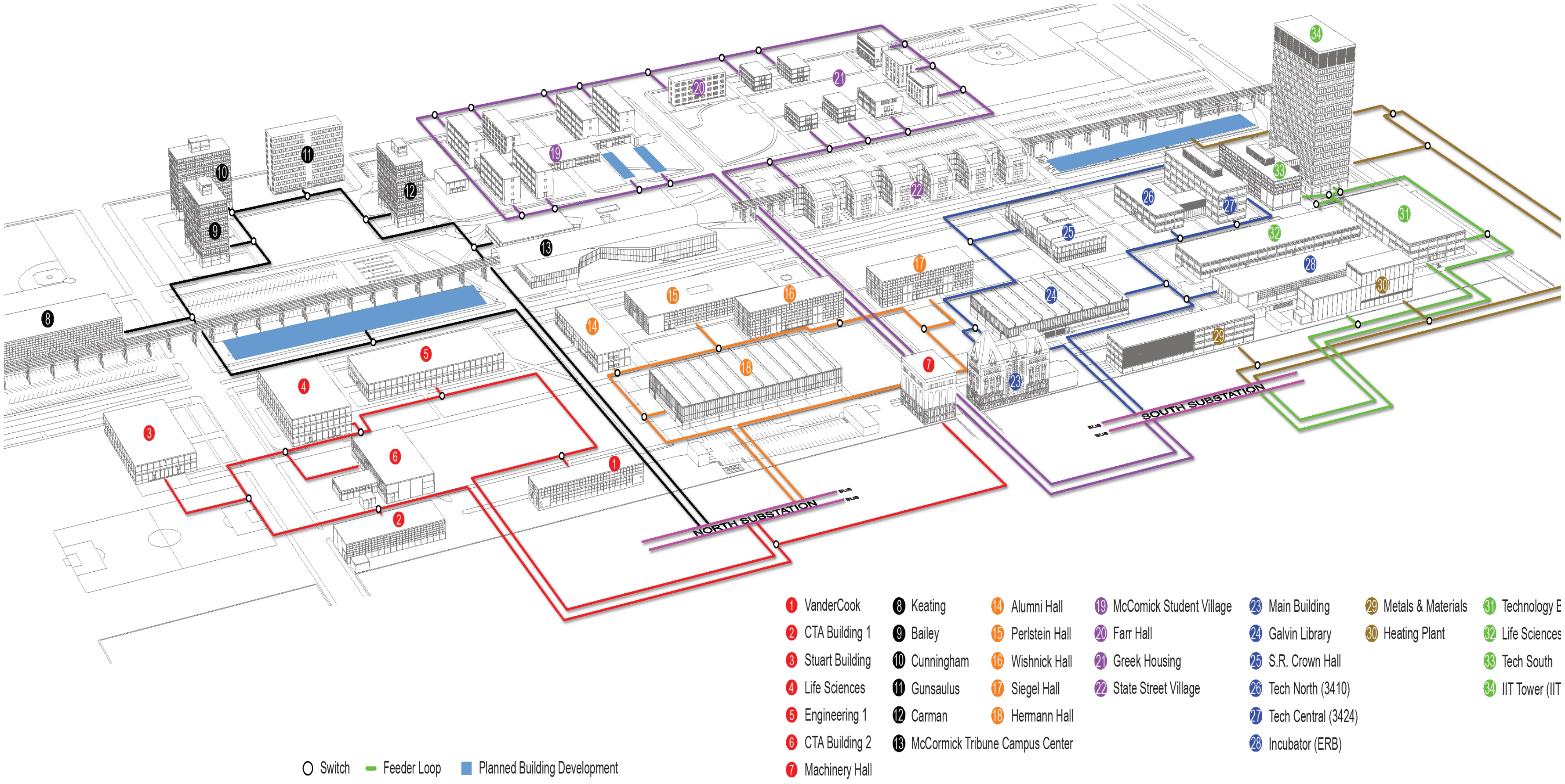
Elements of Perfect Microgrid at IIT

- Reliability
  - Physical and cyber security
  - Rapidly detect, respond, communicate, and restore

- Sustainability with storage
  - Provide distributed supply of energy (local gas power plant)
  - Leverage low carbon generation sources (PV, wind)

- Energy Efficiency
  - Campus controller with real-time pricing of electricity
  - Building controllers / smart grid for demand response

Loops at Perfect Microgrid



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HRDS Switches at IIT Microgrid

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Microgrid Components

ZBB Flow Batteries

ZBB EnerStore 50 kWh Module

Cell Stacks

ZBB EnerStore Assembly –
Milwaukee, WI

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Roof-Top Solar at the Microgrid

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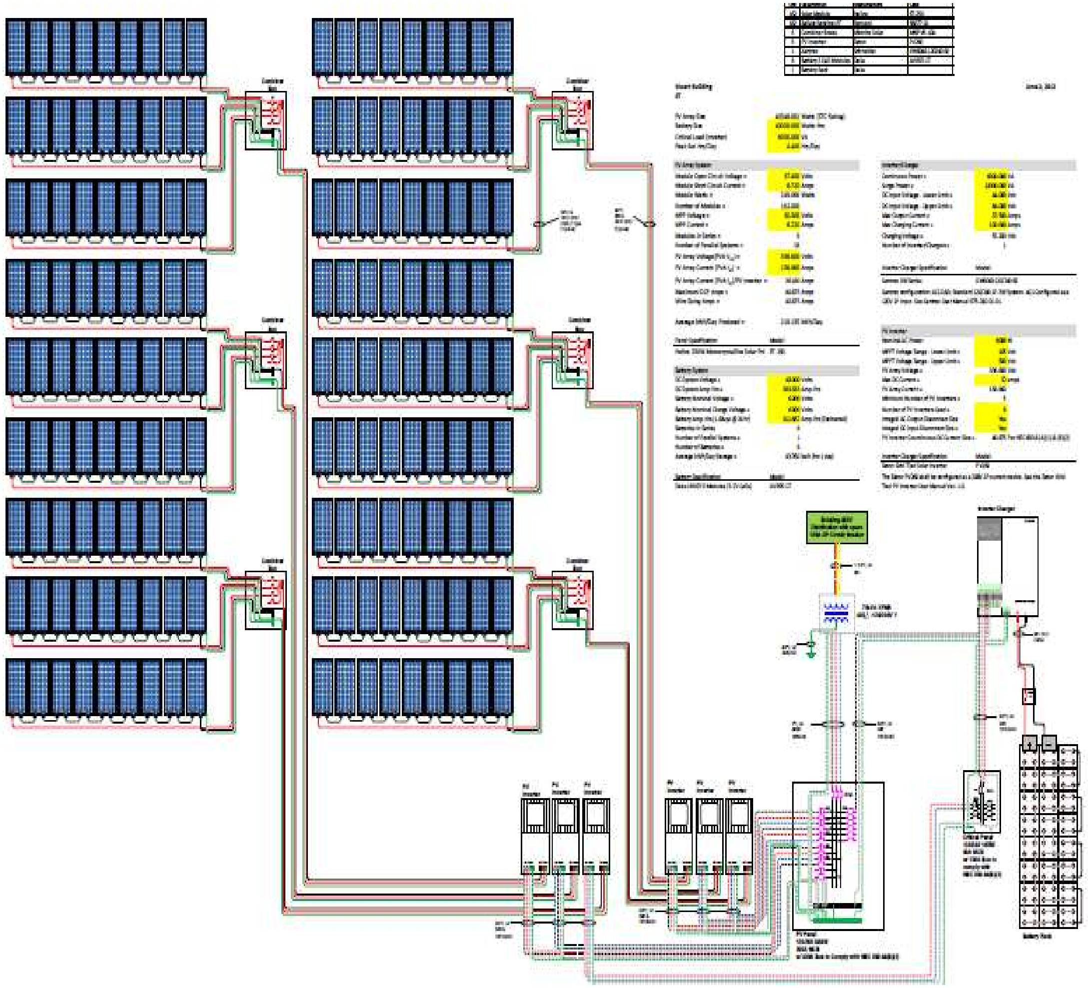
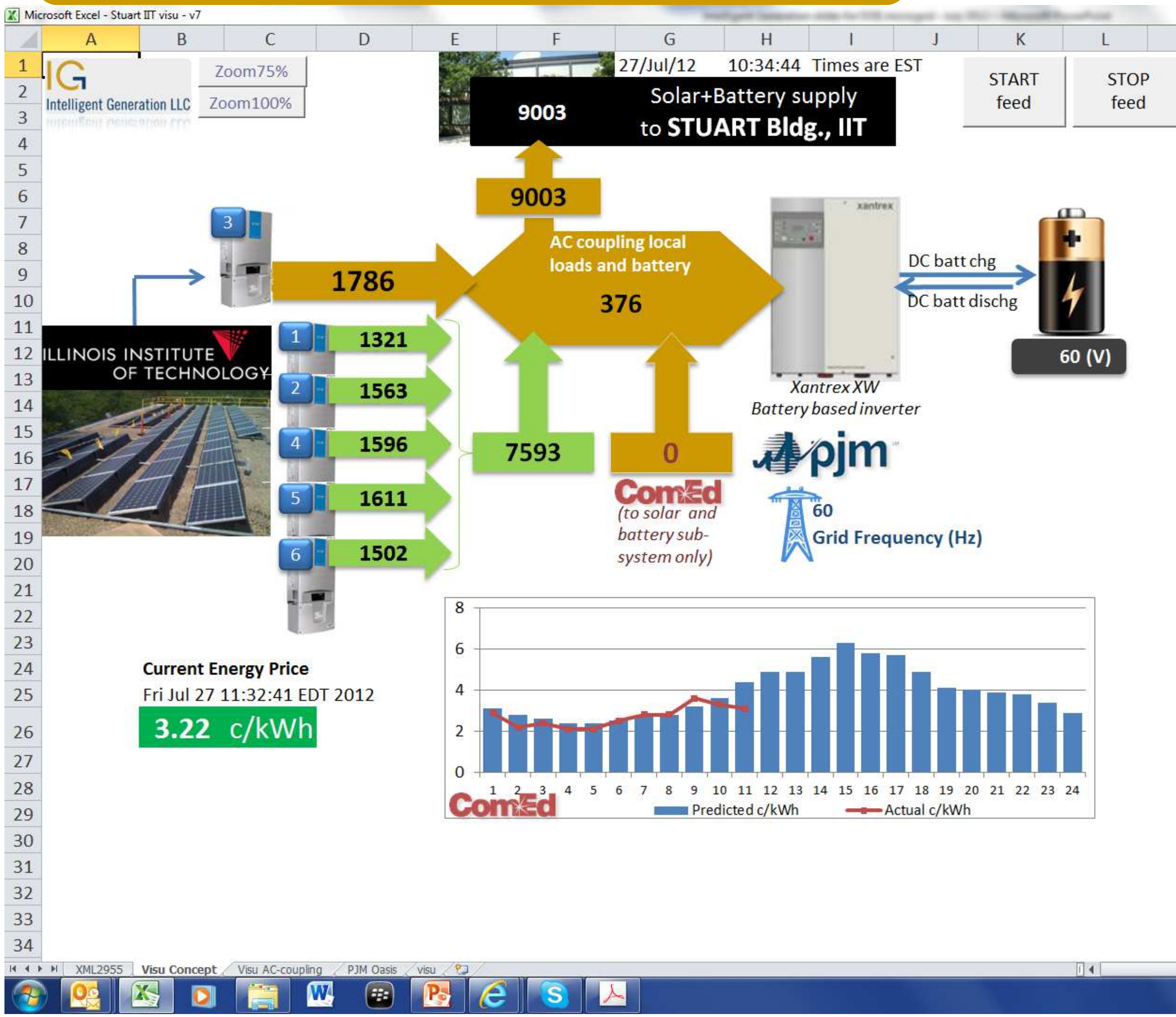
Solar PV at IIT



Intelligent Generation



- IG software remotely controls battery to achieve economic benefits.
- Services include:
  - PV firming
  - Demand charge reduction
  - Capacity charge reduction
  - Arbitrage
  - Frequency

Level 2 Stations | 1 DC Quick Charge Station

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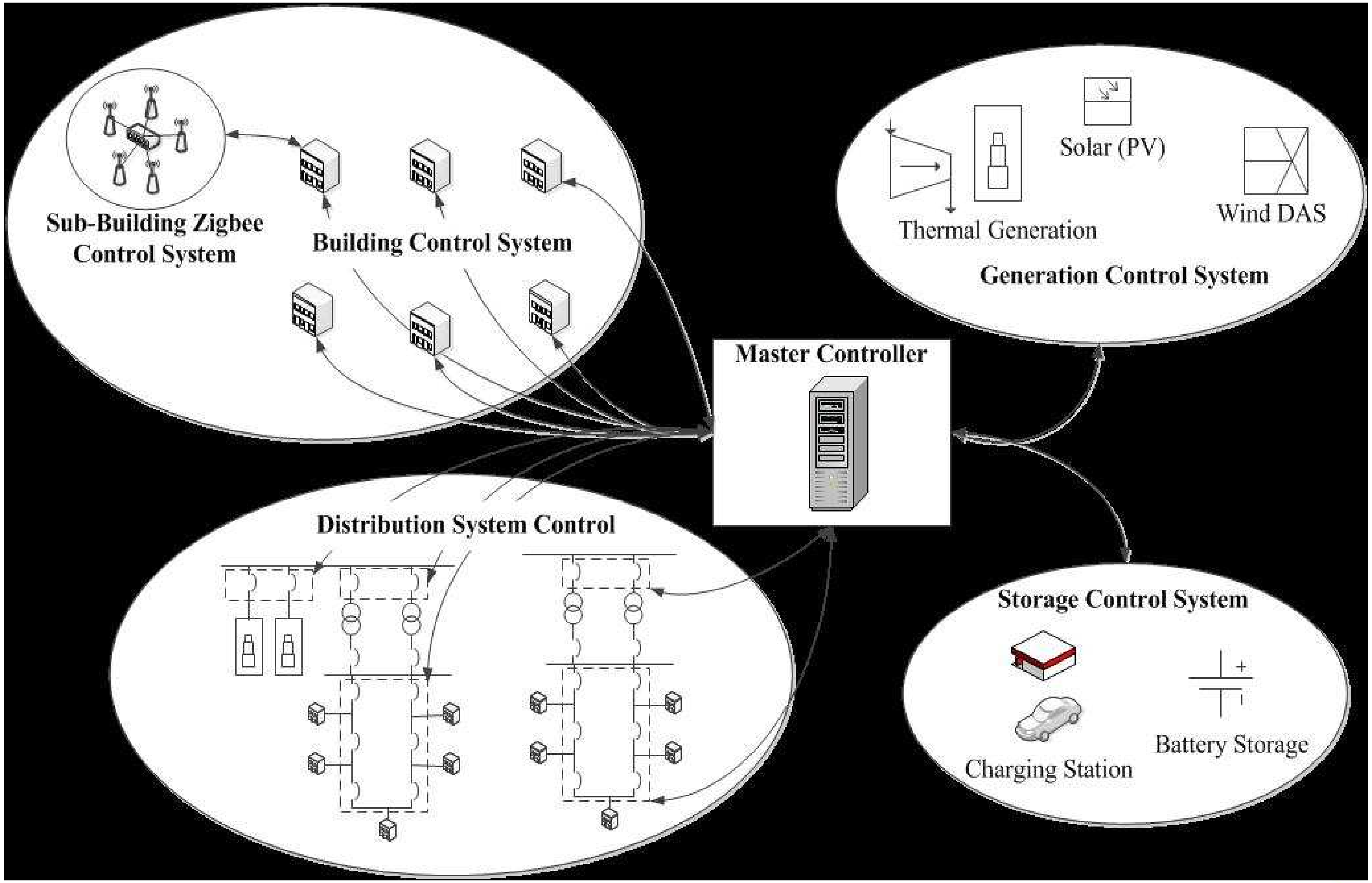
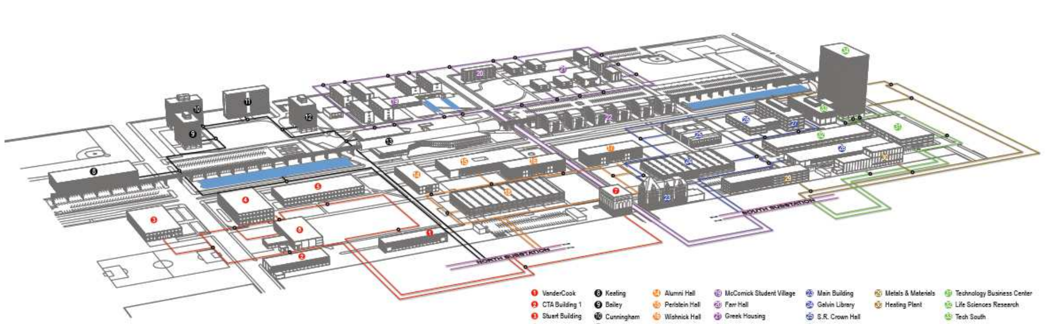
Microgrid Master Controller



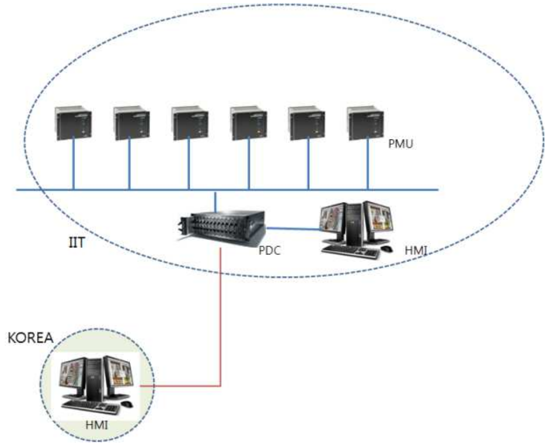
PMU: Local Area Monitoring System

Campus Microgrid
Illinois Institute of Technology

High Reliability Distribution System (drawing not to scale)
at the Illinois Institute of Technology - Main Campus



Smart PMU



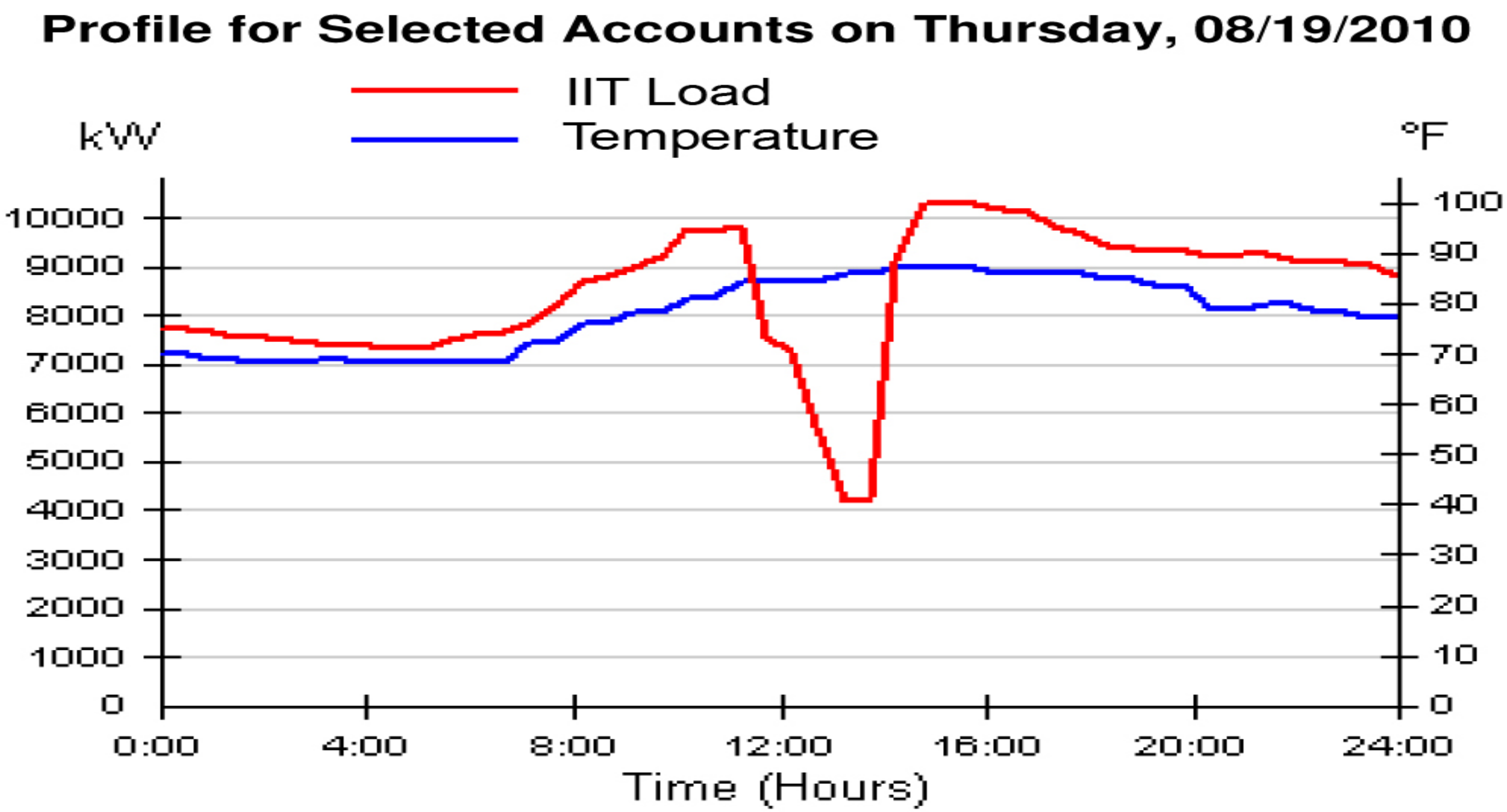
- PMU Demonstration for microgrid application
- LAMS for Campus Microgrid field test
- Enlarge PMU application field & Enhance microgrid technology

Master Controller Formulation

- Master controller is responsible for the economic operation of the microgrid based on signals received from HRDS switches.
- It monitors the status of HRDS switches using the SCADA system.
- It implements a three level hierarchical control (master, building, sub-building)
- It forecasts the real-time price of electricity and optimizes the hourly stochastic unit commitment/dispatch of local generation.
- Forecast errors of day-ahead load and wind speed and random outages of microgrid DG/distribution lines are considered.
- Monte Carlo representation of outages is applied and the Latin Hypercube Sampling (LHS) technique is used to develop a large number of scenarios with equal probabilities.

Integration of building automation with demand response and some optimization.

Peak Load Reduction Capability at Microgrid



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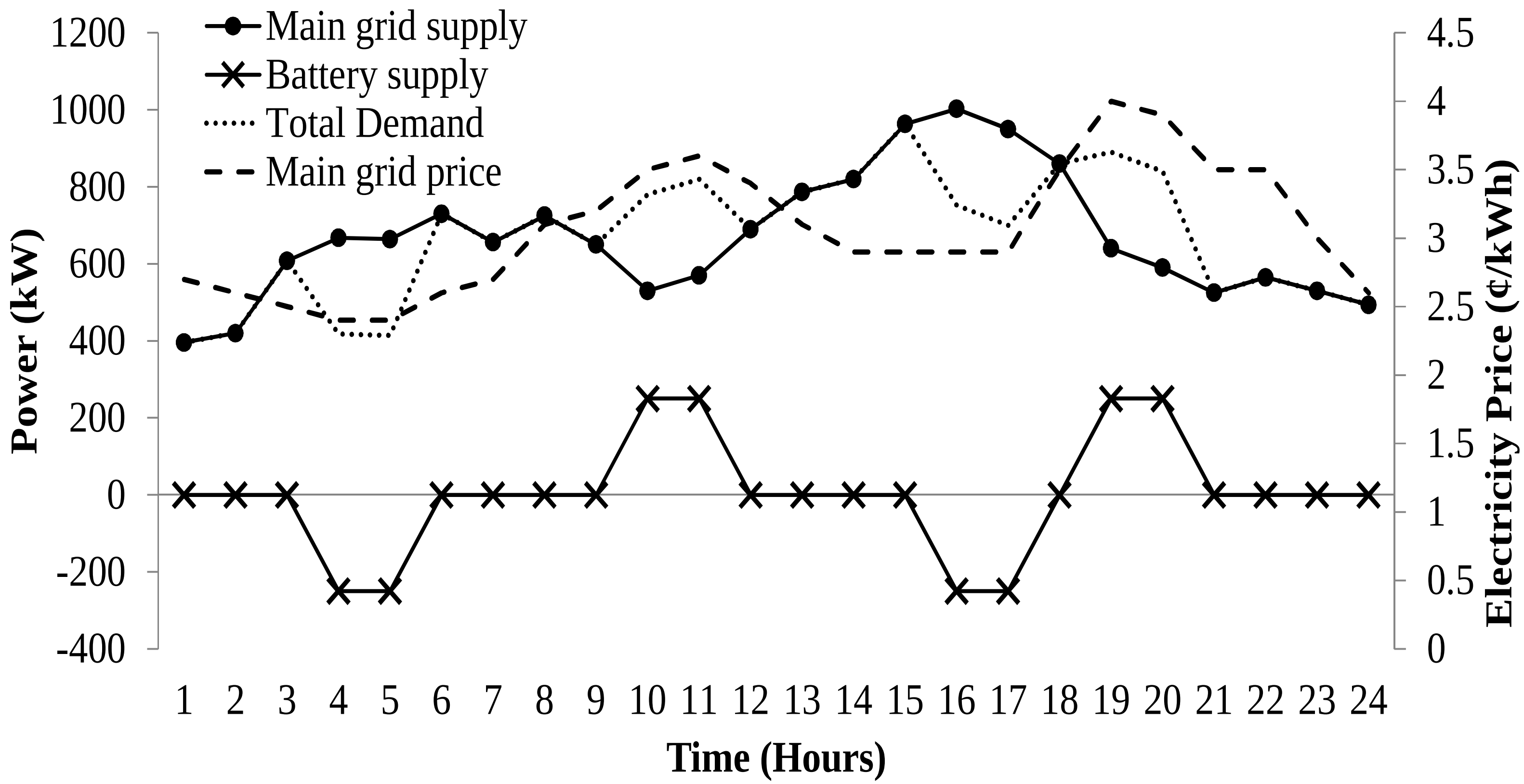
Optimal Control of IIT Microgrid



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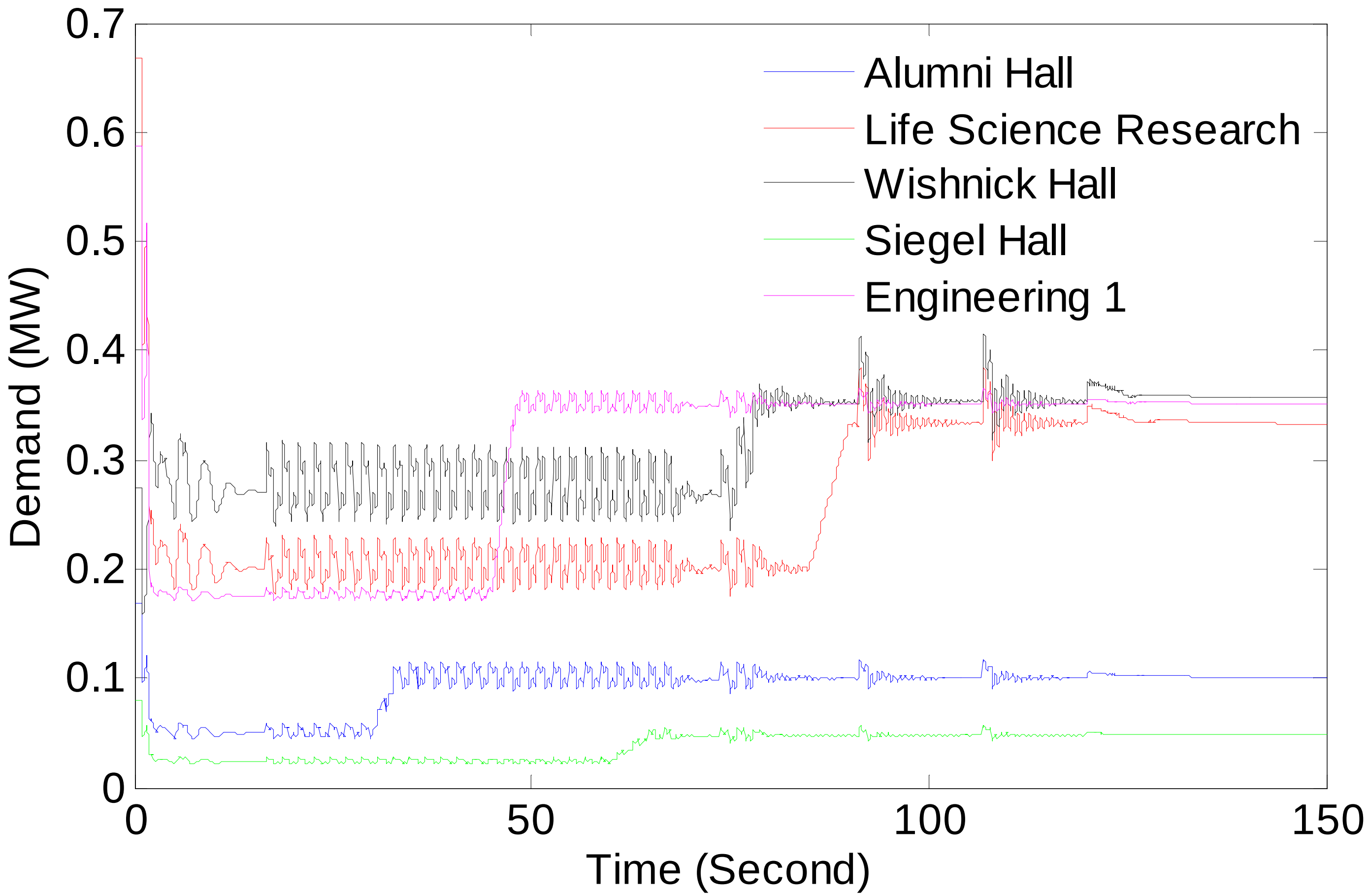
Reliability Evaluation – Stochastic Solution

- The installation of HRDS and storage will lead to the best expected reliability and economic indices.

Case	No HRDS	HRDS	HRDS + Storage
Exp. SAIDI	1.22	0.18	0.04
Exp. SAIFI	3.29	0.59	0.37
Exp. CAIDI	1.73	0.36	0.04
Exp. CAIFI	2.69	0.68	0.29
Exp. Operation Cost	224,073	146,899	120,038
Exp. Energy not Supplied	1,216.21	251.07	175.10
LOLE	13.153	2.360	1.467

Load Restoration



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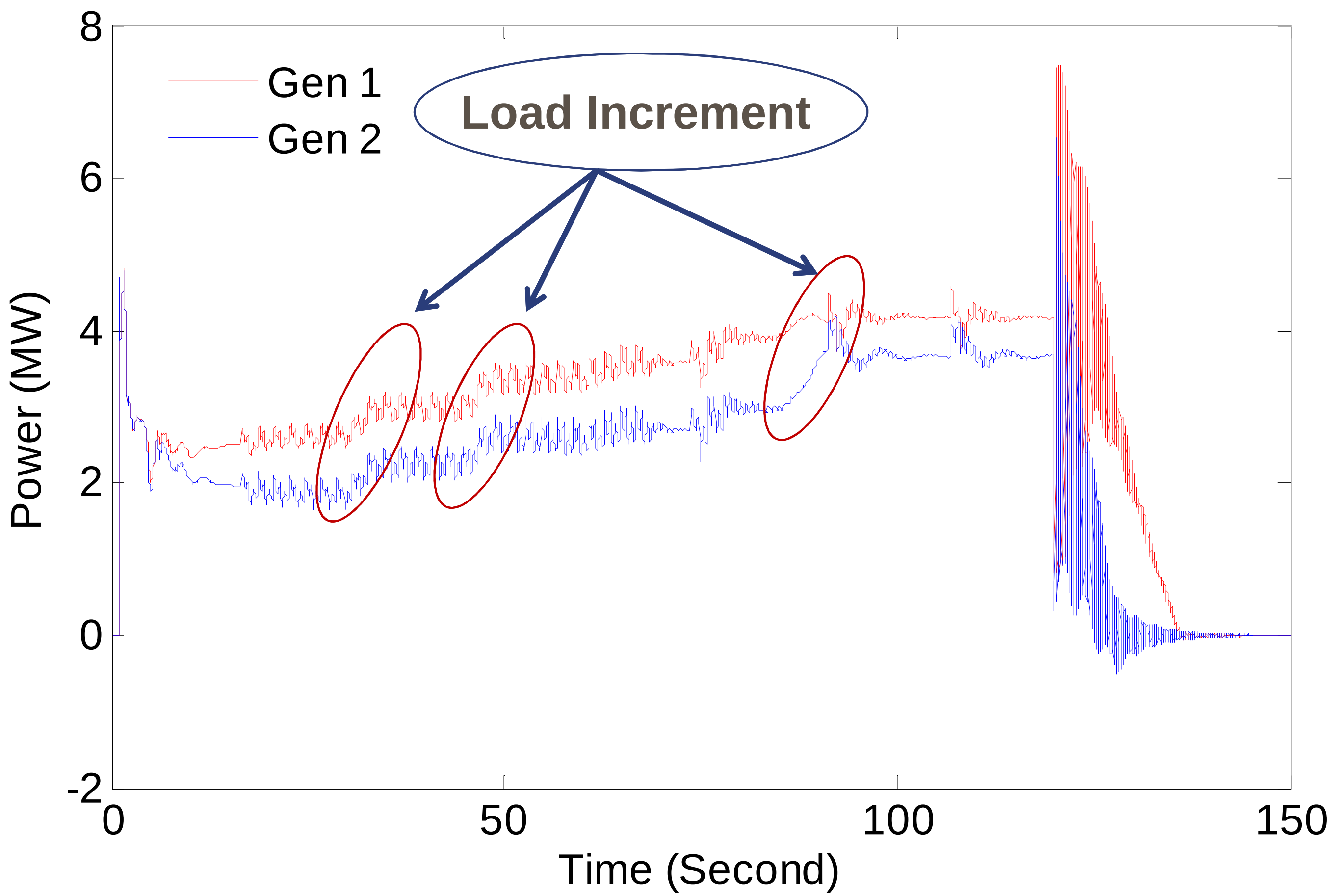
Load Sharing Among Generators



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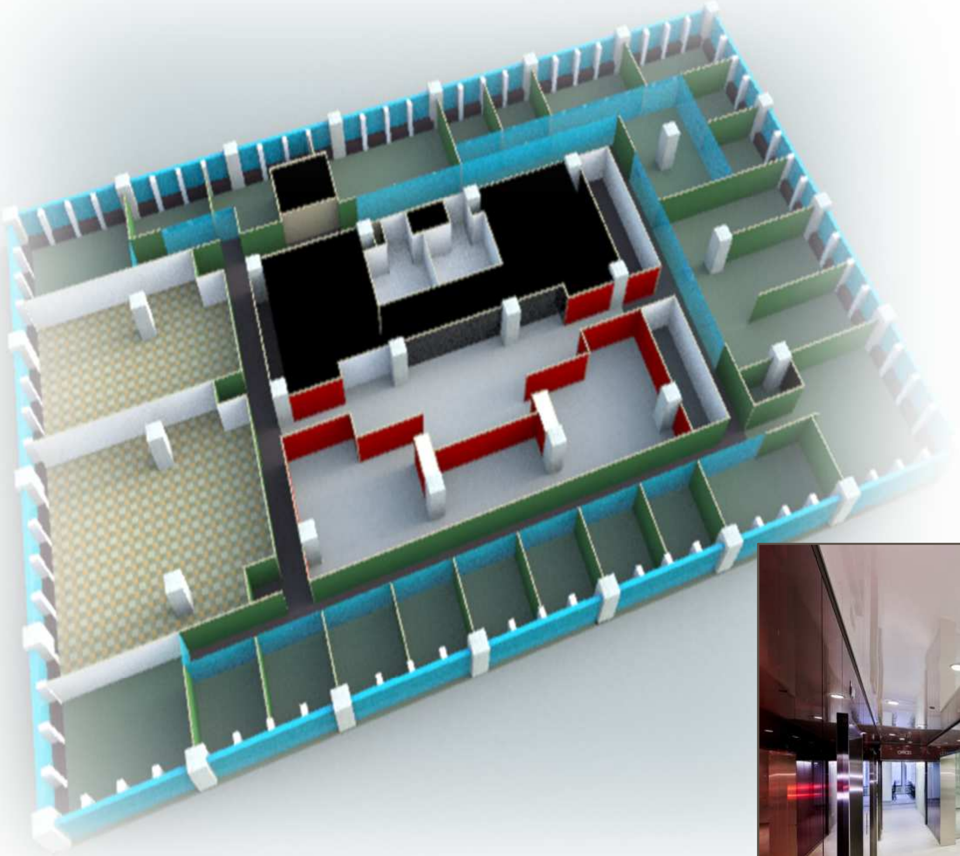

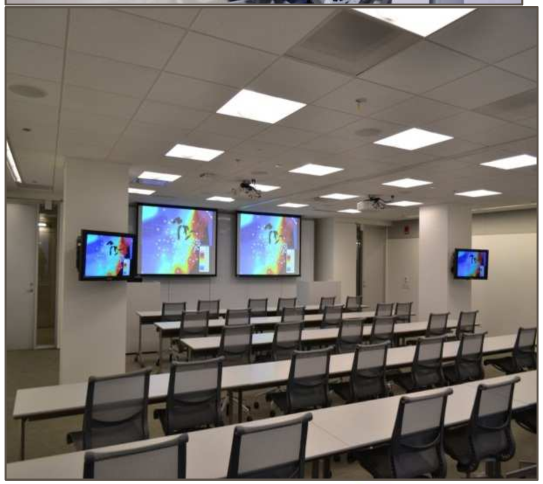

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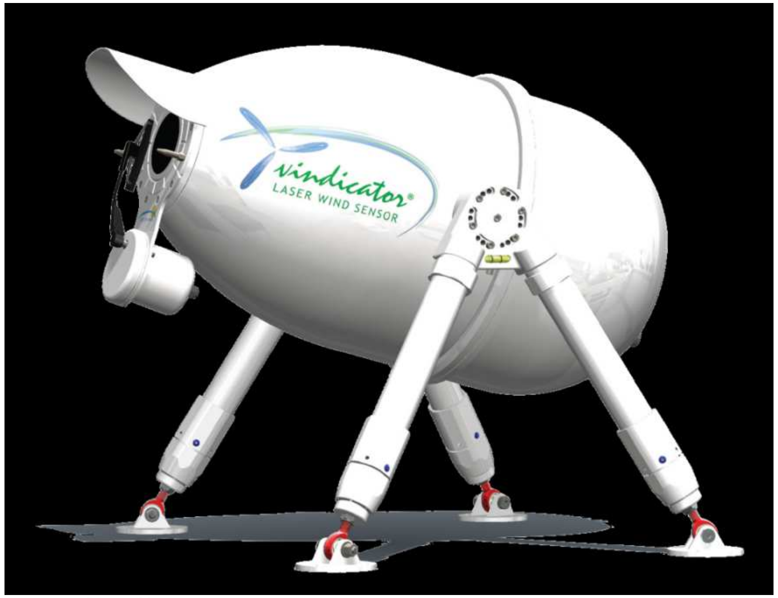

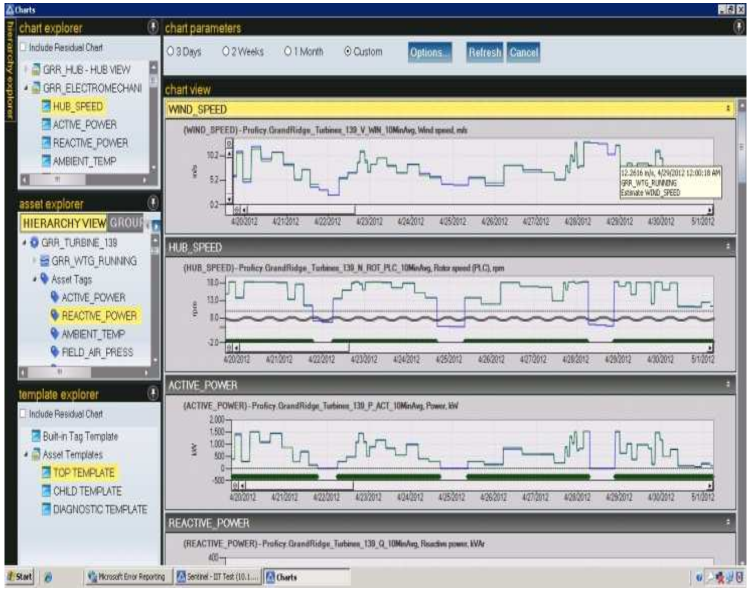

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Tabletop Model of the Microgrid

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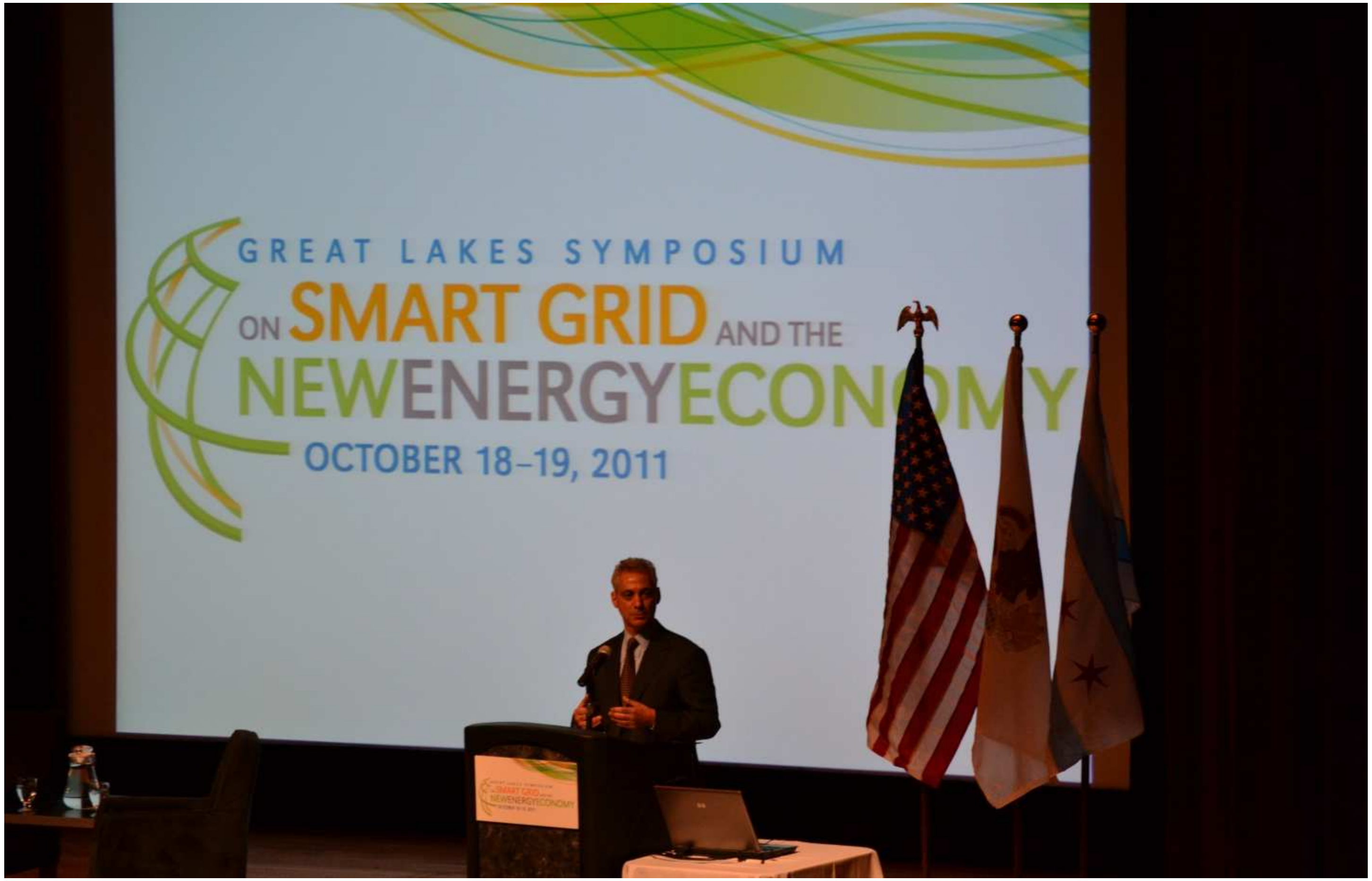
Operator Training Room at the Center

2011 IEEE Great Lakes Symposium



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ILLINOIS WINDWORKING GROUP

Advancing Wind Power in Illinois Conference
Thursday and Friday, July 21-22, 2011

At Illinois Institute of Technology
Main Campus, Hermann Hall
3241 S. Federal Street, Chicago, IL 60616

Conference Co-Hosted by:
Center for Renewable Energy at Illinois State University and
Galvin Center for Electricity Innovation at Illinois Institute of Technology

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Upcoming Events at the Galvin Center

Wind Powering America 12th Annual All-States Summit, May 9, 2013

2013 IEEE Great Lake Symposium on Smart Grid and the New Energy Economy, September 23-25, 2013