Perfect Power Prototype for Illinois Institute of Technology

Final Technical Report

DOE Award Number: DE-FC26-08NT02875

Project Period: October 1, 2008 to September 30, 2014

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December 29, 2014

Acknowledgement

This report is based upon the work supported by the U. S. Department of Energy under Award Number DE-FC26-08NT02875. On behalf of the members of this project, I would like to thank the U.S. Department of Energy for making this project possible. The many tasks of this six-year study could not have been completed without the dedicated effort of all members of this project. We look forward to continuing our technical and educational collaborations, and utilizing the expertise developed as part of this project, beyond the completion of the proposed tasks.

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Disclaimer

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List of Abbreviations

AC	Alternating Current
ANSI	American National Standards Institute
ARRA	American Recovery and Reinvestment Act of 2009
BCR	Benefit Cost Ratio
CCGTs	Combined-cycle Gas Turbine
CEO	Chief Executive Officer
CO2	Carbon Dioxide
DC	Direct Current
DER	Distributed Energy Resource
DG	Distributed Generation
DOE	Department of Energy
DPF	Distributed Power Flow
DR	Demand Response, Distributed Resource
ECE	Electrical and Computer Engineering
ECEDHA	Electrical and Computer Engineering Department Heads Association
EECS	Electrical Engineering and Computer Science
EMT	Electromagnetic Transient Simulator
EPRI	Electric Power Research Institute
EPS	Electric Power System
ESS	Energy Storage System
EV	Electric Vehicle
FLISR	Fault Detection, Location, Isolation, and Service Restoration
GE	General Electric
GEI	Galvin Electricity Initiative
GENCO	Generating Company, Generation Company
GIS	Geographical Information System
HRDS	High Reliability Distribution System
IDC	Internet Data Center
IEEE	Institute of Electrical and Electronics Engineers
IIT	Illinois Institute of Technology
IITRI	IIT Research Institute
IPS	Intelligent Power Solutions
ISO	Independent System Operator
KERI	Korea Electrotechnology Research Institute
Kg	Kilogram
kpph	Kilo Pascals Per Hour
kV	Kilovolt
kW	Kilowatt
kWh	Kilowatt-hour

LED	Light Emitting Diode
LMP	Locational Marginal Price
LR	Lagrangian Relaxation, Loss Reduction, Load Redistribution
MAS	multi-agent system
MATLAB	MATrix LABoratory
MBTU	Million British Thermal Unit
MEF	Marginal Emission Factor
MMC	Microgrid Master Controller
MPPT	Maximum Power Point Tracking
MS	Master of Science
MW	Megawatt
MWh	Megawatt-hour
NAE	National Academy of Engineering
NETCS	National Electric Transmission Congestion Study
NPV	Net Present Value
PBUC	Price-based Unit Commitment
PCC	Point of Common Coupling
PD	Protective Device
PETSc	Portable, Extensible Toolkit for Scientific Computation
PEV	Plug-in Electric Vehicle
PhD	Doctor of Philosophy
PHEV	Plug-in Hybrid Electric Vehicle
PI	Principal Investigator
PMU	Phasor Measurement Unit
POMS	Power Market Simulator
PS	Pumped-storage Hydro
PSCAD	Power System Computer Aided Design
PV	Photovoltaic
R&D	Research and Development
RDSI	Renewable and Distributed Systems Integration
RFC	ReliabilityFirst Corporation
RTP	Real-time Pricing
SCADA	Supervisory Control and Data Acquisition
SCED	Security-constrained Economic Dispatch
SCUC	Security-constrained Unit Commitment
THD	Total Harmonic Distortion
TEPPC	Transmission Expansion Planning Policy Committee
TS	Transmission Switching, Transient Stability Simulator
UPS	Uninterruptible Power Supply
V2G	Vehicle-to-grid
VP	Vice President
VVC	Volt-VAR Control

WECC	Western Electricity Coordinating Council
WINS	Wind Integration Simulator
WLAN	Wireless Local Area Network

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1. Executive Summary

The Renewable and Distributed Systems Integration (RDSI) Program within the R&D Division of the Office of Electricity Delivery and Energy Reliability, Department of Energy sought to develop and demonstrate new distribution system configurations integrated with distributed resources. The smart grid program supported by the American Recovery and Reinvestment Act of 2009 (ARRA) aimed at modernizing the nation's electric energy system and significantly affecting utility investments in the electric power sector, thereby contributing to job creation and preservation and economic recovery. These efforts are critical to achieving the nation's ambitions for renewable energy development, electric vehicle adoption, and energy efficiency improvements.

Starting in October 2008, Illinois Institute of Technology (IIT), in collaboration with over 20 participating members, led an extensive effort to develop, demonstrate, promote, and commercialize a microgrid system and offer supporting technologies that will achieve Perfect Power at the main campus of IIT. A Perfect Power system, as defined by the Galvin Electricity Initiative (GEI), is a system that cannot fail to meet the electric needs of the individual end-user. The Principle Investigator of this Perfect Power project was Dr. Mohammad Shahidehpour, Director of the Robert W. Galvin Center for Electricity Innovation at IIT.

There were six overall objectives of the Perfect Power project.

- Demonstrate the higher reliability introduced by the microgrid system at IIT. This objective has been met. The IIT Microgrid is equipped with High Reliability Distribution System (HRDS), which includes seven loops for enhancing its reliability. IIT has not experienced any outages since the loops have been installed resulting in an estimated savings due to avoided outage downtime of $500,000 per year.
- Demonstrate the economics of microgrid operations. This objective has been met. The Net Present Value (NPV) of the IIT Microgrid project is calculated to be approximately $4.6 million over the next 10 years, primarily due to the deferral of costly substation upgrades and expansion.
- Allow for a decrease of fifty percent (50%) of grid electricity load. This objective has been met. On August 19, 2010, the campus load was reduced by 60% through curtailing building loads, shifting campus loads, and dispatching the natural-gas turbine.
- Create a permanent twenty percent (20%) decrease in peak load from 2007 level. This objective has been partially met. The 2007 peak load was 12,921 kilowatt (kW). Without considering the natural increase of load as a result of increasing student enrollment and research activities, three out of the six years since 2007 had a reduction of over 20% and all six years had a reduction of over 17%.
- Defer planned substation through load reduction. This objective has been met. Pending upgrades to the Fisk substation by the utility, totaling $2.0 million and the installation of a third substation on the east campus planned by IIT at a cost of over $5.0 million were deferred due to the installation of the IIT Microgrid.
- Offer a distribution system design that can be replicated in urban communities. This objective has been met. The successful operational history of the IIT Microgrid in the Chicago area suggests that this type of microgrid design can be replicated in urban communities. Additionally, the local electric utility, ComEd, is planning on developing the Bronzeville

Community Microgrid (10 megawatt (MW) peak demand) and interconnecting it with the IIT Microgrid (12MW peak demand) making it the first-ever cluster of a private and a utility microgrid in a metropolitan region of the United States.

During the six-year period, the Perfect Power project demonstrated a replicable model for leveraging advanced microgrid technology that automatically responds to utility, Independent System Operator (ISO), and electricity distribution system signals, changes, and interruptions in a way that provides demand reduction support, increased reliability, and enhanced resilience. The stated goals of the Perfect Power project were achieved with a phased approach.

- Prepare IIT's infrastructure for Perfect Power improvements. A conceptual design was established and campus substation supply underwent reliability improvements. IIT conducted building energy efficiency upgrades and a detailed design which was completed for the campus distribution system.
- Deploy advanced campus distribution system based on High Reliability Distribution System (HRDS) design. This design which completed three loops and leverages seven feeder loops is working in concert with intelligent high-speed switches to isolate any single fault without interruption of power to buildings.
- Modify existing gas turbines and deploy distributed energy resources including solar photovoltaic, energy storage system, and electric vehicle charging stations. This goal enabled IIT to provide ancillary services including demand response and spinning reserve.
- Develop and deploy a master controller. This goal provided a master controller for full system monitoring capability and demand response capability.
- Address key technology gaps including advanced distribution fault detection, ZigBee wireless infrastructure, demand response control, and advanced distribution controls. Technologies were developed and are available for pilot testing.

The major achievements in the Perfect Power project include the completion of the IIT Microgrid and the establishment of a smart grid education and workforce training program.

- IIT Microgrid is a representative of an economically viable microgrid which includes (1) Distributed Energy Resources (DERs); (2) An optimal electrical network for locations of DERs, microgrid switches, critical and noncritical loads, microgrid protection scheme, and interfaces with the ComEd utility system.
    - IIT Microgrid has a peak load of about 12 MW, which can be operated in grid-connected and island modes, and is capable of integrating new sustainable energy sources. The total generation capacity is 12,342kW, including 8,000kW of natural gas turbines, 300kW of solar generation, 8kW of wind generation, and 4,034kW backup generation. The IIT Microgrid includes a 500 kilowatt-hour (kWh) flow battery and several small size storage devices.
    - IIT Microgrid is equipped with HRDS, which includes seven loops for enhancing its reliability. Each HRDS loop utilizes Vista underground closed loop fault-clearing switchgear with SEL-351 directional over-current protection relays. The fault isolation takes place in a quarter of a cycle by automatic breakers. The communication system is via fiber optic cables which facilitate the coordination between switches. IIT has not experienced any outages since the loops have been installed.

- The components of the IIT Microgrid, other than HRDS, include DERs, meters and phasor measurement units (PMUs), and building controllers. DER units include dispatchable units such as natural-gas turbine generator and battery storage units, and non-dispatchable units such as solar photovoltaic (PV) and wind turbine units. The storage units at IIT include a flow battery and several lead-acid batteries. Building controllers provide control and monitoring functions for building loads on campus. The IIT Microgrid is equipped with building meters and 12 PMUs which report building electricity consumptions and instantaneous voltage and current of DER units (at a sampling rate of one signal per cycle) to the master controller.

- IIT Microgrid has achieved significant resiliency, efficiency, economic, and environmental benefits.
  - Resiliency Benefits: In extreme circumstances, IIT Microgrid enhances its operation resilience by a real-time reconfiguration of underground distribution assets, real-time islanding of critical loads, and real-time optimization of power supply resources. In such cases, IIT Microgrid has access to uninterruptible fuel sources, has black start capability, is in compliance with IEEE 1547[1] on islanding and reconnection, and is capable of continuously supplying critical loads and supporting its future critical loads.
  - Efficiency Benefits: IIT Microgrid operation has achieved a 6.51% improvement in the campus energy efficiency (saving 64,481MBtu annually), from the base year (June 1, 2008 to May 31, 2009) to the current year (June 1, 2013 to May 31, 2014), with demand response and on-site natural gas power plant and renewable energy resources.
  - Economic Benefits: The Net Present Value of the IIT Microgrid project is amounted at $4,597,683.32 over the next 10 years, or $383.14/kW, due mainly to deferred substation upgrade and expansion, improved operation reliability (fewer outages) and the efficient utilization of local generation. The pending upgrades to the Fisk substation by the utility, totaling $2,000,000, were deferred due to the installation of the IIT Microgrid. The installation of a third substation on the east campus planned by IIT at a cost of over $5,000,000 was deferred due to the IIT Microgrid. The annual savings due to avoided outage downtime is estimated to be $500,000.
  - Environmental Benefits: IIT Microgrid has achieved a 6.58% reduction in annual CO2 emission (saving 3,457,818kg), from the base year to the current year, with the addition of renewable generation resources, storage, and demand response.

- This project has established a fully-functional Smart Grid Workforce Training Program as part of the operation of the Robert W. Galvin Center for Electricity Innovation (Galvin Center). The Galvin Center has contributed greatly to the education of smart grid workforce and exchange of smart grid technology.
  - Located on the 16th floor of the IIT Tower, the 16,000-square-foot Gavin Center contains offices, exhibition rooms, classrooms and student workrooms, acting as a hands-on experience center for Smart Grid, microgrid and energy technology and

[1] IEEE 1547 (Standard for Interconnecting Distributed Resources with Electric Power Systems) is a standard meant to provide a set of criteria and requirements for the interconnection of distributed generation resources into the power grid.

  - education. The Galvin Center provides a perfect setting for continuing the smart grid education and workforce development.
  - The Galvin Center has developed a website (http://iitmicrogrid.net/ and http://iitmicrogrid.net/education.aspx) on the IIT Microgrid and smart grid workforce training. The website includes all the activities related to the IIT Microgrid and workforce training development, including events, media reports (videos and photos), publications, etc. The website has been constantly updated to include the latest development.
  - The Galvin Center has hosted since 2011 four annual Great Lakes Symposium on Smart Grid and the New Energy Economy. The Symposium has featured keynote and plenary sessions, technical presentations, and tutorials by international experts on smart grid applications. The Symposium is a one-of-a-kind event that breaks new ground in smart grid design and development and showcases smart grid best practices from around the country along with new technologies and ideas that are spurring innovation, growing state economies, reducing emissions and empowering consumers to conserve and save. The Center will continue to host the annual symposium and make it a flagship conference of smart grid training.
  - The Galvin Center has hosted high-impact workshops (e.g., DOE Microgrid Workshop, National Academy of Engineering Smart Grid Symposium), highly technical workshops (e.g., Electric Vehicle Technologies Workshop, Electrical Energy Storage Technologies and Applications Workshop), and policy-oriented outreach workshops (e.g., Illinois Smart Grid Policy Forum, Wind Consortium Conferences). The Galvin Center will continue to host such workshops to continue its mission on smart grid education.

- Research supported by this project resulted in
  - 85 technical talks and keynote speeches at global smart grid forums
  - 57 journal publications and 5 conference publications
  - 43 awarded scholarships for hosting notable authorities at Galvin Center
  - 13 PhD degrees awarded by Galvin Center
  - 2 MS degrees awarded by Galvin Center
  - 7 technical certificates and recognition plaques awarded to Galvin Center

- IIT Microgrid represents one of the signature projects that were implemented by the IIT's Galvin Center over the last five years. Galvin Center has continuously improved the IIT Microgrid's footprint by introducing several new technological advances in hybrid AC/DC buildings, interconnected microgrids, LED streetlights in smart cities, and microgrid cyber security.

The major lessons learned in the Perfect Power project include

- Identify the energy delivery objectives for erecting a microgrid (e.g., economics, reliability, resilience, off-grid operations)
- Identify the metrics for operating a successful microgrid (e.g., level of peak load reduction, level of base load reduction, reliability enhancement)
- Assess the state of the existing loads, the local distribution system, and the on-site generation resources before embarking on the design of a microgrid

- Create a credible design including the design of hierarchical control system and components, the estimated cost of the microgrid, and the rate of return for the proposed establishment
- Make sure that there is a dependable team of technicians and engineers available for maintaining the microgrid as components are expected to fail often when the microgrid is first put in operation
- Consult and work closely with the local utility company as its support is critical for the successful operation of a microgrid

2. Introduction

The Illinois Institute of Technology (IIT) was awarded by the U.S. Department of Energy to develop, demonstrate, promote, and commercialize a system and supporting technologies that will achieve Perfect Power at the main campus of IIT. A "Perfect Power" system, as defined by the Galvin Electricity Initiative (GEI), is a system that cannot fail to meet the electric needs of the individual end-user. The project started in October 2008 and ended in September 2014. The Principle Investigator of this project is Dr. Mohammad Shahidehpour, Director of the Robert W. Galvin Center for Electricity Innovation at IIT.

Project Objectives: The overall objectives of the project include: (1) Demonstrate the higher reliability introduced by the microgrid system at IIT; (2) Demonstrate the economics of microgrid operations; (3) Allow for a decrease of fifty percent (50%) of grid electricity load; (4) Create a permanent twenty percent (20%) decrease in peak load from that of 2007 (12,921 kW); (5) Defer planned substation through load reduction; and (6) Offer a distributed system design that can be replicated in urban communities.

Project Scope: The project demonstrated a replicable model for leveraging advanced technology to create microgrids that automatically respond to utility, Independent System Operator (ISO), and electricity distribution system signals, changes, and interruptions in a way that provides key demand reduction support and increased reliability. The scope of the work is listed as follows:

1) Prepare IIT's infrastructure for Perfect Power improvements. A conceptual design was established and campus substation supply underwent reliability improvements. IIT conducted building energy efficiency upgrades and a detailed design which was completed for the campus distribution system.
2) Deploy advanced campus distribution system based on High Reliability Distribution System (HRDS) design. This design which completed three loops and leverages seven feeder loops is working in concert with intelligent high-speed switches to isolate any single fault without interruption of power to buildings.
3) Modify existing gas turbines and deploy distributed energy resources including solar photovoltaic, energy storage system, and electric vehicle charging stations. This goal enabled IIT to provide ancillary services including demand response and spinning reserve.
4) Develop and deploy a master controller. This goal provided a master controller for full system monitoring capability and demand response capability.
5) Address key technology gaps including advanced distribution fault detection, ZigBee wireless infrastructure, demand response control, and advanced distribution controls. Technologies were developed and are available for pilot testing.

Project Team: The project was led by IIT. Key project team members (in alphabetical order) include Azimuth Energy, Exelon/ComEd, Galvin Electricity Initiative, S&C Electric, Schneider Electric, Schweitzer Engineering, and ZBB Energy. Other project partners include (in alphabetical order) Alstom Grid, Archamerica Inc., Ciycor Global LLC, Continental Electrical Construction Company, CTC Engineering, Inc., Dymax Service Inc, Eaton Corporation, Electrical Contractors' Association of City of Chicago, Endurant Energy, G&W Electric, Intelligent Power Solutions, McCluskey Engineering Corporation, McCoy Energy, OSIsoft, Silver Spring Networks, Ujaama Construction, Veriown energy, and Wiedman Power System Consulting.

Project Background: The objective of the Perfect Power project at IIT was to deploy the first prototype of the Galvin Electricity Initiative (GEI) Perfect Power infrastructure, which would increase substantially the use of distributed resources for supplying power to the university during peak load periods as well as during emergency periods while providing necessary ancillary services in support of the local utility electric distribution system. Therefore, this project directly met the need of the RDSI Program within the R&D Division of the Office of Electricity Delivery and Energy Reliability, which is to demonstrate peak load reduction on distribution feeders with the implementation of distributed energy and energy management systems at a cost competitive with system/capacity upgrades.

The Perfect Power Project at IIT was a key part of the vision of the Galvin Electricity Initiative. The Initiative began right after the 2003 Northeast Blackout with a small team of thought leaders from the electric power industry led by Kurt Yeager, former President of the Electric Power Research Institute. In early summer 2006, IIT and Endurant Energy participated in a special meeting of the Initiative on microgrids. In early fall 2006, S&C Electric and Commonwealth Edison joined the team and the Perfect Power Project at IIT was created with financial and technical support from the Galvin Electricity Initiative. In addition, IIT and Endurant Energy each sent members of the Perfect Power Prototype team to the Quality Leadership Training Program presented by the Joseph Juran Center at the University of Minnesota and jointly hosted by the Juran Center in late 2006 and Motorola in early 2007. The two-week executive training course was specifically designed for progressive electric power industry leaders. The Perfect Power Prototype team members focused on improving the quality of the IIT power grid throughout the training course.

Since the launching of the Perfect Power Project at IIT, the team has developed a comprehensive report that covers the need for microgrids, as well as a detailed plan for implementing the various technologies and processes necessary for meeting the need. IIT and Endurant Energy have analyzed the electric power demands at each of the buildings on campus and developed load duration curves. IIT and Endurant Energy also have investigated the various options for providing electric power on-site, including the use of the two existing 4 MW natural gas fired turbines, the smaller building-sized existing emergency backup generators, the additional planned generation sources, including new renewable resources and new electric power storage facilities. IIT and S&C Electric have completed a preliminary material condition assessment of the existing campus electric distribution system. In addition, IIT and S&C Electric have developed a new High-Reliability Distribution System (HRDS) architecture that will become the backbone for deploying all of the other advanced capabilities. IIT and Commonwealth Edison have finished an extensive performance review of the distribution utility assets, including advanced diagnostic testing and analysis. Finally, IIT and Commonwealth Edison have launched a demand response project at IIT to research the various options with the goal of determining the optimal mix of demand response technologies.

The approach taken by the Perfect Power Project at IIT was initially developed by a team of electric power industry experts under the support of the Galvin Electricity Initiative. The senior personnel of the project team spent more than a year applying the general framework to the specific needs of the university as well as the specific university infrastructure. The progress made up to early 2008 was very encouraging to the point that the Board of Trustees at IIT was ready to invest on this project after the team presented the overall vision and project plan. The funding opportunity provided by the Department of Energy expedited this project. The IIT Perfect Power microgrid has since become a flagship project of IIT.

3. Project Overview

The Renewable and Distributed Systems Integration (RDSI) Program within the R&D Division of the Office of Electricity Delivery and Energy Reliability, Department of Energy sought to develop and demonstrate new distribution system configurations integrated with distributed resources. The smart grid program supported by the American Recovery and Reinvestment Act of 2009 (ARRA) aimed to modernize the nation’s electric energy system and significantly affect utility investments in the electric power sector, thereby contributing to job creation and preservation and economic recovery. These efforts remain to be critical to achieving the nation’s ambitions for renewable energy development, electric vehicle adoption, and energy efficiency improvements.

This project has contributed to the national efforts in smart grid development in two major aspects:

- Completion of the IIT Perfect Power Microgrid (IIT Microgrid) and establishment of a replicable microgrid model
- Establishment of the state-of-the-art smart grid education and workforce training program

This section presents an overview of this project. The technical outcomes of this project are presented in Section 4 and the smart grid education and workforce training program is presented in the Appendix.

3.1 Overview of IIT Microgrid

Founded in 1890, Illinois Institute of Technology (IIT) is a private, independent, nonprofit, Ph.D.-granting research university with programs in engineering and science, architecture and design, business and law, human sciences, and applied technology. Starting from the campus substations, shown in Figure 3.1, IIT owns, manages and operates its microgrid underground distribution system. The distribution system topology consists of seven loops that provide redundant electricity supply to the end consumers. A cross-tie feeder between the two campus substations allows a seamless operation of the IIT Microgrid in case of a failure in the shared feeder with the utility or one of IIT feeders in the North or the South Substation.

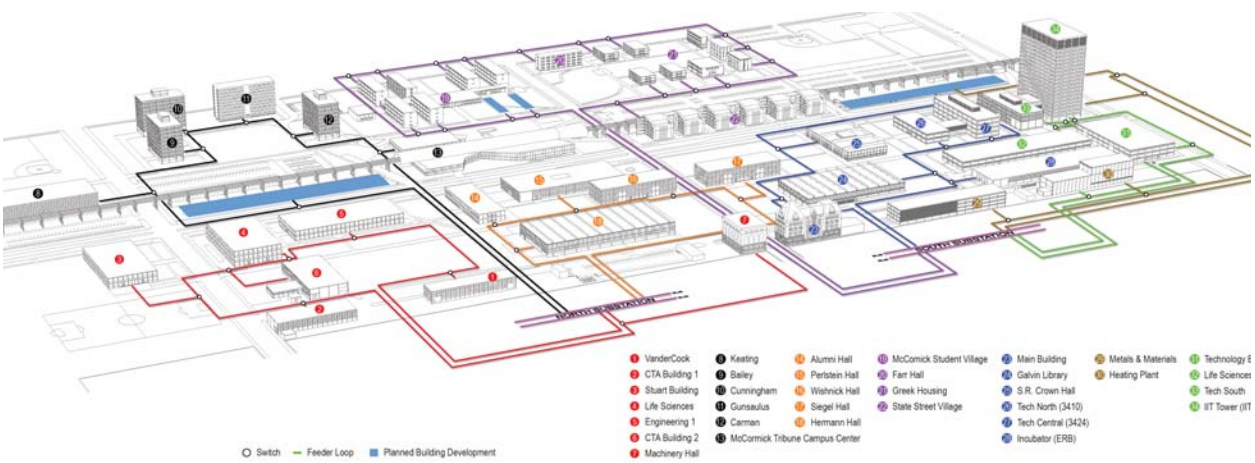

Figure 3.1: IIT Microgrid based on looped distribution system

IIT Microgrid, funded mostly by a grant from the U.S. Department of Energy as well as State[2] and philanthropic contributions, empowers the campus consumers with the objective of establishing a microgrid that is economically viable, environmentally friendly, fuel efficient, highly reliable, and resilient with a self-healing capability. IIT Microgrid enhances its operation reliability by applying a real-time reconfiguration of power distribution assets, real-time islanding of critical loads, and real-time optimization of power supply resources. The total generation capacity of the IIT Microgrid is 12,342kW, including 8,000kW of natural gas turbines, 300kW of solar generation, 8kW of wind generation, and 4,034kW backup generation. The campus includes a 500kWh flow battery and several small size storage devices.

For the decade preceding the implementation of IIT Microgrid, the university experienced major outages within the campus infrastructure and the utility feeders, which resulted in partial or complete loss of loads in buildings and research facilities including experimental data and subjects. The substantial annual loss of revenue included replacement costs of damaged equipment, personnel and administrative costs of restoring and sustaining research and educational experiments, and cost of aggravation associated with disrupted academic classes, laboratories, and other campus events such as conferences interrupted by campus outages. IIT Microgrid has offered the opportunity to eliminate costly outages and power disturbances, provide an economic supply of hourly loads, reduce peak loads, and mitigate greenhouse gas emissions.

The IIT Microgrid project was structured around developing and implementing core strategies and investments at three separate but closely linked aspects including: (1) The IIT Microgrid project specifies the priorities and types of investments that can enhance its power quality and reliability while optimizing the economic energy flow; (2) IIT Microgrid manages its resilience in extreme circumstances which is based on holistic design and operation of physical infrastructures; and (3) The IIT Microgrid project offers education programs for introducing various smart grid options to electricity consumers in large and enticing the campus community participations for implementing the listed microgrid milestones.

The operation of the IIT Microgrid includes a three-level hierarchical control (campus, building, and sub-building levels) that offered the following incentives:

1) Demonstrate the higher reliability introduced by the microgrid system at IIT;
2) Demonstrate the economics of microgrid operations;
3) Allow for a decrease of fifty percent (50%) of grid electricity load;
4) Create a permanent twenty percent (20%) decrease in peak load from 2007 level;
5) Defer planned substation through load reduction;
6) Offer a distributed system design that can be replicated in urban communities.

3.2 IIT Microgrid System Design

IIT Microgrid is a representative of an economically viable microgrid which includes (1) Distributed Energy Resources (DERs); (2) An optimal electrical network for locations of DERs, microgrid switches, critical and noncritical loads, microgrid protection scheme, and interfaces with the ComEd utility system.

[2] State of Illinois

3.2.1 Microgrid Boundaries

IIT Microgrid is located 2.5 miles south of downtown of Chicago (Figure 3.2, left) and is bounded by major streets, highways, and railroads (Figure 3.2, right).

Figure 3.2: IIT Microgrid boundary

3.2.2 Electrical Circuit Diagram

IIT Microgrid is connected to the ComEd utility grid through two substations and three 12.47 kV circuits shown in Figure 3.3. Each 12.47 kV circuit is rated at 7 MW. IIT Microgrid has a peak load of about 12 MW, which can be operated in grid-connected and island modes, and is capable of integrating new sustainable energy sources. IIT Microgrid is equipped with a looped high-reliability distribution system (HRDS), which includes seven loops shown in Figure 3.5 for enhancing its reliability, where three loops are connected to the North Substation and four loops are connected to the South Substation. The two substations are tied for enhancing the microgrid operation. In comparison, traditional distribution systems are mostly radial, where a point of failure may cause the outage of downstream users.

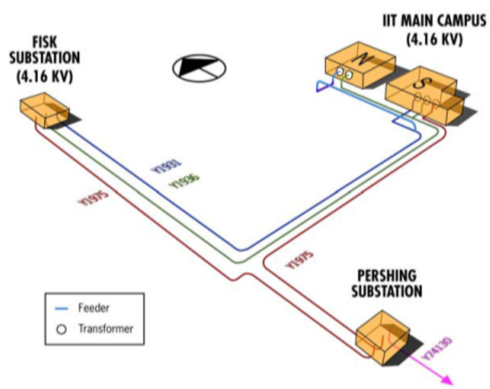

Figure 3.3: IIT Microgrid connection to utility grid

The components of the IIT Microgrid in Figure 3.4 and Figure 3.5 include DERs, HRDS switches, meters and phasor measurement units (PMUs), and building controllers. DER units include dispatchable units such as natural-gas turbine generator and battery storage units, and non-dispatchable units such as solar PV and wind turbine units. The storage unit includes a flow battery and several lead-acid batteries.

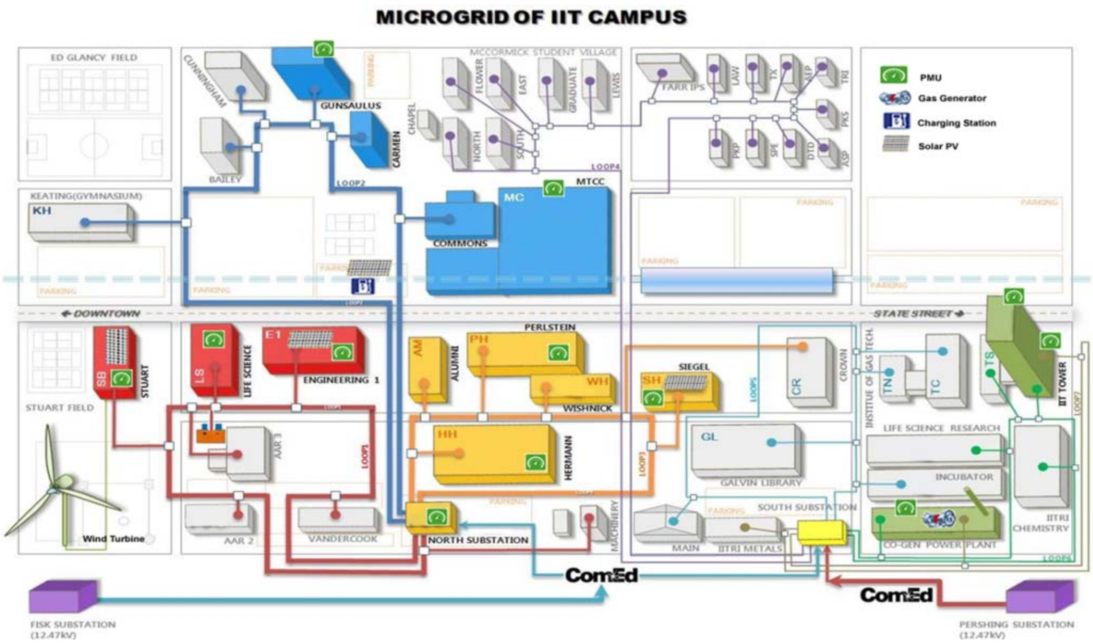

Figure 3.4: IIT Microgrid based on looped distribution system

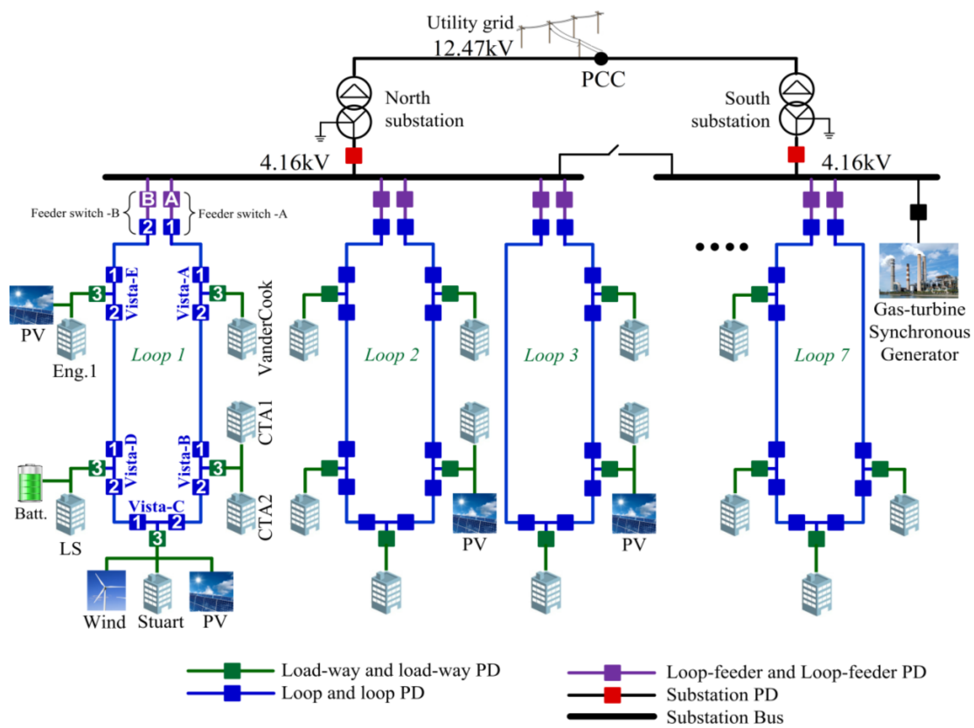

Figure 3.5: DER units and HRDS at IIT Microgrid

Building controllers provide control and monitoring functions for building loads on campus. Each HRDS loop utilizes Vista underground closed loop fault-clearing switchgear with SEL-351 directional over-current protection relays. The fault isolation takes place in a quarter of a cycle by automatic breakers. The communication system is via fiber optic cables which facilitate the coordination between switches.

IIT has not experienced any outages ever since the loops have been installed. IIT Microgrid is equipped with building meters and 12 PMUs which report building electricity consumptions and instantaneous voltage and current of DER units (at a sampling rate of one signal per cycle) to the master controller.

3.2.3 Distributed Energy Resources

IIT Microgrid includes various types of distributed energy resources: 300kW solar PV generation, 8kW wind turbine unit, 8MW natural-gas turbine power plant (existing and upgraded for this project), 4,034kW backup generation (existing), and 250kW/500kWh flow battery storage. As IIT owns, manages and operates the underground electricity distribution system, it does not require any interconnection application.

Solar PV Generation

A total of 300 kW of solar PV cells are installed, including 280 kW on three building rooftops (one shown in Figure 3.6) and a 20 kW solar canopy at the electric vehicle charging station (shown in Figure 3.7) to supply portions of IIT campus load. There is a plan to add another 300 kW of solar PV before the end of 2016. Solar PV units are not dispatchable and use maximum power point tracking (MPPT) controls to maximize the solar power output for a given insolation.

Figure 3.6: Solar panel in Siegel Hall

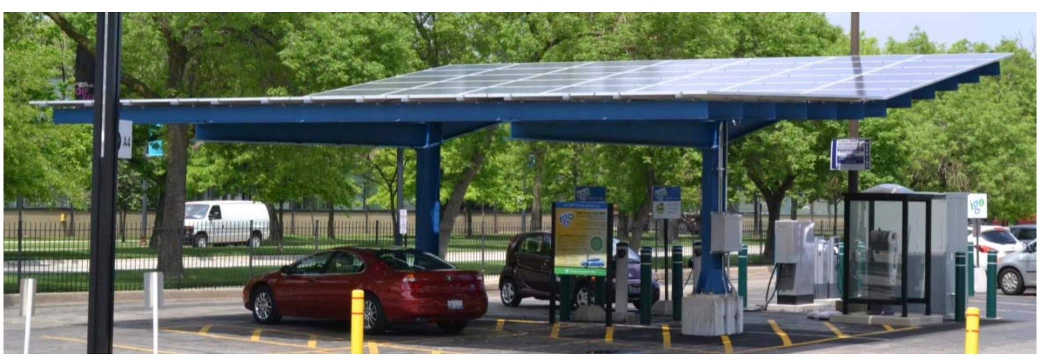

Figure 3.7: Solar panel in charging station

Wind Turbine Unit

An 8kW wind turbine unit, shown in Figure 3.8, is installed on the north side of the campus in the Stuart soccer field, connected to Loop 1. The cut-in and cut-off wind speeds for this turbine are 4.5m/s and 25m/s, respectively, and the turbine has a diameter of 8 meters diameter and a swept area of 50 square meters.

Natural-Gas Turbine Power Plant

Figure 3.9 to Figure 3.11 show the full-scale model, exterior, and interior of the natural-gas turbine generator located at the IIT campus. IIT Microgrid is equipped with an 8MW natural-gas fired power plant with two 4MW Rolls Royce gas-turbines. The natural-gas turbine consists of five sections including air intake, compressor, combustor, turbine and exhaust. The air sucked into the inlet is compressed by the compressor and mixed with fuel (natural-gas) to form an air-fuel mixture. The mixture is burned in the combustor to form a high-pressure gas, which drives the turbine. The synchronous generator installed on the turbine shaft will convert the mechanical energy into electrical energy.

Figure 3.8: Wind turbine unit at IIT

Figure 3.9: Natural-gas turbine generator model at IIT

Figure 3.10: The exterior of the natural-gas turbine generator

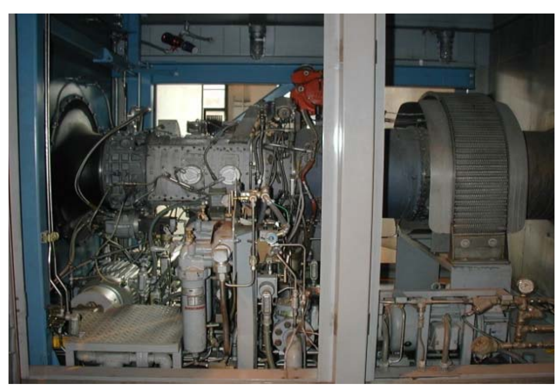

Figure 3.11: The interior of the natural-gas turbine generator

Flow Battery Storage

IIT Microgrid is equipped with a 500kWh flow battery storage system (including ten 50kWh battery cells) with 250kW power capacity which is connected to Loop 1. The 250kW/500kWh flow battery is connected to Loop 1 of the seven-loop system and housed in a portable shipping container, as shown in Figure 3.12. Figure 3.13 shows a stack of the flow battery and the battery inverter which can regulate the real and reactive power output.

The battery system utilizes two ZBB inverters rated at 125 kW each and connected in parallel. Inverter efficiency is > 95% at rated load and reactive power can be controlled within a range of +/- 0.8 power factor. The operating temperature is from -30°C to 50°C. The inverter has received UL1741[3] design certification and meets IEEE 519[4] for total harmonic distortion (THD). They normally operate in setpoint mode, charging at night and discharging during the day over approximately a 4 hour time period. They can operate in voltage source mode.

Figure 3.12: IIT Microgrid flow battery

Figure 3.13: Battery storage unit and inverter

Electric Vehicle Charging Stations

IIT Microgrid includes one of the first “DC Quick Charge” electric vehicle charging stations (left side of Figure 3.14) in the country, which provides full charge of an EV in 15-20 minutes. Additionally, IIT Microgrid includes six new “Level 2” charging stations (right side of Figure 3.14) that can charge an electric vehicle in 5-6 hours.

Building Backup Generators

IIT Microgrid is equipped with 11 backup generators with a total capacity of 4,036 kW scattered at various buildings around the IIT campus. General test and inspection of these generators are performed

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[3] UL1741 is the Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources.

[4] IEEE 519 is the IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems.

weekly, biweekly or monthly and transfer load tests are performed quarterly or annually. A detailed description of these generators is listed in Table 3.1.

Figure 3.14: Electric vehicle charging stations

Table 3.1: Building backup generators at IIT Microgrid

Building	Generator Size	Make	Inspection Frequency	Load Test Frequency
Life Sciences Research	200kW	Energy Dynamics	Weekly	Quarterly
Life Sciences Research	1020kW	Kohler	Weekly	Quarterly
IIT Tower	300kW	Katolight	Weekly	Quarterly
McCormick Lounge	55kW	Onan	Weekly	Annually
Engineering Research Building	80kW	Kohler	Every 4 weeks	Annually
Engineering Research Building	125kW	Cummins	Every 4 weeks	Annually
Wishnick Hall	206kW	Generac	Every 4 weeks	Annually
Co-Gen	300kW	Cummins	Every 4 weeks	Annually
Technology Business Center	750kW	Caterpillar	Every 2 weeks	Annually
Stuart Building	500kW	Generac	Every 2 weeks	Annually
IIT Tower	500kW	Caterpillar	Every 2 weeks	Annually

3.2.4 Electrical Loads

Critical Loads

Critical loads at IIT Microgrid are shown in

Table 3.2. The three most critical facilities (Tier 1) include Stuart Building, Life Science Building, and IITRI Life Science Research. The IIT data computing center (150kW) is located at Stuart Building and equipped with UPS. The life science labs (250kW) are located at the Life Science Building and supported by the flow battery. The IITRI Life Science Research Labs (600kW) is supported by local backup generation. Tier 2 critical loads include two buildings in the University Technology Park, which are partially supported by local backup generation.

Non-Critical Loads

Other non-critical loads at IIT Microgrid are shown in Table 3.3.

Table 3.2: Critical loads at IIT Microgrid

	Name	Address	Building Code	Peak Load (kW)
Tier 1	Stuart Building	10 West 31st	SB	320
	Life Sciences	3105 South Dearborn	LS	610
	IITRI Life Sciences Research	35 West 34th	LSR	600
Tier 2	IIT Tower	10 West 35th	IT	1600
	Technology Business Center	3440 South Dearborn	TBC	780

Table 3.3: Non-critical loads at IIT Microgrid

Name	Address	Building Code	Peak Load (kW)
Academic Buildings			
Alumni Memorial	3201 South Dearborn	AM	150
S. R. Crown Hall	3360 South State	CR	230
Engineering 1	10 West 32nd	E1	520
Perlstein Hall	10 West 33rd	PH	305
Siegel Hall	3301 South Dearborn	SH	240
Wishnick Hall	3255 South Dearborn	WH	240
Facilities Services			
Heating Plant	3430 South Federal	HP	80
Machinery Hall	100 West 33rd	MH	110
University Technology Park			
Incubator	3440 South Dearborn	INC	300
Technology Park	3424 S. State St.	TC,TS,TN	1050
Athletic Building			
Keating Hall	3040 South Wabash	KH	250
Fraternities/Sororities			
Alpha Epsilon Pi	3350 South Michigan	AE	130
Alpha Sigma Alpha	3340 South Michigan	TX	180
Alpha Sigma Phi	3361 South Wabash	AS	170
Delta Tau Delta	3349 South Wabash	DT	160
Kappa Phi Delta	3330 South Michigan	TE	170
Phi Kappa Sigma	3366 South Michigan	PK	150
Pi Kappa Phi	3333 South Wabash	KP	160

Triangle	3360 South Michigan	TR	150
Rental Property			
Materials & Metals Building	3350 South Federal	MTB	300
Vandercook	3140 South Federal	VA	85
Residence Halls			
East Hall	71 East 32nd	RE	170
Fowler Hall	3241 South Wabash	FO	160
Graduate Hall	70 East 33rd	RG	150
Lewis Hall	70 East 33rd	RL	200
McCormick Lounge	3241 South Wabash	MC	220
North Hall	71 East 32nd	RN	90
Residence – Dining	71 East 32nd	RD	100
South Hall	71 East 32nd	RS	110
State Street Village	3301 South State	SV	330
Bailey Hall	3101 South Wabash	BA	150
Carman Hall	60 East 32nd	CA	250
Cunningham Hall	3100 South Michigan	CU	130
Gunsaulus	3140 South Michigan	GU	150
Student Services			
Auto Lab	3240 South Federal	AL	80
Chapel	65 East 32nd	CH	30
Farr Hall	3300 South Michigan	FH	235
Galvin Library	35 West 33rd	GL	500
Hermann Hall	3241 South Federal	HH	200
Main Building	3300 South Federal	MB	200
The Commons	3200 South Wabash	CO	75
McCormick Tribune Campus Center	3201 South State	MTCC	480

The peak load in 2007 was 12,921 kW. The historical peaks since then are summarized in Table 3.4. Without considering the natural increase in load as a result of increasing student enrollment and research activities, the campus since 2007 has had a reduction of over 17%.

Table 3.4: Sustained Peak Load Reduction

Year	2007	2008	2009	2010	2011	2012	2013
Peak Load (kW)	12,921	10,638	10,475	10,125	10,342	10,263	10,619
Reduction		17.7%	18.9%	21.6%	20%	20.6%	17.8%

3.2.5 Thermal Loads

The thermal loads on the IIT Microgrid are mostly steam loads for heating, humidification and domestic hot water. The thermal loads are between 7 kpph (min) and 75 kpph (max). On December 6, 2013 when the outside air temperature was 20 °F, the system load was about 45 kpph (35 kpph on the north and 10 kpph on the south side of the campus). The steams are generated at the IIT Power Plant. The plant generates 105 psig steam. Most of the buildings on the northwest side of the campus use 15 psig steam. Some research buildings on the southwest side of the campus, such as the IIT Tower, need 60 psig steam due to research or cage washing or other requirements. The natural gas pipeline feeding the two gas turbines at the IIT Power Plant is located 3500 South Federal Street.

3.2.6 Other Connected Devices

Meters and PMUs

The IIT Microgrid is equipped with building meters and PMUs which report building electricity consumptions to the master controller. The master controller will receive an energy consumption update every 15 minutes. Approximately 30% of building consumptions at IIT are shiftable loads, which can be served when the electricity price is lower. The IIT Microgrid is equipped with 12 PMUs that monitor and record the real and reactive generation and consumption in real time and provide the information on instantaneous voltage and current of DER units (including the magnitude and phase angle) at a sampling rate of one signal per cycle to the master controller. **Error! Not a valid bookmark self-reference.** shows a PMU installed at the North substation.

Figure 3.15: PMU at North Substation

Building Controllers

Building controllers facilitate the building consumption management at IIT Microgrid. The reduction in building consumptions is accomplished by defining several operating modes representing consumption levels in each building. Once the operation mode for each building is set by the master controller, the building controller will send signal to sub-building controllers to set the requested load level associated with the selected mode and feeds back the confirmation signal to the master controller to acknowledge the mode change. The building controllers are also able to monitor and control the energy flow within the buildings including hot and chilled water flow, heating and cooling loads and monitoring the temperature of different spaces within the building. Figure 3. shows the buildings equipped with building controllers in Loop 1 in which the blue squares represent command signals from the master controller and the green squares represent acknowledgment signals originated from the building controllers.

HRDS Switches

The HRDS at IIT utilizes underground closed-loop fault-clearing Vista switchgear with SEL-351 directional over-current protection relays. The fault isolation takes place in a quarter of a cycle by automatic breakers. The communication via fiber optic cables facilitates the coordination between VISTA switches. In HRDS, at least two simultaneous failures in the cable segments feeding a building from both paths will lead to a complete outage in the building. As the chances of two coincident failures is far less than single failures in cables feeding the interruption indices of the buildings are improved significantly by the installation of HRDS system. Figure 3. shows the installation of an underground HRDS switch at IIT.

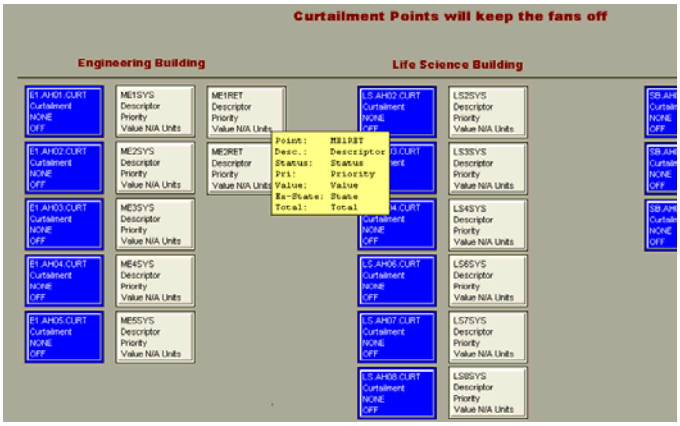


Figure 3.16: Building controllers showing the status of controllable loads in three buildings in Loop 1

Figure 3.17: Installation of underground HRDS switch

3.2.7 IIT Microgrid Master Controller

A major element of the IIT Microgrid is its master controller. The microgrid master controller (MMC) applies a hierarchical control via SCADA to ensure reliable and economic operation of the IIT Microgrid. It also coordinates the operation of HRDS controllers, on-site generation, storage, and individual building controllers. Intelligent switching and advanced coordination technologies of the MMC through communication systems facilitates rapid fault assessments and isolations in the IIT Microgrid.

The MMC performs day-ahead and real-time optimal scheduling for the IIT microgrid. The MMC monitors all loads and resources, performs a “security constrained unit commitment” (SCUC) for the day ahead operation, and performs a “security constrained economic dispatch” (SCED) for the current day operation. It also considers weather forecasts and solar/wind forecasts in the analysis. It dispatches modes and setpoint for each resource every 10 minutes. The MMC economically optimizes the energy flow at three levels—campus, DER / building, and sub-building. Building meters provide the MMC with individual building load profiles enabling it to communicate and adjust sub-building loads through building controllers. The MMC also receives the day-ahead price of electricity, weather data, wind speed, cloud coverage and other data for utilizing the renewable sources in the microgrid. The MMC then runs a day-ahead scheduling optimization algorithm to optimize the use of microgrid local generation and balance the hourly DR (load curtailment and shifting of non-essential microgrid loads) for minimizing the cost of supplying the microgrid load. At times, the MMC will consider DR rather than power purchases from the grid.

The MMC offers the opportunity to eliminate costly outages and power disturbances, supply the hourly load profile, reduce daily peak loads, and mitigate greenhouse gas production. The MMC includes the implementation of additional functions for load shedding and coordinating demand response signals with the other controllers for peak demand reduction. In demand response mode, the MMC will shift loads or shutoff loads according to predetermined load priorities. Part of the load shedding will be accomplished by shutting off power to entire building through smart switches and the rest will be accomplished by communicating directly with specific loads distributed across the campus via the ZigBee network and building controllers.

Figure 3.16 shows the configuration and framework of IIT Microgrid, in which seven loops are included. The North Substation feeds three loops and the South Substation supplies energy to the other four loops. Each building is supplied by redundant feeders to ensure that it is fed by an alternate path in case of an outage. IIT Microgrid utilizes Vista underground closed loop fault-clearing switches that can sense the cable faults and isolate the faulted section with no impact on other sections in a microgrid.

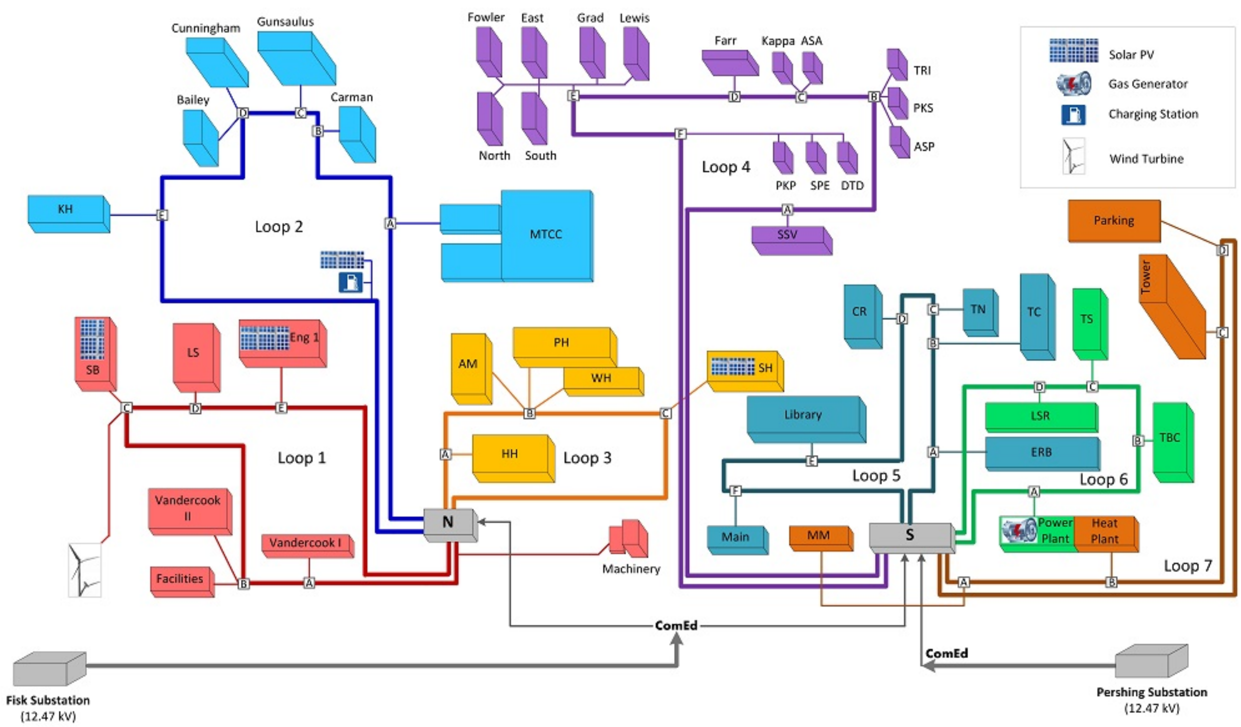


Figure 3.16: Framework of IIT Microgrid

The MMC in Figure 3.17 applies a tri-level (primary, secondary, and tertiary) control for a seamless transfer to an island mode. The primary control utilizes the droops for sharing loads among DER units and avoiding circulating currents among DER units because of different set points on real and reactive power dispatch. The secondary control restores the nominal frequency of power supply in islanded operation. The tertiary control applies an economic dispatch in grid-connected and islanded modes. Figure 3.18 shows the one-line diagram of the IIT Microgrid, which uses the OSIsoft PI system. The OSIsoft PI System, which serves as the software platform of the MMC, is the industry standard in enterprise infrastructure for management of real-time data and events. The PI system offers the SCADA information for managing the real-time outage information and alarm systems at IIT.

Figure 3.19 shows the hierarchical framework of the MMC applied in IIT's Microgrid project. In Figure 3.19, the monitoring signals provided to the master controller indicate the status of DER and distribution components, while the master controller signals provide set points for DER units and building controllers. Building controllers will communicate with sub-building controllers through a Zigbee wireless control and monitoring system to achieve a device level rapid load management.

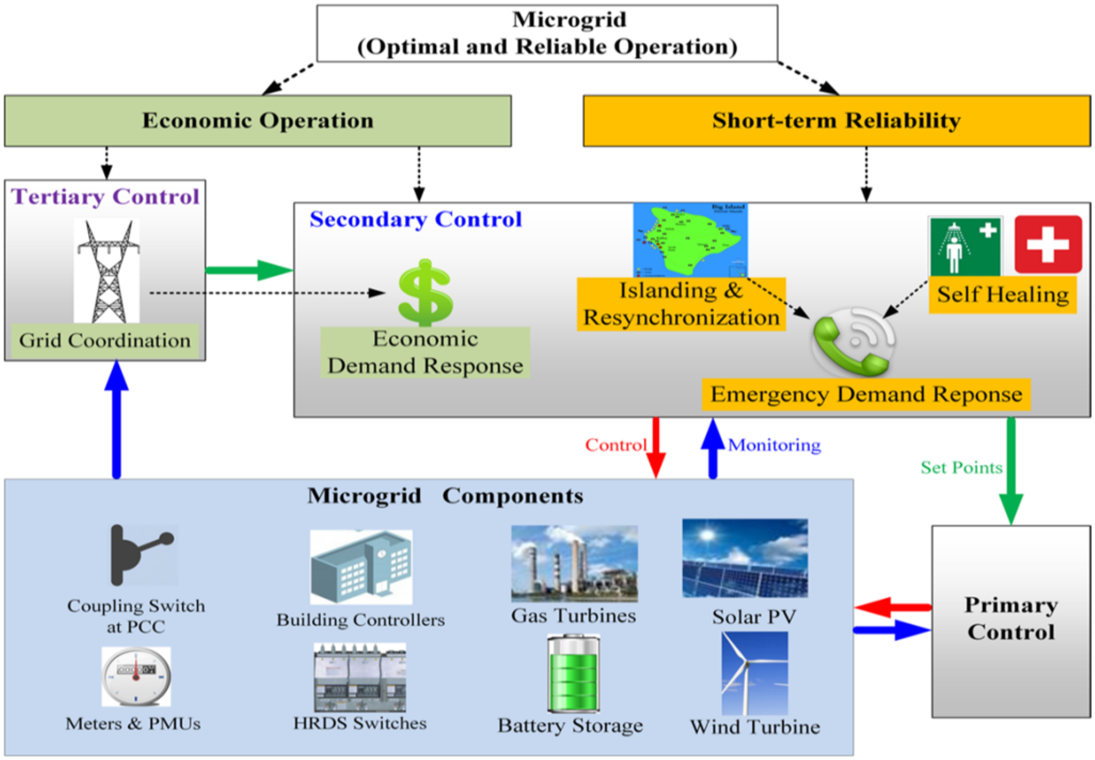


Figure 3.17: Objectives and functions for the operation and control of an AC microgrid

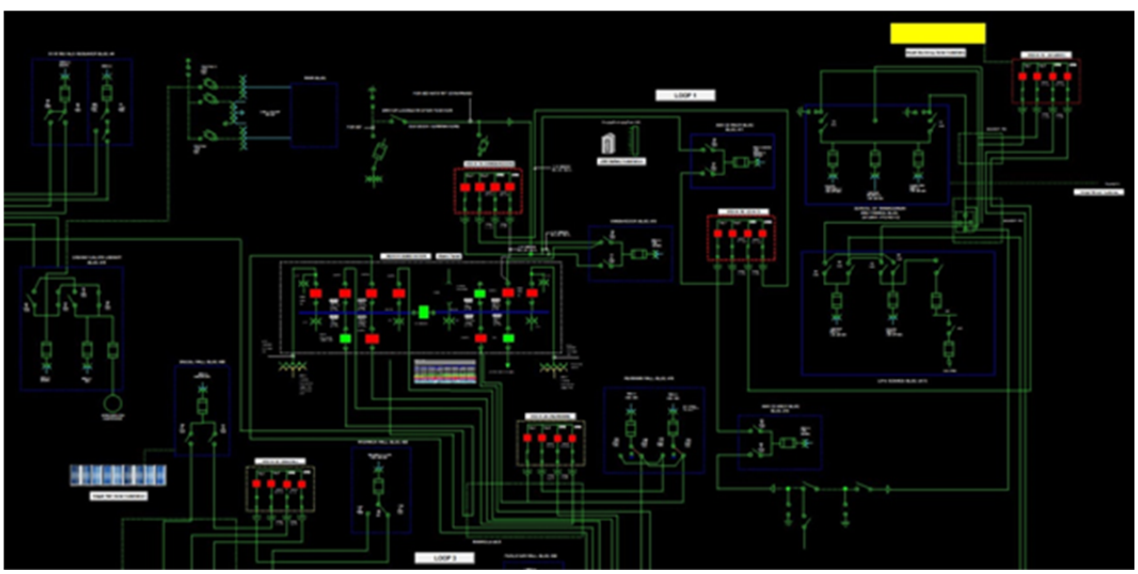
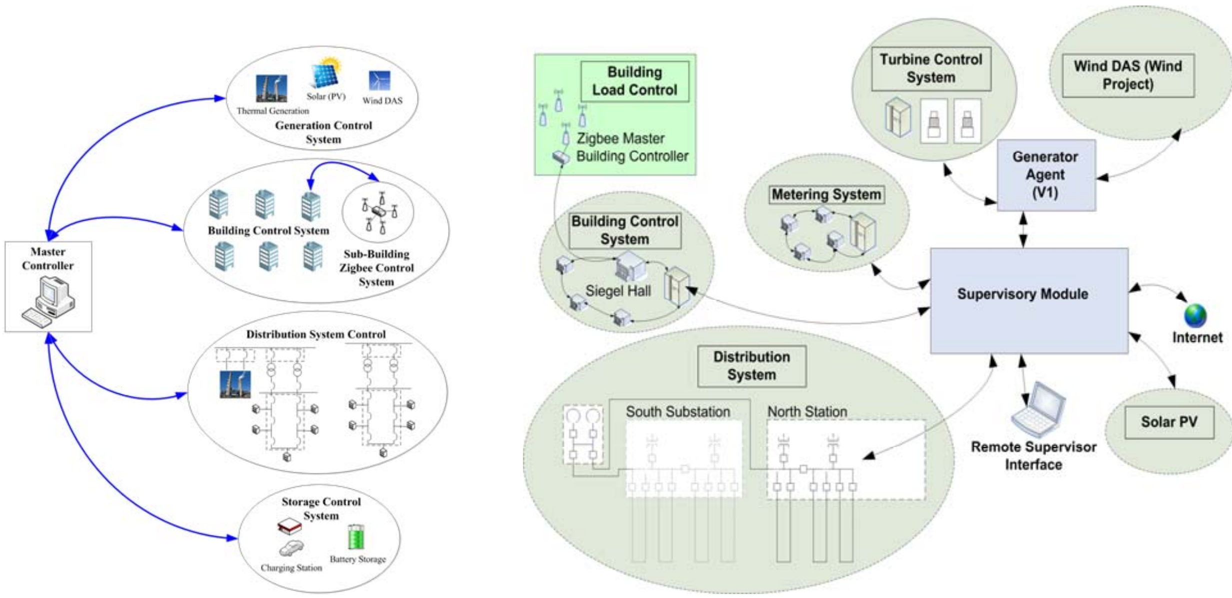


Figure 3.18: SCADA system based on the PI System for the IIT Microgrid



(a) (b)

Figure 3.19: Architecture of IIT Microgrid master controller

Figure 3.20 shows the communication interface of the MMC. There is a firewall which separates the subnet, to which the MMC and all the devices belong, from the outside internet, in order to protect the security of the IIT Microgrid. The MMC communicates with the devices installed within IIT Microgrid through communications protocol like Modbus, BACnet, DNP3, etc., depending on the type of connected devices.

The MMC performs day-ahead and real-time optimal scheduling for the IIT Microgrid. For day-ahead scheduling, the input/output data of master controller are listed as follows.

- Input data
  - Forecasted electricity/natural gas prices
  - Forecasted weather information
  - Distribution cable information including the scheduled maintenance information
  - Forecasted load, wind generation, solar generation
  - Initial battery storage status
  - Initial charging stations status
- Output data
  - Hourly dispatched generation for gas generator
  - Hourly charging/discharging energy for battery storage
  - Hourly supplied energy by local utility
  - Hourly shedding/shifting results for building load
  - Hourly active/reactive power flow information on each distribution cable
  - Hourly microgrid operation costs
  - Hourly energy cost of local utility

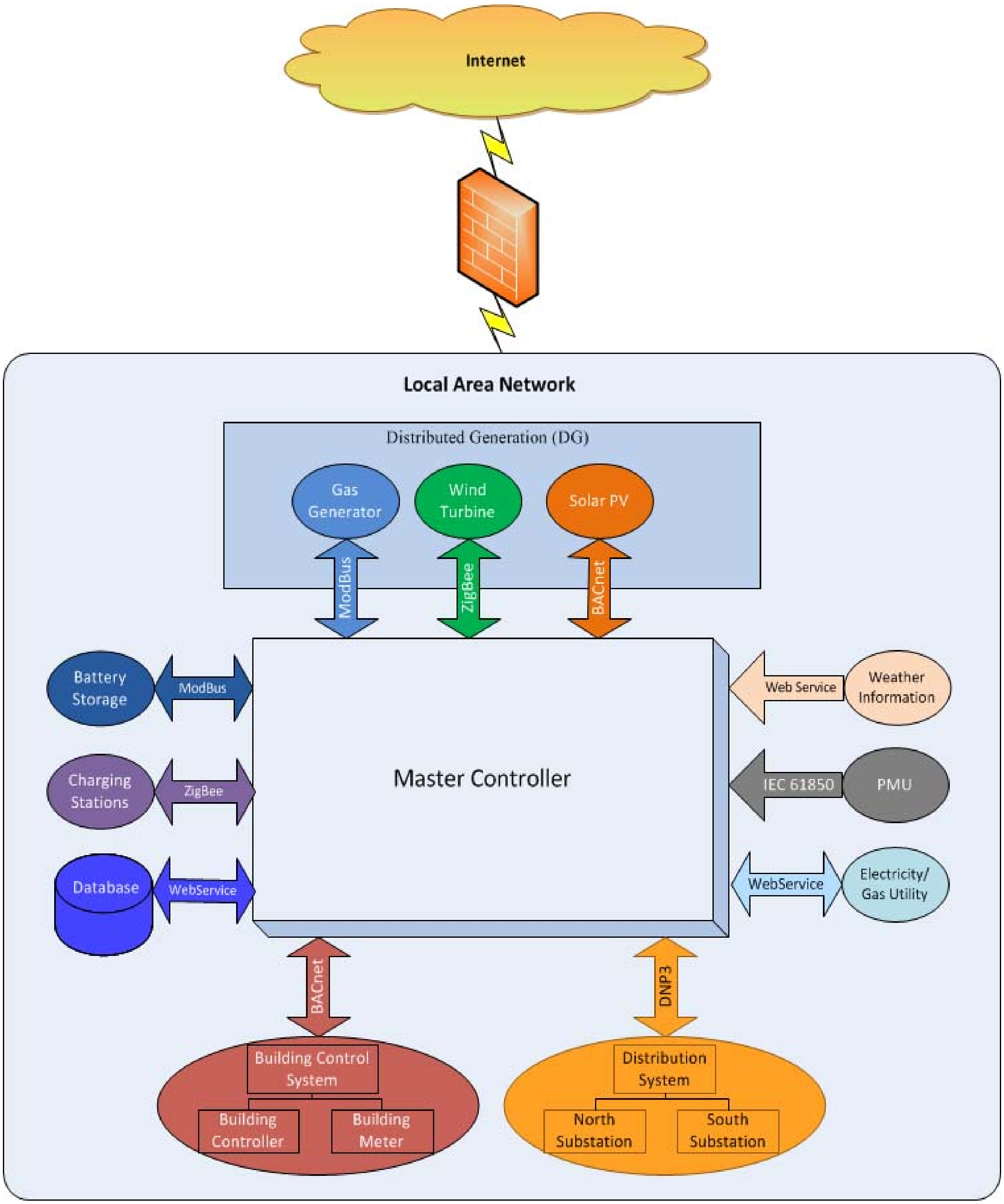


Figure 3.20: Functional diagram of IIT Microgrid master controller

The input/output data for real-time schedule are listed as follows.

- Input data
    - Real-time electricity/natural gas price provided by Utility
    - Real-time building load, wind turbine generation and solar PV generation acquired through the SCADA system
    - Distribution cable information including the maintenance and outage information
    - Battery Storage Status
    - Charging Stations Status
- Output data
    - Dispatched generation for gas generator
    - Charging/Discharging results for battery storage
    - Energy supplied by local utility
    - Shedding/Shifting results for building load
    - Active/Reactive power flow information on each distribution cable
    - Microgrid operation costs
    - Cost of energy supplied by local utility

Generally, the day-ahead schedule is hourly schedule for reliability and economics. Real-time schedule provides the reference for real operation and control of all controllable components within the IIT Microgrid.

Figure 3.21 to Figure 3.26 show sample input and output interfaces of the IIT MMC. The input data for the MMC include physical data and forecasted data. Figure 3.21 show the physical data which include gas turbine, utility, battery storage, distribution cable, wind turbine and solar PV. The forecast data are shown in Figure 3.22 which includes temperature, electricity price, wind speed, natural gas price, and solar irradiance. Figure 3.23 shows the economic dispatch results for all generation resources. Figure 3.24 shows the operation cost and dispatched load results. Power flow solution is shown in Figure 3.25 and the power flow information can be viewed on each distribution cable. Figure 3.26 is the interface for sensitivity analysis.

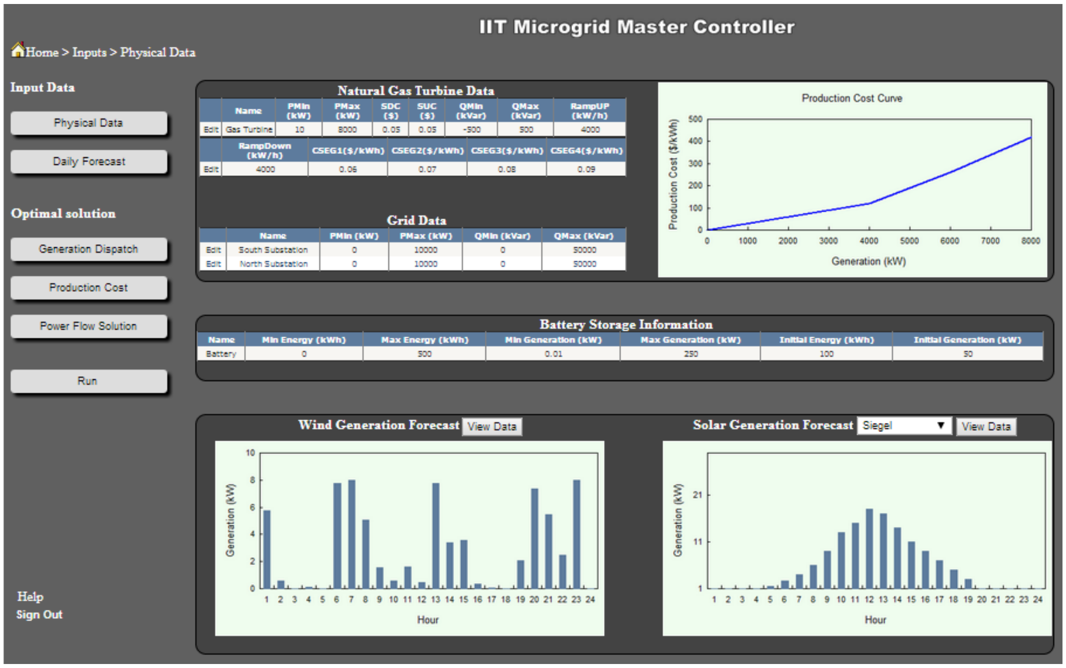


Figure 3.21: Interfaces for physical data

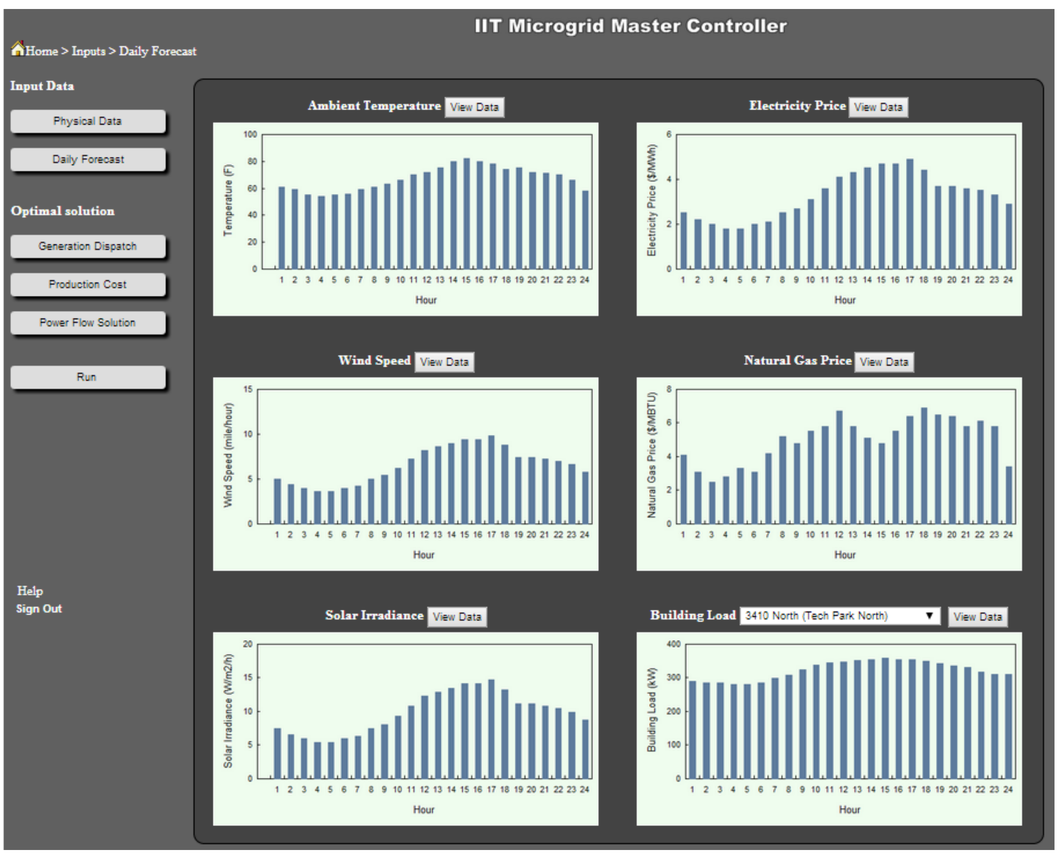


Figure 3.22: Interfaces for forecasted data

Figure 3.23: Dispatch results

Figure 3.24: Production costs and dispatched loads

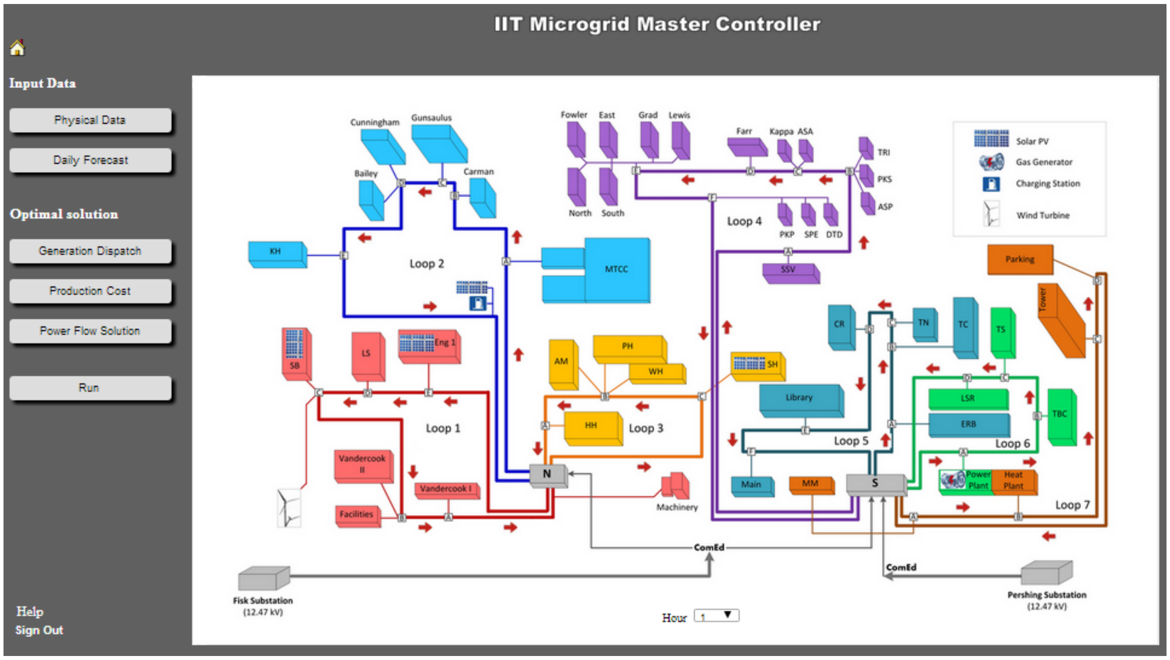


Figure 3.25: Power flow results

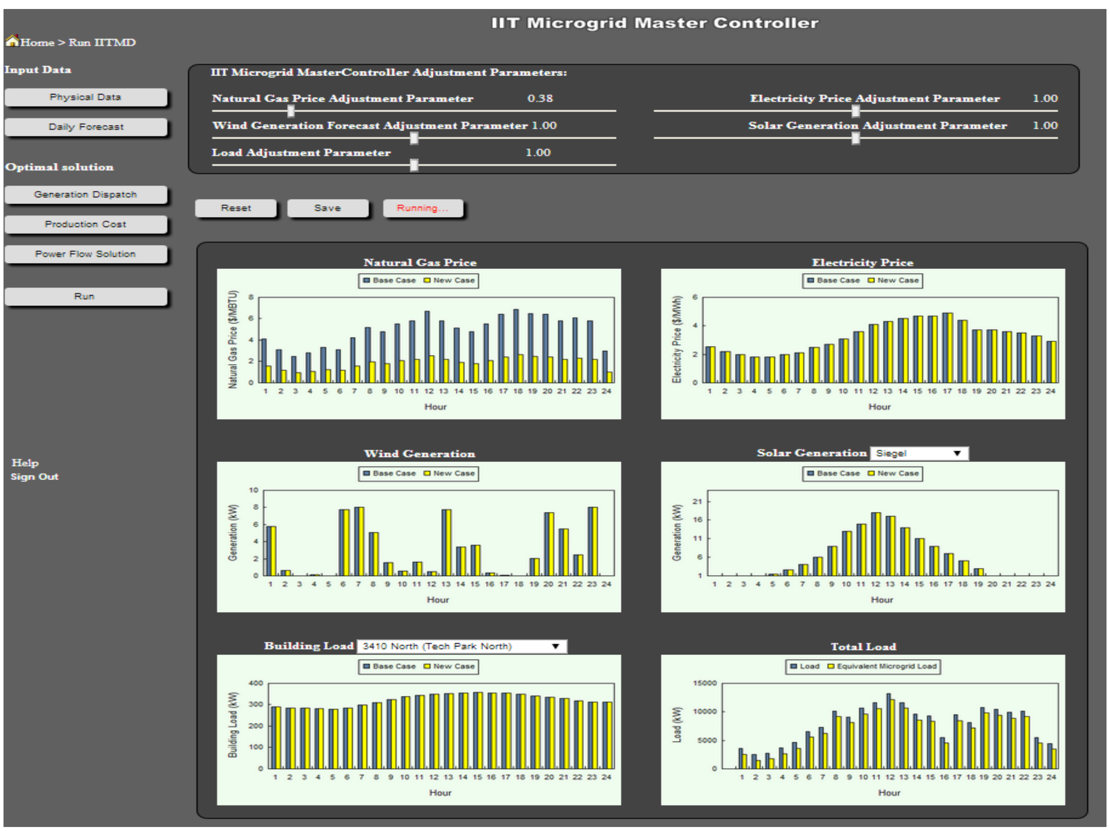


Figure 3.26: Sensitivity analysis

3.2.8 Recent Developments

IIT Microgrid has been undergoing continuous improvements by introducing new technologies for the enhancement of energy generation, delivery, and utilization. Several more recent developments at the IIT Microgrid which are beyond the competition period are presented in this section.

Hybrid AC/DC Building

Figure 3.27 shows the ongoing development of a hybrid AC/DC architecture for Keating Hall which is located at Loop 1 of the IIT Microgrid. The AC portion is completed in August 2014 and the DC portion is planned for completion in June 2015. The Keating Hall is seamlessly integrated to the main IIT Microgrid and is fully monitored and controlled by the IIT MMC. The benefits of a hybrid AC/DC architecture for the Keating Hall include: energy efficiency, as it reduces losses incurred by the converters; reliability, as it supplies the DC load in two parallel AC and DC paths; and living laboratory, as it demonstrates a testbed for the economic, reliable, resilient, efficient, and flexible coordination of autonomous AC and DC systems. The hybrid AC/DC architecture for Keating Hall is very flexible which can be used for testing various configurations by connecting/disconnecting the DC-DC controller, the DC-AC inverter, and the DC-AC/AC-DC bidirectional converter. For instance, disconnecting the main microgrid feed will have the Keating Hall power supplied by solar PV and the battery, i.e., islanded operation of the building.

Interconnected Microgrids

The local electric utility ComEd is planning on building and operating the Bronzeville Community Microgrid depicted in Figure 3.28 with a 10MW peak demand, which will be tied to the IIT Microgrid (12MW peak demand), making it the first-ever cluster of a private and a utility microgrid in a metropolitan region of the United States.

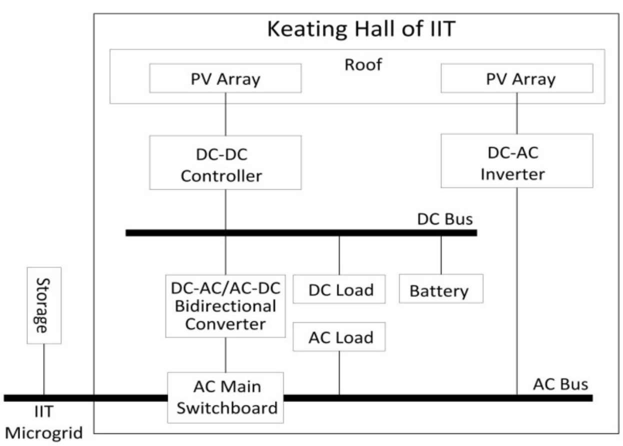


Figure 3.27: Hybrid AC/DC building at the IIT Microgrid

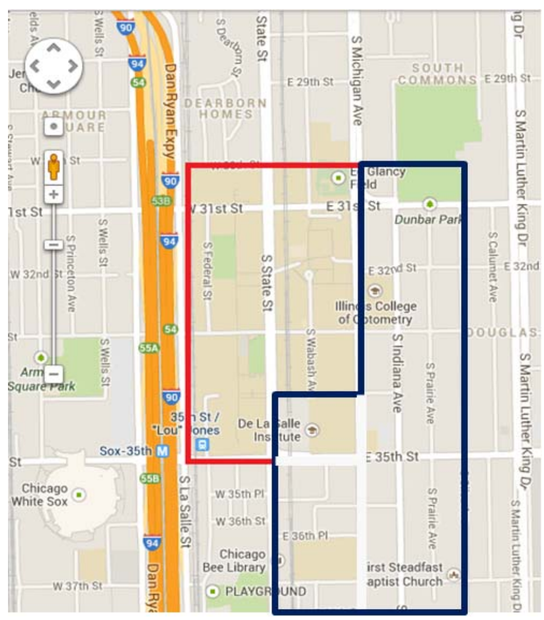


Figure 3.28: Interconnected IIT Microgrid (in red) and Bronzeville Community Microgrid (in blue)

LED Streetlights and Microgrid Cyber Security

One of the new additions to the IIT Microgrid is the capability for testing and implementing the cyber security of wireless networks. The city of Chicago is planning on installing thousands of LED streetlights which will be equipped with the Silver Spring Networks wireless networked communication and control system for a remote and centralized control of streetlights. However the wireless networked communication and control system is subject to cyber attacks that may turn the entire City of Chicago into darkness. The current street lighting system in Chicago is old and inefficient, and costs the City millions of dollars a year to operate and maintain them. Figure 3.29 shows the old vs. the new lighting systems.

Old High Pressure Sodium (HPS) Lamps | New High Efficiency LED Fixtures

Figure 3.29: Lighting system for smart cities

4. Results and Discussions

This section discusses the outcomes of proposed project.

4.1 Benefits of the IIT Microgrid

This section discusses the benefits of the IIT Microgrid. IIT Microgrid project started in August 2008 and the majority of the project was completed in May 2013. Thus, we have chosen June 1, 2008 to May 31, 2009 as the base year and June 1, 2013 to May 31, 2014 as the current year for the purpose of benefit analysis.

4.1.1 Resiliency Benefit

Black Start Capabilities of the IIT Microgrid

Black start is initiated using an onsite diesel generator installed in the natural gas plant to start one 4 MW gas turbine followed by the second 4 MW gas turbine. Controllable loads will then be connected followed by uncontrollable loads. In each step, the amount of the power to be connected is determined by taking into account the available energy storage in order to avoid large frequency and voltage deviations during the process of load connection.

The two 4MW-Allison Turbines at IIT are used to achieve fast-start capability for peaking service and islanding. The IIT MMC will start generators and storage devices, control local loads based on predetermined sequence of operation and load reduction priority schemes, and automatically switch loads to alternate transformers, campus feeds and substation as required by conditions.

1) Preparation for black start

In order to avoid large frequency and voltage deviations in the black start process, IIT Microgrid was sectionalized around each local generation resource with black start capability to allow it feed its surrounding area or its own loads.

2) Starting the Generators

The battery and a small generator installed in the IIT Natural Gas Power Plant will start one 4MW gas turbine followed by the second 4MW gas turbine.

3) Connection of loads

Controllable loads will be connected followed by uncontrollable loads. In each step, the amount of power to be connected is determined by taking into account the available energy storage in order to avoid large frequency and voltage deviations during the process of load connection.

Compliance with IEEE 1547 on Islanding and Reconnection

In terms of islanding and reconnection, IEEE Std 1547 has the following requirements:

- IEEE Std 1547-2003-4.1.5 states that the distributed resource (DR) shall not energize the area electric power system (EPS) when the area EPS is de-energized.
- IEEE Std 1547-2003-4.1.7 states that where required by the area EPS operating practices, a readily accessible, lockable, visible-break isolation device shall be located between the area EPS and the DR

unit. The location of isolation device need not be at the PCC but between the area EPS and the DR unit, and it does not preclude installing any required isolation device at a location that is otherwise allowable.

- IEEE Std 1547-2003-4.2.1 states that the DR shall cease to energize the area EPS for faults on the area EPS circuit to which it is connected.
- IEEE Std 1547-2003-4.2.6 states that after an area EPS disturbance, no DR reconnection shall take place until the area EPS voltage is within Range B of ANSI C84.1-1995 and frequency of 59.3 Hz to 60.5 Hz.
- IEEE Std 1547-2003-4.4.1 states that for an unintentional island in which the DR energizes a portion of the area EPS through the PCC, the DR interconnection system shall detect the island and cease to energize the area EPS within two seconds of the formation of an island.

1) Islanding

The MMC for IIT Microgrid will start and stop generators and storage devices, control local loads based on predetermined sequence of operation and load reduction priority schemes, automatically switch loads to alternate transformers, campus feeds and substation as required by conditions, to place a building or the entire campus in island mode. In case of an island being formed in IIT campus, an anti-islanding element detects the island and disconnects the IIT Microgrid from the ComEd utility network within the required time following the IEEE Std 1547. The islanding criteria are listed in Table 4.1 and Table 4.2. When islanded, IIT Microgrid will maintain the frequency 59.3 Hz < f < 60.5 Hz and the voltage 0.95 p.u. < v < 1.05 p.u. at PCC.

Table 4.1: IIT Microgrid islanding criteria based on voltage ranges

Voltage (V) range (p.u.)	Proposed maximum islanding time (s)
V < 0.5	0.16
0.5 ≤ V < 0.8	2.00
1.1 ≤ V < 1.2	1.00
V ≥ 1.2	0.16

Table 4.2: IIT Microgrid islanding criteria based on frequency ranges

Frequency (f) range in Hertz (Hz)	Proposed maximum islanding time (s)
f > 60.5	0.16
f < {59.8-57.0} (adjustable set point)	Adjustable 0.16 to 300
f < 57.0	0.16

The transition from grid-connected mode of operation to island mode was successfully demonstrated once through controlled testing with the entire process managed by the MMC. The islanding event was triggered by a simulated permanent fault on the utility side of the PCC. The microgrid frequency dropped slightly at islanding because the microgrid generation was less than the microgrid load. The battery discharged within 10–11.5 seconds after islanding to maintain the frequency. The MMC next sent secondary control signals to the natural gas turbine and energy storage system to restore the rated frequency and voltage (4.16 kV and 60 Hz). Discharging of the battery stopped when the 60-Hz frequency was restored. The wind turbine and solar PV units do not participate in frequency and voltage regulation.

Immediately after islanding, the MMC provided emergency DR to prevent a sustained drop in microgrid frequency and voltage as the natural gas turbine had a ramping limit. The MMC sent load curtailment signals through tertiary control to building controllers to curtail the campus load from 11 MW and 5.5 MVAr to 4 MW and 2 MVAr (the amount of load supplied by the natural gas turbine and solar PV and wind unit before islanding).

Once the microgrid frequency and voltage were stabilized, the MMC sent signals to building controllers to perform load restoration through tertiary control. The primary controls of the natural gas turbine and battery storage responded to load increments by adjusting the frequency with each step. The secondary control stabilized the microgrid voltage and frequency before increasing the load in the next step. The MMC adjusted the set points of battery storage units and building controllers through tertiary control until the total served load reached 8 MW and 4 MVAr.

The islanding mode is exercised 4-5 times per year to verify the IIT microgrid is ready to function in emergency cases. No abnormal or extraordinary events have been experienced. The microgrid has not yet automatically islanded due to an actual loss of power from the main grid.

2) Reconnection

The reconnection procedure is similar to that of the black start. The reconnection requirements are listed in Table 4.3.

Table 4.3: IIT Microgrid reconnection requirements

Frequency difference (Δf, Hz)	Voltage difference (ΔV, %)	Phase angle difference (ΔΘ, °)
0.1	3	10

Restoration of normal operation of the utility grid was simulated and the MMC initiated tertiary control actions to resynchronize the microgrid with the utility grid. The MMC sent secondary control signals to both the natural gas turbine and the battery storage unit to minimize the voltage magnitude and phase differences between the microgrid and the utility grid prior to resynchronization.

The MMC dispatched a 59.9 Hz setpoint to the natural gas turbine to adjust the microgrid frequency for phase angle synchronization. The MMC also set the reference frequency of the battery storage unit equal to the microgrid frequency so that the battery maintains its dispatch during resynchronization. The voltage setpoints for the natural gas turbine and battery storage unit were set at the rated value by the MMC. When all resynchronization conditions were satisfied, the coupling switch at the PCC was closed.

The MMC then reset the reference frequency of the battery storage unit to 60 Hz through secondary control and sent tertiary control signals to building controllers to restore the load from 8 MW and 4 MVAr to 11 MW and 5.5 MVAr. Once resynchronized, the MMC managed the optimal hourly dispatch of DER units and building loads, taking into consideration the available energy in the battery storage unit. Back in grid-connected mode, the utility grid set the microgrid voltage and frequency and the primary and secondary controls did not respond to fluctuations in campus load. After resynchronization the real power flow from the utility grid to the microgrid was increased to 7 MW and the microgrid resources served the remaining 4 MW of the campus load.

It should be noted that automatic islanding in response to a utility grid outage and automatic resynchronization after clearing of the outage have not been demonstrated. The testing was conducted under a controlled setting and the islanding sequencing was done manually to ensure no loss of power to the campus. When in normal grid-connected mode, it has been demonstrated that the MMC can perform its function to economically dispatch the microgrid resources and loads.

Critical Facilities in the IIT Microgrid

The critical facilities at IIT shown in

Table 3.2 are two academic buildings: Life Sciences (610kW) and Stuart Building (320kW); and three university technology park buildings (Technology Business Center (780kW), IIT Tower (1.6MW), IITRI Life Sciences Research (600kW). The three most critical facilities include Stuart Building, Life Science Building, and IITRI Life Sciences Research. The IIT data computing center (150kW) is located at Stuart Building and equipped with UPS. The life science labs (250kW) are located at the Life Science Building and supported by the 250kW/500kWh flow battery. The IITRI Life Science Research Labs (600kW) is supported by local backup generation.

Meeting Customer-defined Objectives

IIT Microgrid has the ability to meet the customer-defined duration to continuously serve all critical loads during utility grid outages. The IIT data computing center (150kW) requires at least one day of uninterruptible operation. The first six hours can be supported by UPS. The life science labs (250kW) requires at least one day of continuous operation. The first two hours can be supported by the 250kW/500kWh flow battery. The IITRI Life Science Research (600kW) requires at least two days of continuous operation. The first day can be supported by local backup generators. IIT Microgrid with its onside natural gas generating units will have an unlimited operating time as long as the natural gas supply is available.

Access to Uninterruptible Fuel Sources

IIT Microgrid has access to uninterruptible fuel sources for generators to serve critical loads for the specified duration. There are two natural gas fired cogeneration units located at the main campus of IIT. These two units will have an unlimited operating time as long as the natural gas supply, located on 35th South Federal Street, is available.

Support Future Added Critical Loads to the IIT Microgrid

The total on-site generation at IIT Microgrid is much larger than its existing critical load. Furthermore, energy efficiency and demand response at IIT result in 20% permanent peak load reduction and a 50% peak load reduction. So the IIT Microgrid will have the capability of supporting any additional critical loads. The most significant critical load that is planned to be at IIT is the Innovation Center building.

4.1.2 Environmental Benefit

For the purpose of this report, summer is defined from June 1st to August 31st and winter is defined from December 1st to February 28th. Table 4.4 show the total electricity imported from the ComEd grid to serve the IIT Microgrid’s electrical and thermal loads from June 1, 2008 to May 31, 2009 as well as the corresponding emission based on the CO2 MEFs for the RFC. Table 4.5 show the total electricity imported from ComEd to serve the IIT’s electrical and thermal loads from June 1, 2013 to May 31, 2014 and the corresponding emission based on the CO2 MEFs for the RFC.

The total CO2 emission in 2009 for the imported electricity to IIT is 39,121,031.17 Kg. The total CO2 emission generated by the IIT's on-site generation is 13,415,011.67 Kg (14,905.57 tons). The total CO2 emission is 52,536,042.84 Kg. The corresponding figures for 2014 are 36,557,658.94 Kg, 12,520,565.50 Kg (13,911.74 tons), and 49,078,224.44 Kg. These results are summarized in Table 4.6.

Reduction in total annual marginal CO2 emissions (%) = 1 - (49,078,224.44/52,536,042.84) = 6.58%

Table 4.4: Total MWh and CO2 emission for imported electricity (June 1, 2008 to May 31, 2009)

Hour of the Day	Summer		Winter		Intermediate	
	MWh	CO2 (Kg)	MWh	CO2 (Kg)	MWh	CO2 (Kg)
1	663.91	420,698.82	451.35	350,129.83	1,002.96	735,038.76
2	651.58	428,304.57	446.9	348,287.01	982.62	708,124.85
3	640.99	421,898.34	443.49	331,195.82	969.63	682,518.95
4	634.92	414,563.34	440.42	313,342.92	956.42	659,254.79
5	628.27	407,537.41	438.05	311,037.75	944.89	646,972.81
6	620.74	383,546.88	438.94	311,635.46	941.07	656,555.68
7	627.77	411,737.82	451.38	341,330.82	969.83	698,185.67
8	648.94	429,192.09	458.44	331,719.67	999.86	703,598.35
9	681.8	428,101.48	466.65	344,343.67	1,038.75	700,626.04
10	716.18	435,494.29	488.99	342,887.70	1,097.92	727,836.05
11	747.13	443,152.21	504.51	348,431.88	1,145.09	755,351.48
12	773.93	438,483.86	510.6	359,634.73	1,174.89	783,267.97
13	787.12	450,959.67	515.67	361,772.50	1,200.46	829,025.08
14	792.3	459,856.08	517.95	366,995.72	1,211.68	809,322.98
15	794.26	487,599.90	517.19	352,645.81	1,214.95	852,880.60
16	795.45	509,687.17	514.92	346,473.14	1,210.46	855,814.42
17	791.01	472,285.75	512.73	355,265.75	1,202.52	821,580.48
18	779.08	464,626.13	513.6	372,401.17	1,182.67	830,441.57
19	755.34	438,039.74	503.69	373,232.25	1,145.10	822,274.78
20	729.1	423,564.93	490.46	328,076.45	1,113.37	758,573.55
21	717.03	391,666.32	485.44	335,184.53	1,101.81	736,981.29
22	701.06	351,343.66	478.68	338,841.74	1,073.37	715,543.36
23	693.21	367,946.43	467.16	363,192.25	1,044.20	733,912.58
24	682.65	395,595.45	459.2	365,140.44	1,028.93	764,895.51

Table 4.5: Total MWh and CO2 emission for imported electricity (June 1, 2013 to May 31, 2014)

Hour of the	Summer	Winter	Intermediate

Day	MWh	CO2 (Kg)	MWh	CO2 (Kg)	MWh	CO2 (Kg)
1	546.24	511,329.54	443.41	356,402.67	925.45	796,605.52
2	533.64	522,964.36	436.33	356,725.25	907.25	766,953.81
3	528.86	511,354.45	432.98	339,233.48	898.28	736,730.69
4	522.33	503,926.52	430.37	320,664.86	885.18	712,312.75
5	520.97	491,476.94	428.52	317,953.58	876.78	697,236.09
6	529.29	449,816.86	433.46	315,574.32	892.66	692,163.69
7	584.50	442,213.71	444.99	346,226.93	944.89	716,613.13
8	621.70	447,996.96	451.01	337,184.90	977.65	719,581.58
9	651.58	447,956.86	455.35	352,890.38	1,008.03	721,982.89
10	672.55	463,744.55	472.75	354,670.61	1,054.76	757,621.09
11	690.24	479,681.41	485.26	362,257.49	1,093.85	790,734.10
12	706.46	480,363.91	491.51	373,603.98	1,129.54	814,718.55
13	712.20	498,400.06	495.38	376,590.41	1,141.32	871,985.88
14	724.09	503,175.76	496.62	382,760.33	1,157.38	847,291.14
15	727.16	532,593.16	496.37	367,436.97	1,163.44	890,644.30
16	731.42	554,305.54	493.56	361,466.86	1,162.77	890,914.50
17	726.80	514,011.16	491.33	370,744.53	1,154.09	856,055.01
18	717.00	504,858.48	492.88	388,059.94	1,140.71	860,989.95
19	688.81	480,345.88	487.49	385,634.48	1,104.50	852,505.09
20	634.17	486,965.00	478.45	336,311.24	1,048.75	805,319.25
21	615.28	456,435.45	468.34	347,417.85	1,024.51	792,585.59
22	604.56	407,428.00	462.57	350,639.04	1,003.12	765,655.29
23	580.99	439,013.30	457.28	371,042.41	971.01	789,231.12
24	569.29	474,363.93	452.28	370,727.38	950.90	827,658.49

Table 4.6: Summary of environmental benefits

Year	Total CO2 Emission for Imported Electricity (Kg)	Total CO2 Emission for On-site Generation (Kg)	Total CO2 Emission (Kg)
2009	39,121,031.17	13,415,011.67	52,536,042.84
2014	36,557,658.94	12,520,565.50	49,078,224.44
Change			-6.58%

4.1.3 Energy Efficiency Benefit

The total imported electricity to IIT in 2009 is 54,523,896.50 kWh. The total electricity generated by the on-site generation is zero. The total energy from on-site generation to serve thermal loads is 364,386,472,881.21 Btu. The total energy supply is 990,320,804,701.21 Btu. The corresponding figures for 2014 are 50,767,083.75 kWh, 256,340 kWh (including solar and wind energy), 340,090,982,497.72 Btu, and 925,839,887,104.10 Btu. These results are summarized in Table 4.7.

Improvement in microgrid energy efficiency (%) = 1 - (925,839,887,104.10/990,320,804,701.21) = 6.51%

Table 4.7: Summary of energy efficiency benefits

Year	Total Imported Electricity (kWh)	Total On-site Electricity (kWh)	Total On-site Generation to Supply Thermal Loads (Btu)	Total Energy Supply (Btu)
2009	54,523,896.50	0	364,386,472,881.21	990,320,804,701.21
2014	50,767,083.75	256,340	340,090,982,497.72	925,839,887,104.10
Change				-6.51%

4.1.4 Economic Benefits

The total design (engineering) cost for the IIT Microgrid is $1,244,606. The total equipment and installation cost is $7,790,185. The cost for project management is $450,000. The total fixed project cost is $9,484,791.

In 2014,

- The IIT Microgrid operation and maintenance cost is estimated as $50,000.
- The ComEd utility indicated that the pending upgrades to the Fisk substation, totaling $2,000,000, were deferred due to the installation of the IIT Microgrid. In addition, planned new housing on east campus combined with expanded academic and research facilities throughout campus will exceed the capacity of the current electricity distribution system. IIT was pursuing the installation of a third substation on east campus at a cost of over $5,000,000. The IIT Microgrid project has deferred the installation. Thus the total deferred cost is $7,000,000.
- The annual savings in electric utility bill, due to the on-campus usage of solar and wind energy (256,340 kWh), is $17,943.80 at a unit price of $0.07/kWh.
- The savings due to avoided outage downtime is estimated to be $500,000.00.
- The production tax credit for utilizing the on-campus solar and wind energy (256,340 kWh) is $5,126.80 at a unit price of $0.02/kWh.
- The total annual saving at the IIT Microgrid is $523,070.60.

Table 4.8 shows the detailed analysis of costs and savings of operating the two natural gas turbines at IIT. It is assumed that both turbines are operated during winter months at a maximum capacity of 2.9MW for a total capacity of 5.8MW, and one unit is operated at 1.4 to 1.8MW during summer months, in order to minimize excess steam production.

It is estimated that in 2015,

- The total electricity generated by the two gas turbines at IIT will be 28,917,600 kWh. The annual savings in electric utility bill due to the on-campus usage of gas-fired power plant is $2,024,232 at a unit price of $0.07/kWh.
- The annual savings in electric utility bill, due to the on-campus usage of solar and wind energy (256,340 kWh) is $17,943.80 at a unit price of $0.07/kWh.

- The production tax credit for the on-campus solar and wind energy (256,340 kWh) is $5,126.80 at a unit price of $0.02/kWh.
- The Emergency Capacity Market Demand Response Program (RPM) at $10,121.00/MW-Year, for the 5,000kW committed by IIT, is valued at $50,605.00.
- The annual savings due to avoided outage downtime is estimated to be $500,000.00.
- The annual IIT Microgrid operation and maintenance cost is estimated as $50,000.
- The natural gas power plant maintenance cost is $347,011.
- The annual natural gas usage for generating electricity is 1,583,104 therms at a unit cost of $0.65/therm, which amounts to a total cost of $1,029,018.
- The total annual saving at IIT Microgrid is $1,171,878.60.

The total net savings for the next eight years (2016-2023) with an escalation rate of 5% is $11,749,916.16. The Net Present Value (NPV) of the IIT Microgrid project, assuming a project duration of 10 years and a discount rate of 10%, is $4,597,683.32. The NPV/kW of the IIT Microgrid is $383.14.

Table 4.8: Operation of natural gas power plant with varying monthly loads based on campus steam and kW demand

Month	Turbine Output (kW)	Steam Output, lbs/h (10% losses)	Electricity Generated (kWh)	Natural Gas Consumed (Therms)	Steam Boiler Reduction of Natural Gas (Therms)	Natural Gas Cost Impact (Therms)
Dec-12	4,500	18,858	3,348,000	(405,108)	221,821	(183,287)
Jan-13	5,800	24,306	4,315,200	(522,139)	285,902	(236,237)
Feb-13	5,800	24,306	3,897,600	(471,610)	258,234	(213,376)
Mar-13	5,000	20,953	3,720,000	(450,120)	246,467	(203,653)
Apr-13	3,800	15,925	2,736,000	(331,056)	181,273	(149,783)
May-13	1,800	7,543	1,339,200	(162,043)	88,728	(73,315)
Jun-13	1,500	6,286	1,080,000	(130,680)	71,555	(59,125)
Jul-13	1,400	5,867	1,041,600	(126,034)	69,011	(57,023)
Aug-13	1,400	5,867	1,041,600	(126,034)	69,011	(57,023)
Sep-13	1,400	5,867	1,008,000	(121,968)	66,785	(55,183)
Oct-13	2,600	10,896	1,934,400	(234,062)	128,163	(105,899)
Nov-13	4,800	20,115	3,456,000	(418,176)	228,976	(189,200)
			28,917,600	(3,499,030)	1,915,926	(1,583,104)

Month	Electricity Cost Savings ($)	Overall Reduction in Natural Gas Cost ($)	Total Savings for Natural Gas and Electricity	Turbine Maintenance Cost ($)	Monthly Cost Savings ($)
Dec-12	234,360	(119,137)	115,223	(40,176)	75,047
Jan-13	302,064	(153,554)	148,510	(51,782)	96,728
Feb-13	272,832	(138,694)	134,138	(46,771)	87,367
Mar-13	260,400	(132,374)	128,026	(44,640)	83,386

Apr-13	191,520	(97,359)	94,161	(32,832)	61,329
May-13	93,744	(47,655)	46,089	(16,070)	30,019
Jun-13	75,600	(38,431)	37,169	(12,960)	24,209
Jul-13	72,912	(37,065)	35,847	(12,499)	23,348
Aug-13	72,912	(37,065)	35,847	(12,499)	23,348
Sep-13	70,560	(35,869)	34,691	(12,096)	22,595
Oct-13	135,408	(68,834)	66,574	(23,213)	43,361
Nov-13	241,920	(122,980)	118,940	(41,472)	77,468
	2,024,232	(1,029,018)	995,214	(347,010)	648,204

The Average CT Steam Output is 4.70 lbs/hr per kW (at 105 psig). The Average Blended Cost of Electricity is $0.07/kWh. The Average Cost of Natural Gas is $0.65/Therm.

Table 4.9 summarizes the costs and savings for the IIT Microgrid. The costs do not include any capital costs for the preexisting gas turbine plant and building back-up generators. The R&D costs were considered a one-time cost and were not included in the financial analysis. The deferral of planned upgrades at the Fisk substation by the utility and the installation of a third substation on the east campus planned by IIT resulted in a savings of $7 million. These deferrals are included in the savings.

Table 4.9: IIT Microgrid financial summary

Item	($) Million
Capital Cost	$9.485
R&D Costs	$4.1
Total Present Value Costs (less R&D costs)	$12.036
Total Present Value Savings	$16.634
Project Net Present Value (NPV)	$4.598
Benefit Cost Ratio (BCR)	1.38

4.2 Sample Data of the IIT Microgrid

Figure 4.1 to Figure 4.9 show sample operating conditions of the IIT Microgrid. The finest time resolution in the IIT Microgrid is 60 samples per second based on the measurements provided by PMUs.

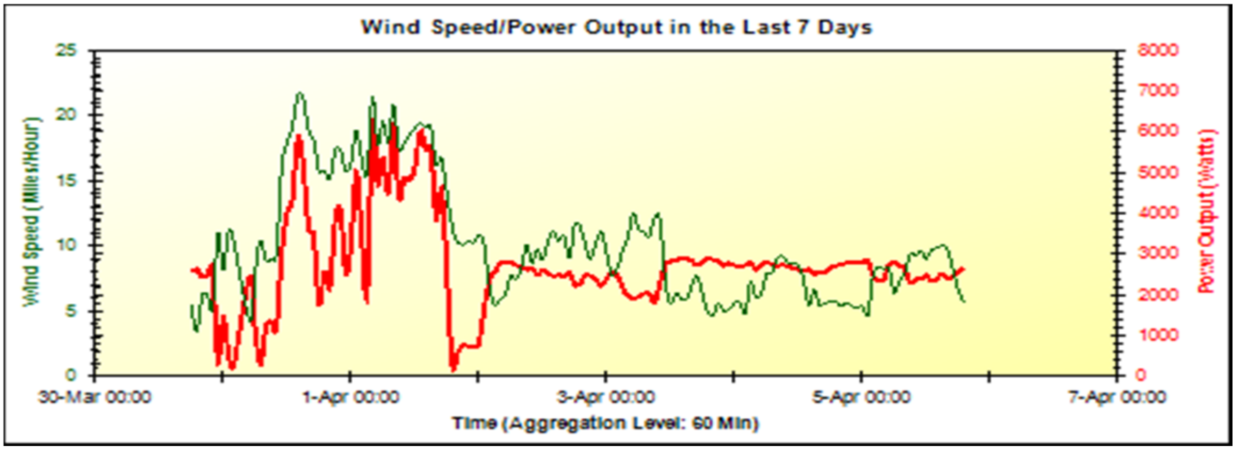


Figure 4.1: Sample wind speed/power output for IIT's 8kW wind turbine

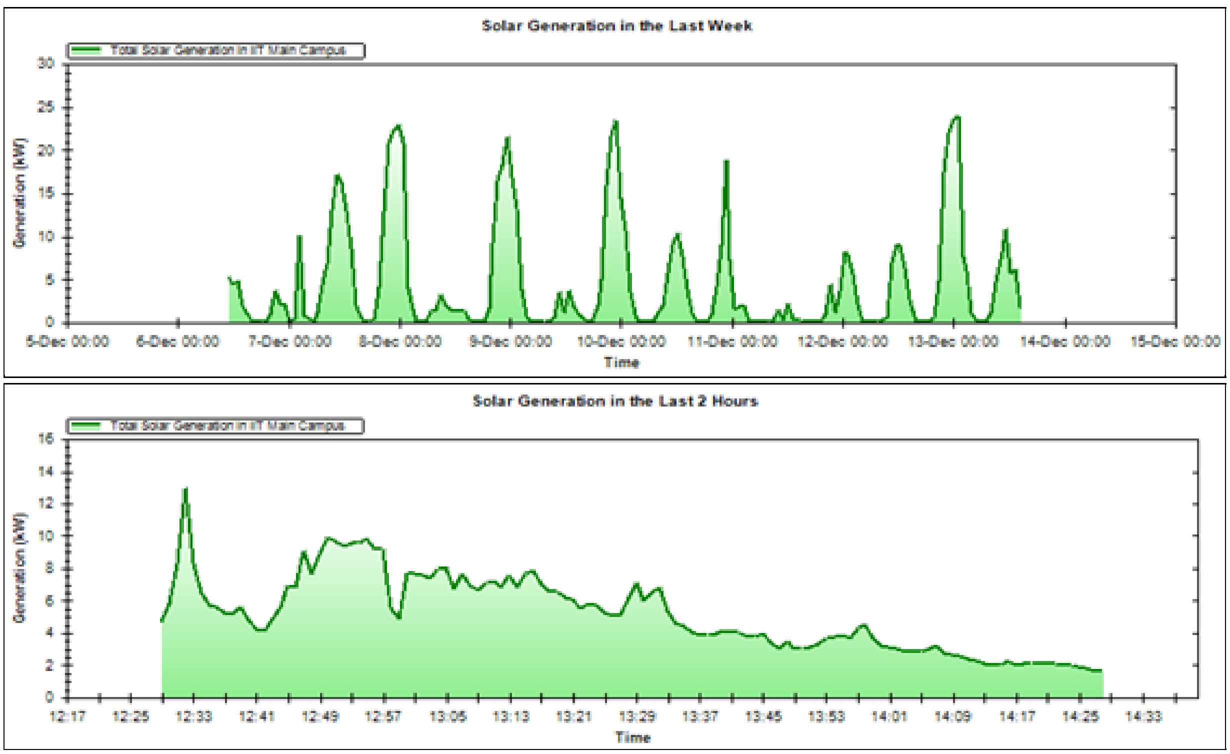


Figure 4.2: Sample generation output for IIT's solar pv installation (1 week and 2 hours)

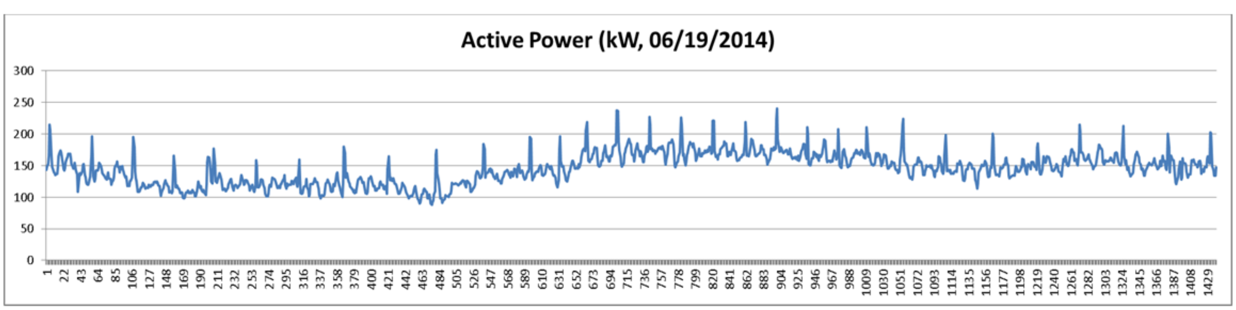


Figure 4.3: Sample active power demand of Keating Hall in Loop 1 of the IIT Microgrid (minute by minute)

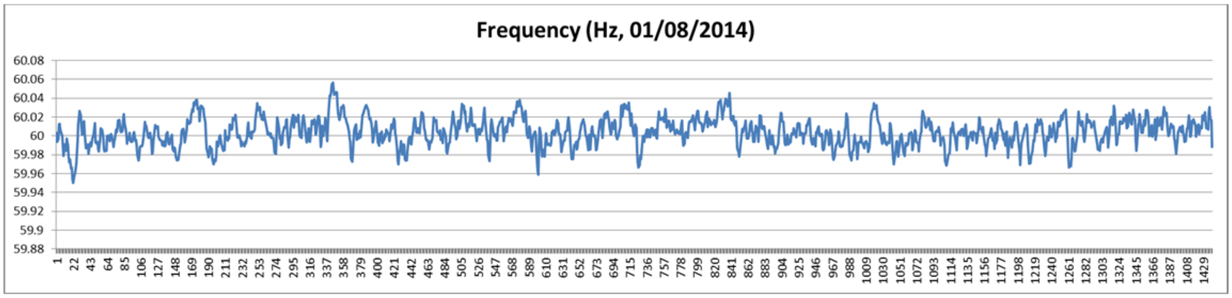


Figure 4.4: Sample frequency of IIT Microgrid (average by minute)

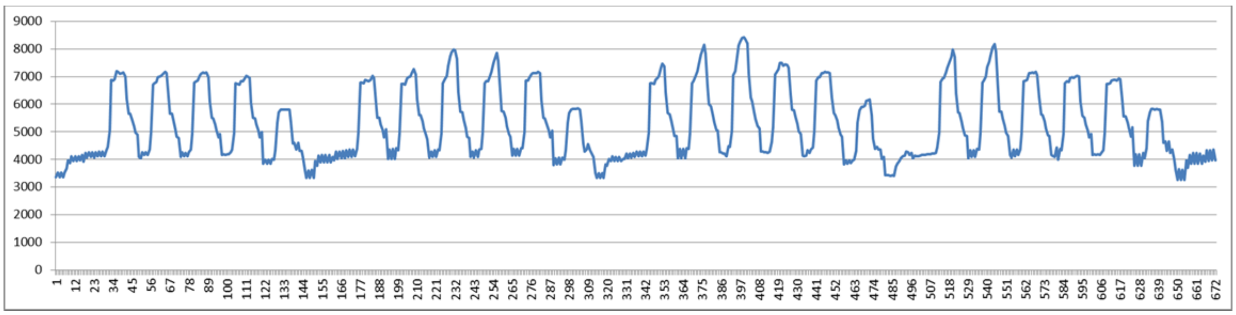


Figure 4.5: Typical hourly load (kW) at the IIT Microgrid in one week

Figure 4.6: Sample hourly load (kW) and real time price ($/MWh) of the IIT Microgrid (summer weekday)

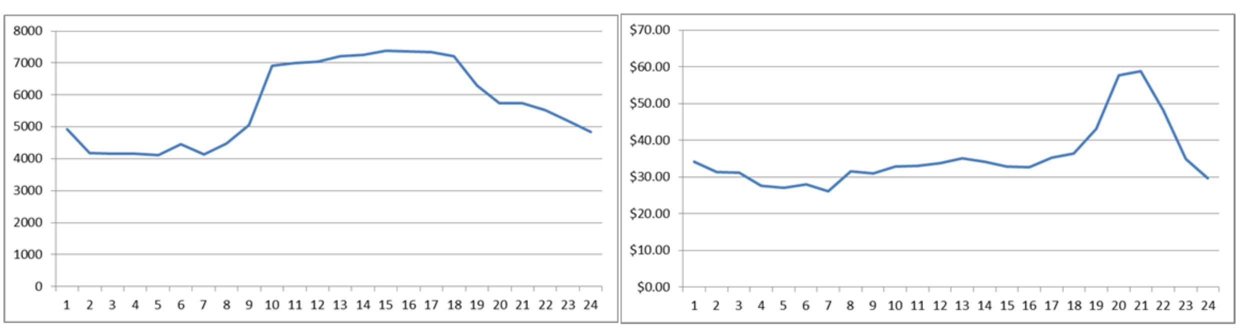


Figure 4.7: Sample hourly load (kW) and real time price ($/MWh) of the IIT Microgrid (winter weekday)

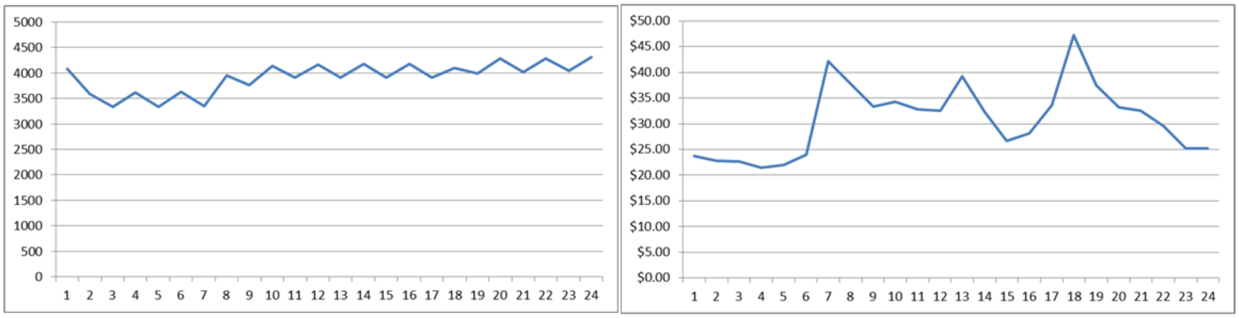


Figure 4.8: Sample hourly load (kW) and real time price ($/MWh) of the IIT Microgrid (weekend)

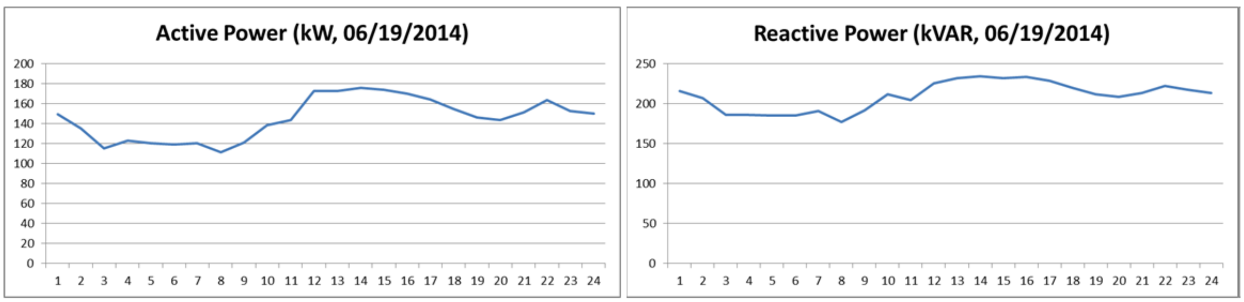


Figure 4.9: Sample hourly active and reactive power load of Keating Hall in Loop 1 of the IIT Microgrid

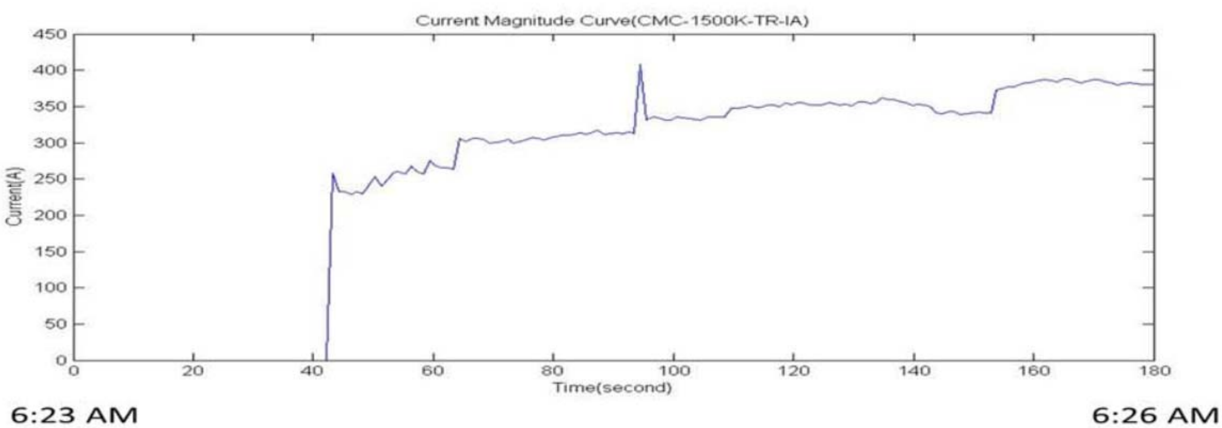


Figure 4.10: Sample current through a building transformer in IIT Microgrid during islanding test

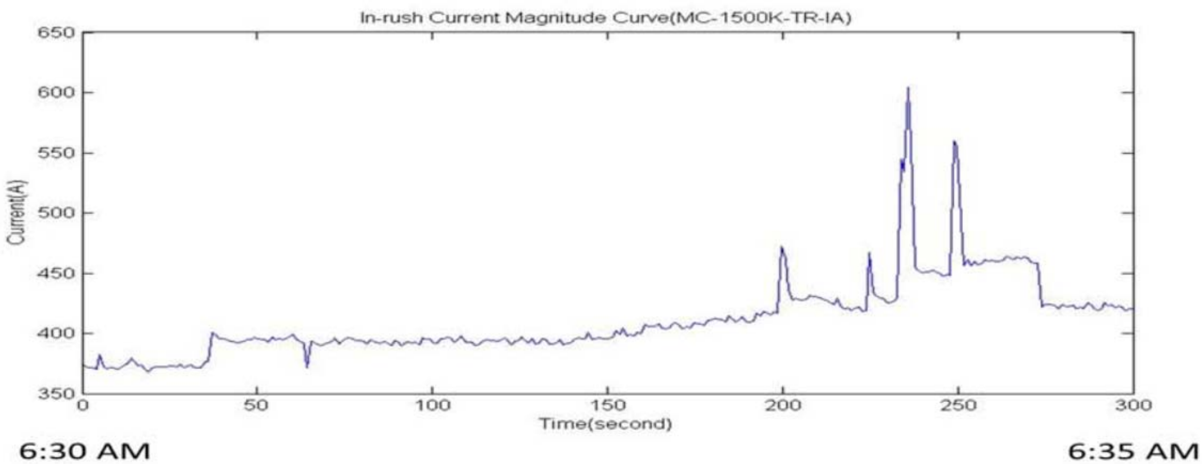


Figure 4.11: Sample current through a building transformer in IIT Microgrid during load restoration

Figure 4.12 shows the hourly generations of the 20kW solar system at Siegel Hall from October 26, 2012 to December 10, 2013. Table 4.10 summarizes the hourly average generations and capacity factors for each month of the above period. The annual capacity factor is about 13.37%, with the maximum of 21.09% occurring in July and the minimum of 4.80% occurring in December.

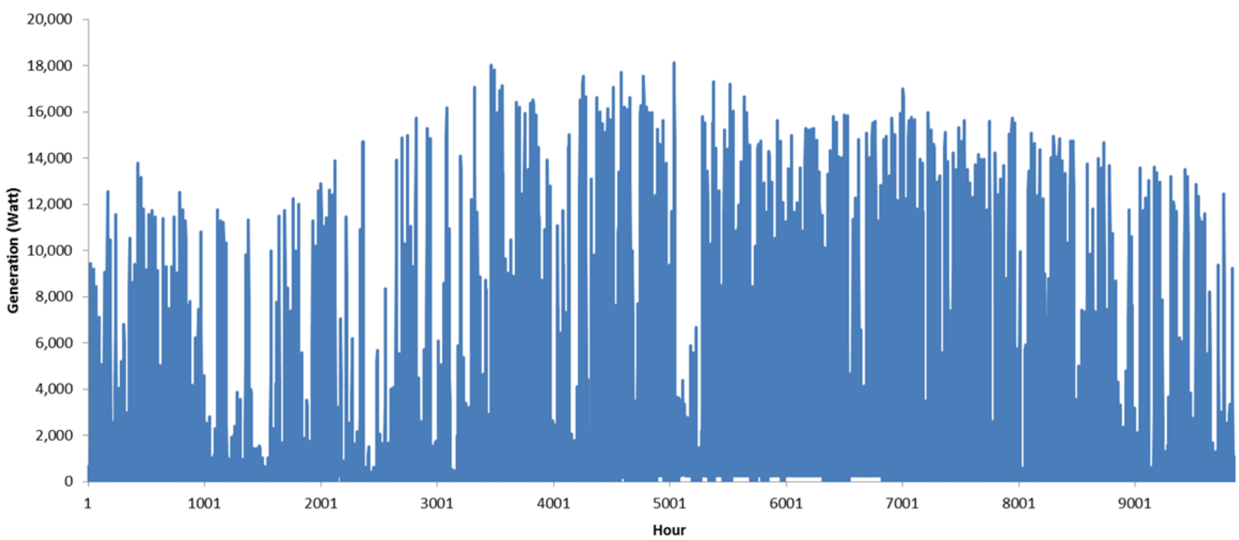


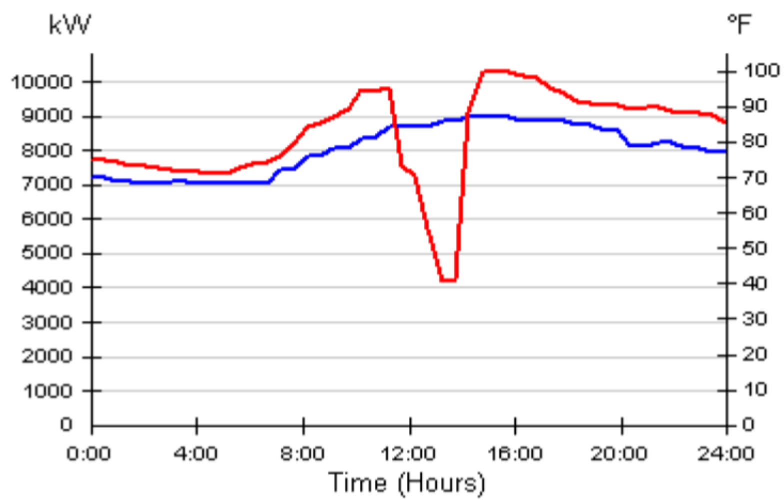
Figure 4.12: Hourly solar generation (Siegel Hall, 10/26/2012 to 12/10/2013)

Table 4.10: Hourly average solar generation and capacity factor (Siegel Hall)

Month	Hourly Average (Watt)	Capacity Factor (%)
October, 2012	1871	9.36%
November, 2012	1983	9.92%
December, 2012	960	4.80%
January, 2013	1575	7.88%
February, 2013	1682	8.41%

March, 2013	2739	13.70%
April, 2013	3225	16.13%
May, 2013	3566	17.83%
June, 2013	3832	19.16%
July, 2013	4218	21.09%
August, 2013	4101	20.51%
September, 2013	3279	16.40%
October, 2013	2507	12.54%
November, 2013	1765	8.83%
December, 2013	967	4.84%
Total	2674	13.37%

Figure 4.13 shows one example of demand response at the IIT Microgrid, which occurred on August 19, 2010. The demand response reduced the campus load seen by the utility from 10MW to 4MW (a reduction of 60%) through curtailing building loads, shifting campus loads, and dispatching the natural-gas turbine at IIT.



(Red line: campus Load; Blue line: ambient temperature)

Figure 4.13: IIT Microgrid demand response on August 19, 2010

Figure 4.14 to Figure 4.16 show conditions of the IIT Microgrid during islanded operation. The transition from grid-connected mode of operation to island mode was demonstrated in one controlled testing. The islanding event was triggered by a simulated permanent fault on the utility side of the PCC. As shown in Figure 4.14, the microgrid frequency dropped slightly at islanding because the available microgrid DER (distributed energy resource) was smaller than its load. There was also a short spike representing the rotating inertia of the natural gas turbine at islanding. The secondary control in the natural gas turbine and battery storage restored the microgrid frequency to 60 Hz once the primary control for load sharing resulted in a lower frequency. The battery discharged shortly after islanding (within 10–11.5 s) to maintain the frequency. The charging stopped when the 60-Hz frequency was restored. The wind turbine and solar PV units (8 kW and 123 kW, respectively) do not participate in frequency and voltage regulation. Immediately after islanding, the MMC provided emergency demand response in order to prevent a sustained drop of microgrid frequency and voltage as the natural gas turbine was faced with a ramping limit. The MMC sent load curtailment signals through tertiary control to building controllers to curtail the campus load from 11.07 MW and 5.54 Mvar to 4.13 MW and 2.07 Mvar (the amount of load supplied by the natural gas turbine and solar PV and wind unit before islanding).

Once the rated microgrid frequency and voltage were stabilized, the MMC sent signals to building controllers to perform load restoration through tertiary control, as shown in Figure 4.15. The MMC first sent secondary control signals to the natural gas turbine and battery storage during the load restoration to maintain the rated frequency and voltage (4.16 kV and 60 Hz). The campus load began to increase progressively from 4.13 MW and 2.07 Mvar to 8.13 MW and 4.07 Mvar. The primary controls of the natural gas turbine and battery storage responded to load increments by adjusting the frequency with each step. The secondary control stabilized the microgrid voltage and frequency before increasing the load in the next step. The natural gas turbine supplied 4 MW and 2 Mvar before load restoration; this was increased to 8 MW and 4 Mvar after load restoration. As shown in Figure 4.16, the MMC adjusted the set points of battery storage units and building controllers through tertiary control. The total served real and reactive load on campus reached 8.38 MW and 4.19 Mvar, respectively. In the meantime, the microgrid voltage and frequency were adjusted by the MMC.

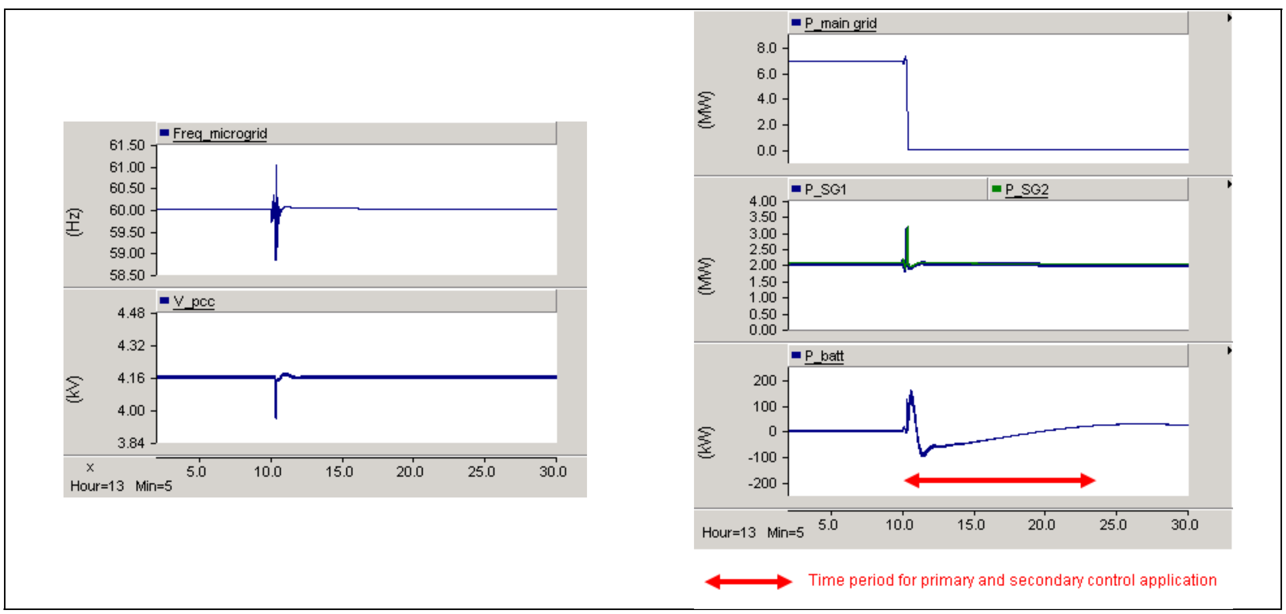


Figure 4.14: Sample microgrid frequency and PCC voltage, active power dispatch of utility grid, distributed generation, and battery when IIT Microgrid is islanded from utility grid

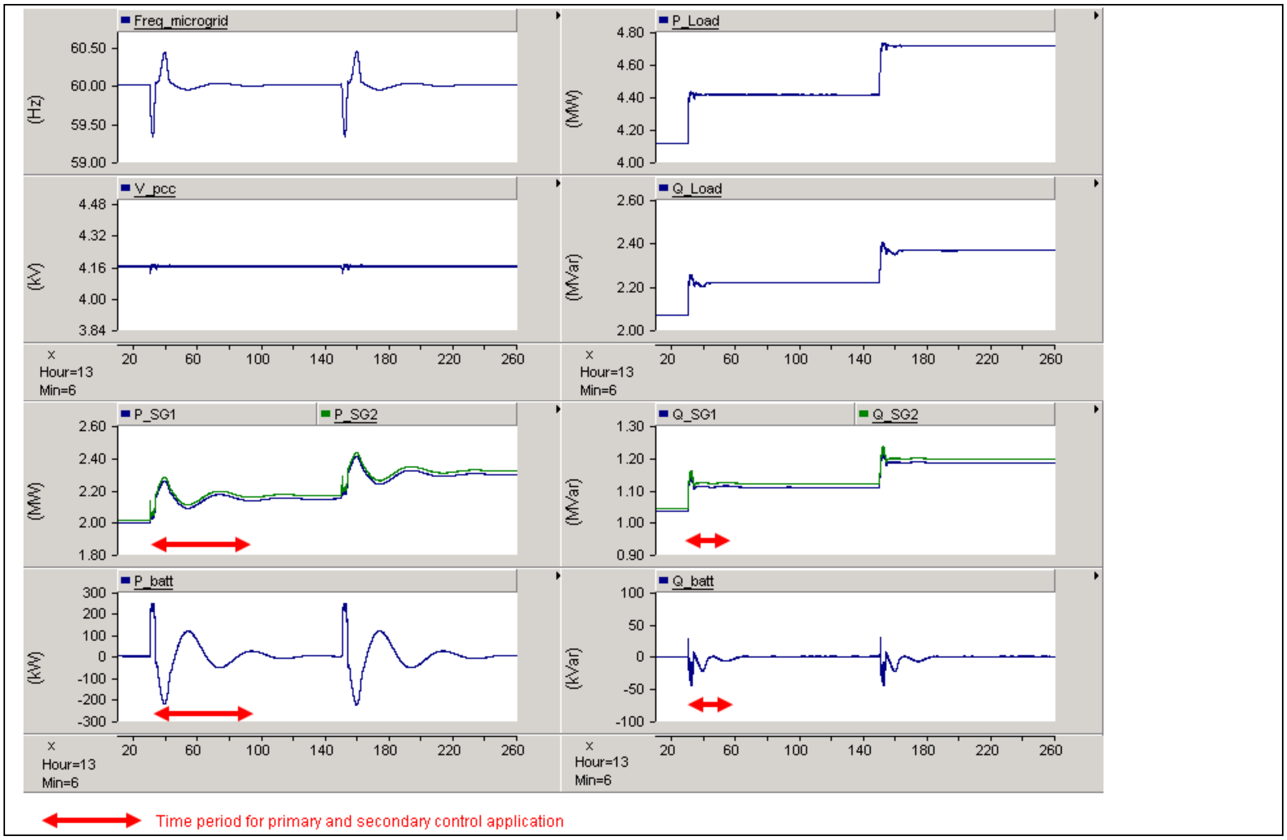


Figure 4.15: Sample microgrid frequency and PCC voltage, active power dispatch of utility grid, distributed generation, and battery during load restoration under islanded microgrid operation

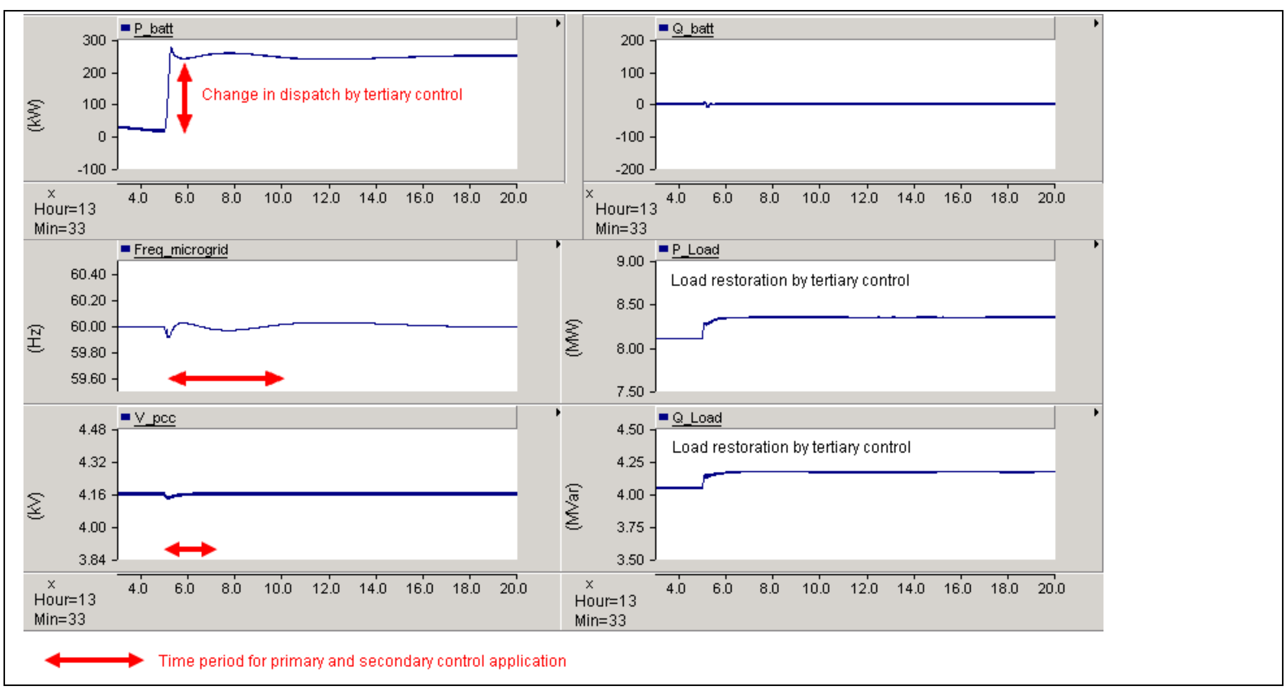


Figure 4.16: Sample microgrid frequency and PCC voltage, dispatch of battery, and campus load during load restoration under islanded microgrid operation

(a) The phase angle difference between the microgrid and the utility grid bus voltages at the PCC and (b) the crucial instants before and after the coupling switch at the PCC is closed. Note that the switch is closed when the angle difference is 2.5°.

Figure 4.17 and Figure 4.18 show conditions of the IIT Microgrid during reconnection to main grid. The transition from the island mode of operation to re-connection with the main grid (ComEd) was demonstrated in one controlled testing. Once the normal operation of the utility grid was restored, it communicated with the master controller through tertiary control to resynchronize the microgrid with the utility grid. The microgrid master controller sent secondary control signals to both the natural gas turbine and the battery storage unit to minimize the voltage magnitude and phase differences between the microgrid and the utility grid prior to resynchronization. The PCC voltage magnitude was at the rated value and the microgrid frequency was slightly lower than its rated value.

The resynchronization process started with a secondary control signal sent by the master controller to the natural gas turbine to adjust the microgrid frequency to 59.9 Hz for phase angle synchronization. The master controller also set the reference frequency of the battery storage unit to be equal to the microgrid frequency so that the battery maintained its dispatch during resynchronization. The voltage magnitude was set at its rated value by the secondary control signal that was sent to both the natural gas turbine and the battery storage unit.

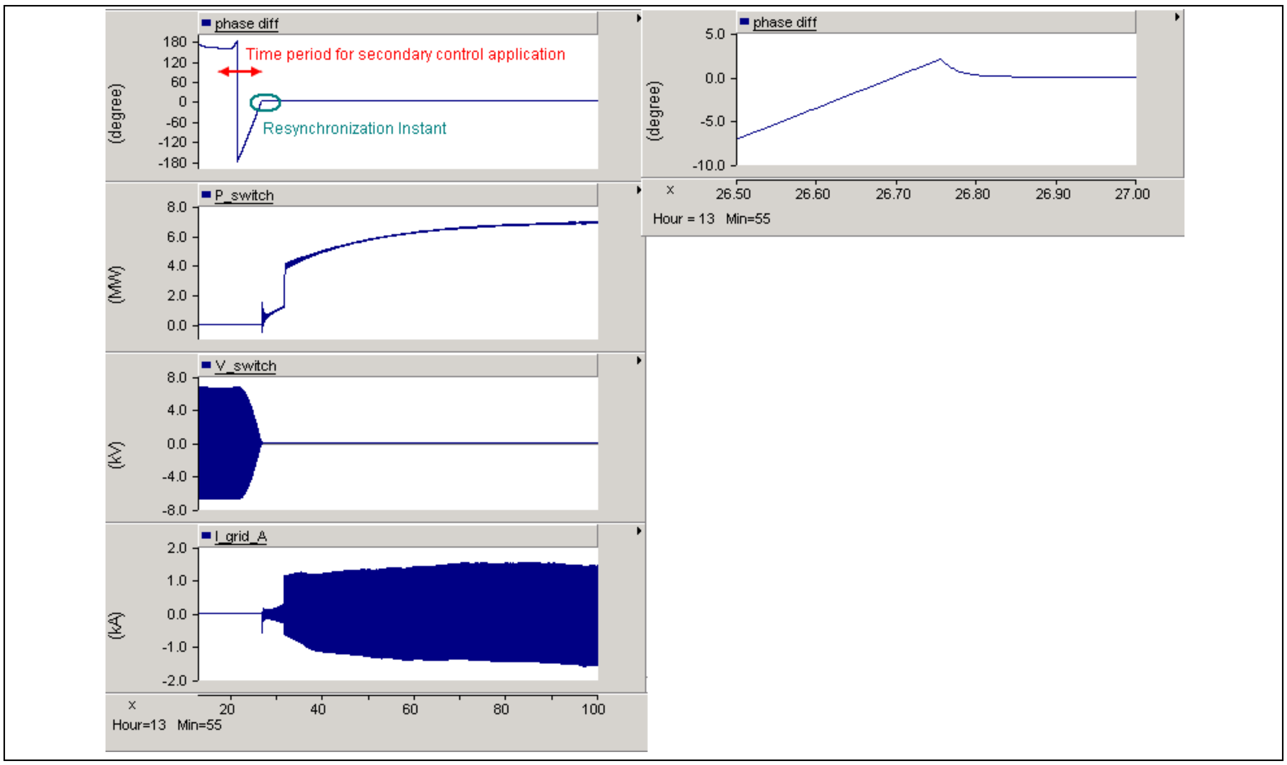
Figure 4.17(a) shows the phase angle difference between the microgrid and the utility grid bus voltages at the PCC, where a positive difference indicates that the utility grid voltage is leading that of the microgrid. The frequency difference (0.1 Hz) between the IIT microgrid and the utility grid caused the voltage phase difference to ramp up. When all resynchronization conditions were satisfied, the coupling switch at the PCC was closed. The green-circled area in

Figure 4.17(a) was redrawn in

Figure 4.17(b), which showed that the coupling switch at the PCC was closed when the angle difference was 2.5°.

Figure 4.17(a) also showed the instantaneous voltage difference at the PCC, the real power flow through the switch, and the instantaneous current through phase A of the coupling switch, both before and after resynchronization.

After resynchronization, the voltage difference was zero when phase A current was increased to 1.33 kA (peak amplitude). The real power flow from the utility grid to the microgrid was increased to 6.94 MW and the other local DER units served the remaining 4.13 MW of the campus load. The master controller also reset the reference frequency of battery storage to 60 Hz through secondary control and sent tertiary control signals to building controllers to restore the load from 8.38 MW and 4.19 Mvar to 11.07 MW and 5.54 Mvar. After resynchronization, the microgrid was connected to the utility grid, and the master controller procured the optimal hourly dispatch of DER units and building loads, taking into consideration the available energy in the battery storage unit. In grid-connected mode, the utility grid set the microgrid voltage and frequency and the primary and secondary controls did not respond to fluctuations in campus load. Figure 4.18 shows that after resynchronization, the generation dispatch of the natural gas turbine was ramped down from 8 MW and 4 Mvar to 4 MW and 2 Mvar and the battery storage unit was no longer dispatched in response to the tertiary control signal from the master controller. The solar PV and wind turbine units generated 123 kW and 8 kW, respectively, and the utility served the remaining 6.94 MW and 3.47 Mvar of load.



(a) The phase angle difference between the microgrid and the utility grid bus voltages at the PCC and (b) the crucial instants before and after the coupling switch at the PCC is closed. Note that the switch is closed when the angle difference is 2.5°.

Figure 4.17: Sample resynchronization conditions at the PCC

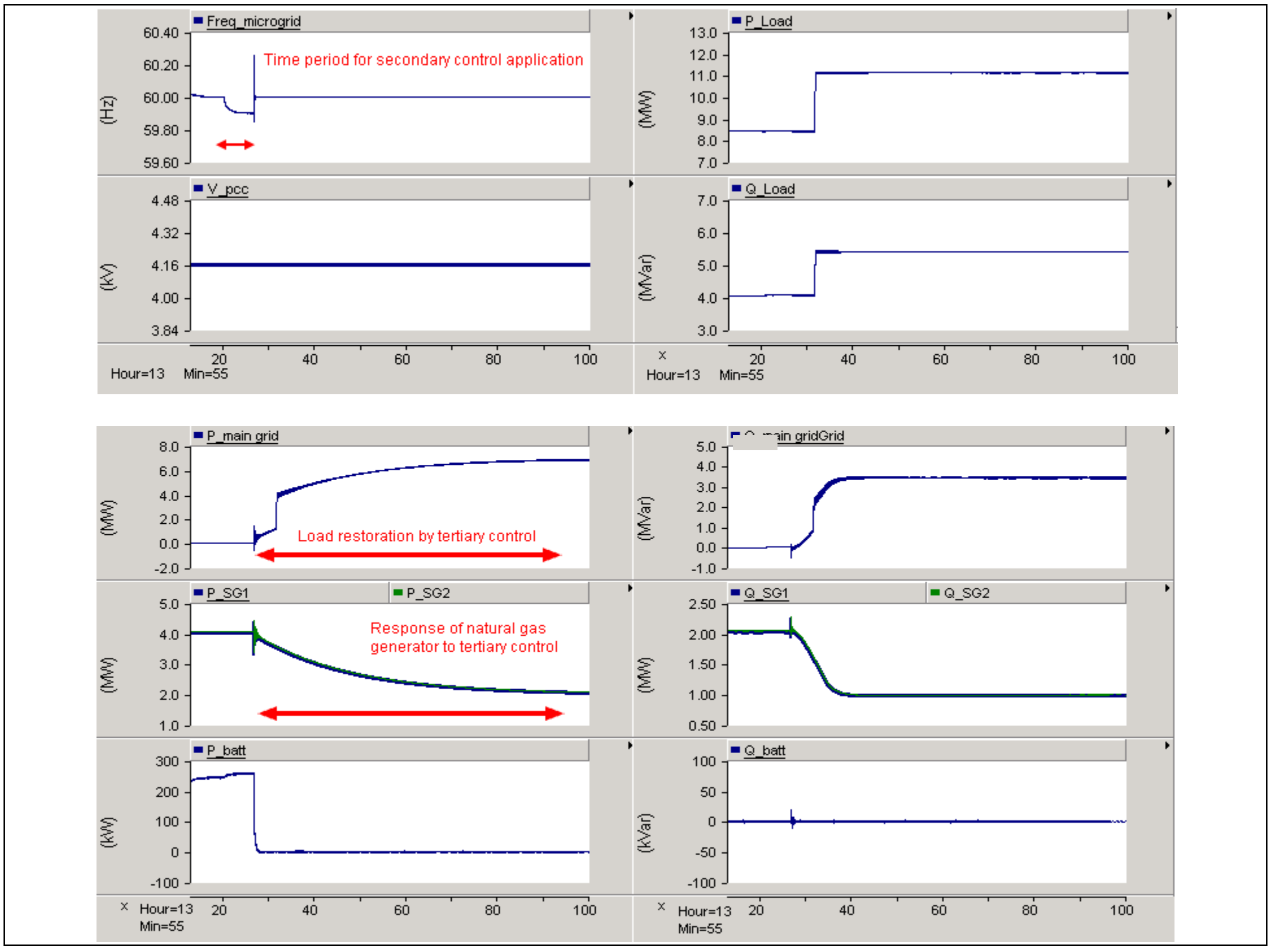


Figure 4.18: Sample microgrid frequency and PCC voltage, active and reactive power dispatch of utility grid, distributed generation, and battery when IIT Microgrid is resynchronized with utility grid

It should be noted that automatic islanding in response to a utility grid outage and automatic resynchronization after clearing of the outage have not been demonstrated. The testing was conducted under a controlled setting and the islanding sequencing was done manually to ensure no loss of power to the campus.

5. Conclusions

During the six-year project period, this project has demonstrated a replicable model for leveraging advanced technology to create microgrids that automatically respond to utility, ISO, and electricity distribution system signals, changes, and interruptions in a way that provides key demand reduction support and increased reliability. This project has made an impactful contribution to the nation's effort in smart grid development and education through the completion of the fully-functional IIT Microgrid and the establishment of a world-class state-of-the-art smart grid education and workforce training program.

The project has deployed the following assets.

- **Microgrid Master Controller**. The MMC performs day-ahead and real-time optimal scheduling for the IIT Microgrid. It uses the OSIsoft PI system for its software platform which is the industry standard in enterprise infrastructure for management of real-time data and events. MMC applications were developed at IIT. The MMC monitors all loads and resources, performs a "security constrained unit commitment" (SCUC) for the day ahead operation, and performs a "security constrained economic dispatch" (SCED) for the current day operation. It also considers weather forecasts and solar/wind forecasts in the analysis. It dispatches modes and setpoint for each resource every 10 minutes. The MMC economically optimizes the energy flow at three levels—campus, DER / building, and sub-building. Building meters provide the MMC with individual building load profiles enabling it to communicate and adjust sub-building loads through building controllers. The MMC also receives the day-ahead price of electricity, weather data, wind speed, cloud coverage and other data for utilizing the renewable sources in the microgrid. The MMC then runs a day-ahead scheduling optimization algorithm to optimize the use of microgrid local generation and balance the hourly DR (load curtailment and shifting of non-essential microgrid loads) for minimizing the cost of supplying the microgrid load. At times, the MMC will consider DR rather than power purchases from the grid.
- **Natural-Gas Turbine Synchronous Generation**. The IIT Microgrid utilizes an existing 8 MW natural gas fired power plant with two 4MW Rolls Royce gas-turbines. The natural-gas turbine consists of five sections including air intake, compressor, combustor, turbine and exhaust. The air sucked into the inlet is compressed by the compressor and mixed with fuel (natural gas) to form an air-fuel mixture. The mixture is burned in the combustor to form a high-pressure gas, which drives the turbine. The synchronous generator installed on the turbine shaft converts the mechanical energy into electrical energy.
- **Solar PV Generation**. A total of 300 kW of solar PV cells are installed, including 280 kW on three building rooftops and a 20kW solar canopy at the electric vehicle charging station to supply portions of the IIT campus load. There is a plan to add another 300 kW of solar PV before the end of 2016. Solar PV units are not dispatchable and use MPPT controls to maximize the solar power output for a given insolation.
- **Wind Turbine Unit**. An 8 kW wind turbine unit is installed on the north side of the campus in the Stuart soccer field, connected to loop 1. The cut-in and cut-off wind speed for this turbine are 4.5 m/s and 25 m/s respectively and the turbine has a diameter of 8 meters and a sweep area of 50 square meters.

- **Battery Storage**. IIT Microgrid is equipped with a 500 kWh ZBB (zinc-bromate) flow battery storage system made up of 10 individual sets of stacks each rated at 50 kWh. Maximum discharge rate is 2 hours (250 kW). The battery storage system is connected to loop 1.
- **Inverter Power Conversion System**. The system utilizes two ZBB inverters rated at 125 kW each and connected in parallel. Inverter efficiency is > 95% at rated load and reactive power can be controlled within a range of +/- 0.8 power factor. The operating temperature is from -30°C to 50°C. The inverter has received UL1741 design certification and meets IEEE 519 for THD. They normally operate in setpoint mode, charging at night and discharging during the day over approximately a 4 hour time period. They can operate in voltage source mode.
- **HRDS Switches**. The HRDS at the IIT Microgrid utilizes underground closed-loop fault-clearing S&C Vista switchgear with SEL-351 directional over-current protection relays. The fault isolation takes place in a quarter of a cycle by automatic breakers. The communication via fiber optic cables facilitates the coordination between VISTA switches. In HRDS, at least two simultaneous failures in the cable segments feeding a building from both paths will lead to a complete outage in the building. As the chances of two coincident failures is far less than single failures in cables feeding the loads, the interruption indices of the buildings are improved significantly by the installation of HRDS system.
- **Meters and PMUs**. The IIT Microgrid is equipped with building meters and twelve PMUs which report building electricity consumption to the master controller every 15 minutes. The PMUs monitor and record the real and reactive generation and consumption in real time and provide the information on instantaneous voltage and current of DER units (including the magnitude and phase angle) at a sampling rate of one signal per cycle to the master controller.
- **Building Controllers**. Building controllers facilitate the building consumption management. The reduction in building consumption is accomplished by defining several operating modes representing different consumption levels in each building. Once the operation mode for each building is set by the master controller, the building controller will send signals to sub-building controllers to set the requested load level associated with the selected mode and feeds back the confirmation signal to the master controller to acknowledge the mode change. Approximately 30% of the building load at IIT are shiftable loads and can be served when the electricity price is lower. The building controllers are also able to monitor and control the energy flow within the buildings including hot and chilled water flow, heating and cooling loads, and can monitor the temperature of different spaces within the building.
- **Building Back-up Generators**. The IIT Microgrid is equipped with 11 backup generators with a total capacity of 4,036 kW scattered at various buildings around the IIT campus. General test and inspection of these generators are performed weekly, biweekly or monthly and transfer load tests are performed quarterly or annually. None of these backup generators are currently integrated into the operation of the microgrid. Efforts are being made to better utilize these resources.

The design concepts of the IIT microgrid are summarized as follows.

- A major element of the IIT Microgrid is the MMC. The MMC applies a hierarchical control (campus, building and sub-building levels) via SCADA to ensure reliable and economic operation of the IIT Microgrid. It also coordinates the operation of HRDS controllers, on-site generation, storage, and the individual building controllers. Intelligent switching and advanced coordination technologies of the MMC facilitate rapid fault assessments and isolations in the microgrid.
- The MMC offers the opportunity to eliminate costly outages and power disturbances, supply the hourly load profile, reduce daily peak loads, and mitigate greenhouse gas production. MMC

functionality also includes load shedding and the coordination of DR signals with the other controllers for peak demand reduction. In DR mode the MMC will shift or shed loads according to predetermined load priorities. Load shedding can be accomplished by shutting off power to an entire building through activation of smart switches or by communicating directly with specific loads distributed across the campus via the ZigBee network and building controllers.

- The IIT microgrid is connected to the local utility grid through its north and south substations, which act as the PCC. The short-term reliability algorithm applied at the MMC considers seamless islanding and resynchronization and applies emergency DR and self-healing in case of major outages on either side of the PCC. The economic operation addresses the optimal generation scheduling of DER units in both grid-connected and island modes and applies economic dispatch to minimize operational cost.
- Three levels of controls (primary, secondary, and tertiary) are utilized to support grid-connected and islanded operations. Primary control utilizes the droop characteristics of the DER units for sharing the microgrid load and prevents large circulating currents among them due to small differences in voltage setpoints. Secondary control performs corrective action to mitigate frequency and voltage errors introduced by droop control when in island operation. Tertiary control manages the flow between the microgrid and the utility grid and provides the optimal scheduling of DER units and loads for both islanded and grid-connected operation of the microgrid. Tertiary control provides ancillary services to the utility grid including voltage and frequency regulation and restoration services. Primary control is performed at the DER level using the local component controls. The centralized secondary and tertiary controls are performed by the MMC.
- Monitoring signals provided to the MMC indicate the status of DER and the other distribution components. Based on the inputs it receives, the MMC provides set points for the DER resources and building controllers. Building controllers then communicate with sub-building controllers through a Zigbee wireless control and monitoring system to achieve device level control for rapid load management. The MMC communicates with the microgrid devices through various communications protocols, depending on the type of connected devices.
- If the microgrid is partly damaged in major outages, the MMC will evaluate the status of microgrid components and restore services to emergency and non-emergency loads sequentially by utilizing dispatchable units (natural-gas turbine and battery storage) which are able to maintain the microgrid voltage and frequency within acceptable ranges. Once the loads are partially restored considering the ramping limits of dispatchable units, the non-dispatchable units (wind turbine and solar PV units) will pick up additional loads. The non-dispatchable units may cause voltage and frequency transients if larger dispatchable DER units are not present in the microgrid. Once the utility grid is restored, the IIT microgrid will be resynchronized to the utility grid and shift from island mode to grid-connected mode after communicating with the utility grid.

The IIT microgrid was demonstrated in both grid-connected and island modes of operation.

- **Grid-connected Operation**. Grid-connected operation of the microgrid was demonstrated extensively. During 2014, the microgrid generated 256,340 kWh from on-site resources (gas turbines, solar and wind). The microgrid is always in continuous operation. The MMC actively monitors the status of the microgrid resources including DR capacity, forecasts expected solar and wind generation, and evaluates natural gas prices and grid electricity prices to determine the optimum operating configuration in real time. The MMC adjusts the operating setpoints of the energy storage system and the natural gas generators every 10 minutes if needed to ensure the operating configuration remains optimal. This is accomplished through a security constrained economic dispatch algorithm. The IIT microgrid also demonstrated its ability to perform DR actions while in grid-connected mode. On August 19, 2010 campus load was reduced by 60% through curtailing building loads, shifting campus loads, and dispatching the natural-gas turbine at IIT. No significant operating events were experience during grid-connected operations.

- **Island Operation**. The transition from grid-connected mode of operation to island mode was successfully demonstrated once through controlled testing with the entire process managed by the MMC. The islanding event was triggered by a simulated permanent fault on the utility side of the PCC. The microgrid frequency dropped slightly at islanding because the microgrid generation was less than the microgrid load. The battery discharged within 10–11.5 seconds after islanding to maintain the frequency. The MMC next sent secondary control signals to the natural gas turbine and energy storage system to restore the rated frequency and voltage (4.16 kV and 60 Hz). Discharging of the battery stopped when the 60-Hz frequency was restored. The wind turbine and solar PV units do not participate in frequency and voltage regulation. Immediately after islanding, the MMC provided emergency DR to prevent a sustained drop in microgrid frequency and voltage as the natural gas turbine had a ramping limit. The MMC sent load curtailment signals through tertiary control to building controllers to curtail the campus load from 11 MW and 5.5 MVAr to 4 MW and 2 MVAr (the amount of load supplied by the natural gas turbine and solar PV and wind unit before islanding). Once the microgrid frequency and voltage were stabilized, the MMC sent signals to building controllers to perform load restoration through tertiary control. The primary controls of the natural gas turbine and battery storage responded to load increments by adjusting the frequency with each step. The secondary control stabilized the microgrid voltage and frequency before increasing the load in the next step. The MMC adjusted the set points of battery storage units and building controllers through tertiary control until the total served load reached 8 MW and 4 MVAr. The islanding mode is exercised 4-5 times per year to verify the IIT Microgrid is ready to function in emergency cases. No abnormal or extraordinary events have been experienced. The microgrid has not yet automatically islanded due to an actual loss of power from the main grid.
- **Reconnection to Main Grid**. Restoration of normal operation of the utility grid was simulated and the MMC initiated tertiary control actions to resynchronize the microgrid with the utility grid. The MMC sent secondary control signals to both the natural gas turbine and the battery storage unit to minimize the voltage magnitude and phase differences between the microgrid and the utility grid prior to resynchronization. The MMC dispatched a 59.9 Hz setpoint to the natural gas turbine to adjust the microgrid frequency for phase angle synchronization. The MMC also set the reference frequency of the battery storage unit equal to the microgrid frequency so that the battery can maintain its dispatch during resynchronization. The voltage setpoints for the natural gas turbine and battery storage unit were set at the rated value by the MMC. When all resynchronization conditions were satisfied, the coupling switch at the PCC was closed. The MMC then reset the reference frequency of the battery storage unit to 60 Hz through secondary control and sent tertiary control signals to building controllers to restore the load from 8 MW and 4 MVAr to 11 MW and 5.5 MVAr. Once resynchronized, the MMC managed the optimal hourly dispatch of DER units and building loads, taking into consideration the available energy in the battery storage unit. Back in grid-connected mode, the utility grid set the microgrid voltage and frequency and the primary and secondary controls did not respond to fluctuations in campus load. After resynchronization the real power flow from the utility grid to the microgrid was increased to 7 MW and the microgrid resources served the remaining 4 MW of the campus load.
- **Black Start**. Black start is initiated using an onsite diesel generator installed in the natural gas plant to start one 4 MW gas turbine followed by the second 4 MW gas turbine. Controllable loads will

then be connected followed by uncontrollable loads. In each step, the amount of the power to be connected is determined by taking into account the available energy storage in order to avoid large frequency and voltage deviations during the process of load connection.

IIT Microgrid, with its HRDS, DER, meters, PMUs, and building controllers, is an economically viable microgrid that has achieved significant resiliency, efficiency, economic, and environmental benefits. The achievement of project objectives is summarized below.

- **Demonstrate the higher reliability introduced by the microgrid system at IIT**. For the decade preceding the implementation of the IIT Microgrid, the university experienced major outages within the campus infrastructure and the utility feeders, which resulted in partial or complete loss of loads in buildings and research facilities including experimental data and subjects. The microgrid is equipped with HRDS, which includes seven loops for enhancing its reliability. IIT has not experienced any outages since the loops have been installed resulting in an estimated savings due to avoided outage downtime of $500,000 per year.
- **Demonstrate the economics of microgrid operations**. The NPV of the IIT microgrid project is calculated to be approximately $4.6 million over the next 10 years, primarily due to the deferral of costly substation upgrades and expansion. Pending upgrades to the Fisk substation by the utility, totaling $2.0 million and the installation of a third substation on the east campus planned by IIT at a cost of over $5.0 million were deferred due to the installation of the IIT microgrid. Improved reliability (fewer outages) and the efficient utilization of local generation also contributed positively to the NPV. The annual savings due to avoided outage downtime is estimated to be $500,000. Other indirect economic benefits include the increased resiliency provided by the microgrid due to its ability to operate in island mode and its black start capability. In addition, microgrid operation has demonstrated improved campus energy efficiency of 6.5% from the base year (June 1, 2008 to May 31, 2009) to the current year (June 1, 2013 to May 31, 2014), through DR and the use of on-site natural gas power generation and renewable energy resources. The IIT microgrid has reduced annual CO2 emissions by 6.6% (saving 3,457,818 kg) compared to the base year through the addition of renewable generation resources, storage, and DR.
- **Allow for a decrease of fifty percent (50%) of grid electricity load**. This objective was met on August 19, 2010 for the first time when campus load was reduced by 60% (10 MW to 4 MW) through curtailing building loads, shifting campus loads, and dispatching the natural-gas turbine.
- **Create a permanent twenty percent (20%) decrease in peak load from 2007 levels**. The 2007 peak load was 12,921 kW. Without considering the natural increase in load as a result of increasing student enrollment and research activities, the campus since 2007 has had a reduction of over 17%.
- **Defer planned substation through load reduction**. Pending upgrades to the Fisk substation by the utility, totaling $2.0 million and the installation of a third substation on the east campus planned by IIT at a cost of over $5.0 million were deferred due to the installation of the IIT microgrid.
- **Offer a distribution system design that can be replicated in urban communities**. The successful operational history of the IIT microgrid in the Chicago area suggests that this type of microgrid design can be replicated in urban communities. Additionally, the local electric utility, ComEd, is planning on developing the Bronzeville Community Microgrid (10 MW peak demand) and interconnecting it with the IIT microgrid (12 MW peak demand) making it the first-ever cluster of a private and a utility microgrid in a metropolitan region of the U.S.

The performance of the IIT Microgrid is summarized below against a common set of performance criteria.

- **Peak load reduction**. On August 19, 2010 IIT demonstrated a peak load reduction of 60% (10 MW to 4 MW) when campus load was reduced through curtailing building loads, shifting campus loads, and dispatching the natural-gas turbine.
- **Improved reliability**. For the decade preceding the implementation of the IIT Microgrid, the university experienced major outages within the campus infrastructure and the utility feeders, which resulted in partial or complete loss of loads in buildings and research facilities including experimental data and subjects. The microgrid is equipped with HRDS, which includes seven loops for enhancing its reliability. IIT has not experienced any outages since the loops have been installed resulting in an estimated savings due to avoided outage downtime of $500,000 per year.
- **Integration of renewables**. IIT successfully deployed 280 kW of rooftop solar and 20 kW of solar on the canopy of the EV charging station. These solar resources as well as a small 8 kW wind turbine generator are considered by the MMC and have been integrated into the operation of the microgrid.
- **Enhanced security and resiliency**. The total on-site generation capacity (12 MW) at IIT is much larger than its existing critical load (slightly less than 4 MW). The ability of the IIT microgrid to operate in island mode with this substantial over-capacity (when compared to critical loads only) provides substantial security and resiliency to the IIT campus in the event of an extended loss of grid power. Further the black start capability of the gas turbine plant provides additional security and resiliency.
- **Increased consumer engagement**. The IIT Microgrid has created substantial consumer engagement among the students, faculty, and community, both directly and indirectly. Daily operation of the microgrid responds to the conditions on the utility distribution system (prices and DR events) as well as optimizes site generation to meet economic and environmental goals. Additionally, the IIT Microgrid has created a platform for the establishment and implementation of new smart grid learning and research programs including a fully-functional smart grid workforce training program as part of the operation of the Robert W. Galvin Center for Electricity Innovation (Galvin Center). On September 22, 2014, the Center for Smart Grid Application, Research and Technology (CSMART) opened. It is a lab dedicated to researching, testing and analyzing the latest smart grid cybersecurity technology.
- **Improved system efficiencies**. IIT reported an improvement in the use of energy of 6.5% through the operation of the microgrid and the integration of the solar and wind resources.
- **Economic value creation**.
    - ***Costs***. The total cost for the IIT microgrid was $13.6M which includes $4.1M for R&D. The capital cost was $9.5M which does not include the cost of the existing natural gas plant (8 MW) or the existing backup generators (approximately 4MW). Based on the total cost of $13.6M and without accounting for the cost of the existing assets, the unit cost was approximately $1.1M/MW. Annual O&M costs for the microgrid are $50K and $347K for the natural gas plant.
    - ***Benefits***. The following benefits were identified at IIT:
        - Energy savings (electric) due to renewable generation — $17.9K per year
        - Energy savings (electric) from natural gas generation — $1.013M per year
        - Revenue from DR — $50.6K per year
        - Revenue from Production Tax Credit — $5.1K per year
        - Deferral of major system upgrades — $7 Million
        - Avoided outage downtime (estimated) — $500K per year
    - ***Financial Analysis***. The NPV of the IIT Microgrid project was determined to be approximately $4.6 million (positive) over the next 10 years and represents a BCR of 1.38 to

1. These results are primarily due to the deferral of the major system upgrades. Improved reliability (fewer outages) and the efficient utilization of local generation also contributed positively to the NPV.

Performance results for the IIT Microgrid are summarized in Table 5.1.

Table 5.1: Summary of Performance for the IIT Microgrid

Objective	Results
Reduce Peak Load	60% of peak load
Improve Reliability	Yes
Enable Integration of Renewables	Yes
Enhance Security and Resiliency	Yes
Increase Consumer Engagement	Yes
Improve System Efficiencies	6.5%
Create Economic Value	+$4.6M (NPV) BCR 1.38

A number of lessons learned during the project period were identified below.

- Identify the energy delivery objectives for erecting a microgrid (e.g., economics, reliability, resilience, off-grid operations).
- Identify the metrics for operating a successful microgrid (e.g., level of peak load reduction, level of base load reduction, reliability enhancement).
- Assess the state of the existing loads, the local distribution system, and the generation resources at the site before embarking on the design of a microgrid.
- Create a credible design including the design of hierarchical control system and components, the estimated cost of the microgrid, and the rate of return for the proposed establishment.
- Make sure that there is a dependable team of technicians and engineers available for maintaining the microgrid as components are expected to fail often when the microgrid is first put in operation.
- Consult and work closely with the local utility company as the support of the local power company is critical for the successful operation of a microgrid.

IIT Microgrid represents one of the signature projects that were implemented by the IIT's Galvin Center over the last five years, serving as a living laboratory for microgrid technology. Galvin Center has continuously improved the IIT Microgrid's footprint by introducing new technologies including hybrid AC/DC building, interconnected microgrids, management of LED streetlights in smart cities, and microgrid cyber security.

The smart grid education and workforce training program, supported by the operational IIT Microgrid and world-class training facilities, has contributed greatly to the education of smart grid workforce and exchange of smart grid technology. The Galvin Center has become a focus of smart grid technology and education in the nation and around the world, hosting two to three groups of visitors every week from K-12 students to senior citizens, from layman of smart grid to domestic and international experts of smart grid, from electrical engineers to venture capitalists, from general public to politicians.

In the 27th Annual Conference of the ECEDHA (Electrical and Computer Engineering Department Heads Association) on March 14, 2011, IIT's Center for Electricity Innovation, the principal unit performing this DOE project, won the Innovation Award from ECEDHA (single award) for establishing the Illinois Institute of Technology as a global leader in microgrids, smart grid technology, and sustainable energy.

The IIT Microgrid will continue to maintain an online presence at http://iitmicrogrid.net/. The Galvin Center will continue to host the Annual Great Lakes Symposium and support smart grid related workshops. In conclusion, the project has ended but the mission of developing, deploying, and demonstrating microgrid technology and offering world-class smart grid education and training will never end.

6. Appendices

6.1 Smart Grid Education and Workforce Training Program

6.1.1 The Robert W. Galvin Center for Electricity Innovation

IIT Microgrid represents one of the signature projects that were implemented by IIT's Robert W. Galvin Center for Electricity Innovation over the last five years. The mission of the Galvin Center is to pursue groundbreaking work in the generation, transmission, distribution, management and consumption of electricity. The Galvin Center is bringing together researchers, industry, government and innovators to "plug-in" to IIT's smart microgrid, research laboratories and Technology Park, creating a hub (or sandbox) for new innovations in advanced grid technology. In January 2012, the Galvin Center completed and moved into a new, state-of-the-art facility designed to house microgrid research, demonstration and education activities. Located on the 16th floor of the IIT Tower, the 16,000-square-foot center contains offices, exhibition rooms, classrooms and student workrooms, acting as a hands-on experience center for Smart Grid, microgrid and energy technology and education.

The Galvin Center has grown to 40 members from academia and industry (funded engineering researchers), 30 PhD student researchers, and 20 undergraduate students in just three years, and has recruited over 100 affiliate members (non-funded participants) from academia and industry for its projects. The Center has secured more than $40 million in funding from the government and private sectors for research and development in microgrids, smart grid technology, and sustainable energy. The Center will have a national impact on the way this country pursues the adoption of a smarter, more efficient, and more reliable electric grid. It is a landmark initiative to create the next generation of power and electrical engineers and leaders and is building a research capability that stimulates entrepreneurs and innovation.

6.1.2 Smart Grid Education and Workforce Training Facilities

The entire IIT campus is operated as a microgrid, with Galvin Center as its hub, and demonstrated as a living laboratory for the smart grid education and training. The microgrid education and training facility at IIT, which hosts tens of smart grid related events annually, prepares the next generation of professionals for the smart grid jobs in the United States. As part of its activities, Galvin Center has established several microgrid demonstration rooms and smart grid education and research laboratories on the 16th floor of the IIT Tower, which are highlighted here. Figure 6.1(a) shows the tabletop model of the campus microgrid which demonstrates the benefits of IIT Microgrid in a laboratory setting. Figure 6.1(b) depicts one of the Power System Operator Training facilities at the Galvin Center. Figure 6.1(c) shows a demonstration room for smart grid consumer applications with household appliances, electric vehicle charger, solar panels, and smart hydro generators. Figure 6.1(d) shows the smart home at the Galvin Center in which the essence of demand response, off-grid generation, and real-time pricing is presented to visitors.

(a): Tabletop Model of IIT Microgrid

(b): Operator Training Room

(c): Smart Appliances

(d): Smart Home

Figure 6.1: Center facility highlight

6.1.3 Web Presence of the Smart Grid Workforce Training Program

The project team has developed a website on the IIT Microgrid and smart grid workforce training. The website includes all the activities related to the IIT Microgrid and workforce training development, including events, media reports (videos and photos), publications, etc. The website has been constantly updated to include the latest development. Figure 6.2 shows a sample web page of the smart grid workforce training program. See http://iitmicrogrid.net/ and http://iitmicrogrid.net/education.aspx for more details.

Figure 6.2: Web presence of the smart grid workforce training program

6.1.4 Great Lakes Symposium on Smart Grid and the New Energy Economy

As part of the smart grid education and workforce training program, the Galvin Center has hosted four annual Great Lakes Symposium on Smart Grid and the New Energy Economy since 2011. A brief description of the themes of the symposiums is listed as follows.

The First Great Lakes Symposium on Smart Grid and the New Energy Economy, October 18-19, 2011

The first Great Lakes Symposium on Smart Grid and the New Energy Economy was held on October 18-19, 2011 on IIT's main campus. The symposium was presented by the Midwestern Governors Association, Illinois Science & Technology Coalition, Illinois Institute of Technology, Galvin Electricity Initiative, Citizens Utility Board, Environmental Defense Fund, Clean Energy Trust, UL, S&C Electric Company, Northwestern University, Argonne National Laboratory, Sierra Club, and Illinois Manufacturing Extension Center. The symposium was sponsored by Commonwealth Edison, Eaton Corporation, General Electric, Silver Spring Networks, and the Joyce Foundation.

The Second Great Lakes Symposium on Smart Grid and the New Energy Economy, September 24-26, 2012

On September 24-26, 2012, the Robert W. Galvin Center for Electricity Innovation hosted the second annual Great Lakes Symposium on Smart Grid and the New Energy Economy, on the Illinois Institute of Technology's campus in Chicago. The Symposium featured keynote and plenary sessions, technical presentations, and tutorials by international experts on smart grid applications. The Symposium is a one-of-a-kind event that breaks new ground in smart grid design and development and showcases smart grid best practices from around the country along with new technologies and ideas that are spurring innovation, growing state economies, reducing emissions and empowering consumers to conserve and save. Participants had the opportunity to engage thought leaders on key policy questions, identify investment and job creation opportunities, and learn about projects already underway. The symposium was technically sponsored by the Robert W. Galvin Center for Electricity Innovation and the IEEE Power and Energy Society. The symposium was financially sponsored by Commonwealth Edison, Environmental Defense Fund, Silver Spring Networks, Ameren Illinois, Eaton Corporation, Landis+Gyr, S&C Electric Company, the Joyce Foundation, OSIsoft, and General Electric.

The Third Great Lakes Symposium on Smart Grid and the New Energy Economy, September 23-25, 2013

On September 23-25, 2013, the Robert W. Galvin Center for Electricity Innovation hosted the third annual Great Lakes Symposium on Smart Grid and the New Energy Economy, on the Illinois Institute of Technology's campus in Chicago. The theme of the symposium is microgrid planning, design, control, and operation. The Symposium scope covers the following general topics:

- Microgrids (planning, design, control, and operation)
- Distributed Energy Resources (sustainability, integration, off-shore wind in Great Lakes)
- Smart Grid Communication and Control (wide area protection, cyber-physical systems, hierarchical control systems)
- End-use Customers (economics, demand response, appliance control, storage, electric vehicle charging)
- Smart Grid Education and Workforce Development (energy industry, K-12 teachers, labor unions, colleges, veterans)

- Smart Grid Automation (buildings, homes, community load aggregation)
- Advanced Metering Infrastructure (hardware technology, security, privacy, data management)
- Smart Grid Devices, Smart Grid System Architecture, and Distributed Software Applications
- Smart Grid Policies, Regulatory Issues, and Standards
- Smart Grid Demonstrations and Best Practices (utilities, military, communities, campuses, test beds)

The symposium was technically sponsored by the Robert W. Galvin Center for Electricity Innovation and the IEEE Power and Energy Society. The symposium was financially sponsored by Commonwealth Edison, Willdan, US Hybrid, S&C Electric, G&W Electric, Johnson Controls, Ameren Illinois, and Veriown Energy.

The Fourth Great Lakes Symposium on Smart Grid and the New Energy Economy, September 22-25, 2014

On September 22-25, 2014, the Robert W. Galvin Center for Electricity Innovation hosted the second annual Great Lakes Symposium on Smart Grid and the New Energy Economy, on the Illinois Institute of Technology's campus in Chicago. The theme of the symposium is community choice aggregation and the role of microgrids in enhancing power system economics and resilience. The Symposium scope covers the following general topics:

- Customer Participation (demand response, appliance control, self-generation, electric vehicle charging)
- Community Choice Aggregation (community load aggregation, community-based energy resources, energy hubs)
- Microgrids (planning, design, control, and operation)
- Renewable Energy Integration (solar farms, distributed energy resources, off-shore wind in Great Lakes)
- Smart Grid Communication and Control (wide area protection, cyber-physical systems, hierarchical control systems)
- Smart Grid Automation (automatic fault location, self-healing, power system resilience)
- Smart Grid Education and Workforce Development (energy industry, K-12 teachers, labor unions, colleges, veterans)
- Advanced Metering Infrastructure (hardware technology, security, privacy, smart grid data management)
- Smart Grid Devices, Architecture, and Distributed Software Applications
- Smart Grid Policies, Regulatory Issues, and Standards
- Smart Grid Demonstrations and Best Practices (utilities, military, communities, campuses, test beds)

The symposium was technically sponsored by the Robert W. Galvin Center for Electricity Innovation and the IEEE Power and Energy Society. The symposium was financially sponsored by Commonwealth Edison, Aria Consulting, Veriown Energy, OSIsoft, Azimuth Energy, G&W Electric, and S&C Electric.

6.1.5 Workshops on Smart Grid Technology

As part of the smart grid education and workforce training program, the Galvin Center has hosted or co-hosted several workshops on smart grid and sustainable energy. A brief description of the workshops is listed as follows and the agendas of the workshops are also attached.

National Academy of Engineering Symposium on Smart Grid Technology Potential and Challenges, May 14, 2014

IIT's Galvin Center for Electricity Innovation hosted NAE sponsored workshop on smart grid, titled Smart Grid Technology Potential and Challenges on May 14, 2014.

DOE Microgrid Workshop, July 30-31, 2012

IIT hosted the 2012 U.S. Department of Energy Microgrid Workshop on July 30-31, 2012. This workshop was held in response to path-forward discussions at the preceding DOE Microgrid Workshop, held in August 2011, which called for sharing lessons learned and best practices for system integration from existing projects in the U.S. (including military microgrids) and internationally. In addition, the purpose of this workshop was to determine system integration gap areas in meeting the DOE program 2020 targets for microgrids and to define specific R&D activities for the needed, but unmet, functional requirements. These activities will serve as the basis for the DOE Microgrid R&D roadmap. The DOE program targets, affirmed at the August 2011 workshop and documented in the workshop report, are to develop commercial scale microgrid systems (capacity <10 MW) capable of reducing outage time of required loads by >98% at a cost comparable to non-integrated baseline solutions (uninterrupted power supply plus diesel genset), while reducing emissions by >20% and improving system energy efficiencies by >20%, by 2020.

Electric Vehicle Technologies Workshop, April 22-23, 2014

IIT's Galvin Center for Electricity Innovation presented an Electric Vehicle Technologies Workshop on April 22-23, 2014, in partnership with Argonne National Laboratory. The Workshop is intended for Utility, transportation, and energy employees and consultants, manufacturers, government employees, academics, graduate students, and other individuals with an interest in electric vehicles and their integration with the smart grid.

Electrical Energy Storage Technologies and Applications Workshop, March 20-21, 2013

IIT's Galvin Center sponsored the Electrical Energy Storage Technologies and Applications Workshop, which was held at Argonne National Laboratory, 9700 South Cass Avenue, Lemont, IL, March 20-21, 2013 9:00-5:00pm. The Workshop is intended for utility employees, energy industry consultants, manufacturers, government employees, academics, graduate students, and other individuals with an interest in energy storage technologies and applications to smart grid.

Illinois Smart Grid Policy Forum, November 4, 2013

IIT's Galvin Center for Electricity Innovation co-sponsored the initial meeting of the Illinois Smart Grid Policy Forum which brought together local, state, and national experts and stakeholders to discuss directions for smart grid development in Illinois on Monday November 4, 2013 8AM-4PM. The meeting was co-sponsored with the Center for Business and Regulation, University of Illinois Springfield and the Center for Neighborhood Technology.

First Wind Consortium Conference, September 30, 2010

On September 30, 2010, IIT's Center for Electricity Innovation hosted the 2010 meeting of the Consortium members on IIT's main campus in Chicago.

Second Wind Consortium Conference, July 20, 2011

On July 20, 2011, IIT's Center for Electricity Innovation hosted the 2011 meeting of the Consortium members on IIT's main campus in Chicago.

6.1.6 Course Development

IIT has developed and delivered three courses related to smart grid. This section presents an overview of those courses.

Microgrid Design and Operation

Microgrids are the entities that are composed of at least one DER and associated loads which not only operates safely and efficiently within the local power distribution network but also can form intentional islands in electrical distribution systems. This course (ECE582: Microgrid Design and Operation) covers the fundamentals of designing and operating microgrids including generation resources for microgrids, demand response for microgrids, protection of microgrids, reliability of microgrids, optimal operation and control of microgrids, regulation and policies pertaining to microgrids, interconnection for microgrids, power quality of microgrids, and microgrid test beds. The syllabus of this course is as follows.

Weeks	Topics Covered
1	Introduction to Smart Grid
2-3	Distributed Generation and Microgrid Concept
4-5	Wind Energy Fundamentals
6	Fundaments of Photovoltaic Power Systems
7	Distributed Generation in Microgrids
8	Energy Storage
9	Microgrid Economics
10-11	Microgrid Control and Operation
12	Active Distribution Networks: Reliability and Economics of Microgrids
13	Control and Operation of Multi-Microgrids
14	DC Microgrid

Elements of Smart Grid

This course covers cross-disciplinary subjects on smart grid that relates to energy generation, transmission, distribution, and delivery as well as theories, technologies, design, policies, and implementation of smart grid. Topics include: smart sensing, communication, and control in energy systems; advanced metering infrastructure; energy management in buildings and home automation; smart grid applications to plug-in vehicles and low-carbon transportation alternatives; cyber and physical security systems; microgrids and distributed energy resources; demand response and real-time pricing; and intelligent and outage management systems. The syllabus of this course is as follows.

ECE 581 – Elements of Smart Grid

Class: W-F 10:00- 11:15 am; Location: PH 131

Instructor: Professor Mohammad Shahidehpour, 222 SH, (312) 567-5737, ms@iit.edu

Office Hours: W and F 2-3 pm (or by appointment)

Grading: HW: 30%, Class participation: 10%, Midterm exam: 25%, Final: 35%

Homework Assignments: Students must review the power point slides before attending the lecture. I will distribute eight technical papers throughout the semester. Students are required to summarize each paper and write a review on the paper within two weeks. Midterm and final exams will include questions on class presentations and the technical papers. Exams will be open book.

Course Schedules

August 25 Mohammad Shahidehpour Professor, IIT
August 27 Steve Blume President, Applied Professional Training
September 1 Mohammad Shahidehpour Professor, IIT
September 3 Christian Herzog President, Software Technologies Group
September 8 John Kelly President, IPS Corporation
September 10 Al Stevens Director, S&C Electric Company
September 15 Ken Zduneck Professor, IIT
September 17 Tony Metke Distinguished Member of Technical Staff, Motorola
September 22 Kui Ren Professor, IIT
September 24 Jim Gagnard President, Smart Signal
September 29 Terry Schuster Director, Energy Connect
September 30 Mohammad Shahidehpour Wind Energy Conference
October 1 Mohammad Shahidehpour Perfect Power Presentation
October 6 Robert Holz Director, Smart Lab
October 8 Tom Hulsebosch West Monroe Partners
October 13 Alireza Khaligh Professor, IIT
October 15 Joshua Milberg Deputy Commissioner, City of Chicago
October 20 Ali Emadi Professor, IIT
October 22 Midterm Exam Midterm Exam
October 27 Paul McCoy President, TransElect
October 29 Tim Stojka CEO, Fast Heat
November 3 Yang Xu Professor, IIT
November 5 Terence Donnelly Senior VP, ComEd
November 10 Mohammad Shahidehpour Professor, IIT
November 12 Mark Pruitt Director, Illinois Power Agency
November 17 Kevin Dennis VP, ZBB Energy
November 19 Tom Overbye Professor, University of Illinois
December 1 Farrokh Rahimi VP, Open Access Technology International
December 3 Mohammad Shahidehpour Professor, IIT
Final Exam

Elements of Sustainable Energy

This course covers cross-disciplinary subjects on sustainable energy that relate to energy generation, transmission, distribution, and delivery as well as theories, technologies, design, policies, and integration of sustainable energy. Topics include wind energy, solar energy, biomass, hydro, nuclear energy, and ocean energy. Focus will be on the integration of sustainable energy into the electric power grid, the impact of sustainable energy on electricity market operation, and the environmental impact of sustainable energy. The syllabus of this course is as follows.

ECE 580 – Elements of Sustainable Energy

Class Meetings: 6:25-9:05 PM, Tuesday; Location: Wishnick Hall 115

Instructor: Zuyi Li, PHD; Office: Room 223, Siegel Hall; Phone: (312) 567-5259; E-mail: lizu@iit.edu

Office hours: 3-5PM, Tuesday, or by appointment.

Textbook: No textbook is required

References

- Gilbert Masters, Renewable and Efficient Electric Power Systems, Wiley, 2004.
- Leon Freris and David Infield, Renewable Energy in Power Systems, Wiley, 2008.
- U.S. Department of Energy, 20% Wind Energy by 2030, 2008.
- Selected papers from the IEEE and other journal publications and conference proceedings.

Grading

Homework:	50%
Exam:	20%
Research Paper:	30%

Course Schedules

Week 1	August 24	Introduction to Sustainable Energy
Week 2	August 31	Renewable Energy Technologies
Week 3	September 7	Variability of Renewable Energy
Week 4	September 14	Operational Issues of Renewable Energy (1)
Week 5	September 21	Operational Issues of Renewable Energy (2)
Week 6	September 28	Operational Issues of Renewable Energy (3)
Week 7	October 5	Planning Issues of Renewable Energy (1)
Week 8	October 12	Planning Issues of Renewable Energy (2)
Week 9	October 19	Planning Issues of Renewable Energy (3)
Week 10	October 26	**Exam**
Week 11	November 2	Other Issues Related to Sustainable Energy (1)
Week 12	November 9	Other Issues Related to Sustainable Energy (2)
Week 13	November 16	Other Issues Related to Sustainable Energy (3)

6.2 Technical Awards

1) Dr. Mohammad Shahidehpour received the IEEE Power and Energy Society Outstanding Power Engineering Educator Award (For leadership in the power engineering field and contributions to the engineering profession and engineering education) in 2012.
2) Dr. Mohammad Shahidehpour Technologist of the Year Award from the Illinois Technology Association (Presented to the individual whose talent has championed true technology innovation, either through new application of existing technology or the development of technology to achieve a truly unique product or service) in 2011
3) Dr. Mohammad Shahidehpour received the Outstanding Engineer Award, IEEE Power and Energy Society Chicago Chapter (for significant leadership and contributions towards IIT's Prefect power microgrid, the IIT's wind consortium, and the IIT's Smart Grid Education and Workforce Development) in 2011
4) In the 27th Annual Conference of the ECEDHA (Electrical and Computer Engineering Department Heads Association) on March 14, 2011, IIT's Center for Electricity Innovation, the principal unit performing this DOE project, won the Innovation Award from ECEDHA (single award) for establishing the Illinois Institute of Technology as a global leader in microgrids, smart grid technology, and sustainable energy. Below is a copy of the citation.
5) Dr. Mohammad Shahidehpour received IIT's First Research Leadership Award (in Recognition of Outstanding Accomplishments in Developing Strong Research Collaborations and Large Scale Research Projects) in 2010
6) Dr. Mohammad Shahidehpour received the Distinguished Service Award, IEEE Power &Energy Society (For serving as General Chair of the 2012 IEEE Innovative Smart Grid Conference)
7) Dr. Mohammad Shahidehpour received the Distinguished Service Award, IEEE Power & Energy Society (For serving as VP of Publications) in 2011

6.3 Technical Publications

6.3.1 Ph.D. Dissertations

Thirteen Ph.D. dissertations resulted from this project.

1) Masoud Barati, Self-Healing In Microgrid Operation And Message-Passing Based Demand Response, Illinois Institute of Technology, July 2013
2) Mohammad Khodayar, Coordination of Storage with Renewable Energy Resources in Power Systems, Illinois Institute of Technology, July 2012
3) Kaveh Aflaki, Large Scale Integration of Sustainable Energy and Congestion Management in the Western Interconnection, Illinois Institute of Technology, July 2012
4) Jie Li, Optimal Behavior Modeling and Analysis of Electricity Market Participants, Illinois Institute of Technology, May 2012
5) Yanling Yuan, Load Redistribution Attacks and Protection Strategy in Electric Power Systems, Illinois Institute of Technology, May 2012

6) Peizhong Yi, Wireless Sensor Network Based Building Automation System, Illinois Institute of Technology, May 2012
7) Shrirang Abhyankar, Development of an Implicitly Coupled Electromechanical and Electromagnetic Transients Simulator for Power Systems, Illinois Institute of Technology, December 2011
8) Wei Tian, Large-scale Simulation of Electric Power Systems for Wind Integration, Illinois Institute of Technology, July 2011
9) Cuong Phuc Nguyen, Power System Voltage Stability and Agent Based Distribution Automation In Smart Grid, Illinois Institute of Technology, May 2011
10) Amin Khodaei, Optimal Transmission Switching in Power System Operation and Planning, Illinois Institute of Technology, December 2010
11) Shaghayegh Bahramirad, Design and Implementation of Hydrokinetic Run-of-River Turbines, Illinois Institute of Technology, December 2010
12) Cong Liu, Interdependency of Gas and Electricity in Restructured Power Systems, Illinois Institute of Technology, July 2010
13) Saeed Kamalini, Security Constrained Expansion Planning of Fast-Response Units for Wind Integration, Illinois Institute of Technology, July 2010

6.3.2 M.S. Theses

Two M.S. theses resulted from this project.

1) Liang Che, Microgrid Operation, Control and Protection at IIT, Illinois Institute of Technology, July 2013.
2) Abhinav Gupta, Cable Modeling and Fault Study for the IIT Perfect Power System, Illinois Institute of Technology, May 2011.

6.3.3 Journal Publications

Fifty-seven journal publications resulted from this project.

1) J. Li, Z. Bao, and Zuyi Li, “Modeling Demand Response Capability by Internet Data Centers Processing Batch Computing Jobs,” IEEE Transactions on Smart Grid, accepted for publication, 2014 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6940321
2) X. Liu, Z. Bao, D. Lu, and Zuyi Li, “Modeling of Local False Data Injection Attacks with Reduced Network Information,” IEEE Transactions on Smart Grid, accepted for publication, 2014
3) Liang Che and M. Shahidehpour, "DC Microgrids: Economic Operation and Enhancement of Resilience by Hierarchical Control," IEEE Transactions on Smart Grid, vol.5, no.5, pp.2517-2526, Sept. 2014 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6882776
4) Yong Jiang, Jianqiang Liu, Wei Tian, M. Shahidehpour, and M. Krishnamurthy, "Energy Harvesting for the Electrification of Railway Stations: Getting a charge from the regenerative braking of trains," IEEE Electrification Magazine, vol.2, no.3, pp.39-48, Sept. 2014 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6912047
5) X. Liu and Zuyi Li, “Local Load Redistribution Attacks in Power Systems with Incomplete Network Information,” IEEE Transactions on Smart Grid, vol.5, no.4, pp.1665-1676, July 2014 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6805238
6) H. Wu, M. Shahidehpour, Zuyi Li, and W. Tian, “Chance-Constrained Day-Ahead Scheduling in Stochastic Power System Operation,” IEEE Transactions on Power Systems, vol.29, no.4, pp.1583-1591, July 2014 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6714594

7) Hongyu Wu and M. Shahidehpour, "Stochastic SCUC Solution With Variable Wind Energy Using Constrained Ordinal Optimization," IEEE Transactions on Sustainable Energy, vol.5, no.2, pp.379-388, April 2014 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6691959
8) Liang Che, M. Khodayar, and M. Shahidehpour, "Adaptive Protection System for Microgrids: Protection practices of a functional microgrid system," IEEE Electrification Magazine, vol.2, no.1, pp.66-80, March 2014 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6774516
9) Z. Chen, L. Wu, and Zuyi Li, "Electric Demand Response Management for Distributed Large-Scale Internet Data Centers," IEEE Transactions on Smart Grid, vol.5, no.2, pp.651-661, March 2014 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6578169
10) W. Tian, Zuyi Li, and M. Shahidehpour, "Renewable Energy Procurement in Illinois," The Electricity Journal, vol. 27, no. 2, pp. 43-51, March 2014 http://www.sciencedirect.com/science/article/pii/S1040619014000293
11) Liang Che, M. Khodayar, and M. Shahidehpour, "Only Connect: Microgrids for Distribution System Restoration," IEEE Power and Energy Magazine, vol.12, no.1, pp.70-81, Jan.-Feb. 2014 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6684680
12) Y. Fu, L. Wu, and Zuyi Li, "Modeling and Solution of the Large-Scale Security-Constrained Unit Commitment," IEEE Transactions on Power Systems, vol.28, no.4, pp.3524-3533, November 2013 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6570740
13) M. Shahidehpour and M. Khodayar, "Cutting Campus Energy Costs with Hierarchical Control: The Economical and Reliable Operation of a Microgrid," IEEE Electrification Magazine, vol.1, no.1, pp.40-56, Sept. 2013 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6648493
14) S. Wang, Z. Li, L. Wu, M. Shahidehpour, and Zuyi Li, "New Metrics for Assessing the Reliability and Economics of Microgrids in Distribution System," IEEE Transactions on Power Systems, vol. 28, no.3, pp. 2852-2861, August 2013 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6480908
15) Hongyu Wu, M. Shahidehpour, and M.E. Khodayar, "Hourly Demand Response in Day-Ahead Scheduling Considering Generating Unit Ramping Cost," IEEE Transactions on Power Systems, vol.28, no.3, pp.2446-2454, Aug. 2013 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6506120
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17) M. Khodayar and M. Shahidehpour, "Stochastic Price-based Coordination of Intra-hour Wind Energy and Storage in a Generation Company," IEEE Transactions on Sustainable Energy, vol.4, no. 3, pp. 554-562, July 2013 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6414618
18) M. Khodayar, L. Wu, and Zuyi Li, "Electric Vehicle Mobility in Transmission- Constrained Hourly Power Generation Scheduling," IEEE Transactions on Smart Grid, vol. 4, no.2, pp.779-788, June 2013 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6476056
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6.3.4 Conference Publications

Five conference publications resulted from this project.

1) X. Liu, K. Ren, Y. Yuan, Zuyi Li, and Q. Wang, "Optimal Budget Deployment Strategy Against Power Grid Interdiction," Proceedings of 2013 IEEE INFOCOM, pp.1160-1168, 14-19 April 2013 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6566907
2) Peizhong Yi, Xihua Dong, Chi Zhou and Shufang Li, "Distributed Opportunistic Scheduling in Power Systems - An Optimal Stopping Approach," 18th World Congress of the International Federation of Automatic Control (IFAC), 2011 http://www.ifac-papersonline.net/Detailed/48693.html
3) Wei Tian, Zuyi Li, Mohammad Shahidehpour, "Transmission Congestion Analysis in the Eastern Interconnection using POMS," IEEE Power and Energy Society General Meeting, Minneapolis, Minnesota, July 2010 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5589508
4) Peizhong Yi, A. Iwayemi, and Chi Zhou, "Frequency agility in a ZigBee network for smart grid application," in IEEE Conference on Innovative Smart Grid Technologies (ISGT), 2010, pp. 1-6, 2010 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5434747

5) A. Iwayemi, Peizhong Yi, Peng Liu, and Chi Zhou, "A Perfect Power demonstration system," in IEEE Conference on Innovative Smart Grid Technologies (ISGT), 2010, pp. 1-7, 2010 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5434737

6.4 Agendas of Conferences and Workshops

The agendas of the four annual *Great Lakes Symposium on Smart Grid and the New Energy Economy* discussed in Section 6.1.4 are attached, followed by the agendas of the workshops discussed in Section 6.1.5.

GREAT LAKES SYMPOSIUM

ON SMART GRID AND THE NEW ENERGY ECONOMY

OCTOBER 18–19, 2011

PRESENTED BY:

MGA Midwestern Governors Association
Illinois Science & Technology Coalition
Illinois Institute of Technology
Galvin Electricity Initiative — Sponsored by The Galvin Project, Inc.
CUB — Fighting for Illinois Consumers Since 1984
EDF Environmental Defense Fund — Finding the ways that work
Clean Energy Trust
UL
S&C
Northwestern University
Argonne National Laboratory
Sierra Club — Founded 1892
IMEC — manufacturing improvement specialists

SPONSORED BY:

ComEd — An Exelon Company
Eaton — Powering Business Worldwide
GE
Silver Spring Networks
The Joyce Foundation

EVENT PROGRAM

WELCOME TO THE

GREAT LAKES SYMPOSIUM ON SMART GRID AND THE NEW ENERGY ECONOMY

We are honored to gather local, regional and national stakeholders who are breaking new ground in smart grid design and development. Policy reform is critical to ensuring that grid modernization spurs innovation, stimulates the economy, improves reliability, reduces emissions and empowers consumers to conserve and save. This is particularly true for the Midwest region.

With three distinct tracks, the Symposium provides an opportunity to engage thought leaders on policy and new smart grid projects and discuss new investment and job creation opportunities.

AGENDA

TUESDAY, OCTOBER 18, 2011

Master of Ceremonies: Dr. Mohammad Shahidehpour
Director of the Robert W. Galvin Center for Electricity Innovation, Illinois Institute of Technology

Welcome and Keynote — AUDITORIUM

8 – 8:50 a.m.	**Registration in Lobby/Gallery**
9 – 9:10 a.m.	**Welcome** **Hon. Rahm Emanuel, Mayor, City of Chicago**
9:10 – 10 a.m.	**Keynote: Smart Grid and the New Energy Economy** **Ellen Alberding**, President, Joyce Foundation **Scott Lang**, President and CEO, Silver Spring Networks **Luke Clemente**, General Manager of Metering & Sensing Systems, GE Energy's Digital Energy Services
10 – 10:15 a.m.	**Leveraging the Convening Power of the PUC** **Doug Scott**, Chairman, Illinois Commerce Commission

MORNING SESSION

	EXPO CENTER	AUDITORIUM
	Midwest Policy Summit	Consumer Track: Path to Perfect Power
10:30 a.m. – Noon	**How Can Smart Grid Technologies Increase the Efficiency between Transmission and Distribution?** • Moderator: Mark Brownstein, Chief Counsel of the Energy Program, Environmental Defense Fund • Philip Moeller, Commissioner, Federal Energy Regulatory Commission • Vladimir Koritarov, Deputy Director of the Center for Energy, Environmental and Economic Systems Analysis, Argonne National Laboratory • Chantal Hendrzak, Director of Applied Solutions, PJM • Paul Centolella, Commissioner, Public Utilities Commission of Ohio	**Leading Practices for Ensuring Consumer Empowerment** • Moderator: Brewster McCracken, Executive Director, Pecan Street Inc. • Eric Dresselhuys, Executive Vice President and Chief Marketing Officer, Silver Spring Networks • Dr. Kristin B. Zimmerman, Manager of Advanced Technology Infrastructure, General Motors Research and Development Center • Dr. Louay Eldada, Chief Science Officer, VP Global R&D, SunEdison

LUNCHEON EXECUTIVE PANEL: The Pursuit of Quality and Innovation — BALLROOM

Noon – 1:30 p.m.

Moderator: **Jim Buckman**, Quality Advisor, Galvin Electricity Initiative
Michael Niggli, President and CEO, San Diego Gas & Electric
Anne Pramaggiore, President and COO, ComEd
Teri Ivaniszyn, Senior Director of Corporate Excellence, Florida Power & Light

TUESDAY, OCTOBER 18, 2011 (Continued)

AFTERNOON SESSION

	EXPO CENTER	AUDITORIUM
	Innovation and Economic Opportunity Track	Consumer Track: Path to Perfect Power
1:30 – 3 p.m.	**Smart Grid and Energy Business Leadership Roundtable** • **Session Kick-Off: A Futurist Point of View:** Michael J. Meehan, Senior Principal Consultant, KEMA • **Integration of Renewable Resources/Energy Storage:** Jay Marhoefer, CEO, Intelligent Generation; Chris Walti, Power Originator, Acciona Energy • **Smart Buildings:** Chris Thomas, Policy Director, Citizens Utility Board; Peter Scarpelli, Vice President of Global Leader of Energy Services, CB Richard Ellis • **Electrified Transportation:** Paul H. Pebbles, Global Electrification Product Manager, OnStar®; Sam Ori, Director of Policy, The Electrification Coalition • **Home/Community Adoption:** Jonathan "JT" Thompson, Smart Appliance Utility Leader, GE Appliances – Home and Business Solutions; Rep. Daniel Biss, Illinois State Representative, 17th District	**Leading Practices for Grid Safety, Reliability and Power Quality** • Moderator: Mike Edmonds, Vice President of Strategic Solutions, S&C Electric Company • David Wade, EVP and COO, Electric Power Board of Chattanooga, Tenn. • Mark Curran, Director of Public Utilities — Electric, City of Naperville, Ill. • Greg Blake, Global Smart Grid Sales Director, GE Energy's Digital Energy Services • Terence Donnelly, Executive Vice President of Operations, ComEd
	Midwest Policy Summit	Innovation and Economic Opportunity Track
3:15 – 4:15 p.m.	**Articulating the Benefits of Smart Grid** • Suzanne Malec-McKenna, Former Commissioner, City of Chicago Department of Environment • David Kolata, Executive Director, Citizens Utility Board • Michael Gregerson, Energy Consultant, Great Plains Institute • Beth Soholt, Director, Wind on the Wires • Jacqueline Voiles, Director of Regulatory Affairs, Ameren Illinois • Wade Malcolm, Global Senior Director for Smart Grid Operations Technology, Accenture	**Innovative Marketplace Quick Pitch Competition** **JUDGES:** • Doug Dillie, Director of Smart Grid Solutions, Eaton Corporation • Mark Zhu, Investment Professional, DTE Energy Ventures • Paul H. Pebbles, Global Electrification Product Manager, OnStar® • Chris Walti, Power Originator, Acciona Energy • Kerri Breen, Principal, Arsenal Venture Partners • Rob Schultz, Senior Director, IllinoisVENTURES • Teresa Esser, General Partner, Capital Midwest Fund • Sam Hogg, Director of Venture Development, NextEnergy • Kirk Colburn, Managing Director, SURGE • Rep. Robyn Gabel, Illinois State Representative, 18th District • Steve Moffitt, Account Executive, GE
4:15 – 4:30 p.m.	BREAK	
4:30 – 5:30 p.m.	**Midwest Smart Grid Pilots: Realizing the Economic Value of Smart Grid** • Moderator: Matthew Summy, President, Illinois Science and Technology Coalition • Nic Stover, Regional Sales Director, Northwest, EnerNOC	

TUESDAY, OCTOBER 18, 2011 (Continued)

AFTERNOON SESSION

4:30 – 5:30 p.m. **Midwest Smart Grid Pilots: Realizing the Economic Value of Smart Grid (Continued)**

- Shaun Summerville, Marketing Program Manager, DTE Energy
- Dan Francis, Manager of gridSMART Policy, American Electric Power
- DeWayne Todd, Corporate Compliance and Regulatory Affairs, Warrick Primary Metals

NETWORKING RECEPTION: 5:30 – 7 p.m.

WEDNESDAY, OCTOBER 19, 2011

Keynote: Smart Grid and Climate Change

9 – 10 a.m. Michael Brune, Executive Director, Sierra Club

MORNING SESSION

EXPO CENTER

Midwest Policy Summit

10 – 11 a.m. **Developing Good Smart Grid Policy**

- Moderator: Lauren Navarro, Attorney, Environmental Defense Fund
- Phyllis Reha, Vice Chair, Minnesota Public Utilities Commission

11 a.m. – Noon **Developing Great Midwest Smart Grid Strategies**

- Moderator: Miriam Horn, Director, Smart Grid Initiatives, Environmental Defense Fund
- Ed Miller, Environment Program Manager, Joyce Foundation
- Tom Catania, Vice President of Government Relations, Whirlpool
- Ade Dosunmu, Senior Director of Strategic Markets, Comverge

AUDITORIUM

Consumer Track: Path to Perfect Power

Leading Practices for Integrating Clean and Efficient Power

- Moderator: John Kelly, Executive Director, Galvin Electricity Initiative
- Sue Tierney, Managing Principle, Analysis Group
- Mike Bull, Manager of Environmental Policy, Xcel Energy
- Shawn Marshall, Executive Director, Lean Energy
- Tom Barwin, Village Manager, Oak Park

ARMOUR DINING ROOM

Innovation and Economic Opportunity Track

Growing the Smart Grid Regional Innovation Cluster Workshop

- Matthew Summy, President, Illinois Science and Technology Coalition
- Dan Bowman, Principal, PricewaterhouseCoopers PRTM Management Consulting
- Oliver Hazimeh, Principal, PricewaterhouseCoopers PRTM Management Consulting
- Jared Racine, Senior Associate, PricewaterhouseCoopers PRTM Management Consulting

LUNCHEON: Midwest Energy Leadership Awards

Noon – 1:30 p.m. Luncheon and Awards Presentation

1:30 – 3 p.m. Tour of the Perfect Power Microgrid at Illinois Institute of Technology

KEYNOTE SPEAKERS

ELLEN ALBERDING

Ellen Alberding is the president and a board member of the Joyce Foundation, which has assets of $800 million and makes grants of $40 million a year for projects to improve the quality of life in the Great Lakes region. The Foundation is a major funder of environmental groups in the Midwest, with a particular focus on water and air quality. Other Foundation priorities include improving educational outcomes for low-income children; employment and workforce issues; and other initiatives that promote democracy and a diverse and thriving culture.

In June 2011, Alberding was appointed Vice Chair of the City Colleges of Chicago, and she joined the board of Skills for America's Future, which works to improve community college training programs through business partnerships. Alberding is also a founder and board member of Advance Illinois, which advocates for public education reform in Illinois. She is a board member of Independent Sector, where she has worked to establish improved accountability and governance standards for nonprofits. She is also a board member of the Economic Club of Chicago, as well as a trustee of the National Park Foundation. She has served as president and chairman of the investment committee for the Chicago Park District pension fund (1993 – 2001); trustee of Aon Funds (2000 – 2003); trustee of the American University of Paris (2007 – 2008); treasurer of Grantmakers in the Arts (a national organization of arts funders); member of the Public Trust Task Force for the Donors Forum of Chicago; and member of the Cultural Advisory Board for the City of Chicago. She is a member of the Commercial Club and the Chicago Network, and serves on the advisory boards of several nonprofit organizations.

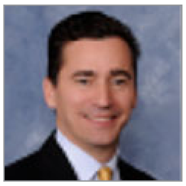
SCOTT LANG

Scott Lang — chairman, president and CEO of Silver Spring Networks — joined the company's founding chief executive in 2004. He brings more than 25 years of leadership, marketing, sales and management experience in the services and utility industries.

Prior to Silver Spring Networks, Lang first worked with Ross Perot at Electronic Data Systems and then joined Perot Systems in 1988, shortly after the company's founding. During his career at Perot Systems, Lang spent 10 years in Europe building the company's international business and went on to lead the Strategic Markets Group, which served the global energy, communications, media, travel and transportation industries.

Under Lang's leadership, Silver Spring Networks was named a 2008 World Economic Forum Technology Pioneer. In 2009, Lang was named Ernst & Young's 2009 Entrepreneur of the Year in Northern California in the clean tech category and Responsible CEO of the Year in the Private Company category by the editors of CRO Magazine.

Lang holds a bachelor's in business administration degree from the University of Mississippi and an executive MBA from The Kellogg School of Management at Northwestern University. He and his wife, Karen, have four daughters.



LUKE CLEMENTE

Luke Clemente is general manager of Metering & Sensing Systems for GE Energy's Digital Energy (DE) business. The DE business provides integrated smart grid solutions and reliable power delivery to electric utilities, as well as supporting the oil and gas and telecom sectors. The Metering & Sensing Systems business contains GE's meters, industrial communications, transformer monitoring and diagnostics product lines.

As DE's Metering & Sensing Systems General Manager, Clemente is playing a leading role in integrating GE's existing DE businesses into a seamless smart grid platform. Some of the businesses to be integrated include metering, substation automation, transmission and distribution control, substation monitoring and diagnostics and Geospatial Information Systems (GIS). As a member of the GE Smart Grid Advisory Board, Clemente works in concert with other senior leaders across GE businesses involved in the smart grid initiative. Some of those GE businesses include GE Appliances, GE Intelligent Platforms, GE Industrial Solutions and GE Transportation (battery storage). In addition to focusing on expanding GE's smart grid portfolio and enhancing its ability to deliver integrated solutions, Clemente and his team are focused on driving increase public awareness globally on the need for a smart grid.

Clemente was was a practicing attorney for several years prior to joining Enron in 1993 as a director for business development. In 1998, he joined GE Energy as a business development manager, where he led a number of acquisitions in the areas of energy sensors and monitoring and diagnostic software. In 2001, Clemente moved to GE Rail (now GE Transportation) as the general manager of business development. In 2003, he was named president for GE Rail-China, based in Beijing. While there, he was instrumental in leading the team to establish and rapidly expand GE Rail's presence in China. In 2006, Clemente became product line general manager for GE Energy's control solutions business, where he executed a successful turnaround strategy focused on profitable growth.

He holds an MBA from Columbia University, a law degree from Syracuse University and a bachelor's degree in mechanical engineering from Manhattan College.

DOUG SCOTT

Doug Scott was appointed by Governor Pat Quinn as chairman of the Illinois Commerce Commission (ICC) effective March 3, 2011. His term expires January 20, 2014.

Prior to his appointment Scott served as director of the Illinois Environmental Protection Agency from 2005 to 2011. During those years he chaired the Illinois Governor's Climate Change and Advisory Committee and was a member of the Midwestern Governors' Association panel charged with developing a regional cap-and-trade system. He was a member of the Air Committee for Environmental Council of States (ECOS) and the USEPA Environmental Financial Advisory Board. He served as chairman of The Climate Registry Board of Directors and co-chair of the Keystone Foundation Energy Board.

Scott was elected a state representative from the 67th district in 1995 and served in the General Assembly until 2001 when he was elected mayor of Rockford, Ill. As mayor from 2001 to 2005, he held leadership positions in the Illinois Municipal League, United States Conference of Mayors and the national League of Cities. He also served as president of the Illinois Chapter of the National Brownfield Association.

Scott holds a bachelor's degree from the University of Tulsa and a law degree from Marquette University.

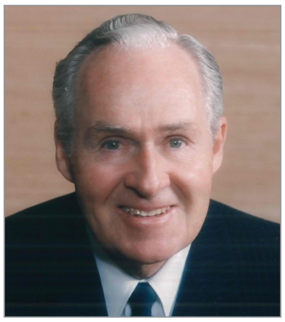
MICHAEL BRUNE

Michael Brune, Sierra Club executive director, came to the Sierra Club from the Rainforest Action Network, where he served seven years as executive director. Under Brune's leadership, Rainforest Action Network won more than a dozen key environmental commitments from America's largest corporations, including Home Depot, Citi, Goldman Sachs, Bank of America, Kinko's, Boise and Lowe's.

Brune's critically acclaimed book, *Coming Clean – Breaking America's Addiction to Oil and Coal*, published by Sierra Club Books in 2008, details a plan for a new green economy that will create well-paying jobs, promote environmental justice and bolster national security. He and his wife, Mary, attribute their ongoing passion for environmental activism in part to concern that their outdoors-loving children, Olivia, 5, and Sebastian, 1, inherit a healthy world. He is particularly interested in promoting programs that link the Club's traditional protection of wild places, including National Parks, to urgently needed climate change solutions.

Brune holds degrees in economics and finance from West Chester University.

IN MEMORIAM



ROBERT W. GALVIN (1922 – 2011), chairman and CEO of Motorola for more than 30 years, was an industry icon that propelled Motorola to a dominant position in the global marketplace. In his retirement, he worked tirelessly to transform our nation's obsolete electric power system into one that is reliable, efficient, secure and clean. A major benefactor of the Illinois Institute of Technology, he founded the Galvin Electricity Initiative in 2005.

Bob Galvin's visionary pursuit of perfect power serves as an inspiration for this Symposium and will continue to guide entrepreneurs for generations.

GREAT LAKES SYMPOSIUM

ON SMART GRID AND THE NEW ENERGY ECONOMY

September 24-26, 2012

TECHNICALLY CO-SPONSORED BY

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OSIsoft.

GE imagination at work

EVENT PROGRAM

SYMPOSIUM AGENDA IN BRIEF

MONDAY • SEPTEMBER 24, 2012			
8:30 am – 12:00 pm	1. Short Course 1	2. Short Course 2	3
1:30 pm – 2:00 pm pm	4. Introduction and Welcome Remarks		
2:00 pm – 3:00 pm	5. Plenary Session: Illinois Smart Grid Deployment		
3:00 pm – 3:30 pm	Afternoon Break		
3:30 pm – 5:15 pm	6. Panel Session: Military Microgrid	7. Panel Session: Electric Vehicles and Mobility in Energy Systems	8
5:30 pm – 7:00 pm	Evening Reception		
TUESDAY • SEPTEMBER 25, 2012			
8:00 am – 8:30 am	Breakfast		
8:30 am – 9:00 am	11. Morning Keynote Session		
9:00 am – 10:00 am	12. Plenary Session: Offshore Wind at Great Lakes		
10:00 am – 10:30 am	Morning Break		
10:30 am – 12:15 pm	13. Panel Session: Wind Turbine Operation and Control	14. Panel Session: Power System Operations with Smart Distributed Systems	1
12:15 pm – 1:30 pm	18. Luncheon and Keynote Session		
1:30 pm – 3:00 pm	19. Plenary Session: Great Lakes Forum on Regulatory Policy		
3:00 pm – 3:30 pm	Afternoon Break		
3:30 pm – 5:15 pm	20. Panel Session: Microgrid Planning and Operation	21. Panel Session: Electric Vehicle Manufacturing in Great Lakes States	2
5:30 pm – 6:15 pm	Networking Reception		
6:15 pm – 8:00 pm	25. Dinner and Keynote Session		
WEDNESDAY • SEPTEMBER 26, 2012			
8:00 am – 8:30 am	Breakfast		
8:30 am– 9:00 am	26. Morning Keynote Session		
9:00 am – 10:00 am	27. Plenary Session: Recovery Act Demonstrations of Smart Grid Development		
10:00 am – 10:30 am	Morning Break		
10:30 am – 12:15 pm	28. Panel Session: Microgrid Storage	29. Panel Session: Utilizing Smart Grid Test Beds in Illinois	3
12:15 pm – 1:30 pm	33. Luncheon and Keynote Session		
1:30 pm – 3:00 pm	34. Plenary Session: Shifting Smart Grid Focus to Customer Driven Performance Outcomes		
3:00 pm – 3:30 pm	Afternoon Break		
3:30 pm – 5:15 pm	35. Panel Session: Smart Grid Innovation in Great Lakes Region	36. Panel Session: Community Choice Aggregation: Progress and Promise	3

3. Short Course 3		
8. Panel Session: Smart Grid Cyber Security and Data Management	9. Panel Session: Transmission Planning Issues for Variable Energy Resources	10. Paper Session: Advanced Distribution Systems
15. Panel Session: Smart Homes. Electric Vehicles and Demand Response	16. Panel Session: Solar Energy Integration	17. Paper Session: Impacts of PHEV on Transportation and Energy Systems
22. Panel Session: Smart Grid Workforce Training and Education	23. Panel Session: Geomagnetic Disturbances on the Power Grid	24. Paper Session: Smart Grid: Policy, Regulation and Customer Engagement
30. Panel Session: Customer Engagement and Empowerment	31. Panel Session: Storage for Power System Operation	32. Paper Session: Smart Grid Monitoring and Cyber Security
37. Panel Session: Smart Homes and Distributed Generation	38. Panel Session: Future of Nuclear	39. Paper Session: Power System Planning

WELCOME TO THE

GREAT LAKES SYMPOSIUM ON SMART GRID AND THE NEW ENERGY ECONOMY

The Organizing Committee of the second annual Great Lakes Symposium on Smart Grid and the New Energy Economy is honored to gather local, regional and national stakeholders who are breaking new ground in smart grid design and development.

Research and development, education, and policy reforms are critical to ensuring that grid modernization spurs innovation, stimulates the economy, improves reliability, reduces emissions and empowers consumers to conserve and save. The second annual Symposium provides an opportunity to engage thought leaders on smart grid projects and discuss investment and job creation opportunities in the Great Lakes Region

KEYNOTE SPEAKER SCHEDULE

Anne Pramaggiore
President and CEO, ComEd
Plenary Session: Illinois Smart Grid Deployment
Hermann Hall Ballroom
Monday, 2:00 pm – 3:00 pm

Richard Mark
President and CEO, Ameren Illinois
Plenary Session: Illinois Smart Grid Deployment
Hermann Hall Ballroom
Monday, 2:00 pm – 3:00 pm

Scott Lang
President and CEO, Silver Spring Networks
Plenary Session: Illinois Smart Grid Deployment
Hermann Hall Ballroom
Monday, 2:00 pm – 3:00 pm

Michael Polsky
President and CEO, Invenergy
Keynote Speaker
Hermann Hall Ballroom
Tuesday, 8:30 am – 9:00 am

Alan W. (Bud) Wendorf
Chairman, President and CEO
Sargent & Lundy
Dinner and Keynote Session
Tuesday, 6:15 pm – 8:00 pm

Mani Venkata
Principal Scientist, Alstom
Luncheon Keynote Speaker
Expo Room
Tuesday, 12:15 pm –1:30 pm

Wanda Reder
Vice President, S&C Electric Company
Keynote Speech
Hermann Hall Ballroom
Wednesday, 8:30 am – 9:00 am

Arlene Juracek
Director, Illinois Power Agency
Luncheon Keynote Speaker
Expo Room
Wednesday, 12:15 -1:30 pm

SYMPOSIUM AGENDA

MONDAY | SEPTEMBER 24, 2012

MONDAY MORNING

8:30 a.m. – Noon

SHORT COURSES

1. **Introduction to Smart Grids and Smart Grid Roadmaps**
   Room: Hermann Lounge

2. **How Today's Grid is Evolving for the 21st Century**
   Room: Hermann Hall – Trustee Dining Room

3. **Microgrids – Designing Their Role in Smart Grid**
   Room: Hermann Hall – 007

MONDAY | SEPTEMBER 24, 2012

MONDAY AFTERNOON

1:30 pm – 2:00 pm

4. Introduction and Welcome Remarks
Hermann Hall Ballroom

- Mohammad Shahidehpour, Chair, Great Lakes Symposium on Smart Grid and the New Energy Economy
- Noel Schulz, President, IEEE Power and Energy Society

2:00 pm – 3:00 pm

5. Plenary Session: Illinois Smart Grid Deployment
Hermann Hall Ballroom

- Chair: Wanda Reder, S&C Electric
- Anne Pramaggiore, President and CEO, ComEd
- Richard Mark, President and CEO, Ameren Illinois
- Scott Lang, President and CEO, Silver Spring Networks

3:00 pm – 3:30 pm

AFTERNOON BREAK
Expo Room

3:30 pm – 5:15 pm

6. Panel Session: Military Microgrids
Hermann Hall Ballroom

- Chair: Tom Podlesak, US Army
- Robert Lasseter, University of Wisconsin-Madison
- Tristan Glenwright, Boeing
- Tarek Abdalla, U.S. Army Engineer Research and Development Center
- Gary Wetzel, S&C Electric
- Doug Houseman, EnerNex

7. Panel Session: Electric Vehicles and Mobility in Energy Systems
McCormick Tribune Campus Center (MTCC) Auditorium

- Chair: Sharon Feigon, CEO, I-GO Cars
- Gary Rackliffe, ABB
- Abas Goodarzi, US Hybrid
- Mike McMahan, ComEd
- Ramteen Sioshansi, Ohio State University
- Michael Abba, Ameren

8. Panel Session: Smart Grid Cyber Security and Data Management
McCormick Tribune Campus Center (MTCC) Ballroom

- Chair: Erich Gunther, EnerNex
- Tony Metke, Motorola Solutions
- Joseph Giampapa, Carnegie Mellon University
- Alfonso Valdes, University of Illinois
- Michael Manske, West Monroe Partners

9. Panel Session: Transmission Planning Issues for Variable Energy Resources
Armour Dining Room

- Chair: Paul McCoy, McCoy Energy Consulting
- Marcelino Madrigal, World Bank
- Beth Soholt , Wind on the Wires
- John Moore, Sustainable FERC Project
- Julija Matevosyan, ERCOT
- Scott Deffenderfer, Ameren

10. Paper Session: Advanced Distribution Systems
Alumni Lounge

- Chair: Amin Khodaei, University of Houston
- *Electricity Fraud Detection by Incorporating PV System Using Support Vector Machines*

  Yonghe Guo and Chee-Wooi Ten, Michigan Technological University
- *An Analytical Approach for Reliability Evaluation of Aged Distribution Systems*

  Masood Parvania, Mahmud Fotuhi-Firuzabad, Sharif University of Technology
- *Online Management Framework for Distribution System with Wind Generation*

  Bhairavi Pandya and Chee-Wooi Ten, Michigan Technological University

5:30 pm – 7:00 pm

EVENING RECEPTION
Expo Room

TUESDAY | SEPTEMBER 25, 2012

TUESDAY MORNING

8:00 am – 8:30 am

BREAKFAST

Expo Room

8:30 am – 9:00 am

11. Keynote Speaker: Michael Polsky, President and CEO, Invenergy

Hermann Hall Ballroom

9:00 am – 10:00 am

12. Plenary Session: Offshore Wind at Great Lakes

Hermann Hall Ballroom

- Chair: The Honorable Robyn Gabel, Representative, 18th District, Evanston, Illinois
- Lorry Wagner, President of LEEDCo
- Jack Darin, Sierra Club
- Mary Ann Christopher, Esq., Law Office of Mary Ann Christopher

10:00 am – 10:30 a.m.

MORNING BREAK

Expo Room

10:30 am – 12:15 pm

13. Panel Session: Wind Turbine Operation and Control

McCormick Tribune Campus Center (MTCC) Auditorium

- Chair: Bill Fetzer, VP, BlueScout Technologies
- Don Doan, GE Intelligent Platforms (Smart Signal)
- Aidan Tuohy, EPRI
- Steve Moffitt, GE Energy

14. Panel Session: Power System Operations: EV Infrastructure and Smart Distributed Systems

Hermann Hall Ballroom

- Chair: Kate Tomford, Illinois Department of Commerce and Economic Opportunity
- Stephanie Cox, Ecotality
- Ted Bohn, Argonne National Laboratory
- Johan Enslin, University of North Carolina
- Paul Myrda, EPRI

15. Panel Session: Smart Homes, Electric Vehicles and Demand Response

Armour Dining Room

- Chair: Jianhui Wang, Argonne National Laboratory
- Vladimir Koritarov, Argonne National Laboratory
- Marty Cohen, Board Chairman, Illinois Science and Energy Innovation Fund
- John Finnigan, Environmental Defense Fund
- Prakash Thimmapuram, Argonne National Laboratory
- Zhi Zhou, Argonne National Laboratory

16. Panel Session: Solar Energy Integration

McCormick Tribune Campus Center (MTCC) Ballroom

- Chair: Mark Handy, KenJiva Energy Systems
- Jeff Smith, West Monroe Partners
- Madeleine Weil, SoCore Energy
- Tom Tansy, SunSpec Alliance

17. Paper Session: Impacts of PHEV on Transportation and Energy Systems

Alumni Lounge

- Chair: Kuilin Zhang, Argonne National Laboratory
- *An Information System for Electric Vehicle Charging Infrastructure Deployment*

  Diego Klabjan and Timothy Sweda, Northwestern University
- *An Analysis of Car and SUV Daytime Parking for Potential Charging of Plug-in Electric Vehicles*

  Yan Zhou, Argonne National Laboratory
- *Dynamics of PEV Driving and Charging Behavior under Intelligent Energy Management Systems*

  Kuilin Zhang, Argonne National Laboratory

TUESDAY | SEPTEMBER 25, 2012

TUESDAY AFTERNOON

12:15 pm – 1:30 pm

18. Luncheon Keynote Speaker

Expo Room

- Chair: Alex Flueck, Illinois Institute of Technology
- Presenter: Mani Venkata, Principal Scientist, Alstom

1:30 pm – 3:00 pm

19. Plenary Session: Great Lakes Forum on Regulatory Policy

Hermann Hall Auditorium

- Chair: Joshu Milberg, Willdan Energy
- Andre Porter, Ohio Public Utility Commission
- Eric Callisto, Wisconsin Public Utility Commission
- Ed Miller, Program Manager, Joyce Foundation

3:00 pm – 3:30 pm

AFTERNOON BREAK

Expo Room

3:30 pm – 5:15 pm

20. Panel Session: Microgrid Planning and Operation

Hermann Hall Auditorium

- Chair: Shay Bahramirad, S&C Electric
- Mani Venkata, Alstom
- Maryam Saeedifard, Purdue University
- Ernst Camm, S&C Electric
- Steve Pullins, Horizon Energy Group
- Mike Presutti, Agentis

21. Panel Session: Electric Vehicle Manufacturing in Great Lakes States

Armour Dining Room

- Chair: Steve Johanns, Eaton
- John Wirtz, Eaton Business Unit Manager
- Angela Strand, Chief Marketing Officer, Smith Electric
- Ron Prosser, CEO, Green Charge Networks and Chair, Smart Grid on the U.S.–China Clean Energy Forum
- John Shen, University of Central Florida

22. Panel Session: Smart Grid Workforce Training and Education

McCormick Tribune Campus Center (MTCC) Auditorium

- Chair: Bruce Hamilton, President, Adica and Smart Grid Network
- Gary Blank, Vice-President, IEEE-USA
- Marge Anderson, Executive Vice President, Energy Center of Wisconsin
- Julie Elzanati, Executive Director, Illinois Green Economy Network
- Matt Shields, Workforce Development Agency, State of Michigan

23. Panel Session: Geomagnetic Disturbances on the Power Grid

McCormick Tribune Campus Center (MTCC) Ballroom

- Chair: Tom Overbye, University of Illinois
- David Wojtczak, ATC
- Scott Dahman, PowerWorld Corporation
- Alan Engelmann, ComEd
- Tom Overbye, University of Illinois

24. Paper Session: Smart Grid: Policy, Regulation and Customer Engagement

Alumni Lounge

- Chair: Alex Tang, Clean Energy Trust
- *Regulation, Competition, and New Technology Adoption: Applying the Bell Doctrine to Retail Electricity Markets*

  Lynne Kiesling, Northwestern University
- *Customer Privacy & The Smart Grid: Where the Policy Debate Presently Stands & the Strategic Steps Utilities Should be Taking Today*

  Will McNamara, West Monroe Partners
- *Infinite-horizon Economic MPC for HVAC systems with Active Thermal Energy Storage*

  David Mendoza-Serrano and Donald Chmielewski, Illinois Institute of Technology
- *Communicating to Engage the Modern Customer in the New Energy Economy*

  David Tilson, West Monroe Partners

5:30 pm – 6:15 pm

NETWORKING RECEPTION

Gallery Lounge

6:15 pm – 8:00 pm

25. Dinner and Keynote Session

- Speaker: Alan Wendorf, Chairman, President, and CEO, Sargent and Lundy

WEDNESDAY | SEPTEMBER 26, 2012

WEDNESDAY MORNING

8:00 am – 8:30 am

BREAKFAST

Expo Room

8:30 am – 9:00 am

26. Keynote Speech

Hermann Hall Ballroom

- Chair: Peter Sauer, University of Illinois
- Presenter: Wanda Reder, Vice President, S&C

9:00 am – 10:00 am

27. Plenary Session: Recovery Act Demonstrations of Smart Grid Development

Hermann Hall Ballroom

- Chair: Joseph Paladino, U.S. Department of Energy
- Jim Hull, DTE
- Olga Geynisman, City of Naperville
- Barry Feldman, Indianapolis Power and Light

10:00 am – 10:30 a.m.

MORNING BREAK

Expo Room

10:30 am – 12:15 pm

28. Panel Session: Microgrid Storage

McCormick Tribune Campus Center (MTCC) Auditorium

- Chair: Troy Miller, S&C
- Tony Siebert, ZBB Energy Corporation
- James J. Greenberger, National Alliance for Advanced Technology Batteries
- Henry Louie, Seattle University
- Mitch Mabrey, Dow Kokam

29. Panel Session: Utilizing Smart Grid Test Beds in Illinois

McCormick Tribune Campus Center (MTCC) Ballroom

- Chair: Robert Greenlee, Illinois Science & Technology Coalition
- Joseph Clair, Illinois Institute of Technology
- Timothy Yardley, University of Illinois
- David Pope, Village of Oak Park
- Rod Hilburn, Ameren

30. Panel Session: Customer Engagement and Empowerment

Hermann Hall Ballroom

- Chair: Scott Binnings, Patton Boggs
- Michael Murray, Lucid Design Group
- Val Jensen, ComEd
- David Hodgson, UK Trade & Investment
- Tom Wieser, PaceControls

31. Panel Session: Storage for Power System Operation

Armour Dining Room

- Chair: Caisheng Wang, Wayne State University
- Daniel Lindenmeyer, Infineon
- Anurag K Srivastava, Washington State University
- Roland Kibler, NextEnergy
- Piyush Desai, Danfoss

32. Paper Session: Smart Grid Monitoring and Cyber Security

Alumni Lounge

- Chair: Zuyi Li, Illinois institute of Technology
- *Video Monitoring Solutions for Utilities – Using video to make a Grid Smarter*

  John McClean, Powerstream Inc.
  Anselm Viswasam, Systems with Intelligence, Inc.
- *How Electrical System Monitoring Improves Facility Efficiency, Reliability and Safety*

  Dave Loucks, Eaton Corporation, Greg Reed, University of Pittsburgh
- *Substation Cybersecurity Architectural Design*

  Pingal Sapkota and Chee-Wooi Ten, Michigan Technological University

WEDNESDAY | SEPTEMBER 26, 2012

WEDNESDAY AFTERNOON

12:15 pm – 1:30 pm

33. Luncheon Keynote Speaker

Expo Room

- Chair: Andrew Barbeau, Robert W. Galvin Center, Illinois Institute of Technology
- Presenter: Arlene Juracek, Director, Illinois Power Agency at State of Illinois

1:30 pm – 3:00 pm

34. Plenary Session: Shifting Smart Grid focus to Customer Driven Performance Outcomes

Hermann Hall Ballroom

- Chair: John Kelly, Perfect Power Institute
- Farokh Rahimi, OATI
- Austin Montgomery, Carnegie Mellon University
- Dave Roberts, OSIsoft
- Paul Alvarez, Wired Group

3:00 pm – 3:30 pm

AFTERNOON BREAK

Expo Room

3:30 pm – 5:15 pm

35. Panel Session: Smart Grid Innovation in Great Lakes Region

Hermann Hall Ballroom

- Chair: Karen Weigert, City of Chicago
- Jay Marhoefer, Intelligent Generation
- Scott Henneberry, Schneider Electric
- Dan Francis, American Electric Power
- Jett Tackbary, West Monroe Partners

36. Panel Session: Community Choice Aggregation: Progress and Promise

McCormick Tribune Campus Center (MTCC) Auditorium

- Chair: Mark Pruitt, Power Bureau
- Ghida Neukirch, Buffalo Grove Deputy Village Manager
- Maria Fields, Joule Assets
- David Kolata, Citizens Utility Board
- Kris Torvik, Wired Group

37. Panel Session: Smart Homes and Distributed Generation

McCormick Tribune Campus Center (MTCC) Ballroom

- Chair: Joyce Coffee, Edelman
- Colin Meehan, Environmental Defense Fund
- Paul Navratil, University of Texas
- Charles O'Donnell, Siemens
- George Thomas, Contemporary Controls

38. Panel Session: Future of Nuclear

Armour Dining Room

- Chair: Michael Corradini, American Nuclear Society
- Jack Grobe, Exelon Nuclear Partners
- Alexander Marion, Nuclear Energy Institute.
- Yoon Il Chang, Argonne National Laboratory
- Scott Bond, Ameren

39. Paper Session: Power System Planning

Alumni Lounge

- Chair: Lei Wu, Clarkson University
- *Probabilistic Production Cost Simulation and Reliability Evaluation of Composite Power System Including Renewable Generators*

  Jintaek Lim, Jinhwan Jang and Jaeseok Choi, Gyeongsang National University, South Korea

  Keonghee Cho, Korea Economic Research Institute (KERI), South Korea

  Junmin Cha, Daejin University, South Korea
- *A Hybrid Method for Long-Term Transmission Lines Expansion in Large-Scale Electric Grids*

  Mohammad Albaijat, University of California at Davis

  Kaveh Aflaki, Illinois Institute of Technology
- *Coordinated Expansion Planning of Generation and Transmission Systems Considering Outage Cost*

  Jintaek Lim, Jinhwan Jang and Jaeseok Choi, Gyeongsang National University, South Korea

  Donghoon Jeon, Korea Electric Power Corporation (KEPCO), South Korea

SYMPOSIUM ORGANIZING COMMITTEE:

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Andrew Barbeau, Chair, Marketing Committee
Annette Lauderdale, Chair, Finance Committee
Barry LeCerf, Chair, Arrangements Committee

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Shay Bahramirad, S&C
Andrew Barbeau, Illinois Institute of Technology
Robert Greenlee, Illinois Science and Technology Coalition
Bruce Hamilton, Adica, Smart Grid Network
Steve Johanns, Eaton
John Kelly, Perfect Power Institute
Joshua Milberg, Willdan Energy Solutions
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NOTES

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Time	Session		
	Sunday | September 22, 2013		
8:30-9:00	**Breakfast Session**		
9:00-12:00	**Short Course 1: Smart Grid Implementations and Lessons Learned**		**Short Course 2: Cyber-Physical Security for Smart-Grid: Threats, Vulnerabilities, and Mitigations**
12:00-1:00	**Lunch Break**		
1:00-4:00	**Short Course 3: Smart Grid Roadmap Creation**		**Short Course 4: Distribution Automation -- System Modeling and Advanced Applications**
	Monday | September 23, 2013		
8:00-8:30	**Breakfast Session**		
8:30-9:10	**Keynote Speech: An Energy Tsunami: What Can Islands Teach Us On What's Coming if We Don't Change?**		
9:15-10:45	Plenary Session: Smart Grid Innovations in Illinois		
10:45-11:00	**Coffee Break**		
11:00-12:30	Panel Session: Solar Energy Deployment	Panel Session: Driving Demand Response in Commercial Buildings	Panel Session: Impact of EV Charging on Energy and Transportation Systems
12:30-1:30	**Lunch Break**		
1:30-3:00	Plenary Session: Virgin Islands Solar PV Initiative		
3:00-3:15	**Coffee Break**		
3:15-5:00	Panel Session: Smart Grid Communications	Panel Session: Will Smart Grid Create New Jobs?	Paper Session: Demand Response and Energy Managements
5:15-6:30	**Networking Reception**		
	Tuesday | September 24, 2013		
8:00-8:30	**Breakfast Session**		
8:30-9:10	**Keynote Speech: Microgrid Evolution in Distribution Service Restoration After a Blackout**		
9:15-10:45	Plenary Session: Microgrids for Enhancing the Grid Resiliency		
10:45-11:00	**Coffee Break**		
11:00-12:30	Panel Session: Wind Energy from the Windy City	Panel Session: Grid Modernization for Power System Enhancement	Panel Session: Clean Energy Manufacturing
12:30-1:30	**Lunch Break**		
1:30-3:00	Plenary Session: Electricity Market and Regulations		
3:00-3:15	**Coffee Break**		
3:15-5:00	Panel Session: Aging Infrastructure and Asset Management	Panel Session: Smart Grid Consumer Education and Workforce Training	Paper Session: Microgrids
5:15-6:30	**Networking Reception**		
	Wednesday | September 25, 2013		
8:00-8:30	**Breakfast Session**		
8:30-9:10	**Keynote Speech: Building Resilience into the Smart Grid**		
9:15-10:45	Plenary Session: Increasing Adoption: Intelligent And Trustworthy Smart Grid		
10:45-11:00	**Coffee Break**		
11:00-12:30	Panel Session: Big Data in Smart Grids	Panel Session: Advanced Electric Vehicle Technology	Paper Session: Power System Operation and Control

Short Courses

Short Courses, Sunday September 22, 2013

Smart Grid Implementations and Lessons Learned, 9:00 am - 12:00 noon
Cyber-Physical Security for Smart-Grid: Threats, Vulnerabilities, and Mitigations, 9:00 am - 12:00 noon
Smart Grid Roadmap Creation, 1:00 pm – 4:00 pm
Distribution Automation -- System Modeling and Advanced Applications, 1:00 pm – 4:00 pm

Symposium Planning and Organization

Symposium Planning and Organization

General Chair, 2013 Symposium
Mohammad Shahidehpour
Robert W. Galvin Center for Electricity Innovation
Illinois Institute of Technology

Symposium Planning Committee
Hamid Arastoopour, IIT
Mohammad Shahidehpour, IIT
Jianhui Wang, Argonne National Laboratory
Shay Bahramirad, S&C Electric

Symposium Local Organizing Committee (Galvin Center, IIT)
Annette Lauderdale, Finances
Margaret M. Murphy, Scheduling
Wei Tian, Web Master
Mehdi Ganji, Registration

Symposium Technical Committee
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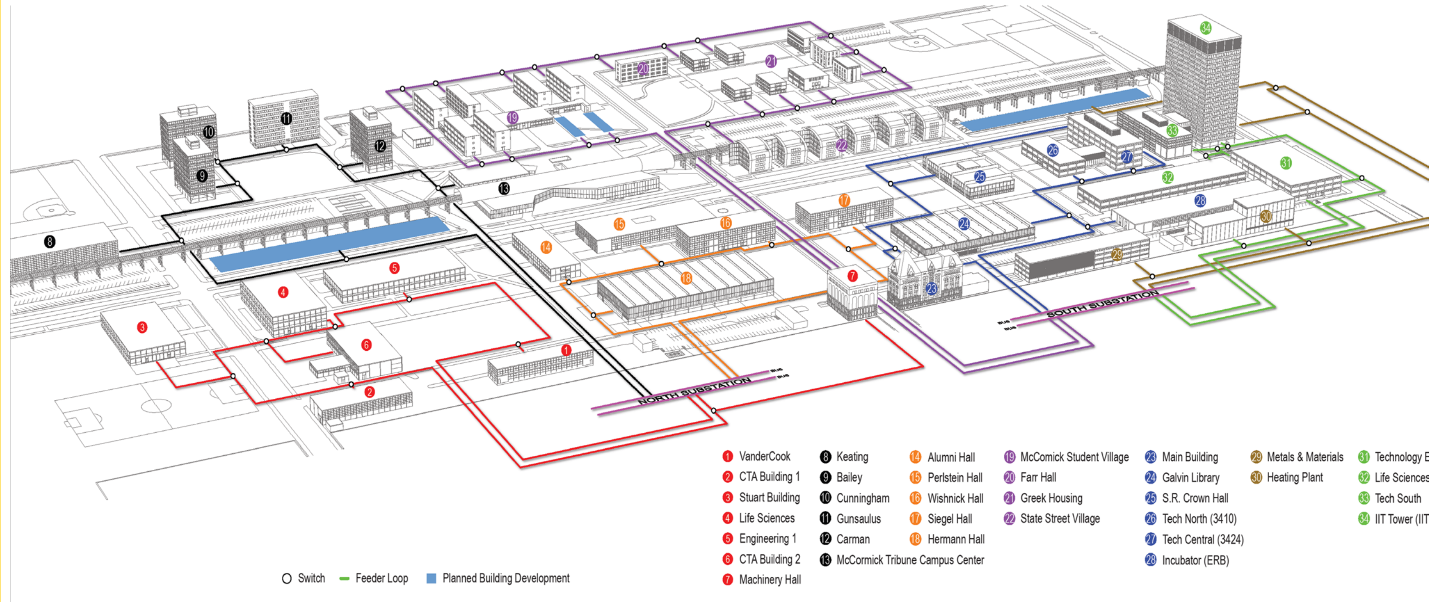
Luciano de Castro, Northwestern University
Dan Gabel, ComEd
Zuyi Li, Illinois Institute of Technology
Steve Pullins, Horizon Energy Group
Amin Khodaei, University of Denver
Josh Milberg, Willdan Energy
Michael I. Henderson, ISO New England
Lin Li, University of Illinois at Chicago
Steve Johanns, Veriown
Mohammad Khodayar, Southern Methodist University
Mark Handy, Kenjiva Energy Systems
Yong Fu, Mississippi State University
Heather Langford, LEED, U.S. Green Building Council
Kuilin Zhang, Michigan Technological University
Phil Fisher, New Generation Power, U.S. Virgin Islands
Marcia Lochmann, Illinois Green Economy Network
John Shen, Illinois Institute of Technology
Farrokh Aminifar, University of Tehran
Harry L. Holtz III, Chicagoland Wind Council
Lei Wu, Clarkson University
Tim Yardley, University of Illinois
Wencong Su, University of Michigan-Dearborn
Bruce Hamilton, Smart Grid Network
Mike Abba, Ameren, Illinois

IIT Microgrid



GREAT LAKES SYMPOSIUM ON SMART GRID AND THE NEW ENERGY ECONOMY

September 23-25, 2013

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E V E N T   P R O G R A M

Monday, September 23, 2013

8:00-8:30am Expo.
Breakfast

8:30-9:10am Ballroom
Keynote Session: An Energy Tsunami: What Can Islands Teach Us On What's Coming if We Don't Change?
Chair: Gerry M. Stokes, Associate Laboratory Director, Brookhaven National Laboratory
Introduction: Michael Garvin, Director, Caribbean Renewable Energy Consortium
Speaker: Steve Johanns, CEO, Veriown Energy

9:15-10:45am Ballroom
Plenary Session: Smart Grid Innovations in Illinois
Chair: Joshua Milberg, Willdan Energy Solutions
Mary Heger, Ameren
Jason Blumberg, Energy Foundry
Bob Greenlee, Illinois Science and Technology Coalition
Wanda Reder, S&C Electric
Karen Weigert, City of Chicago

10:45-11:00am Expo
Coffee Break

11:00-12:30pm Alumni Lg.
Panel Session: Solar Energy Deployment
Chair: Mark Handy, Kenjiva Energy Systems
Sharon Feigon, I-GO Car Sharing
Jeremy Jones, SoCore
Jeff Smith, West Monroe Partners
Bradley Klein, Environmental Law & Policy Center
Harry Ohde, IBEW-NECA Technical Institute

11:00-12:30pm Ballroom
Panel Session: Driving Demand Response in Commercial Buildings
Chair: Heather Langford, U.S. Green Building Council
Sila Kiliccote, Lawrence Berkeley National Lab
James Fine, Environmental Defense Fund
Michel Kamel, MelRok
Scot Duncan, Enerliance

11:00-12:30pm Hermann Lg.
Panel Session: Impact of EV Charging on Energy and Transportation Systems
Chair: Kuilin Zhang, Michigan Technological University
On Distributed Charging Control of EVs at Residence with Power Network Constraints
Wann-Jiun Ma and Vijay Gupta, University of Notre Dame
Ufuk Topcu, University of Pennsylvania
A Corridor-Centric Approach to Planning Electric Vehicle Charging Infrastructure
Yu (Marco) Nie and Mehrnaz Ghamami, Northwestern University
A Framework for Investigating the Impact of EV Charging on Distribution Systems with the Integrated Modeling and Simulation of Transportation Network
Wencong Su, University of Michigan-Dearborn
Modeling PEV Charging Behavior in an Integrated Activity-Based Demand and Dynamic Network Modeling Framework
Kuilin Zhang, Michigan Technological University

12:30-1:30 pm Expo.
Lunch Break

1:30-3:00 pm Ballroom
Plenary Session: Virgin Islands Solar PV Initiative
Chair: Phil Fisher, New Generation Power
Senator Craig W. Barshinger, Committee on Energy and Environmental Protection
Heru Oforii-Atta, University of the Virgin Islands
Courtney Mayes, University of the Virgin Islands
Michael Garvin, Caribbean Renewable Energy Consortium

3:00-3:15pm Expo
Coffee Break

3:15-5:00 pm Ballroom
Panel Session: Smart Grid Communication
Chair: Jim McClanahan, West Monroe Partners
Deb Burton, Verizon
Tony Burge, Siemens
Craig Newman, Airspan Networks
Dan Frein, West Monroe Partners
Tim Valin, West Monroe Partners

3:15-5:00 pm Hermann Lg.
Panel Session: Will Smart Grid Create New Jobs?
Chair: Marcia Lochmann, College Partnerships, Illinois Green Economy Network
Michael Abba, Ameren
Kathleen Thigpen, ComEd
Christopher Reese, Lewis and Clark Community College
Jeff Oder, Lake Land Community College

3:15-5:00pm Alumni Lg.
Paper Session: Demand Response and Energy Management
Chair: Michael I. Henderson, ISO New England
Demand Shaping Through Load Shedding and Shifting Using Day-Ahead and Real-Time Prices
Rodrigo Carrasco, Columbia University
Ioannis Akrotirianakis and Amit Chakraborty, Siemens
Multistage Stochastic Optimal Operation of Energy-Efficiency Building with CHP System
Ping Liu and Yong Fu, Mississippi State University
Evolving Integration of Demand Response
Jeremy Laundergan, EnerNex
Modeling and Stability Analysis of Multi-Energy Complementary Small Power System
Chen Shuyong, China Electric Power Research Institute, and Ji Xiaodong, Northeast Dianli University

The 2013 Symposium presentations are available at www.greatlakessymposium.net/download.

Tuesday, September 24, 2013

8:00-8:30am Expo.
Breakfast

8:30-9:10am Ballroom
Keynote Session: Microgrid Evolution in Distribution Service Restoration After a Blackout
Chair: Jianhui Wang, Argonne National Laboratory
Speaker: Steve Pullins, President, Horizon Energy Group

9:15-10:45am Ballroom
Plenary Session: Microgrids for Enhancing the Grid Resiliency
Chair: Shay Bahramirad, S&C Electric
Math Bollen, University of Luleo Sweden
Mark McGranaghan, EPRI
Anuradha Annaswamy, MIT
Steve Pullins, Horizon Energy Group
Thomas Basso, National Renewable Energy Laboratory (NREL)

10:45-11:00am Expo
Coffee Break

11:00-12:30pm Alumni Lg.
Panel Session: Wind Energy from the Windy City
Chair: Harry L. Holtz III, Chicagoland Wind Council
Joseph Reisinger, Broadwind Energy
Nicolai Schousboe, Jeff Smith, Nate Kipnis, Jonathan Nieuwsma, Citizens' Greener Evanston
Dan McDevitt, Nordex
Steve **Spethmann**, Suzlon Wind Energy Corporation

11:00-12:30pm Ballroom
Panel Session: Grid Modernization for Power System Enhancement
Chair: Dan Gabel, ComEd
Michelle Blaise, ComEd
Mike McMahan, ComEd
Carol Bartucci, ComEd

11:00-12:30pm Hermann Lg.
Panel Session: Clean Energy Manufacturing
Chair: Lin Li, University of Illinois at Chicago
Just-For-Peak: Buffer Inventory For Peak Electricity Demand Reduction of Manufacturing Systems
Lin Li, University of Illinois at Chicago
Manufacturing Scheduling for Electricity Cost and Peak Demand Reduction in a Smart Grid Scenario
Fu Zhao, Purdue University
Cost Benefit Analysis of Solar and Wind Local Power Generations for Greenhouse Gas Emission Mitigation
Chris Yuan, University of Wisconsin-Milwaukee
Smart Grid Vision for Computing
Dan McCaugherty, Athena Sciences Corporation

12:30-1:30 pm Expo.
Lunch Break

1:30-3:00 pm Ballroom
Plenary Session: Electricity Market and Regulations
Chair: Luciano de Castro, Northwestern University
Jeff Orcutt, Illinois Commerce Commission
Evelyn Robinson, PJM Interconnection
Joseph Paladino, U.S. Department of Energy
Paul Alvarez, Wired Group

3:00-3:15pm Expo
Coffee Break

3:15-5:00 pm Alumini Lg.
Panel Session: Aging Infrastructure and Asset Management
Chair: Amin Khodaei, University of Denver
Ernst Camm, Consulting and Analytical Studies, S&C Electric
Daniel Lindenmeyer, Infineon Technologies
Kenneth Elkinson, Doble
Peter Tyschenko, ComEd
Dan Brotzman, ComEd

3:15-5:00 pm Hermann Lg.
Panel Session: Smart Grid Consumer Education and Workforce Training
Chair: Deborah J. Buterbaugh, U.S. Department of Energy
Jo Winger de Rondon, Council for Adult and Experiential Learning (CAEL)
Victoria Busch, Ameren
Clare Butterfield, Illinois Science & Energy Innovation Foundation (ISEIF)
David Kolata, Illinois Citizens Utility Board (CUB)
Kathleen Thigpen, Exelon

3:15-5:00pm Ballroom
Paper Session: Microgrids
Chair: Doug Houseman, EnerNex
Microgrid as a Platform: A Holitic Approach to Campus Energy Solution Design
Stephen F. Schneider, SAIC
An Examination of Microgrids as a Form of Energy Generation Decentralization
Paul Rodriguez and Ryan Franks, National Electrical Manufacturers Association (NEMA)
Still Plenty of Room at the Bottom: Development of a Mesh Microgrid Network and Microclimate for Nalanda University
Jeffrey Boyer and Sachin Anand, dbHMS
Dichotomous Markov Noise Technique to Model Wind Power Uncertainty in Microgrid Operation
A. Kargarian, S. Yarahmadian, M. Sepehrifar, and Y. Fu, Mississippi State University
Local False Data Injection Attacks Against Power Grid
Xuan Liu and Zuyi Li, Illinois Institute of Technology

The 2013 Symposium presentations are available at www.greatlakessymposium.net/download.

Wednesday, September 25, 2013

8:00-8:30am Expo.
Breakfast

8:30-9:10am Ballroom
Keynote Session: Building Resilience into the Smart Grid
Chair: Peter Sauer, Grainger Chair in Electrical Engineering
Speaker: William H. Sanders
Interim Department Head, Electrical and Computer Engineering, and Director, Coordinated Science Laboratory, University of Illinois

9:15-10:45am Ballroom
Plenary Session: Increasing Adoption: Intelligent And Trustworthy Smart Grid
Chair: Tim Yardley, University of Illinois
Ralph Muehleisen, Argonne National Laboratory
Jim Eber, ComEd
Brian Deal, University of Illinois
Tom Glennon, Honeywell Building Solutions

10:45-11:00am Expo
Coffee Break

11:00-12:30pm Ballroom
Panel Session: Big Data in Smart Grids
Chair: Spencer Zirkelbach, S&C Electric
Mel Gehrs, Silver Spring Networks
Dan Rosanova, West Monroe Partners
Jessica Bian, NERC
Paul Myrda, Electric Power Research Institute

11:00-12:30pm Alumni Lg.
Panel Session: Advanced Electric Vehicle T echnology
Chair: Wencong Su, University of Michigan-Dearborn
Power Electronics with Electrified Automobile Systems
Kevin Bai, Kettering University
Unplugging the Electric Car
Chris Mi, University of Michigan-Dearborn
Impacts of EV's on Distribution Reliability and Mitigation Techniques
Visvakumar Aravinthan, Wichita State University
Model Predictive Control-based Power Dispatch for Distribution Systems Considering Plug-in Electric Vehicle Charging Uncertainty
Wencong Su, University of Michigan-Dearborn

11:00-12:30pm Hermann Lg.
Paper Session: Power System Operation and Control
Chair: Mohammad Khodayar, Southern Methodist University
Enabling Efficient, Responsive and Resilient Buildings: A Collaboration Between the United States and India
Chandrayee Basu and Girish Ghatikar, Lawrence Berkeley National Lab
Prateek Bansal, Johns Hopkins University
Unit Commitment with Variable Wind Generation: A Game Theoretical Approach
Wei Wei, Shengwei Mei, and Feng Liu, Tsinghua University, China
A New Probabilistic Production Simulation Method of Renewable Energy Generator Farm integrated with ESS
Jinhwan Jang, Jintaek Lim, Sunghun Lee, Yeonchan Lee, and Jaeseok Choi, Gyeongsang National University, South Korea
Development of Real Time Radar Visual Style Information System of Power System Integrated Health Index
Jintaek Lim, Jinhwan Jang, Jaeseok Choi, Gyeongsang National University, South Korea
Hongseok Choi, Korea Power Exchange, South Korea
Mahmud Fotuhi-Firuzabad, Sharif University of Technology, Iran
Post-Hurricane Transmission Network Outage Management
Ali Arab, University of Houston
Amin Khodaei, University of Denver
Suresh K. Khator, University of Houston
Kevin Ding, CenterPoint Energy
Zhu Han, University of Houston
Robust Look-ahead Economic Dispatch In Real-Time Market
Hongxing Ye and Zuyi Li, Illinois Institute of Technolog

The 2013 Symposium presentations are available at www.greatlakessymposium.net/download.

GREAT LAKES SYMPOSIUM ON SMART GRID AND THE NEW ENERGY ECONOMY

September 22-25, 2014

TECHNICALLY CO-SPONSORED BY

robert w. galvin center for electricity innovation at ILLINOIS INSTITUTE OF TECHNOLOGY

WISER [WANGER INSTITUTE FOR SUSTAINABLE ENERGY RESEARCH AT ILLINOIS INSTITUTE OF TECHNOLOGY]

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EVENT PROGRAM

Tuesday, September 23, 2014

8:00-8:30 am (Expo. Center)

Breakfast

8:30-9:30 am (McCormick Ballroom)

Opening Remarks and Introduction to Smart Grid Initiatives:

- **Terry Donnelly,** Executive Vice President and Chief Operating Officer, ComEd

Keynote Session: Cyber Security for Energy Delivery Systems

- **Dr. Carol Hawk, Manager,** U.S. Department of Energy

9:35-10:45am (McCormick Ballroom)

Plenary Session: Resilient Power Grids

Chair: Steve Johanns, CEO, Veriown Energy

- **Terry Donnelly,** Executive Vice President and Chief Operating Officer, ComEd
- **Wanda Reder,** Vice President, Power Systems Solutions, S&C Electric
- **Math Bollen,** STRI, Sweden (European Perspective)

10:45-11:00 am (Expo. Center)

Coffee Break

11:00-12:30 pm (Hermann Lounge)

Panel Session: Smart Street Lighting

Chair: Dan Gabel, Manager, Smart Grid and Technology , ComEd

- **Dan Gabel,** Manager, Smart Grid and Technology , ComEd
- **Mel Gehrs,** Consultant, Silver Spring Networks
- **Steve Davis,** President, The Will Group
- **Bob Myers,** Managing Deputy Commissioner, Chicago Department of Transportation

11:00-12:30 pm (McCormick Ballroom)

Panel Session: The Human and Technology Elements in the Energy Equation

Chair: Clare Butterfield, Program Director, Illinois Science and Energy Innovation Foundation

- **Anna Markowski,** Community Projects Manager, Elevate Energy
- **Sarah Moskowitz,** Outreach Director, Citizen's Utility Board
- **Rev. Brian Sauder,** Executive Director Faith in Place
- **Yann Kulp,** VP, Residential Energy Solutions Prosumer North America, Schneider Electric
- **Sara Hochman,** Managing Director, Energy Foundry

12:30-1:30 pm (Expo. Center)

Luncheon: The Renewable Energy Academic Collaboration Hub (R.E.A.C.H. Consortium) and, The Emerging Energy Technology Electronic Market (E.E.T.E.M.)

Chair: Phil Fisher, Founder, R.E.A.C.H. Consortium

- **Mohammad Shahidehpour,** VP, R.E.A.C.H. Consortium
- **Michael Garvin,** Program Director, E.E.T.E.M.
- **Thomas A. Rietz,** Professor of Finance, University of Iowa
- **The Honorable Litesa Wallace,** Representative, Illinois House 67th District
- **Lloyd Hyde,** Honorary Consul General of Jamaica in Chicago
- **Cristal Thomas**, Deputy Governor, State of Illinois (invited)
- **The Honorable Danny K. Davis,** Congressman, IL 7th District

1:30-3:30 pm (McCormick Ballroom)

Plenary Session: Center for Smart Grid Applications, Research, and Technology

Chair: Carol Bartucci, Director, IT, Smart Grid Initiatives, ComEd

- **Tom Hulsebosch,** Manager, Energy & Utilities and Sustainability Practices, West Monroe Partners
- **Dave Roberts and Mike Mihuc,** OSIsoft
- **Scott Blackburn,** VP of Client Delivery , Silver Spring Networks
- **Patrick Burgess,** Project Manager, Smart Grid Lab Partnership, Illinois Institute of Technology

3:30-3:45 pm (Expo. Center)

Coffee Break

3:45-5:30 pm (McCormick Ballroom)

Panel Session: Renewable Energy Economics and Resilience

Chair: Tom Hulsebosch, West Monroe Partners

- **Marc Lopata,** President, Azimuth Energy
- **Vijay Bhavaraju,** Senior Manager, Eaton Corporation
- **John Mueller,** CEO and Chairman, G&W Electric Company
- **Tao Hong,** Professor, University of North Carolina
- **Aaron Joseph**, Deputy Sustainability Officer, Office of the Mayor, City of Chicago

3:45-5:30 pm (Hermann Lounge)

Panel Session: Microgrid Design and Operation

Chair: Jianhui Wang, Argonne National Laboratory

- **A Novel Microgrid Demand-Side Management System for Manufacturing Facilities;** Terance J. Harper, William J. Hutzel, N. Athula Kulatunga, and J. Christopher Foreman, Purdue University; Aaron L. Adams, Alabama A&M University
- **Using a Battery Energy Storage System to Enhance Stability in an Islanded Microgrid;** Stephen M. Cialdea, John A.Orr, Alexander E. Emanuel, Tan Zhang, Worcester Polytechnic Institute
- **A High-availability and Fault-tolerant Distributed Data Management Platform for Smart Grid Applications,** Ni Zhang, Yu Yan, Shengyao Xu, and Wencong Su, University of Michigan-Dearborn

5:30-6:30 pm (Expo. Center)

Networking Reception

The 2014 GLS Symposium presentations are available at www.greatlakessymposium.net/download.

Wednesday, September 24, 2014

8:00-8:30 am (Expo. Center)

Breakfast: Women in Power - Importance of Diversity and Inclusion in Energy Industry

8:30-10:00 am (McCormick Ballroom)

Plenary Session (In conjunction with Breakfast): Women in Power - Importance of Diversity and Inclusion in Energy Industry

Chair: Dr. Shay Bahramirad, Manager, Smart Grid and Technology, ComEd

- **Michelle Blaise,** Senior Vice President, Technical Services, ComEd
- **The Honorable Sue Rezin,** Minority Spokesperson, Senate Energy Committee, and Senator, 38th District
- **Carrie Hightman,** Executive Vice President and Chief Legal Officer, Nisource
- **Dr. Anne Evens,** CEO, Elevate Energy
- **The Honorable Ann McCabe,** Commissioner, Illinois Commerce Commission

10:05-10:45 am (McCormick Ballroom)

Keynote Session: The Honorable Doug Scott, Chairman, Illinois Commerce Commission

10:45-11:00 am (Expo. Center)

Coffee Break

11:00-12:30 pm (McCormick Ballroom)

Panel Session: Community Microgrid Implementation

Chair: David Chiesa, Director of Microgrids and Commercial & Industrial Market Segment , S&C Electric Company

- **Paul Gogan,** Manager, Electric Distribution Reliability & Planning, WE Energies
- **John Kelly,** PEER Program Lead, Green Building Certification Institute
- **Philip Barton,** Microgrid and Advanced Reliability Program Director, Schneider Electric
- **Parviz Famouri,** Professor, Lane Department of Computer Science & Electrical Engineering, West Virginia University

11:00-12:30 pm (Hermann Lounge)

Panel Session: Smart Grid Workforce Development

Chair: Marcia Lochmann, Director of College Partnerships, Illinois Green Economy Network

- **David Loomis,** Professor of Economics, Director, Center for Renewable Energy, Executive Director, Institute for Regulatory Policy Studies Illinois State University
- **Robert Clark,** Professor of HVACR and Facilities, College of DuPage
- **Chris Miller,** Professor of Industrial Technology, Heartland Community College
- **Marcia Lochmann,** Director of College Partnerships, Illinois Green Economy Network

12:30-1:30 pm (Expo. Center)

Luncheon Speaker: The Honorable Don Harmon, Senator, 39th District, Illinois

1:30-3:30 pm (McCormick Ballroom)

Plenary Session Public-Private Collaborations: municipal, academic, and industry perspectives

Chair: Caralynn Nowinski, Executive Director, UI LABS

- **Joe Svachula,** VP, Distribution Engineering and Smart Grid, ComEd
- **David Pope,** Past-President, Village of Oak Park
- **Jeff Malehorn,** CEO, World Business Chicago
- **Kim Nelson,** Executive Director, US State and Local Government Solutions, Microsoft

3:30-3:45 pm (Expo. Center)

Coffee Break

3:45-5:30 pm (McCormick Ballroom)

Panel Session: Municipal Aggregation as a Channel for Smart Grid Deployment

Chair: Mark Pruitt, Galvin Center for Electricity Innovation, IIT

- **Brittany Gifford,** Smart Grid Program Manager, City of Chicago
- **Curt Volkmann,** Clean Energy Specialist, Environmental Law & Policy Center
- **Sharon Hillman,** Executive Vice President Regulatory Affairs and Business Development, MC^2 Energy Services

3:45-5:30 pm (Hermann Lounge)

Panel Session: Resource Scheduling and Demand Response

Chair: Dr. Mohammad Khodayar, Southern Methodist University

- **Stochastic Day-Ahead Resource Scheduling for Economic Operation of Residential Green House,** Xuanchen Liu, Yi Guo, Jingwei Xiong, Wencong Su, University of Michigan-Dearborn
- **Demand Shaping Through Load Shedding and Shifting Using Day-Ahead and Real-Time Prices,** Rodrigo A. Carrasco, Columbia University, Oannis Akrotirianakis, and Amit Chakraborty Siemens Corporation
- **Energy Pricing and Dispatch for Smart Grid Retailers**: A Two-stage Two-level Optimization Approach, Wei Wei, Feng Liu, and Shengwei Mei, Tsinghua University, China
- **Mains Operation by Using Learning Mechanisms in a Semi-Decentralized Control Architecture,** Sebastian Kochanneck and Hartmut Schmeck, Institute for Applied Computer Science and Formal Description Methods (AIFB), Karlsruhe Institute for Technology (KIT), Karlsruhe, Germany

5:30-6:30 pm (Expo. Center)

Networking Reception

The 2014 GLS Symposium presentations are available at www.greatlakessymposium.net/download.

Thursday, September 25, 2014

8:00-8:30 am (Expo. Center)

Breakfast

8:30-9:10 am (McCormick Ballroom)

Keynote Session: Fidel Marquez Jr., Senior Vice President, Legislative and External Affairs and Chief Governmental and Community Relations Officer, ComEd

9:15-10:45 am (McCormick Ballroom)

Plenary Session: Overcoming Challenges - Demand Response & Peak Load Reduction

Chair: Heather Langford, Director, LEED, U.S. Green Building Council

- **Farid Katiraei,** Executive Advisor - Director of *Renewables* and Sustainability, Quanta Technology
- **Heather Langford,** Director, LEED, USGBC
- **Ella Sung,** Grid Integration Group, Lawrence Berkeley National Laboratory
- **Martin Rovers**, Director of Energy Services and Solutions, Power Stream, Ontario, Canada.
- **Russell Carr,** Senior Engineer, Arup, San Francisco, CA
- **Peter Sopher,** Energy Policy Analyst, Environmental Defense Fund

10:45-11:00 am (Expo. Center)

Coffee Break

11:00-12:30 pm (McCormick Ballroom)

Panel Session: DG/Microgrid and Communications

Chair: Dr. Amin Khodaei, University of Denver

- **Jim McClanahan,** Senior Principal, West Monroe Partners
- **Alfonso Valdes,** Managing Director, Smart Grid Technologies, University of Illinois at Urbana-Champaign
- **Zhu Han,** Professor, University of Houston
- **Richard Harada,** Business Development Manager, Siemens
- **Vladimir Koritarov,** Deputy Director, Center for Energy, Environmental, and Economic Systems Analysis, Argonne National Laboratory

11:00-12:30 pm (Hermann Lounge)

Paper Session: Smart Grid Implementation

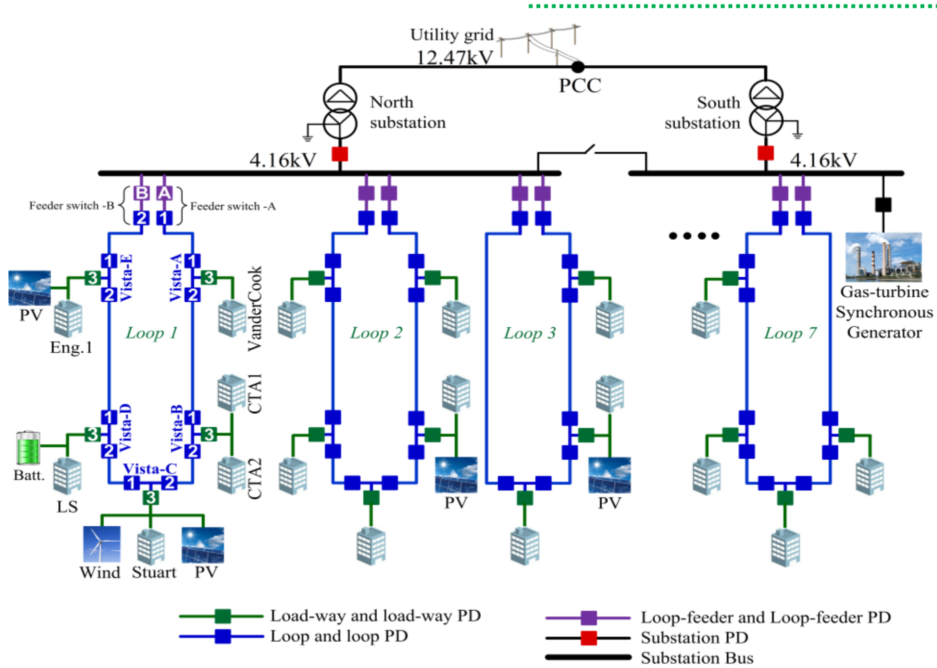
Chair: Dr. Lei Wu, Clarkson University

- **Data Life Cycles in Future Residential Multi-Commodity Energy Management Systems,** Fabian Rigoll, Christian Gitte, and Hartmut Schmeck, Institute AIFB, Karlsruhe Institute of Technology, Germany
- **Smart Meters and Dynamic Pricing Need Each Other,** David Becker, Elevate Energy, Chicago
- **CIGRE/CIRED C4.24 – power quality in the future grid – first introduction**
  Math H.J. Bollen and Sarah K. Rönnberg, Luleå University of Technology, Electric Power Engineering Group, Skellefteå, Sweden, and Francisc Zavoda, IREQ, Montreal, Canada
- **Deriving Benefits from Smart Grid Investment,** Jeremy Laundergan, MSE, PMP, Director, Utility Services Consulting, EnerNex
- **Unified Control Fatigue Distribution and Active Power in Wind Farms,** Yongxin Su, Bin Duan, C.H. Duan and F.T. Liu, Xiangtan University, China

12:30-1:30 pm (Expo. Center)

Concluding Lunch

IIT Microgrid: Hierarchal Overview



Short Courses, Monday September 22, 2014

Hermann Auditorium

3241 South Federal Street, Chicago, IL 60616

Cybersecurity Technology and Applications

Manimaran Govindarasu, Iowa State University 8:30 - 10:00
Nipesh Patel, Silver Spring Networks 10:00 - 11:00
Kevin Jin, Illinois Institute of Technology 11:00 - 12:00
Lunch Break 12:00 - 1:00
Saman Zonouz, Rutgers University 1:00 - 2:30
Paul Cotter, West Monroe Partners 2:30 - 3:30
Dave Roberts, OSIsoft 3:30 - 4:30
Mehdi Ganji, Smart Home Demonstration & Applications, Robert W. Galvin Center for Electricity Innovation 4:30-5:30

Symposium Planning and Organization

General Chair, 2014 Symposium

Mohammad Shahidehpour
Robert W. Galvin Center for Electricity Innovation
Illinois Institute of Technology

Symposium Planning Committee

Mohammad Shahidehpour, IIT
Jianhui Wang, Argonne National Laboratory
Shay Bahramirad, ComEd

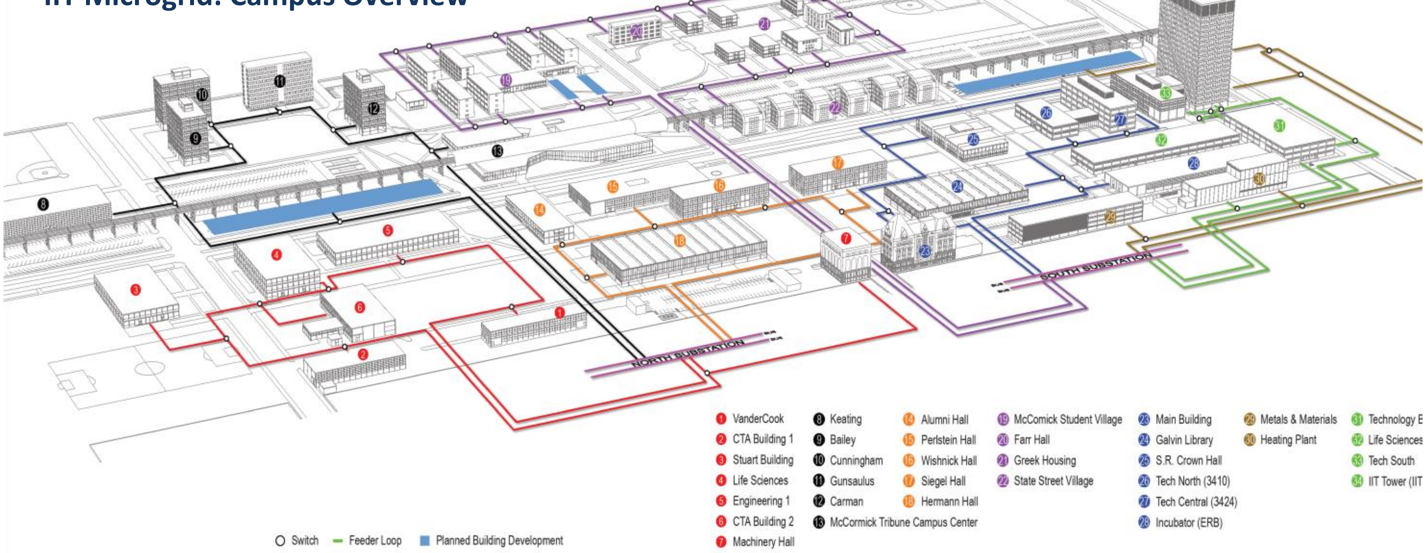
Symposium Local Organizing Committee (Galvin Center, IIT)

Annette Lauderdale, Finances
Wei Tian, Web Master
Monica Ochaney, Marketing
Mehdi Ganji, Scheduling
Wenlong Gong, Registration

Symposium Technical Committee

Wanda Reder, S&C Electric Company
Dan Gabel, ComEd
Zuyi Li, Galvin Center for Electricity Innovation, IIT
Amin Khodaei, University of Denver
Steve Johanns, Veriown Energy
Mohammad Khodayar, Southern Methodist University
Cong Liu, Argonne National Lab
Saeed Kamalinia, S&C Electric Company
Kaveh Aflaki, ComEd
Mark Pruitt, Galvin Center for Electricity Innovation, IIT
Farrokh Aminifar, University of Tehran
Ayden Noohi, S&C Electric Company
Yong Fu, Mississippi State University
Heather Langford, LEED, U.S. Green Building Council
Phil Fisher, New Generation Power, U.S. Virgin Islands
Ghazale Haddadian, Illinois Institute of Technology
Marcia Lochmann, Illinois Green Economy Network
John Shen, Illinois Institute of Technology
Lei Wu, Clarkson University
Wencong Su, University of Michigan-Dearborn
Carol Bartucci, ComEd
Tom Hulsebosch, West Monroe Partners

IIT Microgrid: Campus Overview



	Monday | September 22, 2014	
8:00-8:30 a.m.	**Breakfast**	
8:30 a.m.-4:30 p.m.	Short Course: Cybersecurity Technology and Applications	
	TUESDAY | September 23, 2014	
8:00-8:30 a.m.	**Breakfast**	
8:30-9:10 a.m.	Opening remarks and Introduction to Smart Grid Initiatives: Terry Donnelly, Executive Vice President and Chief Operating Officer, ComEd Keynote Session: Dr. Carol Hawk, Manager, Cyber Security for Energy Delivery Systems, U.S. Department of Energy	
9:15-10:45 a.m.	Plenary Session: Resilient Power Grids	
10:45-11:00 a.m.	**Coffee Break**	
11:00 a.m.-12:30 p.m.	Panel Session: Smart Street Lighting	Panel Session: The Human and Technology Elements in the Energy Equation
12:30-1:30 p.m.	**Luncheon: The Renewable Academic Collaboration Hub (R.E.A.C.H. Consortium) and, The Emerging Energy Technology Electronic Market (E.E.T.E.M.)**	
1:30-3:30 p.m.	Plenary Session: Center for Smart Grid Applications, Research, and Technology	
3:30-3:45 p.m.	**Coffee Break**	
3:45-5:30 p.m.	Panel Session: Renewable Energy Economics and Resilience	Paper Session: Microgrid Design and Operation
5:30-6:30 p.m.	**Networking Reception**	
	Wednesday | September 24, 2014	
8:00-8:30 a.m.	Breakfast: Women in Power - Importance of Diversity and Inclusion in Energy Industry	
8:30-10:00 a.m.	Panel Session (In conjunction with Breakfast): Women in Power - Importance of Diversity and Inclusion in Energy Industry	
10:00-10:45 a.m.	Keynote Session: The Honorable Doug Scott, Chairman, Illinois Commerce Commission	
10:45-11:00 a.m.	**Coffee Break**	
11:00 a.m.-12:30 p.m.	Panel Session: Community Microgrid Implementation	Panel Session: Smart Grid Workforce Development
12:30-1:30 p.m.	**Luncheon Speaker: The Honorable Don Harmon, Senator, 39th District, Illinois**	
1:30-3:30 p.m.	Plenary Session: Public-Private Collaborations: municipal, academic, and industry perspectives	
3:30-3:45 p.m.	**Coffee Break**	
3:45-5:30 p.m.	Panel Session: Municipal Aggregation as a Channel for Smart Grid Deployment	Paper Session: Resource Scheduling and Demand Response
5:30-6:30 p.m.	**Networking Reception**	
	Thursday | September 25, 2014	
8:00-8:30 a.m.	**Breakfast**	
8:30-9:10 a.m.	Keynote Session: Fidel Marquez Jr., Senior Vice President, Legislative and External Affairs and Chief Governmental and Community Relations Officer, ComEd	
9:15-10:45 a.m.	Plenary Session: Overcoming Challenges - Demand Response & Peak Load Reduction	
10:45-11:00 a.m.	**Coffee Break**	
11:00 a.m.-12:30 p.m.	Panel Session: DG/Microgrid and Communications	Paper Session: Smart Grid Implementation
12:30-1:30 p.m.	**Concluding Lunch**	

ILLINOIS INSTITUTE OF TECHNOLOGY

NATIONAL ACADEMY OF ENGINEERING

National Academy of Engineering (NAE)
Regional Meeting – Illinois Institute of Technology
Smart Grid Technology Potential and Challenges
Wednesday, May 14, 2014

IIT Hermann Hall, 3241 South Federal Street, Chicago, IL 60616

AGENDA

Wednesday, May 14, 2014

11:00 a.m. – Noon	National Academy of Engineering (NAE) Business meeting – NAE members only *Hermann Hall, Armour Dining Room (lower level)*
Noon – 1:00 p.m.	Luncheon – NAE members only

Symposium, Topic: Smart Grid Technology Potential and Challenges
Hermann Hall, Ballroom (main level)

1:15 p.m.	Welcome remarks – John Anderson, President, IIT
1:30 p.m.	NAE President, C. D. Mote, Jr.
2:00 p.m.	Anjan Bose, Regents Professor, School of EECS, Washington State University *The Evolution of Control for The Smart Transmission Grid*
2:25 p.m.	H. Vincent Poor, Michael Henry Strater University Professor of Electrical Engineering, Princeton University *Smart Grid: The Role of the Information Sciences*
2:50 p.m.	BREAK, *Hermann Hall, Gallery Lounge*
3:10 p.m.	John R. Birge, Jerry W. and Carol Lee Levin Professor of Operations Management, University of Chicago Booth School of Business *Recognizing Uncertainty with Incentives to Make the Grid Smart* and *Efficient*
3:35 p.m.	Mohammad Shahidehpour, Director, Robert W. Galvin Center for Electricity Innovation, IIT *Microgrid: A New Hub in Energy Infrastructure*
4:00 p.m.	Panel discussion moderated by Alan Cramb, Provost, IIT
4:45 p.m.	Closing Remarks – Alan Cramb, Provost, IIT
5:00 – 6:00 p.m.	Reception, *Hermann Hall, Gallery Lounge*

Free parking is available.

AGENDA

DOE Microgrid Workshop

July 30-31, 2012

IIT Galvin Center for Electricity Innovation

10 W. 35th Street, 16th Floor, Chicago, IL 60615

Sunday, July 29

6:00-7:30 pm Pre-workshop Reception at the Galvin Center

Day 1, Monday, July 30

8:00 **Continental Breakfast at the Galvin Center**

8:30-9:30 am Opening Plenary Session

- **Welcoming Remarks**
  Andrew Ross, Chief Operating Officer, State of Illinois

- **Panel on International Microgrid Development**

  Dan Ton, Program Manager, DOE, USA (Moderator)

  Nikos Hatziargyriou, Professor, National Technical University of Athens, Greece

  Dae Kyeong (DK) Kim, Principal Researcher, KERI, Korea

  Tatsuya Shinkawa, Chief Representative, NEDO, Japan

  Merrill Smith, Program Manager, DOE, USA

9:30-3:00 pm Lessons Learned and Best Practices on Microgrid Development and Operations

9:30 **Sendai Microgrid (Japan)**

Satoshi Morozumi, NEDO

Keiichi Hirose, NTT Facilities

Hiroshi Irie, Mitsubishi Research Institute

10:15 **Break**

10:30 **Microgrid with an Open, Scalable Architecture**

Ross Guttromson/Steven Glover, Sandia National Laboratories

Day 1, Monday, July 30

9:30-3:00 pm Lessons Learned and Best Practices (continued)

11:15 **Selected European Microgrid Demonstrations**

Philipp Strauss, Fraunhofer IWES, Germany

Ernst Scholtz, ABB AG, Germany

Noon **Lunch (Provided by the Workshop)**

1:00 **Twentynine Palms Marine Base Microgrid**

Sumit Bose, GE Global Research

Marques Russell, US Marine Corps

1:45 **Santa Rita Jail Microgrid**

Eduardo Alegria, Chevron Energy Solutions

2:30 **Campus Microgrid at the Illinois Institute of Technology**

Mohammad Shahidehpour, Illinois Institute of Technology

3:15 **Break**

3:30-5:00 pm Identification of Technical Topics for Further Definitization at Day-2 Breakout Sessions

3:30 **Brainstorming Session to Identify a List of Technical Topics of Interest**

Facilitated discussions to draw a list of technical topics of interest from attendees based on what they have heard from lessons-learned presentations and their own knowledge and experience. The preliminary list of topics developed by the Workshop Planning Committee and distributed to the attendees will be used as a starting point of session discussions to make additions, deletions, and changes.

4:30 **Identification of the Top-12 Technical Topics from the List for Day-2 Discussions**

Show of hands by attendees for voting each technical topic identified of interest to be either on the top-12 or non-top-12 list.

5:00-5:30 pm Organization of Day-2 Breakout Sessions

Two technical topics from the top-12 list will be assigned to a breakout session for Day-2 discussions. Each attendee will be asked to join one of the six breakout sessions established for Day 2; reassignment of attendees will be made, if necessary, for balanced, adequate representations in each breakout session. The facilitator/note-taker for each session will be introduced to session attendees.

5:30 **Adjourn for the Day**

6:30-8:00 pm Workshop Reception at the Museum of Science and Industry

Day 2, Tuesday, July 31

8:00 **Continental Breakfast at the Galvin Center**

8:30-1:30 pm Concurrent Breakout Sessions #1-6

For each technical topic assigned, facilitated discussions to develop an actionable plan. A list of questions developed by the Planning Committee should be referred to while developing the following action plan elements:

- Framing of the topic
- Current technology status
- Needs and challenges
- R&D scope
- R&D metrics

Noon **Lunch (Provided by the Workshop)**

2:00-4:00 pm Closing Plenary

2:00 **Report-out by Spokesperson of Each Breakout Session (~15 minutes each, including Q/A)**

- Session 1a: Definition of Microgrid Applications Interfaces, and Services
- Session 1b: Open Architectures that Promote Flexibility, Scalability, and Security
- Session 2: Modeling, Analysis, & Design
- Session 3: DC Power and Microgrid Integration
- Session 4a: Steady State Control and Coordination – Internal Services within a Microgrid
- Session 4b: Steady State Control and Coordination – Interaction of Microgrid
- Session 5: Transient State Control and Protection
- Session 6: Operational Optimization

3:30 **Feedback and Facilitated Discussion from Attendees Including Recommendations and Next Steps**

3:50 **Closing Remarks**
Dan Ton and Merrill Smith, Program Managers, DOE Smart Grid R&D Program

4:00 **Workshop Adjourn**

4:00 – 5:30 pm Tour of IIT Microgrid (Optional)

5:30 Shuttle bus(es) returning to the Renaissance hotel

Wednesday, August 1

8:00 – 11:00 am Tour of S&C Facilities (Optional)

Electrical Energy Storage Technologies and Applications Workshop

Register at

https://secure.touchnet.com/C20090_ustores/web/product_detail.jsp?PRODUCTID=782&SINGLESTORE=true

Who Should Attend? Utility employees, energy industry consultants, manufacturers, government employees, academics, graduate students, and other individuals with an interest in energy storage technologies and applications to smart grid

Dates: March 20-21, 2013 9:00-5:00pm

Deadline for registration: March 8. Space is limited. We encourage participants to register early. Note: For site access, foreign national participants require special clearance that can take up to 4 weeks for approval.

Fees: $195 (includes CD of workshop materials, refreshments, and lunch)

Location: **Argonne National Laboratory**, 9700 South Cass Avenue, Lemont, IL

Lodging: A list of hotels onsite and nearby Argonne can be found at **http://nano.anl.gov/users/hotels.html**

Sponsored By: **Robert W. Galvin Center for Electricity Innovation**, Illinois Institute of Technology, http://www.iitmicrogrid.net/

SESSIONS	SPEAKERS
March 20 9:00-10:30am Introduction to Energy Storage	**Mohammad Shahidehpour,** Bodine Chair Professor of ECE and Director, Galvin Center for Electricity Innovation, Illinois Institute of Technology **Jeff Chamberlain,** Deputy Director of Development & Demonstration, Argonne Joint Center for Energy Storage Research, Argonne National Laboratory
11:00am-12:30pm Electrochemical/Battery Storage Technologies	**Leon Shaw,** Professor of Materials Engineering and Rowe Family Endowed Chair Professor in Sustainable Energy; Director, Center of Energy Storage and Conversion, Illinois Institute of Technology
1:30-3:00pm Grid-Scale Energy Storage	**Vladimir Koritarov,** Deputy Director, Center for Energy, Environmental, and Economic Systems Analysis, Argonne National Laboratory
3:30-5:00pm Distributed Energy Storage	**Ali Nourai,** Director, Electricity Storage Association; Executive Consultant, KEMA
March 21 9:00-10:30am Electric Vehicles and Vehicle-to-Grid	**Ted Bohn,** Principal Engineer, Center for Transportation Research, Advanced Powertrain Research and Vehicle-Grid Connectivity, Argonne National Laboratory

11:00am-12:30am Economics and Financing of Energy Storage	**Paul Denholm,** Senior Energy Analyst, Energy Forecasting and Modeling Group, National Renewable Energy Laboratory
1:30-3:00pm Electric Industry Perspectives on Storage	**Ralph Masiello,** Innovation Director and Senior Vice President, KEMA
3:30-5:00pm Argonne Storage Hub and Tour of Lab Facilities	**George Crabtree,** Argonne Distinguish Fellow and Director, Argonne Joint Center for Energy Storage Research, Argonne National Laboratory

Motive:
Recently, the U.S. Department of Energy awarded $120 million to establish a Joint Center for Energy Storage Research at Argonne. The Joint Center will bring together multidisciplinary researchers from the government, academia, and industry to overcome critical scientific and technical barriers and create new breakthrough energy storage technology. The Workshop which is sponsored by the Robert W. Galvin Center for Electricity Innovation at Illinois Institute of Technology will provide a timely introduction to these exciting market developments.

Learning Objectives

- Fundamentals of energy storage and its applications
- State-of-the-art and emerging energy storage technologies
- Performance criteria for energy storage technologies and applications
- Energy storage marketplace
- Costs and benefits for energy storage at the grid and distributed scales
- Interconnectivity of energy storage with the electric grid
- Research, development, and deployment challenges for energy storage technologies
- Introduction to Argonne's energy storage R&D and partnerships

Electric Vehicle Workshop

Who Should Attend? Utility, transportation, and energy employees and consultants, manufacturers, government employees, academics, graduate students, and other individuals with an interest in electric vehicles and their integration with the smart grid.

Dates: April 22-23, 2014 9:00-5:00pm

Deadline for registration: April 21. Space is limited. We encourage participants to register early. Note: For site access, foreign national participants require special clearance that can take up to 4 weeks for approval.

Location: Argonne National Laboratory, 9700 South Cass Avenue, Lemont, IL, 60439

Lodging: A list of hotels onsite and nearby Argonne can be found at **http://nano.anl.gov/users/hotels.html**

Sponsored By: Robert W. Galvin Center for Electricity Innovation, Illinois Institute of Technology, (DOE Grant # DE-OE0000449)

SESSIONS	SPEAKERS
April 22, 2014 9:00-9:15 am Welcome and Introduction	Mohammad Shahidehpour, Professor and Director, Galvin Center for Electricity Innovation, IIT
9:15-10:15 am Introduction to Vehicles & Transportation	Donald Hillebrand, Director of Energy Systems Division, Argonne National Laboratory
10:30am -11:30 am Electric and Hybrid Drivetrains	Mengyang Zhang, Senior Engineering Manager, Eaton Aerospace
11:30am-12:30 pm Model Based System Engineering	Aymeric Rousseau, Manager of Systems Modeling and Control Group, Argonne National Laboratory
1:30 -3:00 pm Electric Vehicle Batteries	Anthony Burrell, Senior Chemist, Manager Electrochemical Energy Storage, Argonne National Laboratory
3:30 -5:00 pm	Rich Scholer, Manager – Electrified Powertrain Systems

Electric Vehicle Charging	Vehicle to Grid Interface, Chrysler Group, LLC; SAE Plug-In Electric Vehicle Communications Task Force Chairman
April 23, 2014 9:00-10:15 am Electric Vehicle Power Electronics	Mahesh Krishnamurthy, Director, Electric Drives and Energy Conversion Lab; Director, Grainger Power Electronics and Motor Drives Lab; Assistant Professor, Department of Electrical and Computer Engineering; Illinois Institute of Technology
10:30 -11:30 am Vehicle Life Cycle Analysis	Michael Wang, Senior Scientist, Manager of Systems Assessment Group, Argonne National Laboratory
11:30am -12:30 pm Consumers – Vehicle Choice	Tom Stephens, Principal Transportation Systems Analyst, Argonne National Laboratory
1:30 -3:00 pm Vehicle Electrification – Policy and Market Transformation	Samantha Bingham, Chicago Clean Cities Coordinator; City of Chicago Environmental Policy Analysis
3:30 -5:00 pm TOUR	Argonne Transportation Technology R&D Center (space is limited)

Abstract:
Electric vehicle technology is a game-changing venture which can provide significant benefits to our economy, environment, and energy security, and upend traditional means of transportation as we are familiar with. However, this transformation will require practical and innovative solutions to overcome technology, market, and infrastructure challenges. The Argonne National Laboratory's world leading transportation research and development program is at the forefront of delivering these solutions. The Workshop, which is sponsored by the Robert W. Galvin Center for Electricity Innovation at Illinois Institute of Technology, and held at Argonne National Laboratory will provide a timely introduction to what, when, and how of transportation electrification.

You are encouraged to attend this timely event, participate in the Workshop deliberations, and visit the Argonne's transportation research facilities.

Learning Objectives

- **Fundamentals of electric vehicles**
- **State-of-the-art and emerging electric vehicle and battery technologies**

- **Electric vehicle marketplace**
- **Costs, benefits, and downsides for transportation electrification**
- **Interconnectivity of electric vehicles with the electric grid**
- **Research, development, and deployment challenges for electric vehicle and battery technologies**

Contact Information:

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Jianhui Wang, Argonne National Laboratory (Email: **jianhui.wang@anl.gov** ; Tel.:1-630-252-1474)
Annette Lauderdale, IIT Galvin Electricity Innovation Assistant Director (Email: **lauderdale@iit.edu** ; Tel.:1-312-567-7955 for refunds and cancellations)

Illinois Smart Grid Policy Forum: *Measuring Progress and Charting Directions*

Chicago, Illinois
November 4, 2013

The Center for Business and Regulation is housed in the College of Business and Management at the University of Illinois Springfield. (www.uis.edu/cbam/cbr) CBR's mission is threefold: (1) to provide educational services to the university community and the broader regulatory community in Illinois; (2) to create an institutional structure to facilitate outreach to and among public and private stakeholder groups concerning important issues in the regulation of business; and (3) to undertake research activities that furthers the understanding of the interaction between regulation and business in order to promote more effective and efficient regulation where necessary.

Center for Business and Regulation
University of Illinois Springfield
One University Plaza MS UHB 4000
Springfield, Illinois, 62703-5407 USA

Phone:+1 217.206.7909
Fax: +1 217.206.7541

E-mail: cbr@uis.edu

www.uis.edu/cbam/cbr

Scope and Purpose: The Illinois Smart Grid Policy Forum has been created to encourage open discussion among stakeholders, policymakers, and other interested parties concerning the development of smart grid in Illinois. Smart grid investments are made to achieve a variety of goals including improved service reliability, direct and indirect cost savings for consumers, and to achieve boarder public policy goals such as integration of local generation and the promotion of smart energy usage. The agenda for this initial meeting provides time for both formal presentations and moderated discussion to encourage interaction between participants. .

Conference Location: Hermann Hall Ballroom, Illinois Institute of Technology, 3241 S. Federal Street, Chicago, Illinois. A two-way video link will be available at Brookens Library Room 141A, University of Illinois Springfield, One University Plaza, Springfield, Illinois.

Who should attend? This policy forum is open to all stakeholders with an interest in smart grid policy development in Illinois.

Registration: To register please visit: https://edocs.uis.edu/Departments/CBR/ISGPF/Nov13/ISGPF_1113.htm or email us at cbr@uis.edu

Registration Fees: This policy forum is free but registration is required. Lunch will be provided at the Chicago location.

Cancellations: Please contact the Center for Business and Regulation at cbr@uis.edu or **217.206.7909** to cancel a registration. Substitutes are encouraged and will be accepted at any time prior to November 4, 2013 by contacting CBR.

Accommodations: Participants are responsible for their own accommodations.

For more information please visit the Illinois Smart Grid Policy Forum web site: https://edocs.uis.edu/Departments/CBR/ISGPF/ISGPF.htm

Center for Business and Regulation
University of Illinois Springfield

Illinois Smart Grid Policy Forum:

Measuring Progress and Charting Directions

Chicago, Illinois
November 4, 2013

Co-Hosted by:

robert w. galvincenter for electricity innovation at ILLINOIS INSTITUTE OF TECHNOLOGY

CNT Sustainable Communities Attainable Results.

Illinois Smart Grid Policy Forum: Measuring Progress and Charting Directions
November 4, 2013
Chicago , Illinois

8:00 am Registration

8:30 am Welcome

***Kathy Tholin**, CEO*
Center for Neighborhood Technology

8:45 am Introduction

***Hon. Ann McCabe**, Commissioner*
Illinois Commerce Commission

9:00 am Keynote Address

***Richard Sedano**, Principal and US Programs Director*
Regulatory Assistance Project

9:30 am:

Session 1: Smart Grid Investment and Job Growth: Concerns and Opportunities

- How is smart grid investment promoting job growth?
- What opportunities exist for grid investment to spur economic growth?
- What obstacles remain to achieving these results ?

Introduction:
***Jeffrey Orcutt**, Policy Advisor to Commissioner del Valle*
Illinois Commerce Commission

Moderator:
***Mark Harris,** President and CEO*
Illinois Science and Technology Coalition

Panelists:
***Mohammad Shahidehpour**, Director,*
Galvin Center for Electricity Innovation, Illinois Institute of Technology

***Larry Ivory**, President*
Illinois Black Chamber of Commerce

***Sara Hochman**, Managing Director*
Energy Foundry

***Terry McGoldrick,** Senior Vice President*
IBEW, Local 15

10:45 am: Morning Break

11:00 am:

Session 2: Consumer Benefits and Smart Grid Investment

- How are consumers benefiting from smart grid investment?
- How can those benefits be measured over time?
- What changes to the approach for overseeing smart grid investment are needed to assure future benefits for consumers?

Introduction:
***Hon. Sherina Maye**, Commissioner*
Illinois Commerce Commission

Moderator:
***Richard Sedano**, Principal and US Programs Director*
Regulatory Assistance Project

Panelists:
***David Kolata**, Executive Director*
Illinois Citizens Utility Board

***Patty Durand,** Executive Director*
Smart Grid Consumer Collaborative

***Anne McKibbin,** Policy Director*
CNT Energy

***Todd Williams,** Managing Director*
Navigant Consulting

Lunch (12:45pm— 2pm)

Luncheon Speaker

***Val Jensen**, Senior Vice-President, Customer Operations*
Commonwealth Edison Company

Sponsored by:

GE Digital Energy

2:00 pm:

Session 3: Local Response to Climate Change and the Value of Smart Grid

- How can smart grid be used locally to address climate change?
- What practical policy changes are needed to promote climate change solutions with respect to smart grid?
- Should state and local policies be coordinated? If so, how?

Introduction:
***Nicole Luckey**, Legal and Policy Advisor to Chairman Scott*
Illinois Commerce Commission

Moderator:
***Robert Lieberman**, Principal*
Regulatory Assistance Project

Panelists:
***Deborah Stone**, Chief Sustainability Officer*
Cook County

***Jack Darin**, Director*
Illinois Sierra Club

***K.C. Doyle**, Sustainability Manager*
Village of Oak Park

3:15 pm:

Session 4: Summary, Roundtable, and Next Steps

- Summary of the day's discussion
- What are the issues, barriers, and policies that need further exploration?
- *Audience Participation*

Introduction:
***Hon. John Colgan**, Commissioner*
Illinois Commerce Commission

Moderator-Springfield:
***Karl McDermott**,* Director
Center for Business and Regulation

Moderator-Chicago:
***Carl Peterson**,* Faculty
Center for Business and Regulation

Panelists:
***David Kolata**, Executive Director*
Illinois Citizens Utility Board

***Jonathan Feipel**, Executive Director*
Illinois Commerce Commission

4:00 pm: Adjourn

Fall 2010 Meeting

A World-Class University-Industry Consortium for Wind Energy Research, Education, and Workforce Development

September 30, 2010
McCormick Tribune Campus Center Ballroom, Illinois Institute of Technology
3201 S. State Street, Chicago, IL
http://www.iit.edu/about/directions_main_campus.shtml

Illinois Institute of Technology was awarded an $8M grant from the U.S. Department of Energy to establish a University-Industry Consortium for Wind Energy Research, Education, and Workforce Development. http://www.iit.edu/departments/pr/mediaroom/article_viewer_db.php?articleID=396. On September 30, 2010, IIT's Center for Electricity Innovation and Wanger Institute for Sustainable Energy Research (WISER) are hosting the Fall 2010 meeting of the Consortium members on IIT's main campus in Chicago. The schedule for the day is as follows:

8:00-8:30 am	Registration and Introduction
8:30-10:45	Discussion on implementation of the DOE-funded Wind Consortium project
10:45-12:00	Tour of the DOE-funded projects at IIT
12:00-1:00 pm	Lunch
1:00-3:00	Symposium on Future of Wind Power Event
3:00-4:00	Reception

MORNING SESSION

The morning session will include presentations by consortium members and discussions of ongoing tasks. The discussions will be followed up by a tour of the DOE-funded projects at IIT.

Presentations (8:30-10:15 am)

Mohammad Shahidehpour, IIT
Frank Bristol, Acciona
Jim Gagnard, SmartSignal
Alan Cain, Innovation Technology Applications, and Ganesh Raman, IIT
Greg Rouse and John Kelly, Intelligent Power Solutions
Alireza Khaligh, IIT
Richard Gowen, Dakota Power
Zuyi Li, IIT
John Birge, University of Chicago

Discussion (10:15-10:45 am)

All Consortium members

Tour of the IIT Projects (10:45-12:00 noon)

- **Wind Turbine Installations.** The wind energy consortium tasks include the installation of two 8-kW wind units at IIT for research and education. The first unit already installed in one of the laboratories at IIT will be demonstrated as part of the campus tour.
- **Perfect Power Smart Microgrid.** IIT has been working on a DOE-funded perfect power project since 2008. The project is converting IIT to a microgrid for enhancing reliability, sustainability, and efficiency of its electricity grid. A tabletop model of the campus buildings is developed and a demonstration of the perfect power concept will be presented to the consortium members and guests.

Lunch (12:00 noon-1:00 pm) at McCormick Tribune Campus Center

AFTERNOON SESSION

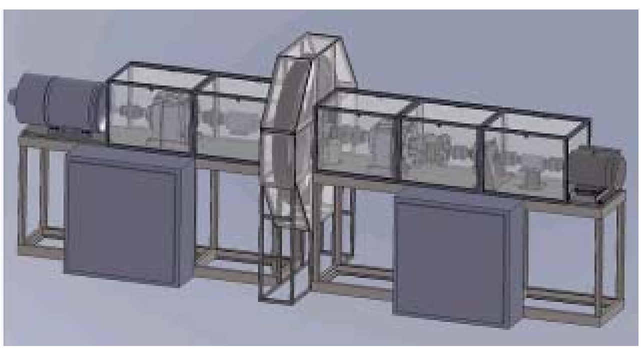
Symposium on Future of Wind Power (1:00-3:00 pm)

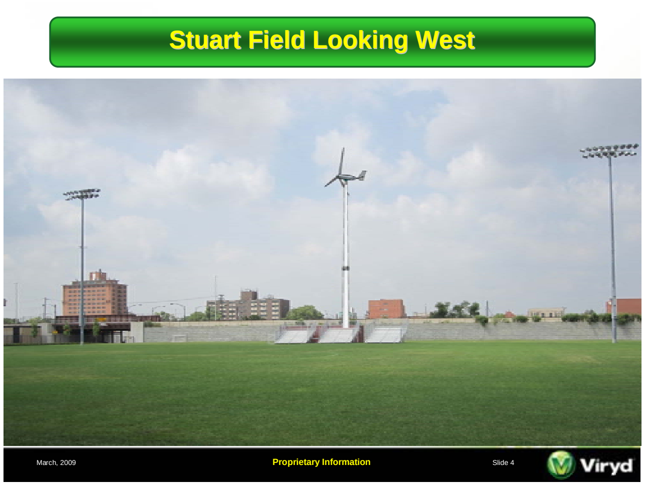
The symposium will bring industry and government leaders together to discuss breakthrough technologies, innovations, and implementation developments in the industry. The state of the Wind Energy industry in the United States is facing numerous challenges, from wildlife and zoning concerns to the deficiencies of our nation's electric transmission grid. Yet, the industry is also being presented with new opportunities, from the country's first offshore wind farms, to new smart grid technologies that allow better integration of intermittent power into the grid.

Symposium Speakers:

- Brian Connor – U.S. Department of Energy
- Sonny Garg – President, Exelon Power & Senior Vice President, Exelon Generation
- Michael Polsky – President/CEO, Invenergy
- Paul McCoy – President, Trans-Elect
- Kurt Yeager – Former President, EPRI / Executive Director, Galvin Electricity Initiative
- Joshua Milberg - First Deputy Commissioner, City of Chicago Department of Environment

Reception (3:00-4:00 pm)





A World-Class University-Industry Consortium for Wind Energy Research, Education, and Workforce Development -- July 20, 2011

McCormick Tribune Campus Center Ballroom, Illinois Institute of Technology
3201 S. State Street, Chicago, IL http://www.iit.edu/about/directions_main_campus.shtml

7:45-8:00 am	Continental Breakfast

Introduction and Welcome Remarks

8:00-8:10	Mohammad Shahidehpour, PI, DOE Wind Consortium Project
8:10-8:15	Brian Connor, U.S. Department of Energy
8:15-8:20	Dave Loomis, Chair, Illinois Wind Working Group Annual Conference

Wind Energy Integration in the Eastern Interconnection

8:20-8:30	Paul McCoy, McCoy Energy and AWC
8:30-8:40	Aidan Tuohy, EPRI
8:40-8:45	Zuyi Li, Electrical and Computer Engineering Department, IIT
8:45-8:55	Panel Discussion

Wind Energy Installation at IIT

8:55-9:05	Marty Price, Viryd
9:05-9:15	C.S. Choi, KERI / Alex Flueck, IIT
9:15-9:25	Greg Rouse, IPS
9:25-9:35	Panel Discussion

9:35-9:50	BREAK

Wind Energy Research and Development

9:50-10:00	Richard Gowen, Dakota Power
10:00-10:10	Jay Giri, Alstom
10:10-10:20	David Chiesa, S&C
10:20-10:30	Panel Discussion

Wind Energy Education and Workforce Development

10:30-10:40	Hamid Arastoopour, Chemical & Biological Engineering Department, IIT
10:40-10:50	Ganesh Raman, MMAE Department, IIT
10:50-11:00	Bob Zavadil, EnerNex
11:00-11:10	Alireza Khaligh, ECE Department, IIT / Dietmar Rempfer, MMAE Department, IIT
11:10-11:20	Panel Discussion

Wind Energy Installation at Grand Ridge

11:20-11:30	Dave Parta, Smart Signal
11:30-11:40	Steve Moffitt, GE
11:40-11:50	Bill Fetzer, Catch the Wind
11:50-12:00	Panel Discussion
12:00	Closing

12:15 pm Ribbon Cutting Event – 8kW Wind Unit at IIT

Hamid Arastoopour, WISER (Moderator)
Mohammad Shahidehpour, Robert Galvin Center for Electricity Innovation
Brian Connor, U.S. Department of Energy
Robert Galvin, Galvin Electricity Initiative
Marty Price, Viryd
Michael Polsky, Invenergy
Kurt Yeager, Galvin Electricity Initiative
Terry Frigo, IIT

2:30 pm Ribbon Cutting Event – 1.5MW IIT Wind Unit at Grand Ridge, Illinois

Andrew Barbeau, IIT (Moderator)
Mohammad Shahidehpour, Robert Galvin Center for Electricity Innovation
Gary Nowakowski, U.S. Department of Energy
Stacy Kacek, Smart Signal
Bill Fetzer, Catch the Wind
James Rafferty, Invenergy

5:30 pm	Adjourn