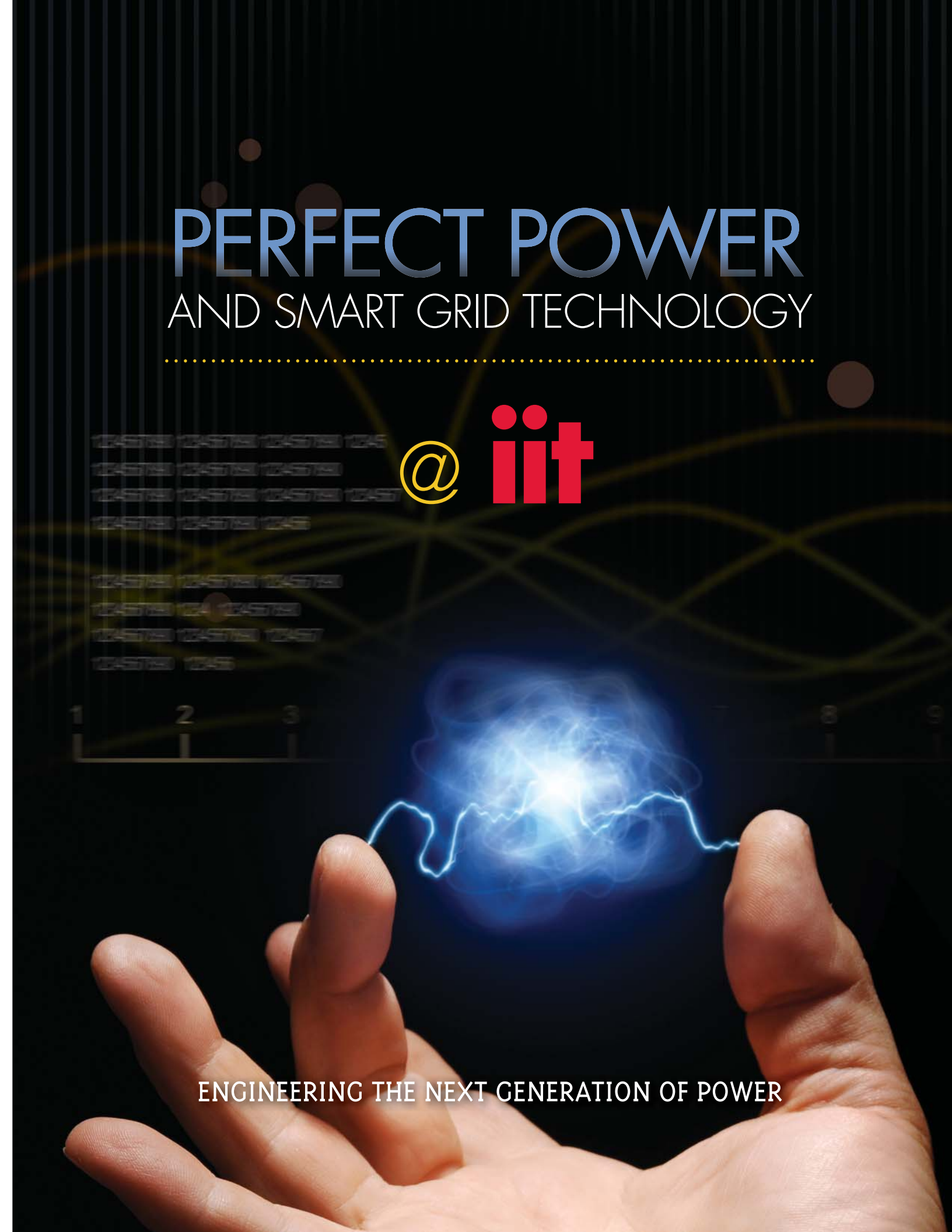
PERFECT POWER
AND SMART GRID TECHNOLOGY

@ iit



ENGINEERING THE NEXT GENERATION OF POWER

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INTRODUCTION

Illinois Institute of Technology (IIT) is launching a Smart Grid Initiative that will establish the University as a global leader in Smart Grid technology and sustainability. This will be one of the major University initiatives over the next decade.

As the world enters a new century, the demand for clean, reliable power is greater than ever. Global energy production is expected to increase 77% by 2030, and pending new demands for power from computers, communication systems, and electric vehicles threaten our current electric grid. The need for an effective, reliable and efficient means to deliver that new energy to meet new demands is near-critical.

IIT has become a leader of this technological revolution by working with the Galvin Electricity Initiative to build the first ever fully-functional Perfect Power system on its Main Campus in Chicago. The Perfect Power system is an implementation of a smart microgrid, and smart grid technology, to achieve an electric system that (1) does not fail, (2) does not harm the environment, and (3) provides for choice in innovation. The Perfect Power system will position IIT as a global leader in Perfect Power and Smart Grid implementation, serving as a hub for manufacturers, academics, and innovators who are looking to explore new horizons in the Smart Grid field.

Smart Grid Initiative at IIT

1. **Perfect Power System.** In 2008, IIT entered into a partnership with the Department of Energy to build the first scalable, replicable Perfect Power system in the world. With additional fundraising, IIT will expand its Perfect Power system campus-wide to create a fully-functioning, gapless and replicable Perfect Power system. The Perfect Power System at IIT will provide a dynamic, large-scale laboratory for researchers and innovators.

2. **Center for Electricity Innovation.** IIT will use this Perfect Power resource to build a national research Center to attract faculty, researchers, innovators, and entrepreneurs to stimulate innovation in the grid technologies of the future, and tackle challenges in the implementation of the Smart Grid.

3. **Enhancing Smart Grid Education.** IIT will pursue funding to attract additional prominent scholars engaged in Smart Grid-related research, and enhance its education of the next generation of Smart Grid engineers and leaders in the United States.

4. **IIT Advanced Energy Research Laboratories.** IIT intends to strengthen its core research resources with the development of new research laboratories. Part of these facilities will be dedicated to the University's growing energy-related research efforts, including in advanced grid technology.

WHAT IS PERFECT POWER?

A Perfect Power System uses Smart Grid technology to create a smart, self-sustaining electric grid system that:

1) DOES NOT FAIL	(100% Reliability)
2) Operates more efficiently	(Reduction in electricity use)
3) Reduces carbon emissions	(Reduce peak load and inefficient power production, and better integrate renewable energy)

In 2008, Illinois Institute of Technology (IIT) entered into a partnership with the Department of Energy to build a prototype of a Perfect Power System on its Main Campus in Chicago. The $12 million project included a $7 million Smart Grid Demonstration Project grant from the U.S. Department of Energy, under authorization from the 2007 Energy Bill.

Implementing the Perfect Power system on a research institution's campus, like IIT, will demonstrate the feasibility, reliability, efficiency, effectiveness, and success of the Perfect Power model. Communities and utilities would be able to replicate the Perfect Power System to create networks of small, self-contained smart microgrids across the world. These modern, small-scale versions of today's huge centralized electric grid will connect to and augment the larger electricity grids.

By working to build the first ever proof-of-concept Perfect Power Prototype on its Main Campus in Chicago, IIT has already established itself as a leader in the Smart Grid technological revolution.

Goals of Perfect Power System demonstration:

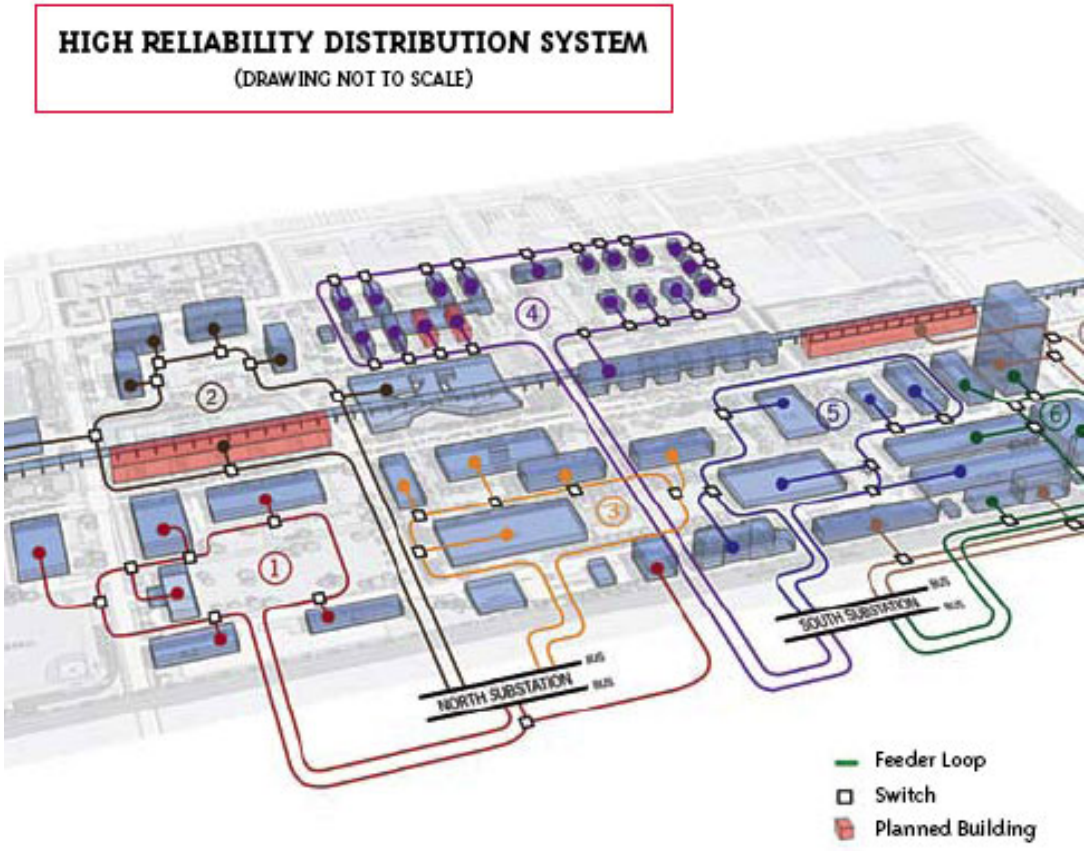
1. The achievement of system-wide Perfect Power and demonstration of its technological viability: Through the implementation of distributed energy and advanced sensing, switching, feeder configuration and controls, IIT's electric power conditions will always meet or exceed each end user's requirements.
2. 50% peak on-demand reduction capability when called upon by the utility.
3. 20% permanent peak demand reduction from the 2007 annual peak demand.
4. Deferral of utility's planned substation upgrades due to the demand reduction achieved.
5. Demonstration of the economic value of Perfect Power, specifically the avoidance of outage costs and the introduction of significant savings and revenue from providing ancillary services.
6. Create a design that can be replicated to any microgrid.
7. Promote the Perfect Power prototype.

How does it work?

Perfect Power is an electricity system based on the idea that a series of self-contained, smart microgrids can be designed to ensure 100% power reliability and can optimally meet the needs and demands of consumers. Microgrids are smaller versions of the nationwide electric grid system. In a Perfect Power system, the smart microgrids are constructed in a loop system with redundant electricity and distributed generation to ensure constant power delivery even in the event of a fault in the grid.

To achieve Perfect Power, the elements listed below must be present and working together as an integrated whole whose performance and value is greater than its parts:

1. A functional smart microgrid with a grid-wide installation of 'smart' meters, substations, distribution switches, sensors and other energy-efficient engineering advances in buildings.
2. A looped, redundant distribution system.
3. A campus-wide intelligent power controller that coordinates distributed devices.
4. Backup generation capacity.
5. Renewable energy sources.
6. Cyber security protections.



PERFECT POWER: SCOPE OF WORK

Status of Work (as of February 2010):

2008 U.S. Department of Energy-Funded Perfect Power Prototype Project:

1) **Construction of 3 Intelligent Self-Healing electricity distribution loops**

   STATUS: PHASE I COMPLETE. The first year of the project included automation of the North Substation and the installation of the first "High Reliability Distribution System" loop. That loop included service to IIT's Hermann Hall, Perlstein Hall, Alumni Hall, Wishnick Hall and Siegel Hall.

   Phase II of the project will complete the loops that serve the far north end of campus, including Stuart Hall which houses our Office of Technology Services main data center, and the loop that serves the north half of the housing side of campus, which includes the hallmark McCormick Tribune Campus Center.

   In this way, IIT will have all four campus functions covered within the installed loops: academic, housing, research, and student support. This coverage will allow for full understanding of the benefits of Perfect Power, and will serve to demonstrate its application to the campus environment.

2) **Modern Energy Management pilot**

   Siegel Hall houses the university's Department of Electrical and Computer Engineering (ECE) and will be used as a demonstration facility for advanced building control integration.

3) **South Substation Upgrade and Perfect Power System Controller Design**

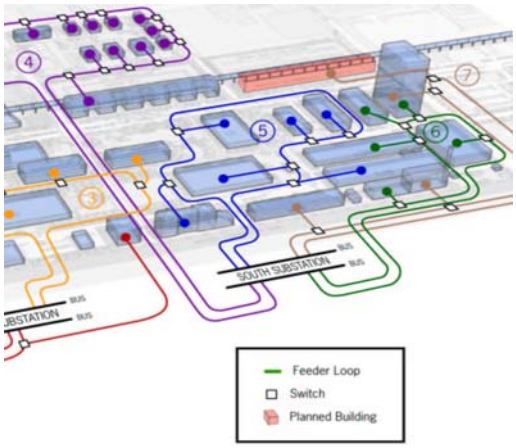
   IIT will upgrade and automate the south substation so that all of the incoming electrical service and over ninety percent of existing on-site generation will be under control of the Integrated Perfect Power System Controller (IPPSC).

Proposed expansion and completion of Perfect Power System:

1) Construction of remaining 4 Intelligent Healing electricity distribution loops
2) Full Modern Energy Management Deployment
3) Expanded gas-fired clean generation
4) Renewable Energy
5) Electric Vehicle Integration
5) Cyber Security
6) Perfect Power System Controller Full Implementation

Campus Intelligent Self Healing Infrastructure

The proposed design for Perfect Power at IIT is based upon the "High Reliability Distribution System" that leverages a continuously energized loop feeder concept, which provides a redundant electric supply to each campus building. Both feeds will be energized and supply electricity to the building, as well as being capable of carrying the entire building load. High-speed, intelligent automated switches will be installed to detect and isolate a fault without loss of power to the building.



- The system will use two substations in two closed-loop configurations to support load requirements as well as load equalization if a fault occurs on a feeder.
- To support new load growth, additional switch units can be added anywhere along the loop system and will adhere to the system design without any changes in relay settings.
- The proposed design can support an additional source for future load expansion.
- The design should be capable of isolating a feeder cable fault in fewer than 10 cycles
- In the case of a single loop cable failure, the design should sustain building power for all buildings, with no interruption

Scope of Work

Task 1 – Sectionalized Loops, Smart Switches, and communications for Campus

- Laying of almost 10,000 feet of new electric cable and conduit to create loop system, upgrade existing cable and transformers to improve reliability and efficiency.
- Installation of over 30 smart switches and secure underground housing (vaults) for 7 campus loops.
- Install smart communication system to enable two-way flow of information over loops.

Task 2 – Complete Upgrade / Replacement of South Substation

- Upgrade South Substation to improve reliability. New substation will include automated breakers and switches that enable sectionalized looped system.
- Install automated breakers and switches that will sense fault conditions and open within 1/4 cycle, simultaneously isolating the fault and allowing power to flow along a secondary feeder route.
- Install high speed, fault interrupting switchgear for the north and south main buses.
- Install automatic high speed transfer system – either at the individual building level, mid-distribution loop level, or substation level.

- Install multifunction directional over-current relays.

Task 4 – Upgrade Existing Switch Stations and Expand Switch Station Capacity

- Install new switch stations/manholes to enable new looped system, alleviate congestion and improve reliability.

Task 5 – Protect All Remaining Above-Ground Electrical Infrastructure

- Move remaining above-ground electrical infrastructure below-ground or inside buildings
- Enclose new smart switches in vaults to provide for protection and improve esthetics.

Modern Energy Management and Efficiency Initiative

The investments in energy management and efficiency will enable the development of real-time metering systems, building automation and load control from the central master controller. In conjunction with the other system investments, this will result in a 20% peak load reduction, and a 50% peak on-demand reduction capability when called upon by Exelon/PJM.

This Initiative will start with a Pilot project in Siegel Hall as part of the DOE-funded proposal, and then be expanded to all campus buildings.

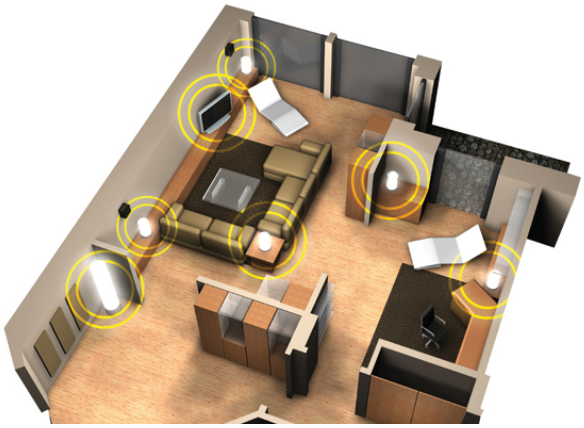
Scope of Work

Task 1 – Install a Modern Utility Information Management System

- Install advanced real-time pricing meters
- Develop real-time data acquisition & storage system, and action interface for meter data.

Task 2 – Expanded Building Automation Systems and Wireless Controls

- Install building automation systems (1 controller per building) in campus buildings, allowing building load control to be managed by central Master Controller.
- Install Zigbee wireless control in campus buildings
- Install wireless enabled panels to manage load control
- Install wireless enabled room energy management sensors (lighting, etc.)



Task 3 – Additional Energy Efficiency

- Implement new IIT Energy Policy on campus, and implement infrastructure and behavior modification plans to increase energy efficiency.

Expanded Gas Fired Clean Generation

The Perfect Power System (PPS) design includes redundant site generation to ensure power to all facilities when ComEd (Utility) power is lost.

Scope of Work

Task 1 – Building Backup Generation

- Install 2,000 kW of total backup generation in 5-6 more buildings that have critical loads.

Task 2 – Substation Backup Generation

- Install 4MW of natural gas engine generators, and connect to main bus, in the south substation and use to feed the loops for that substation.
- Install capability for substation backup generators to generate revenue in demand response and capacity markets to help offset their costs.

Task 3 – Turbine Automation

- Enable automated starting of power plant natural gas turbine in event of power loss.
- Turbine has already been configured for quick (manual) starts.
- Overhaul hot section, gearbox and de-ionization system for power plant natural gas turbine.

Task 4 – Uninterruptable Power Supplys

- Install 4,000 kW of Uninterruptible Power Supplys (UPS) in coordination with substation generators to carry system load for more than 120 seconds until generators are up and synchronized, using either flywheel or battery technology depending on the application.

Renewable Energy

The Perfect Power System (PPS) design allows for the effective integration of community-scale and building-scale renewable energy sources into the microgrid. The installed wind turbines and solar PV arrays will cut carbon emission by reducing the peak energy consumption purchased from the local utility. On-site generation will also ensure a baseline of power to essential facilities, in conjunction with energy storage, when utility power is lost.

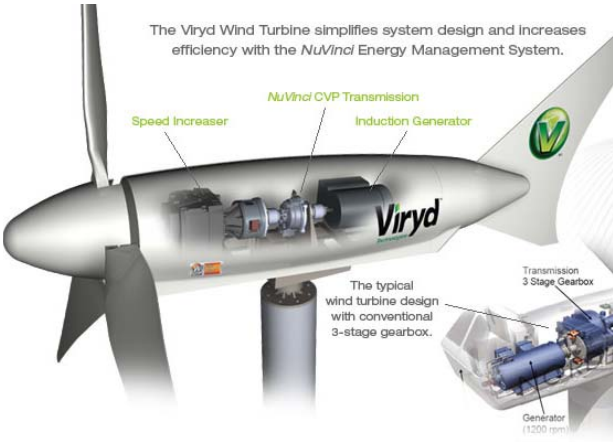
Scope of Work

Task 1 – Expand Renewable Generation (Solar PV) Integration

- Install six 50 kW solar PV arrays (300 kW total) on campus rooftops to allow for integration of renewable generation with Perfect Power System, and plug-in hybrid electric and pure electric vehicles.

Task 2 – Install new DOE-funded Wind Generation technology

- Wind Energy Consortium – In 2009, IIT was awarded an $8 million grant from the U.S. Department of Energy to lead a Wind Consortium Research project to develop the next generation of Wind Turbine technology. IIT will install a test turbine, a GE 1.5 MW turbine, at a nearby existing wind project and a smaller test turbine on its main campus. The project will test advanced concepts for rotor control and drive train control, robust sensors for blades, and improved aero elastic models to improve wind turbine performance and reliability.



Task 3 – Incorporate Energy Storage

- Install 2,000 kWh energy storage reservoir to match the generation capability of solar PV with the load demand of a commercial building, and charge needs of electrified vehicles.

Electric Vehicle integration

The Perfect Power design allows for the effective integration of electric vehicles into the microgrid, utilizing their energy storage capacity to balance the system-wide load, and coordinate battery recharging at the most economical times.

Scope of Work

Task 2 – Incorporate Electric Vehicle Charging Station

- Install electric vehicle charging stations that are incorporated with the storage system and Perfect Power System.

Task 3 – Incorporate Vehicle-to-Grid (V2G) Services into IIT's Perfect Power System

- Install Vehicle-to-Grid (V2G) system, including two-way meter and accounting software, to use electric vehicle storage capability to support the Perfect Power System grid.

Advanced Cyber Security Features

The Perfect Power System needs to be protected against various communication-oriented and/or physical-compromise-oriented malicious attacks and threats in addition to random faults of individual components. IIT will design and develop a comprehensive security treatment for the Perfect Power System and set up a software and hardware security solution framework with the following subtasks.

Scope of Work

Task 1 – Key Management and Authentication for Communication Security and Access Control

- Design and develop an efficient and attack-resilient key management that can appropriately assign keys to various system units/components so that later on these system units can securely communicate with each other.

Task 2 – Intrusion Detection Module for Real-time System Monitoring

- Design an intrusion detection module that can monitor the system operating status in real time and detect against physical compromise oriented attacks, including disabling a selected subset of system units, compromising & controlling a selected subset of system units, and utilizing them for further attacks subsequently, etc.

Task 3 – Security Enhancements for the SCADA System and DNP3 Protocol

- Develop and enhanced security mechanism for SCADA system and DNP3 protocol.

Task 4 – Security Enhancements for Advanced ZigBee Wireless Networks

- Design and develop power-efficient, low-cost security algorithms and mechanism to provide solutions to Zigbee wireless network vulnerabilities, while balancing the tradeoffs between security and simplicity.

Task 5 – Validating via Simulation and Field Testing

- Develop an attack simulator that simulates communication-oriented and physical-oriented attacks to validate security solutions.
- Test the security solutions resulting from the proposed research, leveraging the Perfect Power System as a test bed for field-testing and demonstration.

Perfect Power System Controller

The Perfect Power System depends on a central Intelligent Perfect Power System Controller that can collect information from the System, and then conduct grid and building automated control to ensure no loss of power to the System, peak load reduction, and increased efficiency.

Scope of Work

Task 1 – Expand Modeling Accuracy and Fault Diagnostic Capabilities

- Modify Intelligent Perfect Power System Controller specification and software to add additional modeling methods beyond two state, to improve state estimation and advanced fault diagnostics in expanded System.

Task 2 –Incorporate Latest Smart Grid and Security Protocols

- Continuously modify Intelligent Perfect Power System Controller to incorporate new communication and security standards and protocols still being developed by the National Institute for Standards and Technology and IEEE.

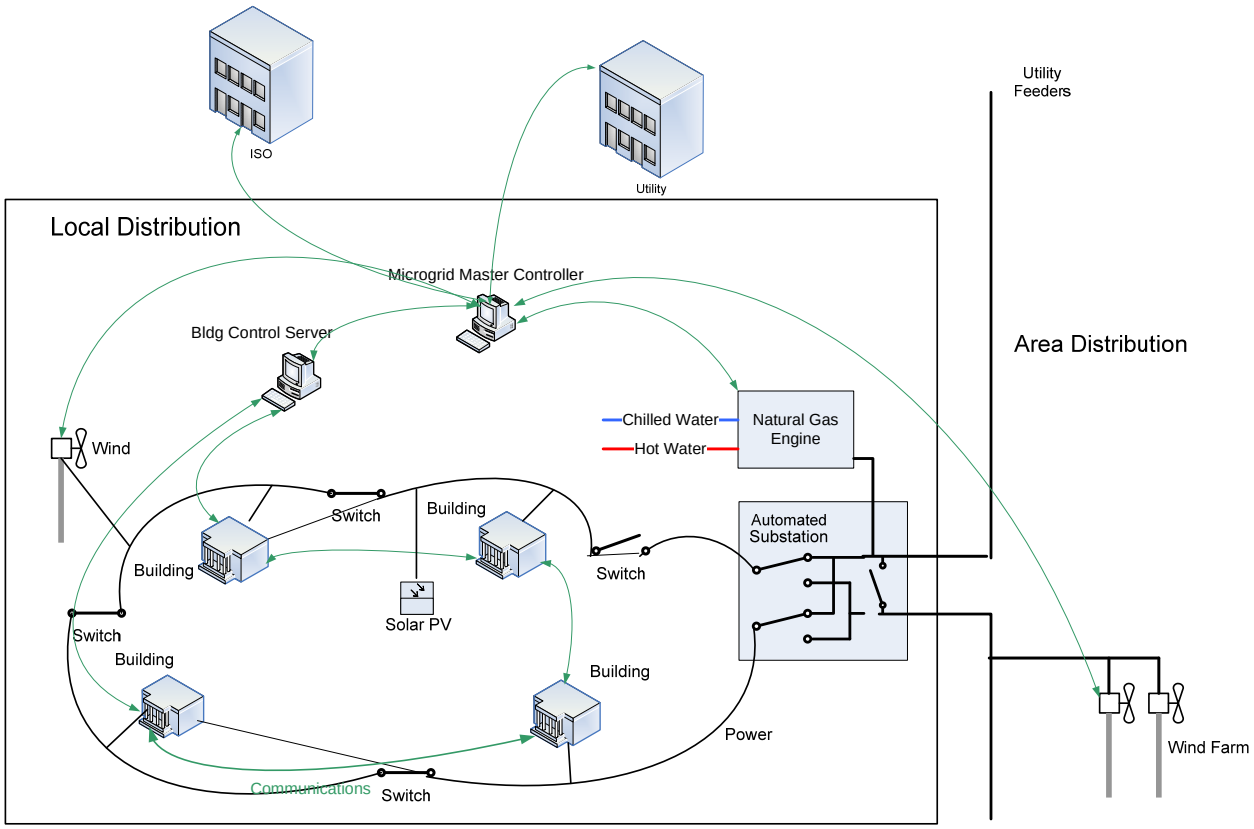
Task 3 – Incorporate Remote Interface

- Develop software for a remote user interface for the Intelligent Perfect Power System Controller so it can be accessed securely from remote computers and web enabled handheld devices.

Task 4 – Incorporate Microgrid Synchronization Coordination

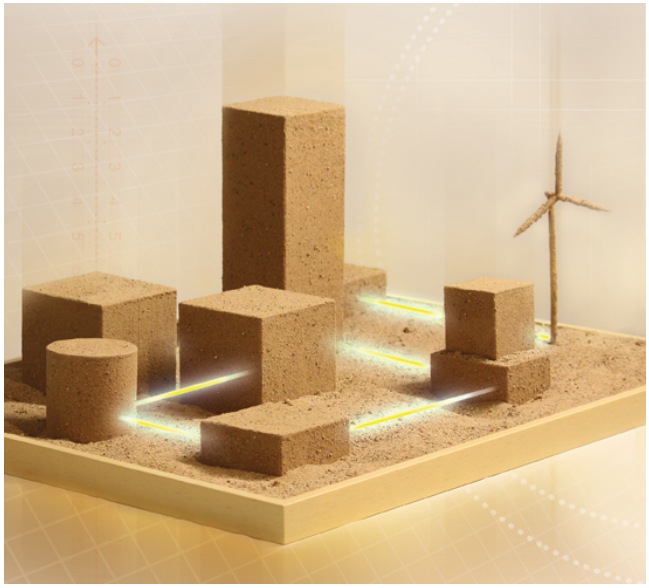
- Develop innovative inverter control for backup generator synchronization in the event ComEd (Utility) power is lost to the system.
- Install controllable inverters between engine and building loads

PERFECT POWER SYSTEM CONTROLLER



CENTER FOR ELECTRICITY INNOVATION

The Perfect Power system will position IIT as a pioneer in electricity delivery and infrastructure, and as a hub, or sandbox, for new research and innovations in Smart Grid technology. IIT will leverage this resource to create a national research center that will become a global "thought-leader" in Smart Grid and Perfect Power research and innovation. The Center for Electricity Innovation will exist under IIT's Wanger Institute for Sustainable Energy Research (WISER), and will be tasked with bringing significant new smart grid and advanced grid technology research funding to the University and acting as a global center for Smart Grid Research.



The Smart Grid model envisions smart appliances that communicate with each other to improve the reliability of the grid, use electricity more efficiently, and allow consumers to take more informed control of their power usage. That means someone is going to have to create smart meters, appliances, air conditioners, heating systems, lighting, power backup systems, and plug-in hybrid systems. IIT's Center for Electricity Innovation will serve as a national resource for innovators who need a thorough research and development support program to develop their technology, and a functioning Smart Grid on which they can develop, demonstrate and evaluate new technologies.

The Center for Electricity Innovation will form a collaboration of faculty, students, researchers, innovators, and entrepreneurs, allowing them research access to IIT's Perfect Power system to "plug-in" and work together to advance Smart Grid research and technology, overcome obstacles to the national adoption and implementation of the Smart Grid, and ensure the security and reliability of the Smart Grid. The Center will seek support from federal, state, and local government sources, as well as private grants and philanthropy, to support advancing Smart Grid technology on a systems level:

> **Initial Focus 1: Interoperability & Systems Integration.** The Center will become a hub for the development and testing interoperability standards for the Smart Grid, and stimulating new interactions between devices. By plugging into the Perfect Power system, researchers and companies will be able to test, evaluate and validate new

technologies on a system level, as opposed to an individual component level, as they are plugged into the controlled environment.

Initial Focus 2: Cybersecurity. New smart grid technologies will challenge the existing electric grid transmission and distribution networks to operate in ways for which they were not originally designed. The Center for Electricity Innovation will use IIT's Perfect Power system to conduct research on system-level cybersecurity measures for the Smart Grid.

Initial Focus 3: Renewable Energy Integration. The Center will put a large emphasis on the integration of locally-generated solar and wind power into the grid. In 2009, IIT was awarded an $8 million grant from the U.S. Department of Energy to lead a Wind Consortium Research project to develop the next generation of Wind Turbine technology. IIT will install a test turbine, a GE 1.5 MW turbine, at a nearby existing wind project and a smaller test turbine on its main campus. The project will test advanced concepts for rotor control and drive train control, robust sensors for blades, and improved aero elastic models to improve wind turbine performance and reliability.

Responsibilities of the Center for Electricity Innovation
1. Pursue public and private funds for advanced grid research at IIT.
2. Guide global Smart Grid research, and become a "thought leader" in this emerging field.
3. Attract and engage researchers from a cross section of fields to join Smart Grid research.
4. Develop a Smart Grid Roadmap that will define the future of Smart Grid deployment and technology development in the United States.
5. Operate the new Smart Grid test beds and laboratories to be developed on IIT's campus.
6. Manage the membership collaboration for researchers and companies looking to "plug in" to IIT's Perfect Power System.
7. Coordinate technology transfer and new entrepreneurial activity for Smart Grid innovations developed in the Center.
8. Organize workshops, conferences, and other training for companies and workers looking to learn more about the Smart Grid and Perfect Power.

SMART GRID EDUCATION

IIT will recruit four new faculty members in power, electrical and computer engineering to expand and complement the Smart Grid and Perfect Power research and instruction led by Mohammad Shahidehpour, Carl Bodine Distinguished Professor and Chairman in the Electrical and Computer Engineering Department.

In order to attract the highest level of talent to IIT and enhance the university's research and education offerings in the field, IIT seeks permanent, sustained funding for the positions through the creation of endowed chairs – the highest honor and distinction awarded to a faculty member. Endowed chairs will allow IIT to enhance and expand advanced grid and energy research initiatives, and recruit faculty who will push the boundaries of innovation and discovery.

Recruiting the best and the brightest minds in the field will support the positive leadership of IIT in the Smart Grid arena, and enable the innovation necessary to ensure academic, research and industry involvement in the IIT Smart Grid Initiative.

Enhanced Power Engineering Education

IIT will leverage the Perfect Power system as a dynamic resource for an enhanced Power Engineering education curriculum. It will provide hands-on learning and research opportunities through its Perfect Power system and Center for Electricity Innovation that will better prepare students to design, innovate and provide leadership on the Smart Grid technologies of the future.

Concentrations in Smart Grid

The addition of prominent endowed chairs will allow IIT to enhance and supplement its standard education offerings in fields related to Smart Grid by adding Smart Grid concentrations and research themes to engineering degree programs. The expanded offerings and themes would be led by faculty initiative, responding to current trends and developments in the engineering fields. Additionally, Smart Grid and Perfect Power-related research being performed by the endowed chairs will provide a unique learning opportunity for their students not available at any other institution.

ADVANCED ENERGY RESEARCH LABORATORIES

IIT is able to embark on this new initiative because it has built a strong research and education foundation through the success of its power engineering program in its renowned Department of Electrical and Computer Engineering. Additionally, the new Wanger Institute for Sustainable Energy Research (WISER) is setting a high bar for successful energy research programs across the country. As IIT embarks on the Smart Grid Initiative, it will use that foundation, and its talented engineering faculty, to build the Perfect Power system, create the Center for Electricity innovation, and pursue new advancements in energy fields.

In order to provide the physical space and technical resources for IIT's energy research activity, IIT is looking to develop new Advanced Energy Research Laboratories.

Within the new Advanced Energy Research Laboratories, the Center for Electricity Innovation will operate a series of state-of-the-art Smart Grid test-beds that are individually designed around and customized for the key technology advances needed for the effective development of the Smart Grid. The laboratories will allow IIT faculty, students, researchers and other interested parties direct access to IIT's Perfect Power system, allowing them to use the System as a test bed for new technology research and Smart Grid systems evaluation. Access to this real-world "sandbox" provides researchers and technology developers with an unrivaled ability to pursue advances in the Smart Grid more efficiently, effectively, and collaboratively.

For faculty and researchers: The Advanced Energy Research Laboratories will provide advanced technology laboratories that allow for the effective development, demonstration, evaluation and refinement of new innovations.

For students: The Advanced Energy Research Laboratories will provide hands-on learning and research opportunities that will better train them to develop and work on the Smart Grid technologies of the future.

For utilities, manufacturers, and start-ups: The Advanced Energy Research Laboratories will be a pre-deployment proving-ground for new Smart Grid and other energy-related technologies, and an opportunity to develop cross-industry and cross-company collaborations to better serve this new market.