GALVIN ELECTRICITY INITIATIVE

ILLINOIS INSTITUTE OF TECHNOLOGY

# IIT Perfect Power Prototype

Final Report
October 15, 2007

Prepared by Endurant Energy:

John F. Kelly
Michael Meiners
Greg Rouse

ENDURANT ENERGY
*Building Sustainable Power…*

Prepared for:

**GALVIN ELECTRICITY INITIATIVE**
and
**ILLINOIS INSTITUTE OF TECHNOLOGY**

# EXECUTIVE SUMMARY

The Galvin Electricity Initiative (the "Initiative") is undertaking the task of demonstrating and open sourcing an improved design for the delivery of electric power. By applying continuous improvement methods to the elements of the United States power grid, the Initiative hopes to achieve the universal adoption of a system design that successfully meets the power needs of every consumer. It calls this ultimate state 'Perfect Power'. The Initiative intends to demonstrate that delivering Perfect Power is not only attainable, but is ultimately the most cost-effective option.

Currently at a "tipping point" in its need for a more efficient and reliable electric power system, the Illinois Institute of Technology (IIT) collaborated with the Galvin Electricity Initiative, S&C Electric, Endurant Energy and Commonwealth Edison (ComEd) to explore system renewal. The team utilized quality principals to design a prototype "Perfect Power" system for the IIT campus. The prototype will demonstrate that cost-effective electric power can be delivered to the consumer precisely as that consumer requires it, without failure and without increasing costs. The prototype will offer IIT the opportunity to make necessary system upgrades while eliminating costly outages, reducing escalating demand and curbing carbon emissions. By pioneering the Perfect Power approach to electricity delivery, the university will attract the attention of the industry, alumni, the research community, prospective students, potential donors and other stakeholders. The Initiative's Perfect Power model includes the following elements:

- Redundant transmission and distribution supply
- Protected distribution - underground
- Self-sustaining infrastructure
- Intelligent distribution system and system controllers
- On-site electricity production
- Demand response capability (temperature setbacks, lighting, major loads)
- Minimal environmental impact including carbon and esthetics
- Technology-ready infrastructure designed to accommodate emerging technologies

The ComEd electricity transmission and distribution to IIT, built over 70 years ago, does not provide for redundancy. To compensate for this, the Perfect Power System prototype provides local generation at the site substations and UPS/backup generation at key facilities to ensure that the campus can operate when grid power is lost and to provide ancillary services to the grid.

The Perfect Power prototype builds upon the High Reliability Distribution System design developed by S&C Electric, a loop system that provides redundant electricity to each building. In this system, any single fault on any of the feeder loops can be isolated without interrupting power to loads. In addition, the Perfect Power prototype includes the Intelligent Perfect Power System Controller which manages the campus electricity distribution and usage. This includes coordinating with ComEd and the PJM ISO to provide ancillary services and demand response. Fortunately, IIT is located in the PJM ISO where ancillary services are valued through payments for spinning reserve and demand response. In addition, IIT can participate in the procurement of electricity in real time, reducing electricity costs by over $1,000,000 annually.

IIT, The Initiative, ComEd and the PJM ISO will together provide a glimpse of a new electricity system paradigm. In this new world, utilities and customers will work together to build local Perfect Power systems that serve the customer and bolster reliability and efficiency across the entire U.S. power system.

# ACKNOWLEDGEMENTS

The Galvin Electricity Initiative sponsored the IIT Perfect Power Prototype project. Kurt Yeager managed and directed the Perfect Power prototype development. The report was prepared through a collaboration of the Illinois Institute of Technology (IIT), the Galvin Electricity Initiative, Commonwealth Edison/Exelon Corporation, S&C Electric, and Endurant Energy.

The following individuals provided critical contributions to the Perfect Power prototype design and report content:

---

Joe Buri, Illinois Institute of Technology

Jim Crane, Exelon Corporation

Alex Flueck, Illinois Institute of Technology

Mohammad Shahidehpour, Illinois Institute of Technology

Brianna Swenson, S&C Electric

---

In addition, the project manager and authors wish to acknowledge the contributions of, and thank the numerous peer reviewers that participated in several Perfect Power prototype review meetings at the Illinois Institute of Technology.

# TABLE OF CONTENTS

# FIGURES



# TABLES

# GLOSSARY

AC – air conditioning
BIPS – building integrated power system
ComEd – Commonwealth Edison
CTQ – critical to quality
EPA – Environmental Protection Agency
GDP – gross domestic product
GTG – gas turbine generator
H.E. – heat exchanger
HMI – human machine interface
HRDS – high reliability distribution system
HRSG – heat recovery steam generator
HVAC – heating, ventilation and air conditioning
IIT – Illinois Institute of Technology
ISO – independent system operator
IPPSC – intelligent perfect power system controller
KV – kilovolt
KVA – kilovolt amperes
KW – kilowatts
KWh – kilowatt-hour
LED – light emitting diode
MW – megawatt
MWh – megawatt hour
NOx – nitrogen oxide
PLC – programmable logic controller
POTT - permissive over-reaching transfer trip
PJM – Pennsylvania, New Jersey, Maryland
PRV – pressure relief valve
PV – photovoltaic
RTU – remote transmitter unit
SAIFI - System Average Interruption Frequency Index
SW – switch
UPS – uninterruptible power supply
V – volts
VAR – volt-amp reactance or reactive power

# 1. THE PATH TO PERFECT POWER

In 2005, former Motorola chairperson Robert W. Galvin formed the Galvin Electricity Initiative to design and promote a power system that cannot fail the end user. By applying Six Sigma quality principles and available technology to enhance the efficiency, reliability and security of our dynamic power system, The Initiative intends to demonstrate that it is both economically plausible and practical to deliver “Perfect Power” to the consumer. The ultimate goal is to meet the needs of the end-user – perfectly, primarily by eliminating outages at the consumer level and lowering costs.

Electricity has been the primary transforming agent of the nation’s economy and society throughout the twentieth century. Today, the power industry is itself transforming. Over the coming decades, the industry will face numerous challenges, namely: much higher reliability and quality requirements posed by the digital economy, pressure to reduce carbon emissions from supply, severe weather, and aging infrastructure.

The path to Perfect Power includes four phases[1]:

1. Phase One: determine the innovations necessary to meet consumers’ needs over the next 10 to 20 years.
2. Phase Two: use these innovations to develop a comprehensive blueprint for achieving and maintaining a system that cannot fail the consumer.
3. Phase Three: develop and implement prototype systems that demonstrate the technical, policy and economic viability of Perfect Power to the industry.
4. Phase Four: open-source the prototypes to entrepreneurs and industry leaders who would use the results to improve system performance.

The Initiative approached IIT in early 2006 to propose using IIT’s main campus as a possible site for the first Perfect Power prototype. IIT is experiencing an average of three outings per year, which cost the university and estimated $500,000 annually. These outages disrupt classes, destroy key experiments, damage equipment, and force staff to schedule key experiments for the evening to minimize risks. At the same time, the university is facing growing demand for energy and the need to add infrastructure to accommodate this growth. IIT is balancing its facilities’ needs with a strong focus on sustainability, and is currently working to improve energy efficiency and reduce consumption. With the aforementioned realities at hand, IIT agreed to explore developing and implementing a Perfect Power System prototype for the IIT campus.

**Quality as a Guiding Principle**

The Galvin Electricity Initiative believes that continuous improvement methods, which have been developed and refined over the past century, provide utility executives and entrepreneurs with a lever for improving quality and spurring innovation in the electricity sector. Mr. Bob Galvin started using quality methods at Motorola in the 1970s. He asserted that the pursuit of perfection allowed Motorola to thrive in the face of fierce international competition. Mr. Galvin now sees an opportunity for utilities to leverage quality methods to achieve perfection, not in a few years, but over the next four decades.

*Perfect Power, in Mr. Galvin’s words, is a journey, not an end state.*

## 1.1. Applying Quality Methods: The First Step

The IIT team, together with utility executives, participated in two training courses on Six Sigma quality methods and principals. These courses were developed by the Joseph M. Juran Center for Leadership in Quality at the University of Minnesota, Carlson School of Management. The purpose of this training was to develop a replicable methodology for creating Perfect Power Systems. The path to Perfect Power leverages the following standard quality methods:

- Determining what is critical to quality (CTQ) from the customers perspective - Voice of the Customer
- Process mapping CTQ's and developing measures that quantify performance or the cost of poor quality
- Failure Modes and Effects Analysis (FMEA) for each process step
- Error proofing, innovative problem solving, and solution set generation
- Prioritization and implementation

The path to Perfect Power begins with defining the customer's needs and a set of metrics that provide evidence that the system has improved. The IIT team developed electricity system performance metrics (see Table 1) based on consumers' needs, applied error proofing to the IIT electricity system design, and developed cost effective means to mitigate failures/system shortcomings.

> "Quality is fundamentally about looking at products through the eyes of the customer", Jim Buckman Joseph M. Juran Center for Leadership in Quality

**Table 1 - Energy System Quality Metrics**

| Metric | Description |
|---|---|
| Interruptions as defined by the customer. This could include a loss of power, loss of a phase, or power quality fluctuation | • Measure interruptions/customer/year - SAIFI<br>• Prioritize customers - life safety, economic loss, damage<br>• Use these criteria to focus limited resources |
| Economic impact of outages | A measure of the real impact of each outage in terms of the impact on customers. Lost productivity, lost product, damaged goods, etc. |
| Asset utilization | The ratio of actual KWh delivered divided by the theoretical capability of the asset (KW times 8760). |
| Esthetics | Cities, developers, and customers are seeking to eliminate the blight caused by overhead distribution systems. |
| Carbon emissions | Reducing carbon footprint to minimize the environmental impacts. |
| Energy Costs | Energy costs compared with a baseline. In the case of IIT, this is the ComEd rates. |

Utilities may find that by working with customers to improve reliability and esthetics, they ultimately contribute to higher profit margins by spurring economic growth and increased asset utilization. Utilities and the cities they serve are competing for business and people. The electricity system can become an economic development feature for the region through improved esthetics, higher reliability, and lower overall costs - including the cost of interruptions.

## 1.2. The Cost of Imperfect Power

Six Sigma quality black and green belts learn that the cost of poor quality is not readily apparent. Specifically, many businesses do not measure the costs associated with quality. One key electricity industry measure for reliability – System Average Interruption Frequency Index (SAIFI)[2] - does not include interruptions resulting from weather damage. In addition, the electricity sector does not measure or track the costs incurred by customers due to a loss of electricity. Without knowing precisely the cost of interruptions, utilities cannot justify investments needed to reduce interruptions and their associated costs. Figure 1 provides a glimpse of the hidden costs of electricity interruptions. Furthermore, utilities do not factor in the impact of poor quality on economic development.

IIT experiences on average three outages per year. Yet there are no records of the cost of these outages. Lacking hard data, IIT management must estimate the costs of interruptions. This includes restoration costs, lost productivity, and ruined experiments.

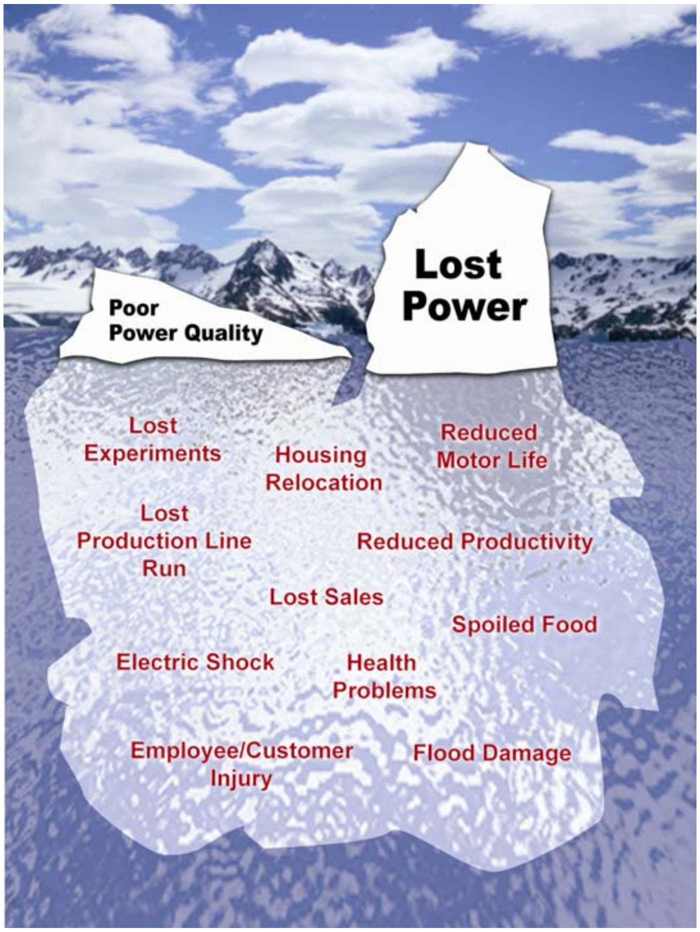



**Figure 1 - Imperfect Power Costs**

Lawrence Berkley National Labs (LBNL) attempted to capture the costs incurred by consumers in a September 2004 study titled, Understanding the Cost of Power Interruptions to U.S. Electricity Consumers[2]. This report reveals that the cost of power interruptions approaches $80 billion annually with the bulk of the cost being born by commercial users (see the adjacent figure from the LBNL report). EPRI estimated the annual cost of interruptions and power quality events at $119 to $188 billion annually. This equates to about 3 to 5 cents per kWh of electricity used each year in the nation[3].

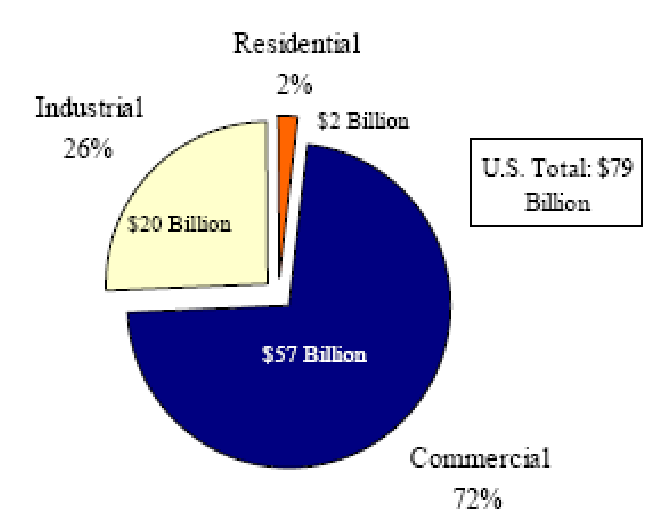



**Figure 2 - Power Interruption Costs**

LBNL recommended that utilities and regulators develop new metrics that will track the cost of interruptions in order to help justify the expenditures associated with improving power quality.

## 1.3. Where to Start?

While the current utility reliability metrics do not capture all power interruptions, these metrics provide a means for identifying a customer or group of customers with higher incidents of interruptions. IIT is a perfect example of a large utility customer that was experiencing approximately three interruptions per year or a SAIFI of approximately three. The electricity industry SAIFI average is 1.2. Utilities or others could initiate perfect Power projects for cities, campuses, or customers that are experiencing more that two to three outages per customer per year. Perfect Power projects should focus on customers with higher reliability requirements – life safety and significant economic loss potential.

**Utilizing Quality to Gain a Competitive Advantage**

According to Joseph M. Juran, founder of the Center for Leadership in Quality, quality is an attitude. Toyota adopted a quality attitude in 1954 and utilized this philosophy to become the world leader in automobile manufacturing. Toyota is focused on continuous improvements in all aspects of their business – quality is their culture. This culture led to continuous improvement in all aspects of the business, including a fundamental strategic shift toward hybrid cars in the early 1990's, well before the rest of the industry. Exceptional companies continuously look for new technology, processes, etc – new marginal practices.

# 2. IIT'S PRESENT ENERGY SYSTEM

The project began with the assessment of IIT's energy system which includes the following major subsystems. This Chapter details the condition of each energy subsystem.

- Area Substation Supply
- Campus Distribution
- Building Distribution
- Backup Power
- Energy Procurement
- Energy Sustainability

## 2.1. Area Substation Supply

Three separate circuits, fed from the Fisk Substation, supply IIT's electricity. Each circuit rating is 7MW. ComEd designs the electricity system to accommodate a single circuit failure. The supply system maximum demand is therefore 14 MW. IIT's highest peak load in the last two years was approximately 10MW.

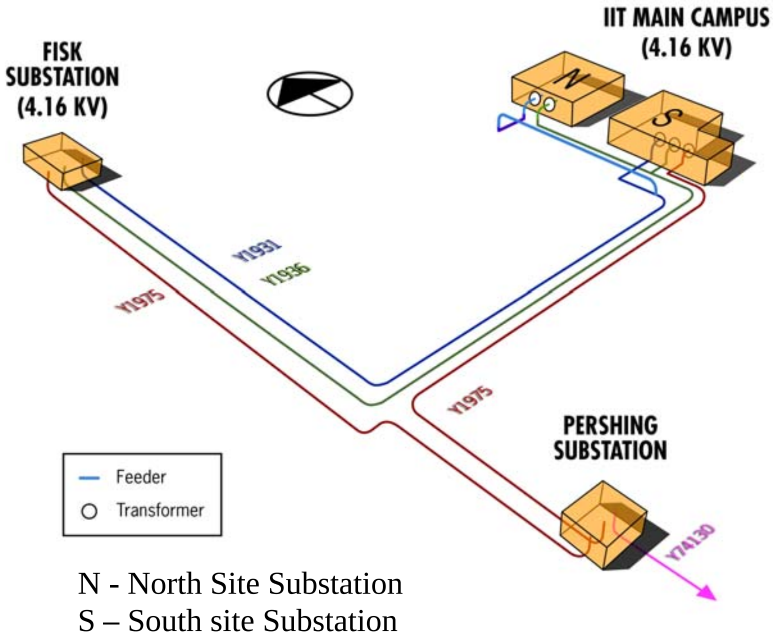



**Figure 3 - ComEd Supply to IIT**

- To the South Substation, all circuits run entirely underground from inside Fisk to transformers inside the substation. Circuits Y1931 (green) and Y1936 (blue), run directly from Fisk, and Y1975 (red) runs from Fisk by way of Pershing Substation.
- To the North Substation, Y1931 and Y1936 run underground until they reach the east side of Interstate 90/94 at $35^{th}$ Street. There, Y1931 emerges and runs north above ground approximately 2,000 feet to a point adjacent to the North Substation, then runs under the Metra train tracks and emerges into an outdoor transformer at the North Substation. Y1936 continues underground to the same location and emerges to enter another outdoor transformer. Y1975 does not supply the North Substation.

## 2.2. Campus Distribution System

IIT's 4,160V campus distribution system consists of the ComEd supply circuits, supply breakers, a north and a south substation, feeder breakers, multiple building feeder cables, building transformers, and transformer supply breakers. Most of IIT's buildings have redundant feeds from different substations. Buildings with redundant feeds utilize manual switches to change the supply source. IIT installed new 12KV cables to address cable failures and increasing demand.

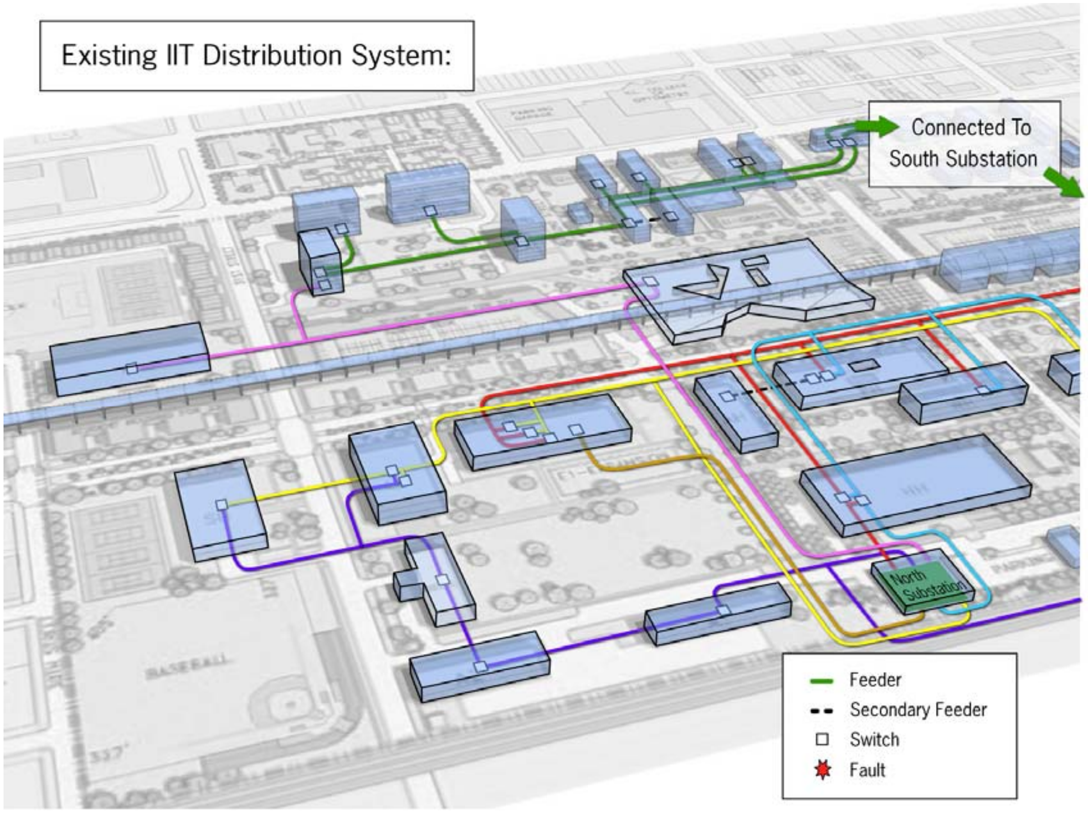



**Figure 4 - Campus Distribution System**

Figures 5 and 6 list the buildings on each feeder and substation. The buildings shown in bold are closed into and fed by the feeder shown (primary feed). The buildings shown in washout can be fed by the designated feeder, however, the feeder switch to this building is currently open(secondary feed). Table 7 provides the full building name for each abbreviation .

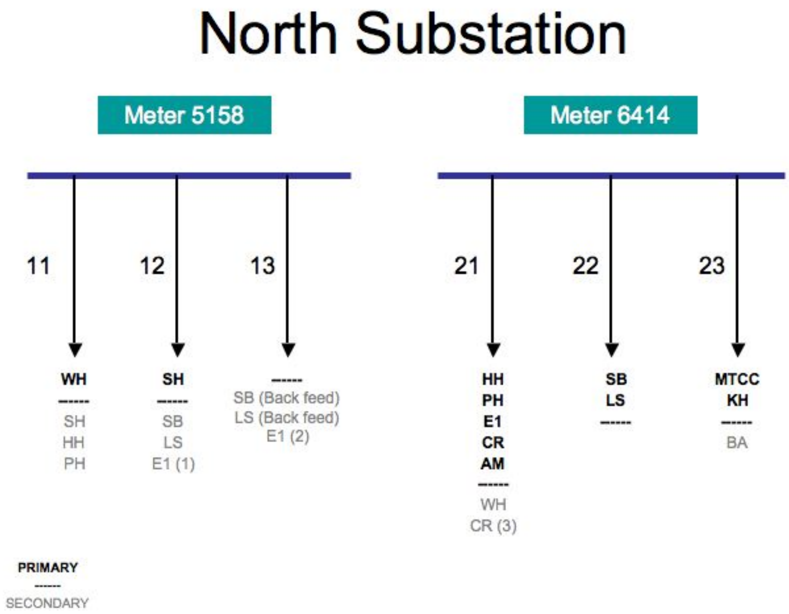



**Figure 5 - IIT North Substation**

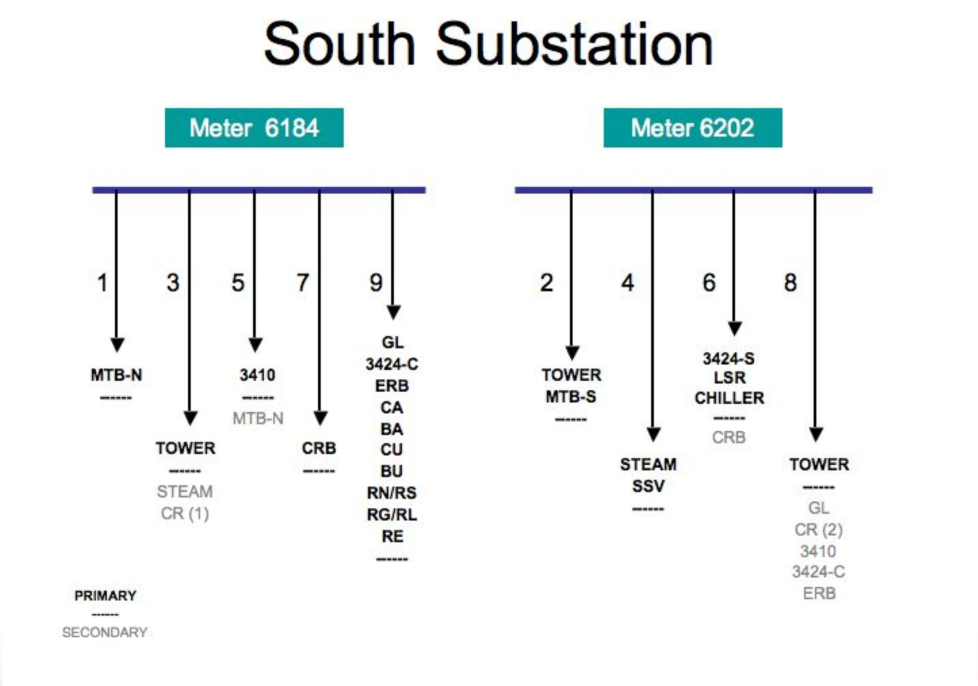



**Figure 6 - IIT South Substation**

## 2.3. Building Distribution System

The IIT Perfect Power team selected Siegel Hall as a research lab for continued improvements to the Perfect Power System and supporting technology. Figure 7 provides a schematic diagram of a typical building energy system for the buildings at IIT. Siegel Hall encompasses many of the infrastructure hurdles the Initiative is working to surmount. Siegel Hall's distribution system consists of two 4,160V feeds from the North Substation. Feeders 12 (primary) and 11 (secondary) provide feeder redundancy through manual switches 176 and 177, respectively, which feed into a 500KVA transformer where power is stepped down to 240V. Typically, two panels on each of the three floors distribute electricity to lights, fans and computers. A high-pressure campus steam system supplies heating.

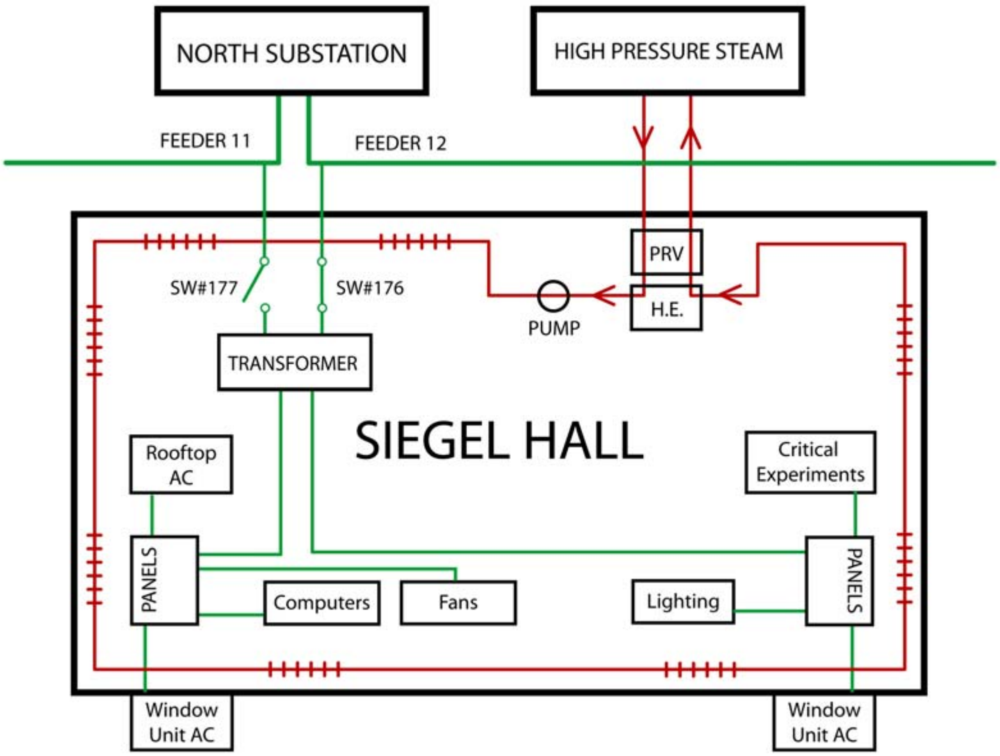



**Figure 7 - Siegel Hall Distribution System**

## 2.4. Backup Power

IIT installed over 2MW of standby generation to protect critical loads. Table 7 lists the buildings with backup generation.

## 2.5. Energy Procurement

IIT purchase electricity from Constellation Energy through a third party contract that expires in December of 2009.

## 2.6. Energy Sustainability

IIT is committed to reducing carbon emissions from energy use. IIT produces carbon dioxide emissions from the combustion of fossil fuels both on and offsite. Campus boilers burn natural gas and fossil-fueled electricity generators supply the purchased electricity. IIT is in the midst of a major upgrade to its heating system, installing more efficient boilers and energy distribution systems that will increase efficiency and reduce carbon emissions.

In order to slow growth in their electricity demand, IIT has embarked on an energy efficiency program to install advanced lighting, windows, chillers, and re-commission buildings. However, due to extensive new construction, consumption will increase by approximately 9,000,000 KWh over the next 10 to 15 years.

The campus can further carbon emission by buying electricity from renewable sources or from the use of on-site renewable, geothermal, or bio-fuel/gaseous fuel-fired generation.

**IIT's Carbon Footprint**

The World Building Council developed standard methods for estimating the carbon emissions from electricity use. This methodology relies on the U.S. Environmental Protection Agency's eGrid database (www.**epa**.gov/cleanrgy/**egrid**/ ) to determine the average carbon emissions from local electricity generation. An analysis of the EPA's EGRID data revealed that the electricity carbon factor for IIT is 1155 lb/MWh, IIT's annual electricity usage is approximately 50,000 MWh, which results in the release of about 30,000 tons of carbon annually to the atmosphere [5].

# 3. PERFECT POWER MODEL DEVELOPMENT METHODS

The team working with the Joseph M. Juran Center for Leadership and Quality learned that Six Sigma quality methods serve as the guiding principles when developing Perfect Power Systems. The methodology involves the steps shown below, which are applied to the IIT campus in this chapter.

1. Determining what is critical to quality (CTQ) from the customers perspective - Voice of the Customer
2. Process mapping CTQ’s and developing measures that quantify performance or the cost of poor quality
3. Failure Modes and Effects Analysis (FMEA) for each process step
4. Error proofing, innovative problem solving, and solution set generation
5. Prioritization and implementation

Utilities can apply this methodology to utility distribution systems, campuses, cities, major developments or one customer. The methodology leverages standard Six Sigma methods. This Chapter summarizes the results of applying these quality methods to the IIT campus energy system.

Utilities, suppliers, and manufacturers can utilize quality methods to improve all aspects of the power delivery business. Utilities such as Public Service New Mexico have trained Six Sigma black and brown belts and applied these methods to improve quality for customers while also lowering costs.

## 3.1. Customer Requirements/Voice of the Customer

The IIT campus serves several different customers with varying needs. This includes students, academic, research, and tenant interests. A loss of power can destroy experiments, result in lost productivity, and require capital resources to mitigate the impacts of the outage and restore power. IIT estimates that outages cost from $50,000 to $500,000 per occurrence (see Chapter 5 on Perfect Power benefits and value.

The IIT team identified the following strategic priorities for IIT’s power system going forward as well as a number of factors that are critical to quality for IIT’s constituents - academics, students, tenants, and administration:

**Table 2 - Voice of the Customer**

| Strategic Priorities | Voice of the Customer, Critical to Quality |
|---|---|
| Improve power reliability and quality | • Not losing multimillion dollar research experiments due to power outages<br>• The ability to run experiments at night due to poor power quality during the day<br>• Infrastructure to support new research, housing, and academic expansion<br>• Not having to temporarily house students due to a power outages |
| Manage energy costs by positioning IIT to participate in real-time pricing and ancillary services markets | • Mitigate costs of energy increases which could rise by 30% in 2007 |
| Build efficiency into all aspects of operation and maintenance of the energy system | • Eliminate existing high pressure steam system requires 24x7 oversight<br>• Increase Overall system efficiency which is currently inefficient |
| Develop a more sustainable energy system | • Reduce carbon emissions<br>• Incorporate sustainable power generation |

## 3.2. Process Mapping

The utility system was divided into the following major processes:

- **Supply** - this included transmission systems, larger area switch stations, area substations, and step down transformers
  - **Site Distribution** - substations, substation breakers, building feeders, building isolation, and communications
    - **Building Distribution –** switches, transformers and circuits within the building
      - **Procurement and Sustainable Energy Systems –** minimizing the energy and environmental impacts of the loads being served

## 3.3. Failure Modes and Effects Analysis/Error Proofing

The IIT Perfect Power team applied Six Sigma quality principals to identify and define the types of failures possible as well as how to prevent failures. According to the Juran Center for Quality many organizations fix problems after the fact, thereby incurring the costs of failure, others avoid fixing problems by adding costs – inspectors and redundancy. The Juran Center for Quality stated that 94% of failures are due to the system, not human error. Error proofing involves the following steps:

Step 1 - Diagram the process identifying each step and sub process.

Step 2 - List the failure mode for each sub process – what can go wrong?

Step 3 - Determine the severity – minor, moderate, major, or catastrophic – see Table 3

Step 4 – Determine the probability – remote, uncommon, occasional, or frequent – see Table 4

Step 5 – Apply the decision tree to the highest priority failures mechanisms based on multiplying probability index by the severity index.

- Single point weakness – no – stop
- Existing control measure – yes – stop
  - Detect and mitigate in an acceptable time frame
- If not proceed to error proofing

Step 6 – Perform error proofing

- Prevent
  - Elimination – eliminate the step or the failure mode
  - Replacement – increase replacement interval and assess condition. Determine and assess reliability metrics, replace human input with electronic recording
  - Facilitation – make it easer to do, reduce wear, operate at lower load, reduce current, improve power quality, etc…
  - Purchase higher quality device
- Minimize effect
  - Detection – monitoring and trending to predict failure before occurrence
  - Mitigation - redundancy

Exhibit B provides the results of the Failure Modes and Effects Analysis (FMEA) and Error Proofing. The team determined the severity and probability for each failure mode. The severity of the impact of a power failure depends upon the severity of the impact of the loss of power on the customer and may vary from customer to customer. See Table 3 for several possible severity designations:

**Table 3 - Failure Severity Designations**

| Severity | Description | Comments |
|---|---|---|
| Major | Loss of life and personal safety | Hospital, nursing home, home care, police, fire, and shelters<br>Manual switching of high voltage feeds can result in damage to equipment and injury to personnel. |
| Major | Significant economic loss | Flooding, manufacturing process, loss of produce/food, etc. Customers in areas subject to flooding can experience significant economic loses, if electricity is lost. |
| Moderate | Economic impact | Loss of productivity |
| Moderate | Esthetics | Cities, universities, and businesses are competing for resources and the esthetics of a site is now more important than ever. Overhead distribution systems and above ground switches and transformers take up valuable land, degrade views and reduces tree planting. |
| Minor | Little to no impact on operations | |

Once the severity was determined then the probability of occurrence was assigned. Table 4 provides the criteria for determining the probability.

**Table 4 - Failure Probability Designations**

| Probability | |
|---|---|
| Frequent | Several times a year |
| Occasional | Every 1 to 2 years |
| Uncommon | Every 2 to 5 years |
| Remote | Every 5 to 30 years |

The probability of occurrence is impacted by the distribution system design, age, and usage. The probability of failure increases depending upon a number of factors – see Table 5.

**Table 5 - Failure Severity Factors**

| Factor | Description |
|---|---|
| Severe Weather | Overhead systems subject to exposure to hurricanes, tornado's, high winds, and or lighting should be assigned a probability of frequent |
| Aging | Underground direct buried cable older than 20 years should be assigned a probability of frequent. |
| Usage | Systems operating at conditions above component ratings should be assigned a probability of frequent |
| Human Error | Above ground systems near roads and not protected from vehicular damage should be assigned a probability of frequent |

The combination of probability and severity were used to determine the type of solution pursued. The higher impact failure modes shown in red were addressed through a design change aimed at eliminating the failure mode. The lower impact failure modes will be resolved through the application of technology or resources to detect and mitigate the failure mode.

**Table 6 - Failure Categories**

| | Major | Moderate | Minor |
|---|---|---|---|
| **Frequent** | | | |
| **Occasional** | | | |
| **Uncommon** | | | |
| **Remote** | | | |

These methods were applied to the IIT campus and the results are shown in Exhibit B. Exhibit B provides a standard list of electricity system sub-processes. The priority weak links include:

- ComEd supply - IIT is located in an area subject to severe weather with only one transmission feed. In addition, the campus is supplied via older direct buried cables that have been experiencing failures. Furthermore, some of the ComEd supply system is still above ground and subject to weather damage. These two conditions result in an offsite power supply rating of "frequent". In addition, the severity of the impact is rated as moderate due to the economic impacts. IIT will need to ensure that the campus can be supplied by a local alternative source.
- Site distribution cables – IIT supplies a number of the campus buildings via direct buried cables. The buildings are supplied by two feeds that must be manually positioned. These failure modes should be eliminated through the Perfect Power design
- South substation – The IIT south substation is over 30 years old and nearing its capacity. The substation should be upgraded and the power feeds reconfigured to move some of the loads to the newer North substation.

The next chapter provides a summary of the results of error proofing.

# 4. SOLUTION: THE PERFECT POWER PROTOTYPE

IIT's Perfect Power distribution system is modeled after the "High Reliability Distribution System" (HRDS) developed and implemented by S&C Electric for the University of California at Santa Barbara. The team separated the campus into logical groups of buildings that will form electricity and thermal loops to maximize reliability and efficiency. Each electricity loop will be continuously energized. In the event of a loss of one section of cable or a switch, the design concept provides for the automatic isolation of faults without interruption of power to any loads. Re-closure is not necessary, but is available.

This system loop configuration is made effective by the use of intelligent switching and breaker coordination technology which provide for rapid assessment and isolation of faults via advanced communications. The Perfect Power system will be managed by an Intelligent Perfect Power System Controller (IPPSC) that monitors and trends critical parameters to determine the system state. The IPPSC will change system operating conditions to maintain the system within the specified limits of operation.

The Perfect Power System will be backed up by on-site generation which is sufficient to carry the entire campus load in the event of a loss of ComEd supply or a grid signal to provide ancillary service.

The Galvin Electricity Initiative identified the following attributes that will contribute to Perfect Power:

- Universal connectivity – connecting communications and electricity, think about services and value, not just KWh
- Power quality – microprocessor embedded into every device – digital power quality
- Portability – allow operation of devices without connectivity – storage
- Smart, self correcting infrastructure – auto coordination, reconfiguration, self healing. Digital switching and controls, sense system state, predict, and act. Isolate, reroute, add generation, and reduce demand – without impacting the consumer
- Value-based Cost – real time communications between devices and system

## 4.1. Perfect Power Elements

- Redundant Transmission Supply (not available at IIT)
- Redundant Area Substation Supply (not available at IIT)
- Self-Sustaining Infrastructure
  - Intelligent distribution system
    - High quality, properly sized cable and transformers
    - Feeder redundancy
    - Automated breakers and switches
    - Automated restoration
    - Coordinated communications
  - On-site electricity generation
    - Substation or building integrated generation
    - UPS/Storage
  - Demand response capability (AC, lighting, major loads)
  - Intelligent Perfect Power System Controller
    - Intelligent monitoring and trending
    - System configuration
      - Island mode
      - Demand response mode
      - Emergency backup mode
      - Response to price signals
      - Load control
- Sustainable/Green Building Technology Capability
  - ASHRAE Proposed Standard 189 or CA Title 24-2005
  - Use of the most advance lighting systems throughout the campus
  - Advanced window glazing, insulation, exhaust heat recovery, and building re-commissioning
  - Direct Current Circuits – provide perfect power quality to state-of-the-art digital laboratories
  - Use of higher efficiency HVAC components, improved insulation, variable air volume controls, soft start motors, and variable speed drives
  - Integration of district energy systems – hot water and/or chilled water loops
  - Installation of advanced building control systems to better manage heating, cooling and lighting
  - Use of enthalpy wheels to recover rejected energy from vented air from research labs, computer labs and other locations that require extensive ventilation.
  - Use of landscaping to provide solar shading and beautify the campus
  - Integration of renewable energy sources and/or procurement of electricity from renewable generators.

## 4.2. Perfect Power Benefits to the End-User

- Economic:
    - Savings
        - Reduced procurement costs
            - Real-time pricing
            - Day ahead demand reduction markets
        - Peak shaving
        - Energy efficiency
        - Improved power factor
        - Reduced and shorter outages
    - Revenue from ancillary services
        - Demand response
        - Spinning reserve
        - Load reduction
        - Grid support programs
            - VAR support
- Functional:
    - Reliability
    - Power quality
    - Power independence
    - Improved sustainability
    - Significant teaching and research opportunities and income

In the pursuit of Perfect Power, the team utilized the following Galvin Electricity Initiative documents as guidance in identifying solution to address failure modes and IIT constituent power needs.

- Master Controller Requirements Specification for Perfect Power Systems, Revision 2, November 9 2006[4]
- The Path to Perfect Power: New Business Opportunities for A Customer-Demand Driven Electricity World, November 2006[1]
- The Galvin Electricity Initiative: Task 3 – Technology Scanning, Mapping and Foresight, March 2006[5] Can box these references I think – note we changed the title of the New Technologies report when we released it to New Technologies Advance Consumer Control

The team then applied these Perfect Power elements and Initiative guidelines to the IIT system to design the IIT Perfect Power prototype.

## 4.3. Redundant Transmission Supply

Since the 2003 Northeast blackout, considerable effort was applied to update and automate transmission functionality and controls. The achievement of redundant or self-healing transmission supply to an area substation provides the most important step in stabilizing an area's power reliability.

## 4.4. Redundant Area Substation Supply

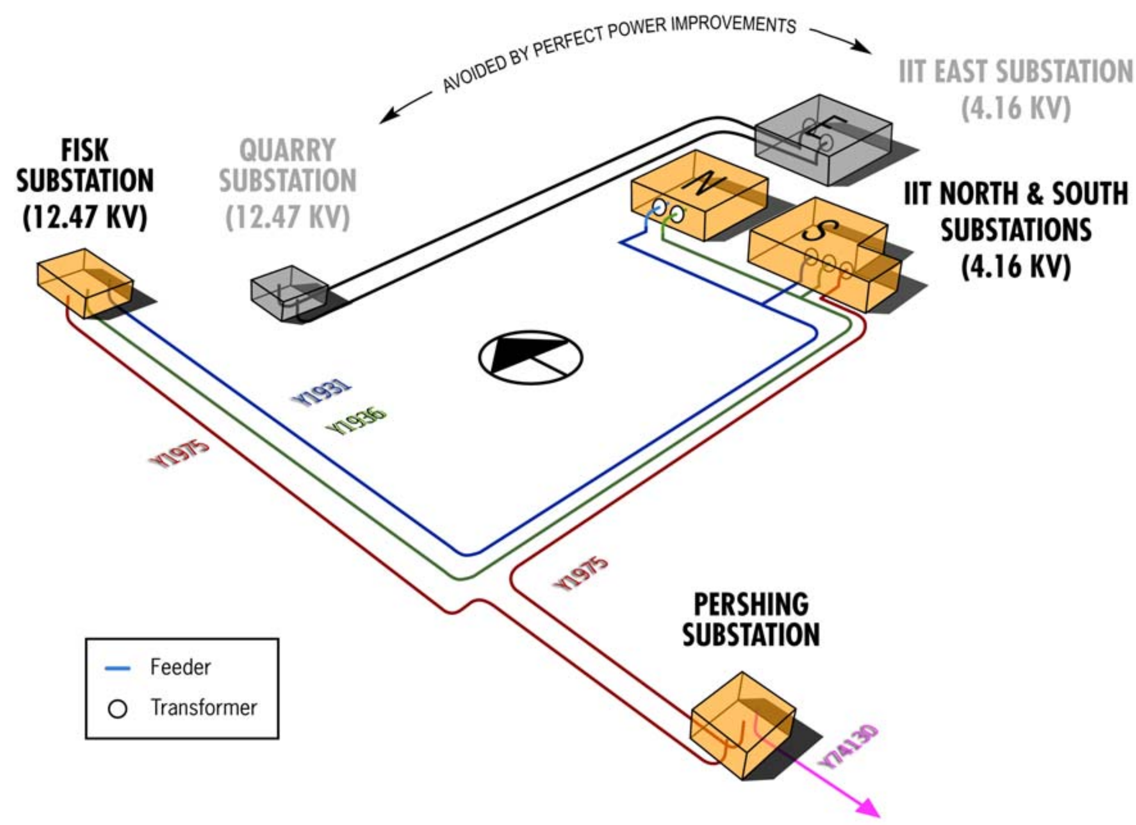



**Figure 8 - Redundant Area Substation Supply**

IIT and ComEd were pursuing a redundant power feed from the Quarry substation to a new substation on the east campus that would support the new housing and other campus improvements. However, the need for an east campus substation can be eliminated through the implementation of the Perfect Power prototype. The increased reliability, demand response capability and the on-site generation provide the desired redundancy.

ComEd estimated the cost of new east substation and associated distribution at approximately $5 million and $3 million, respectively.

ComEd will underground the remaining overhead supply along LaSalle Street and will provide animal protection for the two exposed transformers feeding the North Substation. ComEd will also perform preventative maintenance on the supply transformers.

IIT will also continue to upgrade its distribution system by installing 12.46KV rated components to lower system resistance losses and provide additional flexibility. This would also eliminate the need for the above ground ComEd transformers that currently step down ComEd distribution voltage of 12.46KV to the switchgear rating of 4,160V.

## 4.5. Self-Sustaining Infrastructure

Self-sustaining electric infrastructure is crucial for the success of a Perfect Power system. The many factors that can negatively affect power supply must be mitigated automatically by the system if outages are to be avoided. Many self-sustaining elements need to work in concert to achieve a true self-sustaining or self-healing electric infrastructure.

### 4.5.1. Intelligent Distribution System

An intelligent distribution system consists of properly-sized cable and transformers capable of carrying the full expected load; feeder redundancy to offer an alternate power supply to buildings where power is interrupted; automated breakers and switches to execute the split second isolation of faults; automated restoration; and a communications system capable of orchestrating this split-second reconfiguration of the system.

### 4.5.2. Properly-Sized Cable and Transformers

The team modeled the campus projected loads based on expected increases in enrollment and planned construction of new and re-commissioned of campus buildings. Transformers will be upgraded where necessary and new cables will be rated at 15KV. This will provide a robust feeder network and give IIT the option of eliminating substation transformers in the future. New transformers will be capable of performing at either 4.16KV of 12.46KV primary voltage. Table 7 outlines the projected loads these cables and transformers will need to serve:

**Table 7 - IIT Building Peak Demand and Abbreviations**

| Building | Abr. | Load (KW) | Building | Abr. | Load (KW) |
|---|---|---|---|---|---|
| 3410 | GTN | 301 | Incubator | ERB | 608 |
| 3424 Central | GTC | 412 | Keating | KH | 326 |
| 3424 South | GST | 412 | Lewis | RL | 141 |
| Alumni | AH | 169 | Life Sciences | LS | 699 |
| Bailey | BA | 289 | Res Hall N | RN | 141 |
| Boiler Plant | CP | 70 | Res Hall S | RS | 141 |
| Carman | CA | 289 | Lewis | RL | 141 |
| Commons | MTCC | 593 | Main | MB | 248 |
| Crown | CR | 242 | Metals N | MTBN | 204 |
| CTA1 | A2 | 49 | Metals S | MTBS | 204 |
| CTA2 | A3 | 123 | Perlstein | PH | 350 |
| Cunningham | CY | 289 | Res Hall N | RN | 141 |
| East Hall | RE | 139 | Res Hall S | RS | 141 |
| Engineering | E1 | 587 | Siegel | SH | 274 |
| Farr | FH | 91 | State Street Village | SSV | 431 |
| Fowler | FO | 139 | Stuart | SB | 318 |
| Galvin | GL | 292 | Tech Bus Center | CRB | 902 |
| Gunsaulus | GU | 289 | Tower | RT | 1810 |
| Hermann | HH | 596 | Vandercook | A1 | 97 |
| IITRI Center | LSR | 669 | Wishnick | WH | 275 |

### 4.5.3. Feeder Redundancy

Feeder Redundancy will allow the re-routing of power to buildings in the event of a fault on a distribution feed. Used in concert with high-speed automated breakers and switches, redundant feeders allow for the instant reconfiguration of the system to keep power flowing to all buildings.

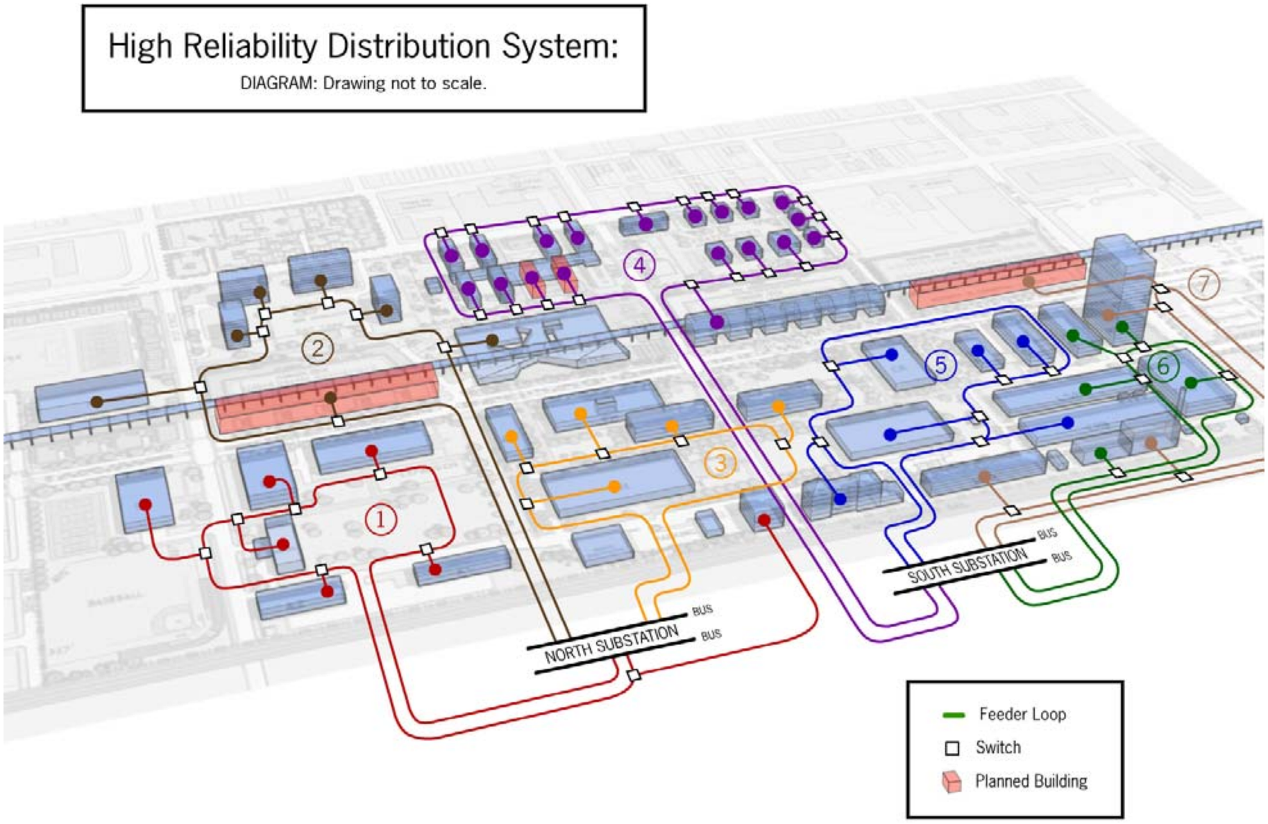



**Figure 9 - High Reliability Distribution Concept**

The HRDS 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 detect and isolate a fault without loss of power to the building.

The proposed HRDS design is reliable, versatile, upgradeable, and cost-efficient. The approach utilizes S&C Vista™ fault-clearing switchgear in a closed-loop system with SEL-351 directional over current protection relays. To meet the Perfect Power design criteria, the following schemes will be implemented:

- A Permissive Over-reaching Transfer Trip (POTT) scheme will be used to protect the underground feeder cables. Using this scheme with the S&C Vista switch and SEL-351 relays results in clearing of primary faults in less than 6 cycles. In addition, a Directional Comparison Blocking scheme is used as a back-up to the POTT scheme.

- Branch line faults will be cleared by the integral Vista Over-current Control, which can operate the fault interrupter to clear the fault in as little as 3 cycles.
- 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 Vista 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 feeder loop designs accommodate the projected building loads shown Table 7. The loop designs evenly distribute power and provide for stable distribution of power.

### 4.5.4. Automated Breakers and Switches

The isolation of faults will be executed by 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. This system of automated breakers and switches will employ:

- High speed, fault interrupting switchgear for the north and south main buses
- Automatic high speed transfer system – either at the individual building level, mid-distribution loop level, or substation level
- Multifunction directional over-current relays
- S&C Vista switches with vacuum fault interrupters

### 4.5.5. Distributed Intelligence

The Perfect Power System's first line of defense is the deployment of intelligent components that can monitor system conditions and take action to sustain proper operation locally. Smart switches combined with UPS and on-site generation will automatically respond to abnormal system conditions to maintain system stability and normal operations.

### 4.5.6. Coordinated Communications

In order for the system to function as a whole, to be efficient and flexible while maintaining a system wide cohesiveness, distributed intelligence will need to be connected and coordinated. In certain fault scenarios, there will be various and competing solution strategies. The proper diagnosis of problems and often the proper *sequencing* of solution steps is crucial, so disparate intelligent parts will have to be both aware of each other and controllable by a system overseer that can orchestrate the actions of the whole system.

The IIT Perfect Power prototype will leverage the research and design capabilities of IIT and ComEd to develop an advanced power communications system. The team will explore technologies ranging from fiber optics that would follow cable conduit to highly flexible and cost-effective ZigBee wireless technology.

### 4.5.7. On-Site Electricity Generation

For sites with redundant transmission and area substation feeds, full coverage of the demand through on-site generation is not required to achieve acceptable levels of reliability. In cases such as IIT where redundant transmission and area substation feeds are not feasible or cost effective, on-site generation increases reliability and provides for demand response. Furthermore, certain customers may require levels of reliability that are beyond even the most reliable distribution systems capability. Reliability is increased in the form of back up and grid-support generation. On-site generation comes in many forms, each with its own advantages and disadvantages based on the application. These range from load-specific back up (75-100KW), to building back up (300-600KW), to substation back up (2-4MW), to district energy (4-20MW) and can encompass renewable sources and UPS flywheels and batteries.

**Table 8 - Time Response for Generation Options**[6]

| Option | Start Time | Discussion |
|---|---|---|
| Diesel Fired Generation | 10 sec | Diesel generators start and load quickly but do not support demand response or real-time pricing due to run time restrictions (emissions limits and fuel storage) |
| Natural Gas-Fired Generation | 1 min | Start times are longer, improved environmental performance provides for longer operation to support demand response and real-time pricing. |
| Uninterruptible Power Supply (UPS) | Instantaneous | UPS ensures that power is not interrupted. However, it typically only provides a few minutes of power and is used to transition to diesels or natural gas-fired generation. IIT will deploy UPS as necessary to support local building Perfect Power needs. |

### 4.5.8. Substation Level Generation

The IIT Perfect Power team plans to install 4MW of on-site generation connected to the North substation to compliment the existing 8MW of generation connected to the south substation. The substation generation will be capable of carrying all of the campus loads in the event of a loss of offsite power. When called upon by ComEd or PJM, these on-site generation sources will support distribution and transmission-level load control programs.

### 4.5.9. Building Integrated Energy Systems

Figure 10 provides an overview of a Building Integrated Energy System which includes redundant electricity supply, efficient hot and chilled water supply, uninterruptible power source and/or generation, renewable energy sources, and an advanced building control system.

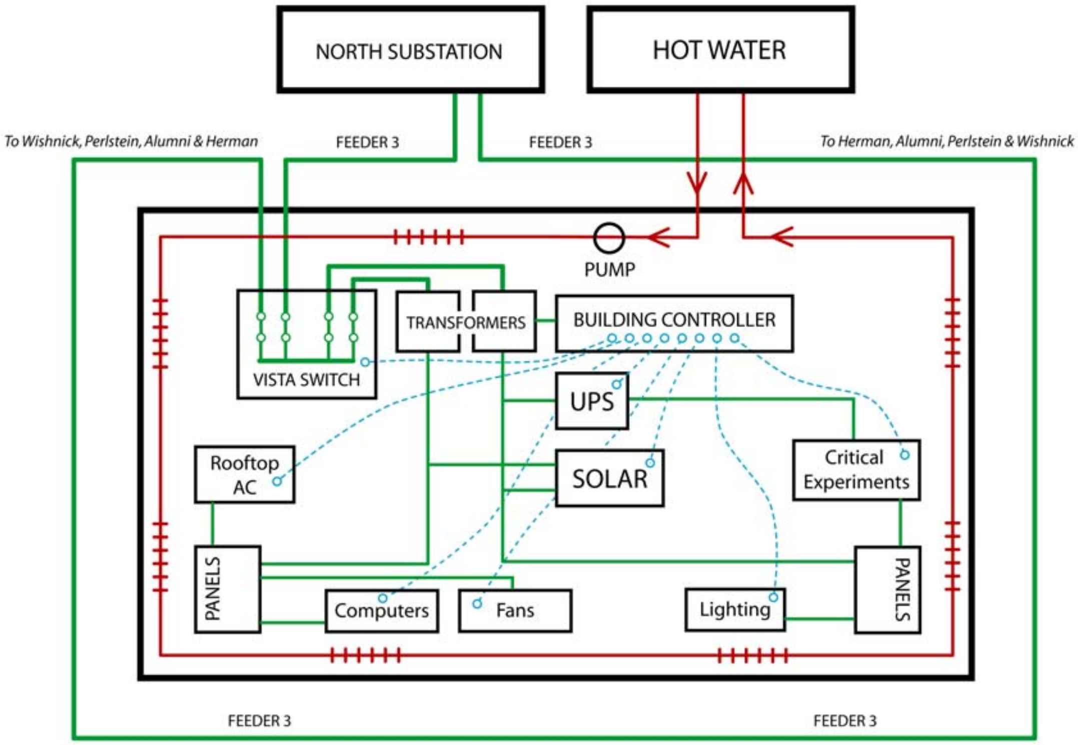



**Figure 10 - Building Integrated Energy System**

In cases where a HRDS system with substation electricity generation cannot be deployed, such as on a radial distribution system, building integrated power systems (BIPS) will provide local generation, power conditioning, and uninterruptible power ride-through capability. This typically requires local generation, inverters, and electricity storage, which is integrated with the building distribution system and loads.

The BIPS system, shown in Figure 11, will include:

- Local building generation to carry the building load for an extended distribution system outage
- UPS/storage to provide electricity while the local generation is starting
- Inverters or power quality conditioning devices
- A load controller to modulate that generator output to gradually unload the UPS and to follow the building loads
- Motor soft start capability for large motor loads such as elevators
- Non-critical load shedding capabilities
- Communication to Intelligent Perfect Power System Controller

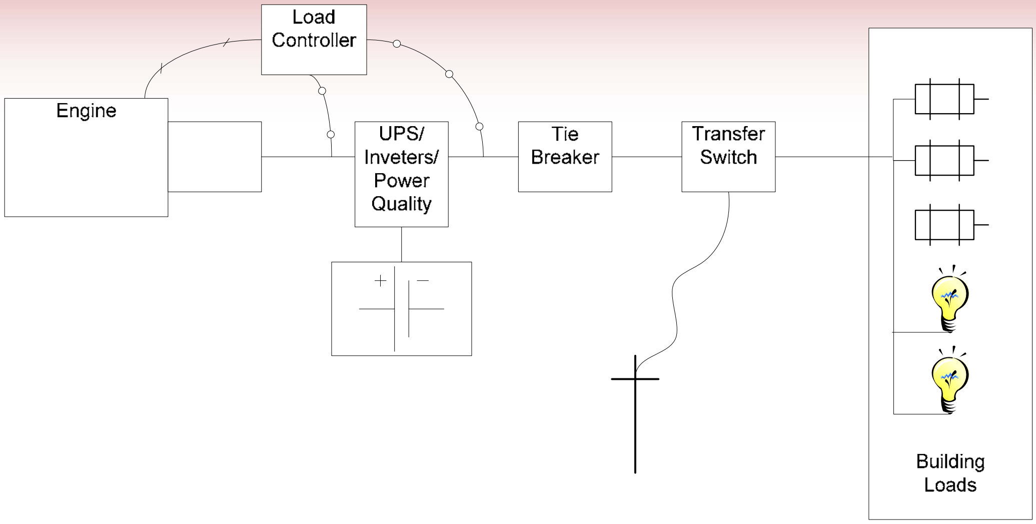



**Figure 11 - Building Integrated Power System**

### 4.5.10. UPS and Electricity Storage

This product can be designed to carry the load of a system for up to 120 seconds - for minor outages on a system that cannot tolerate even milliseconds without power (such as data and server centers) and as such is an important part of a self-sustaining infrastructure. A UPS can be coordinated with generators to carry system load for more than 120 seconds - this would be coordinated with IIT's substation generators. The UPS would instantly assume the load during an outage event and supply ride-through power until the generators are up and synchronized.

The UPS can utilize either flywheel or battery technology depending on the application. The Perfect Power prototype will utilize flywheels for loads where a small UPS footprint is necessary.

### 4.5.11. Demand Response Capability

Demand response capability consists of a two-fold approach. In some cases, building circuits can be switched off by the HRDS controller. For greater flexibility and precision, additional load controllers provide demand response control. A demand response load controller will operate the loads.

Figure 12 provides an electricity load duration curve for IIT. The x-axis is hours in the year and the y-axis is demand in KW. This curve reveals that IIT achieves a 10,000KW peak demand for one hour each year and uses a minimum of about 4,000KW in every hour of the year or base load. This figure also reveals the projected impact of IIT participating in the real-time pricing and demand response markets. Based on historic data, the real time price will exceed the operating cost of on-site generation 1,000 to 1,500 hours per year. IIT would run the on-site generation when the real time price exceeds the operating cost, reducing the peak demand for those days. In addition, IIT will deploy demand response capabilities to reduce another megawatt of IIT's peak demand. The combined generation and demand reduction strategies will reduce peak demand by at least 3,000KW.

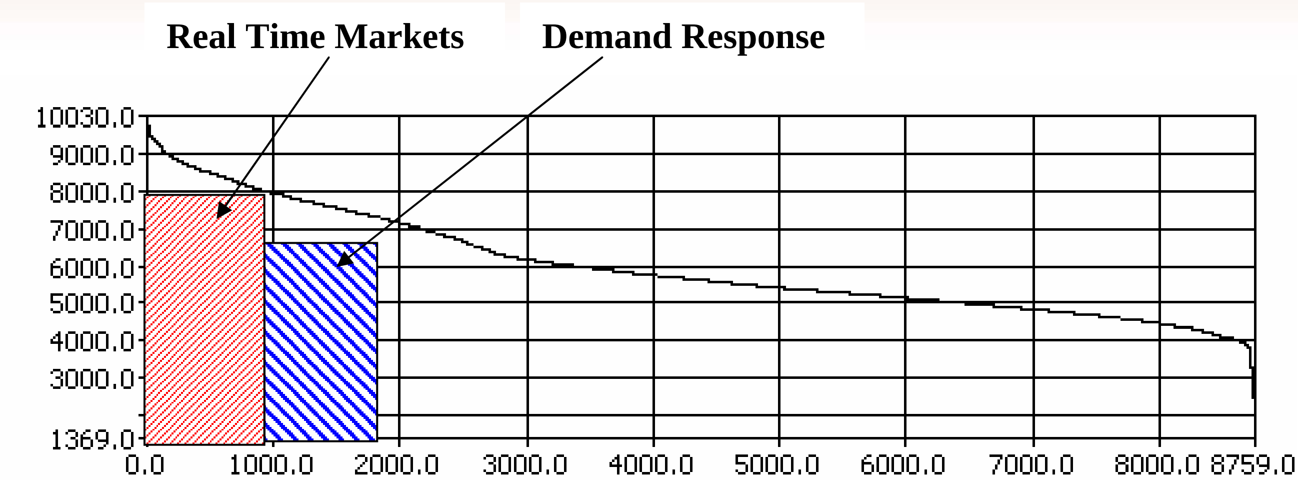



**Figure 12 - Projected Impact of Entering Real-time Pricing and Demand Response Markets on Current Load Duration Curve**

### 4.5.12. Intelligent Perfect Power System Controller

The Intelligent Perfect Power System Controller (IPPSC) is designed to optimize system performance. This includes reconfiguring the Perfect Power System to respond to threats and economic conditions. The Intelligent Perfect Power System Controller will then remotely configure the Perfect Power system to maintain stability.

The IPPSC, shown in Figure 13, will be an agent-based control system designed to interface with and coordinate the actions of controllers distributed around campus such as controllers for the HRDS, generation and building controllers. The IPPSC will consist of a supervisory agent and specialized agents that will interface with controllers distributed around campus. The primary role of the supervisory agent is to gather information from the outside world and determine modes of operation for the other agents distributed around campus. The specialized agent controller is used to provide functions and decision making ability not normally available in master controllers for generator sets, distribution systems or building load management systems.

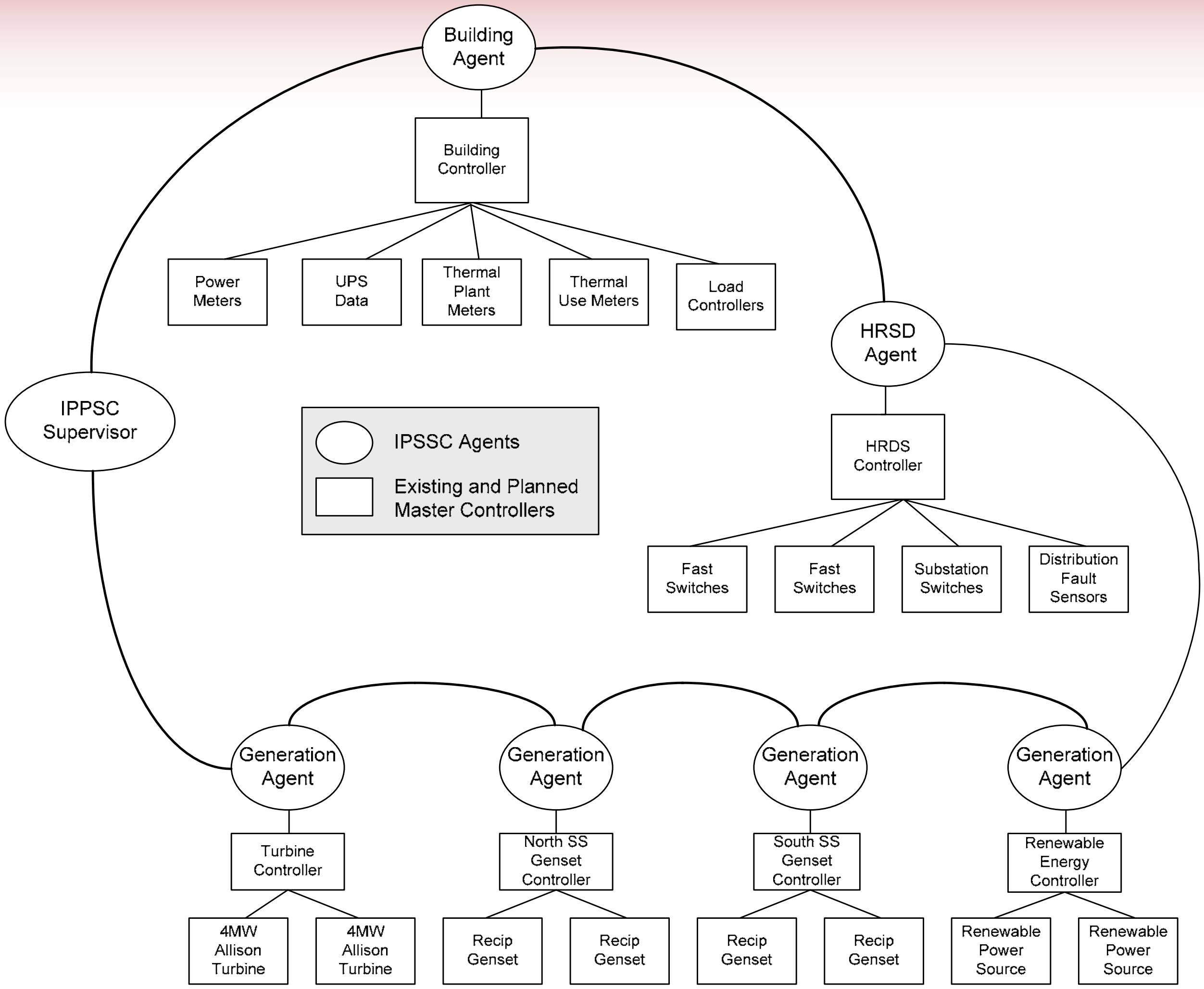



**Figure 13 - IPPSC Agent Concept**

Some of the IPPSC's tasks will include:

- Starting and stopping local generators and storage devices
- Controlling local loads based on predetermined sequence of operation and load reduction priority scheme
- Automatic switching of loads to alternate transformers, campus feeds, and substations.
- Placing a building or the entire campus in island mode

The overall site energy system control scheme will consider economic, environmental, comfort, threats and other end-use objectives to make decisions regarding the proper operating modes and sequences. The IPPSC enables perfection by anticipating system needs and taking action to mitigate threats to system reliability and performance. The IPPSC coordinates with agent controllers to manage the safe and reliable operation of the Perfect Power System, namely:

- Local generation
- Storage devices
- Demand response elements
- Smart switch controls
- Power quality devices

- The IPPSC continually evaluates both existing and possible conditions and chooses operating modes and operating conditions of local devices to maintain required reliability and power quality. This includes a dedicated SCADA system with user-friendly Human Machine Interface (HMI) and/or other intelligent operating systems.

**Intelligent Monitoring, Trending, Detection and Mitigation**

The backbone of the Perfect Power system is an intelligent trending, detection and mitigation system that collects thousands of inputs, trends these parameters, determines their potential impact, and changes the system operation to mitigate the consequences of adverse trends.

The monitoring and communications system includes the robust deployment of lower cost mesh sensors and modules that communicate via a wireless and wired IP-standardized communications network. This includes:

- Advanced meters at each breaker down to the main building panels which measure voltage, frequency, current, reactive power, power consumption, and harmonics, as well, as individual building loads (lighting, chillers, fans, and plug loads)
- Weather conditions and lightning sensors
- Signals from the IPPSC to dispatch generation based on PJM real time electricity and natural gas prices
- Local generation and storage output levels, storage capacity and fuel supply status

Some of the important trending functions include:

- Power vs. frequency curves
- Voltage vs. reactive power curves
- Power quality metrics and compensation
- Lightning detection and isolation of the campus when a threat is present
- Comparing overall power levels (real and reactive) with desired levels and taking action to sustain the desired levels
- Detecting voltage disturbances on the utility system and making a quick decision (within a few cycles) as to whether or not to stay connected or separate as an island
- Discriminating between disturbances originating on the utility system versus those originating on the Perfect Power System in order to initiate appropriate switching and protection steps
- Sensing and isolating faults while rerouting power to ensure power supply to all loads

**System Configuration**

The Intelligent Perfect Power System Controller will configure the system into different modes based on input from either the system or the operator. The specific modes of operation include:

- Grid Parallel Normal – system operates local generation and storage based on price signals, power quality needs, and projected electric loads for the day. This allows the campus to leverage real time prices by hedging higher electricity prices through the use of demand response and local generation
  - Economic optimization – selects the most economic sources, changes source supply, provides and records ancillary services (e.g. VAR's provided to utility grid)
  - Economics calculator, recorder, and forecaster – estimates savings based on calculating and comparing optimized configuration cost with the cost of operating in a non-optimized configuration. Utilizes tariff rates and real time prices.
  - System risk manager
  - Generator load dispatch models
  - Ancillary services calculator
  - Renewable generation tracker – forecasts and records renewable generation and credits
  - Real time price response capability
- Unplanned Island mode – able to match local generation with demand
  - Black start capability
  - Recover within 2 minutes with UPS/diesel to protect critical loads
- Planned island mode – approaching storm or threat, system isolates
- Safe Mode will override economic and efficiency factors to stabilize the grid – UPS/Inverters protect key facilities while generation starts in anticipation of more significant events. Normal economic optimization features are disabled. Local system conditions are monitored and loads/generators/power quality devices are operated to maintain the system within set point conditions
- Demand response mode

## 4.6. Sustainable/Green Building Technology Capability

The Perfect Power System will help IIT achieve its sustainability goals by reducing pollutant and carbon emissions through energy conservation, leveraging renewable resources, and reducing peak demand that strains the distribution system and increases energy costs[7]. IIT developed an Energy Master Plan in 2006 to provide a comprehensive strategy for maximizing energy efficiency and introducing renewable energy options. The energy master plan specifies energy efficiency improvements that will reduce electricity consumption by 11 million KWh and reduce natural gas consumption by nearly 1 million therms. These represent annually a 20% reduction in electricity consumption and a 10% reduction in natural gas consumption by IIT. This equates to a reduction of about 6,000 metric tons of carbon annually[8].

Energy consumption will be reduced through the following initiatives:

- Use of the most advance lighting systems throughout the campus – LED’s, day lighting, T8 fixtures, compact fluorescent lamps, and occupancy sensors.
- Advanced window glazing, insulation, exhaust heat recovery, and building re-commissioning designed to reduce building energy losses to the environment.
- Use of higher efficiency HVAC components, improved insulation, variable air volume controls, soft start motors, and variable speed drives
- Conversion of portions of the campus to high efficiency hot water loops and disconnecting these buildings from the high pressure steam loop.
- Installation of advanced building control systems to better manage heating, cooling, and lighting
- Use of enthalpy wheels to recover rejected energy from vented air from research labs, computer labs, and other locations that require extensive ventilation.
- Use of landscaping to provide solar shading and beautify the campus

# 5. PERFECT POWER BENEFITS

A power system that never fails to meet the customer's every functional need but is out of the financial reach of that customer is not perfect. Perfect Power meets the economic needs of the customer as well as the functional. The IIT Perfect Power prototype demonstrates that the very improvements that make it functional also make it affordable – not only saving the customer money but in some cases producing revenue.

IIT's Energy Master Plan specifies a vision that provides an efficient and effective energy system that enables and facilitates the planned university expansion and supporting facilities, faculty, staff and research space. The Strategic Objectives are to provide the required reliability to the facilities, manage costs, provide for peak power cost mitigation, reduce the campus's carbon footprint, and provide for employee and student safety. In addition, the Perfect Power prototype is designed to expand research and education grant opportunities.

Energy consumption at IIT is expected to increase with added students, staff, residents, research companies and tenants contributing to the growing use of campus facilities. In addition, by 2010 (2) new resident halls are planned to accommodate the increase in facility usage.

The proposed Perfect Power prototype addresses a number of existing and future campus needs. The campus is outgrowing the existing electrical distribution system in several areas and critical components are beyond or fast approaching the end of their useful life. This Perfect Power Prototype provides an opportunity to replace worn out components while applying the Perfect Power design in such a way as to eliminate extended outages at the campus.

## 5.1. Avoided Distribution System Upgrades

ComEd has indicated that the Perfect Power prototype will defer pending upgrades to the Fisk substation totaling approximately $2,000,000. In addition, planned new housing on east campus combined with expanded academic and research facilities throughout campus will exceed the capacity of the current site electricity distribution system. IIT was pursuing a third substation on east campus at a cost of over $5,000,000. The Perfect Power design will meet the new electricity demand and address reliability concerns without installing a new substation.

## 5.2. Reduced Energy Costs

The Perfect Power system positions IIT to purchase lower cost real time electricity and reduce peak energy demand which costs more. An analysis which compared the current electricity procurement agreement against the 2005 and 2006 real-time prices, determined that IIT would have saved approximately $1,000,000 per year purchasing electricity in real time while using the generation to cap the electricity price. IIT and ComEd are located in the Pennsylvania, New Jersey, and Maryland (PJM) Independent System Operator (ISO), which provides for the opportunity to purchase lower cost electricity in real time. Entering the real-time markets without a means for hedging hourly price spikes could result in a sizable increase in electrical costs. Electricity prices can reach $1 or more per KWh in peak periods. However, the IIT proposed on-site generation can be operated to mitigate peak demand prices, effectively capping prices at the operating costs of the on-site generation - 8 to 10 cents/KWh.

## 5.3. Reliability and Power Quality Benefits

The IIT campus experiences an average of three outages per year resulting in restoration costs, lost productivity and lost experiments that, in some cases, cannot be recovered. The Perfect Power prototype will ensure that no single failure in any of the distribution system feeder circuits will result in an interruption of power. In addition, the on-site generation will be increased to carry the entire campus's electricity demand during ComEd supply interruptions. This will provide for the automatic restoration of electricity to all campus facilities within 5 minutes of a ComEd supply outage. Critical campus loads/equipment has or will be equipped with Uninterruptible Power Sources (UPS) to bridge the five minute gap.

**Table 9 - Outage Costs**

| Cost | Impacts | Monetary Value |
|---|---|---|
| Lost Productivity | 3000 people at $30/ person for four hours | $360,000 |
| Restoration and Recovery | Temporary power equipment and staff resources | $100,000 |
| Recovery of Research Experiments | 5 experiments, 400 hours each, $30/hr | $60,000 |
| | Total | $520,000 |

Table 9 summarizes the measurable costs of power outages. With Perfect power, the IIT campus would also experience a number of benefits that are not currently measured. This includes extended equipment life due to improved power quality. One example is longer motor life due to elimination of voltage sags.

## 5.4. Improved Safety

The Perfect Power system will provide IIT with a significantly more robust energy system that can respond to weather, aging, and other threats, ensuring power to students, teachers, and tenants during emergencies. In addition, the Perfect Power system will automate high voltage switching throughout the campus, eliminating the potential for personal and equipment damage resulting from human error.

## 5.5. Ancillary Services

The Perfect Power system will position IIT to provide ancillary services to ComEd and PJM. This includes 10MW of spinning reserve, 3MW of permanent demand reduction, and the ability to supply imaginary power or VAR's. This provides a unique opportunity to participate in real time pricing, spinning reserve, capacity, and energy demand markets. The IIT Perfect Power system can leverage two 4MW turbines and the proposed 4 MW of substation sited generation to provide ancillary services to the PJM ISO. Specifically, IIT can participate in the following markets:

**Real-time pricing –** The PJM ISO allows for purchase of electricity in real time. Most facilities do not engage in real time markets due to price volatility risks. However, the Perfect Power system provides IIT with the ability to generate electricity for the entire campus at a fixed price, thereby providing a hedge when real time prices exceed 7 to 8 cents per KWh. This will allow IIT to purchase electricity from the lower cost real time markets and deploy its backup generation when the price of electricity exceeds 7 to 8 cents/KWh (backup generation marginal cost). This would result in approximately a $1,000,000 in savings based on the current Constellation contract electricity costs and 2005/2006 PJM real-time prices (see Figure 14). This represents a 25% reduction in annual IIT electricity expenditures.

**Spinning Reserve** – 2006 was the first year that demand reduction was allowed to participate in the spinning reserve market. This requires reduction of load within 10 minutes of receiving a request from the PJM ISO. The value of this market is minimal.

**Day-Ahead Economic Load Response** - IIT can bid a price in the day-ahead market specifying the times and duration that the demand reduction is available. PJM ISO will call on IIT the day before with a request for KW and a time slot.

In order to support real-time markets, IIT would need to upgrade the two 4MW natural gas fired turbines that are currently configured to provide prime power and steam to the campus. This will provide a local redundant power source and position IIT to purchase lower cost real-time electricity.

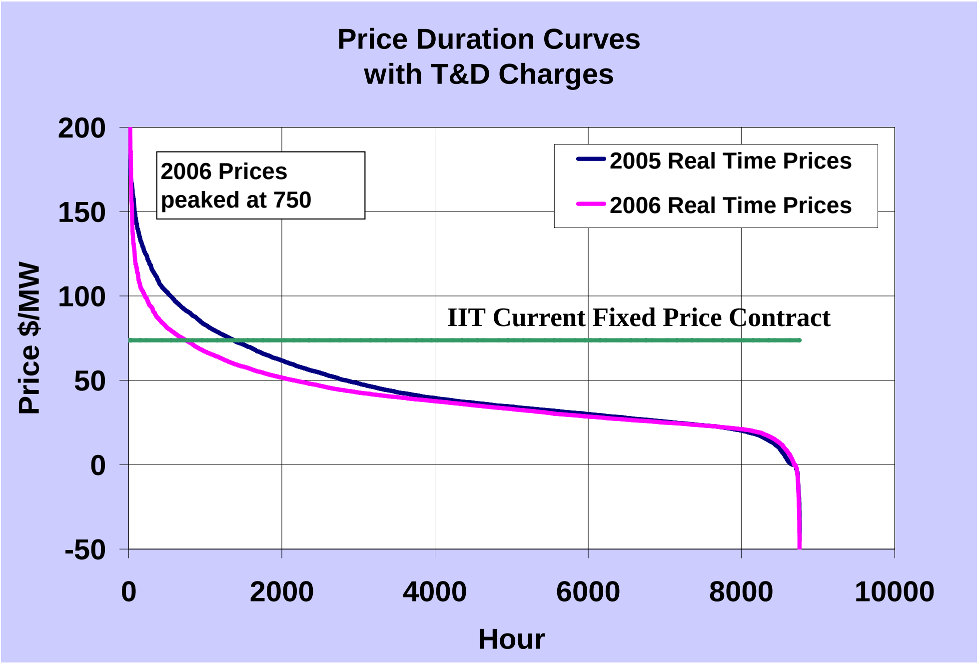



**Figure 14 - PJM Midwest Price Duration Curve Comparing Real Time Prices to IIT Contract**

## 5.6. Economic Development

The proposed improvements to the IIT electrical distribution system and the Perfect Power prototype position IIT as a test bed for research and education opportunities. IIT can serve as a living laboratory for the most advanced distribution system concepts and control technologies. This includes ComEd IPRO projects, Federal and State research grants, and NSF research and education grants. Implementation of perfect power at IIT will provide a powerful resource for attracting students and government/industry funding. The Electrical Engineering school expects to raise an additional $1,000,000 per year due to the added campus features and functions.

# 6. BUILDING PERFECT POWER

Because many upgrades cannot be supported without a prerequisite improvement to the infrastructure, IIT's Perfect Power system would be implemented in phases:

Phase 1 - Perfect Power Foundation and Sustainability
Phase 2 – Real Time Pricing/Ancillary Service
Phase 3 – Perfect Power, Distribution System Reliability and Automation
Phase 4 – Distribution Level Peak Demand Reduction

## 6.1. Phase 1 - Perfect Power Foundation and Sustainability

Phase 1 will prepare IIT's infrastructure for Perfect Power improvements. This includes completing the planned energy efficiency improvements and preventative maintenance to the ComEd supply system. The team will also complete detailed Perfect Power system engineering designs.

### *Task 1.0 – Energy Efficiency Upgrades*

IIT's sustainability goals as addressed in the Energy Master Plan will be accomplished in part by reducing pollutant and carbon emissions through energy conservation, leveraging of renewable resources, and reduction of peak demand which strains the distribution system and increases energy consumption and costs. Task 1 is part of an ongoing effort at IIT and is not included in the Perfect Power costs. Specific upgrades include:

- Advanced lighting systems throughout the campus – LED's, day lighting, T5 and T8 fixtures, compact fluorescent lamps, and occupancy sensors.
- Advanced window glazing, insulation, exhaust heat recovery, and building re-commissioning designed to reduce building energy losses to the environment.
- Higher efficiency HVAC systems, soft start motors, and variable speed drives.
- Landscaping to provide solar shading and beautify the campus
- Local high efficiency hot water loop systems which will supply building clusters.

### *Task 2.0 – Substation Supply Reliability*

The IIT North and South substations are supplied through three 12.47KV feeds originating from ComEd's Fisk area substation. Each feed is rated at approximately 7MW. The system is designed to accommodate the loss of one feed, providing IIT with about 14 MW of supply. However, the Fisk station is within 1MW of its rated capacity.

The three ComEd circuits that serve the IIT campus have experienced five failures over the past three years. ComEd performed high voltage integrity diagnostic testing to identify degraded cable sections. ComEd replaced two cable sections failed this diagnostic test. In addition, 2000 feet of remaining overhead cable will be buried completing the under grounding of IIT's supply from ComEd. The site transformers will be modified to provide animal protection and ComEd will perform thermal imaging and other standard preventive maintenance activities to verify transformer condition.

IIT will continue to replace the older cable throughout the campus. New cable electric cable will be rated at 12.47KV to increase capacity and reduce resistance losses.

### *Task 3.0 – Perfect Power System Design and Engineering*

The team will develop a detailed design for the Perfect Power model developed in this report. S&C Electric will lead this task, providing electrical schematics, wiring diagrams, bills of materials, and physical installation drawings. Endurant Energy will provide engineering support for the installation of the new generation.

## 6.2. Phase 2 – Real-Time Pricing/Ancillary Service

Phase 2 will provide the capability for IIT to enter real-time pricing and ancillary service markets with the installation of 4MW of natural gas generation to supplement IIT's two existing 8MW gas turbines and work in concert with the deployment of version 1 of the IPPSC (see Phase 2 Task 3.0). This new capability will provide for approximately 20% load reduction.

### *Task 1.0 – Install 4MW of Distributed Generation at Campus Substation*

Task 1.0 includes installing 4MW natural gas fired engine driven electricity generators.. This task includes engineering, constructing, installing and procuring the engines, switchgear, controls and balance of plant. The controls will include the modes compatible with the version 2 and version 3 specifications of the IPPSC (see Phase 3) for coordinating the generators with the loads and switches on campus. The engine generators and associated switchgear will be installed in the boiler house. Two retired boilers will be demolished and removed to create space for the new generation.

### *Task 2.0 – Turbine Fast Start and ComEd/PJM Portal*

In Task 2.0, IIT will install a ComEd/PJM communications gateway. The gateway will obtain price and ancillary service signals which will start local generators. In addition, the existing 8MW Allison Turbine cogeneration packages, located at IIT, will be retrofitted for fast start capability and to provide reliable duty for planned standby peaking service. This includes:

- Replacing the UV detectors in both gas turbine compartments,
- Installing a De-NOx water re-circulation loop to ensure required de-ionized water quality is available prior to initiating water injection to the gas turbine,
- To increase the availability and start-on-demand reliability, the existing Eaton variable frequency drives should be replaced with new, current design devices, suitably sized for the applicable duty cycle(s).
- Replacing the Woodward 511 with an Allen Bradley ControLogix PLC.
- Replacing the existing air/oil cooler to increase capacity.
- Modifying the control system programmable logic controllers to minimize the purge cycle time, reflecting the reduced downstream volume, thereby reducing the overall start time of the onsite generation. Further PLC modification may be required to remove inter-related permissives and signal "handshaking" between the GTG PLC and the de-commissioned HRSG controls.

### *Task 3.0 - Intelligent Perfect Power System Controller, Version 1*

Version 1 of the Intelligent Perfect Power System Controller (IPPSC) will include the functions required for entering the real time and ancillary service markets. This will include the ability to receive dispatch signals from Energy Connect for the various markets mentioned the ability to dispatch the gas turbines and the engine generator sets. Features for demand response and load shedding will be installed in Phase 3.

## 6.3. Phase 3 – Distribution System Reliability and Automation

Phase 3 is for the deployment of the advanced campus distribution system based on S&C Electric's High Reliability Distribution System (HRDS) design. This design leverages seven feeder loops working in concert with intelligent high-speed switches to isolate any single fault without interruption of power to buildings.

### *Task 1.0 IPPSC, Version 2*

Version 2 of the IPPSC will include implementing the functions for communicating and setting the interface with HRDS controller. In the event of a power outage, the IPPSC will have to coordinate with the HRDS concerning which building to switch on as the onsite generation comes online.

### *Task 2.0 – Substation Automation*

The IIT North Substation, installed only 10 years ago, includes switches and breakers that can be automated so that it is compatible with the HRDS system. The upgrades to the North Substation include conversion of microprocessor relays, new electronic meters, and advanced relays. Relays will be compatible with HRDS system when implemented.

The South Substation needs significant upgrades. Work at the South Substation will include replacing existing circuit breakers with new vacuum breakers, conversion to microprocessor relays, electronic meters, and advanced relays. Relays will be compatible with HRDS system when implemented.

### *Task 3.0 –High Reliability Distribution System Installation*

The purpose of this task is to design and develop the High Reliability Distribution System (HRDS) for the IIT campus. The HRDS will be based on the Perfect Power System model and will leverage S&C Electric's HRDS concept. The team separated the campus into logical groups of buildings that will each be placed on a HRDS loop. The HRDS loop will be continuously energized. In the event of a loss of one section of cable or a switch, the design concept provides for the automatic isolation of faults without interruption of power to any loads. Re-closure is not necessary, but is available. This system includes intelligent switching and breaker coordination technology that provides for rapid assessment and isolation of faults via a series of switches, breakers, advanced sensing, and advanced communications.

The proposed High-Reliability Distribution System is designed to be reliable, versatile, upgradeable, and cost-efficient. The approach utilizes S&C Vista™ fault-clearing switchgear in a closed-loop system with SEL-351 directional over current protection relays. To meet the Perfect Power design criteria, the following schemes will be implemented:

- A Permissive Over-reaching Transfer Trip scheme (POTT) will be used to protect the underground feeder cables. Using this scheme with the S&C Vista and SEL-351 relays results in clearing of primary faults in less than 6 cycles. In addition, a Directional Comparison Blocking scheme is used as a back-up to the POTT scheme.
- Branch line faults will be cleared by the integral Vista Over current control, which can operate the fault interrupter to clear the fault in as little as 3 cycles.
- 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 Vista 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 HRDS system will provide redundancy across the campus in the event of failures in the campus distribution system. The HRDS will also include its own SCADA systems for displaying the status of the campus distribution system, controlling the switches and coordinating with the IPPSC. The HRDS controller will include modes compatible with the IPPSC. For example, when the IPPSC is in normal grid parallel mode, the HRDS will perform self-healing tasks. In the unplanned island mode, the HRDS will be programmed to open switches to shut off power to all buildings. As generation comes online, the buildings can be incrementally switched back on.

## 6.4. Phase 4 – Distribution Level Peak Demand Reduction

In Phase 4, IIT will deploy peak load reduction measures, UPS, renewable energy sources, and final upgrades to the IPPSC. The team will install advanced demand response capability at the building level including UPS, renewable, controls on major electric loads (e.g. chillers, lighting, and building thermostats). The IPPSC will coordinate this demand response capability with on site generation to provide a robust demand response capability. The system will be capable of providing greater than 10MW of demand response capability.

### *Task 1.0 – Install UPS at Critical Buildings*

Perfect Power requires meeting the electricity needs of each individual customer without fail. For customers such as research laboratories with sensitive experiments, uninterruptible power supply will be needed. For these loads, UPS will be installed at the building and tied to the specific load where possible. In the event of a loss of utility power, UPS will support the load until on-site generation comes on line.

### *Task 2.0 - IPPSC, Version 3*

Version 3 of the IPPSC will include the implementation of additional functions for load shedding and coordinating demand response signals with the other controllers. In demand response mode, the IPPSC will shutoff loads according to predetermined load priorities. Part of the load shedding will be accomplished by shutting off power to entire buildings through the HRDS switches and the rest will be accomplished by communicating directly with specific loads distributed across the campus via the ZigBee network.

### *Task 3.0 – Peak Load Reduction Capability*

Load reduction for both starting and island mode during a blackout and for demand response can be accomplished two ways. The first method is to use the intelligent switches in the HRDS to turn off specific circuits that may contain loads such as chillers and non-essential lighting. The second method is to turn off loads and re-adjust thermostats using the load controllers under the Siemens building controllers. The agents for the building controller and HRDS will coordinate the optimal load shedding scheme depending on local conditions.

### *Task 4.0 – Solar PV*

The use of Solar PV will be used at IIT to reduce peak loads during the day. In the event of a demand response event, the output from the installed Solar PV will be forecasted and factored into the demand response scheme.

# 7. PERFECT POWER TIMELINE AND COSTS

Table 11 summarizes the estimated cost for each Perfect Power prototype implementation phases. Exhibit E provides the basis for these cost estimates. The project is projected to span five years.

- The first phase started by IIT several years ago and currently near completion, built the foundation for this project by improving the overall efficiency of the campus and the reliability of the ComEd supply system. These completed or underway Phase 1 activities are not included in the overall budget.
- The second phase includes modifying the existing site turbines for fast start capability and adding sufficient additional generation at the substation level to carry the entire campus demand. This phase will prepare IIT to participate fully in the demand response or day-ahead markets which will lower energy costs by over $1,000,000 annually. These savings will come from purchasing electricity in real time. This phase will also provide for continued operation of the IIT campus in the case of a loss of offsite power. Finally, this phase will allow IIT to provide demand response and spinning reserve services to ComEd and PJM.
- The third phase will create a redundant and intelligent distribution system that interfaces with a dynamic campus wide energy system controller. This phase will ensure continuous service to IIT buildings in the event of a site cable or switch failure. S&C vista switches automatically and instantaneously reconfigured when a fault is detected.
- The fourth phase will provide local UPS, solar, and demand response capability to complete the Perfect Power prototype. Phase 4 will enable the full demand response capability.

The estimated Perfect Power cost is $12,800,000 for all phases. As noted in Chapter 5.0, the Perfect Power upgrades will eliminate the need for increased site substation capability. IIT will avoid the estimated $5,000,000 cost of a new east campus substation. Furthermore, IIT determined that approximately $2,000,000 of the Perfect Power costs shown in Table 10 is needed to replace aging electric system equipment. Perfect Power will cost IIT approximately $10,800,000 in additional investment beyond the needed electricity system repairs and replacements.

This additional investment will be more than offset by the savings associated with procuring electricity in real time, revenue from providing ancillary services, and the avoidance of outage costs – see Table 10.

**Table 10 - Monetary Benefits Summary**

| Benefit | Period | Savings |
|---|---|---:|
| Electricity cost | Annual | $1,000,000 |
| Avoided ComEd Substation Upgrades | One time | $2,000,000 |
| Outage Costs | Annual | $500,000 |
| Avoided IIT Distribution Upgrades | One time | $5,000,000 |

**Table 11 – Costs for the Implementation of Perfect Power at IIT**
**See Exhibit E for a detailed cost basis for each task**

| ID | Item | Phase 2 Ancillary Service | Phase 3 HRDS | Phase 4 Demand Response |
|---|---|---|---|---|
| | Time Frame, years | 2.5 | 3 to 4 | 4 to 5 |
| | **Phase 1 Costs** | | | |
| 1 | Engineering/Project Management | $1,000,000 | | |
| 2 | Turbine Upgrades (Fast Start) | $1,000,000 | | |
| | **Phase 2 Costs** | | | |
| 3 | New Generation | $3,600,000 | | |
| 4 | IPPSC, V1 | $500,000 | | |
| | **Phase 3 Costs** | | | |
| 5 | IPPSC, V2 | | $400,000 | |
| 6 | North Substation Automation | | $500,000 | |
| 7 | South Substation Automation | | $900,000 | |
| 8 | Intelligent Switches | | $2,500,000 | |
| 9 | HRDS Loop Cables | | $1,300,000 | |
| | **Phase 4 Costs** | | | |
| 10 | UPS/Storage | | | $200,000 |
| 11 | IPPSC, V3, Demand Response | | | $500,000 |
| 12 | Solar PV | | | $100,000 |
| 13 | Transformers | | | $300,000 |
| | **Phase Totals** | $6,100,000 | $5,600,000 | $1,100,000 |
| | **Total Cost w/o generation** | $8,700,000 | | |
| | **Total Cost with generation** | $12,800,000 | | |

# 8. REFERENCES


1 The Path to Perfect Power: New Business Opportunities for A Customer-Demand Driven Electricity World, Galvin Electricity Initiative, 3412 Hillview Avenue, Palo Alto, CA 94304, (650) 855-2400, www.galvinelectricity.org, November 2006.

2 Lawrence Berkley National Labs Report, Understanding the Cost of Perfect Power interruptions to U.S. Electricity Consumers, September 2004, prepared by Kristina Hamachi LaCommare and Joseph H. Eto Ernest Orlando.

3 Department of Energy, Energy Information Association, Annual Energy Outlook 2006 Table A8 reports that the U.S. used 3,730 billion KWh in 2004.

4 Master Controller Requirements Specification for Perfect Power Systems Rev. 2.1, Galvin Electricity Initiative, 3412 Hillview Avenue, Palo Alto, CA 94304, (650) 855-2400, www.galvinelectricity.org, November 2006.

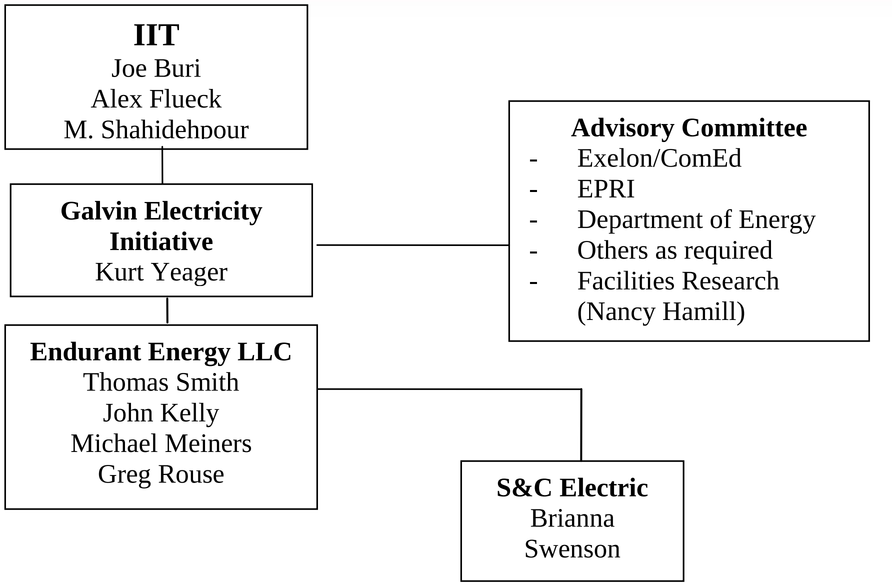
5 The Galvin Electricity Initiative: Task 3 – Technology Scanning, Mapping and Foresight, Galvin Electricity Initiative, 3412 Hillview Avenue, Palo Alto, CA 94304, (650) 855-2400, www.galvinelectricity.org, March 2006.

6 Based on May 21, 2007 meeting with Endurant Energy, IIT and Patten Power, the local CAT dealer.

7 Illinois Institute of Technology Main Campus Energy Master Plan, March 22, 2006

8 World Business Council Greenhouse Gas Protocol, Imported electricity emissions factors are from http://www.ghgprotocol.org/templates/GHG5/layout.asp?type=p&MenuId=OTAx which provides a spreadsheet tool with CO2 emission factors. For this region a factor of 1.237 lbs/KWh is provided.

# EXHIBIT A: PROJECT TEAM




| Name | Affiliate | Phone | Email |
|---|---|---|---|
| Kurt Yeager | Galvin Initiative | (650) 855-2400 | KYEAGER@epri.com |
| Joe Buri | IIT Facilities | (312) 567-8982 | buri@iit.edu |
| Alex Flueck | IIT Faculty | (312) 567-3625 | flueck@iit.edu |
| Michael Lynch | IIT Facilities | (312) 567-8992 | lynch@iit.edu |
| David Schmidt | IIT Facilities | (312) 567-3992 | Schmidt@iit.edu |
| Mohammad Shahidehpour | IIT Faculty | (312) 567-5737 | ms@iit.edu |
| Nancy Hamill | Facilities Research | (847) 712-6251 | nhg@FacilitiesResearch.com |
| Susan Anicich | Exelon/ComEd | (773) 838-4368 | Susan.anicich@exeloncorp.com |
| Brad Schug | Exelon/ComEd | (630) 437-2749 | Brad.schug@exeloncorp.com |
| Jeff Williams | Exelon/ComEd | (312) 394-3095 | jeffreyr.williams@exeloncorp.com |
| Jim Crane | Exelon/ComEd | (630) 576-7034 | james.crane@exeloncorp.com |
| Brianna Swenson | S&C Electric | (773) 513-9382 | bswenson@sandc.com |
| Don Von Dollen | EPRI | (650) 855-2679 | dvondoll@epri.com |
| Dave Crudele | EPRI | (518) 596-8842 | dcrudele@epri.com |
| John Kelly | Endurant Energy | (630) 453-8696 | John.kelly@endurantenergy.com |
| Michael Meiners | Endurant Energy | (773) 505-4070 | Michael.meiners@endurantenergy.com |
| Thomas Smith | Endurant Energy | (630) 240-7510 | Thomas.smith@endurantenergy.com |
| Greg Rouse | Endurant Energy | (630) 299-8454 | Greg.rouse@endurantenergy.com |

# EXHIBIT B:  FAILURE MODES AND EFFECTS ANALYSIS

## ComEd Supply

| Sub-Process | Failure Modes | Severity | Probability | Solution Set |
|---|---|---|---|---|
| ComEd Substation IIT fed from the Fisk Substation | Lose supply power due to system event or weather<br>Component failure | Major | Remote | Install east substation to provide a redundant external supply from Quarry Substation<br>Install new feed to north and south substations from Quarry<br>Develop island mode capability<br>Install backup power at key facilities<br>Install lighting detection and switch to safe mode during a threat |
| ComEd Substation Breaker | Overload trip | Major | Remote | Current supply rating is 14MW; assuming one of three feeds is lost.  IIT peak load is 10MW.  ComEd could move other site loads to another substation |
| | Nuisance or fault | Major | Remote | IIT has one redundant supply; however, north and south substation feeds do not have an automatic crosstie.  Install automatic cross tie switch |
| 12.47KV Feeder, three total | Cable failure - lost feeder due to weather, equipment failure, or human error | Major | Frequent | Install automatic crosstie |
| | | | | |
| | | | | |
| | | | | |
| | Truck knocks down pole | Major | Remote | All underground except 2000 feet, underground remaining overhead lines. |
| | Lightning strike damages equipment | Major | Remote | All underground except 2000 feet, underground remaining overhead lines. |
| | | | | |
| | | | | Install lightning protection on all key equipment |
| | Cable failure | Major | Frequent | Install automatic crossties |
| | | | | Install east substation to provide a redundant external supply. |
| | | | | Install new feed to north and south substations |
| | Loss of a phase | Major | Remote | Install advanced metering and isolation capability<br>Install automatic crossties |
| | Voltage sag | Minor | Remote | Install local generation and/or power conditioning equipment |
| Transformer | Animal, weather, lightning, accident | Major | Remote | Protect transformer from animals and weather |

## EXHIBIT B: FAILURE MODES AND EFFECTS ANALYSIS

# Campus Distribution

| **Sub-Process** | **Failure Mode** | **Severity** | **Probability** | **Solution Set** |
|---|---|---|---|---|
| IIT North and South Buses | Over capacity | Moderate | Frequent | Automatic reconfiguration of loads<br>Upgrade substation |
| | Power quality | Moderate | Need metering data | Active power quality filters. |
| | | | | Condition monitoring (V, current, frequency) |
| | Equipment failure due to aging | Major | Moderate | Replace south substation |
| | | | | |
| Building Feeder | Over Capacity | Moderate | Varies | Install new cable, transfer load |
| | Aging – short to ground | Major | Uncommon | Replace older cables |
| | | | | Backup power and electricity storage |
| | | | | Automatic reconfiguration of loads |
| Communications | Wire fault or damage | Moderate | Frequent | Wireless communications |
| | Router failures | Moderate | Uncommon | Redundancy |
| | | | | Intelligent agent system |
| | | | | State estimation and optimization |
| | | | | Advance pattern recognition and visualization |
| | | | | Dynaflo distributed series impedance sensors |
| | | | | |

## EXHIBIT B: FAILURE MODES AND EFFECTS ANALYSIS

# Building Distribution

| Sub-Process | Failure Mode | Severity | Probability | Solution Set |
|---|---|---|---|---|
| **Electricity** | | | | |
| North or South bus | Lost power | Major | Occasional | Backup power and electricity storage |
| Supply feeder | Lost power | Major | Occasional | Redundant feed, backup power and electricity storage |
| Supply switch | Manual operation | Major | Remote | Solid state transfer switches |
| | | | | |
| Transformer | Overload | Moderate | Frequent | Install demand control at major loads |
| | Voltage sag | Moderate | Need data | Upgrade transformer and/or install UPS/Inverter |
| | Harmonic distortion | Moderate | Need data | Upgrade transformer and/or install UPS/Inverter |
| | | | | |
| Panel Feeder | Over Capacity | Moderate | Frequent | Change from aluminum to copper wire |
| Distribution Panel | Power quality | Moderate | Need data | |
| Load Breaker | Failure to open | Major | Remote | |
| | Overload trip | Major | Remote | |
| Load Feeder | Short | Major | Remote | |
| | | | | |
| **Heating** | | | | |
| Steam supply | Loss of steam system | Major | Occasional | Install local hot water backup or convert to hot water |
| PRV | Valve failure | Major | Uncommon | PM, replace with QA component |
| Heat exchangers | Fouling | Major | Remote | PM |
| Pumps | Motor or pump failure | Major | Occasional | PM/trend performance, replace with QA component |
| | | | | |
| **Cooling** | | | | |
| Compressor | Motor failures | Major | Uncommon | PM |
| Fan | Motor failures | Major | Uncommon | PM |
| Damper | Mechanical or electric | Major | Uncommon | PM |
| | | | | |
| **Building Isolation** | Unable to isolate from fault | | | Automate load shedding and sequencing |

## EXHIBIT B: FAILURE MODES AND EFFECTS ANALYSIS

# Building Integrated Power System (Generation, Storage, Heating, and Cooling)

| Sub-Process | Failure Mode | Severity | Probability | Solution Set |
|---|---|---|---|---|
| Starting power | Battery stolen | Major | Occasional | Lock up batteries |
| | Battery discharge | Major | Occasional | Automatic recharging |
| | | | | |
| Generator Cooling | Water quality | Moderate | Uncommon | Include water quality management |
| | Improper flow | Major | Uncommon | Proper design |
| | Failed pump | Major | Uncommon | Purchase high quality pumps, Mil Spec |
| | Temp Control Valve | Major | Remote | Purchase high quality, Mil Spec |
| | Exhaust blockage | Major | Remote | Pressure Alarm |
| | Improper ventilation | Major | Uncommon | Temp Alarm |
| | Failed vent fan | Major | Uncommon | Temp Alarm |
| | | | | |
| Load Transient | Grid disturbance trip | Major | Frequent | Active harmonic filtering |
| | Lightning strike trip or damage to equipment | Major | Frequent | Start unit as storm approaches and isolate |
| | Exceed inrush | Moderate | Occasional | Automate and sequence load shedding and starting |
| Spark plugs | Short | Moderate | Occasional | PM |
| | | | | Trend gap and condition post maintenance |
| | | | | Monitor O2, coil voltage, |
| Generator | Winding short | Major | Uncommon | Trend voltage input signal versus power output |
| Fuel supply | Run out of fuel oil | Major | Occasional | Utilize natural gas engine |
| Gas compressor | Motor | Major | Remote | Purchase high quality motors |
| Voltage Regulation | Low voltage | Moderate | Frequent | Automatic load sequencing |
| | | | | |
| | | | | |
| | | | | |

# EXHIBIT B: FAILURE MODES AND EFFECTS ANALYSIS

## Procurement and Sustainability

| Sub-Process | Failure Mode | Severity | Probability | Solution Set |
|---|---|---|---|---|
| Asset Utilization | Higher capital costs due to poor utilization of site distribution components | Moderate | Frequent | Prioritize loads and develop load transfer and shed capability |
| | | | | Reduce cooling loads |
| | | | | Energy storage |
| | | | | Monitor all feeder loads |
| | | | | Install generators or electricity storage for demand response |
| | | | | |
| Efficiency | Poor process efficiency | Major | Frequent | Advanced lighting, windows, and HVAC |
| | | | | Improve building envelop and controls |
| | | | | Exhaust heat recovery via sensible wheel |
| | | | | Install real time price response capability |
| | | | | Occupancy sensors and smart thermostats |
| | | | | Variable speed drives |
| | | | | Solar shading |
| Energy Costs | Inability to take advantage of lower cost of real time pricing | Major | Frequent | Develop the capability to supply 6 to 8MW of campus loads utilizing backup power, storage, demand response, and cogeneration. |
| | Ancillary services | NA | NA | Supply VAR's, demand response |
| | Carbon reduction | NA | NA | On-peak cogeneration to offset carbon emissions |
| **Sustainability** | | | | |
| Reduce carbon footprint | Procurement of coal generated electricity during on-peak periods | Major | Frequent | On-peak cogeneration to offset coal purchases |
| | Poor energy efficiency | Major | Frequent | See above |
| | | | | Building shading using trees which also consume carbon |
| | | | | |
| Increase use of renewable sources | Low renewable resource | Major | Frequent | Solar hot water, PV, |
| | | | | Purchase renewable generation |
| | | | | Geothermal |

# EXHIBIT C:  SOLUTIONS SET

| Upgrade | Purpose/Benefit | Specification[1] | | |
|---|---|---|---|---|
| **Enabling Technologies/Perfect Power Foundation – Transition to a 12KV platform** | | | | |
| Replace north and south substation | Replace aging equipment, upgrade to 15KV, advanced switchgear and controls for HRDS loops, eliminate transformers at substation | | | |
| Campus Distribution Conductors/Cables – 15KV | Increase capacity  and reduce losses | 15KV | | |
| Automate Building Switches | Enable remote and automatic reconfiguration of building loads and enable self healing mechanisms | Solid state transfer switches, quarter cycle response time, smart switches which isolate fault and reroute power to alternate sources | | |
| Building Transformers | Replace aging equipment and improve power quality | Install transformers that can be switched from 4KV to 12KV | | |
| Building Feeder Meters | Install advanced metering | Monitor power, reactive power, harmonics | | |
| Building Distribution Conductors/Cables - Copper | Increase capacity of existing aluminum conductors | | | |

[1] List of key functions, requirements, features.

# EXHIBIT C: SOLUTIONS SET

| Upgrade | Purpose/Benefit | Specification[1] | | |
|---|---|---|---|---|
| Loop system/redundant building feeds | | Coordinate with substation and fast intelligent switches. This system needs to include an HRDS controller compatible with the IPPSC | | |
| High speed dedicated communications network | Provide data gateway to various controllers around campus. Enables controllers to operate autonomously without Intelligent Perfect Power System Control should it fail | | | |
| **Intelligent Monitoring** | | | | |
| System meters | | | | |
| Weather monitoring and lightning sensors | Temperature, humidity and barometric pressure used for forecasting loads and solar panel generation. This data combined with the lightning sensor will be used for threat assessment. | | | |
| PJM real time price signals | Used to forecast purchased electricity and initiated self generation mode | Compatible with requirements of the IPPSC. | | |
| Local generation and storage | Used to predict and notify users when a failure or maintenance issue may be imminent. | | | |

# EXHIBIT C: SOLUTIONS SET

| Upgrade | Purpose/Benefit | Specification[1] | | |
|---|---|---|---|---|
| **Intelligent Perfect Power System Controller** | | | | |
| Develop Perfect Power system modes of operation | Provide for modes of operation which sustain system operation | Island mode, safe mode, real-time pricing models | | |
| Automatic load shedding and sequencing | Supports islanding, demand response and power quality functions. | | | |
| **Intelligent Trending, Detection, and Mitigation** | | | | |
| Power Quality (frequency, voltage, power, reactive power, harmonics) | Used to establish mode to improve power quality | | | |
| Lighting detection and supply system imbalance | Isolate grid to protect from damage and outage | | | |
| State estimation and optimization, pattern recognition, and visualization | Used to forecast loads, outputs and trends. | | | |
| **Local Generation/Demand Response** | | | | |
| Backup gas fired generators | Local generation will be installed at the substation to backup the grid in the event of an outage or poor power quality and used for reducing cost for electricity. | Needs to be able to carry planned campus loads. Must be able to operate in grid parallel and island modes | | |
| UPS/Storage | Ride through capability for specified building circuits | Needs to have enough capacity to allow substation generation to come online | | |
| Install load controllers on large equipment | Provide for ability to match building output with generator capability | | | |
| Generator Controllers | Used to generators, calculate cost of generation using data from Intelligent Perfect Power System Controller and data gateway | Generation controller need to be compatible with the Intelligent Perfect Power System Controller requirements. | | |

## EXHIBIT C: SOLUTIONS SET

| Upgrade | Purpose/Benefit | Specification[1] | | |
|---|---|---|---|---|
| Renewable Generator Controllers | To dispatch renewable generation and coordinate with Intelligent Perfect Power System Controller. | Should include the ability to forecast the output of PV panels and wind turbines | | |
| **Support Systems** | | | | |
| Retrofit turbines for backup power | Provide for redundancy and ability to take advantage of real-time pricing and start quickly for backup power | | | |
| New feeds from Quarry substation to north and south buses | Provide redundancy | | | |
| System protection | Eliminate risk of animal and weather damage | Animal protection, lighting protection | | |
| Transformer PM's | Ensure system performance | | | |
| Hot water system PM's | Ensure system performance | | | |
| Replace transformer fluids | Ensure system performance | | | |
| **Sustainability** | | | | |
| Advanced lighting | Reduce electricity and natural gas consumption and associated carbon emissions | T8, LED, day lighting, compact fluorescent lamps, occupancy sensors | | |
| Advanced windows | Reduce electricity and natural gas consumption and associated carbon emissions | Tinted. Low-E windows. | | |
| Building re-commissioning | Reduce electricity and natural gas consumption and associated carbon emissions | Improved insulations, reduce leakage, occupancy sensors, smart thermostats, | | |

# EXHIBIT C: SOLUTIONS SET

| Upgrade | Purpose/Benefit | Specification[1] | | |
|---|---|---|---|---|
| Higher efficiency HVAC | Reduce electricity consumption and associated carbon emissions | Higher coefficient of performance, variable speed drive motors | | |
| Exhaust heat recovery | Reduce electricity and natural gas consumption and associated carbon emissions | Sensible wheel | | |
| Solar shading | Reduce electricity and natural gas consumption and associated carbon emissions<br>Improve campus esthetics<br>Consume carbon | | | |
| Solar hot water | Reduce natural gas use and carbon emissions | | | |
| Geothermal | Reduce natural gas use and carbon emissions | | | |
| High efficiency hot water loops for groups of buildings | Reduce natural gas use and carbon emissions | | | |
| Integrate hot water systems with local generation | Reduce natural gas use and carbon emissions | | | |

.

# EXHIBIT D: IPPSC REQUIREMENTS

**Controller Monitoring and Inputs**

It is important for the controller to include historical trends for, among others:

- Static switch positions
- Total building usage – KWh
- Fans usage – KWh
- Chillers - -KWh
- Lighting – KWh
- Plug Load – KWh
- Local generation – KWh
- Battery stored energy – KWh
- Net thermal storage output – KWh
- Thermal stored energy – KWh
- Degree-days (heating or cooling)
- Heating and cooling degree days
- Weather prediction-likelihood of thunderstorms, lighting detection (i.e., outages)
- Electricity and gas pricing (real time and day ahead) – $/KWh, $KW, and $/KW
- Ancillary costs - $/KWh, $KW, and $/KW
- Daily or hourly demand response market value, $/KW
- $CO_2$ or other emissions value streams in $/KWh
- Hourly temperature
- Utility system event notices and information
- Utility daily load shape
- Local generation and storage availability and capacity
- Utility tariff costs which are used to estimate savings
- Utility and MicroGrid power quality – reactive power, harmonics, load variations,
- Solar and wind forecast—expected KWh per standard 1KW rated unit
- Wind and solar measurements

**Monitoring, Diagnostics, and Intelligent Learning**

- Local load forecasting – building load profiles based on weather projections, aggregation and price optimization through the dispatch of local sources
- Key component condition assessment
    - Generator efficiencies
    - System losses
- Comparing power levels (real and reactive) with desired levels

# EXHIBIT D: INTELLIGENT PERFECT POWER SYSTEM CONTROLLER REQUIREMENTS

- Environmental condition prediction and response
- Electricity and natural gas price forecasting

**Modes of operation**

The IPPSC is continually evaluating both existing and possible conditions and choosing operating modes and operating conditions of local devices to maintain required reliability and power quality. The specific modes of operation include:

- Grid Parallel Normal – system operates local generation and storage based on price signals and power quality needs.
    - Economic optimization – selects the most economic sources, changes source supply, provides and records ancillary services (e.g. VAR's provided to utility grid)
    - Economics calculator, recorder, and forecaster – estimates savings based on calculating and comparing optimized configuration cost with the cost of operating in a non-optimized configuration. Utilizes tariff rates and real time prices.
    - System risk manager
    - Generator load dispatch models
    - Ancillary services calculator
    - Renewable generation tracker – forecasts and records renewable generation and credits
    - Real time price response capability
- Unplanned Island mode – able to match local generation with demand,
    - Black start capability
- Planned island mode – approaching storm or threat, system isolates
- Grid Parallel Disturbance/Emergency – UPS/Inverters protect key facilities while generation starts in anticipation of more significant events. Normal economic optimization features are disabled. Local system conditions are monitored and loads/generators/power quality devices are operated to maintain the system within set point conditions
- Internal Fault - include smart switches which sense and isolate the fault while rerouting power to ensure power to all loads

**Protection Scheme**

- It must have the ability to detect voltage disturbances on the utility system and make a quick decision (within a few cycles) as to whether or not to stay connected or separate as an island.
- It should discriminate between disturbances originating on the utility system versus those originating on the MicroGrid in order to initiate appropriate switching and protection steps.

# EXHIBIT D: INTELLIGENT PERFECT POWER SYSTEM CONTROLLER REQUIREMENTS

- In transitioning to islanded mode, any generation and load imbalances must be identified and quickly eliminated through load shedding or use of dynamic stabilizer devices to insure proper voltage and frequency conditions on the island.
- The control scheme and generation should be able to handle expected campus load variations and motor starts on campus and manage the expected fluctuations from other distributed generation on the system, up to about 10% of the system capacity.
- All of the above objectives should be accomplished without nuisance mode transitions that degrade power quality and reliability.
- All of the above should also be accomplished while providing suitable protection for and not interfering with the successful and safe operation of the utility system to which the campus is connected.

**Specialized Agent Controllers**

The overall campus energy system control scheme will consider economic, environmental, comfort, threats and other end-use objectives to make decisions regarding the proper operating modes and sequences. The IPPSC will anticipate system needs and take action to mitigate threats to system reliability and performance. The IPPSC supervisor coordinates with the specialized agent controllers distributed around the IIT Campus to manage the safe and reliable operation of the Campus's MicroGrid. The existing and planned agent controllers at the IIT campus include controllers for the:

- High Reliability Distribution system and the associated intelligent fast switches.
- The Campus Integrated Power System (Generators)
- The Building Management Systems
- Renewable Power Generation
- Storage devices
- Load Controllers for Demand Response

**User interface**

The IPPSC user interface (UI) allows designation of user preferences and characteristics of physical resources located within the micro-grid. Preferences for electric service reliability are expressed within the UI by ranking load priority orders among end-uses. Information sources that provide economic information on supply system conditions, fuel costs for local generation, and other operating economics and constraints are also configured via the UI. An underlying assumption is that by default, user settings are configured to enable automated response of resources, switches, and loads to latest system and market conditions.

- User default setup
- Preference configurations
- User alerts
- Web based interface

# EXHIBIT E:  PERFECT POWER COSTS

# EXHIBIT E: NOTES ON PERFECT POWER COSTS

1. **Engineering:** $400,000 is for S&C Electric to design the HRDS for the IIT campus. $100,000 is included for the design of the new generation.
2. **New Generation/ Boiler Removal Costs** are based on the cost to install 4MW of natural gas engine generation in current steam plant building. The engines will be installed in place of existing steam boilers the costs include removal of the boilers. The cost buildup is shown below.

| Item | Cost |
|---|---|
| 2M Cat 3520 | $ 900,000 |
| 2M Cat 3520 | $ 900,000 |
| Switchgear Room AC | $ 10,000 |
| Black start Panel | $ 5,000 |
| BOP Controls | $ 50,000 |
| Instrumentation and Control | $ 100,000 |
| Remote Radiators | $ 30,000 |
| Silencers | $ 50,000 |
| Plumbing | $ 10,000 |
| Transformers | $ 100,000 |
| gas run | $ 10,000 |
| sewage/drainage | $ 10,000 |
| Motor Control Center | $ 30,000 |
| Switchgear | $ 400,000 |
| Electrical | $ 10,000 |
| Ventilation | $ 10,000 |
| Engineering | $ included in #1 |
| Building Permit | $ 5,000 |
| Air Permit | $ 15,000 |
| Interconnect Permit | $ 15,000 |
| Labor | $ 262,500 |
| Project Management | $ 297,250 |
| ***Subtotal*** | ***$ 3,219,750*** |
| $/KW | $ 805 |
| Boiler Removal | $ 380,250 |
| **Total** | **$ 3,600,000** |

# EXHIBIT E:  PERFECT POWER COSTS

3. **Turbine Fast Start/Maintenance Costs** for the turbine upgrades include modifying and replacing the controls to allow the gas turbines to start faster.  Costs also include turbine hot section overhauls.

| Item | Cost |
|---|---|
| replace outdated and nonfunctional fire detection units | $ 16,000 |
| automate and update water De-NOx loop | $ 17,000 |
| Replace start motor variable frequency drives | $ 49,000 |
| Retrofit of existing turbine and BOP controllers | $ 98,000 |
| Replacement of oil/air cooler | $ 68,000 |
| Automate priming oil pressure during start | $ 10,000 |
| De-commission HRSG controls for quicker starts | $ 10,000 |
| Rebuild Gas Boost Compressors | $ 20,000 |
| Replace GTG water injectors | $ 16,000 |
| Turbine hot section overhaul for two turbines | $ 396,000 |
| Gas Compressor Overhaul/Repairs | $ 100,000 |
| **Total** | **$ 800,000** |

4. **Version 1 of the IPPSC** includes the functionality for entering the real time price markets.  This includes functions for gathering real time price data, predicting campus loads from weather data, and deploying the Version 1 of the generation agent controllers and the supervisory agent for the IPPSC.

| **IPPSC Version 1** | |
|---|---|
| **IPPSC** | |
| Design and Development, Quality | $ 413,000 |
| hardware | $ 8,000 |
| com gear | $ 1,000 |
| installation | $ 10,000 |
| setup | $ 10,000 |
| | |
| **Turbine Agent** | |
| hardware | $ 8,000 |
| com gear | $ 1,000 |
| installation | $ 10,000 |
| setup | $ 10,000 |
| | |
| **Engine Agent** | |
| hardware | $ 8,000 |
| com gear | $ 1,000 |
| installation | $ 10,000 |
| setup | $ 10,000 |
| | |
| **Total** | **$ 500,000** |

# EXHIBIT E:  PERFECT POWER COSTS

5. **Version 2 of the IPPSC.** This Version is required for controlling the campus distribution system and includes additional functions for the IPPSC and deploying the distribution controller agent.

| **IPPSC Version 2** | |
|---|---|
| **IPPSC** | |
| Development and Engineering | $ 315,000 |
| weather station | $ 3,000 |
| Setup | $ 10,000 |
| | |
| **Turbine Agent** | |
| Setup | $ 10,000 |
| | |
| **Engine Agent** | |
| Setup | $ 10,000 |
| | |
| **Distribution Agent** | |
| hardware | $ 8,000 |
| com gear | $ 1,000 |
| installation | $ 20,000 |
| Setup | $ 23,000 |
| | |
| **Total** | **$ 400,000** |

6. **North Substation Upgrade Costs** are included here for automating the recently upgraded North Substation. This includes conversion to microprocessor relays, electronic meters, and substation RTU for nine breakers. Relays will be compatible with HRDS system when implemented.

7. The **South Substation** needs to be rebuilt. This includes replacing existing circuit breakers with eleven new vacuum breakers, conversion to microprocessor relays, electronic meters, substation RTU. Relays will be compatible with HRDS system when implemented. This plan eliminates the need to replace the switchgear structure and eliminates the need to build a temporary bus.

8. **Intelligent Switches:** These costs are for installing the intelligent switches and controllers for the HRDS system. Cost include 17 3-way Vista switches at ~$45K each, 5 4-way Vista switches at ~$60K each, 4 5-way Vista switches at ~$75K each and 7 6-way Vista switches at ~$90K each. Installation is included in the total cost.

9. **HRDS Loop Cables:** This includes the costs for installing the cables required to complete the HRDS loops. Approximately 2 miles of additional cable will be added.

10. **UPS/Storage:** A place holder is included here for an additional UPS system. IIT was not sure if an additional UPS would be required or if its costs would be included in with the Perfect Power System as it would most likely be installed on an as needed basis. The costs included here should be sufficient for a 150 KW flywheel UPS system.

# EXHIBIT E:  PERFECT POWER COSTS

11. **Version 3 of the IPPSC** includes functions required for demand response.  This will include controllers for load response and renewable generation and functions for coordinating generation, load shedding and island mode start sequencing.  Approximately $391,000 will be required for finishing the installation of a Siemens building energy management system on the campus.

| **IPPSC Version 3** | |
|---|---|
| **IPPSC** | |
| Setup | $ 10,000 |
| | |
| **Turbine Agent** | |
| Setup | $ 8,000 |
| | |
| **Engine Agent** | |
| Setup | $ 8,000 |
| | |
| **Distribution Agent** | |
| Setup | $ 15,000 |
| | |
| **Building Agent** | |
| Hardware | $ 8,000 |
| com gear | $ 1,000 |
| Installation | $ 10,000 |
| Setup | $ 20,000 |
| | |
| **Renewable Generation Agent** | |
| Hardware | $ 8,000 |
| com gear | $ 1,000 |
| Installation | $ 10,000 |
| Setup | $ 10,000 |
| | |
| **Siemens Bldg Controller Installations/Upgrades** | $391,000 |
| | |
| **Total** | **$500,000** |

12. These costs are for demonstrating a **Solar PV** system with the Perfect Power System.  Costs are for an approximate 10KW system.
13. **Transformers:**  These costs are for upgrading transformers that are projected to be overloaded in the next few years and costs for transformers required for the new housing and parking.  Near term load growth is expected to be 1KVA or less.  Future load growth is expected to be an additional 2 KVA.  Transformers were estimated at $35/KVA.  Funds are also included for installation and running cable.