Demonstration of Commercial Energy Storage Device in Edge-of-Grid Application With and Without a Fuel Cell

Plus Broader Market Feasibility Study for Commercial Applications

Final Report 08-08
July 2008

New York State
Energy Research and
Development Authority

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Demonstration of Commercial Energy Storage Device in Edge-of-Grid Application With and Without a Fuel Cell

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Final Report

Prepared for the

New York State Energy Research and Development Authority

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NOTICES

ABSTRACT

This contract covered two distinct different projects: a utility demonstration of battery storage powered either by a fuel cell or by a weak grid; and market research study into the use of battery storage for demand reduction.

Together with Delaware County Electric Cooperative (DCEC) Gaia installed an 11kW / 20kWh energy storage device (PowerTower) at a residence in Delhi, N.Y. The intention of the project was that PowerTower would provide all the power needed for the residence. The energy would be provided first by a 5kW Plug Power fuel cell (to demonstrate the viability of off-grid distributed power) and subsequently by the utility to demonstrate utility support at edge-of-grid conditions. In addition to funding from NYSERDA, the project received support for data acquisition from the U.S. Department of Energy through Sandia National Laboratories and their subcontractors, Enernex Inc. DCEC also received funding from the U.S. Department of Energy and the Propane Education & Research Council to finance the installation and testing of the fuel cell for twelve months.

The demonstration showed that battery-based energy storage can enable the use of low-powered distributed generation and also help boost an overloaded distribution grid. It also demonstrated how the use of load management could reduce the load profile of the residence from nominal 20kW to less than 11kW.

The only problem associated with the PowerTower during the course of the demonstration was short-term flicker, a power quality problem that often surfaces in micro grids with a weak generation source. In this case, the problem was exacerbated because the PowerTower was operating in current support mode, which made voltage fluctuation worse. Laboratory tests showed that if the PowerTower could be operated in voltage support mode, short-term flicker would not have been an issue. This would have required the fuel cell to provide DC power instead of AC power to the PowerTower or the installation of a separate battery charger. Another, more energy-efficient solution, would have been to change all the incandescent light bulbs with fluorescents, which are less prone to pass on short-term flicker as a visible phenomenon.

In the market research project we analyzed the data for a wide range of businesses located in a wide range of utility service territories. The market research determined that, at this point, demand charge rates do not support the use of battery storage for demand reduction alone if installed by the end user. However, with increasing electricity rates and potential participation in ISO-sponsored load reduction programs, the economics may be attractive in a few years. Battery energy storage can still be quite attractive for utilities to reduce their peak demands and potentially for renewable energy providers such as Photovoltaic (PV) systems, as it can help to firm the supply of otherwise intermittent renewable energy sources.

In addition to these emerging markets, Gaia has found a market in providing extended backup for both residences and commercial users, and in many places Gaia is helping customers avoid the use of environmentally-unfriendly generators or install hybrid storage/generator systems with smaller generators, which can provide more kWh per BTU of fossil fuel.

KEYWORDS

Distributed energy storage
Distributed generation
Peak load reduction
Fuel cell
Propane fuel
Propane generator
Modular stationary power
Battery based power systems
Integration of distributed generation

ACKNOWLEDGEMENTS

We would like to thank NYSERDA for granting this project to us at a crucial point in our business development and Delaware County Electric Cooperative for inviting us to work in the demonstration project. We would also like to thank Sandia National Laboratories and Enernex for help in the data collection and making it available to the greater population.

For the market study, we would like to thank Con Edison for supporting us through out all phases of the project and making utility data available to us.

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SUMMARY

This report focuses on the battery-energy storage system part of the demonstration project plus the market research part. The fuel cell specific part, as covered under the separate U.S. Department of Energy project and spearheaded by DCEC, has been covered in a separate report (DE-FC36-04GO14239) issued by DCEC. This report includes an appendix.

1. DESCRIPTION OF PROJECT

PROJECT BACKGROUND

Electricity supply-related problems

Electric utilities are increasingly becoming constrained in their ability to meet peak load as demand increases. From 1980 through 2000, New York State's annual peak demand for electricity grew 5.1 times as much as the State's population. This problem is particularly significant at peak load periods; from 1995 to 2000, New York's peak load grew by 2,700 megawatts, while generation capacity increased by only 293 megawatts. Similar problems are being faced by utilities throughout the United States.

As demand for high-quality electricity grows, and consumers sprawl into more remote areas and demand service from their utility, distribution systems are becoming constrained in their ability to deliver electricity to consumers, particularly at periods of peak load. At the same time, utilities have been unable to install the necessary transmission and distribution assets to keep up with this demand.

High cost and siting difficulties are preventing many utilities from upgrading their transmission lines and substations to meet growing peak demand. The cost to utilities of installing new transmission and distribution line extensions can reach four to eight dollars per foot, or $20,000 to $40,000 per mile, and in remote areas this expansion may only service a few dwellings making the return on investment unfeasible. Replacing old transmission and distribution lines can cost even more because many lines are buried and conduit is undersized to serve larger cables. For example, Southern California Edison recently estimated that it would cost $54 million to replace 300 miles of cable, a cost of $180,000 per mile. Similarly, utilities have difficulty stringing new lines through neighborhoods that are prone to fight these installations. This problem was illustrated recently by community resistance to the proposed installation of a 1,200 MW transmission line over 200 miles from Oneida County to Orange County, N.Y. by New York Regional Interconnect.

Gaia's MSPS solution

Under NYSERDA contract 7279, Gaia developed the PowerTower for commercial deployment. The PowerTower is a modular stationary power solution ("MSPS") which uses electrochemical storage techniques to compliment existing electric utility product and service offerings. The commercial unit can be configured to provide anywhere from 5.5kW with 10kWh to 16.5kW with more than 30kWh of energy storage. An 11kW / 10kWh version is shown below in Figure 1. Currently, energy storage is provided using advanced sealed lead-acid batteries. The PowerTower is also capable of operating with other types of energy storage, including advanced batteries of different chemistries such as NiMH and supercapacitors. The unit can be outfitted with remote IP-based monitoring and control. The proprietary communications and control element provides bi-directional communication and control capabilities to users and operators of the PowerTower. This software allows the PowerTower to control generation devices for maximum efficiency, and to sense and respond to peak demand by switching loads from the grid to the PowerTower's energy storage component. It also allows a utility to communicate remotely with the PowerTower and alter set points to dispatch power when necessary. Potential uses for the product range from simple electrical backup to peak shaving and integration with and control of distributed generation. It is the first product of its kind to receive an ETL listing (to UL 1741) as a complete and pre-assembled unit.

As of today, Gaia has more than 300 PowerTowers installed in the U.S. and abroad and has recorded more than one million hours of operations.

- Modular energy storage and management system
- Current sizes up to 16.5kW three-phase power output with scalable battery modules
- Turnkey design for easy integration with buildings and utility systems
- Components:
    - Energy storage
    - Power electronics
    - Proprietary communications and control software
- System designed for easy scalability and interaction between multiple PowerTower units

Figure 1: Commercial version of Gaia's MSPS solution sold under the PowerTower brand

<u>Energy storage / fuel cell demonstration</u>

The Delaware County Electric Cooperative (DCEC) residential fuel cell demonstration project was part of a national residential fuel cell project organized by the National Rural Electric Cooperative Association (NRECA) and partially funded by the United States Department of Energy (DOE). DCEC was working cooperatively with the First Rochdale Cooperative of New York City to develop a more robust data set (project taken over by EnergyNow!), with the intention to create a more complete and accurate model of residential fuel cell usage in combination with appropriately designed and sized energy storage solutions. DCEC conducted the residential fuel cell demonstration project to benefit the objectives of the DOE's hydrogen program, as well as to benefit the cooperative's members. The fuel cell demonstration project fit into the context of DCEC's and NRECA's program for the evaluation and enhancement of renewable energy, distributed generation, and energy storage technologies. This program is designed to highlight technologies with the capacity to provide clean, reliable, and cost-effective energy supplies to their members. The fuel cell project investigated the feasibility of using fuel cells as an alternative to line extension in rural areas, and the energy storage component of the demonstration showed how the size of the distributed generation could be minimized and made more reliable, and alternatively, how energy storage could provide demand reduction on the distribution grid and thereby defer the need for costly upgrades to the grid.

Market analysis for commercial applications of distributed modular storage systems

Under NYSERDA contract 8720, Gaia committed to build on the success of the development of PowerTower and conduct a detailed and precise study of the viability for the wide scale commercial deployment of this advanced electricity storage technology.

This study included three parts which tested the application of electricity storage technology in distinct markets:

- Demand Reduction – this portion of the study identified industries with the proper 'peaky' energy usage profile, established contact, and performed energy consumption audits and analyses to assess commercial viability for a 11kW demand reduction device depending on the local utility tariffs;

- Backup Power for Residences – here, the study identified candidates for the storage function of PowerTower and implemented backup power during the blackout/brownout prone summer months. Analysis consisted of geographic centers of receptivity, as well as the proper sizing/configuration for typical residences or businesses; and

- Grid support for end-of-line rural utility cooperatives – this area focused on identifying markets for immediate adoption of storage technology as part of the grid, replacing the need for transmission and distribution build out.

PROJECT BREAKDOWN

The project was broken into a number of major tasks including: PowerTower assembly and installation; Test Matrix; and Market study. These tasks were further broken down into subtasks, listed below:

WORK SCOPE

Subtask 1: Demonstration – Assemble 11kW / 20kWh PowerTower

Subtask 2: Demonstration – Install PowerTower at site

Subtask 3: Demonstration – Performance check of installed system

Subtask 4: Demonstration – Perform test matrix

Subtask 5: Demonstration – Uninstall PowerTower

Subtask 6: Market Study – Electrical audits

Subtask 7: Market Study – Analyze data from audits and demonstration

Subtask 8: Market Study – Obtain utility and other market data

Subtask 9: Monthly reporting

Subtask 10: Interim market feasibility study report

Subtask 11: Assemble final report

Subtask 12: Generate whitepaper

Subtask 13: Give presentation

2. POWERTOWER HARDWARE DESIGN AND MANUFACTURING

SIZING OF BATTERY ENERGY STORAGE SYSTEM

The electrical service at the test site was rated at 200A (24 kW) continuous draw. However, our own measurement taken from December 27, 2004, to January 25, 2005, showed an average consumption around 2 kW, with some peaks reaching 13.5 kW. That led the team to believe that an 11 kW PowerTower would be able to service the whole house most of the time, except for a few instances. Those instances could be addressed by momentarily disconnecting non-critical loads.

PowerTower Specifications

Manufacturer	Gaia Power Technologies, Inc.
Model	GPT2-48-11000-20
Continuous Power	11,000 W
Energy Storage	20 kWh
AC Input Voltage	240 Vac
DC Input Voltage	48 Vdc
Total Harmonics Distortion	<5%
Efficiency (Peak)	96%
Size H x W x D (each unit)	60" x 39" x 18.5"
Weight (each unit)	1,050 lbs
Features	Demand Reduction Load Control Remote Control Fuel Cell Control

Figure 2: Gaia Power Technologies PowerTower specifications – one unit had two inverter chargers and 10 kWh of batteries; the second unit had 20 kWh of batteries but 10kWh was not connected

The electricity consumption measurements also led us to believe that 20 kWh of batteries would be more than enough to provide a good electrical buffer and provide extended cycle life. The standard 11 kW PowerTower has 10 kWh of batteries, therefore, we added another unit dedicated to another 10 kWh of batteries. This unit had a total of 20 kWh of batteries installed but 10 kWh were never connected.

This PowerTower was also equipped with a GaiaMon control system as well as load shedding hardware. Normally the GaiaMon controller is built into the PowerTower itself, but in this case the project had a separate rack mount system to host the data acquisition system, local area network equipment, and the satellite communication system. We decided to have the GaiaMon controller in the same rack. We also included the hardware drivers for the load shedding function in the same enclosure. That gave us easier access for eventual service and modifications. The GaiaMon controller, as well as the Enernex-specified data acquisition equipment, are shown in Figure 3.

Figure 3: GaiaMon controller and DAQ system

INVERTER CHARGERS

The PowerTower employed two Xantrex SW Plus 5548 inverter/chargers. These inverters are of a very robust design and has been used in both on-grid and off-grid installations for years. In addition, this model is the only inverter charger on the market that comes with two AC inputs with an internal transfer switch. This makes it relatively simple to integrate two energy sources such as in this project, where the PowerTower was connected to both the fuel cell and utility power. Furthermore, the inverter firmware includes algorithms for limiting the current going into the inverter and blends the incoming AC power with power from the batteries to supply the AC loads on the output.

Inverter Specifications	
Manufacturer	Xantrex, Inc
Model	SW Plus 5548
Continuous Power	5,500 W
100 mSec Surge	105 A
AC Input Voltage Range	80 - 149 Vac
DC Input Voltage Range	44 - 66 Vdc
Total Harmonics Distortion	<5%
Efficiency (Peak)	96%

Figure 4: The Xantrex SW inverter and electrical specifications

In addition to the data acquisition built into the inverters, the PowerTower had separate voltage and current measurement systems on the input and the load side.

HIGH-ENERGY BATTERIES

There are quite a few battery technologies on the market today. Each battery technology has advantages and inherent limitations that make them practical or economical for only a limited range of applications. Our commercial PowerTower uses a sealed lead acid battery. The brand and model depends on the application, but for off-grid applications, Gaia uses sealed AGM lead acid batteries from Concorde Battery Corporation in California. We chose to use the same battery for this project.

Based on our research for off-grid applications, we identified Concorde's line of SunXtender sealed AGM lead acid batteries. These batteries had a good reputation for operation with solar panels, which require a significant number of cycles. According to their specifications, these batteries should be able to cycle up to at least 500 times at 80% depth of discharge.

Concorde is also a supplier of batteries to the aviation market, indicating that they have developed a track record for quality control and performance over time. Figure 5 lists the basic specifications for the SunXtender battery.

Battery Specifications	
Manufacturer	Concorde Battery Corporation
Model	PVX-1080T Solar Battery
Nominal Capacity at 25°C and C/24 Rate	108 Ah
Length	12.9"
Width	6.75"
Height	8.96"
Weight	70 lbs

Figure 5: Concorde SunXtender battery and specifications

The nominal capacity at a 24-hour discharge rate is rated as 108Ah, but as can be seen in Figure 6, the capacity can be even higher at lower discharge rates.

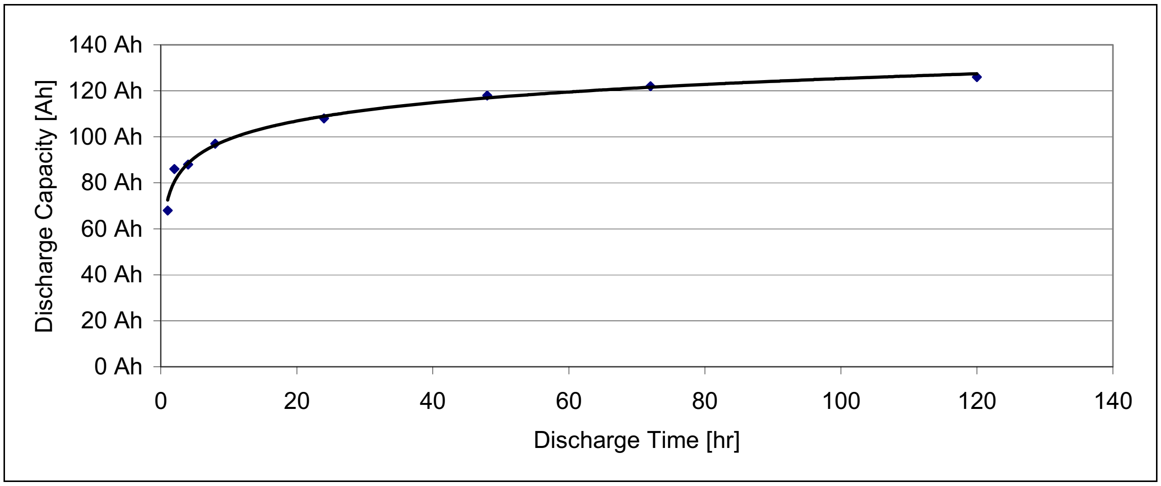


Figure 6: Capacity versus discharge time for Concorde SunXtender PVX-1080

<u>**Fuel Cell**</u>

The fuel cell was specified by DCEC. They chose a unit from Plug Power that was designed to operate as a primary power source. The fuel source was propane, and the fuel cell was equipped with a desulphurization bed to remove any sulfur impurities plus a reformer unit that converts the hydrocarbons into hydrogen for the fuel cell and carbon dioxide. The fuel cell was also designed to provide heating for a local heating loop.

Fuel Cell Electrical Specifications	
Manufacturer	Plug Power, Inc
Continuous Power at 25°C	5,500 VA
AC Input Current	60 A
100 mSec Surge	78 A
Continuous Output at 25°C	46 A
AC Input Voltage	120 Vac
AC Input Voltage Range	80 - 149 Vac
DC Input Voltage (Nominal)	48 Vdc
DC Input Voltage Range	44 - 66 Vdc
Total Harmonics Distortion	<5%
Efficiency (Peak)	96%

Figure 7: The Plug Power fuel cell and electrical specifications

3. TEST SITE, FUEL CELL, AND UTILITY INTERCONNECTION

Utility Interconnection Requirements

The PowerTower is certified to UL1741 "Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources." This certification ensures that the product will adhere to utility requirements for interconnection. In addition, the PowerTower was not intended to sell electricity back to the local grid, which simplified the interconnection greatly. The Plug Power fuel cell was also certified to UL1741. This certification was necessary because in one of the operating modes the fuel cell bypassed the PowerTower and provided the electricity directly to the house. As the house consumption would sometimes be lower than the fuel cell production, the fuel cell would sell the excess electricity back to the grid.

Test Site Connection

The outline of the electrical installation for the project is shown in Figure 8. In order to accommodate the PowerTower and the fuel cell, and also allow for operational flexibility, a new distribution panel plus an automatic transfer switch was installed between the grid meter and the existing 200A main panel.
The PowerTower's two AC inputs, one of which was connected to the fuel cell through a 120/240 V split phase transformer.

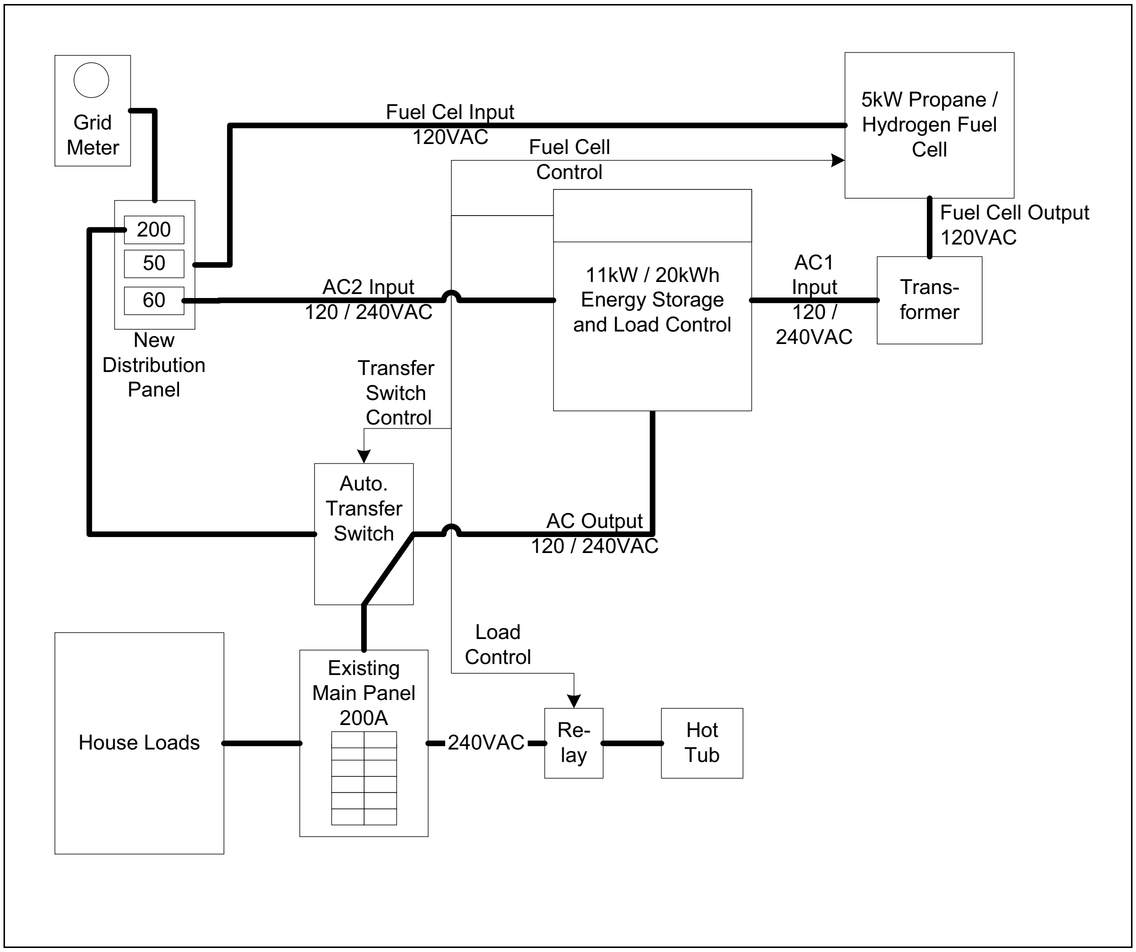


Figure 8: One-line diagram of electrical installation

4. SOFTWARE DEVELOPMENT

DEMAND REDUCTION ALGORITHMS

Demand Reduction Method: Constant Power Into PowerTower

Our approach to demand reduction follows the method used in NYSERDA contract 7279 and our initial testing at deployments of several PowerTowers at Starbucks. The PowerTower is connected to a subset of the loads at the site, including non-continuous loads such as motors and heaters. The PowerTower is continually sensing the power demand at the load. If the load requires a power level above a set threshold that characterizes a peak demand, stored energy is used to supplement or replace the power required from the primary power source. This reduces the peak demand as seen from the power entry point or billing meter. Peak demand reduction is realized only for power peaks required by the specific loads serviced by the energy storage and delivery system. An example of the demand reduction is given in Figure 9 below.

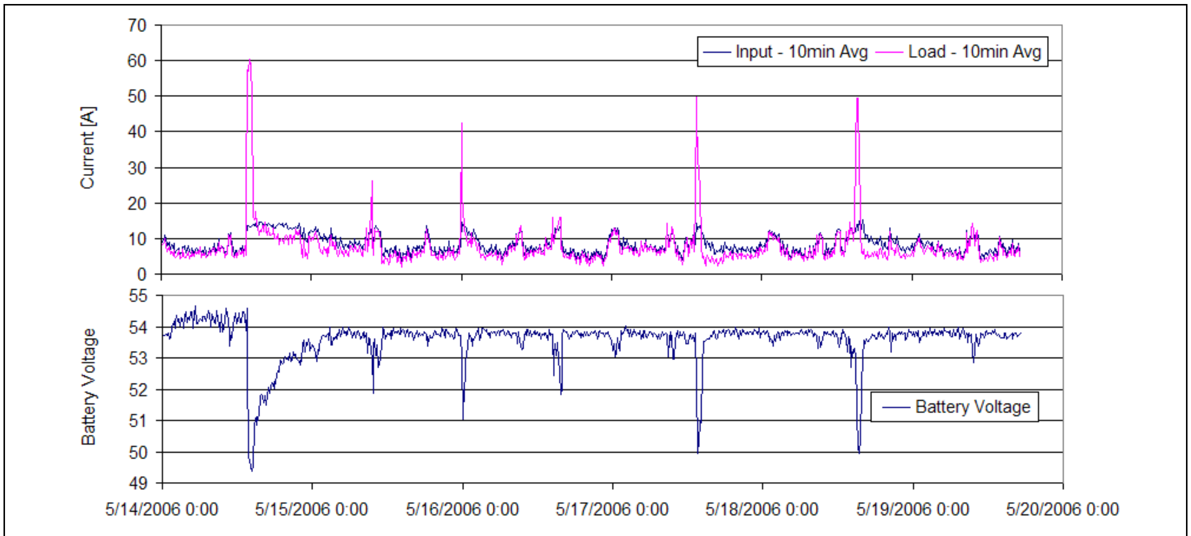


Figure 9: Demand reduction example from test site

For this project we refined the control software further and incorporated automatic adjustment of the input current based on average power consumption and state of charge of the batteries. This was done based on the fuel cell's need to operate at constant power for as long as possible, combined with the need to respond to changes in residential usage pattern. As we did not have direct access to the fuel cell controls, the PowerTower could send out a request for change, which would be picked up by the EnerNex Concentrator and pushed to the fuel cell. At the same time the PowerTower would restrict its input current to the new setting as well. In order to simplify the control, the PowerTower could adjust the fuel cell output to three levels: nominal 1 kW, 2 kW, and 3 kW.

In addition to controlling the input power, the PowerTower was also equipped with load shedding capability. Through the use of relays, up to two loads could be turned off in case the total load exceeded the

11 kW constant power capabilities of the PowerTower. Only when the combined load plus the disconnected load fell below the threshold would the disconnected load be turned on again. The main variable load was the outdoor hot tub, which was the only load necessary to disconnect from time to time. When the hot tub was bypassed later in the project the load shedding mechanism was not used.

REMOTE MONITORING AND CONTROL

In this project Gaia cooperated with EnerNex on data acquisition. As a result, it was necessary to make our data available for EnerNex. EnerNex specified a set of hardware equipment from Dranetz-BMI Signature Systems. This hardware configuration met all of the IEC and IEEE standards that will facilitate defendable results – especially in harmonically distorted and unbalanced conditions. This hardware was also equipped with a web interface connection to the Gaia PowerTower on-board controller and a serial connection to Plug Power's proprietary on-board controller. This system also allowed the on-site data storage requirements to be met.

Using the Dranetz system as a bridge, we were able to control the output power of the fuel cell from the PowerTower. However, we did not have control over any other fuel cell parameters.

As part of monitoring, we received status data at Gaia's central servers in Peekskill; this data could be extracted using our online reporting service for analysis locally. The same data was also picked up by EnerNex and made available online together with the data collected by the EnerNex data acquisition system. A one-line diagram showing the data acquisition points is show below in Figure 10.

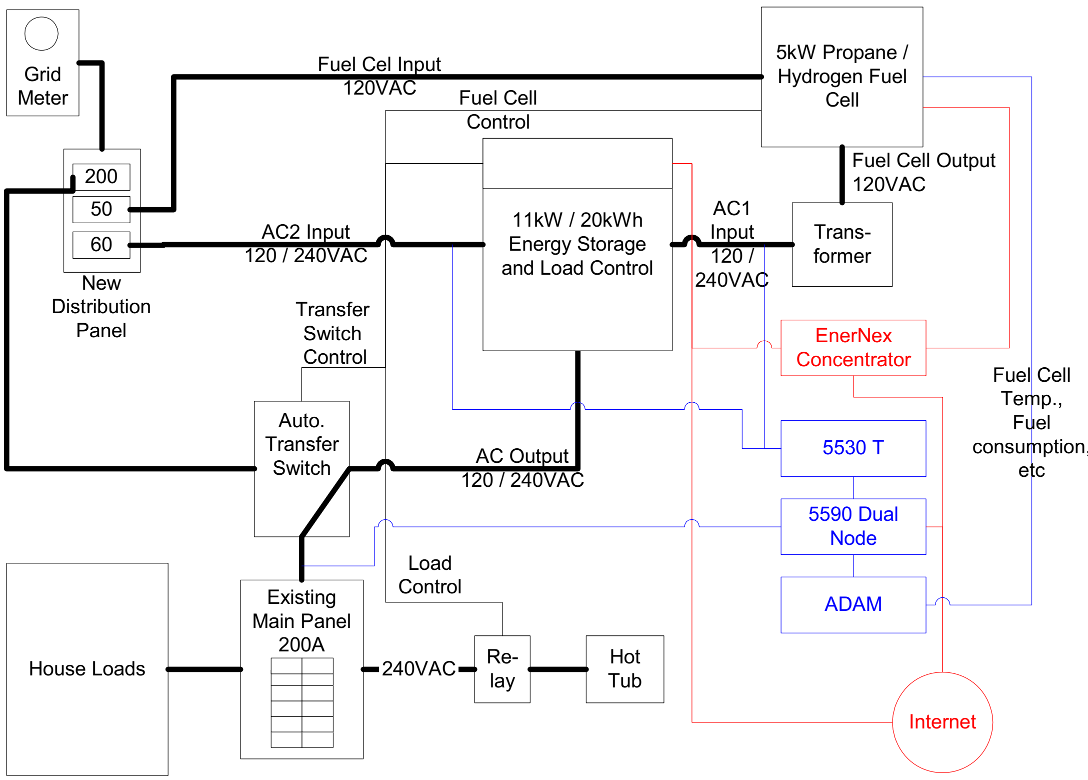


Figure 10: One-line diagram including data acquisition modules and controls

5. DEMONSTRATION

HISTORICAL DATA FOR TEST SITE

DCEC is very advanced in metering technology. Since 2002, they have had advanced meters installed at all their customers, which report energy consumption and maximum power demand (30 minutes rolling average) on a daily basis. Figure 11 below shows three years of demand and energy consumption for the demonstration site. Both the demand and the consumption are trending upward, and there is a step up in both demand and consumption at the end of 2004 when an outdoor hot tub was installed.

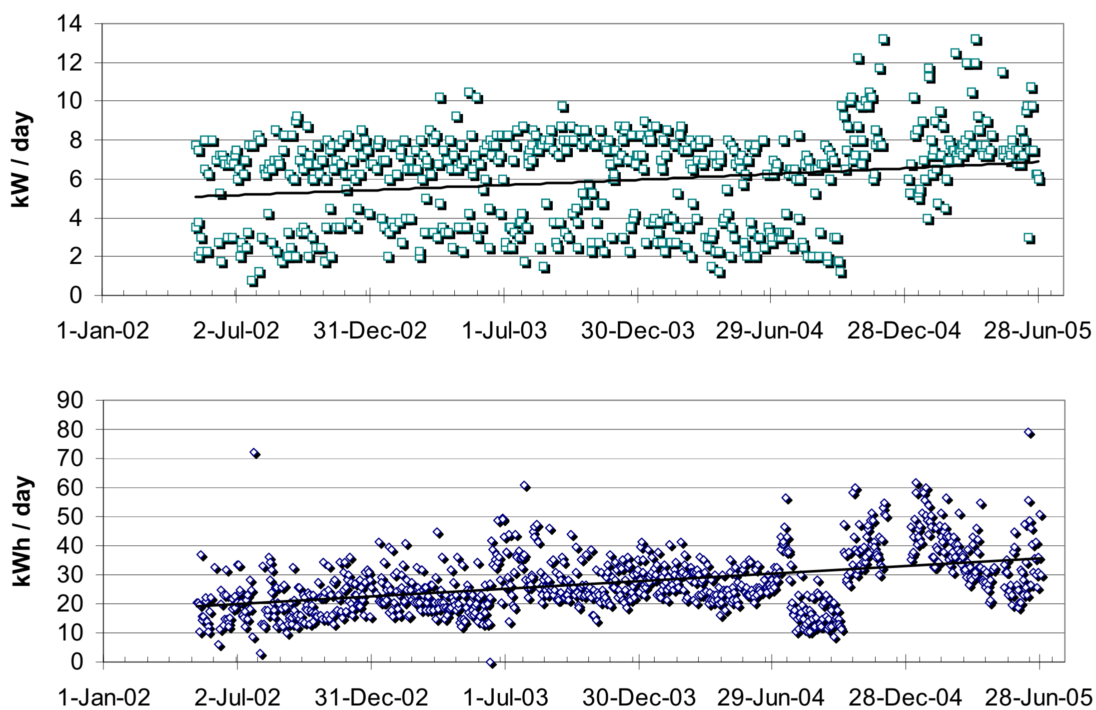


Figure 11: DCEC records of daily demand and energy consumption for demonstration site

In addition to the utility data, Gaia installed its own data acquisition equipment at the demonstration site. The unit was a Fluke Hydra multi channel DAQ system, which was set to measure the voltage and current on both incoming phases in one-minute intervals.

Two full months of data can be seen in Figure 12 and Figure 13. The utility data is also included in the charts for reference.

The measured data and the utility data correlate well, with a few exceptions. The utility peak demand data is based on a ratcheting average of peak demands in a specific 15-minute interval – for example, the average peak could be determined during a time period from 12:00 a.m. to 12:15 a.m. The exact switchover from one time period to the next is unknown and although the one-minute interval measurements from Gaia's data logging equipment can be averaged over 15 minutes, this is a moving average which may span more than one of the corresponding utility's peak measurement periods. This can introduce a discrepancy of several kilowatts in some instances. Combined with this, the Gaia data logger returns an instantaneous measurement once every minute and can include start-up spikes, which in reality only last several seconds, but may be interpreted as a one-minute-long peak demand, somewhat skewing the result.

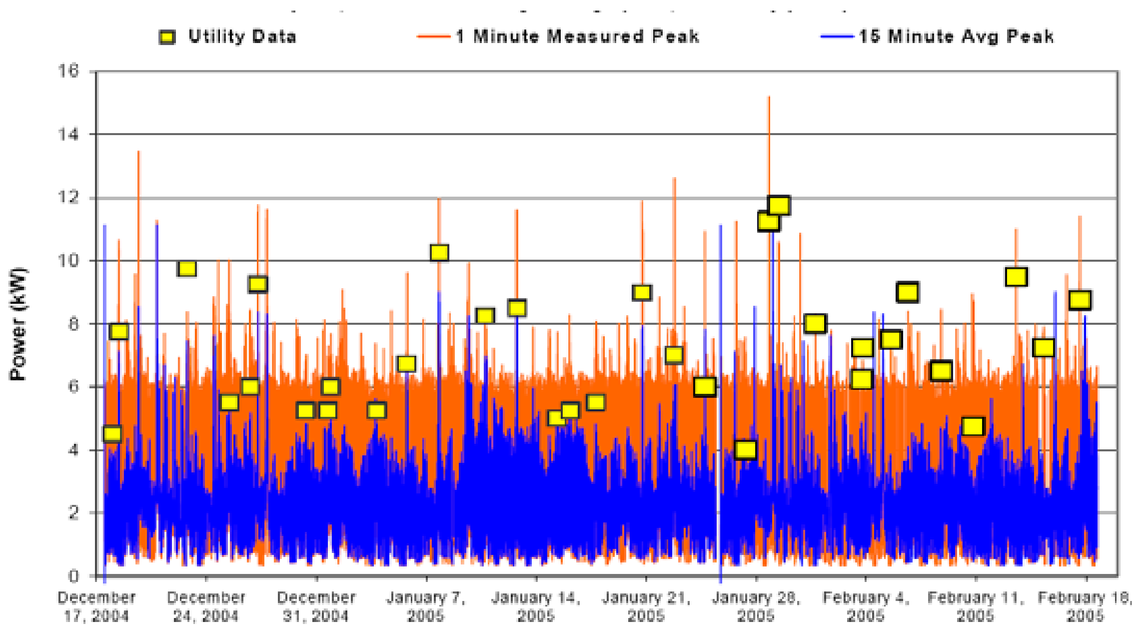


Figure 12: Two months of demand measurements prior to installation

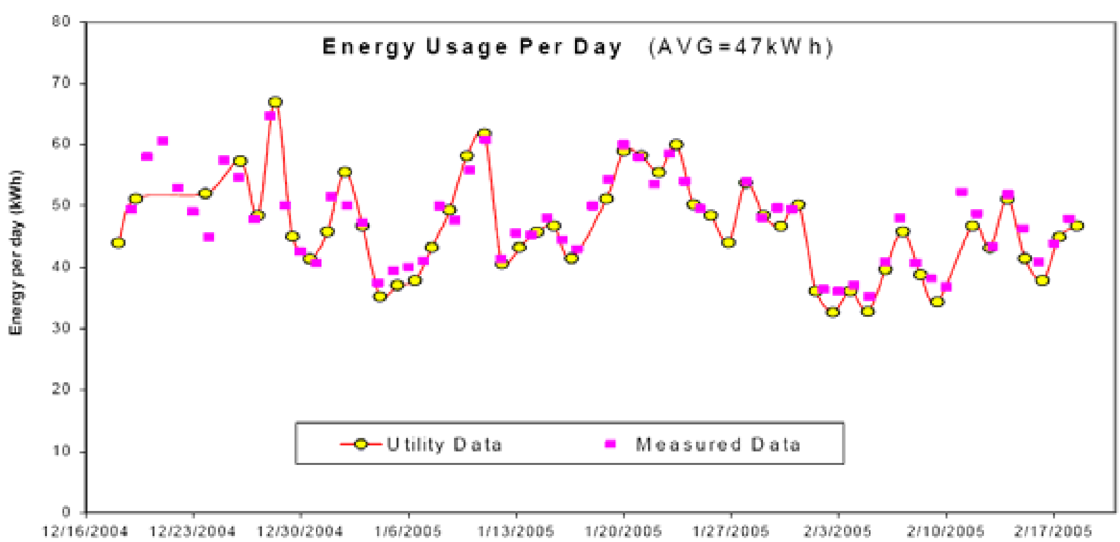


Figure 13: Two months of daily energy consumption measurements prior to installation

An additional item that may be noted is that in some instances the utility data may not show an actual peak demand that occurred due to data corruption that can happen in the one-way power line communication that the utility uses. This results in a “lost” peak, which is not recorded by the utility. Although these discrepancies should be noted, when both data sets are interpreted together, an accurate picture of the power and energy requirements of the residence can be well illustrated.

Figure 14 shows that the power demand shows regular peaks. These peaks are associated with the cycling on and off of the heating elements in the hot tub.

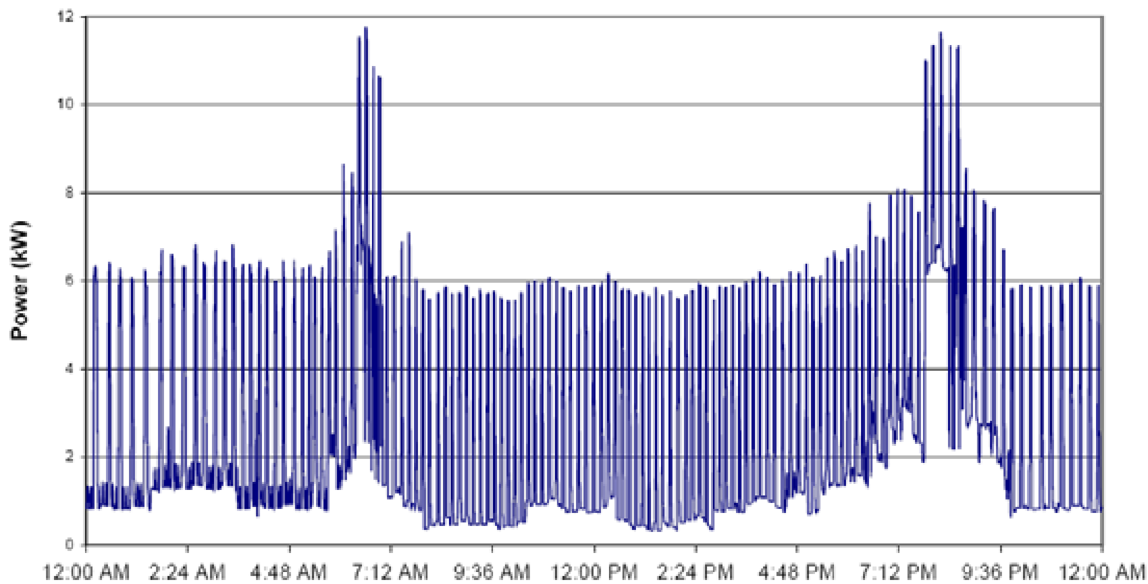


Figure 14: Power Demand throughout December 27, 2004 shows intermittent peaks from the hot tub

The analysis of the utility data continued up the installation of the PowerTower. Figure 15 shows the power demand and energy consumption around the time the PowerTower was installed. Immediately after installation, the PowerTower was operated in demand reduction mode, which is reflected in the utility data. On the day of commissioning, energy consumption increased in order to charge the batteries fully, but thereafter it stabilized at the same level as prior to the installation. This would indicate that the operation of the PowerTower only marginally contributes to total energy consumption of the residence.

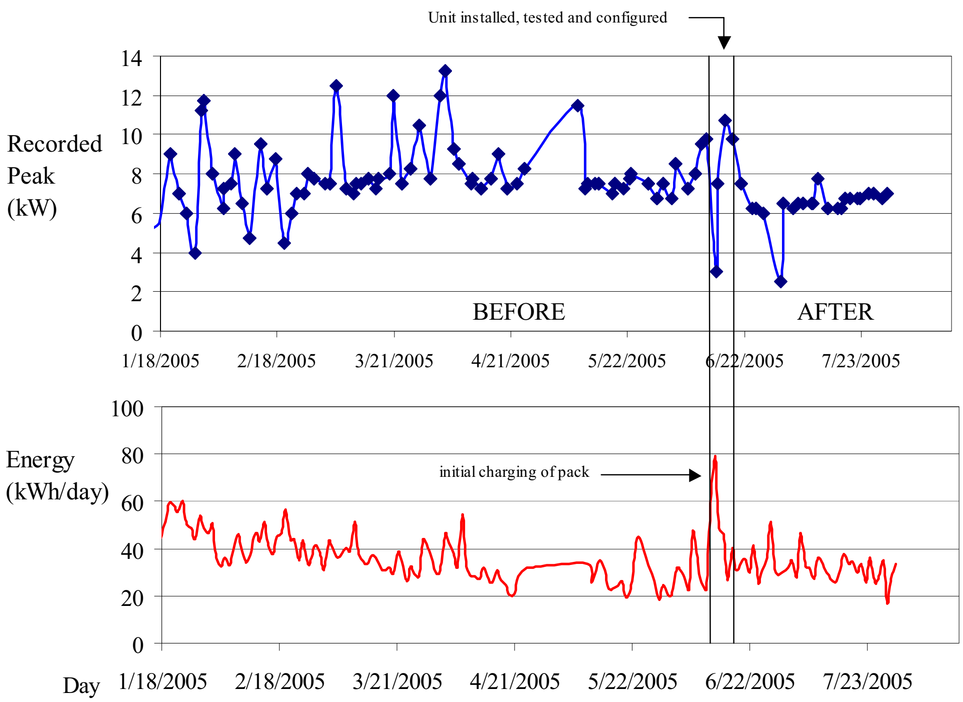


Figure 15: Tweedie residence utility data before and after installation of the Gaia PowerTower

DEMONSTRATION PERIOD

The total demonstration time was scheduled to be 18 months. The first 12 months were energy storage powered by fuel cell, and the last six months were energy storage powered by utility. During the final six-month period both energy storage and fuel cell were taken offline and put back online for various reasons, which will be elaborated on later in the report. The analysis of the fuel cell is described in Appendix C.

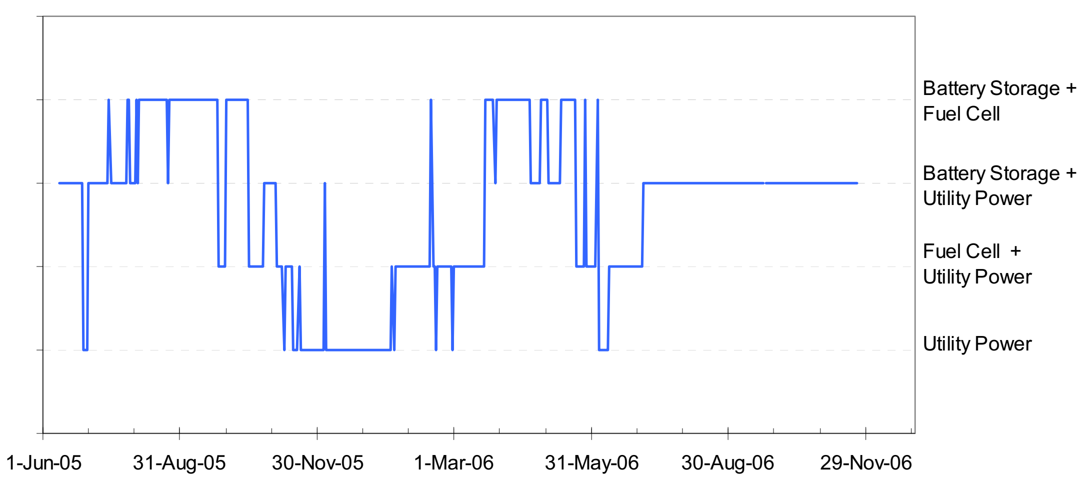


Figure 16: Operation of PowerTower and fuel cell during the duration of the demonstration

Figure 16 illustrates the four operational modes during the demonstration: utility power; fuel cell + utility power; battery storage + utility power; and battery storage + fuel cell. During the fuel cell demonstration, the PowerTower was online 45% of the time, and the fuel cell was online 67% of the time. This is slightly lower than the 72% reported in the fuel cell final report and is attributed to a slightly different number of total demonstration days. For the total demonstration, the PowerTower was online 63% of the time.

Only reason for PowerTower being offline:

- Short-term flicker

Main reasons for fuel cell being offline:

- Alcohol poisoning of reformer de-sulfurization filters
- Inverter replacement
- Stack replacement

DEMAND MANAGEMENT FOR FUEL CELL

The PowerTower's main function was to perform demand reduction for a very limited generation source, which was the fuel cell. The nominal rating for the fuel cell was 5kW, and the peak demand of the demonstration site was at least 11kW; the PowerTower was employed to provide the difference. Furthermore, the average power demand of the demonstration site was less than 1.5kW, and the fuel cell was not very efficient in changing its output rapidly, therefore, it was desirable to operate the fuel cell as close to the average power demand as possible. This meant that the PowerTower had to provide most of the peak demand.

Figure 17 shows the apparent power going from the fuel cell and into the PowerTower, and Figure 18 shows the apparent power out of the PowerTower for almost the same period. The average fuel cell output is kept below 3kVA with a few peaks reaching 4kVA even though the average PowerTower output would reach more than 6kVA and a maximum of 10kVA, which is close to the design specification of 11kW.

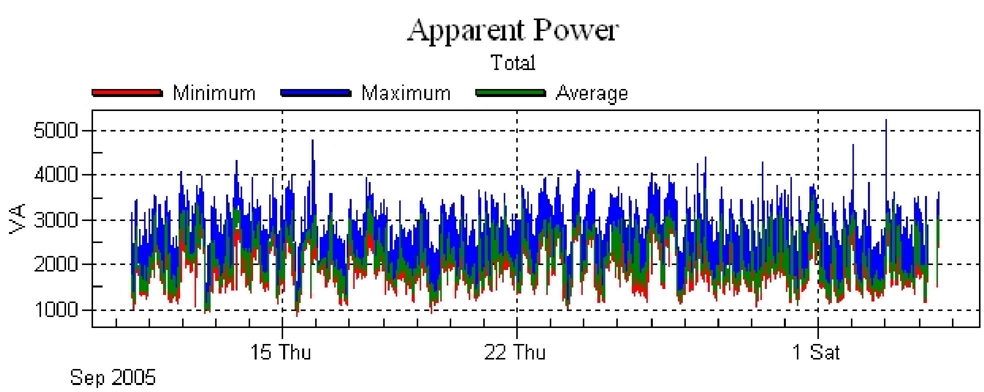


Figure 17: PowerTower power in / fuel cell out – September 11, 2005 to October 4, 2005

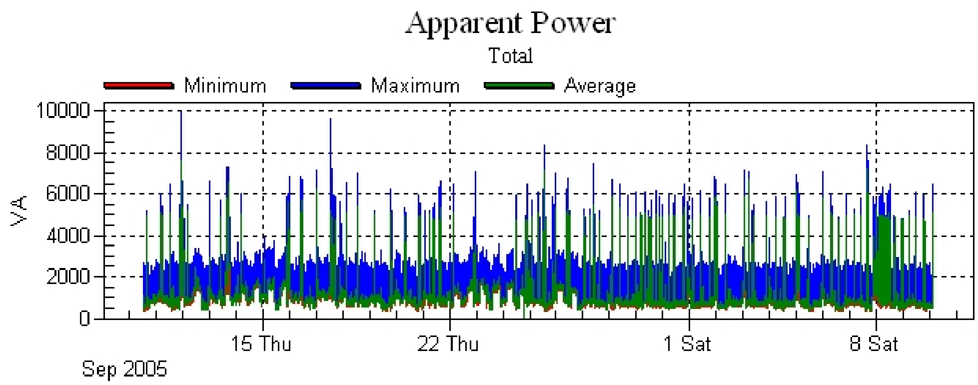


Figure 18: PowerTower power out – September 11, 2005 to October 4, 2005

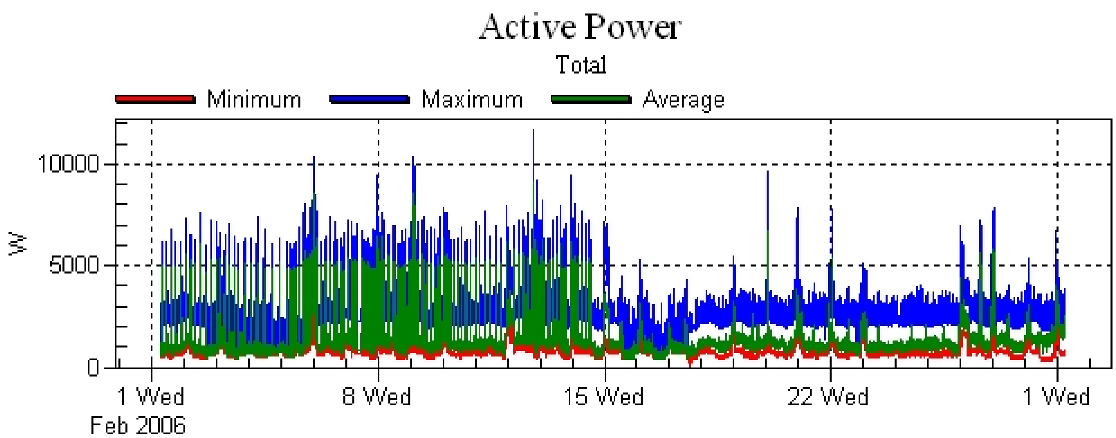


Figure 19: Total system load – the hot tub was removed from the system February 14

The PowerTower operated with three set points for the input power and corresponding fuel cell set point: 1.25kW, 2.5kW, and 4.5kW. It was not deemed desirable to operate the fuel cell at its theoretical maximum output.

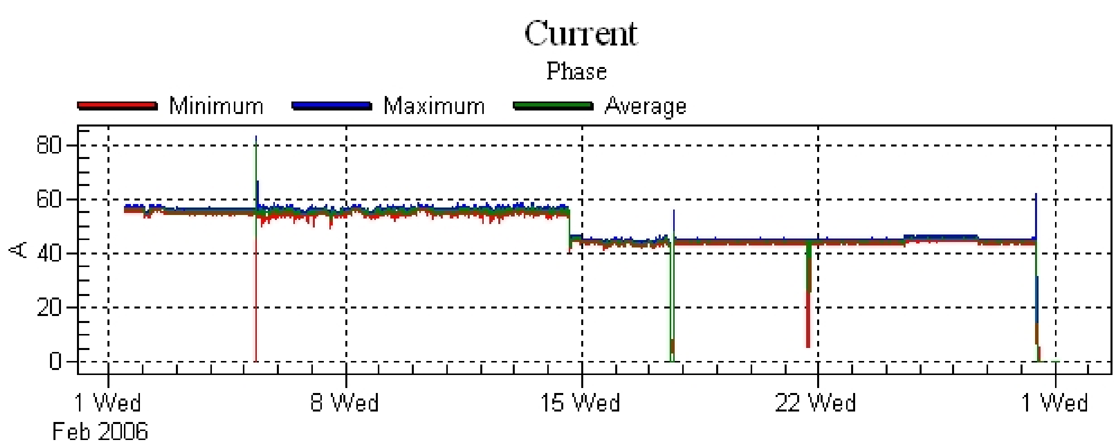


Figure 20: Fuel cell output – the battery storage was brought online February 14

Although no input data for the battery storage are available prior to 9 p.m. GMT, it can be seen how the storage system reduced the fuel cell set point. The subsequent increase can only be attributed to the fuel cell initially overcompensating and then finding a steady state.

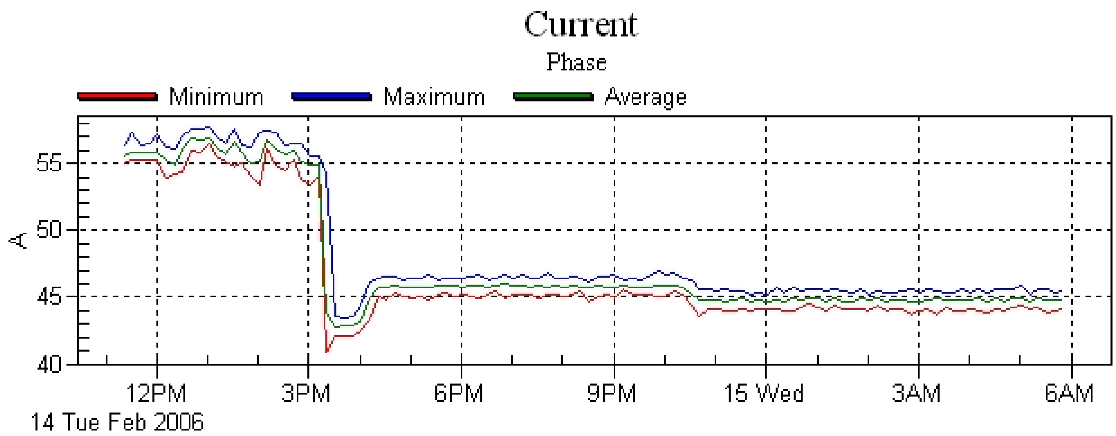


Figure 21: Fuel cell output – time is given in EST

Figure 22 and Figure 23 show the battery voltage measured using one of the inverters and the battery current measured using the battery monitor, respectively. It should be mentioned that 40VDC could be considered 100% discharged. As seen in the figures, the battery voltage fluctuates significantly and the current shifted frequently between discharge and charge. This would indicate that the fuel cell output was relatively well matched with the load, and the batteries are hardly discharged during normal operation.

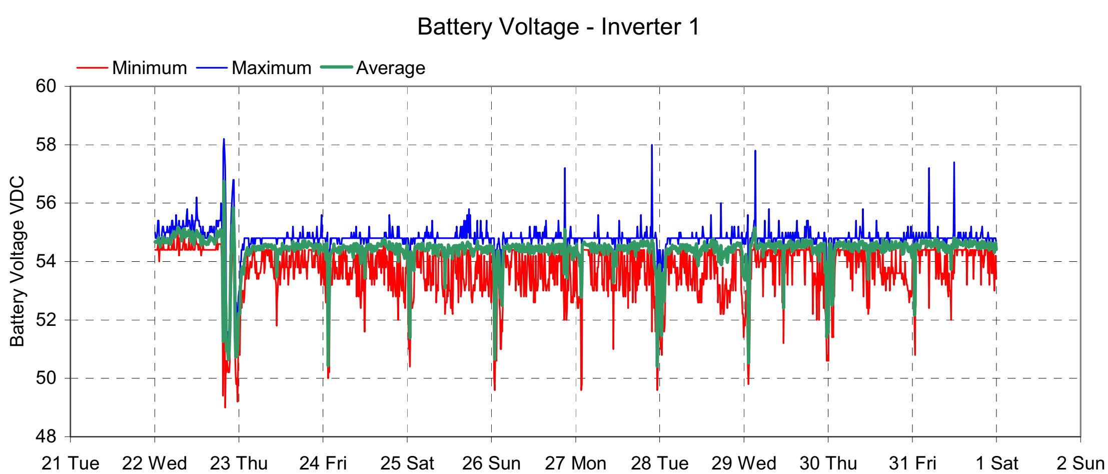


Figure 22: PowerTower battery voltage (inverter leg 1)

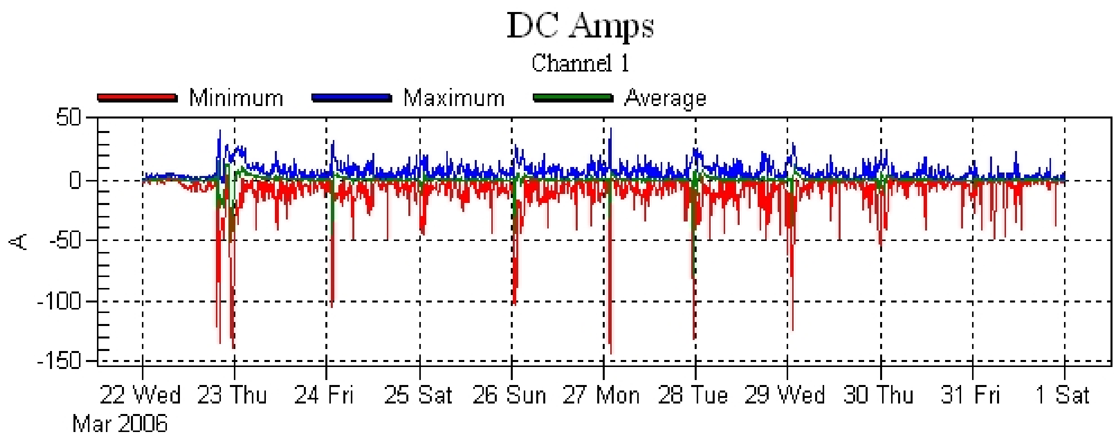


Figure 23: PowerTower battery current (battery monitor) – negative current equals discharge and positive equals charge

LOAD MANAGEMENT

Initially, when the hot tub was powered through the PowerTower, the total load could exceed the capacity of the PowerTower. In those cases the load management software would temporary disconnect the hot tub heaters from the loads, which would bring the demand within the 11kW continuous output limit.

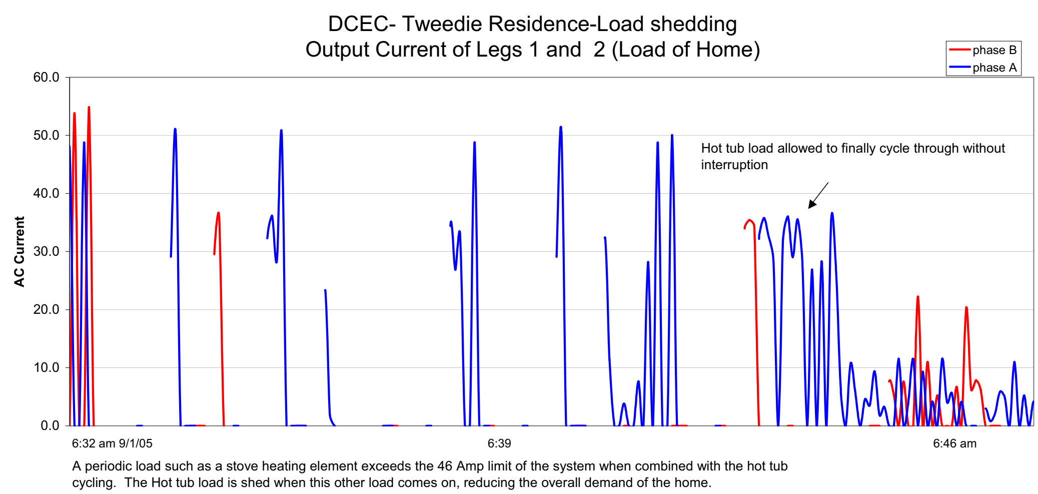


Figure 24: Load shedding example from September 1, 2005 using event-triggered data

The PowerTower's load management control software successfully identified and reduced a combination of loads exceeding the system's 11kW continuous output as shown in Figure 24. The PowerTower could supply up to 25kW for five seconds and these 10-second peaks of 14kW are easily handled prior to shedding. The response of the PowerTower (and its fuel cell source) to a changing load profile was excellent.

After the hot tub was removed from the PowerTower loads in an attempt to solve the flicker issue, no other loads were used for load shedding. This caused the system to shut down a few times due to overload when the load exceeded 11kW, for instance, when the homeowner used electric welding equipment at the site.

SYSTEM EFFICIENCY

An important aspect of using energy storage for demand reduction relates to system efficiency. Both the inverter / chargers and the batteries introduce loss during operation due to the internal resistance of the components. Figure 25 shows the comparison of energy efficiency of the inverter charger and the battery during discharge. The inverter curve is calculated using a simple mathematical equation considering only internal consumption and internal resistance[1], and the battery curve is based on manufacturing data for the Concorde battery used in this project and assuming a two-hour discharge equals 100% load. Total efficiency is calculated by multiplying the two curves.

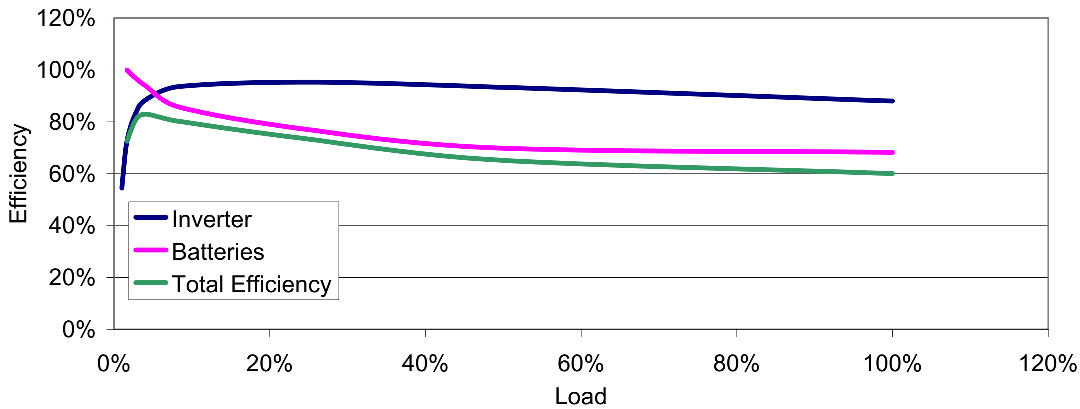


Figure 25: Approximate inverter and battery discharge efficiency versus load

In addition to loss during discharge, there will also be loss during charge. Loss during charge will depend on the rate of charge, thus the round-trip efficiency is lower. The largest contributor to the inefficiency is the battery. There are battery technologies on the market today that have significantly better efficiency than lead acid batteries. For example, sodium nickel chloride batteries, lithium ion batteries, and lead carbon batteries have lower internal resistance, which would reduce the loss.

As illustrated in Figure 23, during the operation in this project the PowerTower oscillated between charge and discharge depending on the loads and the state of charge of the batteries. This made it difficult to calculate a daily efficiency number. However, based on the gross assumption that in any given 24-hour period the batteries would have been fully charged at least once, it is possible to calculate the system efficiency by taking a 24-hour rolling average of energy being provided by the PowerTower and divide that with the 24-hour rolling average of the energy going into the PowerTower. Figure 26 shows the input and output power data for 25 days in September 2005, which included the hot tub. The efficiency for that period is illustrated in Figure 27 and shows an average efficiency of 77%.

---

[1] $$Eff = \frac{\left(P_{In} - P_{RUN} - R_i\left(\frac{P_{IN}}{V_{IN}}\right)^2\right)}{P_{IN}}$$ Where P_{IN} is power in; P_{RUN} is base power consumption; V_{IN} is voltage

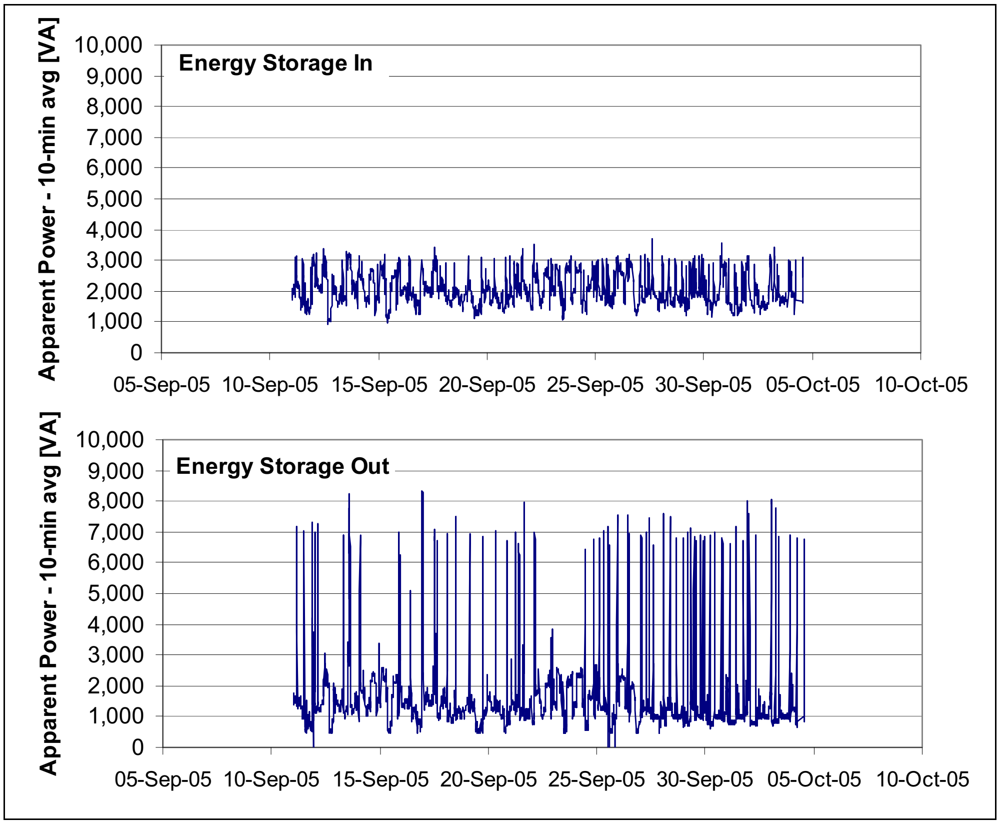


Figure 26: PowerTower In and Out from September 11, 2005 to October 11, 2005 – loads include the hot tub

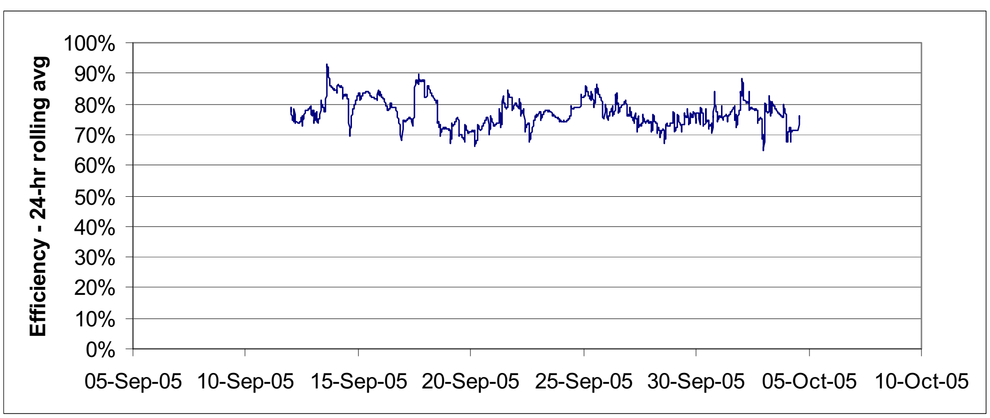


Figure 27: The efficiency from September 11, 2005 to October 11, 2005 based on a 24-hour rolling average – assumes that the batteries are fully recharged at least once in any 24-hour period; average efficiency is 77%

The same calculation was done for 48 days in the spring of April 2006, after the hot tub was no longer powered by the PowerTower. The power in and out of the PowerTower is given in Figure 28, and the efficiency is given in Figure 29. In this case, the average efficiency was calculated to be 65%. The chart also suggests that the efficiency decreases at a lower load.

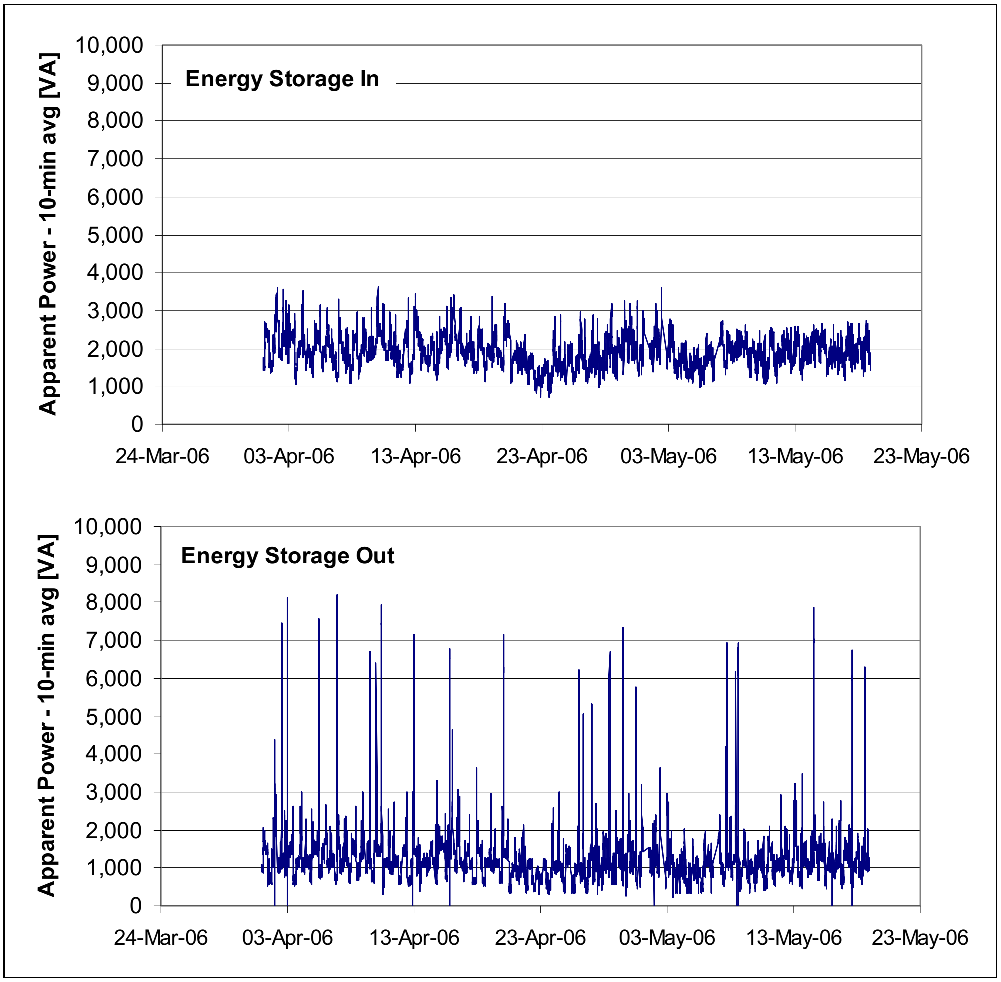


Figure 28: PowerTower In and Out from April 1, 2006 to May 18, 2006 – hot tub not included

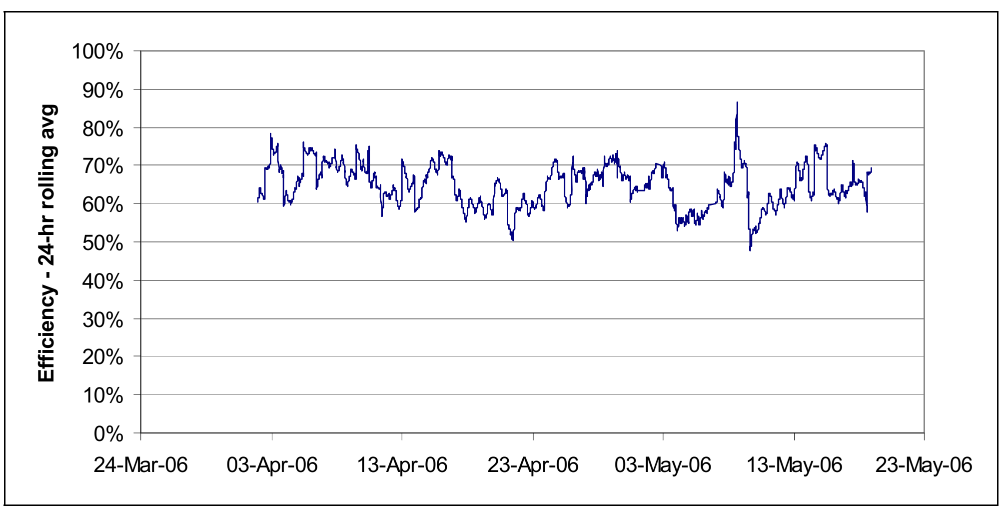


Figure 29: The efficiency from April 1, 2006 to May 18, 2006 based on a 24-hour rolling average – assumes that the batteries are fully recharged in any 24-hour period; average efficiency is 65%

The chart in Figure 30 is based on the combined data from 9/2005 and 4/2006, where the first set had the hot tub included. Even though the data are somewhat scattered, there is a clear correlation between the 24-hour average power and the efficiency. As the batteries are used more, the PowerTower spends less time in float charge and inverters operate at the top of their efficiency, increasing overall system efficiency.

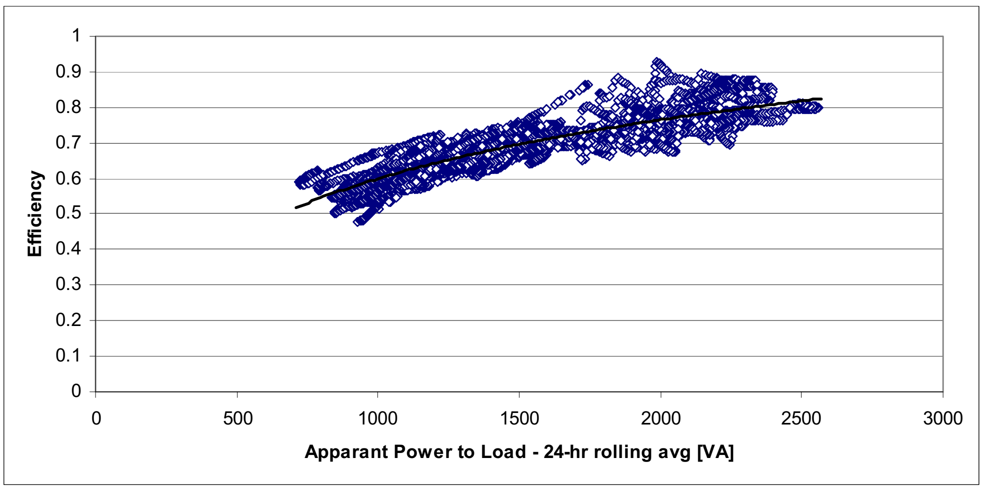


Figure 30: PowerTower efficiency versus 24-hr average load – based on data from Figure 26 and Figure 28

In this project we did not have the ability to reduce the output of the fuel cell below approximately 1kW or shut it off completely, and based on the results it would appear that the system efficiency decreased the closer we kept the fuel cell to a constant low value.

It is clear from these results that the efficiency of the system is highly dependent on how it is operated and the degree of control that can be had over the source. It is obvious that for a large-scale commercial deployment, it would make sense to integrate an efficiency optimization algorithm into the control algorithms.

SHORT-TERM FLICKER ISSUE

After the system operated for a period of time, the homeowner started to complain about flicker in his light sources, which were mostly traditional incandescent lights. When we inspected the issue, the local project manager could not see any flicker; the lead project manager could not see any flicker; but the Gaia technical service engineer could see flicker. Anecdotally, the flicker was worse when energy storage was powered by the fuel cell, but it was still present when energy storage was powered by utility. As a baseline, the house owner did not see any flicker when energy storage was bypassed, even when the fuel cell operated in parallel with the grid.

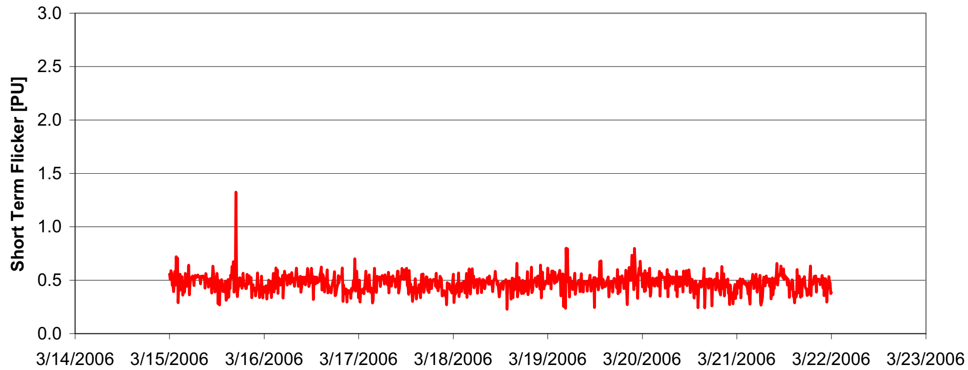


Figure 31: Short-term flicker - weak grid

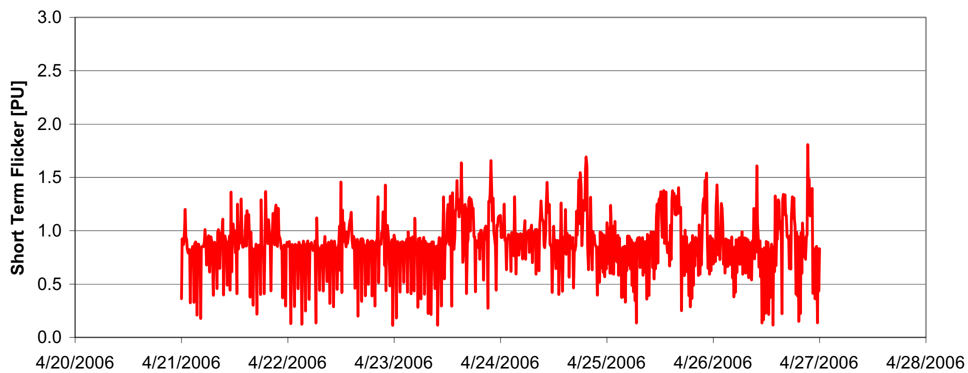


Figure 32: Short-term flicker - weak grid into energy storage

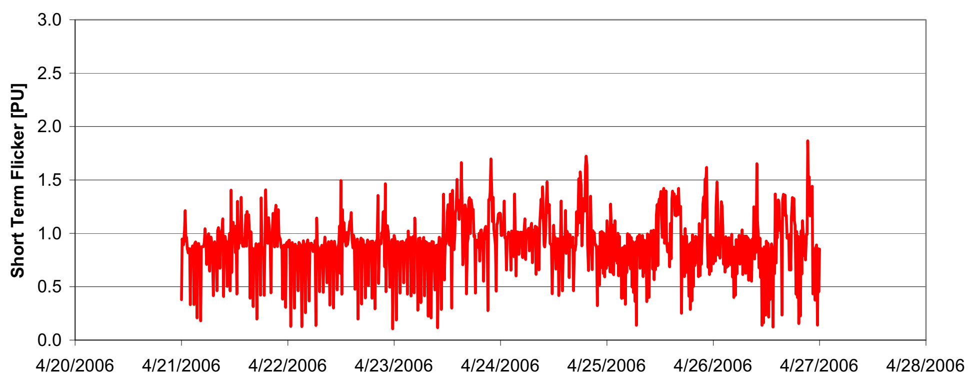


Figure 33: Short-term flicker - weak grid and energy storage – load

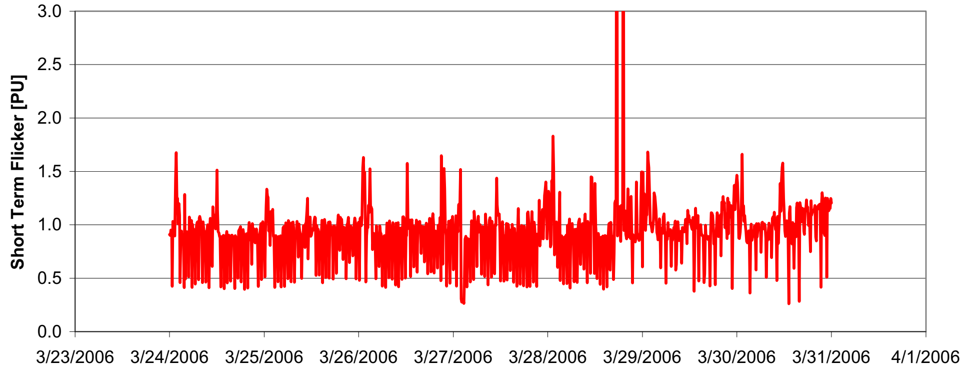


Figure 34: Short-term flicker - fuel cell into energy storage

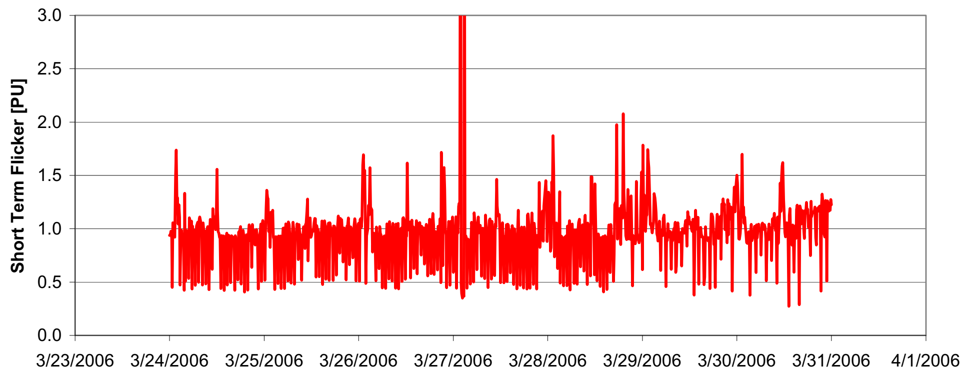


Figure 35: Short-term flicker - fuel cell and energy storage – load

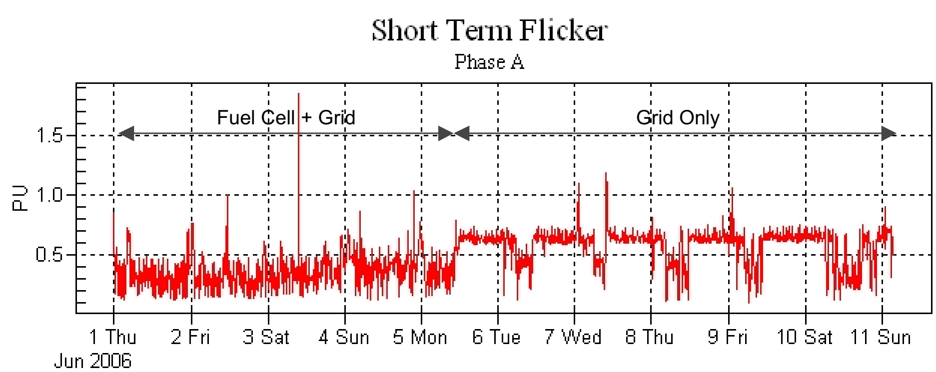


Figure 36: Short-term flicker - Fuel cell + grid versus only grid

The grid at the test site was measured to have a short-term flicker around 0.5 PUs. Introducing the energy storage device increased the flicker by more than 80% on the input side and an additional 3% on the output side. Finally, using the fuel cell as a source increased the flicker by 13%, but using it in parallel with the grid and without the energy storage (sell back mode) reduced the flicker by 25% in reference to the grid.

Table 1: Short term flicker - test site summary

Energy Source	Energy Storage	Short Term Flicker	
		Before Energy Storage	After Energy Storage
Weak Grid	No	0.50	Not Active
Weak Grid	Yes - Demand Reduction	0.87	0.90
Fuel Cell	Yes - Demand Reduction	0.95	0.97
Weak Grid + Fuel Cell	No	0.37	Not Active

In demand reduction mode, the energy storage device will follow the voltage of the source, but if the demand exceeds the input limit, the inverter will inject battery power to the load by increasing the voltage.

The amplitude of any voltage fluctuation can therefore be slightly increased in demand reduction mode. In case of a sudden increase in demand, it will take a finite period of time for the inverter and batteries to meet the increase. If the source cannot support the initial increase, the system will experience voltage sag. If the load is less than the upper limit of the source, power may be diverted to charge the batteries. This will result in a slight decrease in output voltage. In back up mode the energy storage device changes from current source to voltage source and the voltage is much more stable as it was proven in the following control experiment.

In order to study the short-term flicker, we conducted a controlled experiment in our laboratory. Using constant loads short-term flicker was measured in a laboratory environment under various conditions. We used an energy storage device similar to the one used in this project, and we varied the amount of demand reduction. First of all, the local grid had flicker values 10% lower than the weak grid, as our facility is situated much closer to the major transmission lines. When operating the PowerTower purely in back up mode, the flicker was only one-fourth of the grid. However, when operated in demand reduction mode, short-term flicker increased significantly, and the maximum increase was found at maximum demand reduction. The results are summarized in Table 2 and Figure 37.

Table 2: Short-term flicker - impact of energy storage device

Strong Grid	Energy Storage	Short Term Flicker
No	Yes - Backup Mode	0.09
Yes	No	0.43
Yes	Yes - Max Demand Reduction	0.85
Yes	Yes - Demand Reduction	0.66

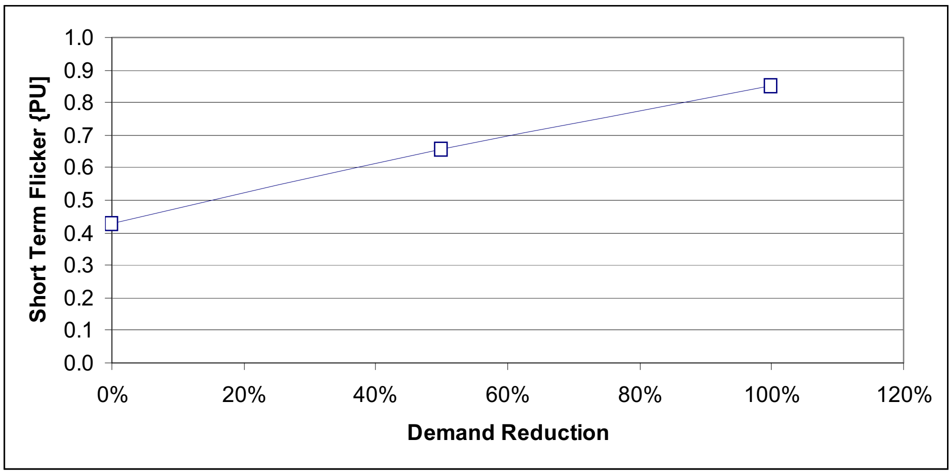


Figure 37: Short-term flicker as function of demand reduction - laboratory experiment

Introduction of an energy storage device used for demand reduction (current source) increased the short-term flicker at the residence. The magnitude of the short-term flicker was a function of the "strength" of the source and the level of demand reduction. A weak source such as the fuel cell further increased the flicker, and increased demand reduction also increased the flicker. However, when used as a voltage source, the energy storage device had short-term flicker values significantly lower than even a strong grid.

For this project, if we had used the fuel cell as a DC source rather than an AC source, we would most likely have solved the flicker issue. Unfortunately, the fuel cell used for this project was not capable of delivering DC power. Alternatively, we could have added another 5.5kW inverter/charger and used the unit as a battery charger. That would also have eliminated the need for the split-phase transformer inserted between the fuel cell and the PowerTower.

DECOMMISION

After the demonstration, the fuel cell was replaced by a 15kW Briggs and Stratton propane generator. Initially, we sought to control the generator using the PowerTower and continue testing to get an idea for the propane savings that could be achieved. However, the testing never got initiated, as the homeowner wanted to remodel his basement and reclaim the space occupied by the PowerTower. Instead, the PowerTower was removed and returned to Gaia. During the decommissioning, it was discovered that two of the battery modules had never been connected, meaning that instead of operating with a nominal 30kWh of batteries, the project had been using 20kWh.

Once in Peekskill, we tested the batteries to assess battery deterioration. We first fully charged the batteries to compensate for any self-discharge during storage, and then discharged the batteries to 10V using an 83.3W discharge rate, which gave an approximately 10 hours discharge. The four batteries in a module were tested together, and the discharge curve for module #1 batteries can be seen in Figure 38. As can be seen, three of the batteries are following almost the same profile, but battery #2 drops out ahead of the other three. Battery #2, however, still has 93% of the capacity of the other three.

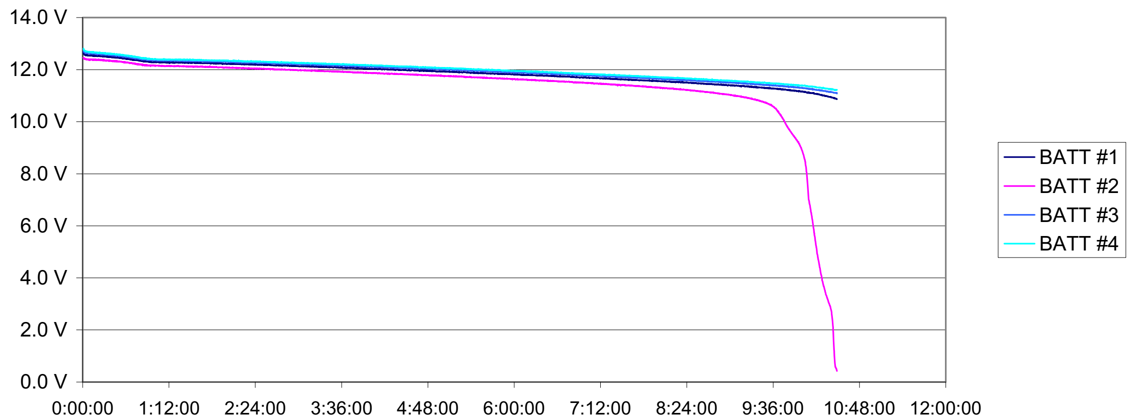


Figure 38: Capacity testing - Module #1

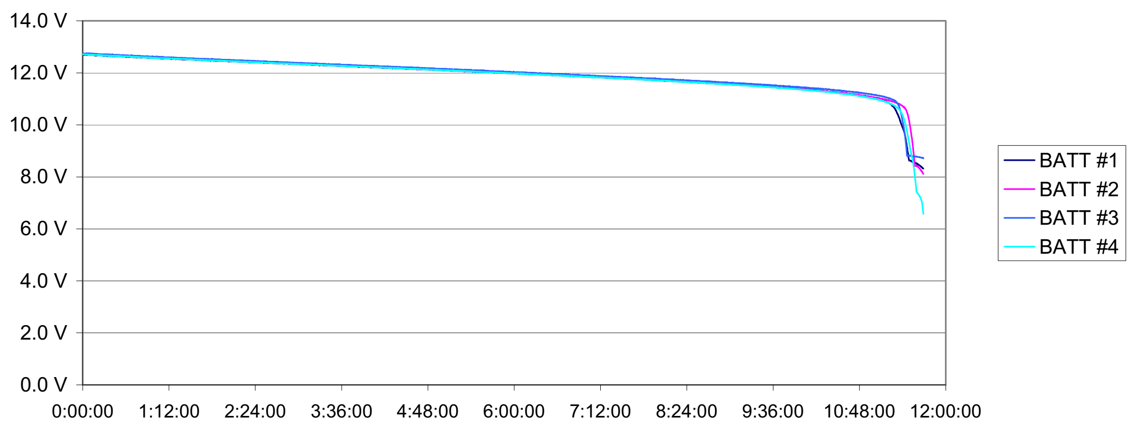


Figure 39: Capacity testing - Module #3

The other modules showed the same behavior. Either the batteries tracked very well together as seen in Figure 39 or one or two batteries dropped out slightly ahead of the others. The testing concluded that the batteries had an average of 0.89kWh remaining capacity, which is 76% of their initial theoretical capacity at that discharge rate.

We also tested module #4 even though we knew it had been disconnected throughout the demonstration. These batteries were down to 61% of their initial capacity.

Table 3: Battery testing after demonstration finish

Module	#1	#2	#3	#4	#5	#6
Battery #1	0.87 kWh	0.87 kWh	0.86 kWh	0.76 kWh	0.00 kWh	0.91 kWh
Battery #2	0.81 kWh	0.91 kWh	0.94 kWh	0.73 kWh	0.00 kWh	0.88 kWh
Battery #3	0.87 kWh	0.91 kWh	0.95 kWh	0.70 kWh	0.00 kWh	0.93 kWh
Battery #4	0.87 kWh	0.88 kWh	0.95 kWh	0.69 kWh	0.00 kWh	0.86 kWh
Active during demonstration	Yes	Yes	Yes	No	No	Yes
Average residual capacity	0.89 kWh	excluding module 4 and 5				
Standard variation	0.04 kWh					
Initial theoretical capacity	1.18 kWh	10 hr discharge rate				
Residual capacity	76%					

The results indicate that the 20kWh was enough to provide demand reduction for the site for at least one year or two. If the full 30kWh of batteries had been in operation, it can be assumed that the loss would have been significantly lower.

It is common practice for lead acid batteries that are cycled frequently to occasionally over charge them (equilibration charge). This is done to bring the voltage of all batteries to the same level if they should have drifted apart due to slight differences in internal resistance. It is also assumed to partly counter the effect of sulfate build up on the electrodes. The risk of sulfate build-up was considered minimal in this project as the batteries would not be regularly completely discharged, and they would not be exposed to extended float charging. Therefore, for the demonstration, we did not equilibrate the voltage of the batteries during operation. However, the performance of the batteries might have benefited from equalizing the batteries, as some of the capacity variation could have been due to some of the batteries operating at lower voltage than the others.

6. MARKETING STUDY

Over the course of the project Gaia conducted several activities within energy audits and installations. They can be divided into four categories:

1. Demand reduction of businesses
2. Back-up of commercial installations
3. Integration of distributed generation in off-grid installations
4. Residential back-up

DEMAND REDUCTION OF BUSINESSES

Gaia has taken a dual approach to marketing the PowerTower into the commercial sector. Realizing that this is a new concept for most businesses, we have undertaken a public relations campaign to create technology awareness and brand recognition. This has been followed up with direct marketing to small businesses with well-defined demographic and geographic properties. We have had numerous conversations with Con Edison to define target industries, and they have allowed us to use their name as an endorsement when we have contacted companies in their service territory.

Based on our trials at three Starbucks locations in New York we managed to get an article into *QSR* magazine. QSR stands for 'Quick Service Restaurants' and represents not only the fast food restaurants, but also diners and other sit-down eating establishments. Based on that article, we received a number of leads from across the country and we followed up on those where the restaurants were serviced by utilities charging a high demand charge.

The economics for demand reduction are highly dependent on the demand charges the local utility is charging. In some cases, businesses have negotiated delivery contracts with energy service companies (ESCOs), in which case they only pay demand charge on the transmission and distribution portion of their demand.

INNOVATION

SHORT-CIRCUITING COSTS

Helping restaurants cope with rising electricity expenses.

Soaring fuel prices mean rising energy costs, and that has sent some business owners scrambling for relief, but new technology provides a possible answer to rising electric bills.

Unlike residential customers, businesses pay both a flat rate per kilowatt-hour for their electric usage and a charge for their peak monthly consumption, measured in kilowatts. When there is a spike in power demand—even for just 15–30 minutes—the electric company calculates that it must constantly make that same capacity available. The utility provider then charges the business customer per kilowatt for the highest recorded peak in the month, even if average consumption is well below this peak.

Avoiding these high-usage charges is the goal of the PowerTower for Demand Reduction, developed by New York-based Gaia Technologies. The device, about the size of a filing cabinet, stores electricity in its battery module. When a demand for peak power occurs in a restaurant, the PowerTower takes over and supplies power from its battery unit, circumventing the power supplied by the electric company and preventing a recorded power spike. As a result, the utility company doesn't charge for the higher rate of usage.

"They've developed the next generation of technology to save money," says Tom Collins, spokesperson for the New York State Energy Research and Development Authority, which provided funding to Gaia for product development.

A secondary application for the device is back-up power. The unit automatically provides power to last through most power outages, allowing for operation of refrigeration systems for 4–6 hours and cash registers for up to 12 hours. It can also be controlled from off-site locations.

Figure 40: QSR magazine article

We have had promising meetings with both NYSERDA and ESCOs to see if we can improve the economics of demand reduction by aggregating the units in order to allow PowerTowers to participate in the NYISO demand reduction program. The relationships between payback time, demand charges, and incentives are illustrated in Figure 41 and it is obvious that the rate of return can be improved on several fronts. However, crucial to participating in any curtailment programs will be the ability to aggregate to at least 100kW of capacity for four hours.

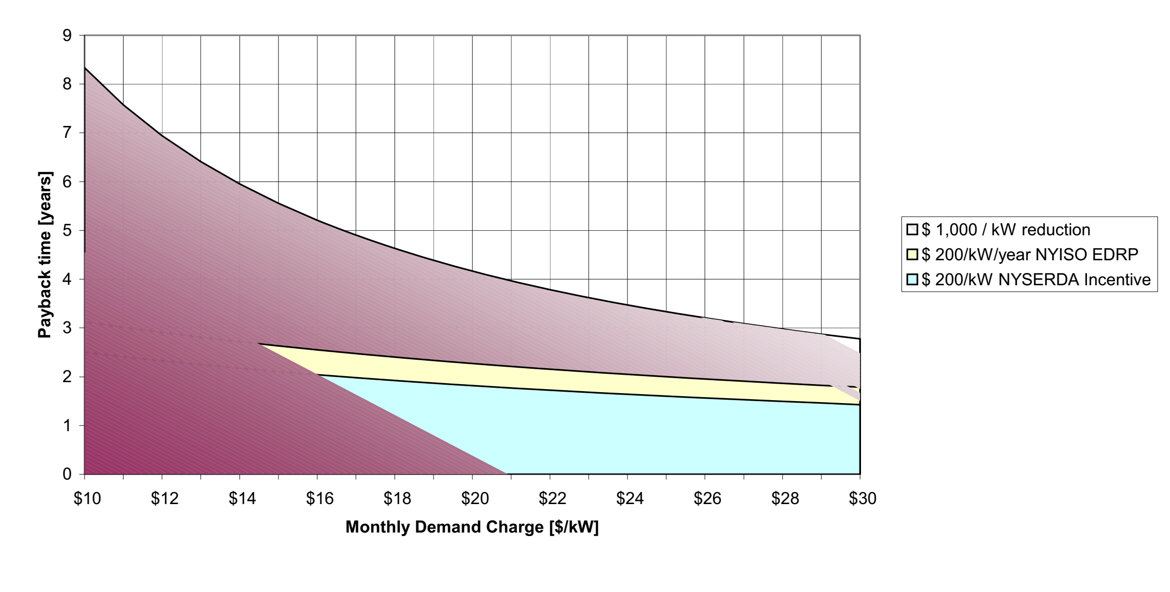


Figure 41: Payback time as function of demand charge and local incentives

In an ongoing project with Southern California Edison, Gaia is demonstrating how multiple PowerTowers can be controlled centrally and operate as one unit. In the project two 5.5kW / 15kWh units, each with 3kW of PV arrays, are controlled over the Internet through a web portal. Several screen shots from this web portal are shown in Figure 42. The same portal will be used for other utility projects as they come on-line. The portal can also be extended to interact with the utility's SCADA communication system.

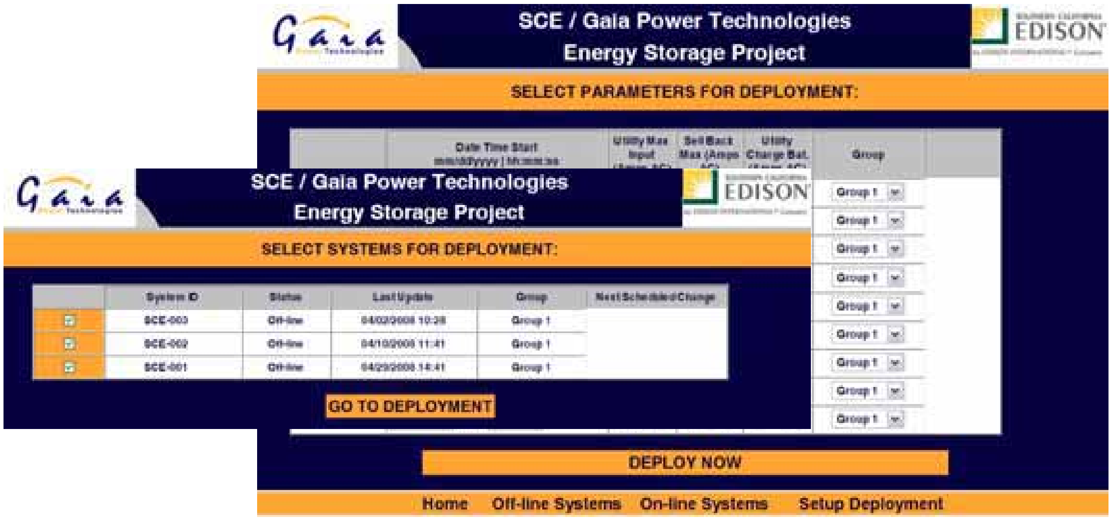


Figure 42: Utility control and deployment web portal

Over the course of the marketing study Gaia contacted both chains and individual businesses that were interested in reducing their electricity costs through demand reduction. For some of the more serious businesses, we conducted an energy audit. The first level of calculations in this audit is based on the company's energy bill, which we could get from Con Edison when the company was located in Con Ed's service territory.

Table 4: Partial list of companies audited for demand reduction

Type	Company	Category	Audit Type		Installation
			Elec. Bill	On-site	
Chains	*A National Gas Station Chain*	Gas station	Yes		
	McDonalds	QSR	Yes	Yes	
	Regis Corp	Hair salons	Yes		
	Starbucks	QSR	Yes	Yes	Yes
	White Castle	QSR	Yes		
	Whole Foods	Food market	Yes		
Individual	American Muffler	Auto repair	Yes		
	Dizzy's Diner	Restaurant	Yes	Yes	
	Rickshaw Dumpling Bar	QSR	Yes		

Based on the data from the electricity bill we calculated a Maximum Power Demand / Average Power Demand Ratio (MD/AV Ratio). This is based on the utility peak demand divided by average hourly energy usage, where the hours are based on business operating hours. Based on our experience, businesses with a MD/AV Ratio of more than 2:1 could be good candidates for battery based demand reduction and can merit a more detailed on-site audit. In the on-site audit, we identify the various equipment onsite and get a more comprehensive understanding of how the business operates. We also install a data acquisition unit to measure the current and voltage on each electrical phase going into the business. Based on those numbers Gaia runs a spreadsheet model to determine the level to which we can anticipate reducing the demand and the amount on energy storage that is needed. In an ongoing project with CUNY and sponsored by NYSTAR we have developed a set of algorithms that can do a more accurate calculation based on the audit data, but the algorithms have not yet been deployed for commercial use.

Despite our initial success with Starbucks, it turns out that QSR businesses are not the best candidates for demand reduction, as they require a relatively large amount of energy storage per kilowatt demand reduction. Our billing data from White Castle and McDonalds suggested as much, and when we did a more detailed study on a McDonalds in Yucca Valley in Southern California (see Figure 43), we found that we could only reduce the demand a few kW using reasonably sized energy storage.

The auto repair shop was the best candidate for demand reduction based on the billing information. Unfortunately, there was not room in the electrical panel for our data acquisition equipment, so we were unable to determine the time and duration of the peak loads.

At this time we do not have the resources to actively pursue potential customers for demand reduction. However, we are still approached from time to time by businesses that are interested in the concept. We expect with the launch of our 30kW unit and especially our 75kW unit that we should be able to pursue these opportunities further.

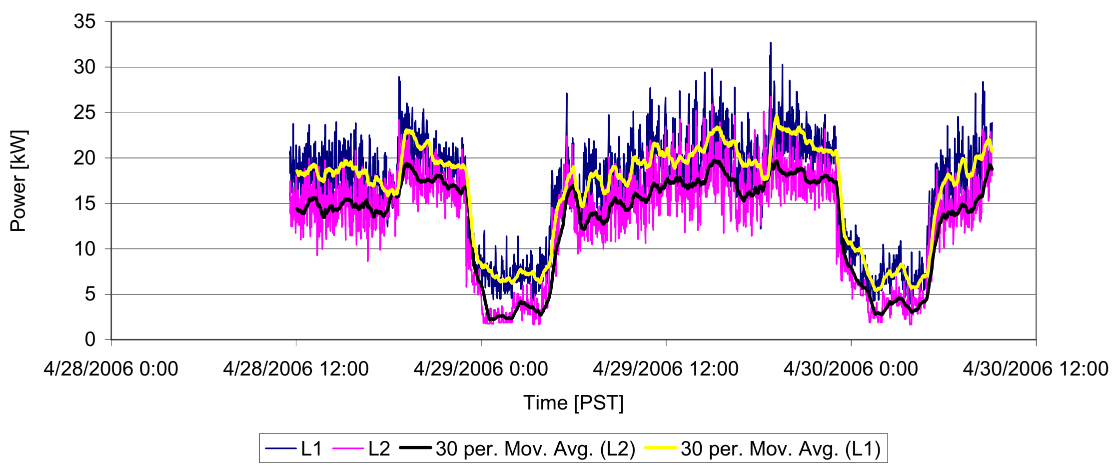


Figure 43: McDonalds in Yucca Valley CA – demand and rolling 30-minute average on phase 1 and 2 measured on the peak period from Friday to Sunday

BACK-UP OF COMMERCIAL INSTALLATIONS

Based on our success in the residential market, we have started to promote our PowerTower for businesses as an alternative to generators and short duration uninterruptible power supplies (UPS). Our first commercial installation was at the W Hotel on Times Square in New York City, where two units are providing extended backup for two communication devices. The W Hotel already has a generator installed, but it is undersized for the hotel and the generator did not back up some equipment, including these communication devices.

Figure 44: Two PowerTowers at Starwood's Times Square W Hotel providing extended backup and demand reduction for a Motorola and a Nextel repeater station

We are targeting certain markets where extended back-up is either desirable to avoid loss of revenue or where regulation demands longer backup time than provided by traditional UPS systems. In some installations we have found that traditional UPS systems of the same size would require the use of 3-phase systems. Because this is not always possible, Gaia's 1 and 2-phase systems have a competitive advantage in those applications.

With the upcoming launch of our 30kW PowerTower based on the inverters currently being developed with the help of a NYSERDA grant, and the launch of the 75kW PowerTower, we expect this segment to see significant growth.

INTEGRATION OF DISTRIBUTED GENERATION IN OFF-GRID INSTALLATIONS

We have had some interest from off-grid distributed generation sites. Gaia now has five installations where we have installed the PowerTower with existing gas or diesel generators. The setup is illustrated in Figure 45. The PowerTower takes over starting and stopping the generator based on battery state of charge and time of day. One installation in New York and one in Vermont use propane generators; in this case, payback time from reduced fuel consumption can be less than a year. The other two installations are located in western Pennsylvania and the sites have their own supply of coal gas. The generator run time has been reduced up to 75%, which resulted in significant environmental improvements and significant increase in generator lifespan. The N.Y. and one of the P.A. installations are shown in Figure 46.

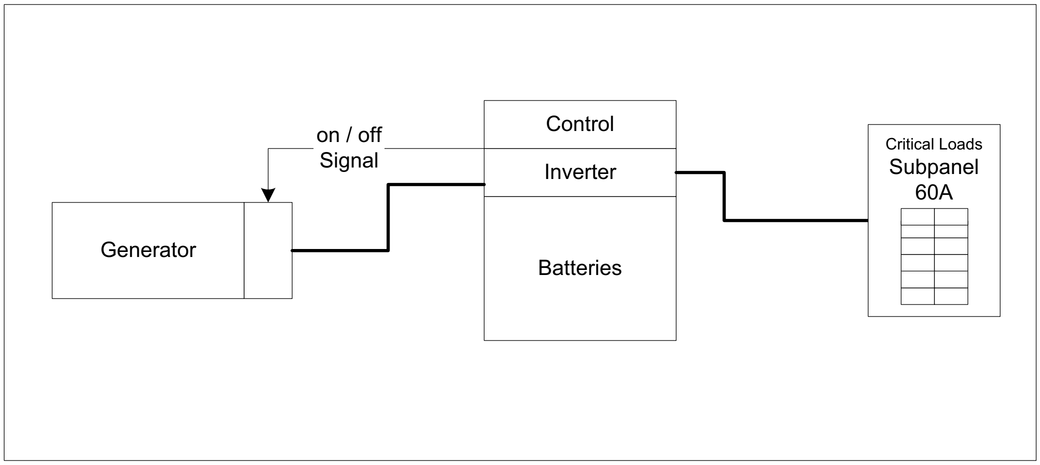


Figure 45: Off-grid energy storage / generator installation – PowerTower turns generator on and off depending on battery state of charge and time of day

The off-grid market is quite fragmented and known for its do-it-yourself mentality, so we have so far chosen to market the PowerTower through solar installers. We realize that it is not all off-grid sites that use solar power as obvious from our own installations, but we feel that the solar installers may be closer to the market than anybody else.

	 
5.5kW / 15kWh 120V / 240V PowerTower charged by propane generator – expected payback time is less than a year.	**5.5kW / 10kWh PowerTower and existing coal gas generator – generator run time expected to be reduced from 60 to 75%.**

Figure 46: Two off-grid installations with generators – in both cases the generator run time will be reduced by at least 60%

RESIDENTIAL BACKUP

To date, our main market has been extended backup for the residential market. We are competing directly with propane and natural gas generators, and we are winning sales based on environmental impact, ease and speed of installations and lifetime cost. Our installations come in a number of varieties:

1. Battery only (Figure 47)
2. Hybrid system with generator (Figure 49)
3. Hybrid system with new solar photovoltaic arrays (Figure 50)
4. Hybrid system retrofitted into existing solar photovoltaic array (Figure 51)

<u>Battery only residential back up</u>

We have actively marketed the PowerTower from Philadelphia to Boston, but with a focus on Long Island N.Y., Westchester County N.Y., and Fairfield County, CT. From our backup power site surveys for residences, we can state that the majority of homes requested backup power for the furnace (including air handlers), refrigeration, basic lighting and outlets, and any necessary pumps (septic, well, sump). The vast majority of homes can be handled by either a 5.5kW or 11kW PowerTower, but in several cases we have sold two or more units to the same residence (see for example Figure 48), and often the customer wants an extra battery module.

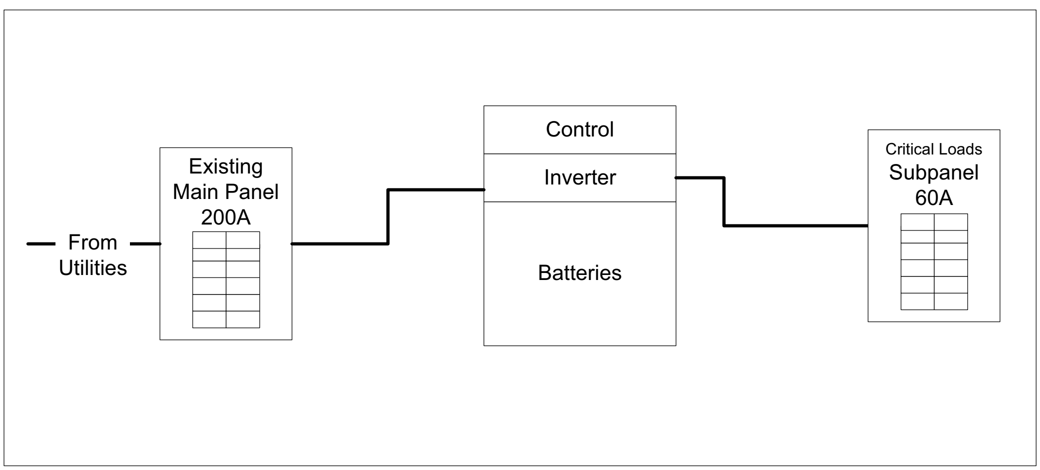


Figure 47: Typical residential back up system

Figure 48: Three 11kW/10kWh PowerTowers are installed for residential backup; the batteries are shared among the three units

To date, we have sold several hundred units, mostly in the Northeast, but also in several other states, and we have exported to several countries. One subset of this market is backup of high-end residential audio visual and home automation equipment. These units are sold exclusively through Richard Gray Power Company, a recognized leader in that segment.

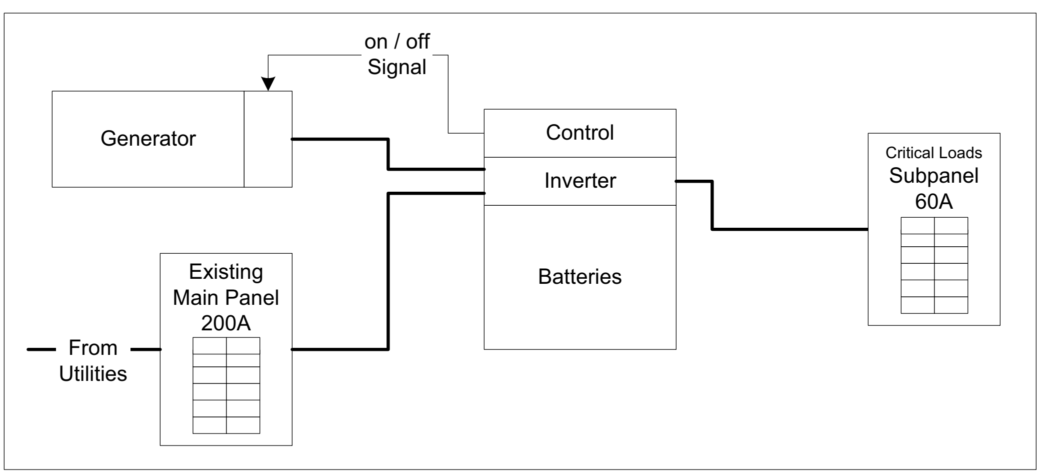


Figure 49: Residential back-up with integrated generator

A significant number of our installations are in conjunction with a generator. In case the generator powers the same critical loads as the PowerTower and has automatic start and stop, the PowerTower can take control of the generator and only start it when the battery voltage reaches a certain threshold. The set-up is shown above Figure 49. This results in much less runtime of the generator and significant fuel savings. In most blackouts the generator will not even be needed.

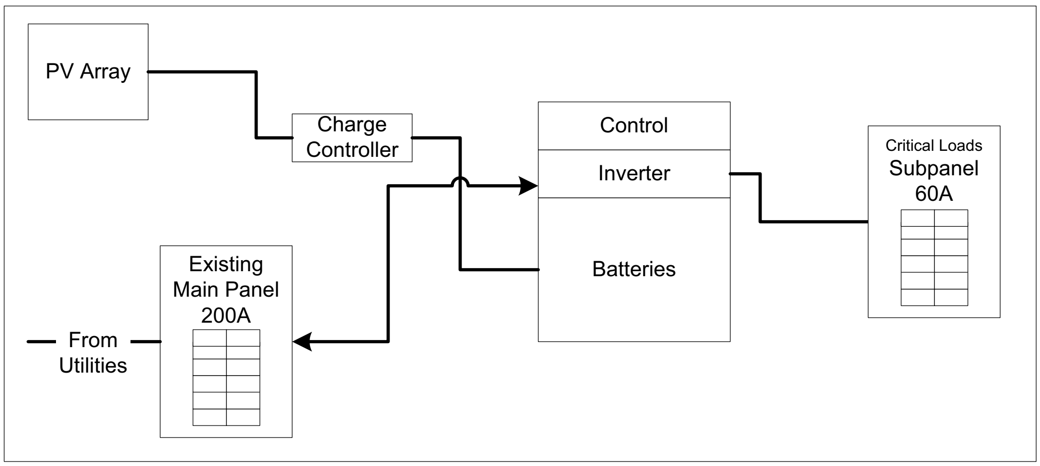


Figure 50: Residential back-up with integrated solar panels and sell-back

As illustrated in Figure 50 Gaia also integrated our PowerTower with solar photovoltaic arrays. To help us in this market we have developed our own solar charge controller, which has two key features: it accepts up to 600VDC versus max 150VDC for existing products; and it incorporates a switch so it can be disconnected from the array. This allows us to sell the PowerTower into existing PV installations, where the charge controller is placed in parallel with the existing grid tied PV inverter, as illustrated in Figure 51, and it is only turned on in case of a black-out where the grid tied PV inverter shuts down. The charge controller is currently moving from prototype to manufacturing.

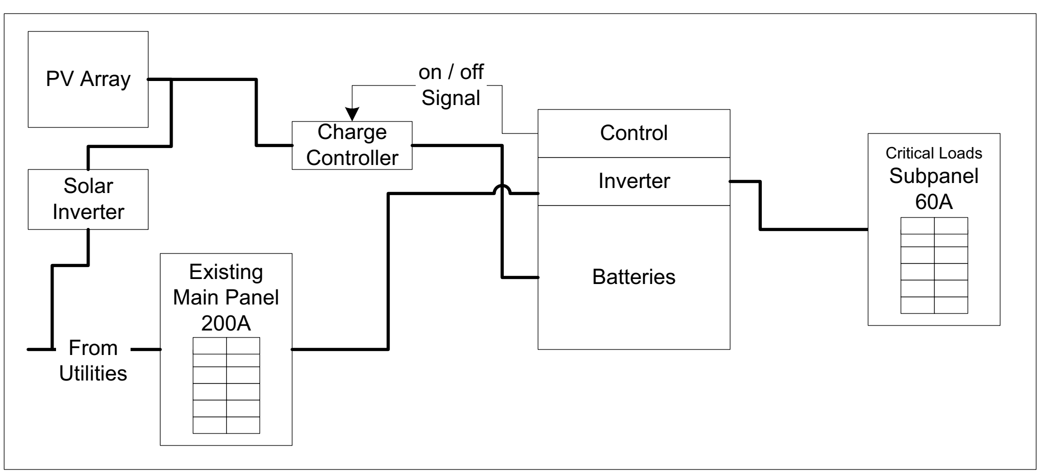


Figure 51: Residential back-up retrofitted into existing solar system

7. TECHNOLOGY TRANSFER

PUBLIC PRESENTATIONS

We presented the project in a number of industry conferences (Presentations are enclosed in Appendix):

- EESAT Meeting, San Francisco, October 2005
- 19th World LP Gas Forum Global Technology Conference, Chicago, October 2006
- EPRI PQA/ADA Conference, Long Beach, June 2007
- Energy Storage Association Meeting, Boston, May 2007

The project also received major media exposure through a PR event on August 11, 2006 organized by DCEC and including local congress representative and DOE as guest speakers. The event was well covered by local press and television.

Figure 52: Greg Starheim, CEO Delaware County Electric Coop – kicks off press event on August 11, 2005

8. METRICS

As of February 23, 2008, Gaia has installed over 3 MW of PowerTowers. They are mainly used for residential back up, but some of them are used in off-grid scenarios as well. As the back-up installations in most cases displace the need for a propane generator, we are displacing a significant amount of propane consumption and associated CO_2 emissions. According to 1999 data, US electric utilities produced an average of 0.61 kg CO_2 per kWh[2]. Assuming a propane generator operates at an average of 50% load during a blackout[3], the propane consumption will be around 0.39 kg per kWh [4,5], which equals 1.17 kg of CO_2 per kWh generated. That means that for every kWh supplied by the PowerTower we can assume that at least 0.56 kg of CO_2 has been avoided. Therefore, based on our installed capacity we are currently reducing the CO_2 emission with more than 1,600 kg for every hour of blackout.

Table 5: Calculated Carbon Dioxide emission savings

US Electricity Production	
Electricity production (fossil + non-fossil)	3.69E+12 kWh
Electricity production related CO_2 emission	2.24E+12 kg
Ratio: CO_2 emission / electricity production	0.61 kg CO_2 / kWh
Assumed Electricity Reliability (North East)	99.7 %
Hours of blackout per year	26.3 hr
Residential Propane Generator	
Average propane consumption (50% load)	0.39 kg propane / kWh
Average CO_2 emission	1.17 kg CO_2 / kWh
Average cost	$0.42 / kWh
Emission reduction	0.56 kg CO_2 / kWh
Gaia PowerTower Installed Capacity	
As of February 1, 2008	3000 kW
Total Emission Reduction per Year	44,000 kg CO_2

In addition to the CO_2 reduction, the PowerTower also improves the local noise environment by emitting very little sound during operation in contrast to most backup generators.

As a direct result of this project, Gaia has increased its number of full time employees from 15 to 22. The job additions have been evenly split between Gaia's New York City office and Peekskill facility.

[2] http://www.eia.doe.gov/cneaf/electricity/page/co2_report/co2report.html#electric Data calculated based on combining fossil fuel and non-fossil fuel generation and divide into total CO_2 emissions. 1999 data was the latest available in sufficient detail.

[3] Our own data suggest that the average need may be even lower. In many cases the average consumption may be as low as 20% of peak consumption.

[4] http://www.onan.com/pdf/standby/a-1422.pdf Onan 15kW gas generator consumes 6.1 liters of propane/hr at 50% load.

[5] http://www.sandia.gov/pv/docs/PDF/ecnmcs3cs.pdf

9. CONCLUSION

The demonstration illustrated that energy storage can be used to enhance distributed generation significantly and that, if necessary, an off-grid micro-power plant can power a residence. The demonstration also showed that in order to ensure the best possible power quality / customer experience, the energy storage must act as a voltage source and not just as a current source. This implies that the generation source must either be DC and charge the batteries directly, or a separate battery charger must be used to convert the AC to DC. The electrical efficiency of the system could also be improved through the use of optimization algorithms and greater control of the generation source.

The market study showed that the economics for customer side demand reduction is not quite there yet, but as the demand charges keep increasing, and in case incentives are put in place, the ROI could make business sense in the future. However, energy storage already can make sense for utilities, who are operating with much higher demand charges and system loads.

In the meantime, Gaia has had great success selling its system to residential customers as backup – either as stand-alone or in a hybrid configuration with a small generator – and we can demonstrate significant environmental impact.

APPENDIX A – INDUSTRY PRESENTATIONS

- Mark H. Schneider and Ib I. Olsen, "Residential energy storage and propane fuel cell demonstration project," EESAT Meeting, San Francisco, October 2005
- Mark H. Schneider, "Residential Fuel Cells: Analysis of Tank Additives on Stack Performance," 19th World LP Gas Forum Global Technology Conference, Chicago, October 2006
- Ib I. Olsen, Jeffery D. Lamoree, and Mark H. Schneider, "Impact on short-term flicker using energy storage and either a fuel cell or utility power as electric source," EPRI PQA/ADA Conference, Long Beach, June 2007
- Ib I. Olsen, Mark H. Schneider, and Greg Starheim, "Residential energy storage and propane fuel cell demonstration project by the Delaware County Electric Cooperative," Energy Storage Association Meeting, Boston, May 2007

Delaware County Electric Cooperative, Inc. A Touchstone Energy® Cooperative
The power of human connections

Residential Energy Storage and Propane Fuel Cell Demonstration Project

by the Delaware County Electric Cooperative, Inc

Mark Hilson Schneider, DCEC
Dr. Ib Olsen, Gaia Power Technologies
October 17, 2005

Acknowledgements

- DCEC and Gaia wish to acknowledge the technical and financial contributions of the following organizations:
  - Department of Energy (DOE) Golden Field Office
  - NYSERDA / DOE Energy Storage Initiative[1]
  - Propane Education and Research Council

[1] This project is part of the Joint Initiative between the New York State Energy Research and Development Authority (NYSERDA) and the Energy Storage Systems Program of the U.S. Department of Energy (DOE/ESS) through Sandia National Laboratories (SNL). Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Other Project Partners

- Plug Power – Fuel Cell Manufacturer
- Gaia Power Technologies – Energy Storage Partner
- Mirabito Fuel Group – Propane
- State University of New York at Delhi – Education and Outreach
- Cooperative Research Network (CRN) – Technology Transfer
- Sandia National Labs } – Data Collection and Analysis
- EnerNex Corporation }
- Energy Now Incorporated – Sister project in Manhattan
- New York Power Authority – Regulatory and Technical Advisors

Project team comprised of policy, technical, and outreach experts.

Rural Electric Coop
Interest in Residential Energy Storage

- Rural Electric Cooperatives frequently must service
  - Very rural
  - Remote
  - Previously un-served or newly expanded residential loads
- Looking for alternatives to our current costly service model
  - ~$50,000 per mile to build or rebuild distribution lines
  - ~$4,000 per year per mile to maintain rights of way and lines
- Residential Energy Storage can
  - Reduce need for line upgrades
  - Enable off-grid residences with reasonably-sized, coop-owned distributed generation

Demonstration Objectives

- Demonstrate viability of grid-independent residence
  - Typical upstate NY residence
  - Total electrical energy needs met by fuel cell
  - Intelligently managed energy storage
  - In-home load control
  - Increased efficiency through thermal recovery
- Validate objectives of propane fuel cells for edge-of-grid residences
  - Measure and report technical performance
  - Provide cost data and economic viability analysis
  - Document maintenance and operations concept enhancements specific to fuel cells in combination with energy storage
  - Promote education of national, state, and local consumers

Technical and economic viability of fuel cell with intelligent energy storage

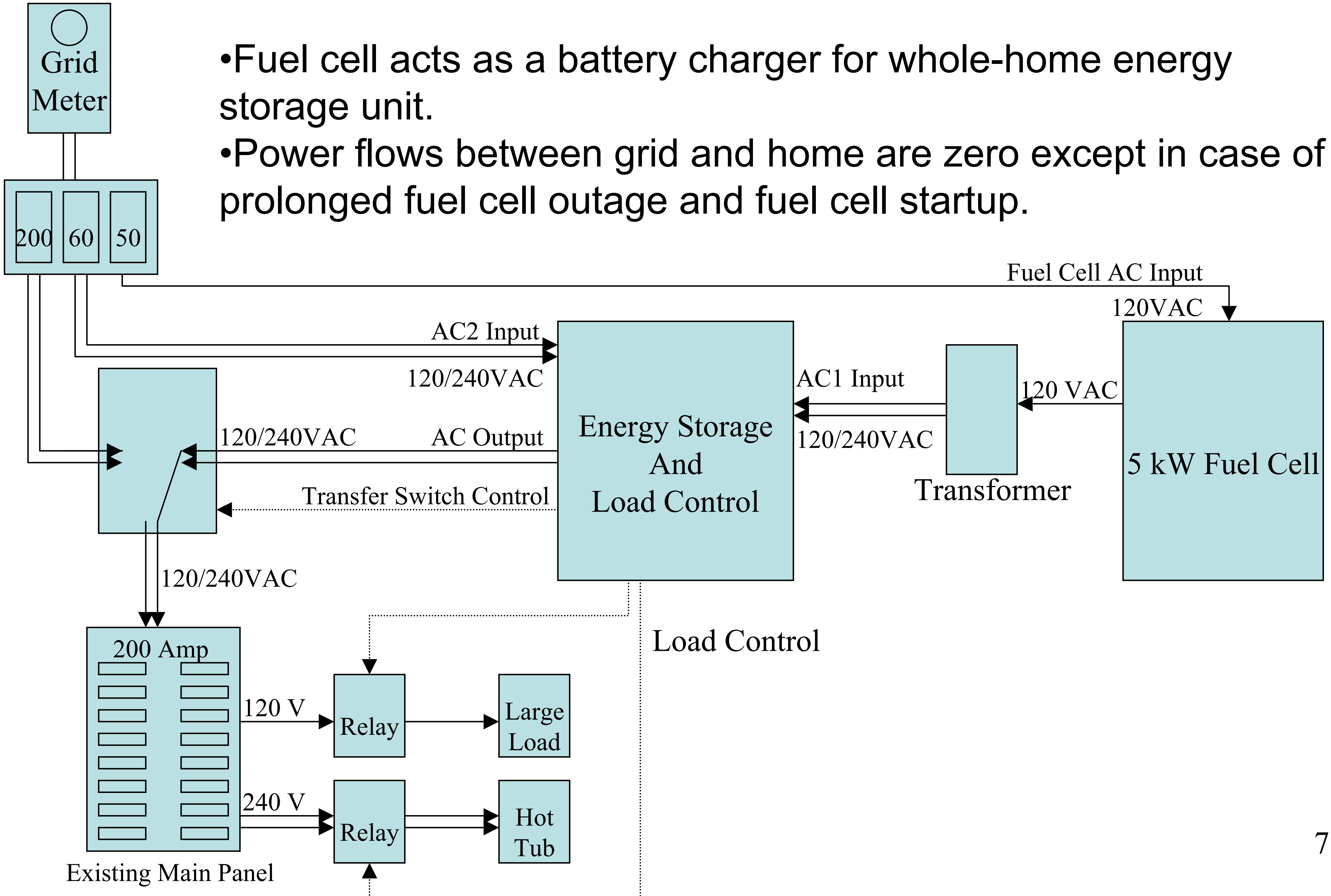
Characterization of the Load

- Avg. Energy use per day: 47.6 kWh
- Max. Energy Usage in 1 day: 67 kWh
- Avg. power draw: 1.98 kW
- Max. power draw: 15.2 kW

- 3 years of 15-minute data
- 3 months of 1-minute data
- Measuring real-time load characteristics and power quality events during the demonstration period

Electrical Design

- Fuel cell acts as a battery charger for whole-home energy storage unit.
- Power flows between grid and home are zero except in case of prolonged fuel cell outage and fuel cell startup.



Project Status

- Installation May 2005, Commissioning June 2005
  - 1000 gal propane tank
  - 5 kW fuel cell
  - Thermal recovery for hot water and space heating
  - Data acquisition and communications equipment

Project Status

- Gaia PowerTower
- 11 kW capacity (2x5.5)
- 600 Ah deep-cycle, lead-acid batteries
- 1 Controller for charge control, inverters, fuel cell output, and in-home load control
- Peak shaving for grid-connected and off-grid

PowerTower Controller

- Responsibilities
  - Charger Control, Inverter Control
  - Fuel Cell Control, In-Home Load Control

- Constraints
  - Limit inverter output below 5.5 kW per leg
  - Limited input to 5 kW from fuel cell
  - Currently 6 kW load shedding capability
- Goals
  - Maintain battery charge state between 50 and 80%
  - Limit fuel cell output set point changes to 6 or fewer per day
  - Minimize or eliminate full load transfers to grid power

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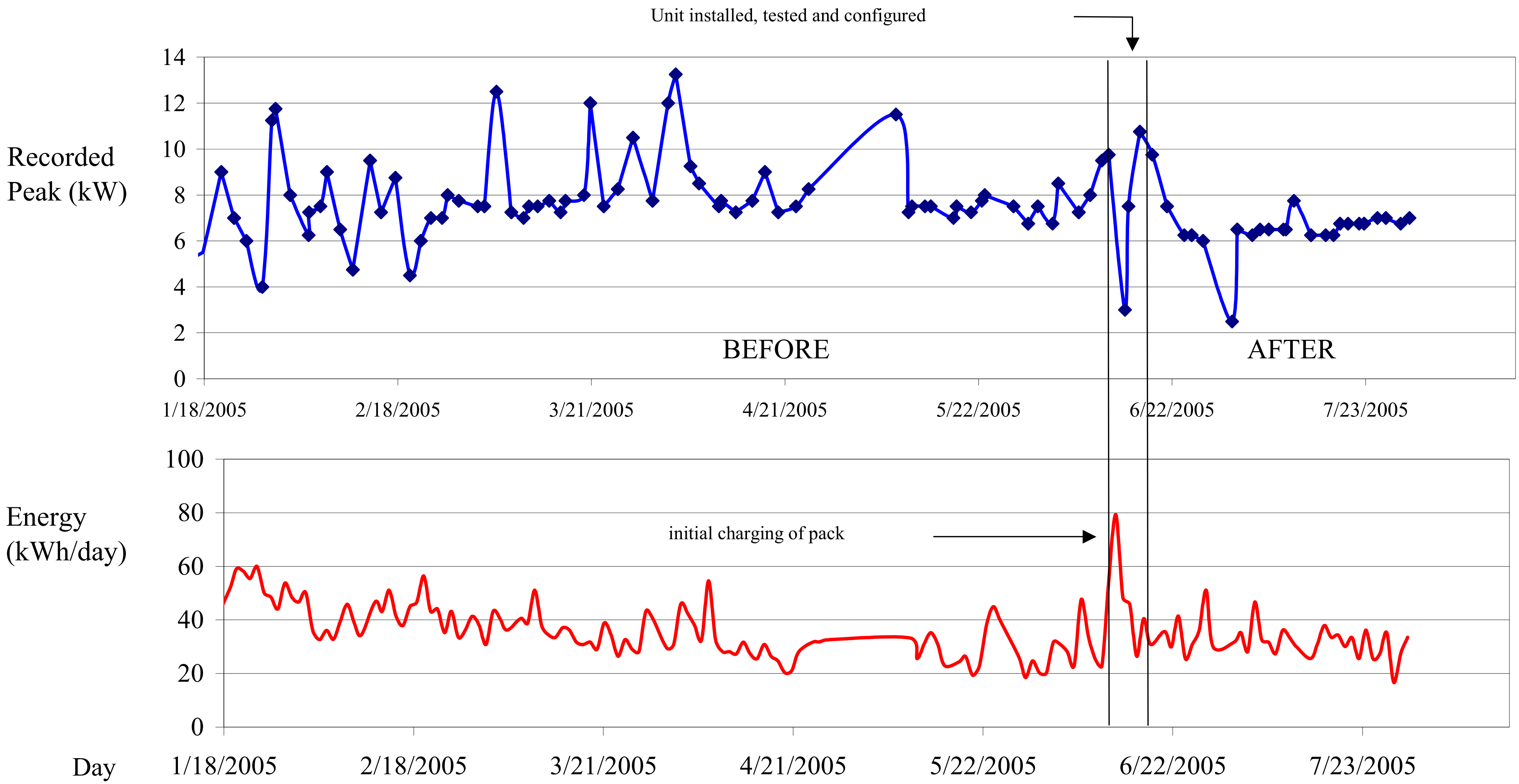
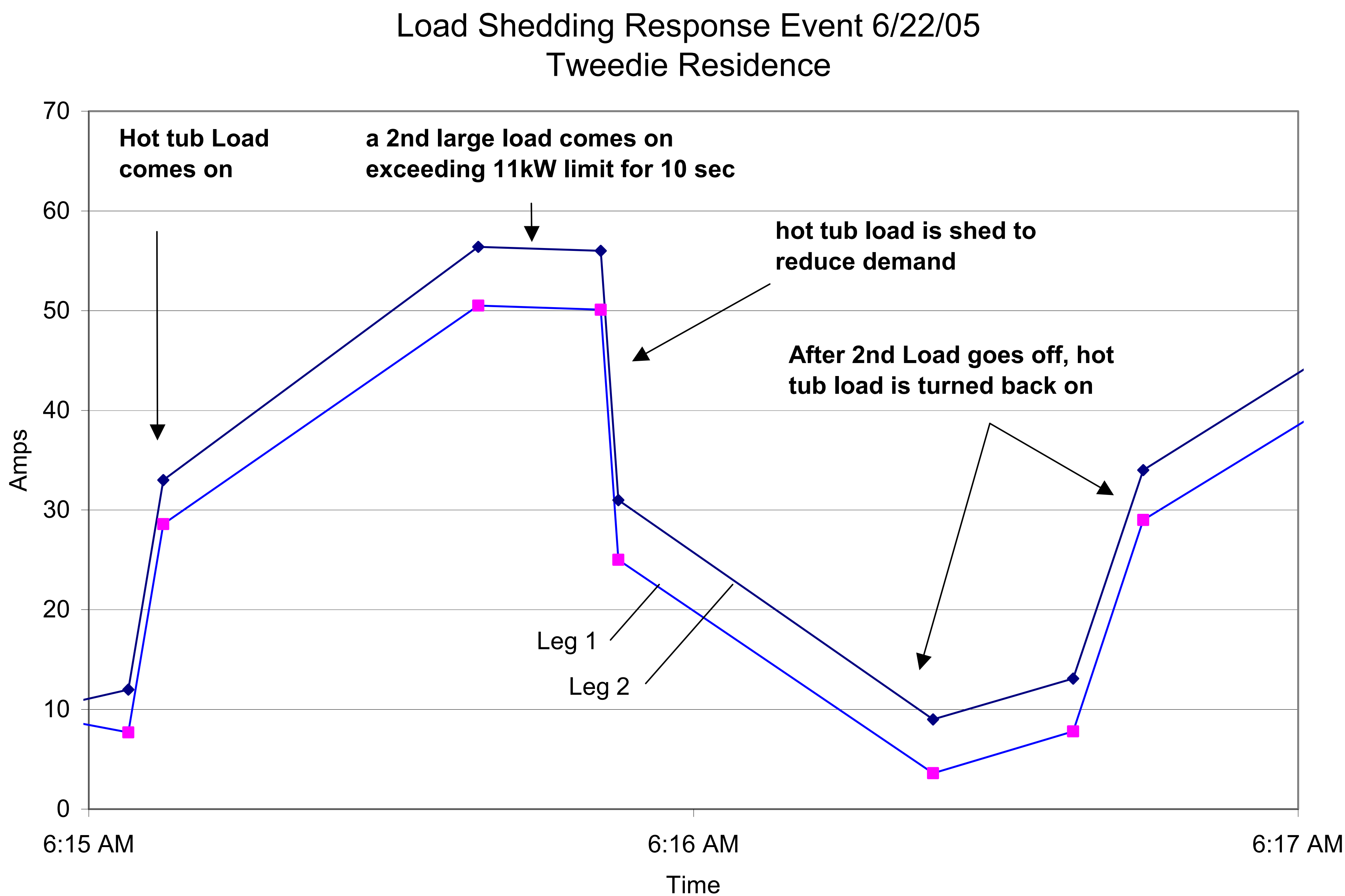
Grid Connected Demand Reduction

Tweedie Residence Utility Data before and after installation of Gaia PowerTower



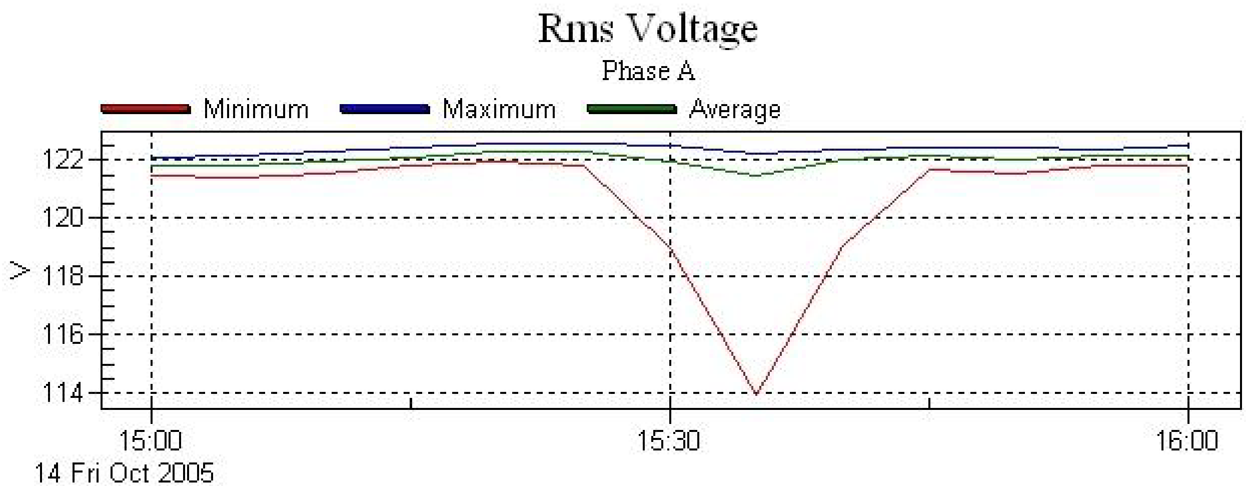
Load Control for Grid Independence



Identified Challenges

- Propane Fuel Cell Related
  - Potential incompatibility between propane tank dehydration additives and fuel reformer/scrubber
  - Integration of controls with energy storage controller
  - Distributed generation products not designed to efficiently and easily integrate with battery storage (e.g. regulated direct current output is not available)

Identified Challenges



- Electrical Design and Energy Storage Related
  - 11 kW inverter limit may not be compatible with a load this large without further optimization of load profile
  - 10 to 20% voltage dips (noticeable to consumer) associated with large startup surge currents of hot tub heater
    - ~2 second delay before PowerTower peak limiting threshold settles in
    - Undersized wiring from fuel cell for this short term pass through current

Future Steps

- Immediate
  - Continue data analysis related to power quality issues
  - Resolve remaining issues with control protocol between energy storage and distributed generation devices
- Short term
  - Work with SUNY Delhi to develop curriculum material to be made freely available to other institutions
  - Continue to improve energy storage controller algorithms for optimum performance
- Long term
  - Complete 1-year demonstration with fuel cell
  - Operate additional 6 months with energy storage in grid-connected mode
  - Final analysis, reporting, and technology transfer

Energy Storage - Critical Technology

- Rural electric cooperatives have energy storage needs that are critical to our core operations and our economic position
  - Residential scale
  - Substation scale
- Look forward to working with many of you on energy storage projects and technologies of common interest
- DCEC thanks our project partners and the EESAT organizers for the opportunity to participate in EESAT 2005

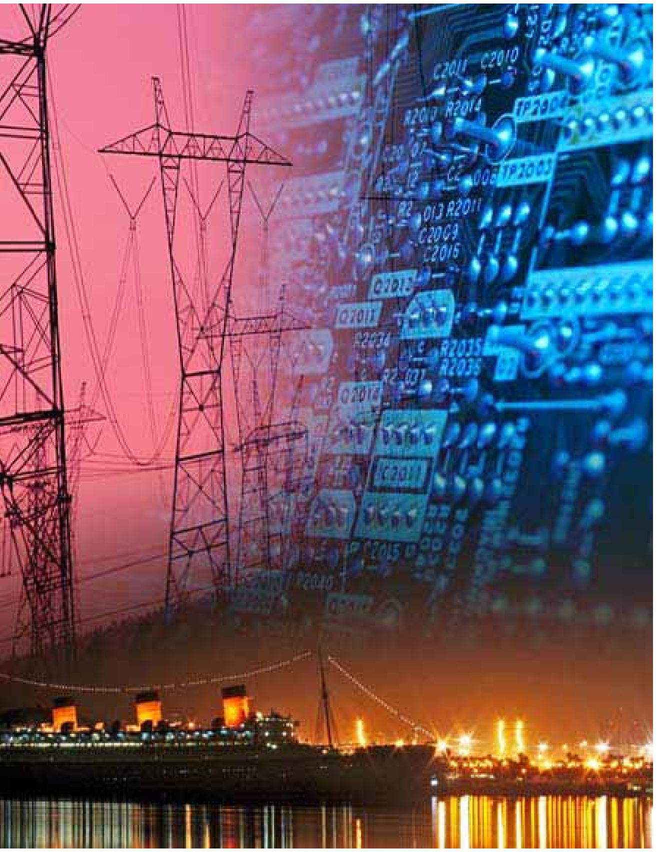
Questions?

EESAT 2005

Mark Hilson Schneider - DCEC

Dr. Ib Olsen – Gaia Power Technologies

October 17, 2005



EPRI Power Quality Applications (PQA) and

Advanced Distribution Automation (ADA)

2007 Joint Conference and Exhibition

Impact on Short-Term Flicker Using Energy Storage and Either a Fuel Cell or Utility Power as Electric Source

Ib I. Olsen, Gaia Power Technologies

Jeffrey D. Lamoree, EnerNex Corp.

Mark Hilton Schneider, Delaware County Electric Cooperative, Inc. / SUNY Delhi

June 12, 2007

Project Description

- Demonstrate viability of grid-independent residence plus significant demand reduction of grid power
    - Typical upstate New York residence
  - Total electrical energy needs met by fuel cell
    - Hydrogen PEM fuel cell with propane gas reformer
    - Increased efficiency through thermal recovery
  - Intelligently managed energy storage
    - In-home load control by energy storage device

- Funding by:
  - New York State Energy Research and Development Authority (NYSERDA) / Department of Energy (DOE) Energy Storage Initiative
  - Department of Energy (DOE) Golden Field Office
  - Propane Education and Research Council

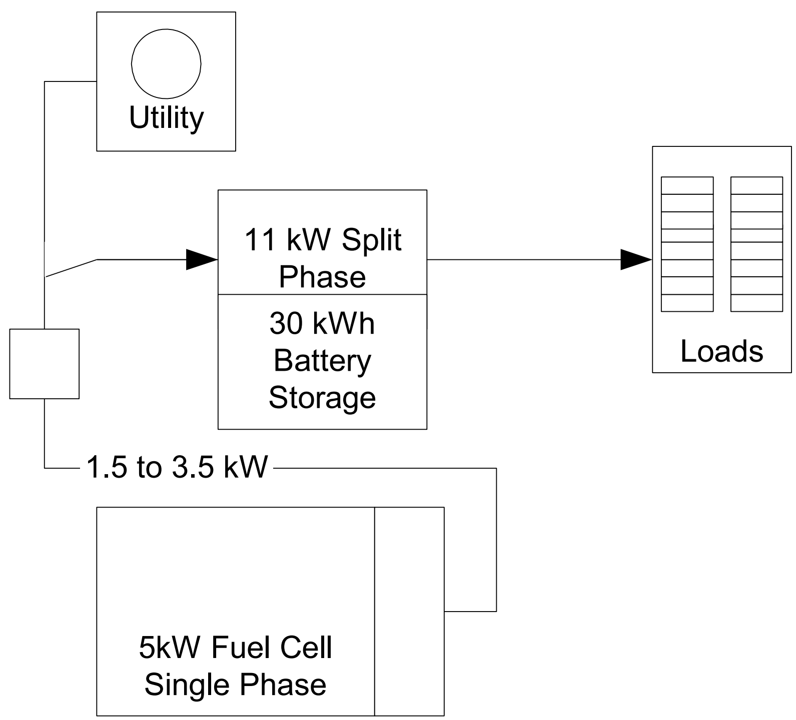
PowerTower
Commercial Energy Storage Device

- Flexible energy storage device
  - Demand reduction and load shifting
  - Load management
  - Extended backup
  - Integration of AC based and DC based distributed generation sources
  - Remote monitoring and control
- Module size
  - 5.5 kW single phase
  - 5 kWh sealed lead acid batteries

Test Site

- The test site was a residential dwelling in rural Delaware County, New York. The house is located on the edge of the utility grid operated by Delaware County Electric Co-op
- Energy storage supplied by Gaia Power Technologies, and propane powered hydrogen fuel cell by Plug Power

Simplified 1-Line Diagram

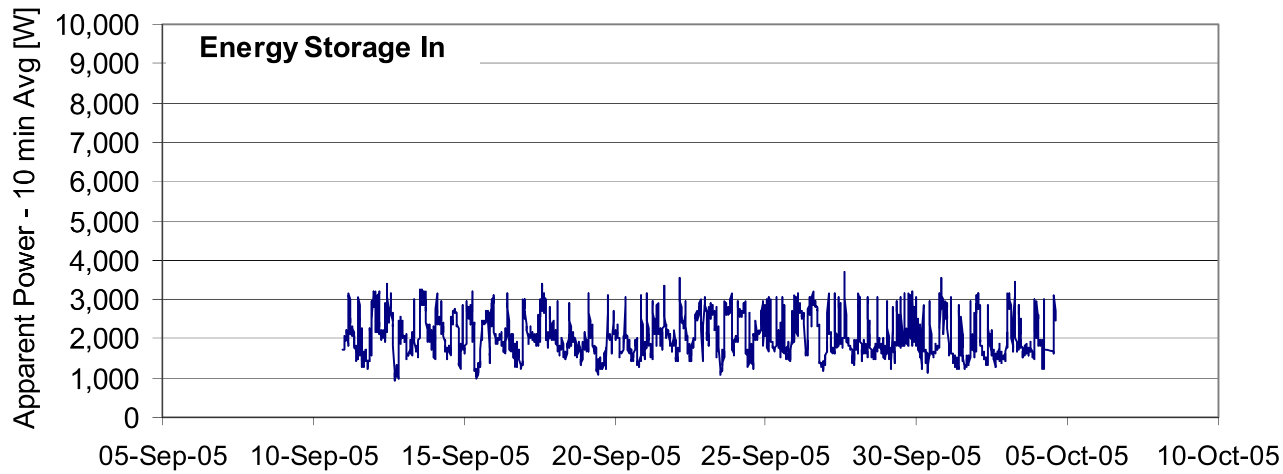


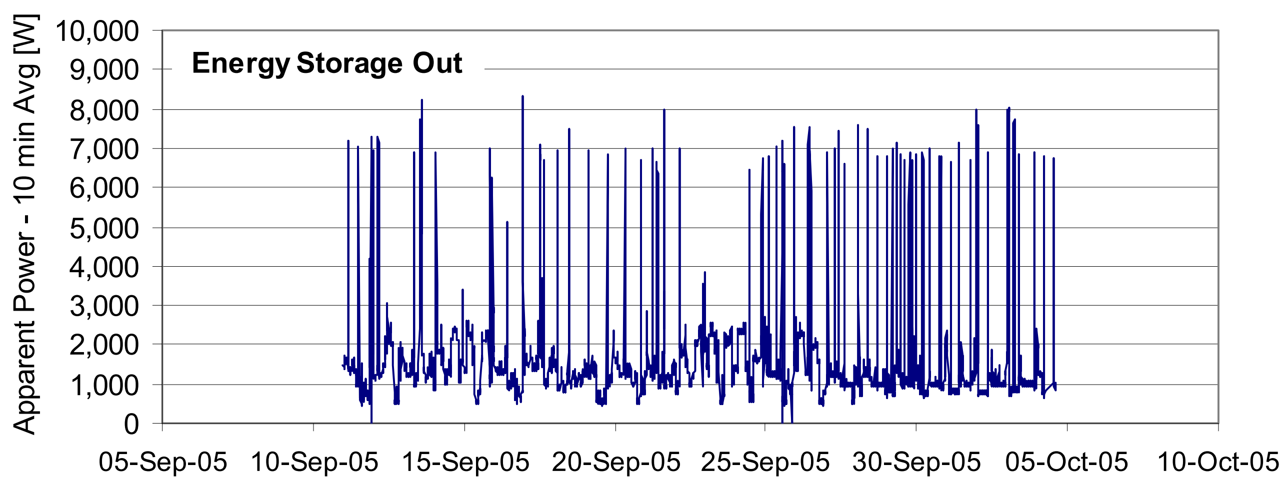
- The house was powered by a combination of an 11kW / 30kWh energy storage device and either a 5kW PEM fuel cell or the utility
- The site was extensively monitored by EnerNex, who deployed Dranetz-BMI Signature Systems data acquisition, and by Gaia, who used on-board data acquisition to monitor power in and out of the energy storage device
  – This might have been the "most instrumented residence in the nation”

Problem Statement

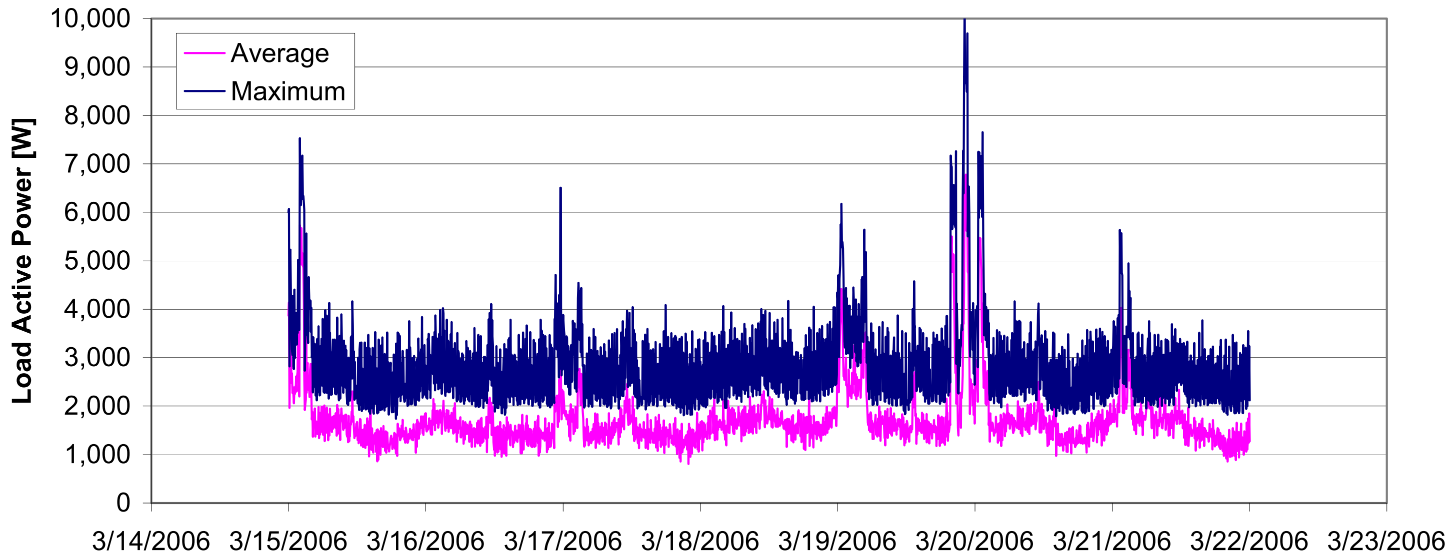
- After operating for a while the house owner started to complain about flicker in his light sources
  - Local project manager could not see any flicker
  - Lead project manager could not see any flicker
  - Gaia technical service engineer could see flicker
- Anecdotally the flicker was worse when energy storage was powered by fuel cell, but still present when energy storage powered by utility
  - House owner did not see any flicker when energy storage was bypassed

House Load
Example – With Hot Tub





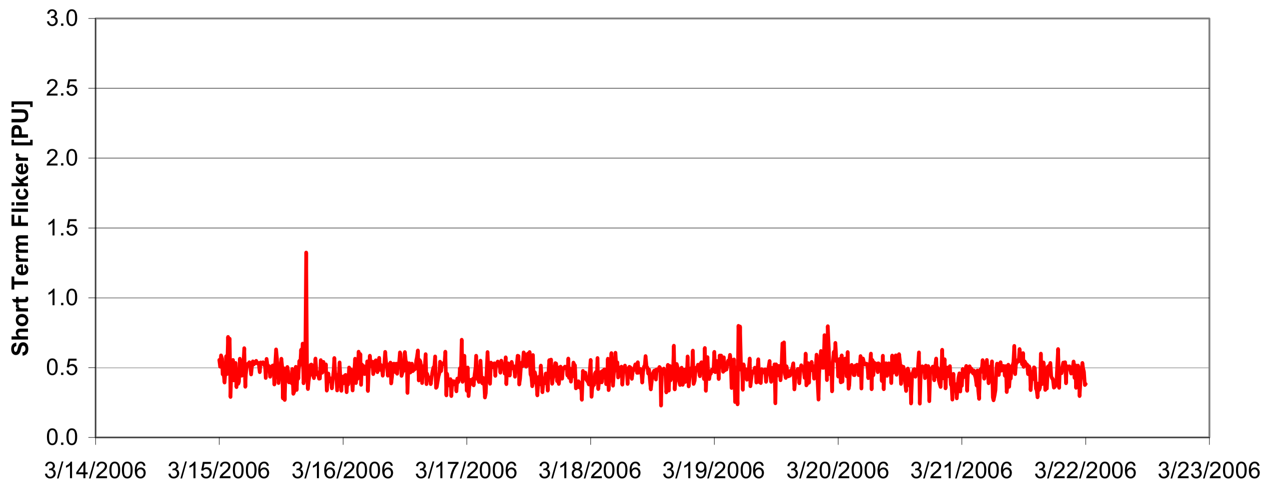
House Load
Example – Without Hot Tub



- The average power varied from 1.5 to 2 kW with maximums exceeding 11kW
  - The heavy load would coincide with the use of several appliances or tools such as welding equipment

Short Term Flicker
Weak Grid and Fuel Cell

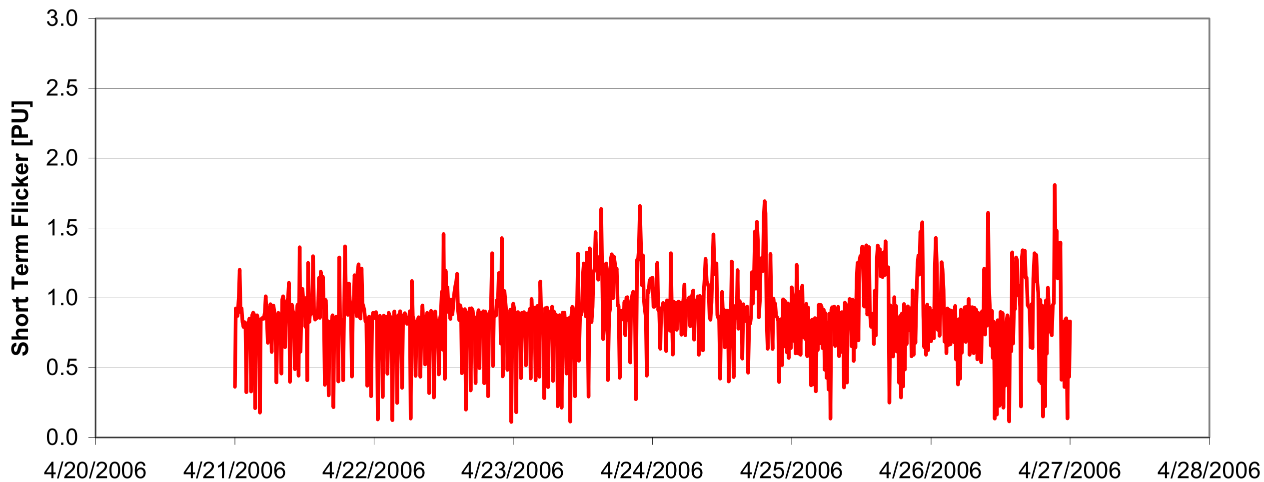
Weak Grid



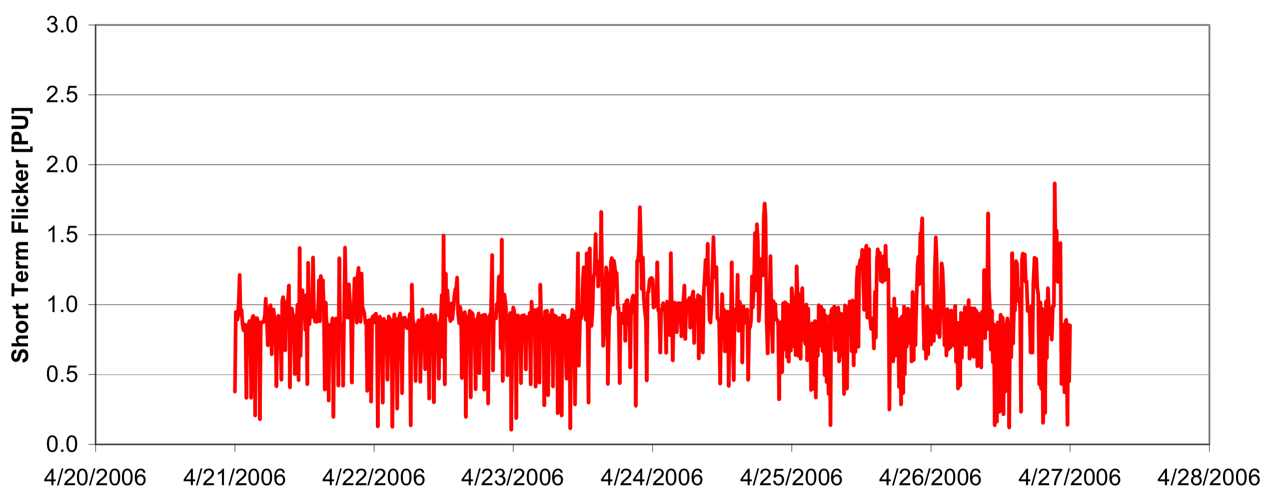
- The Short Term Flicker was determined at the input to the energy storage device and at the main panel
- The energy storage device was powered by either the grid or the fuel cell

Short Term Flicker
Weak Grid and Energy Storage

Weak Grid into Energy Storage

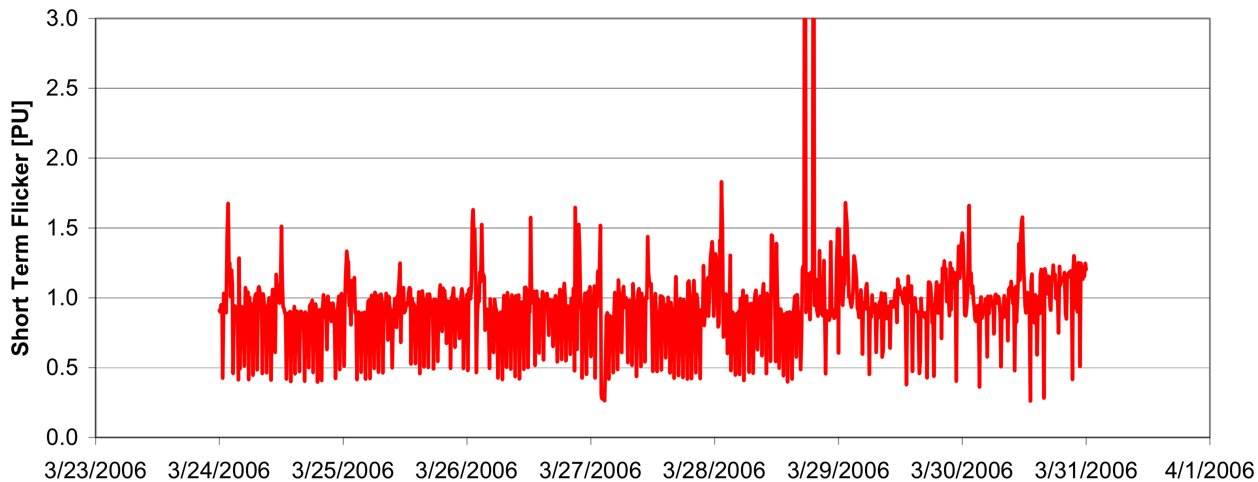


Weak Grid & Energy Storage Load

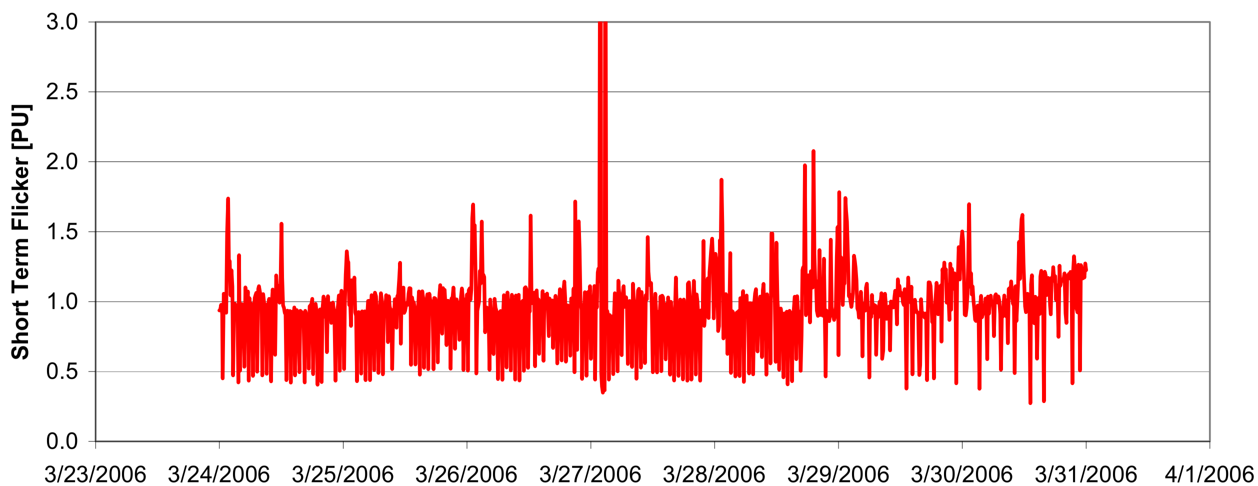


Short Term Flicker
Fuel Cell and Energy Storage

Fuel Cell into Energy Storage



Fuel Cell & Energy Storage Load



Short Term Flicker
Weak Grid Summary

- The grid at the test side was measured to have a short term flicker around 0.5
- Introducing the energy storage device increased the flicker with more than 80% on the input side and an additional 3% on the output side
- Using the fuel cell as source increased the flicker with 13%

Energy Source	Energy Storage	Short Term Flicker	
		Before Energy Storage	After Energy Storage
Weak Grid	No	0.47	Not Active
Weak Grid	Yes - Demand Reduction	0.87	0.90
Fuel Cell	Yes - Demand Reduction	0.95	0.97

Energy Storage Device Electrical Interaction

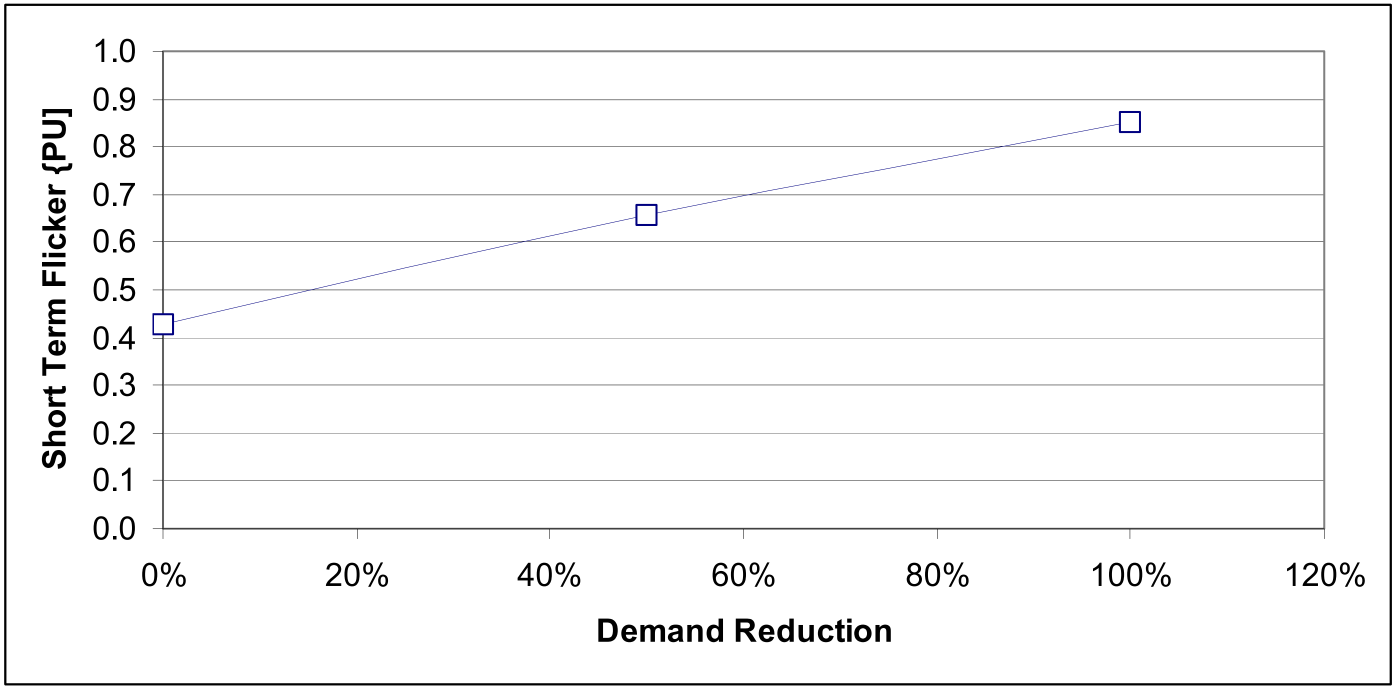
- In demand reduction mode the energy storage device will follow the voltage of the source, but if the demand exceeds the input limit, the inverter will inject battery power to the load by increasing the voltage
  - The amplitude of any voltage fluctuation can therefore be slightly increased in demand reduction mode
- In case of a sudden increase in demand, it will take a finite time for the inverter and batteries to meet the increase
  - If the source cannot support the initial increase, the system will experience a voltage sag
- If the load is less than the upper limit of the source, power may be diverted to charge the batteries. This will result in a slight decrease in output voltage
- In back up mode the energy storage device changes from current source to voltage source and the voltage is much more stable

Impact of Energy Storage Device Controlled Experiment

- Using constant loads short term flicker was measured in a laboratory environment under various conditions
- The local grid had flicker values 10% lower than the weak grid
- When operated in back up mode the flicker was only ¼ of the grid
- When operated in demand reduction mode short term flicker increased significantly
  - Maximum increase was found at maximum demand reduction

Strong Grid	Energy Storage	Short Term Flicker
No	Yes - Back Up Mode	0.09
Yes	No	0.43
Yes	Yes - Max Demand Reduction	0.85
Yes	Yes - Demand Reduction	0.66

Impact of Energy Storage Device Flicker vs. Demand Reduction



- Based on the laboratory test we can establish a clear correlation between level of demand reduction and magnitude of short term flicker

Conclusion

- Introduction of an energy storage device used for demand reduction (current source) increased the short term flicker at a residence
- The magnitude of the short term flicker was a function of the "strength" of the source and of the level of demand reduction
  - A weak source increased the flicker
  - Increased demand reduction increased the flicker
- When used as voltage source the energy storage device had short term flicker values significant lower than the grid
  - Using the fuel cell as a DC source rather than an AC source would most likely have solved the flicker issue
- A lot of the data used in this presentation are placed into public domain and can be downloaded from:
  - http://www.storagemonitoring.com/nyserda-doe/CriteriaSelection.aspx

Thank You

Residential Fuel Cells: Analysis of Tank Additives on Stack Performance

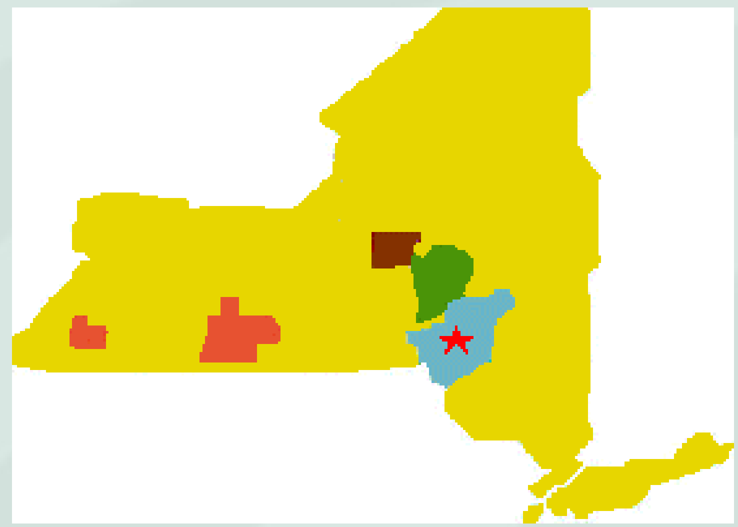
Mark Hilson Schneider
Engineering Manager
Delaware County Electric Cooperative, Inc.

October 20, 2006

Delaware County Electric
Cooperative, Inc.®

Company Overview

- Headquarters: Delhi, NY
- Geographic Area Served:
  - Counties: Delaware, Schoharie, Otsego, Chenango
- 800 miles of distribution lines
- 5,000 member/customers
- 30 Employees
- System Load: ~15MW peak
- Member of National Rural Electric Cooperative Association (NRECA)
- Vital utility provider to the greater Catskill Mountain area



Delaware County Electric Cooperative, Inc.

Partners/Collaborators

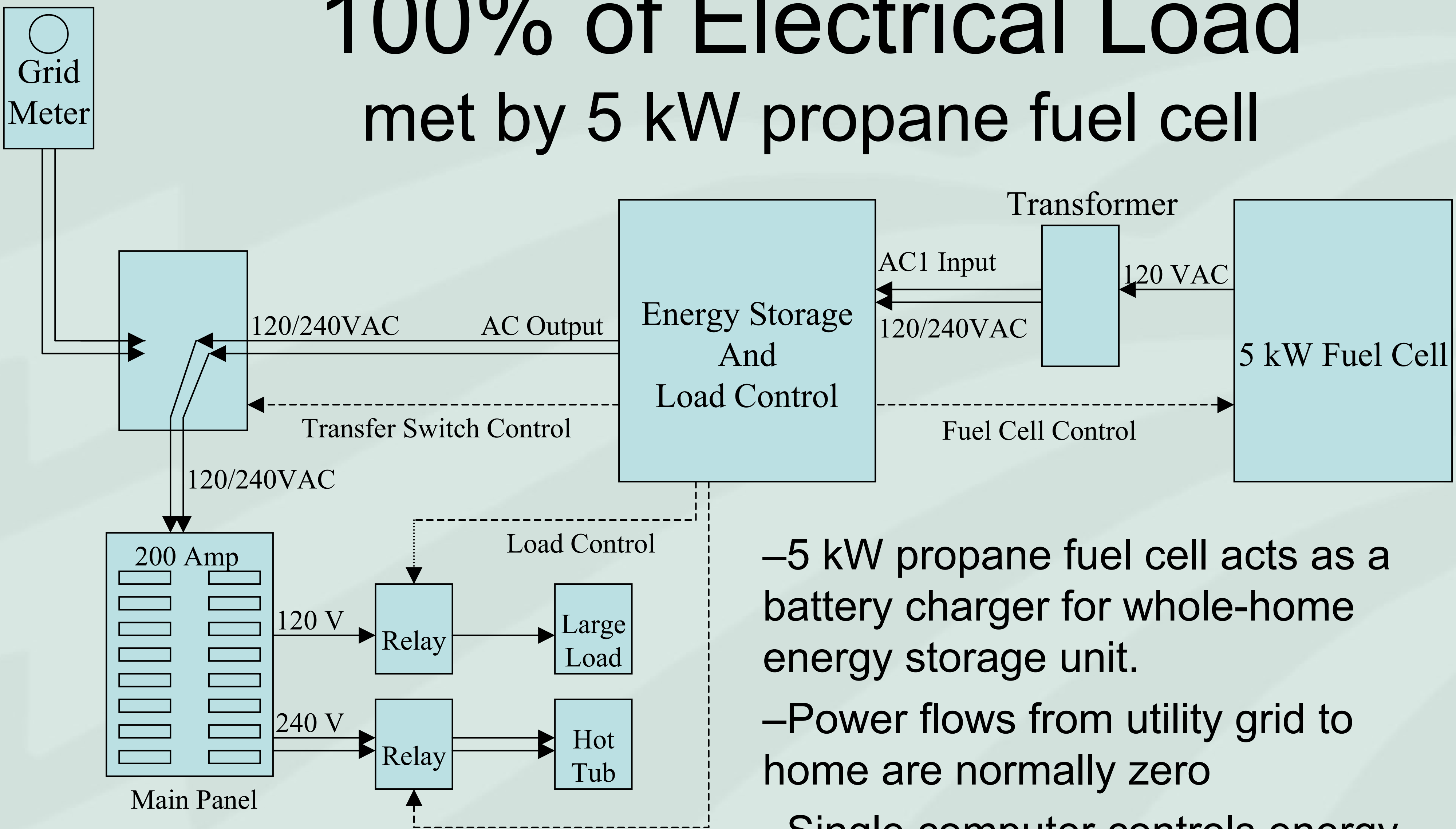
- ***Funding:***
- Department of Energy Golden Field Office
- New York State Energy Research and Development Authority (NYSERDA)
- National Rural Electric Cooperative Association (NRECA) / Cooperative Research Network (CRN)
- Energy Now! Inc.
- Propane Education and Research Council

- ***Technical contribution:***
- Gaia Power Technologies, Inc.
- Sandia National Laboratories
- Mirabito Fuel Group
- New York Power Authority
- Plug Power, Inc.
- ***Education and outreach:***
- State University of New York College of Technology at Delhi (SUNY Delhi)
- Lansing Community College (Michigan)
- ***Data analysis / reporting:***
- EnerNex Inc.

Objectives

- ***Demonstrate viability of grid-independent home***
  - typical upstate NY residence
  - total electrical energy needs met by 5 kW propane fuel cell
  - intelligently managed energy storage
  - in-home load control
  - increased efficiency through thermal recovery
  - education of state and local consumers

100% of Electrical Load
met by 5 kW propane fuel cell



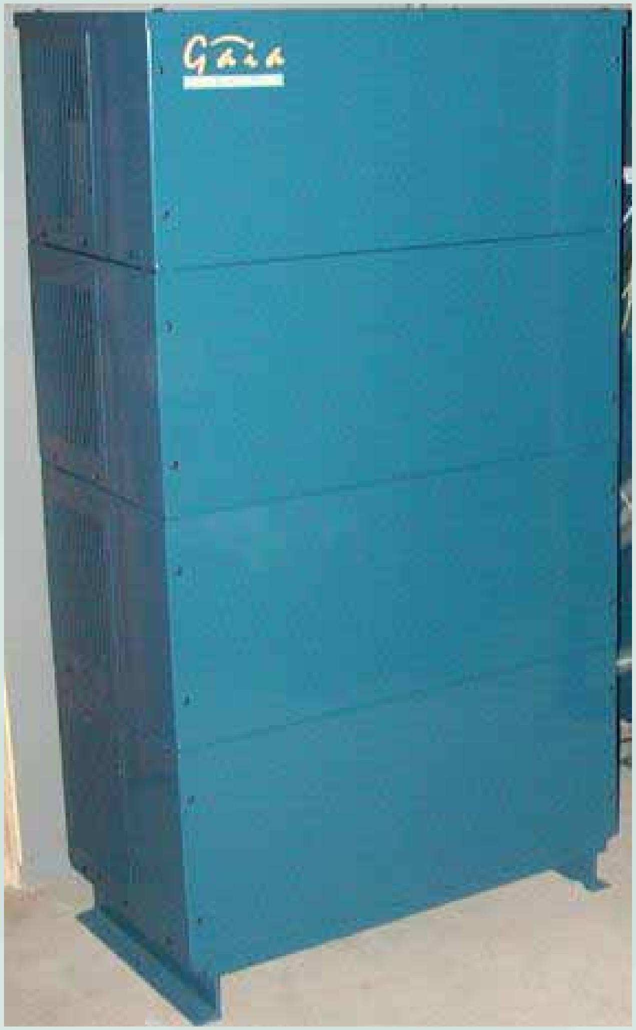
– 5 kW propane fuel cell acts as a battery charger for whole-home energy storage unit.

– Power flows from utility grid to home are normally zero

– Single computer controls energy storage, load control, and fuel cell set-points

5 kW PEM Fuel Cell

11 kW / 600 Ah Energy Storage



inverters meet demand in real time

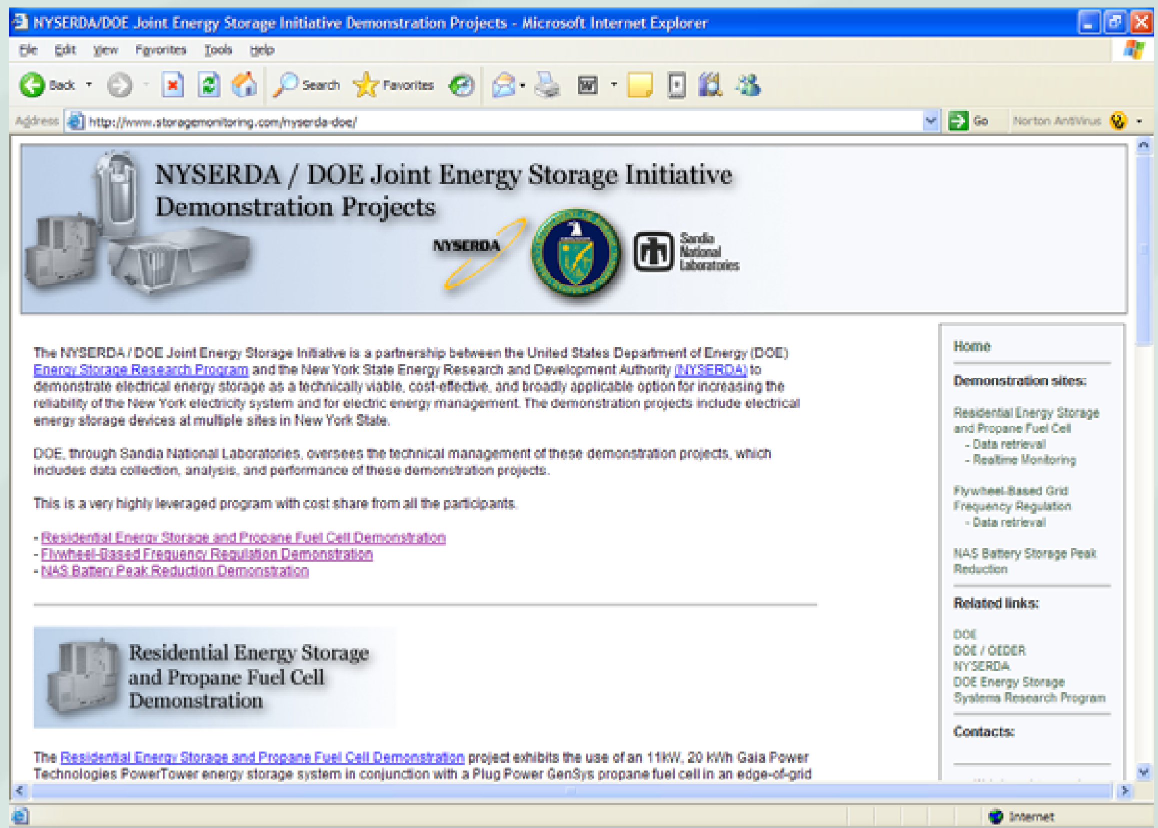
up to 3 days of energy stored in batteries

Consumer Education

- Educate general public, extension service, and policy makers through news media, press events, and site tours
- Target industry and academia through conference presentations and publications
- Target local and regional educators with seminar at local college
- Target rural electric cooperatives through out the nation through the National Rural Electric Cooperative (NRECA) fuel cell program

Knowledge Transfer

- Public Internet access to project data
- http://www.storagemonitoring.com/nyserda-doe/
- Real time and historical data recordings available for many performance parameters and settings



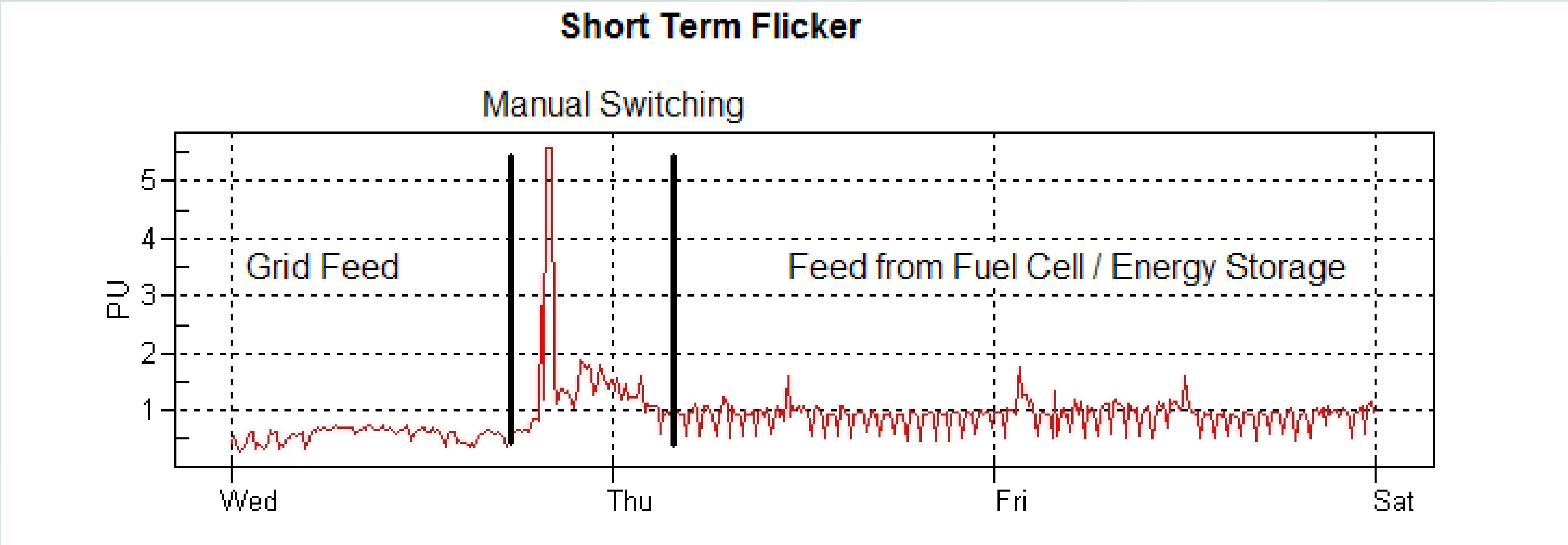
Technical Challenges

- Flickering lights
- Thermal recovery control
- Propane additive impacts on fuel cell stack

Host family (Dad and son pictured) endured flickering lights for much of the demonstration period.

Delaware County Electric Cooperative, Inc.

Technical Challenge – Flickering Lights

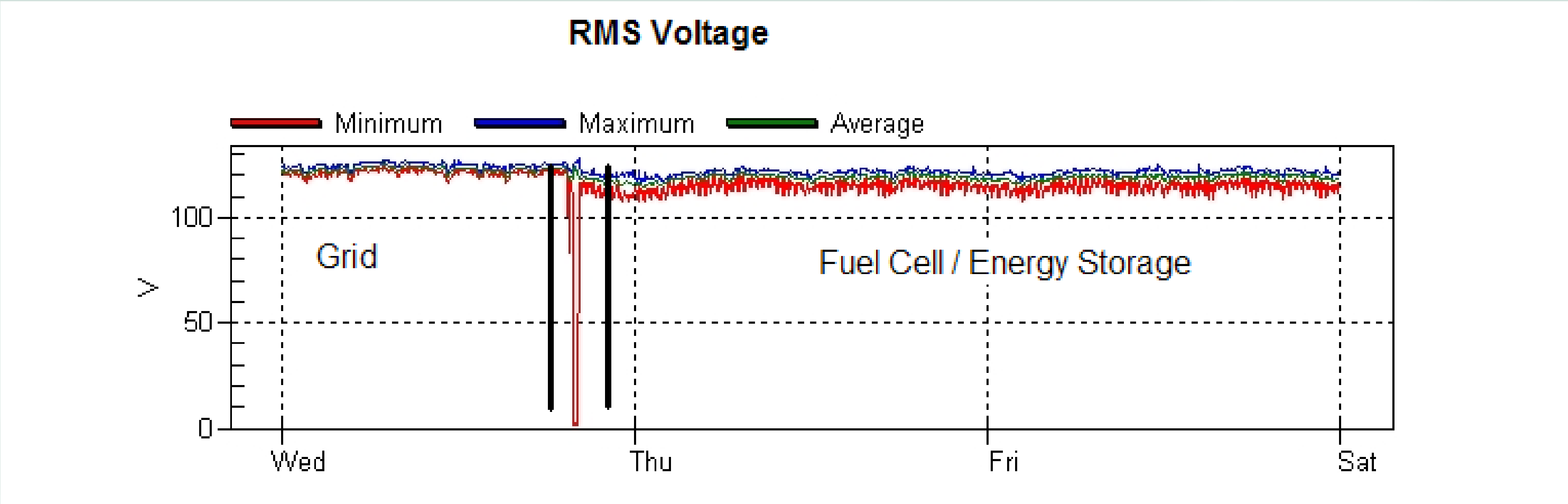


- short term flicker becomes problematic to human perception at roughly 1 PU
- significant short term flicker seen with fuel cell and energy storage compared to grid

Flicker – Assessing Source

- slow response time of the inverters to load changes
- relative weakness of distributed generation source as compared to grid
- frequent voltage manipulation by inverters to control charge state
- presence of large loads with short cycling periods

Flicker Solutions



- startup current limiting devices on large loads can be a <u>partial solution</u>
- capacitors on the load side of the inverters can be a <u>partial solution</u>
- biggest contributor to a <u>full solution</u>
  - reduce the cycling of battery charger in/out of charge state

Technical Challenge – Thermal Recovery

- Thermal recovery system required excessive conservatism to avoid over-cooling the fuel cell
- Space heating thermostat had to be turned down
- Fuel cell control system must be improved to become sufficient to protect itself from over-cooling

Tank Additives & Infant Stack Failure

- Liquid petroleum gas distributors introduce ~2500 ppm by volume of methanol into newly installed propane tanks
- methanol is preferentially physically absorbed on the surface of alumina-based desulfurization materials
- reduced desulfurization performance results in sulfur breakthrough and stack contamination/failure
- subsequent stack performance fine after stack and desulfurization tank replacement indicating methanol concentrations are reduced to tolerable levels
- fuel cell vendor confirms that infant stack mortality has been observed in every propane installation involving a new tank (utilizing alcohol to de-water tank)

Tank Installation and Additive

Infant Stack Failure - Solutions

- calculate the amount of methanol required for de-watering of tank and add no more than necessary
- make desulfurization bed larger or change earlier and more frequently during startup phase
- use an absorbent material that would allow methanol to pass through but would preferentially absorb sulfur containing compounds (difficult / expensive)
- introduce a low-cost sacrificial pre-filter to absorb water and methanol (e.g., high porosity alumina)

Future Work

- Replace fuel cell with 15 kW propane generator
  - expect vastly reduced flicker
  - generator has higher peak power output and will run only ~6% of time to meet whole house load
- Continue data collection through December 2006
- Complete technical analysis
  - O&M history, efficiency, power quality reporting January 2007

Project Summary

Technology Viability:

Although there are technical challenges to be overcome by the fuel cell and propane industries, the project demonstrates that very small distributed generation assets can provide the full energy requirements (electrical and thermal) of residences if used with intelligent energy storage

Market Opportunity:

Off-grid and edge-of-grid residences can meet all of their home energy needs with low capital cost and small generation equipment in conjunction with energy storage

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Residential Energy Storage and Propane Fuel Cell Demonstration Project

Dr. Ib Olsen, Gaia Power Technologies
Mark Hilson Schneider, SUNY Delhi
Greg Starheim, Delaware County Electric Cooperative, Inc.
May 23, 2007

Delaware County Electric Cooperative, Inc.
Delhi STATE UNIVERSITY OF NEW YORK COLLEGE OF TECHNOLOGY
Gaia Power Technologies

Acknowledgements

- DCEC, SUNY Delhi, and Gaia wish to acknowledge the technical and financial contributions of the following organizations:
  - NYSERDA / DOE Energy Storage Initiative[1]
  - Department of Energy (DOE) Golden Field Office
  - Propane Education and Research Council

[1] This project is part of the Joint Initiative between the New York State Energy Research and Development Authority (NYSERDA) and the Energy Storage Systems Program of the U.S. Department of Energy (DOE/ESS) through Sandia National Laboratories (SNL). Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Demonstration Objectives

- Demonstrate viability of grid-independent residence
  - Typical upstate NY residence
  - Total electrical energy needs met by fuel cell
  - Intelligently managed energy storage
  - In-home load control
  - Increased efficiency through thermal recovery

Demonstration Equipment

5 kW Plug Power PEM Fuel Cell

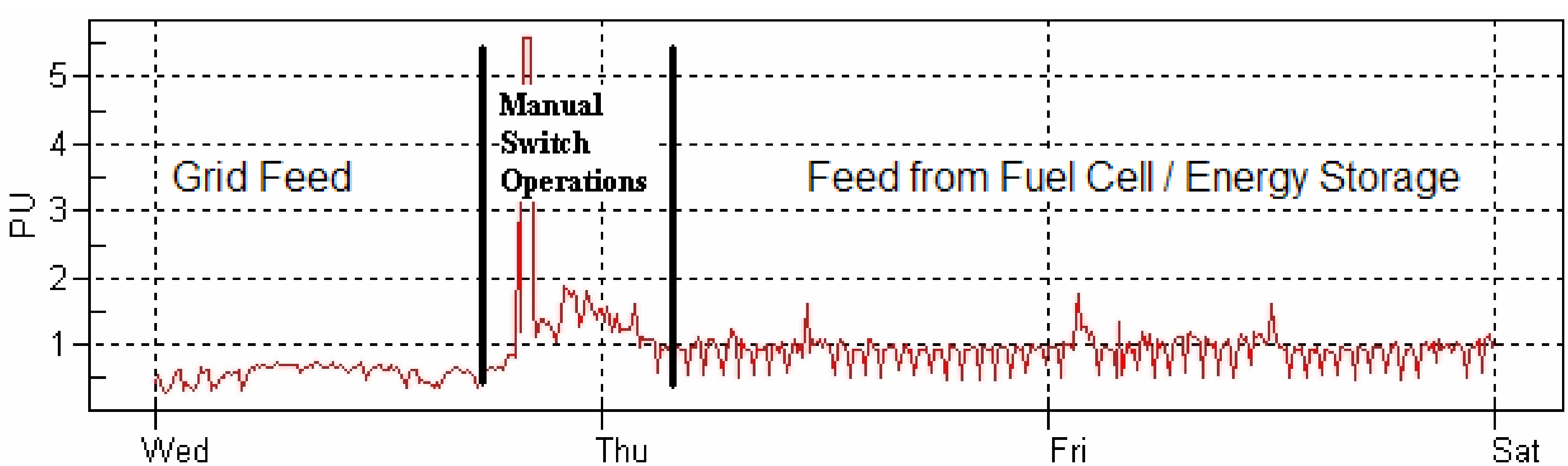
Gaia 11 kW Power Tower

Energy Storage Device

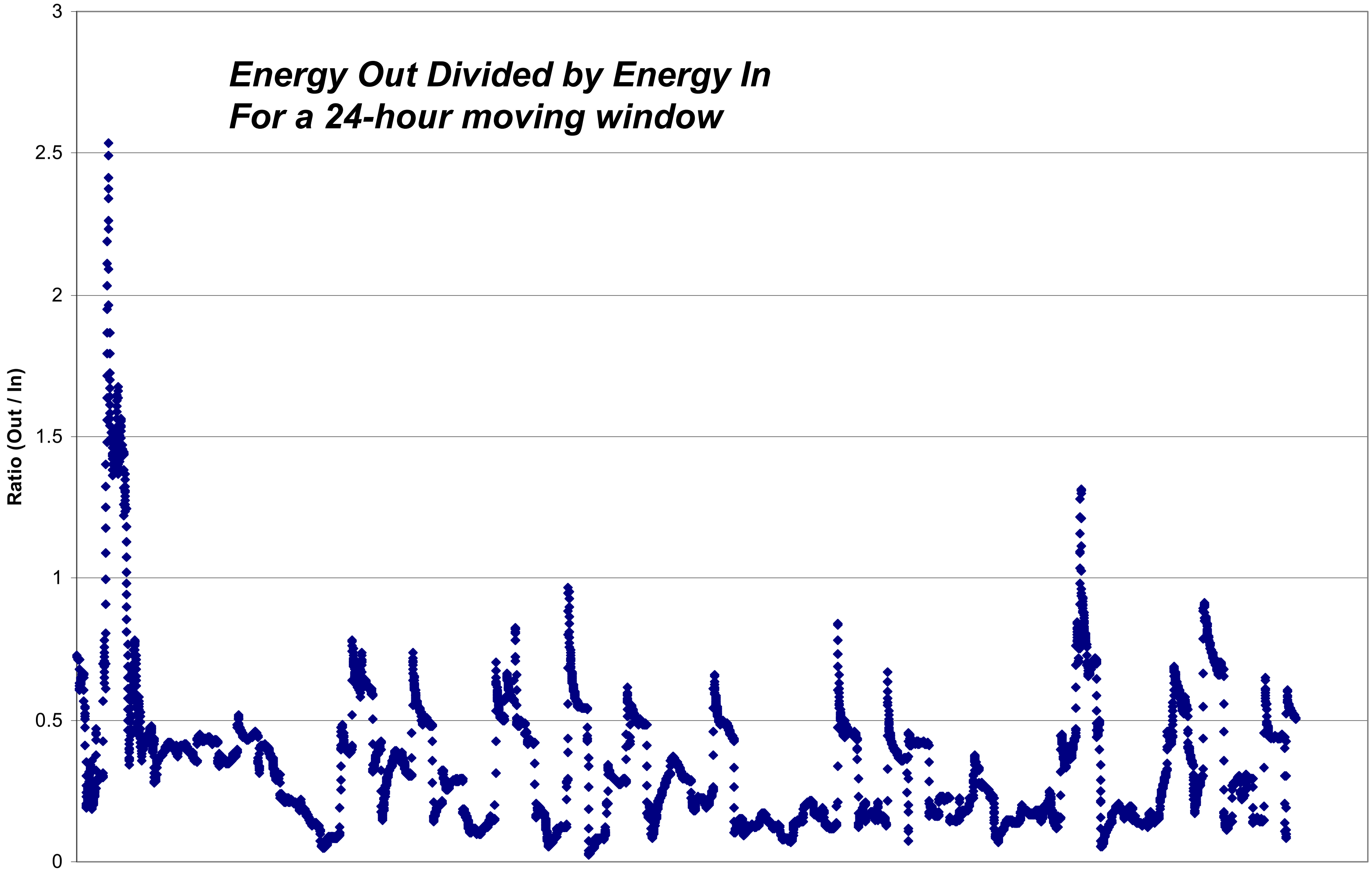
- 2 x 5.5 kW inverters
- 1600 Ah deep-cycle, lead-acid batteries
- 1 Controller for charge control, inverters, fuel cell output, and in-home load control

- 11 kW Power Capacity of inverters is adequate given intelligently managed in-home load control
- 20 kWh Energy Capacity of batteries was substantially more than required by the application
- Reliability of energy storage equipment was good
  - 98% availability over 2 year period
  - Inverters/chargers had undergone excessive cycling due to need for fuel cell to operate at low and constant output

- Short term flicker was noticeable
- Caused by
  1. Step functions in load
  2. Poor power quality from fuel cell
  3. Weak power source in fuel cell
  4. Inverter/charger voltage manipulations



Battery Energy Balance



Round Trip Efficiency

- Average round trip efficiency over demonstration period: **39%**
- Why so far below theoretical efficiencies?
  - Fuel cell required Power Tower to stay in float state frequently and for long periods of time
  - Relatively low usage as a fraction of inverter/charger capacity meant that inverter/charger parasitic loads represented a larger portion of the total power consumption
- Both causes can be remedied with a more application-appropriate distributed generation source.

Economics

- Installed cost
  - $14,810 published utility price for energy storage system hardware
  - $1,100 electrical contractor installation price
  - Installed cost per kW: $1446 / kW
  - Installed cost per kWh storage: $530 / kWh
- Total cost per kWh delivered to load
  - $1.46 if paired with 5 kW fuel cell[1]
  - $0.62 if paired with 15 kW propane generator[1]
  - $1.37 if propane generator without energy storage[1]

[1]Based on $0.90 /kWh fuel cell generation rate, $0.44 /kWh propane generator generation rate at full load, 26% generator efficiency at full load, 24% efficiency at 50% load, and 5% efficiency at very low load.

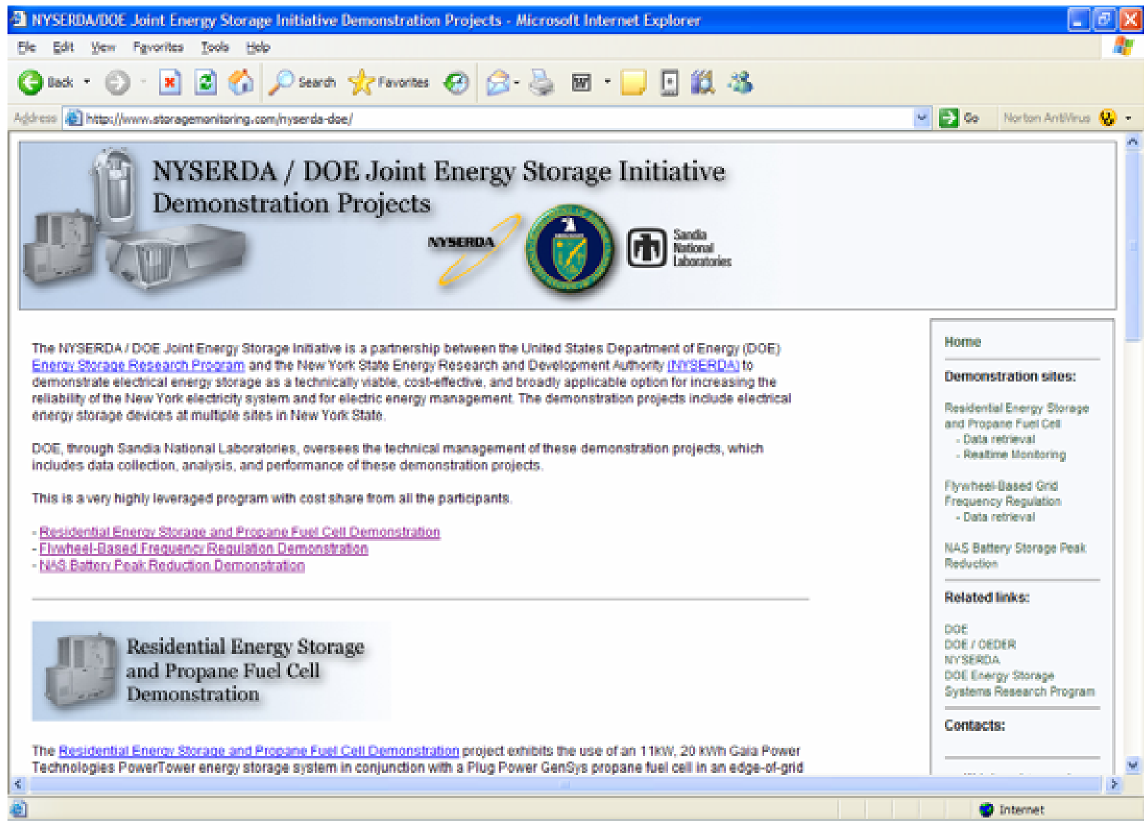
Value to the Utility

- Used without distributed generation, energy storage can benefit the distribution utility
- Construction Deferral
  - ~$50,000 / mile construction cost
- Annual Maintenance
  - ~$4,000 / year

Complete Access to Project Data

- http://www.storagemonitoring.com/nyserda-doe/

- Data recordings available for many performance parameters and settings
- Real-time data was available during demonstration period.



Project Follow-Up and Next Steps

- Residential-Scale Energy Storage
  - Compare performance of project system to similar systems with other distributed generation sources (generators and PV)
  - Combine with thermal energy storage to highlight the potential for energy storage in residential applications
- Utility-Scale Energy Storage
  - Expand to ~300 kW capacity
  - Compare performance of sodium nickel chloride (ZEBRA) and lead acid based asymmetrical supercapacitor
  - Demonstrate the dual value stream to the distribution utility and an industrial consumer

APPENDIX B – FINAL TECHNICAL REPORT - RESIDENTIAL FUEL CELL DEMONSTRATION BY THE DELAWARE COUNTY ELECTRIC COOPERATIVE, INC.

Final Technical Report

Residential Fuel Cell Demonstration
by the Delaware County Electric Cooperative, Inc.

Project Ending: January 31, 2007 (*official DOE end date*)

Recipient: Delaware County Electric Cooperative, Inc.
Award Number: DE-FC36-04GO14239

Delaware County Electric Cooperative, Inc.

Acknowledgements

Delaware County Electric Cooperative, Inc. wishes to recognize and thank the sponsors of this demonstration project.

The majority of non-DCEC funds for this project were provided under contracts with the following organizations:

- Department of Energy (DOE) Golden Field Office
- NYSERDA / DOE Energy Storage Initiative[11]
- Propane Education and Research Council

The project team also wishes to extend our special thanks to the Board of Directors, management, and dedicated employees of the Delaware County Electric Cooperative. Without their hard work and support, the project could not have been successful.

[1] This project is part of the Joint Initiative between the New York State Energy Research and Development Authority (NYSERDA) and the Energy Storage Systems Program of the U.S. Department of Energy (DOE/ESS) through Sandia National Laboratories (SNL). Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Project Title
Residential Fuel Cell Demonstration by the Delaware County Electric Cooperative, Inc.

Funding Period
Starting October 1, 2004
Ending January 31, 2007

Project Recipient
Delaware County Electric Cooperative, Inc.

Award Number
DE-FC36-04GO14239

Working Partners

Entity	Primary Contact	Contact Information
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National Rural Electric Cooperative Association – Cooperative Research Network (CRN)	Bob Gibson Senior Program Manager	4301 Wilson Boulevard Arlington, VA 22203 bob.gibson@nreca.coop (703) 907-5853 phone (703) 907-5518 fax
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Energy Now! (role formerly held by 1st Rochdale Cooperative)*	Tom Thompson Principal	306 Amherst Road Pelham, MA 01002 tomtomsun@comcast.net (413) 253-6680 phone (917) 886-4793 mobile
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	President	Knoxville, TN 37922-2337 jeff@enernex.com (865) 691-5540 x131 phone (865) 691-5046 fax
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Plug Power, Inc.	Vinny Cassala Customer Relationship Manager	968 Albany-Shaker Road Latham, NY 12110 vincent_cassala@plugpower.com (518) 782-7700 x1228 phone (518) 782-7909 fax
New York Power Authority	Guy Sliker Research and Development Technology	23 Main Street White Plains, NY 10601.3170 guy.sliker@nypa.gov (914) 287-3792 phone (914) 681-6860 fax
State University of New York College of Technology at Delhi	David Addison Dean of the Technology Division	SUNY Delhi 2 Main St. Delhi, NY 13753 addisodb@delhi.edu (607) 746-4070 phone

*Due to financial conditions unrelated to the project, former partner 1st Rochdale Cooperative has transferred its NYSERDA contract and the incumbent cost-sharing responsibilities to Energy Now, Inc., owned and managed by former 1st Rochdale Cooperative employee Tom Thompson.

Cost-Sharing Partners

Entity	Primary Contact	Contact Information
New York State Energy Research and Development Authority (NYSERDA)	Jim Foster Program Manager Joe Sayer Sr. Program Manager	17 Columbia Circle Albany, NY 12203-6399 jmf@nyserda.org jhs@nyserda.org
Gaia Power Technologies	Ib Olsen Chief Technology Officer	116 John Street, suite 820 New York, NY 10038 olsenii@gaiapowertech.com (212) 732-5507 phone (212) 732-5597 fax
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	Greg Starheim General Manager / CEO	39 Elm Street PO Box 471 Delhi, NY 13753 greg.starheim@dce.coop (607) 746-2341 phone (607) 746-7548 fax

DOE Managers

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Department of Energy Golden Field Office	Reg Tyler Program Engineer	Golden Field Office 1617 Cole Boulevard Golden, CO 80401-3393 reginald.tyler@go.doe.gov (303) 275-4929 phone (303) 275-4753 fax

Project Objective

This project will demonstrate the viability of grid-independent operation of a typical upstate NY home whose total electrical energy needs will be met by a propane fueled fuel cell. The demonstration will combine intelligently managed energy storage, in-home load control, and combined heat and power to optimize the performance of the fuel cell as a whole-home energy source. The project will contribute to enhanced awareness and knowledge among consumers, rural electric cooperatives, fuel cell manufacturers, energy storage manufacturers, educators, and staff members of national agencies and laboratories through a process including public awareness events, publications, educational programs, and technology transfer. The project will validate the following objectives of propane fueled hydrogen fuel cells for edge-of-grid residences:

- measure and report technical performance
- provide raw cost data and economic viability analysis
- document maintenance and operations concept enhancements specific to residential fuel cells
- share safety related vulnerabilities analysis and lessons learned
- promote education of state and local consumers.

Executive Summary

This demonstration project contributes to the knowledge base in the area of fuel cells in stationary applications, propane fuel cells, edge-of-grid applications for fuel cells, and energy storage in combination with fuel cells.

The project demonstrated that it is technically feasible to meet the whole-house electrical energy needs of a typical upstate New York residence with a 5-kW fuel cell in combination with in-home energy storage without any major modifications to the residence or modifications to the consumption patterns of the residents of the home.

The use of a fuel cell at constant output power through a 120-Volt inverter leads to system performance issues including:

- relatively poor power quality as quantified by the IEEE-defined short term flicker parameter
- relatively low overall system efficiency

Each of these issues is discussed in detail in the text of this report.

The fuel cell performed well over the one-year demonstration period in terms of availability and efficiency of conversion from chemical energy (propane) to electrical energy at the fuel cell output terminals. Another strength of fuel cell performance in the demonstration was the low requirements for maintenance and repair on the fuel cell.

The project uncovered a new and important installation consideration for propane fuel cells. Alcohol added to new propane storage tanks is preferentially absorbed on the surface of some fuel cell reformer de-sulfurization filters. The experience on this project indicates that special attention must be paid to the volume and composition of propane tank additives. Size, composition, and replacement schedules for the de-sulfurization filter bed should be adjusted to account for propane tank additives to avoid sulfur contamination of fuel cell stacks.

Despite good overall technical performance of the fuel cell and the whole energy system, the demonstration showed that such a system is not economically feasible as compared to other commercially available technologies such as propane reciprocating engine generators.

Background

The project was conceived as a means to help overcome the DOE technical barriers for fuel cell validation and simultaneously test the hypothesis that propane-fueled fuel cells can become a practical alternative to costly primary power line extensions to serve extremely rural residences. As shown in Figure 1, this fuel cell and energy storage demonstration project serves the objectives of the DOE, NRECA, and DCEC.

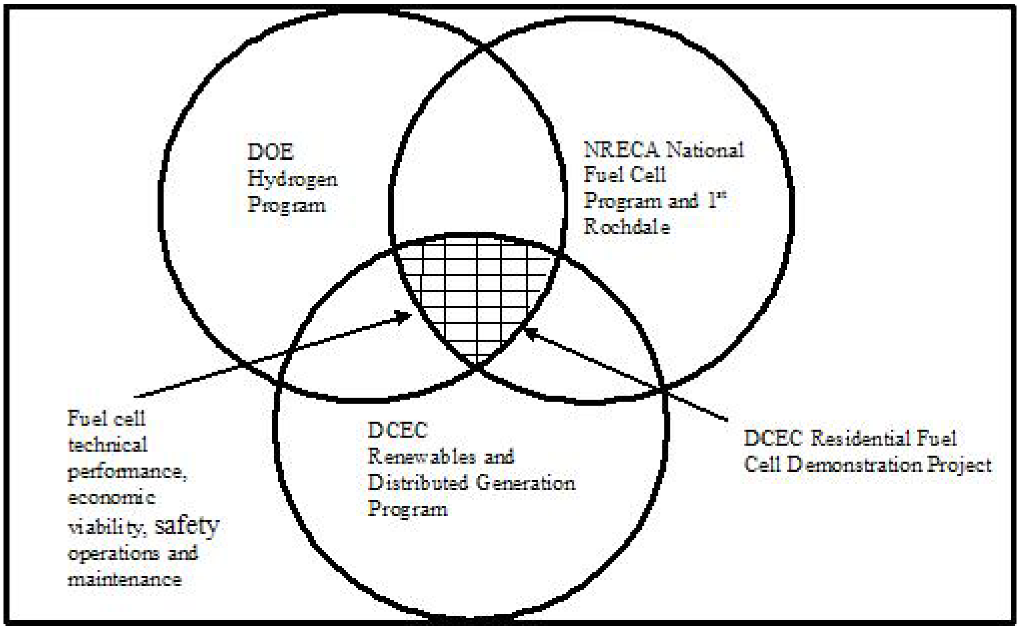


Figure 1 Intersection of Common Objectives Among DOE, NRECA, and DCEC

The relevant DOE hydrogen and electricity co-production technical barriers include the following:

- Cost and durability not statistically validated
- Permitting, codes, and standards not established for fuel cells in or around buildings
- Lack of operational and maintenance experience.

Although this is a one-year fuel cell project, DCEC has been collecting base load data at the demonstration site for the past three years using 15-minute averaged data supplied by DCEC's automated meter reading system. Figures 2 and 3 display summaries of the home's peak demand and energy consumption data from May 2002 through January 2005.

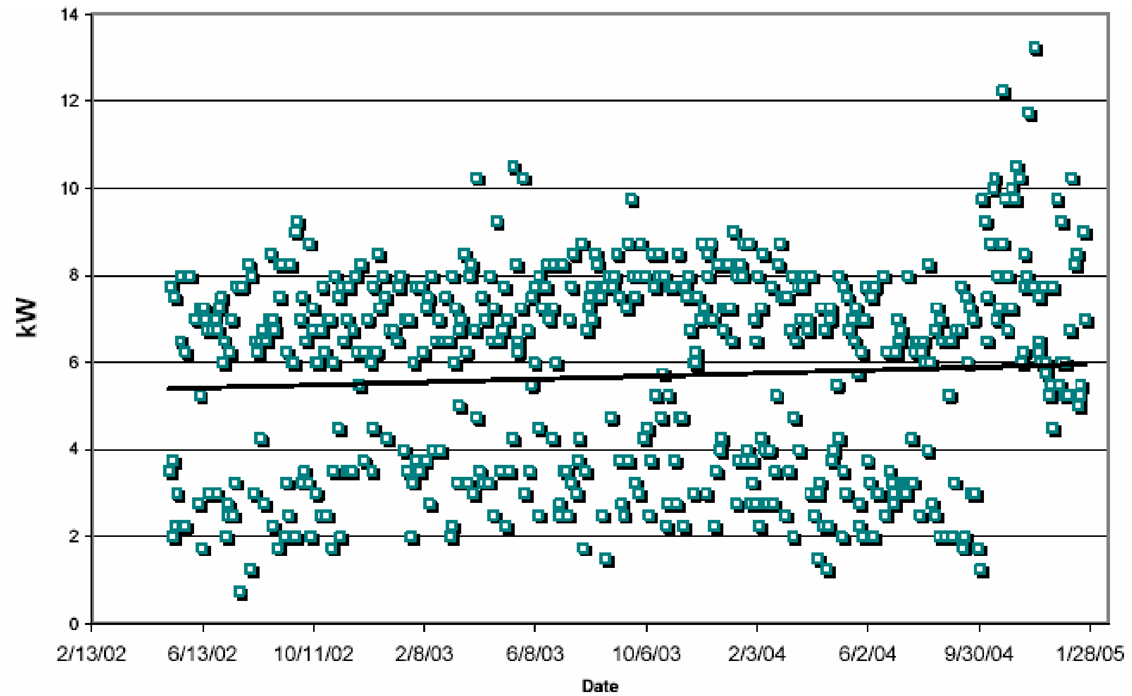


Figure 2 Historical Peak Power Demand for Fuel Cell Host Residence

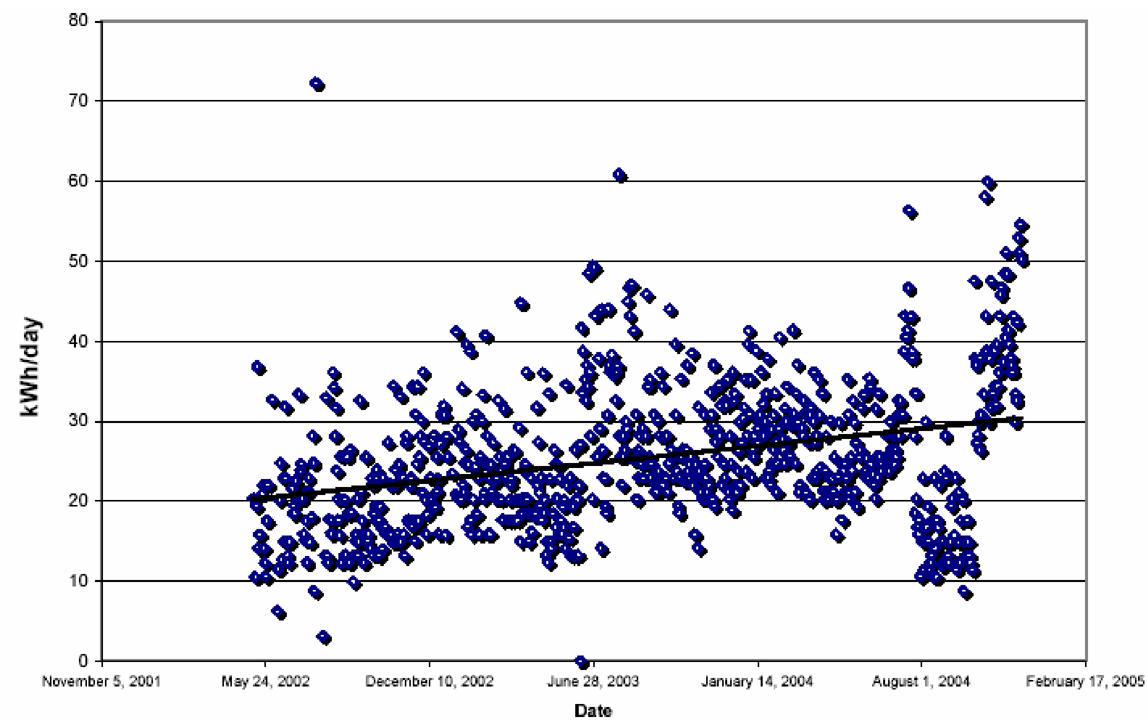


Figure 3 Historical Daily Energy Consumption for Fuel Cell Host Residence

Based on the historical data, the host residence is trending toward higher peak demands and energy consumption. The addition of a hot tub at the residence during 2004 is responsible for much of that upward trend. Peak power consumption was measured to be approximately 13.5 kW using energy consumed during a moving 15-

minute window to calculate power. Average power consumption has been below 1.5 kW over the three year data collection period, but appears to be approximately 2 kW in recent months. As this data demonstrates, a typical upstate NY residence has been selected for the demonstration, which serves as a challenging testing ground for the combination of fuel cell and energy storage.

Summary of Project Activities

DCEC installed a propane fuel cell and energy storage system at the demonstration site in May of 2005, commissioned the equipment in June of 2005, and began a one-year demonstration period on July 5, 2005. During the one-year demonstration period, DCEC collected performance data, conducted education and outreach events that utilized the demonstration site, performed and documented the maintenance activities required to operate the fuel cell, and performed additional testing in order to fully characterize the technical performance and economic viability of the installation. Following completion of the one-year demonstration period, DCEC and its partners have continued to analyze and report on the demonstration project at a number of academic and industry events throughout the United States.

Overview of Installation

The installation consisted of several major subsystems:

- Propane storage, metering, and delivery piping
- Fuel cell
- Thermal recovery system
- Electrical system including electrical energy storage
- Data acquisition system

Propane Subsystem

The propane subsystem consisted of a 1,000 gallon underground storage tank, buried pipe to deliver the propane to the load, pressure regulation, and a pulse-producing propane meter. In the picture below, an employee of project partner Mirabito Fuel Group is preparing terminations on the pedestal that supported the propane meter and pressure regulator, which was positioned between the underground storage tank and the fuel cell.

Fuel Cell Subsystem

The fuel cell was a Plug Power GenSys propane fuel cell with 5 kW maximum sustained output. The fuel cell was delivered from the manufacturer with a self contained reformer, cell stack, inverter, controller, and battery for black start. The picture below shows the fuel cell being moved into place by DCEC personnel using a leased skid steerer.

Thermal Recovery Subsystem

The thermal recovery subsystem consisted of a thermal recovery loop that circulated a glycol/water mixture between the fuel cell and the residence's utility room. There were two thermal loads that were capable of pulling heat from the thermal recovery loop:

1. a tank-type heat exchanger that pre-heated domestic hot water before entering a traditional hot water heater

2. a length of baseboard radiators in the basement of the residence through which the glycol/water mixture flowed

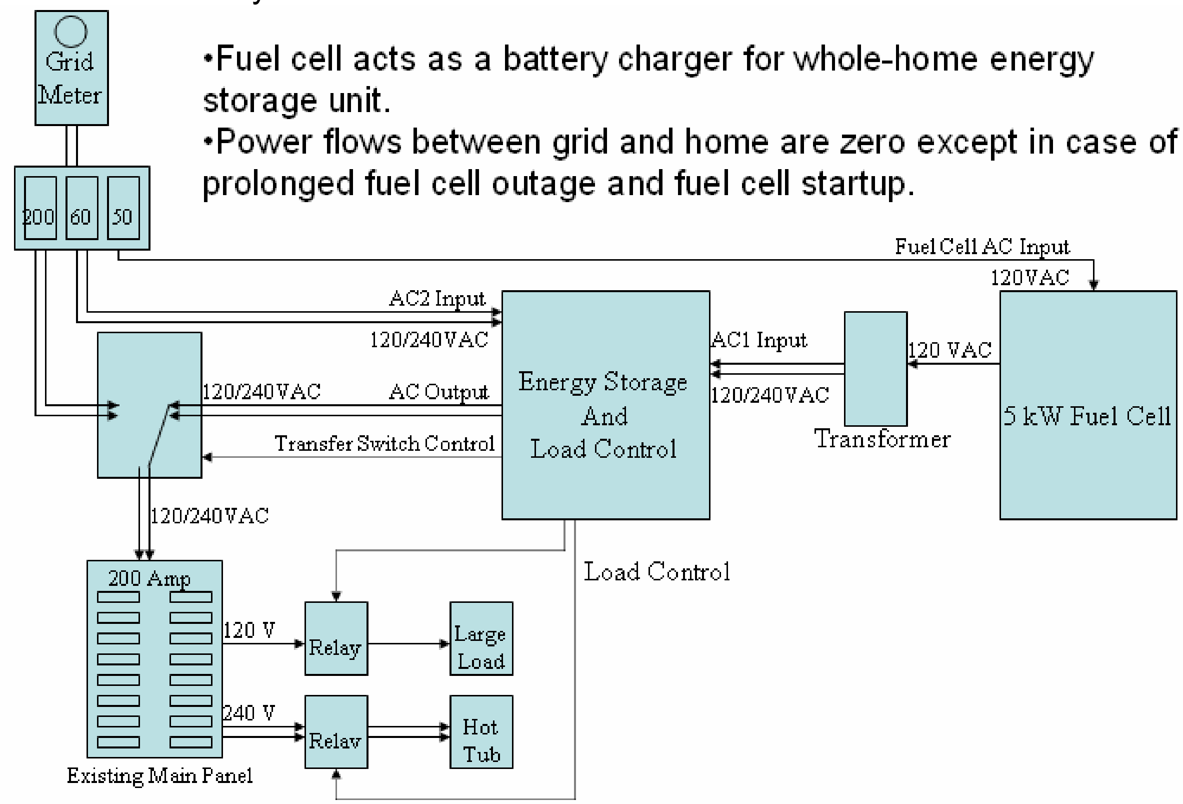
When the thermal recovery system was in its normal state, the glycol/water mixture would circulate through the hot water heat exchanger to preheat the domestic hot water. When the thermostat in the basement called for heat, a diverter valve caused the glycol/water mixture to flow through the baseboard heaters instead of the heat exchanger. The picture below shows employees of Dubben Brothers Plumbing service installing the baseboard heaters in the basement. Due to the fact that the thermal recovery loop operated at temperatures lower than typical baseboard heating applications, very long sections of baseboard radiators were installed in order to get sufficient heat transfer into the room.

Electrical Subsystem

The electrical subsystem consisted of the following components:

- an electrical energy storage system from Gaia Power Technologies
- a transformer to take a single phase 120-Volt input and provide a split phase 240-Volt output
- a controllable transfer switch to switch between the local generation input (fuel cell and energy storage) and the utility grid input
- a set of load control relays that were controlled by the Gaia controller and interrupted large loads (e.g., hot tub heater) when the total home load was greater than the capacity of the local generation system could support

During most of the demonstration period, the fuel cell was operated at a steady output between 1.5 and 2 kW. The output from the fuel cell was either used in real time by the electrical load of the home or it was used to charge the batteries in the energy storage system. The graphic below is a schematic representation of the electrical subsystem.

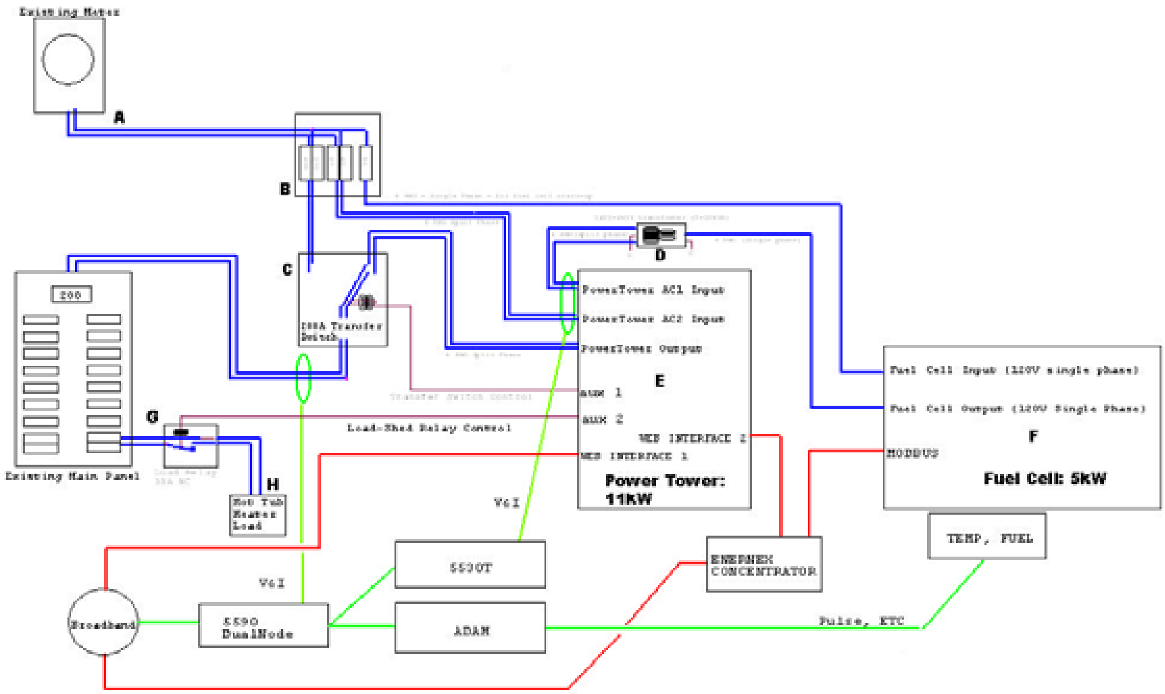


<u>Data Acquisition System</u>

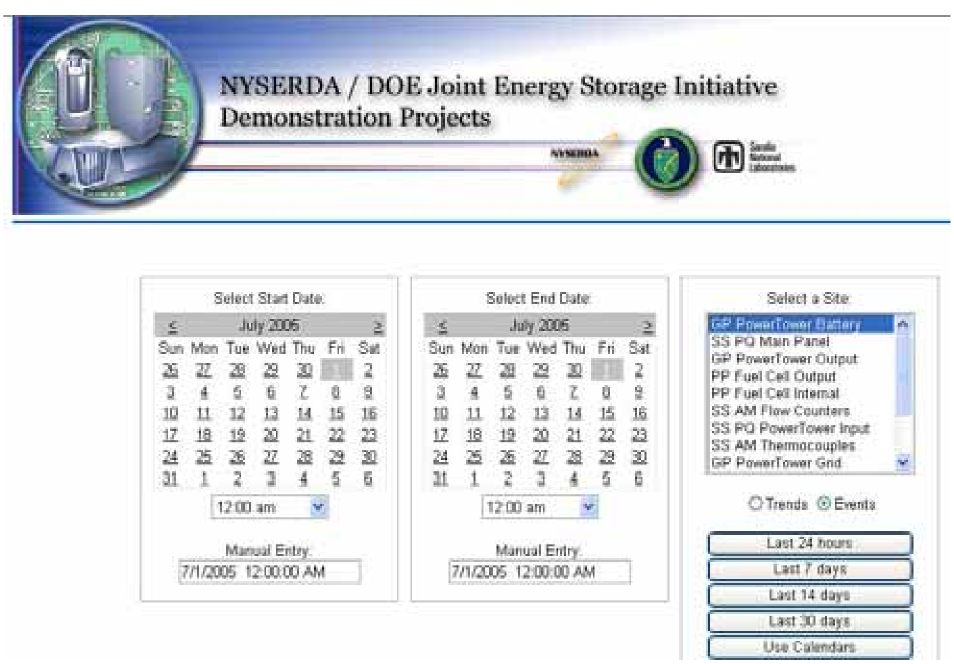
The data acquisition system monitored and recorded the following information in real time:

- true RMS current and voltage on both legs of the fuel cell feed into the energy storage device and the consumption at the home's main panel
- temperatures on the inlet and outlet of the thermal recovery loop
- flow in the thermal recovery loop
- ambient conditions outside the home
- internal fuel cell settings, self-reported fuel consumption, and self-reported electrical output
- internal energy storage device settings, self-reported battery charge state, and self-reported power flows in and out of the batteries
- propane meter pulse counts

The graphic below is a schematic representation of the data acquisition system employed at the demonstration site.



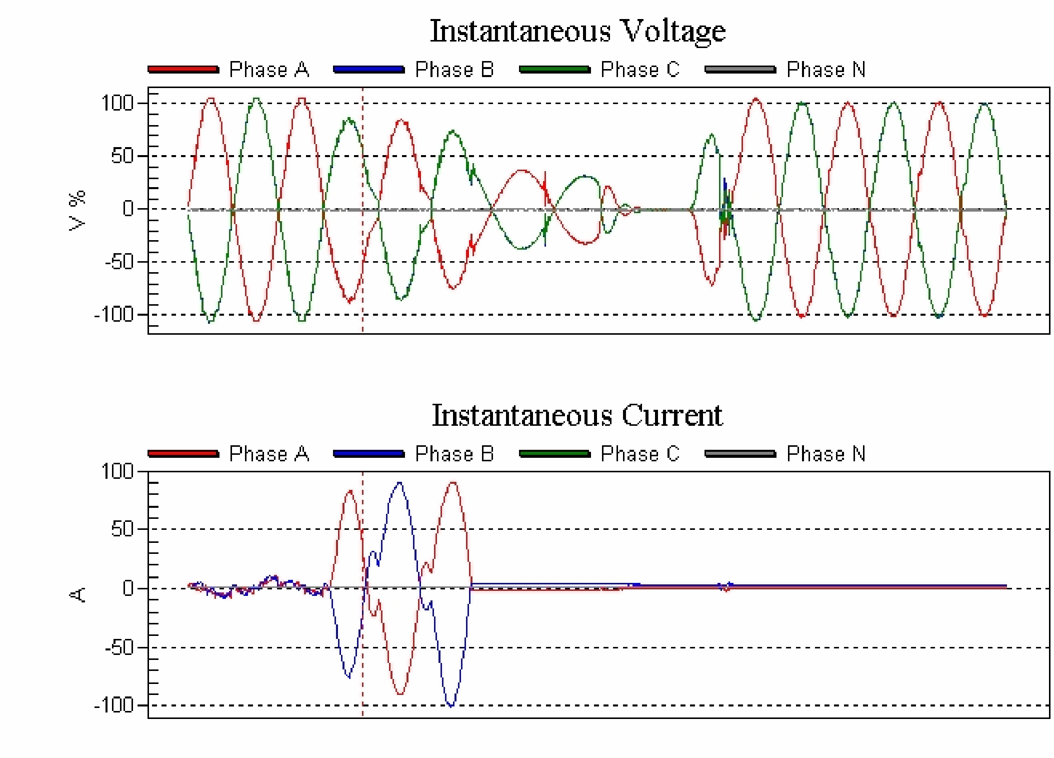
Due to the remote setting of the demonstration residence, a satellite internet connection was installed to facilitate data transfer of the monitored parameters to project partners. The data was made available to the public in real time and for downloading of historical data at the DOE/NYSERDA web page hosted by EnerNex Corporation: http://www.storagemonitoring.com/nyserda-doe/fuelcell.shtml. Historical data will continue to be available on the EnerNex web site for some time into the future. The picture below shows the DOE/NYSERDA web site where project data is available for viewing, graphing, and downloading in comma separated text format.



Role of Energy Storage
It would be impossible for DCEC to utilize a fuel cell to serve the energy needs of an off-grid residence without using energy storage. Three forms of energy storage were used for the demonstration:

1. Chemical energy storage in propane
   The 1000-gallon propane tank was a convenient, clean, and energy-dense means to store enough energy to meet approximately six months of the residential need.
2. Electrical energy storage in batteries
   The lead-acid batteries were essential to handle the non-dipatchable, constant output of the fuel cell and respond to the peaks and valleys of the residential electric load.
3. Thermal energy storage in a hot water tank
   The thermal energy storage in the hot water heat exchanger tank allowed heat to be captured opportunistically as available from the fuel cell. The captured heat could then be made available to the domestic hot water supply as hot water was used in the home.

Technical Performance
Transient Response
The figure below shows a power quality recording of the input to the energy storage device while it is being fed by the fuel cell through a split phase transformer (120 V – 120/240 V) in response to a large step function in current.



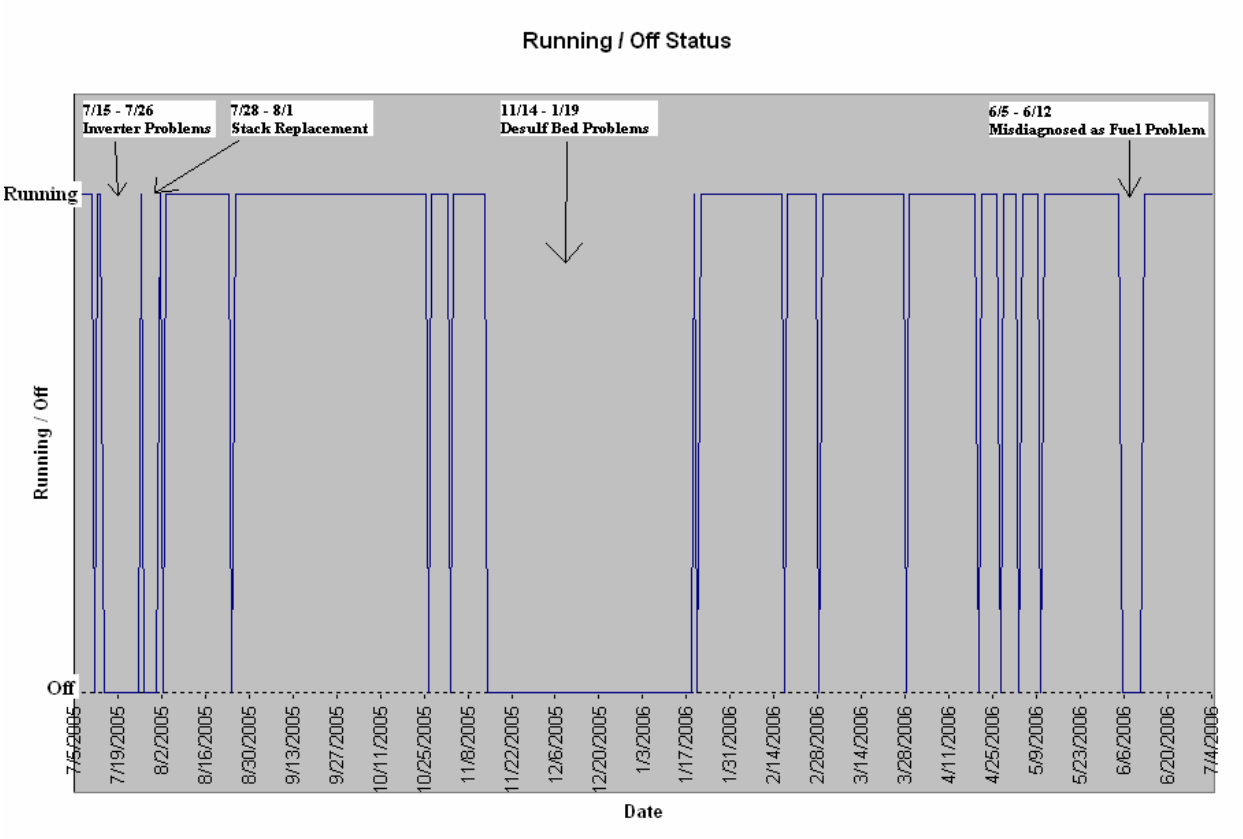
The fuel cell's response to the step function current demand is typical of a weak distributed generation source. This data capture is typical of the recordings of many similar power quality "events" that occurred during the one-year demonstration period. This recording and many others are available at the project data clearinghouse website hosted by EnerNex Corporation at http://www.storagemonitoring.com/nyserda-doe/. Other forms of power quality events captured and available on the website include instantaneous swells, transients, instantaneous sags, and temporary interruptions.

Cold Start Time

A cold start timed test was performed on June 21, 2005 during the installation and commissioning period. The start-up time commenced when the start button on the fuel cell was pressed and ended when the fuel cell entered the full running state, meaning that the reformer, stack, and system are all in their running states. The cold start time was measured to be 3 hours and 19 minutes.

Availability

The Plug Power GenSys 5 kW propane fuel cell was running and providing power 71.8% of the one-year demonstration period. The figure below shows the periods during which the fuel cell was running and when the fuel cell was off. The fuel cell was run at all times when it was available to run, so percent run time is equivalent to percent availability in this case.



The fuel cell shut down a total of twenty-four (24) times during the one-month commissioning period and the one-year demonstration period. Appendix B to this report lists each of the 24 shutdowns, the error message associated with the shutdown, the time to recover from the shutdown, and any intervention required in order to restore the fuel cell to an operating state. There were only four periods during the one-year demonstration period during which the fuel cell was unavailable for more than one day. Each of those outages lasting more than one day is noted on the figure above.

The table below summarizes the outages and the actions that were required to recover from outages.

Outage Recovery Type	Number of Occurrences in 13 Months
Auto restart by the fuel cell with no intervention by a human or external control system	10
Repair or maintenance requiring human intervention	8
Manual restart requiring human intervention, but no repair or maintenance required	5*
No restart occurred because the fuel cell demonstration period was complete	1

*The manual restart count of five includes two manual starts that followed planned shutdowns during the installation and commissioning process.

<u>kWh Production</u>

Over the course of the demonstration period, the fuel cell produced a total of 10,940 kWh of energy. Dividing the number of kWh produced by the number of running hours for the fuel cell gives a value of 1.75 kW average production level. The fuel cell was most frequently set at an output setting of 2 kW, which is 40% of the fuel cell's rated continuous output.

<u>Electrical Efficiency</u>

The fuel cell consumed 1,992 gallons of propane to produce 10,490 kWh of electricity. The table below shows the values that were used to calculate the overall electric efficiency of the fuel cell.

Description of Quantity	Value
Cubic ft propane / gal propane	36 SCF/gal
Higher heating value of propane*	2520.5 BTU/SCF
Gallons of propane consumed	1992 gal
kWh electric produced	10,940 kWh

*Higher heating value of propane is a measured value. Measurements were performed by Empact Analytical. Details of the propane analysis are shown on page 28 of this report.

Using the quantities in the table above, the efficiency for the fuel cell averaged over the one-year demonstration period was 20.7%.

Thermal Recovery

The ability to extract more energy from the fuel cell adds to the overall efficiency of the demonstration. Due to a problem with the pulse-producing water flow meter in the combined heat and power loop, a flow rate of four gallons per minute was assumed for all one-minute periods during which there was non-zero flow. The CHP supply and return temperatures for each one-minute period were measured and recorded, allowing energy values to be calculated for each one-minute period. The table below shows the values that were used to calculate the energy recovered through thermal recovery from the fuel cell.

Description of Quantity	Value
Mix of Glycol and Water in CHP loop	38.8% glycol mix
Density of glycol/water mix (representative)	1.06 g/cm^3
Specific heat of glycol/water mix (representative)	3.6 Joules/gram °C
Cubic centimeters / gallon	3785.4 cm^3/gal
kWh per Joule	$2.77X10^{-7}$ kWh/Joule

Using the quantities in the table above, the total energy recovered through thermal recovery over the one-year demonstration period was 1736 kWh. With the addition of the energy recovered from thermal recovery, the total fuel cell efficiency (electric plus heat) was 23.9%.

Durability

In this analysis the concept of durability is applied to the fuel cell stack itself, whereas the concept of availability was applied to the whole fuel cell as a system. There were two stacks utilized over a 13-month period including the one-year demonstration period and the one-month installation and commissioning period. The first stack experienced reduced cell voltage due to sulfur contamination and was replaced after approximately 632.5 hours of stack operation. Note that the 632.5 hours of stack operation includes only those hours that the fuel cell system was in full running mode and ignores those hours during which the fuel cell system was in some phase of its startup sequence.

The second and final stack utilized by the fuel cell logged a total of approximately 6060 hours before its final shutdown on July 5, 2006. Throughout the stack’s life, it was producing power at less than half of its rated capacity in an effort to match the average power needs of the host residence. This de-rating of the fuel cell could have contributed to the high durability of the second stack.

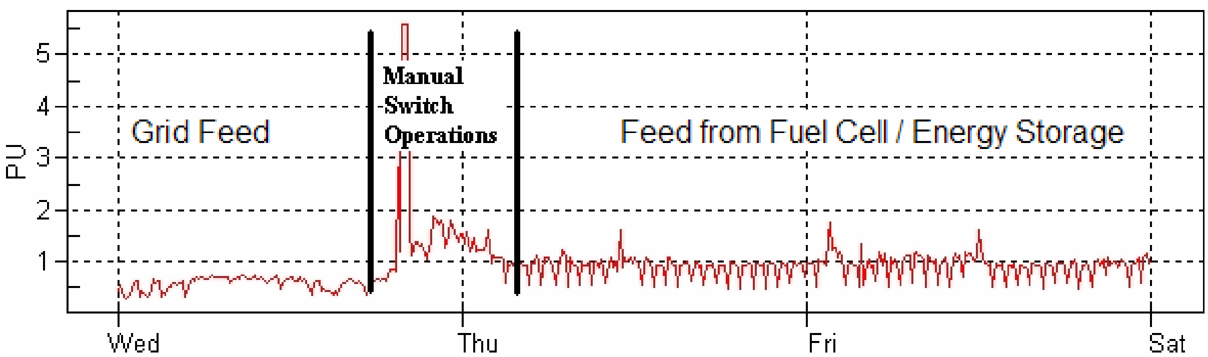
Survivability

In this analysis the term survivability is interpreted to mean the fuel cell systems ability to continue to operate and not be damaged by low ambient temperatures. The stack itself was never allowed to experience extreme cold because, as a practical matter, it was known that extreme cold had the potential to inflict severe damage on the stack.

The fuel cell operated in the full range of Upstate New York weather conditions without any damage or apparent degradation of performance. The fuel cell operated in a minimum ambient temperature of -10.7 degrees Celsius (12.8 degree Fahrenheit). The temperature gauge that recorded ambient conditions was located in close proximity to a protected corner between the main part of the host residence and its attached garage. The fuel cell was also located in this semi-protected area. Although lower outdoor temperatures were experienced in the vicinity of the residence during the demonstration period, the fuel cell itself did not experience temperatures lower than 12.8 degree Fahrenheit. The picture below shows the semi-protected corner where the fuel cell and temperature gauge were installed.

Power Quality

Power quality data and homeowner feedback from the demonstration project provided valuable insights into the impacts of power quality on the quality of life of residents within a home. From the homeowner perspective, the presence of light flicker was the only noticeable impact of power quality problems during the demonstration. The IEEE-defined quantity called short term flicker is a way of quantifying and comparing the flicker phenomenon in a standard and consistent manner. The figure below shows the unitless short term flicker quantity plotted across a period of time that included straight grid-feed to the energy storage device and the fuel cell feed to the energy storage device. The flicker measurements were recorded at the home's main panel, where it is most indicative of the overall flicker level experienced in the home.



Note that the y-axis label of PU stands for "per unit," which is another way of saying that short term flicker is a unitless quantity. During periods when the utility grid was feeding the energy storage device, the short term flicker values were in the range of 0.5 to 0.8. During the periods when the fuel cell was feeding the energy storage device, the short term flicker values were in the range of 0.5 to 1.5 with frequent peaks above 1.0. By definition, a short term flicker value of 1.0 indicates a level of flicker that would be noticeable to 50% of the human population.

The short term flicker data was corroborated by the experience of the home owner and the project team. During a typical day at the demonstration residence, the home owner met with three other members of the project team. Light flicker was evident or noticeable to the home owner and one project engineer. Two other project engineers could not detect the presence of light flicker. This "subjective" nature of flicker impacts makes this issue even more important to equipment manufacturers, resellers, and installers. Flicker must be assessed and addressed through objectively quantifiable means because each human will experience flicker to a different degree.

The power quality data and home owner experience on this project indicate a need for fuel cells and all distributed generation equipment to be designed and tested for a range of power quality impacts including flicker and total harmonic distortion. It is noteworthy that a fuel cells output power can comply with industry standard power quality curves such as the Computer Business Equipment Manufacturing Association (CBEMA) curve and still present power quality problems to homeowners. For example, the voltage fluctuations that caused the flicker issues for this demonstration were often less than 2% of the absolute voltage value and lasted lass than 150 ms. These types of fluctuations would not violate the CBEMA curves, but definitely caused flicker that was noticeable to the homeowner.

<u>Noise</u>

The Plug Power published noise level for their GenSys fuel cell product is <65 dBA at 1 meter. The experience with noise on this demonstration was anecdotal but it did reinforce the idea that the GenSys noise levels are very low over all modes of operation, startup, and shutdown. Even standing within 15 feet of the fuel cell, it would be impossible to know whether it was running or off based on noise output. The loudest noise produced by the fuel cell, which was infrequent and intermittent, was a radiator fan startup noise. The radiator fan startup noise was audible from tens of feet away from the fuel cell, but was not loud enough to be heard from within the residence. Overall, noise was a non-issue for the project team and the homeowner throughout the demonstration.

Emissions

DCEC hired Eastmount Environmental to perform emissions testing on the fuel cell at the demonstration site under typical startup conditions of the demonstration. Eastmount utilized a portable laboratory, which housed gas analysis equipment, calibration equipment and gases, and data recording equipment. Eastmount also did flow rate measurements that, when combined with the composition analysis, could be used to calculate total emissions rates for all the measured stack gas constituents.

The following narrative was produced by Eastmount Environmental and summarizes the emissions test data and methods. Detailed test results and calibration data are available upon request from DCEC.

EASTMOUNT ENVIRONMENTAL SERVICES, LLC
Air Quality Specialists

August 17, 2006

Mr. Mark Schneider
Delaware County Electric Cooperative, Inc.
P.O. Box 471
39 Elm Street
Delhi, NY 13753

**RE: Test Results for Emissions Testing on Tweedie Site Fuel Cell
Eastmount Environmental Services Project #06-086**

Dear Mr. Schneider:

Please find enclosed the results for the emissions testing that was conducted on the Tweedie Site fuel cell on July 26, 2006. This submittal includes one-minute averages of all parameters measured plus volumetric flow rate calculations, supporting field data, and calibration gas certificates. All data are reported in Appendix A (attached).

The test period occurred from 13:30 to 15:17. In general, NOx and SO_2 emissions were insignificant throughout the operating cycle. However, CO and total hydrocarbon (THC) emissions were very high during unit startup. As the unit warmed up and stabilized, CO emission diminished from 2500 ppm (off-scale) to approximately 10 ppm over a period of 50 minutes. However THC emissions, which began at 30,000 ppm (off-scale) at start-up, never dropped below 500 ppm during the test period.

The exhaust gas flow rate was measured at 73 wet standard cubic feet per minute or 70 dry standard cubic feet per minute. This data was used to calculate pound per hour emissions. Pound per hour emissions of CO and THC are included on the emissions summary sheets at the front of Appendix A.

Eastmount utilized the test methods listed in Table 1 on the following page for the corresponding test parameters.

SEAPORT INDUSTRIAL PARK • 65 PARKER STREET - UNIT 3 • NEWBURYPORT, MA 01950
TEL: 978.499.9300 • FAX: 978.499.9303 • E-MAIL: INFO@EASTMOUNT.COM • INTERNET: WWW.EASTMOUNT.COM

Table 1 – Test Parameters

Parameter	Test Method
Nitrogen Oxides	EPA 7E
Sulfur Dioxide	EPA 6C
Carbon Monoxide	EPA 10
Total Hydrocarbons	EPA 25A
Oxygen / Carbon Dioxide	EPA 3A
Volumetric Flow Rate	EPA 2

Eastmount Environmental Services, LLC appreciates the opportunity to support your air quality management and control programs. If you have any questions regarding this submittal or require additional information, please do not hesitate to call me or David Caron at (978) 499-9300. It was a pleasure working with you on this program.

Sincerely,

EASTMOUNT Environmental Services, LLC

Anthony M. Stratton
Vice President, Technical Services

Costs and Economic Viability

This demonstration has considered two factors related to costs and economic viability. The first of these factors is up-front cost and the second of these factors is cost per kWh over the life of the fuel cell.

Up-front Costs

The project costs for this demonstration project were much higher than the costs would have been to install and commission a residential fuel cell without all of the ancillary equipment and personnel costs associated with project planning, data acquisition, monitoring, and reporting. On the other hand, certain equipment was donated to this project that would have been a cost to a "typical" installation. With that in mind, the table below was developed, which summarizes the up-front costs associated with installing and commissioning a "typical" residential fuel cell. No adjustments have been made for changes in equipment or service prices since the unit was installed in 2005. Presumably many costs have gone up while fuel cell costs have decreased, but the table below does not have any speculative information as to how those prices may have changed since 2005.

Description of Cost Area	Amount
Fuel cell equipment purchase and delivery	$75,700
Energy storage system equipment purchase	$14,810
Ancillary electrical equipment including transfer switch, split phase transformer, and new breaker panel and electrical contractor	$4.278
Thermal recovery equipment purchase and plumbing contractor	$4,658
Equipment rental	$1,244
Propane storage, metering, and piping system including 1000 gallon tank	$3,140
Ground restoration, seeding, planting	$499
Total up-front cost	$100,055

The total up-front cost of $100,055 purchased and installed a 1000 gallon propane tank, 5 kW PEM fuel cell, 11 kW / 20 kWh energy storage system, and all ancillary equipment and services. Although the electrical energy storage and thermal recovery systems add significantly to the installed cost, the electrical energy storage is arguably necessary for an off-grid application and the thermal recovery is economically beneficial over the life of the fuel cell.

Cost per kWh

The up-front costs of the fuel cell installation are relatively straight-forward to calculate and do not require any gross assumptions, but the calculation of cost per kWh requires several assumptions that impact the result. The most conservative calculation approach is to assume that the fuel cell has no useful life after the one-year demonstration period and calculate a cost per kWh based on the actual costs during that one year. Since the fuel cell was supported by Plug Power's warranty throughout the year, there were no equipment maintenance costs other than DCEC's labor. The following values were used to calculate a cost per kWh for a fuel cell with a one-year life:

Description of Assumption	Value
Total up-front cost including installation	$100,055
Maintenance cost for one year	$3,808
Fuel costs for 1-year (including cost of fuel left in tank)	$3,614
kWh produced by the fuel cell	10,940

Based on the values in the table above, a cost per kWh for the project's fuel cell with a one-year life was $9.82 / kWh [($100,055 + $3,808 + $3,616)/10,940 kWh].

Enhanced Operations and Maintenance Concepts

Existing Operations and Maintenance Documentation

For the most part, DCEC was able to follow the recommended and published operations and maintenance procedures and schedules recommended by Plug Power and those procedures and schedules were adequate with few exceptions.

One minor exception was the manner in which thermal recovery was controlled by the fuel cell. The fuel cell has a built-in thermal recovery mechanism that diverts coolant from the radiator to a thermal recovery loop. The thermal recovery function can be enabled or disabled manually through the maintenance interface on a personal computer connected to the fuel cell. However, on the particular GenSys model utilized by this project, the fuel cell did not respond to low temperature conditions in the coolant loop by disabling thermal recovery in an automated fashion. Therefore, the human operator or maintainer of the fuel cell system had to moderate the amount of heat being pulled through the thermal recovery loop by adjusting the heat load within the residence. For example, the space heating thermostat in this demonstration project had to be turned down to avoid excessive heat extraction through the thermal recovery loop. This problem significantly impacted the effectiveness of the thermal recovery system for this demonstration, but the fix to this problem is relatively easy and can be made within the operating software of the fuel cell. It is believed that Plug Power has already addressed this concern for any future releases.

In addition to this minor concern regarding thermal recovery, there was one significant operations and maintenance finding of this demonstration project.

Problem Description

Industry practices in the propane distribution business have not been well understood by fuel cell manufacturers. Established operations and maintenance practices related to the fuel cell reformer's desulfurization bed were found to be incompatible with the established propane industry practice of injecting methanol into new propane fuel storage tanks. The result of the incompatible practices was a failure of the fuel cell stack. DCEC recommends to fuel cell manufacturers that they change their operations and maintenance practices to better handle the presence of alcohol in the propane fuel.

Specific Failure Mechanism

It is typical for propane distribution companies to add methanol or another alcohol to new propane tank installations. The purpose of the additive is to combine with water vapor that may be present inside the tank and carry it out of the tank into the fuel load, which in this case is the fuel cell. If water vapor is left trapped in the propane tank, corrosion is accelerated and can shorten tank performance and useful life. The alcohol is added to the tank in quantities sufficient to remove most or all of the water vapor.

As fuel is consumed by the fuel cell, alcohol is also boiled out of the propane tank with the propane. As the fuel enters the fuel cell's reformer it passes through a desulfurization bed, which contains small porous beads impregnated with proprietary combinations of catalysts that promote the capture sulfur-containing compounds. The porous beads work on the principle of a combination of chemical and physical absorption onto their large surface areas. The alcohols are preferentially physically absorbed onto the surface of the beads. The alcohols occupy surface area and block access to that same surface by sulfur-containing compounds. As a result, sulfur-containing compounds are allowed to pass through the desulfurization bed to the remainder of the reformer process and into the fuel cell stack.

Once sulfur-containing compounds reach the fuel cell stack, they can deposit themselves on the proton exchange membrane, thus blocking pathways for the desired process in the stack. Reduced membrane effectiveness leads to lower cell voltages and ultimately to the stack's inability to produce the required power. If the stack fails due to sulfur contamination, the only maintenance option is to remove the affected stack and replace it with a properly functioning stack.

Similar Experience in other Installations

Plug Power personnel were very helpful in diagnosing and repairing the problems caused by alcohol in our propane. Plug was also able to provide data from all their other propane fuel cell installations that had occurred as of November 2005. Twenty-three (23) propane-fueled Plug GenSys units had been installed as of November 2005. Twenty-two (22) of those units had experienced sulfur contamination and stack failure within six (6) weeks of commissioning. The one unit that did not experience a similar failure was installed at a location with an existing propane tank (not new), so no alcohol was added to the tank in the weeks or months preceding the fuel cell.

Recommended Changes to Operations and Maintenance Practices

There are a number of strategies that could be employed to minimize or avoid alcohol's impacts on the performance of the desulfurization bed. Some examples include:

1. Work with the propane provider to minimize the amount of alcohol injected into the propane tank.
2. Plan on changing the desulfurization bed after a very short initial operating period.
3. Add an inexpensive pre-filter based on low cost silica/clay pellets that would provide a large surface area for alcohol physical absorption.

Propane Fuel Testing

DCEC hired Empact Analytical Systems to perform compositional and heat content analysis on the propane gas at two points in the demonstration period. The material below is an example of the test results from a November 7, 2005 sample of the fuel taken just upstream from the inlet on the fuel cell.

COMPONENTS	NORM. MOLE%	GPM @ 14.696	GPM @ 14.73
HELIUM	0.00	-	-
HYDROGEN	0.01	-	-
OXYGEN/ARGON	0.00	-	-
NITROGEN	0.27	-	-
CO2	0.01	-	-
METHANE	0.04	-	-
ETHANE	0.23	0.061	0.062
PROPANE	97.59	26.829	26.891
ISOBUTANE	0.92	0.300	0.301
N-BUTANE	0.92	0.289	0.290
ISOPENTANE	0.01	0.004	0.004
N-PENTANE	0.00	0.000	0.000
HEXANES+	0.00	0.000	0.000
TOTAL	100.00	27.484	27.547

	BTU @ 60 DEG F	14.696	14.73
LOW	NET DRY REAL=	2361.2	2366.7
	NET SATURATED REAL=	2320.1	2325.5
HIGH	GROSS DRY REAL =	2565.2	2571.1
	GROSS SATURATED REAL =	2520.5	2526.4

SPECIFIC GRAVITY (AIR=1 @14.696 PSIA 60F) : 1.5551
COMPRESSIBILITY FACTOR : 0.98250

NOTE: REFERENCE GPA 2261(ASTM D1945 & ASME-PTC), 2145, & 2172 CURRENT PUBLICATIONS

The testing asked of Empact did not include any tests that would indicate the amounts or types of specific compounds that have a tendency to foul the desulfurization bed. If such testing can be conducted economically, it may be advisable have testing done that would help fuel cell operators predict the useful life of a desulfurization bed in the presence of some alcohol. Empact did perform a test to determine the amounts and types of sulfur-containing compounds in the fuel. An example of those results is shown below.

TEST PROCEDURE / METHOD: SULFUR BY GAS CHROMATOGRAPH SCD350 *

COMPONENT	SULFUR ppm mole (ul/L)	SULFUR ppm wt (ug/g)
Hydrogen Sulfide (H2S)	3.9	3.0
Carbonyl Sulfide (COS)/Sulfur Dioxide (SO2)	1.1	0.9

Note that undetected sulfur-containing compounds have been omitted from the results above for the sake of clarity.

Safety Vulnerabilities and Lessons Learned
DCEC worked with the local code enforcement officer and with our own staff with expertise in the codes published by the National Fire Protection Association to establish the guidelines for safe installation and operation of a propane fuel cell in a residential setting. It was agreed that for this installation we would treat the fuel cell just like one would treat a propane generator. This means that we used the propane connection, setbacks from residences and other structures, and electrical protections that one would normally associate with a propane generator.

DCEC believes that this approach was adequate and did not encounter any additional safety vulnerabilities. Installations of any propane fueled distributed generation would have similar safety risks including combustible gases, hot surfaces, and electrical hazards. There were no occurrences of accidents or near-accidents on the demonstration site throughout the installation, commissioning, or operation of the fuel cell.

In considering potential safety hazards that could be present with fuel cells that one might not be exposed to with generators, only the presence of hydrogen gas comes to mind. The presence of redundant hydrogen sensors within the fuel cell reformer area were a reasonable protection against the build-up of hydrogen gas to explosive levels.

Education of State and Local Consumers
DCEC and the whole project team worked throughout the one-year demonstration to use the demonstration as a learning tool for state and local consumers of energy. There were a large number of radio, television, newspaper, and magazine articles that covered the demonstration project and its associated technologies (fuel cells and energy storage). In addition, project team members, primarily from DCEC, made a number of presentations on the project and its technologies at local schools, Rotary Clubs, Legion Halls, town meetings, and annual meetings of the cooperative members. There were three events in particular that helped to raise the public's awareness of fuel cells and energy storage as relevant technologies to their energy futures:

1. Press event and commissioning celebration in Delhi, NY and Sidney Center, NY on August 11, 2005.
2. Fuel Cell and Energy Storage Educators' Seminar at the State University of New York College of Technology at Delhi on May 9, 2006.
3. Cornell Cooperative Extension clean and renewable energy housing tour in Sidney Center, NY on June 3, 2006.

<u>Press Event and Commissioning Celebration</u>
DCEC hosted a large press event and fuel cell commissioning celebration on August 11, 2005. The event was well attended by local and regional members of the press as well as local, state, and state-wide elected officials. The keynote speaker at the event was Representative Maurice Hinchey.

Members of the press and our elected officials were invited to the demonstration site to see the fuel cell and energy storage equipment as they powered the home.

<u>Fuel Cell and Energy Storage Educators' Seminar at SUNY Delhi</u>

DCEC worked with SUNY Delhi and the Community College of Lansing Michigan to co-develop and co-teach a seminar targeted toward secondary and post-secondary educators. The event was well attended by college faculty, high school teachers, vocational educators, and community leaders from the local region and from Lansing, MI. The seminar elevated awareness of fuel cells and energy storage among the attendees and provided some teaching materials, which could then be used by conference attendees when they returned to their own classrooms. The picture below shows one of the faculty members from Lansing, MI giving a presentation on how fuel cells and energy storage fit into the larger context of clean and renewable energy technologies.

<u>Cornell Cooperative Extension Housing Tour</u>
The Cornell Cooperative Extension Housing Tour was an opportunity for Mark Schneider, the project manager, to present to approximately 80 people on fuel cells and energy storage, with specific data and lessons learned integrated from the actual demonstration experience. In addition to hearing this presentation, participants made a brief stop at the fuel cell demonstration site to see the fuel cell in action.

Patents
No patents have been applied for or resulted from this award.

Publications / Presentations
In addition to the education and outreach events described earlier in this report, the following publications and presentations have been created by project team members and affiliates using data or other relevant information from the demonstration project*:

- Presentation at the Electrical Energy Storage Applications and Technologies conference (EESAT 2005) in San Francisco, CA on October 17, 2005.
- Paper published in the proceedings of the EESAT 2005 conference.
- Presentation at the 19th World LP Gas Forum Global Technology Conference in Chicago, IL on October 18, 2006.
- Presentation at the Energy Storage Association annual meeting in Boston, MA on May 23, 2007.
- Presentation at the EPRI Power Quality Applications (PQA) 2007 and Advanced Distribution Automation (ADA) Joint Conference, Long Beach, CA on June 10, 2007.

*This publications and presentation list omits those presentations and publications that resulted directly from the DOE's peer review process and annual meetings.

Comparison of Accomplishments to Objectives and Goals

DCEC and its project partners are proud of the fact that we have accomplished each of the project goals that we set for ourselves and those that were set for us by the Department of Energy and our other project sponsors.

This project demonstrated the viability of grid-independent operation of a typical upstate NY home whose total electrical energy needs were met by a propane fueled fuel cell. The demonstration combined intelligently managed energy storage, in-home load control, and combined heat and power to optimize the performance of the fuel cell as a whole-home energy source. The project contributed to enhanced awareness and knowledge among consumers, rural electric cooperatives, fuel cell manufacturers, energy storage manufacturers, educators, and staff members of national agencies and laboratories through a process including public awareness events, publications, educational programs, and technology transfer. The project validated the following objectives of propane fueled hydrogen fuel cells for edge-of-grid residences:

- measured and reported technical performance
- provided raw cost data and economic viability analysis
- documented maintenance and operations concept enhancements specific to residential fuel cells
- shared safety related vulnerabilities analysis and lessons learned
- promoted education of state and local consumers.

Appendix A – Demonstration Site Log

The contents of Appendix A are the result of the interpretation and transcription of the site log, which was maintained by DCEC personnel throughout the demonstration period. The site log begins on April 28, 2005 with the first pre-installation work and ends on July 27, 2006 with the removal of the fuel cell. Certain hand-drawn sketches and other details have been omitted from this version of the site log in the interest of efficiency, but those details remain on file in the original site log at DCEC.

Digital photos have been added in certain log entries for the benefit of the reader. These photos are a sampling of the digital photos that remain on file at DCEC.

Throughout the site log, the following individuals are listed by their last names only:

- Randy Brown, plumber, Dubben Brothers Plumbing Service
- Bob Coager, DCEC employee
- Jim Green, DCEC employee
- Erich Gunther, EnerNex Corporation
- Randy Hillis, plumber, Dubben Brothers Plumbing Service
- Jan Morawski, Plug Power Inc.
- Ib Olsen, Gaia Power Technologies
- Nick Pasquale, Gaia Power Technologies
- Mike Pietrantoni, DCEC employee
- Al Reed, DCEC employee
- Ron Schmitz, DCEC employee
- Mike Sackett, DCEC employee
- Mark Schneider, DCEC employee
- Mike Simonds, electrician, Simonds Electric
- Greg Starheim, DCEC General Manager
- Chris Todd, Gaia Power Technologies
- Steve Watkins, DCEC employee

<u>04/28/2005</u>
Pietrantoni, Schneider, Reed, Sackett, Schmitz

- Installed Signature Systems Dual Node PQ Monitoring device on main panel
- Problem with CT clamp size
- Unloaded fuel cell and placed on cross arms adjacent to planned installation location

- Reviewed site plan and elevation sketches, making notes

05/02/2005
Schneider, Chuck Barnes (Culligan Water, Inc.)

- Met Chuck Barnes of Culligan Water on site
- Tested water from the faucet in the basement closest to the entrance from the well
- Hardness = 3 grains per gallon
- pH = 6
- Total Dissolved Solids = 59 mg/liter
- Iron = less than ½ ppm

05/05/2005
Pietrantoni, Schmitz

- Dropped of loads of sand and stone in front yard adjacent to planned fuel cell installation location

05/09/2005
Coager, Green, Reed, Pietrantoni

- Dropped of excavator rented from Ackerly and Sons
- Excavated below fuel cell site
- Trenched to house
- Removed water line in way of house penetration in the sill
- Put water valve where filtration unit will be installed

05/10/2005
Reed, Pietrantoni, Brown, Simonds

- Randy Brown from Dubbens Brothers Plumbing service began running lines between house and fuel cell
- Mike Simonds from Simonds Electric began running conduit between house and fuel cell
- Reed and Pietrantoni began digging propane tank hole, but broke hydraulic line on the back hoe due to old kink in line

05/11/2005
Reed, Pietrantoni, Brush crew, Mirabito

- Finished excavation for 1000 gallon propane tank
- Set tank with larger excavator from Walton Highway department
- Laid in sand in fuel line trench and around propane tank

- Got another load of sand so as to have 6” cover over entire tank
- Bill and Mark from Mirabito finished up gas meter connections and left ~2 PM
- Set fuel cell~1:30 PM with Tweedie driving skid steerer

- Don Buel planted flowers
- Johnson and Little planted evergreens around fuel cell, etc.
- Filled in remainder of propane tank hole
- Used truck 51 to move extra dirt out to back of Tweedie property
- Cleaned up rock and left site ~3:15 PM

05/12/2005
Reed, Pietrantoni

- Pietrantoni and Al installed pipe for satellite dish
- Arrived at ~2 PM and departed ~3 PM

05/13/2005
Pietrantoni, Simonds

- Installed plywood on electrical wall in basement
- Installed bi-fold doors to separate project/utility room from finished basement area
- Arrived ~9 AM and departed ~11 AM

05/18/2005
Reed, Pietrantoni, Schneider, Brown, Hillis

- Mirabito hooked up gas line – tested OK

- Dubben Bros. working on plumbing in basement and outside
- Arrived ~9 AM and departed ~3:30 PM

05/26/2005
Reed, Pietrantoni, Simonds, Brown, Hillis, Schneider, Satellite Installers
- Satellite dish and modem installed and tested
- Took outage in the afternoon to tie in the automated transfer switch in the basement
- Confirmed with Tweedie that we can install flow meter and thermocouples in the outdoor wood boiler line
- Decided basement thermostat for fuel cell thermal recovery will be on side of basement stairs
- On-site design change – moved relay rack down the wall to between the transfer switch and the Power Tower to facilitate CT and voltage probe connections to the Dranetz BMI data loggers
- Satellite installers suggested looking for between 75 and 80 on signal strength whenever we disconnect and reconnect the satellite modem from the coaxial cable
- Arrived ~9 AM and departed ~4:45 PM

05/27/2005
Reed, Pietrantoni, Simonds
- Placed cement around below-ground anti-twist horizontal member for added stability
- Simonds continued electrical connections
- Re-tuned satellite dish following cement work
- Arrived ~9:30 AM and departed ~3:00 PM

05/31/2005
Pietrantoni, Simonds

- Made final fuel cell AC connections
- Arrived ~9:00 AM and departed ~1:30 PM

06/01/2005

Reed, Pietrantoni, Schneider, Brown, Hillis

- Made final connections for de-ionized water and drains
- Installed fuel cell stack and therminol coolant
- Changed plans and moved DI drain into septic collection instead of simple floor drain due to difficulty in reaching floor drain without inconveniencing home owner
- Brown and Hillis fixed problem with Tweedie well to achieve 40 psi for DI water panel
- Arrived ~9:30 AM and departed ~3:15 PM

06/02/2005

Reed, Pietrantoni, Schneider, Morawski, Gunther, Bill from Mirabito

- Opened up fuel cell and prepared for Plug Power arrival
- When Plug arrived, began establishing communications between the fuel cell main board (SARC) and laptop computer with serial cable
- Determined that when using the HP laptop, must bring docking station to avoid the need for cable adapter, which causes problem for communicating with the SARC
- Mirabito performed leak test on full propane line from tank to fuel cell and found no leaks
- Mike Simonds worked on communications connections
- Had communications problems between the SARC and the inverter controller, so Morawski reseated cables and boards and problems seemed to go away, cause unknown
- Checked DI water panel with Morawski's flow meters and achieved a 7:1 flow ratio between waste water and de-ionized water flow to fuel cell
- Morawski helped check for and remove all bubbles from the therminol and glycol systems
- Schneider took propane samples in tedlar bag and cylinder containers, ambient temperature ~70 F with low to moderate humidity
- Morawski showed Reed and Pietrantoni how to use Tools/Control Algorithm/humidity control to fill water and have the solenoid automatically stop water fill – controlled by the fuel cell, want check box checked to avoid over-filling
- Put the fuel cell in start-up mode
- Erich from EnerNex arrived ~12:10 PM to confer with Schneider and Simonds about remaining control and data acquisition wiring connections
- ~12:30 PM DI water is OK in humidifier and DI tank
- For data acquisition, 1st device power. Then CT's and voltage probes both in transfer switch downstream toward main panel
- Discussed 12 V power supply for ADAM module – Erich says OK – can run on <9V if necessary

- Unpacked all analog data acquisition modules (ADAM modules) and seated them in their backplane
- Determined the need for ~100 feet of thermocouple extension cable and a 6 foot serial cable to complete the ADAM 5000 installation for analog inputs
- Discussed wire types for data acquisition
  - Shielded 4-wire OK for pulse meters
  - Questions 4-wire shielded for thermocouples and needs to check with BMI engineers
  - CAT5 OK for all else
- Discovered that SkyCasters satellite internet provider has changed IP address space from original scheme to the following:
  - 67.45.172.10 thru .14 for inside addresses
  - 67.45.172.9 for modem
  - 255.255.255.248 for mask
- 1:45 PM fuel cell entered full running mode for the first time
- 2:30 PM fuel cell had 36.29 A current output
- Morawski
- Erich completed IP configuration and confirmed EnerNex office connectivity to all data loggers on site
- Erich downloaded ADAM software and installed it
- Morawski suggested we should acquire a small space heater for E-stop conditions. – one that will fit inside the fuel cell.
- Morawski suggested we confirm that the water lines are heat taped from the basement to the fuel cell
- Fuel cell amp output is very unstable – Morawski speculates that the instability is caused by alcohol in the propane.
- ~3:00 PM put the fuel cell in slow shutdown mode and achieved full shutdown ~3:10 PM

06/03/2005

Gunther, Schneider, Simonds

- Arrived ~7:00 AM
- Erich performed most data acquisition configuration work from hotel over night
- Had trouble getting Info Node to talk to ADAM 5000 over serial port
- Mike Simonds arrived ~8:00 AM
- Simonds ran Cat5 cables to remaining sensor points
- Simonds, Mark, and Erich finalized termination positions in the ADAM 5000 module

5017 Card

Chan0	Outside Temperature
Chan1	Outside Humidity

5080 Card

Chan 0	LPG Flow

Chan 1	CHP Loop Flow
Chan 2	Outdoor Boiler Flow
Chan 3	Oil Burner Timer (left empty at this time)

5018 Card

Chan 0	Thermocouple, CHP From Fuel Cell #20
Chan 1	Thermocouple, CHP Return to Fuel Cell #2
Chan 2	Thermocouple, From Outdoor Boiler #22
Chan 3	Thermocouple, Return to Outdoor Boiler #21

- Tested thermocouple input V0+, V0-
    - Erich to confirm Red/Blue on +/-
    - 5018 module working
    - Erich to confirm how to specify range for thermocouples
- Tested pulse counting meter
    - removed pressure valve from propane line to create a large flow
    - 5080 module working
- Could not test outdoor temp/humidity sensor because it is on back order
- Summary of issues for Erich
    - RS232/485 from Info Node to ADAM 5000
    - Thermocouple connection polarity and range specification
- As of 10 AM, we resumed PQ monitoring and ended the gap in data collection

06/10/2005

Schneider, Simonds, Grinaldi, Olsen, Pasquale

- Schneider and Simonds arrived ~8:30 AM
- Grinaldi, Olsen, and Pasquale from Gaia arrived ~11 AM
- Pulled all power tower equipment from the truck and moved to basement
- Discovered power tower racks needed more than 5 feet as anticipated
- Decided to move ADAM 5000 module up the wall slightly to allow power tower underneath is
- Relay rack will sit in front of automated transfer switch
- Checked computer communications
    - IP address assigned 67.45.172.11
    - Default gateway 67.45.172.9
    - Info Node .14
    - Data Node .13
- Completed battery connections and all power tower connections
- Started battery charge toward full charge state
- Gaia Power left site ~4:15 PM
- Spoke to Burl McEndree at 303-637-0150 regarding propane testing
- Pulled a propane tube sample to test for mercaptan
    - Devised an ambient pressure propane test sample collection system using an empty and clean water bottle with the normal twist-off cap hole on one end and 2 additional smaller holes cut in the other end

  - Propane enters the bottle through the normal twist-off cap hole in the top of the plastic bottle
  - One of the two new holes is used to insert a sampling tube
  - The second of the two new holes remains open, which allows propane to flow out of the bottle such that ambient pressure is maintained
- Test results of mercaptan test
  - saw dark orange line ~2 ppm
  - gray line well beyond 120 ppm
  - after re-reading directions, believe that gray line is unrelated to mercaptan
  - will send test tube for review by Empact Analytical
- Mark left site ~5:15 PM

06/14/2005
Pasquale, Schneider
- Arrived on site ~10:45 AM
- Nick added current transformers (CTs) to the transfer switch running back to power tower so power tower will know when to cut itself back in the event of overload conditions
- Mark unable to perform propane testing because he doesn't have the required tedlar bag
- Spoke to Empact Analytical and they will overnight tedlar bag
- Worked by e-mail with Erich of EnerNex from 1 PM to 5 PM
  - Router/firewall (encore) from Skycasters came mis-configured
  - Could not resolve configuration issues
  - Sent config file to EnerNex and Skycasters for their review
- Nick and Mark left site ~5:15 PM

06/16/2006
Pietrantoni, Schneider, Simonds, Reed
- Mark and Mikes arrived ~8:45 AM
- Started fuel cell to test battery storage system
- Mark took propane samples ~9 AM
- Reed arrived ~9:30 AM
- After starting fuel cell got an E-stop with error codes as follows
  - 1.929, FS7 Press.2 FS9 14.3.13
  - 2.524, Air Comm 14.3.1.7
  - 3.525, Fuel Comm
  - 4.546, ATO loss 14.3.10
- We opened electronics enclosure as per error code instruction to watch LEDs and hit started fuel cell again
- Hit start button twice to by-pass the 8 minute enclosure air purge
- Fuel cell went into manual mode and on into startup mode
- Nick from Gaia arrived ~10:45 AM

- Mike Simonds switched the grid and the power tower inputs in the transfer switch such that the Power Tower became the primary input to the transfer switch and the grid became the secondary input to the transfer switch
- Now when you look at the transfer switch front panel, the LED's indicate the following conditions:
  - LED next to utility pole symbol lit – means that Power Tower is available
  - LED next to generator symbol lit – means that grid is available
  - LED below the utility pole symbol lit – means that the Power Tower is currently feeding the main panel
  - LED below the generator symbol lit – means that the grid is currently feeding the main panel
- Noted that the symbols on the front panel of the transfer switch are now counter-intuitive
- This configuration allows the transfer switch to see the combination of the fuel cell and energy storage (Power Tower) as the primary input
- Nick connected a second LinkSys BEFSR41 router as 67.45.172.13 and tested communication through this new router (to be called the Gaia router) to his laptop. Communications worked fine from laptop to Internet.
- From Nick's laptop on the Gaia router
  - Ping 67.45.172.9 – timeout
  - Ping 67.45.172.10 – reply Encore
  - Ping 67.45.172.11 – timeout
  - Ping 67.45.172.12 – reply Data Node
  - Ping 67.45.172.13 – reply new Gaia router
  - Ping 67.45.172.14 – timeout
- Reset Gaia router to static IP address 67.45.172.11
- From Nick's PC on Gaia router, logged into www.direcwaysupport.com
- Confirmed modem address 67.45.172.9
- Repeated ping tests
  - Ping 67.45.172.9 – reply from modem
  - Ping 67.45.172.10 – reply Encore
  - Ping 67.45.172.11 – reply Gaia router
  - Ping 67.45.172.12 – reply Data Node
  - Ping 67.45.172.13 – reply Dual Node Info Node
  - Ping 67.45.172.14 – reply Dual Node Data Node
- Called Darren at EnerNex 865-691-5540 x120
- Darren pinged entire IP range
  - Got responses except for Encore (.10)
- Network test PC setup
  - IP - 10.0.105.16
  - Submask - 255.255.255.0
  - Default router - 10.0.105.1
- <u>~3:01 PM closed cutout between fuel cell and Power Tower – no problems</u>
- <u>~4:12 PM manually moved transfer switch position such that house load fed from Power Tower – no problems</u>

- ~4:40 PM flipped main breaker upstream of feed to fuel cell to off position such that fuel cell could no longer see grid voltage – fuel cell transitioned from grid parallel mode to standby mode and continued feeding Power Tower.
    - Voltage on grid connection to fuel cell 0.2 V
    - Voltage on grid connection to Power Tower <1.7 V
- ~4:46 PM manually switched back main panel to grid
- Anomaly observed – Gaia inverter controller reset itself with each grid power switching event – don't understand this behavior
- Summary of Gaia Power Tower test modes
    - Fuel cell charging batteries: OK
    - Fuel cell limited to 9 Amps/phase: OK
    - Fuel cell feeding Power Tower, feeding loads including hot tub to a max of 31-32 Amps/phase: OK
    - Fuel cell feeding Power Tower, feeding loads including hot tub to a max of 31-32 Amps/phase while fuel cell limited to 9 Amps/phase: OK
    - Grid drop out: OK
    - Fuel cell drop out: OK
- ~4:51 initiated slow/long shutdown on fuel cell
- ~4;54 error code (512)(0) on fuel cell
- ~5:04 PM noticed fuel cell restarting itself, pushed shutdown button
- Could not test load control circuits today due to bad transformer for relay circuits so Mike Simonds will bring replacement
- ~5:15 PM left site (Simonds, Schneider, Pasquale)

06/21/2005

Schneider, Simonds, Reed, Pietrantoni, Brown

- ~8:30 AM Schneider arrives on site and Simonds waiting for him there
- Simonds replaced transformer for load control
- One relay works but the other does not
- ~9:06 AM powered up fuel cell with single press of start button (did not by-pass enclosure air purge)
- ~9:14 AM, communications came up right away
- Note that we are trying communications to my laptop with laptop's base station instead of USB to serial converter cable – direct DB-9 connection – still see frequent communications errors with fuel cell
- DI water fill indicator reads 118% upon startup – bad sensor?
- ~9:30 AM Randy Brown arrived and put thermocouples into thermal exchange loops
- ~9:49 AM humidifier reached water level of 2.8 and dropped down again
- ~10:25 AM Randy Brown pressure tested CHP loop and found leak in the manual bleed valve within the fuel cell
- ~12:25 fuel cell went into Running/Running/Running
- called Vinny at Plug Power to find out when CHP loop is enabled
- Vinny stated after Running/Running/Running
- CHP loop held exactly 9 gallons

- 38.8% glycol mixture
- 5 gallons glycol at 70%
- 4 gallons distilled water

- When fuel cell went into full running state, CHP loop started at ~130 degrees, then settled in at ~100 degrees
- Reed adjusted DCEC distribution system voltage down by 2 Volts to avoid distributed generation assets like the fuel cell seeing over-voltage on their grid inputs
- Communications still went bad occasionally for a few seconds every once in a while, even with straight serial connection between the laptop and the fuel cell
- Exercised transfer switch a couple times and fuel cell handled very well, Power Tower also handled very well
- Randy Brown departed ~1:30 PM
- ~2:39 PM fuel cell showed low cell alert and then shut itself down with error codes:
  - 500 (low cell trip alert)
  - 503 (fuel cell contactor retry timing out)
- Troubleshooting ModBus connection from EnerNex Widget to fuel cell

RS422	RJ45 on Fuel Cell SARC	Outside Colors	Cat5 Inside Colors
Y	TX+	Blue	Blue
Z	TX-	Black	Blue White
B	RX-	Red	Green
A	RX+	Green	Brown White

- Pietrantoni, Reed, and Erich left @ 5:20 PM

<u>06/24/2005</u>
Schneider

- IP configurations
  - 10.0.105.12 Data Node user: admin, password: password
  - 10.0.105.13 Data Node user: admin, password: password
  - 10.0.105.14 Info Node user: admin, password: password
- RJ45 terminations on white Cat5 cables
  - Tab up, blank, blank, blue on white, blue, blank, blank
- RJ11 terminations
  - Black, red, green, yellow

<u>06/28/2005</u>
~8:30 PM call from Tweedie to Schneider

- Tweedie having trouble with electric in house
- Running air conditioner, hot tub, and vacuum simultaneously

- Schneider instructed Tweedie to turn off output breakers on Power Tower while on the phone – resulted in transfer switch sensing lack of voltage from Power Tower and switching input from Power Tower to grid
- Schneider arrived on site ~9 PM
- Wedged a tool in the load management contact closure to hold down manual close button
- Schneider left site ~9:30 PM

06/29/2005
Schneider

- Checked for reason for Internet being down
- 15 Amp breaker in main panel was flipped off
- Flipped 15 Amp breaker back on in main panel
- Sent e-mail notification to Gaia and EnerNex and both confirmed that connectivity had been restored
- Confirmed modem settings on fuel cell
- Still no response from fuel cell modem
- Called Plug Power at 518-782-4000 and talked to Dave
- Dave had some additional modem tests before deciding to send me a new SARC board
- Recorded the following information from the LPG gas meter nameplate
    - Make American Meter Co.
    - Model AC-250
    - S/N 03D459568
- Called iMAC at 800-955-4GAS and they told me that the meter outputs 10 pulses per revolution
- Still need to confirm the volume of gas per revolution of the AC-250 meter
- Did a manual transfer to grid at ~2:35 to avoid any unnecessary problems for Tweedie between now and Friday
- Pulled a stain tube of propane to send to Larry Osgood at the Propane Education and Research Council
- Saved stats file and system ID information from the fuel cell in preparation for the SARC upgrade planned for Friday
- Commanded fuel cell to power down ~3:03 PM
- Recorded Amp ratings on communications equipment to be certain that the circuit is not overloaded, resulting in breaker tripping
    - EnerNex Widget .1 A
    - Gaia Router .1 A
    - EnerNex Router .1A
    - VSR-30 VPN .5 A
    - UPS 12 A
        - Gaia Controller
        - Ethernet Switch .5 A
        - Modem 1.3 A
    - Data Node .2 A

  - Info Node .5 A
  - **Total** **13.5 A**

<u>07/01/2005</u>
Pasquale, Schneider, Reed

- Breaker trip research
  - Measured current on input/output of transformer for load control – no spikes
  - Inconclusive
- Found loose wire between controller relay and transfer switch – fixed
- Replaced power supply for Gaia controller to see if the resets will stop occurring with transfer switching events
- Added dedicated UPS for Gaia controller to reduce impact of switching events on the Gaia controller
- Removed ~15 feet from the length of the signal wires between the Gaia controller and the Power Tower
- Installed a manual bypass switch for Tweedie in case of future power problems in the house
  - Hardware only solution
  - Bypasses relay board on the controller
  - Holds transfer switch in exercise position
  - Holds 28 volts on the hot tub relay
- Tested manual bypass several times
  - During one test we had a possible reboot of the Gaia controller upon transfer action but possibly confounded by having hands in the controller hardware at the time of the test
  - Other tests worked fine
- Reed replaced the SARC on the fuel cell
- Powered up the fuel cell into manual mode just fine
- Modem still did not work
- Tried various things on the phone with Plug Power tech support
- Isolated the problem at the connector for the RJ-11 on the Power Distribution Board (PDB)
- Found if I pushed the connector up into the plug just right I got a good connection
- Successfully tested modem in both directions (call-in, call-out)
- Had Morawski from Plug Power set power output settings to 2 KW, 3 kW and 4kW because these settings were not available locally to me
- Upon completion of configuration by Plug I tried a startup sequence on the fuel cell
- E-stopped due to “lack of fuel”
- Upon E-stop, system called Plug and sent e-mail to me (at least comms are working)
- Per suggestion by Vinny at Plug Power, purged LPG line just before entry into fuel cell
- Ran fuel cell startup sequence again

- Fuel cell was running at ~5:40 PM
- Nick made a DB-9 connector for the ModBus connection to the EnerNex Widget using the following color scheme;

TxA(-)	Blue/White	Pin 8
TxB(+)	Blue	Pin 3
RcvA(-)	Green	Pin 2
Rcv B(+)	Brown/White	Pin 7
Signal Grounds	Green/White	Pin 6
Signal Grounds	Brown	Pin 4

- Called EnerNex to confirm ModBus connection
  - Erich confirmed that Comm1 is active but could not confirm commands because he didn't know the Plug Power commands
- Left EnerNex widget on EnerNex router
- Left stand-alone Data Node on Lan port of VPN through no-hub cable
- Nick left site ~4:30 PM
- Mark left site ~4:50 PM

07/06/2005
Schneider

- Arrived ~12:30 PM
- Moved all local network connections onto VPN connection
- Re-routed all cables and tied them down on communication rack
- Did not do anything with the fuel cell
- Left site ~5:30 PM

07/11/2005
Schneider

- When I arrived on site ~10:30 AM, one of the UPS's was beeping and showing the LED blinking on and off
- I plugged that UPS directly into the outlet just below the main panel and the beeping stopped
- I started the fuel cell and 10:40 AM.
- Fuel cell immediately failed due to inverter communications.
- Restarted the fuel cell ~10:50 AM
- I examined why the outdoor temp/humidity sensor is not working
  - Did not see any wiring problem
  - Contacted Jack at EnerNex by e-mail
  - Per Jack King, missing 125 Ohm, 1% resistors across input terminals
- Looked at ModBus connection problem
  - http://10.0.105.20/test-cgi/modbus-cgi.cgi?startreg=240&numregs=2

07/14/2005
Pietrantoni, Reed, Schneider

- arrived on site ~8:45 AM

- Installed new inverter on fuel cell
- Very hot/humid conditions
- Completed inverter change-out ~10:45 AM
- Noted that the new inverter is different model than the one we removed
- Started fuel cell into manual mode and saw immediately that we had bad inverter communications
- Wiggled the wires to RJ11 in inverter breaker panel
- Restarted after complete power down and the error was gone
- Saw low battery warning – realized that 2 breakers were off, so we corrected the problem and error went away

07/14/2005
Schneider
- Documented as-built
- Documented data logging equipment connections

Data Node	
V_A	L1 from Fuel Cell to Power Tower
V_B	L2 from Fuel Cell to Power Tower
V_C	Jumper L2 from Fuel Cell
V_N	Not Used
I_A	L1 input to Power Tower (either Fuel Cell or Grid, depending on operating state)
I_B	L2 input to Power Tower (either Fuel Cell or Grid, depending on operating state)
Eth	Ethernet connection to Ethernet switch
Dual Node	
V_A	L1 input to House Main Panel (also known as the output from the Transfer Switch, which can be fed by the Grid or the Power Tower depending on operating state)
V_B	L2 input to House Main Panel (also known as the output from the Transfer Switch, which can be fed by the Grid or the Power Tower depending on operating state)
V_C	Jumper L2
I_A	L1 input to House Main Panel
I_B	L2 input to House Main Panel
Comm1	To ADAM Module
Eth	Ethernet to Ethernet Switch
ADAM Module	
5017 Input Card V_0	Outdoor Temperature
5017 Input Card V_1	Outdoor Humidity
5080 Input Card C0A	LP Gas Pulse Counter Flow Meter
5080 Input Card C1A	Combined Heat and Power Loop Pulse Counter Flow Meter

5080 Input Card C2A	Outdoor Boiler Pulse Counter Flow Meter
5080 Input Card C3A	Reserved for Future Use (Oil Burner Pulse Counter)
5018 Input Card 0	Thermocouple Temperature in CHP Loop from Fuel Cell
5018 Input Card 1	Thermocouple Temperature in CHP Loop return to Fuel Cell
5018 Input Card 2	Thermocouple Temperature in Loop from Outdoor Boiler
5018 Input Card 3	Thermocouple Temperature in Loop return to Outdoor Boiler
RS232	Connected to Duel Node port Comm1

- Documented network connections
- An as-build sketch from 07/11/2005 is omitted from this Appendix, although the sketch is found in the original site log on file at DCEC
- Left site ~2:20 PM while fuel cell was still approaching full running state
- Left site in configuration to push all power generated by the fuel cell back on the DCEC distribution grid

07/19/2005
Schneider, Pietrantoni, Reed

- Investigated reason for shutdown status of fuel cell
- Downloaded all log files and sent to Plug Power
- Pietrantoni re-wired mod-bus connection as follows

TX+	Blue	Pin 3
TX-	Blue/White	Pin 8
RX-	Green	Pin 2
Rx+	Brown/White	Pin 7
Gnd	Green/White	Pins 4&6
V+5	Brown	Hooked to nothing

- Pietrantoni determined that a smaller solder gun is required
- Reed put 125 Ω resistors on ADAM 5017 module inputs 0 and 1 and shorted the remainder
- Left site ~11:05 AM

07/26/2005
Pietrantoni, Reed, Schneider

- Arrived on site ~9:30 AM
- Called Rob at Plug Power and got instructions as to how to proceed
- Power up Fuel Cell to manual mode
- Error message appeared as follows: Abort_DATA_Transfer Error Code 131
- Spoke to Dave at Plug Power tech support. Dave instructed us to check modem enabled, power down unit and restart to the manual mode. Once in the manual mode, unplug the computer from the fuel cell so that he can call into the fuel cell.

- Rob Lowen from Plug Power called and asked us to power down, remove plug B (2nd from the left) from the SARC for 10 to 15 seconds, then re-plug plug B into the SARC.
- Left fuel cell in a mode where Plug Power could work on it remotely over the modem connection.
- Pietrantoni re-wired mod-bus connection, eliminating the V+5 connection. No luck with this or other pin-outs.
- Left site ~12:30 PM

07/19/2005
Schneider

- Arrived on site ~7:30 AM
- Fuel cell LED indicator was lit and the fuel cell was throwing some heat.
- Plugged computer into the fuel cell local port and started the service software.
- Fuel cell was in full running mode (running/running/running) and there was an H_2 stoich alert.
- ~7:53 AM DC measured voltage at BT3 POS Sensor in battery compartment 24.9 V to grand and – terminal.
- ~7:57 measured load to neutral AC voltage of 126.3 V
- ~8:00 measured DC voltage out of stack in the range of 65.4 to 67.4 V with a steady voltage of 66.8 V DC after about 2 minutes of monitoring

07/29/2005
Schneider, Starheim (DCEC), Indera, Dave (Plug Power), Tweedie and son Alex (home owners)

- Arrived ~10:30 PM
- Took pictures of equipment and home owners, inside and outside the home
- Left site ~12:15 PM

08/01/2005
Schneider, Pietrantoni, Reed

- Arrived ~10 AM
- Removed old fuel cell stack and installed new stack
- Started fuel cell ~1:50 PM
- Left system in a state that Plug could call into it
- Left site ~2:30 PM

08/03/2005
Schneider

- Arrived ~6:30 AM
- Fuel cell power up but not running

- Connected PC to local port on fuel cell, started service software
- Issued startup command to fuel cell ~6:42 AM
- Left site ~6:55 AM

08/03/2005
Pietrantoni, Reed, Morawski (Plug Power)

- Morawski started the fuel cell to run some tests
- Morawski confirmed that the Inverter had the wrong set points when the new inverter was installed on 07/14/2005.
- Morawski changed out the inverter again with one he had brought with him from Plug and had the correct inverter settings in it.
- Morawski restarted the fuel cell , which went to running/running/running state ~11:30 AM
- Morawski ran some additional tests to confirm that it was the inverter causing our shutdown problems prior to today.
- Morawski, Reed, and Pietrantoni discussed the possibility of a 2.0 kW fuel cell output setpoint, but did not implement it yet.
- Left site with fuel cell in running/running/running state at ~12:30 PM

08/10/2005
Pietrantoni

- Confirmed that fuel cell is still running/running/running and providing power to the Power Tower
- Confirmed that Transfer Switch is in the “normal mode,” meaning that power is flowing through the Transfer Switch from the Power Tower to the House Main Panel.
- Pietrantoni installed plywood and insulation around the conduit entrance to the basement of the house and did some site clean up.
- Left the site ~9:30 AM

08/24/2005
Schneider, Pietrantoni

- Arrived ~1:00 PM
- Came to check fuel cell shutdown
- Upon our arrival, the fuel cell had restarted itself automatically and was in running/running/running mode.
- We contemplated connecting the fuel cell’s user interface panel to the fuel cell, but it can not be connected unless the fuel cell is in shut-down state and we did not want to shut the fuel cell down.
- Departed ~1:35 PM

08/30/2005

Schneider, Watkins (DCEC), Pasquale (Gaia), Morawski (Plug Power)

- Arrived ~11 AM
- ~11:23 AM, Nick opened the circuit breaker to the Power Tower AC grid input and 3 seconds later the Transfer Switch took an automated action to switch to the grid feed (away from the Power Tower feed)
- The fuel cell shut down due to loss of inverter communications
- Morawski restarted the fuel cell
- Performed tests
    - Test 1
      - while running the Power Tower from the grid and net metering from the fuel cell, increased power consumption on Power Tower AC2 from grid
      - saw that FC no longer needed to push as much power back to grid FC inverter voltage able to drop because no longer pushing as much current back to grid
      - had 2 burners on stove, a fan, and a bunch of lights on to create pulsating load
    - Test 2
      - closed cut-out between FC and Power Tower
      - at first, FC "passed thru" grid power from grid and provided whatever portion it could provide
      - FC ramped up to 4 kW and stayed there
      - Stack voltage improved by ~2 Volts due to re-hydration
      - When FC pushing small amount of power to grid, only small voltage rise
    - Test 3
      - Adjusted the temperature control on the hot tub to 100 degrees Exercised load controller manually
      - Checked FC for spike that might cut inverter out
      - Saw no problems
- Nick from Gaia
    - After bringing power in from the fuel cell, the new APC UPS for the Gaia controller was resetting. It was removed and the controller was hooked to the surge suppressor output of the original remaining UPS. (full transfer load-size tracking will be disabled while Gaia controller not on UPS)
- As of 2:36 PM, running FC as battery charger
    - Fuel cell outputting 2 kW
    - Power Tower taking in power on AC1 from FC
- Departed ~2:45 PM

09/13/2005
Schneider, Morawski (Plug Power)

- Arrived ~8:30 AM

- Morawski got ModBus connection working on fuel cell
- Departed ~11:30 AM

10/05/2005
Sackett, Pietrantoni
- Reset power to communications rack
- Checked propane level ~30%

10/10/2005
Schneider
- Arrived ~8:00 AM
- Powered down Gaia controller
- Waited 1 minute
- Power back up Gaia controller

10/31/2005
Schneider
- Checked on FC status, which was powered down upon Schneider's arrival
- Checked battery voltage of 30.5 Volts

11/02/2005
Reed, Pietrantoni, Schneider
- Charged upper 2 batteries in FC both to ~11.9 Volts
- Re-connected all batteries
- Pressed start on fuel cell ~10:44 AM
- FC entered manual mode ~10:50 AM
- Through service interface, issued command "grid charge"
- FC shut down due to low voltage
- Put charger on lower left battery and then realized we had connected the terminals backwards on one of the batteries so we reconnected the terminals correctly
- Started FC again
- Set modem answer to 1 ring to facilitate Plug Power dial-in to FC
- Called Plug tech support and had them dial in
- Left site ~ 11:50 AM

11/03/2005
Schneider
- Arrived ~9:15 AM
- Purge sample propane sample point downstream of propane meter, connect vacuum cylinder, open valve inlet on cylinder, sample for 2 minutes, close valve, remove cylinder

- Tape empty/dry plastic water bottle on sampling point, allow propane to purge the contents of the plastic bottle for a minute or two
- Take 2 stain tube samples from the plastic bottle
- Stain tube results:
    - 5 ppm
- Took cylinder back to office to prep for shipping
- Left site ~10:00 AM

11/14/2005
Reed, Pietrantoni
- Arrived ~9:00 AM
- Changed desulphurization bed and air filter on FC
- Left fuel cell in the off-state per Mark S.
- Departed ~10:30 AM

11/15/2005
Schneider
- Arrived ~9:30 AM
- Pressed FC start button to engage fans and SARC
- Left site ~10:15

11/16/2005
Schneider
- Arrived ~7:45 AM
- Used Mirabito gas leak detector
- Followed gas line into FC to desulf tank and out of desulf tank
- ~8:00 AM put unit into startup mode
- Set number of modem rings to 1
- Returned gas leak detector to Mirabito
- Came back to check on FC around 8:45 AM – startup sequence looking good
- Had one shutdown event during startup due to insufficient fuel purging desulf tank
- Vinny from Plug remotely restarted and everything went fine

11/22/2005
Schneider
- Arrived ~8:45 AM
- Pushed start button
- Plugged computer into serial port on FC
- Cleared PDC shutdown messages
- Commanded startup ~9:00 AM
- Checked dual node power quality equipment
    - Data node portion showing normal heartbeat on power LED
    - Info node portion showing fast heartbeat

11/16/2005
Schneider
- Arrived ~4:45 PM
- Put 1.5 kW heater in main FC compartment and ran extension cord to house power
- Power down FC
- Left site ~5:00 PM

11/30/2005
Reed, Sackett, Schmitz, Schneider
- Took apart desulf bed connections
- Cleaned connections
- Re-taped with Teflon
- Reconnected
- Found wear on gas line outlet from desulf tank (5 psi fuel gas pipe trac pipe) where rubbing against blower
- Taped with electrical tape to prevent further wear
- Powered up unit ~10:20 AM
- Set rings to 1 and put into startup
- ~11:20 AM FC shut itself down (error HW ESTOP TCO 01 PRE7 FG4 L1)

12/05/2005
Schneider, Pasquale (Gaia)
- Performed voltage drop tests on Power Tower

12/20/2005
Reed, Pietrantoni, Schneider
- Performed leak test with combustible gas detector and soapy water
- Unable to identify specific location of leak in reformer of FC

01/12/2006
Pietrantoni, Sackett, Schneider
- Arrived ~11:30 AM
- Replaced desulf tank
- Checked for split rings on top/bottom of desulf tank
- Used 2 crescent wrenches to tighten connections
- Noted that the tank, which we just received, was dented in multiple locations and scratched and that the lower tank handle on desulf tank was bent
- ~11:45 put FC in manual mode
- Manually opened solenoid 1 AB (fuel solenoid)
- FC E-stopped within 2 minutes of solenoid 1 AB being opened
- Put FC in manual mode again
- Soaped up junction points in fuel line
- Opened Solenoid 1 AB ~12:20 PM

- No bubbles in the soapy water
- Gas leak detector made some noise at the other end of the 6" hose connecting to the solenoid, but no bubbles indicating a leak
- Put FC in startup ~12:50 PM

01/17/2006
Reed, Pietrantoni, Morawski (Plug)
- Arrived ~9:00 AM
- Changed out desulf tank and rechecked connections
- Pietrantoni left site ~11 AM
- Morawski installed new software on FC
- Checked a few other items and started fuel cell
- Left site at 12:38 PM with the FC in startup mode with Plug tech support monitoring via modem

01/19/2006
Reed, Schneider
- Arrived on site ~2:30 PM
- Plugged space heater in to protect against freezing during shutdowns
- Noted FC was shut down
- Checked phone line at fuel cell with analog phone line by making phone a local phone call – phone line was fine
- Called Morawski at Plug – he dialed in and put FC into startup mode
- Left site ~3:00 PM

02/14/2006
Reed, Pietrantoni, Schneider, M. Simonds, D. Simonds
- Simonds ran hot tub ckt into 1st 200 Amp breaker panel and routed around the load control relays
- Ran new basement receptacles into main house panel empty breaker location
- Adjusted orientation on satellite dish such that modem reported signal strength at 73 from a prior value of 50
- Added small amount of therminol to FC coolant reservoir
- Connected laptop to serial port on FC
- Changed # modem rings to 1
- Called Rob at Plug Power and had him dial in
- Set fan voltage to 0.9 Volts
- Set low power output setting to 2 kW
- Changed # modem rings back to 8
- Chris and Ib from Gaia confirmed that load controls now routed around
- ~11:14 AM switched transfer switch out of manual over-ride to automatic mode using the toggle switch on the Gaia controller
- Noticed a noise coming from the hot water heat exchanger
- Switched back to manual over-ride
- Noticed that noise continued

- Switched one last time back to auto mode
- Confirmed that the hot tub was heating correctly

03/22/2006

Schneider, Todd (Gaia)

- Performed series of tests with step loads to analyze voltage dip (short term flicker) issue
- Used Picoscope 3000 (www.picotech.com) with M1053 differential probes
- With the power tower and transfer switch in manual bypass mode, AC1 (from FC) open, and AC2 (from grid) closed, performed experiment A to establish baseline voltage dip in the presence of large switching loads in home
    - Turned oven on 450 degrees F
    - Turned 2 large burners on stove top
    - Turned microwave on for 30 seconds and then off
    - Recorded 126.3 Volts max and 121.7 Volts minimum during experiment A monitoring AC2 input to Power Tower
- With the Power Tower and transfer switch still in manual bypass mode, AC1 closed, and AC2 closed, performed experiment B1
    - Oven set at 450 degrees F
    - Well pump kicked on and off
    - Recorded 121.8 Volts max and 118.3 Volts minimum during experiment B1 monitoring AC1 input to Power Tower
- With the Power Tower and transfer switch still in manual bypass mode, AC1 closed, and AC2 closed, performed experiment B2
    - Oven set at 450 degrees F
    - Turned 2 large burners on stove top
    - Turned microwave on for 30 seconds and then off
    - Recorded 121.8 Volts max and 116.4 Volts minimum during experiment B2 monitoring AC1 input to Power Tower
- Took Power Tower and transfer switch out of manual bypass mode and put it in auto mode
- Now transfer switch passing power from Power Tower to main house panel
- With the Power Tower and transfer switch in auto mode, AC1 closed, and AC2 closed, performed experiment C
    - Oven set at 450 degrees F
    - Turned 2 large burners on stove top
    - Turned microwave on for 30 seconds and then off
    - Recorded 122.6 Volts max and 112.9 Volts minimum during experiment C monitoring output of Power Tower
- With the Power Tower and transfer switch in auto mode, AC1 open, and AC2 closed and locked on, performed experiment D
    - Oven set at 450 degrees F
    - Turned 2 large burners on stove top
    - Turned microwave on for 30 seconds and then off
    - Recorded 126.1 Volts max and 120.3 Volts minimum during experiment D monitoring output of Power Tower

- Killed the grid input to everything on site
- With the Power Tower and transfer switch in auto mode, AC1 open, and AC2 unavailable, performed experiment E
    - Oven set at 450 degrees F
    - Turned 2 large burners on stove top
    - Turned microwave on for 30 seconds and then off
    - Recorded 120.1 Volts max and 112.3 Volts minimum during experiment E monitoring output of Power Tower
- To synchronize real-world time with the timestamps on the data recording equipment and the time stamp in the Gaia controller, a final 30-second cycle on the microwave was performed at 3:29 PM on Chris's cell phone
- ~4 PM met with home owner Randy Tweedie to look at light dimming symptoms
- Chris Todd was able to see the same symptoms as Tweedie
- Symptoms were most obvious when turning loads on and off
- Direct connected PC to FC and reset the setpoint to "2" before leaving
- Left site ~4:35 PM

03/28/2006
Reed, Pietrantoni, Schneider
- Replaced gas sensor and air sensor
- Restarted FC

04/27/2006
Schneider
- Connected PC to FC
- Completely powered down FC
- Re-powered FC
- Started Plug maintenance application on the PC
- Put unit in startup ~1:37 PM

05/02/2006
Remotely Ib and Edvin (Gaia)
- Late afternoon did a remote software upload and rebooted Gaia controller

05/10/2006
Reed, Pietrantoni, Schneider
- Powered down FC
- Replaced prox air solenoid
- ~2:05 PM powered up FC
- ~2:19 PM put FC into startup mode
- Visual inspection of all equipment in utility room of home
- New hot water heat exchanger controller has been installed by home owner's contractor

05/20/2006

Randy Tweedie (homeowner)

- Switched bypass switch so that main panel is directly grid-fed in response to power quality issues in home

05/25/2006
Schneider

- Cycled power on VPN router, in-house network router, and Gaia widget
- Called DCEC office and had Alain check the real-time data access to the site
- Real-time data is working fine after reboots of network equipment

06/07/2006
Reed

- Did a visual inspection of propane tank
- Tank gauge read 40% full
- Pressure gauge downstream of propane meter not functioning

06/08/2006
Reed

- Did a visual inspection of propane tank
- Tank gauge read 40% full
- Made no changes to valve positions
- Pressure gauge downstream of propane meter read ~12 inches of water

06/12/2006
Schneider

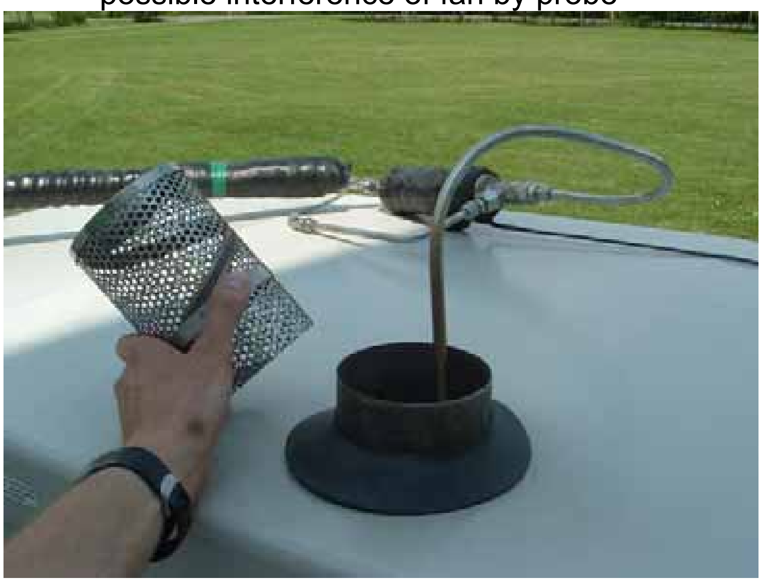
- Arrived ~4:35 PM
- Did a visual inspection of propane tank
- Tank gauge read 40% full
- Pressure gauge downstream of propane meter not functioning
- Closed T-valve to pressure gauge, removed gauge, blew into open feed to gauge causing needle to move
- Briefly opened T-valve to confirm positive pressure in fuel line and heard/smelled gas coming out of the opening where gauge is normally attached
- Re-attached gauge to propane piping, opened T-valve, and read 12.5 inches of water
- Put fuel cell into startup mode
- Startup seemed normal
- Left site ~5:00 PM

07/26/2006
Schneider, Dave (Eastmount Environmental)

- Arrived ~7:45 AM
- Ran 4 power cords to portable test lab

- Used stainless piping to create a probe for FC stack

- Powered on FC ~8:55 AM
- Checked comms with FC good
- Removed FC stack cover and inserted test probe into stack after checking for possible interference of fan by probe



- Checked for leaks, then vacuum in test line
- ~9:30 AM began calibration of test gear with calibration gases Dave brought with him
    - First ran gases directly into instrument
    - Then ran calibration gases through loop including the entire tube from the test probe back to the test lab

- Note that sketch of test lab calibration and test setup is available in the original site log, but it was not duplicated in this appendix in the interest of time
- Data was sampled every 2 seconds and averaged over 30 samples such that 1-minute averages are recorded in the electronic data log

- Started up FC at 10:07 (time per Schneider wrist watch, which is 2 minutes ahead of Eastmount system time of 10:05)
    - Sys state = reformer purge, FC state = ref scr warmup, Reformer state = drain LTS
- At ~10:08 AM, reformer state changed to DI fill
- Dave measured the inside diameter of the FC exhaust stack to be 4 inches and set up pito tube for flow measurements in the exhaust stream
- Discovered that a FC solenoid was freezing open that was preventing the fuel cell humidifier vessel from filling all the way
- Between 1:09 and 1:15 PM we removed the solenoid and capped off the tube so that the humidifier vessel could complete its fill operation

- ~1:30 PM the Reformer state changed to ATO flow
- ~1:31 PM the Reformer state changed to Purge state
- ~13:29 (Eastmount system time) on Dave's data we noted that the total hydrocarbons peaked above 100 ppm range, so Dave switched to the 1000 PPM scale. We may have lost 1 or 2 minutes of THC data in transition between 0-100 PPM range and 0-1000 PPM range.
- Between 1:40 and 1:45 PM took flow measurements in the stack
  - 87 degrees
  - 29 molecular weight assumed

- Validated flow measurement with separate S-type flow measurement device
- Stack temperature at 3:02 PM was 150 degrees F
- 3:21 auto shutdown and restart by FC
- ~3:23 PM manual shutdown by Schneider
- Dave re-ran system calibration
- Left site ~4:00 PM

07/27/2006
Pietrantoni, Schneider, Morawski (Plug)

- Arrived ~7:30 AM
- Powered up FC to get last event and stats logs
- Disconnected AC power at outdoor manual disconnect
- Morawski disconnected batteries
- Moved fuse to spare position
- Pietrantoni disconnected and partially drained the thermal protection for the water line
- Disconnected and partially drained the CHP loop
- Turned off propane at meter and tank
- Pietrantoni disconnected propane from FC
- Morawski removed catalyst, but it was still warm from running yesterday so he was a little worried about temperature

- Morawski removed the desulf tank
- Pietrantoni drained therminol
- Using boom truck, lifted FC to flat bed truck

- Also placed hazardous materials in two containers on flat bed truck in front of FC

Note that the original site log book continues beyond 07/27/2006 and covers on-site work related to data collection equipment, communications gear, and energy storage equipment involved in a companion project to the fuel cell project.

Appendix B – Fuel Cell Shutdown Log

The table in Appendix B is a summary of the shutdown events that the fuel cell experienced during the 1-year demonstration period starting with the first full startup event on June 2, 2005.

Shutdown Date	Description	Affected Subsystem	Next Full Startup*	Mitigation & Repair Notes
6/2/2005	Manual Shutdown	All	6/16/2005	N/A
6/16/2005	Manual Shutdown	All	6/21/2005	N/A
6/21/2005	FC_CONTACTOR_RETRY_TIMEOUT Low Cell Trip Alert Inverter Communications	Stack Health Processor	7/1/2005	Replaced main processor (SARC), purged fuel line
7/11/2005	Inverter Communications	Processor	7/11/2005	Auto Restart
7/14/2005	Manual Shutdown	All	7/14/2005	Replaced Inverter
7/15/2005	Inverter Related	Inverter	7/26/2005	Manual Restart
7/27/2005	TC10_ATO_1_LOW_SD,310	Anode Tail Gas Oxidation Module	7/27/2005	Auto Restart
7/28/2005	LOW_CELL_TRIPS_MAXED_SD,502	Stack Health	8/1/2005	Replaced stack
8/2/2005	TC10_ATO_1_LOW_SD,310	Anode Tail Gas Oxidation Module	8/2/2005	Auto Restart
8/2/2005	STACK_COOL_OUTLET_LOW_ALERT,236	Low Stack Temperature	8/3/2005	Replaced inverter (again)
8/24/2005	O2_CH4_HIGH_SD,512	Reformer	8/24/2005	Auto Restart
10/26/2005	STACK_COOL_INLET_LOW_SD, 240	Low Stack Temperature	10/26/2005	Auto Restart
11/2/2005	HW_ESTOP_FG1_L5, 531	Hardware E-stop	11/2/2005	Charge Batteries and correct battery breaker position

Shutdown Date	Description	Affected Subsystem	Next Full Startup*	Mitigation & Repair Notes
11/14/2005	Manual Shutdown for desulf tank change-out and air filter replacement	All	1/19/2006	Multiple propane leak tests, replaced desulf tank, Plug installed new software
1/20/2006	O2_CH4_HIGH_SD, 512	Reformer	1/20/2006	Auto Restart
2/17/2006	O2_CH4_HIGH_SD, 512	Reformer	2/17/2006	Auto Restart
2/28/2006	STACK_COOL_INLET_LOW_SD, 240	Low Stack Temperature	2/28/2006	Auto Restart
3/28/2006	HW_ESTOP_SARC_L0, 534	Hardware E-stop	3/28/2006	Replaced gas sensor and air sensor
4/20/2006	O2_CH4_HIGH_SD, 512	Reformer	4/20/2006	Auto Restart
4/27/2006	HW_ESTOP_SARC_L0, 534	Hardware E-stop	4/27/2006	Manual Restart
5/3/2006	O2_CH4_HIGH_SD, 512	Reformer	5/3/2006	Auto Restart
5/10/2006	HW_ESTOP_SARC_L0, 534	Hardware E-stop	5/10/2006	Replaced Prox air solenoid
6/5/2006	O2_CH4_HIGH_SD, 512	Reformer	6/12/2006	Manual Restart
7/5/2006	HW_ESTOP_SARC_L0, 534	Hardware E-stop	N/A	N/A

*The term "full startup" is used to indicate that the system, fuel cell, and reformer are all in their running states. It was not uncommon for the fuel cell to abort a startup attempt and either auto-restart or require a manual restart. The shutdown events in this table are those shutdown events that follow a full startup. If a startup event was not fully successful, that startup event is not shown in this Appendix.

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