Energy Research and Development Division
FINAL PROJECT REPORT

DEMONSTRATION OF COMBINED HEAT AND POWER TECHNOLOGY AT A DATA CENTER

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PREFACE

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ABSTRACT

An innovative combined heat and power (CHP) system was demonstrated at a data center in California. The CHP technology that was demonstrated is the Hybrid UPS system, which was recently introduced by Capstone Turbine Corporation. This technology is based on commercially available Capstone microturbine technology that has been utilized in many applications in California and throughout the world. For this demonstration project, the Hybrid UPS technology was configured for CHP operation using a Thermax absorption chiller.

Compared to a conventional uninterruptible power supply (UPS), the results of this demonstration showed that a CHP Hybrid UPS system could reduce annual costs by 20 to 44 percent depending on the operating schedule and prevailing utility rates. These cost savings are achieved with the CHP Hybrid UPS system while continuing to meet data center power reliability requirements.

Keywords: Combined heat and power, distributed generation, microturbine, absorption chiller, data center, uninterruptible power supply

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EXECUTIVE SUMMARY

Introduction

Data centers consume an estimated 2 percent of all electricity in California. These facilities have a high demand for electricity to power servers and to drive air conditioning equipment required to cool critical computing assets. The population of data centers continues to grow, putting additional stress on the electric grid. While progress has been achieved in reducing the energy intensity of data centers, there remains a large potential to reduce both electricity consumption and electric demand in these facilities.

One option for reducing electricity consumption and electric demand at data centers is to utilize combined heat and power (CHP). CHP is well suited for data centers because these facilities have a high electric demand and a high coincident cooling demand. Electricity from a CHP system can be used on site, and thermal energy can be recovered in a CHP system with an absorption chiller to produce chilled water for space cooling. CHP is a more efficient alternative for generating electricity and chilled water compared to utilizing grid electricity, thereby reducing electricity consumption.

While the energy efficiency benefits of CHP are well matched to data center needs, the adoption of CHP has been slow for data centers and other critical load facilities. One barrier to CHP is the relatively high capital cost. In a critical load facility, such as a data center, there is an opportunity to mitigate CHP capital costs by using a CHP system to replace or augment conventional uninterruptible power supply (UPS) hardware. All data centers are designed with a UPS system to provide power in the event of a grid outage. A conventional data center UPS system, which typically includes power electronics and batteries integrated with one or more emergency backup generators, can cost several million dollars. CHP, if designed properly, can offset the cost of a conventional UPS system and provide energy efficiency benefits.

Purpose

The purpose of this project was to demonstrate an innovative Hybrid CHP/UPS technology that was recently introduced by Capstone Turbine Corporation. This technology is based on commercially available Capstone microturbine technology that has been deployed in a wide range of applications in California and throughout the world. For this demonstration project, the pre-existing UPS technology was reconfigured for hybrid CHP operation using a Thermax absorption chiller. The following performance goals were established:

- Increase energy efficiency – Demonstrate overall efficiency of 59-66 percent (lower heating value basis for natural gas fuel)
- Generate on-site electricity – Produce 174 kW of net electric power
- Deliver chilled water – Produce 77 tons of cooling capacity
- Avoid NOx emissions – Reduce NOx emissions by 80 percent compared to grid electricity

- Reduce energy costs – Show a reduction of 18- 41 percent in energy costs depending on CHP operating schedule

Process

Southern California Gas Company owns and operates a data center in Monterey Park, California, and this site was selected for the demonstration. Regatta Solutions is a distributor for Capstone products, and Regatta, Capstone, and Thermax designed a CHP Hybrid UPS system using three microturbines and one Thermax absorption chiller to meet partial load requirements for the Monterey Park data center. Regatta served as the general contractor, and installed the hardware. The CHP Hybrid UPS system was commissioned in 2014, and measurement and verification data was collected over a six month period from August 2014 through January 2015.

Results

Demonstration results are summarized in **Table 1**. The CHP Hybrid UPS system showed lower electric output, chilled water production, and overall efficiency compared to the goals. While these technical performance characteristics did not meet the goals, the CHP Hybrid UPS system did save a significant amount of electricity for the Monterey Park data center, and these energy savings are reflected in the energy cost results that are shown in **Table 1**. As indicated, energy costs were reduced by 20- 44 percent depending on the operating scheduled for the CHP Hybrid UPS system. The energy cost results were positively impacted by changes in utility rates that occurred between project initiation in 2012 and project conclusion in 2015. During this time period, gas rates decreased and electricity rates increased, thereby improving the economics of the CHP Hybrid UPS system.

Table 1: Performance Results

Metric	Goal	Result	Comparison to Goal [1]
CHP Efficiency	66% [2]	52%	-22%
	59% [3]	57%	-5%
Electric Power	174 kW	155 kW	-11%
Chilled Water	77 tons	55 tons	-29%
NOx Emissions	Reduce by 80%	66%	-18%
Energy Costs	Reduce by 18% (continuous operation – 24 hrs./day)	20%	+13%
	Reduce by 41% (mid-peak and on-peak)	44%	+8%

Notes:
Differences may occur due to rounding.
Based on electric power and chilled water production.
Based on electric power and thermal energy extracted from microturbine exhaust stream.

As demonstrated, the CHP Hybrid UPS system reduced NOx emissions by 66 percent compared to NOx emissions associated with the consumption of grid electricity. The goal for reducing NOx emissions was set at 80 percent based on grid emission characteristics available in 2012 when the project was initiated. The actual reduction in NOx emissions was calculated based on grid emission characteristics available in 2015. Between 2012 and 2015, NOx emissions from the grid were reduced, and this change is the primary factor that contributed to a lower NOx emission result (66%) compared to the goal (80%).

Benefits to California

There are an estimated 1,200 data centers in California that collectively consume 5.2 billion kWh of electricity each year. A conservative market impact projection was developed based on the adoption of 50 CHP Hybrid UPS systems, each with a capacity of 500 kW (electric power plus cooling). The impact of installing 50 CHP Hybrid UPS systems is estimated to save California data centers nearly 98,000 MWh of electricity each year and reduce electric demand by 25 MW. At 15.3 ¢/kWh, the CHP Hybrid UPS technology will help these data centers collectively save $15 million each year.

In addition to helping data center owners and operators reduce energy costs, the CHP Hybrid UPS technology also provides benefits to California ratepayers. Reduced consumption of grid electricity avoids NOx emissions and other criteria pollutants, which provides environmental benefits for all residents in California.

CHAPTER 1: Introduction

A combined heat and power (CHP) system was demonstrated at a data center owned and operated by Southern California Gas Company (SoCalGas). The CHP system was designed with Capstone Hybrid Uninterruptible Power Supply (Hybrid UPS) microturbine technology integrated with a Thermax absorption chiller. The Hybrid UPS technology is intended to provide highly reliable electric power to meet the uninterruptible power needs of data centers and other critical load facilities. Compared to conventional data center UPS systems, which are based on power electronics and batteries with emergency generators (often diesel powered), the Hybrid UPS technology offers the following potential benefits:

- Reduced capital expenditure for UPS hardware (newly constructed critical power needs)
- Reduced energy costs (new application or retrofit)
- Reduced utility electric load (new application or retrofit)

This chapter provides an overview of the project, and is organized as follows:

- Motivation for project
- Goals
- Team
- Status

1.1 Motivation for Project

Studies suggest that data centers consume 1.6 to 2.2 percent of electricity used in the United States.[1, 2] Using a rounded value of 2 percent, data centers in California consumed 5.2 billion kWh of electricity in 2013 (total California electricity consumption of 262 billion kWh in 2013).[3] Between 2005 and 2010, data center electricity use in the United States increased by 36 percent.[4] This high growth rate contributes to stress on the electric grid, which can lead to higher electricity costs and/or reduced grid reliability.

Data centers have a high demand for electricity to power servers and to drive air conditioning equipment required to cool critical computing assets. While progress has been achieved in

[1] J. Koomey, 2011, Growth in Data Center Electricity Use 2005 to 2010, www.analyticspress.com/datacenters.html .
[2] E. Masanet et al., 2011, Estimating the Energy Use and Efficiency Potential of U.S. Data Centers, Proceedings of the IEEE, vol. 99, no. 8, web link.
[3] U.S. Energy Information Administration, 2013, Electricity Data Browser, http://www.eia.gov/electricity/data/browser/
[4] J. Koomey, 2011, Growth in Data Center Electricity Use 2005 to 2010.

reducing the energy intensity of data centers, there remains a large potential to reduce both electricity consumption and electric demand in these facilities.

One option for reducing electricity consumption and electric demand at data centers is to utilize combined heat and power (CHP). CHP is well suited for data centers because these facilities have a high electric demand and a high coincident cooling demand, which can be satisfied with an exhaust-driven absorption chiller. CHP is a more efficient alternative for generating electricity and chilled water compared to utilizing grid electricity, thereby reducing electricity consumption and electric demand.

While the energy efficiency benefits of CHP are well matched to data center needs, the adoption of CHP has been slow for data centers and other critical load facilities described.[5, 6] One barrier to CHP is the relatively high capital cost. In a critical load facility, such as a data center, there is an opportunity to reduce the impact of CHP capital cost by using a CHP system to replace or augment conventional uninterruptible power supply (UPS) hardware.

Capstone recognized that CHP systems could offer additional benefits to data centers if CHP systems could be designed as an alternative to conventional UPS hardware. In response to this need, Capstone launched the Hybrid UPS product to provide data centers with all of the benefits associated with CHP technology plus the added benefit of avoiding the cost of installing or replacing conventional UPS hardware.

Unlike a conventional UPS system that is only called upon during a grid outage, the Hybrid UPS CHP technology is capable of operating on a continuous basis to provide electricity heating and/or space cooling. In the event of a grid outage, the Hybrid UPS functions like a conventional UPS system, and immediately provides seamless power to critical circuits.

A conventional data center UPS system consists of power electronics and batteries with one or more emergency backup generators.[7] Batteries provide seamless power to the critical load in the event of an unplanned electric grid outage. This allows for emergency backup generators to start and carry the load for any extended outage.

The cost of a conventional UPS system varies widely between data centers depending on the required electrical power capacity, specific hardware, and complexity of the control strategy. While the UPS function is vital, the cost of a conventional UPS system is high given that most UPS systems are only needed to back up the grid for a few hours each year.[8]

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[5] U.S. Environmental Protection Agency, Combined Heat and Power Partnership, *Combined Heat and Power – Energy Savings and Energy Reliability for Data Centers*, web link, accessed January 2015.

[6] Capstone Turbine Corporation, *Combined Heat and Power Use in Data Centers*, web link, accessed January 2015.

[7] A common backup generator is a diesel engine integrated with an electric generator.

[8] In 2013, customers in Southern California Edison's service territory were without power for an average of 1.6 hours (94.5 minutes), 2013 Corporate Responsibility Report, p9, web link, accessed January 2015.

1.2 Goals

The purpose of this project was to demonstrate the benefits of a Hybrid UPS technology at a data center in Monterey Park, California. Prior to this demonstration project, the Hybrid UPS technology had only been installed at one data center in New York.[9]

For this demonstration project, the Hybrid UPS technology was configured for CHP operation using a Thermax absorption chiller. Specifications for the CHP Hybrid UPS system are shown in **Table 2**.

Table 2: Major CHP Hardware

System	Manufacturer	Description	Capacity Goal
Microturbine	Capstone	Hybrid UPS product based on natural gas-fired C65 microturbine	3 microturbines with net electrical output of 174 kW
Absorption chiller	Thermax	Double effect, exhaust-fired	1 chiller with capacity to produce 77 tons of chilled water using microturbine exhaust

In the proposal prepared for this project, four performance goals were established for the CHP Hybrid UPS system (see **Table 3)**. The overall efficiency goal was set at 66 percent based on the lower heating value (LHV) of natural gas. In **Table 3**, overall efficiency represents the percentage of energy input (natural gas) that is converted to useful energy output (electricity and chilled water). The electric demand reduction in **Table 3** (247 kW) includes both the electricity produced by the CHP Hybrid UPS system and the offset electricity that results from displacing chilled water normally produced with an electric chiller with chilled water from the CHP Hybrid UPS system.

Table 3: Performance Goals in Proposal

Metric	Goal
CHP Efficiency	66% (LHV basis)
Electric demand reduction	247 kW
NOx reduction	80%
Energy cost reduction	18% to 41% (depending on operating mode)

For the analysis presented in this final report the overall efficiency and electric demand goals were expanded to separate the impacts of the absorption chiller. These expanded goals are shown in **Table 4**. As indicated, the overall CHP efficiency was divided into two efficiency metrics – one based on the chilled water output and the other based on the amount of thermal energy extracted from the microturbine exhaust. The electric demand reduction was also divided into two separate metrics – one based on the amount of electricity produced from the

[9] Capstone Turbine Corporation, *Syracuse University Green Data Center,* web link, accessed January 2015.

microturbines and the other based on the amount of chilled water produced from the absorption chiller.

Table 4: Performance Goals for Project

Metric	Goal	Basis
CHP Efficiency	66%	Electric power plus chilled water production
	59%	Electric power plus thermal energy extracted in chiller
Electric Power	174 kW	Net electric power
Chilled Water	77 tons	---
NOx Emissions	Reduce by 80%	Comparison to grid
Energy Costs	Reduce by 18%	Continuous operation [1]
	Reduce by 41%	Mid-peak and on-peak operation [2]

Notes:
Continuous operation corresponds to 8,760 hrs/yr (24 hrs/day).
Mid-peak and on-peak operation correspond to the time periods used in the electric tariff that applies to the Monterey Park data center. These time periods result in 3,915 hrs/yr of operation.

1.3 Team

This demonstration project was sponsored by the California Energy Commission (CEC) with Public Interest Energy Research (PIER) funding. SoCalGas provided co-funding and provided the Monterey Park demonstration site. The project team, along with primary responsibilities, is shown in **Table 5**.

Table 5: Project Team

Team Member	Role
ICF	Prime contractor; project management; technical analysis
SoCalGas	Data center host site (Monterey Park, CA); technical guidance; co-funding
Capstone	Microturbine manufacturer; integration of microturbines and absorption chiller (with Thermax)
Thermax	Chiller manufacturer; integration of absorption chiller and microturbines (with Capstone)
Regatta	Capstone distributor; general contractor; installation and commissioning
DE Solutions	Measurement and verification
IBM Global Financing	Lease financing
Local subcontractors	Budlong & Associates (mechanical and electrical engineering); Nova Controls (electrical integration design and consulting)

1.4 Status

This project commenced in 2012, and the CHP Hybrid UPS system was commissioned in 2014. Performance data was collected between August 2014 and January 2015, and this set of performance data was used as the basis for developing the results discussed in this final report.

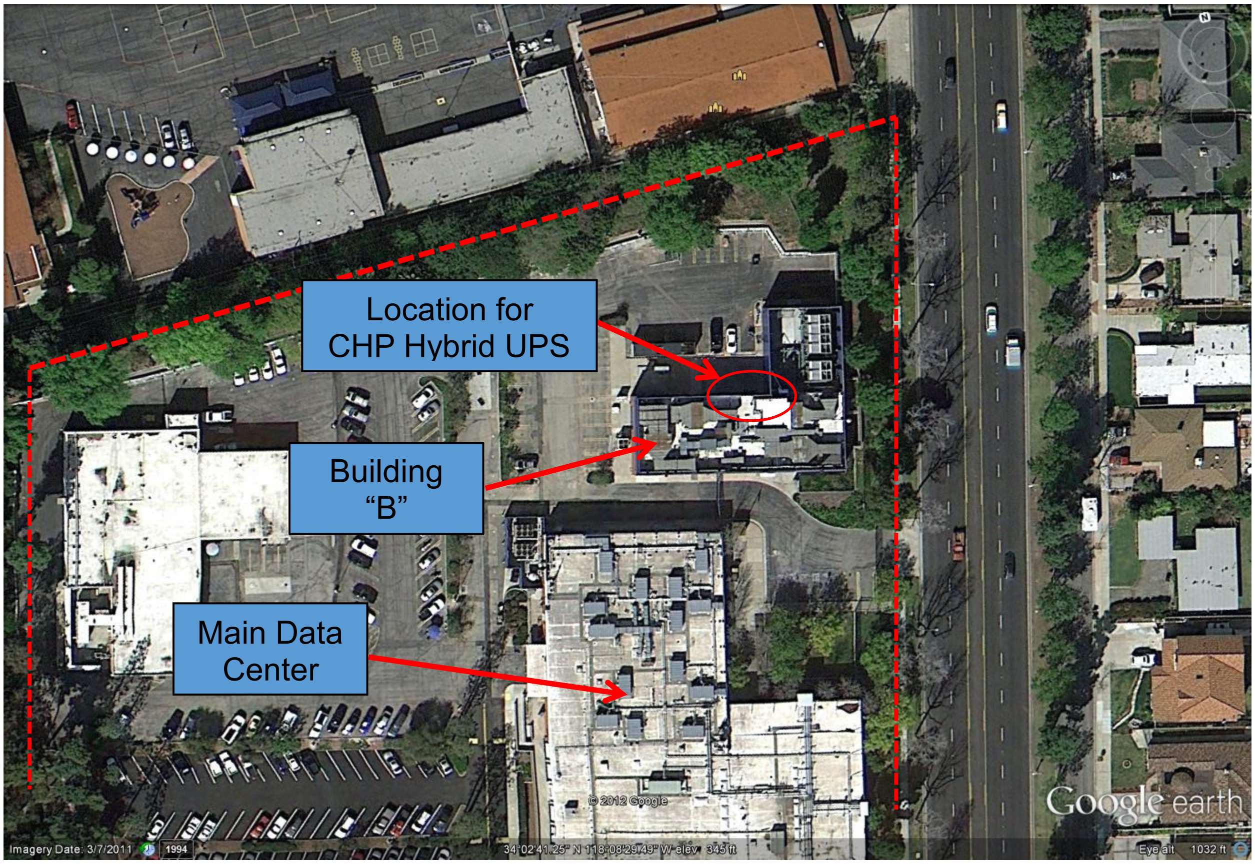
Each microturbine installed at the Monterey Park data center was permitted by the South Coast Air Quality Management District (SCAQMD) to operate with a NOx emission limit of 9 ppm and a CO emission limit of 10 ppm.[10] In January 2015, the three microturbines were tested for compliance. All three microturbines satisfied the NOx limit, with recorded values of 3-4 ppm. However, one unit measured 14 ppm CO, exceeding the 10 ppm limit. This microturbine was taken out of service in January 2015. As of February 2015, Capstone was planning to repair this microturbine with the expectation that it would be returned to service in compliance with the SCAQMD air quality permit. As of February 2015, the CHP Hybrid UPS system continued to operate with two microturbines, producing electricity and chilled water.

[10] Emission limits are based on 15% oxygen.

CHAPTER 2:
Data Center Demonstration Site

The demonstration site is a data center owned and operated by SoCalGas. **Figure 1** shows an aerial view of the data center campus, which is located in Monterey Park, California. This aerial view shows the site prior to installing the CHP Hybrid UPS system.

Figure 1: Aerial View of Data Center in Monterey Park, California



Source: Google Earth

2.1 Physical Description

Building "B," which is adjacent to the main data center building, contains mechanical equipment (e.g., chillers and cooling towers) that provides space cooling for the data center. Building "B" also contains two battery strings – one Liebert and one Mitsubishi – that are used for UPS purposes. Near Building "B" there are two 2 MW diesel emergency generators. These generators and the Liebert and Mitsubishi battery strings function as a conventional UPS system.

The CHP Hybrid UPS system, which is described in more detail in Chapter 3, was installed at the Building "B" location. Three Capstone microturbines were installed in an exterior location adjacent to Building "B", and a Thermax absorption chiller was installed inside Building "B." A photograph of the installed microturbines is shown in **Figure 2**. The Thermax absorption chiller is located on the other side of the wall (behind the exhaust manifold shown in **Figure 2**).

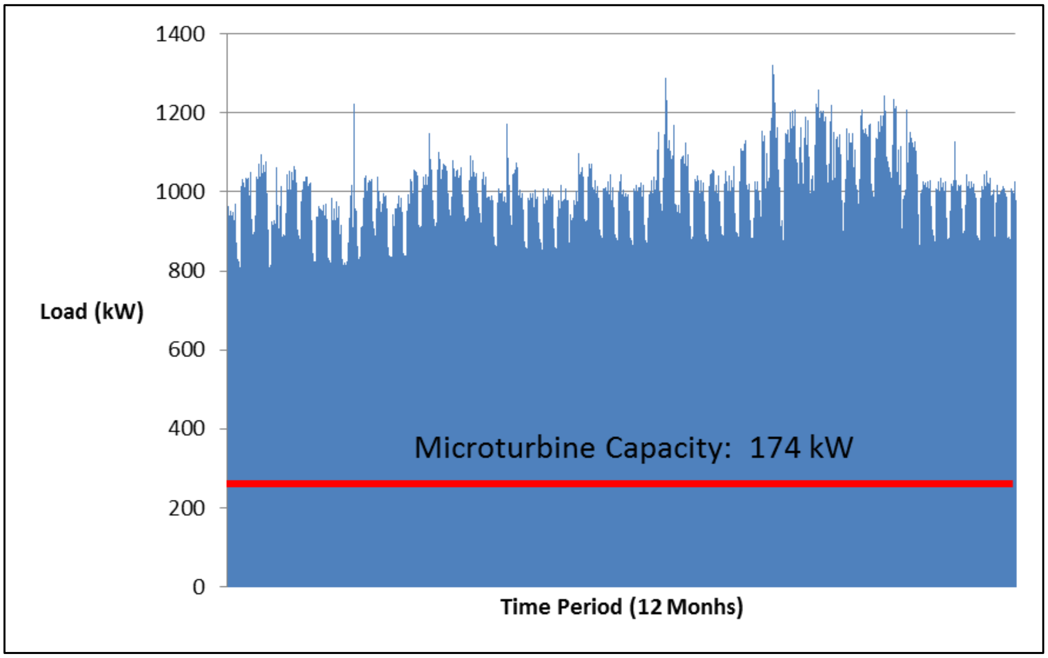
Figure 2: Capstone Microturbines at Monterey Park Data Center

Source: Regatta

2.2 Energy Loads

Figure 3 shows the data center electricity consumption over a 12 month time period. This chart also shows the full load electricity production expected from the CHP Hybrid UPS system. As indicated, the CHP Hybrid UPS system was designed to produce a maximum power output of 174 kW, which is below the facility load of 800 to 1,000 kW. With this design, all of the electricity from the CHP Hybrid UPS system is expected to be used on-site, and no electricity is expected to be exported to the grid.

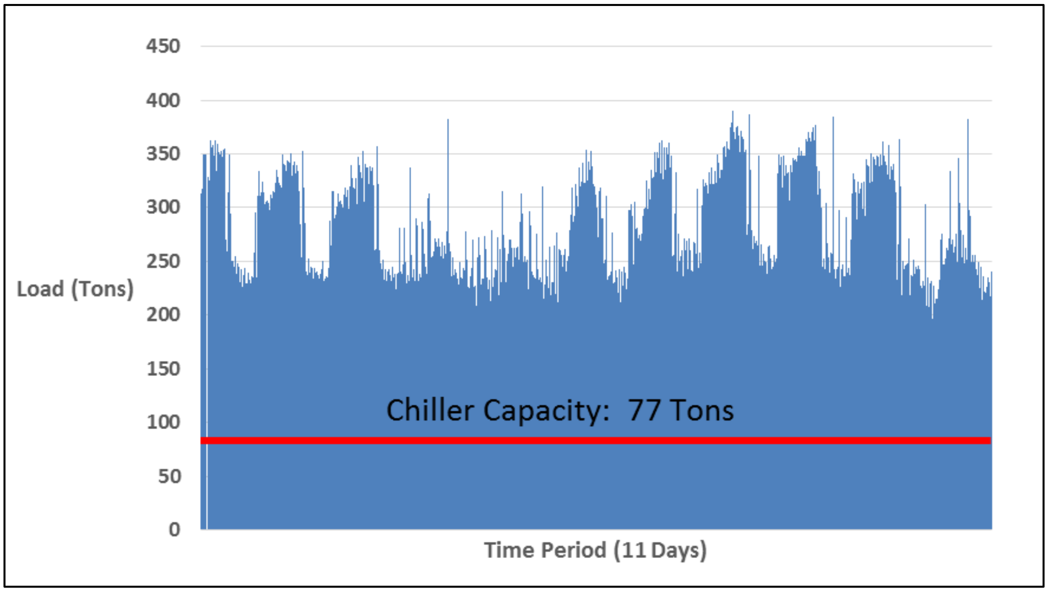
Figure 3: Electric Demand (November 1, 2011 – October 31, 2012)



Source: ICF

Figure 4 shows the facility's chilled water demand for an eleven day period in August, 2012. As indicated, the facility has a chilled water requirement of 250 to 350 tons. The CHP Hybrid UPS system was designed to satisfy a portion of this load (77 tons). With this design, it is expected that the chilled water produced from the CHP Hybrid UPS system will be fully utilized at all times.

Figure 4: Chilled Water Demand (August 22 – September 1, 2012)



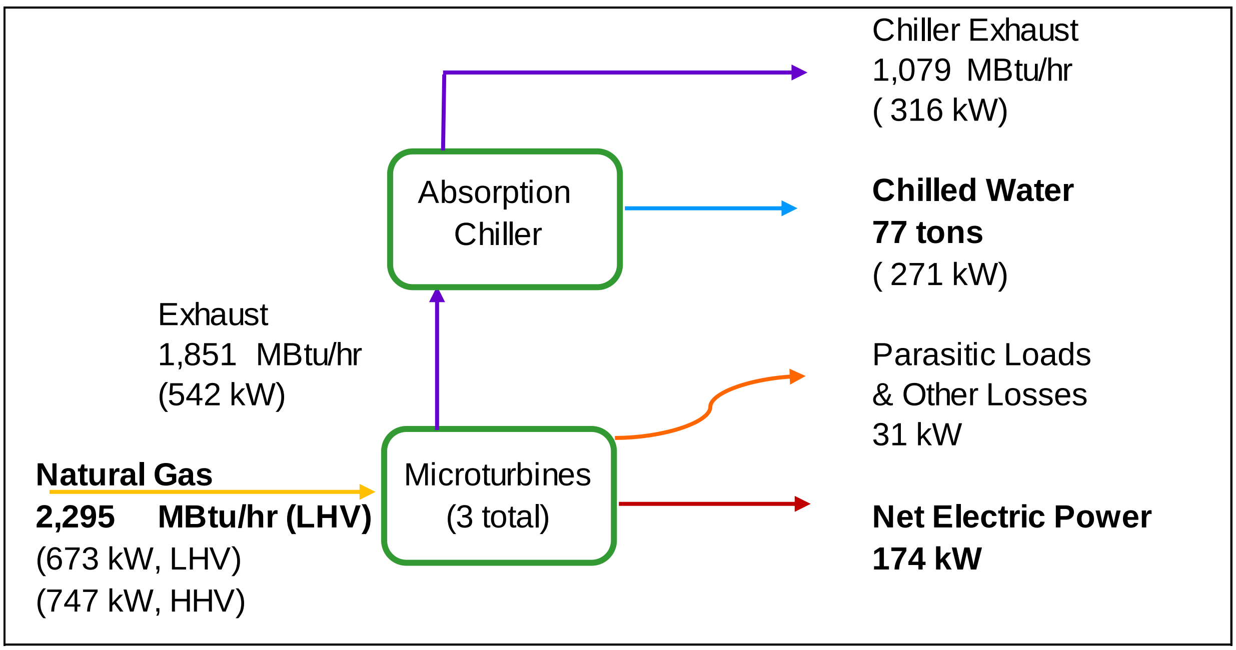
Source: ICF

CHAPTER 3:
CHP System Design

3.1 Conceptual Design

Figure 5 shows an energy balance for the conceptual design of the CHP Hybrid UPS system. The performance shown in this figure is based on the nominal specifications for the Capstone microturbines and the Thermax absorption chiller. **Appendix A** provides details of how these performance estimates were calculated. Based on this conceptual design, the three microturbines consume 2.3 MMBtu/hr of natural gas (LHV), and produce 174 kW of net electric power along with 77 tons of chilled water.

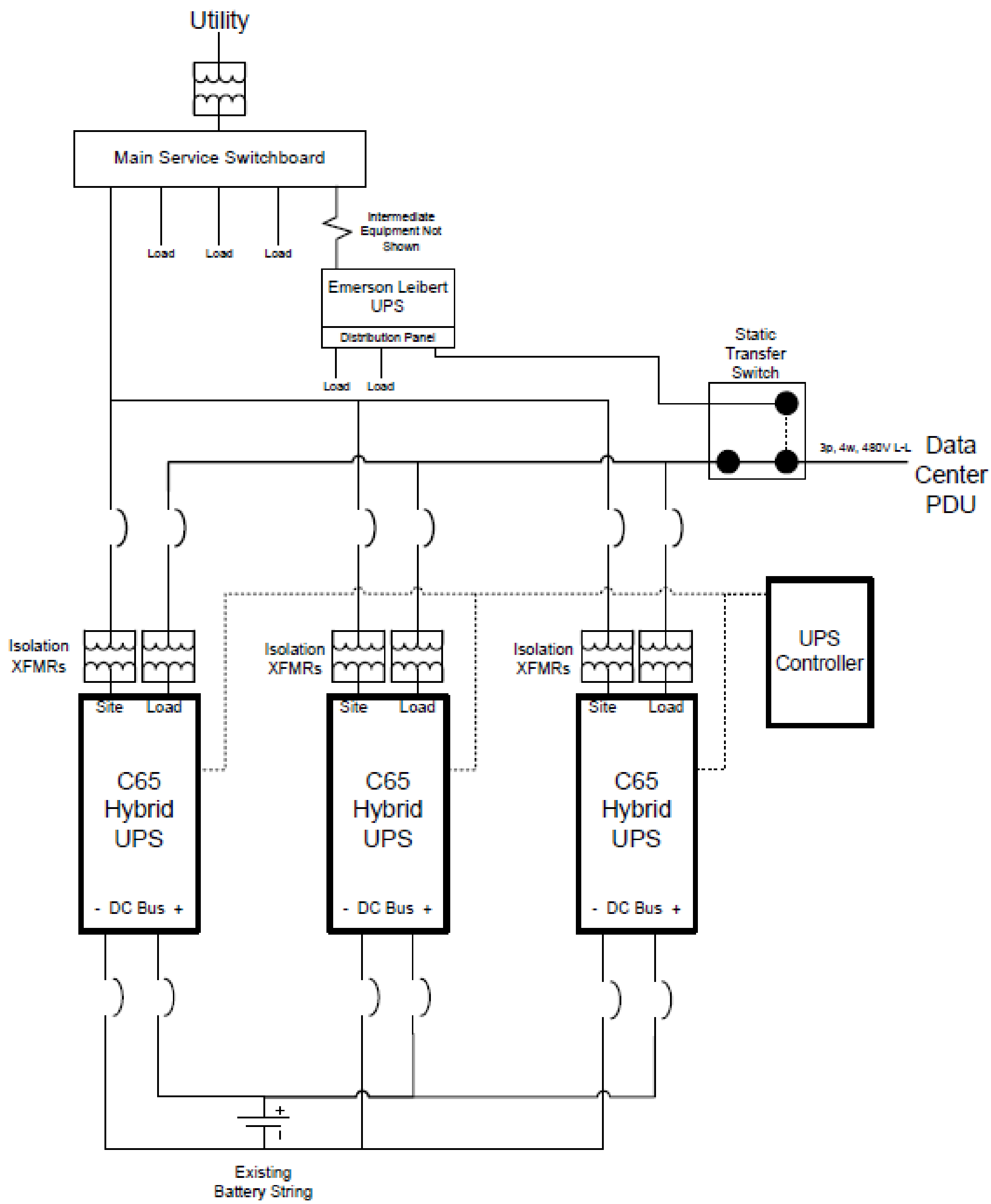
Figure 5: Energy Balance for CHP Hybrid UPS System



Source: ICF

Figure 6 shows the electrical plan for integrating the CHP Hybrid UPS system into the Monterey Park data center. In this design, the three microturbines provide power to a dedicated critical load through a static transfer switch (STS). The STS is also backed up by the pre-existing conventional UPS system, which consists of Liebert and Mitsubishi battery strings and 4 MW of diesel emergency generator capacity (diesel generators not shown in figure).

Figure 6: Single Line Electrical Diagram for Hybrid UPS at Monterey Park Data Center



Source: Capstone

A critical load with a maximum electrical demand less than the output of two microturbines was selected for connection to the Hybrid UPS. In this design, the critical load can be satisfied by any two of the three microturbines, thereby providing "n+1" redundancy should one of the microturbines not operate as expected during an electric grid outage. In addition to "n+1" redundancy from the Hybrid UPS, the critical load can be supplied from the second STS or the conventional UPS if required.

The Hybrid UPS system is designed to operate in three modes as summarized in **Table 6** (additional details in **Appendix B**). In the "standard UPS" mode, the Hybrid UPS system functions exactly like a conventional UPS system. The microturbines are off and are energized in the event of a grid outage. A battery string seamlessly supports the critical load until the microturbines are online. In the "high efficiency" mode, the CHP Hybrid UPS system operates like a typical CHP system, providing electricity and chilled water. The third operating mode is "emergency backup." The Hybrid UPS system switches to emergency backup immediately upon detecting a grid outage. If the microturbines are not running at the time a grid outage is detected (i.e., standard UPS mode) batteries carry the load while the microturbines are started and brought into service (startup time from an off condition to full load requires approximately 2 minutes).

Table 6: Hybrid UPS Operating Modes

Operating Mode	Electric Grid Condition	Microturbine Condition
Standard UPS	Normal	Off
High Efficiency	Normal	On
Emergency Backup	Out	On

For the Monterey Park data center, the Hybrid UPS system is expected to be operated in the high efficiency mode. This operating approach provides the maximum economic benefit for this site.

3.2 Performance Modeling Results

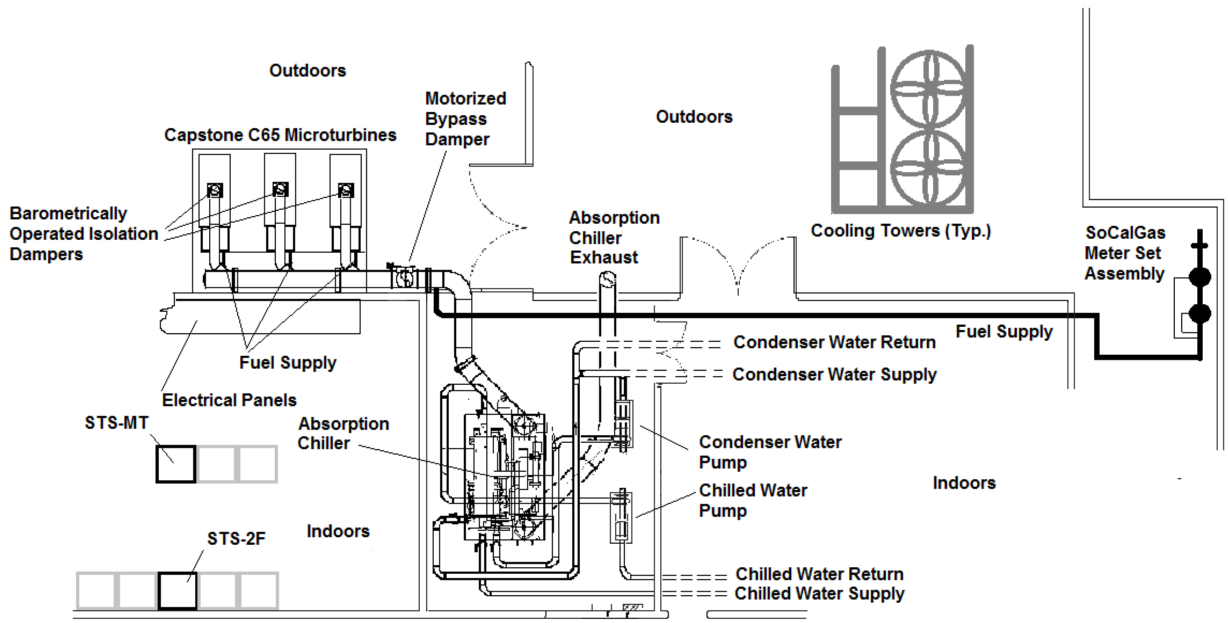
A modeling analysis was completed to assess the expected performance of the CHP Hybrid UPS system over a 12-month time period. The results of the performance modeling differed somewhat from the conceptual design described in Section 3.1. The conceptual design was developed during the proposal phase of this project and was based on ISO conditions.[11] The performance modeling was based on expected atmospheric conditions over a 12-month time period and included expected benefits of offsetting energy losses from a traditional UPS system. For the performance modeling, the turbine inlet temperatures tended to be higher than ISO conditions, which led to slightly lower performances for the microturbines, and to improved performance for the absorption chiller. In general, microturbine performance is better (i.e., more power output) on cold days and absorption chiller performance is better (i.e., more chilled water output) on hot days.

[11] International Standards Organization (ISO) conditions are 59 ^{o}F, 14.7 psia, and 60% relative humidity.

3.3 System Design

Figure 7 shows a plan view of the installation (a scaled site plan is included in **Appendix C**). The outdoor components are shown in the upper portion of the diagram, and the indoor components in the lower portion. The natural gas flows from the SoCalGas meter set assembly (far right) to the three microturbines (upper left). Barometrically operated dampers are used to close the exhaust duct when an individual microturbine is not running. The motorized bypass damper is used to divert the microturbine exhaust flow to an exhaust stack if the absorption chiller needs to be taken out of service. The duct carries hot exhaust gas from the microturbines to the absorption chiller and then to the exhaust stack. The location of the static transfer switch bank is indicated in the lower left of the figure, and the location of the cooling towers is indicated in the upper right.

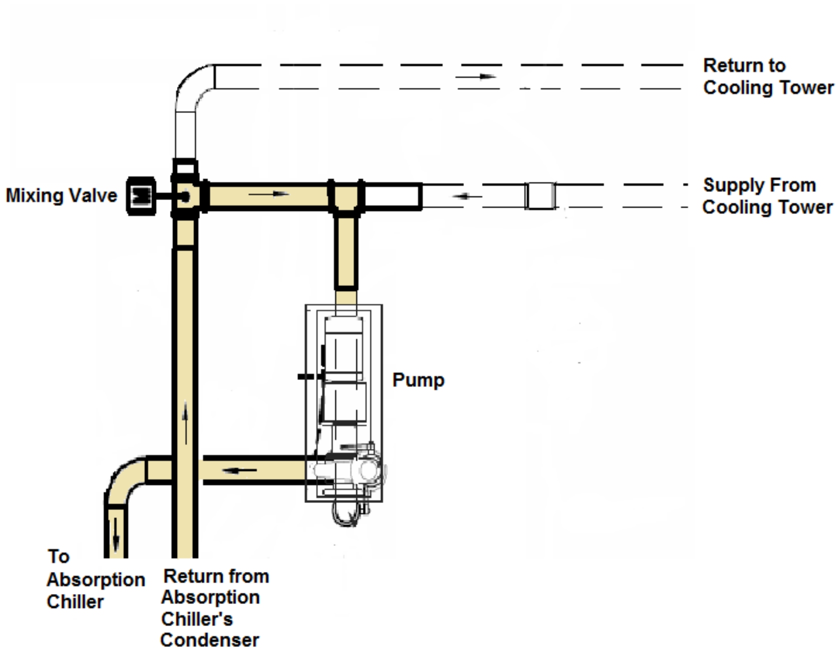
Figure 7: Site Plan



Source: ICF

One design challenge that was encountered was control of the cooling water supplied to the Thermax absorption chiller. The cooling towers provide 70°F water, which is the desired temperature for the existing electric chillers at the Monterey Park data center. The optimal temperature for the cooling water supplied to the absorption chiller, however, is 85 °F. This problem was solved by installing a mixing valve that allows the 70°F cooling tower water to be tempered using the condenser return water, which is at 97 °F. With this design (see **Figure 8**), 85 °F water can be supplied to the Thermax absorption chiller.

Figure 8: Cooling Tower Water Tempering Scheme



Source: ICF

CHAPTER 4: Permitting, Installation, and Startup

4.1 Permitting

In addition to a building permit from the city of Monterey Park, the CHP Hybrid UPS installation required an interconnection agreement from Southern California Edison (SCE) and an air quality permit from the South Coast Air Quality Management District (SCAQMD).

4.1.2 Interconnection Agreement

SoCalGas submitted an application to SCE for an interconnection agreement in 2013 (about one year before the microturbines were commissioned). There were a few iterations of supplying additional documentation to SCE and answering questions. After conducting an on-site inspection of the electrical hardware installed for the CHP Hybrid UPS system, SCE issued an interconnection agreement in July 2014.

4.1.2 Air Quality Permit

At the beginning of this project, Capstone was anticipating that the microturbines would be required to meet emission limits of 9 ppm NOx and 40 ppm CO (at 15% O_2). SCAQMD, however, required that the microturbines meet a lower CO limit of 10 ppm. In October 2013, SCAQMD issued an air quality permit with a NOx limit of 9 ppm and a CO limit of 10 ppm for each microturbine.

4.2 Hardware Installation and Startup

The general contractor, Regatta Solutions, started construction at the Monterey Park data center in October 2013. Construction concluded in July 2014, and Regatta then initiated commissioning activity with support from Capstone, Thermax, SoCalGas personnel, and local contractors at the Monterey Park site. Data collection commenced in August 2014. The following pages show photographs taken during the construction phase.

Figure 9: Location Selected for Microturbines

Figure 10: Concrete Pad

Figure 11: Microturbines Located on Concrete Pad

Source for photos on this page: Regatta

Figure 12: Microturbine Transformers

Figure 13: Static Transfer Switch

Figure 14: Absorption Chiller

Figure 15: Condenser Water Mixing Valve

Source for photos on this page: Regatta

Figure 16: Microturbines and Exhaust Manifold

Figure 17: 3-Way Bypass Damper

Figure 18: Fuel Gas Compressors (Gas Packs)

Figure 19: Main Utility Gas Meter

Source for photos on this page: Regatta

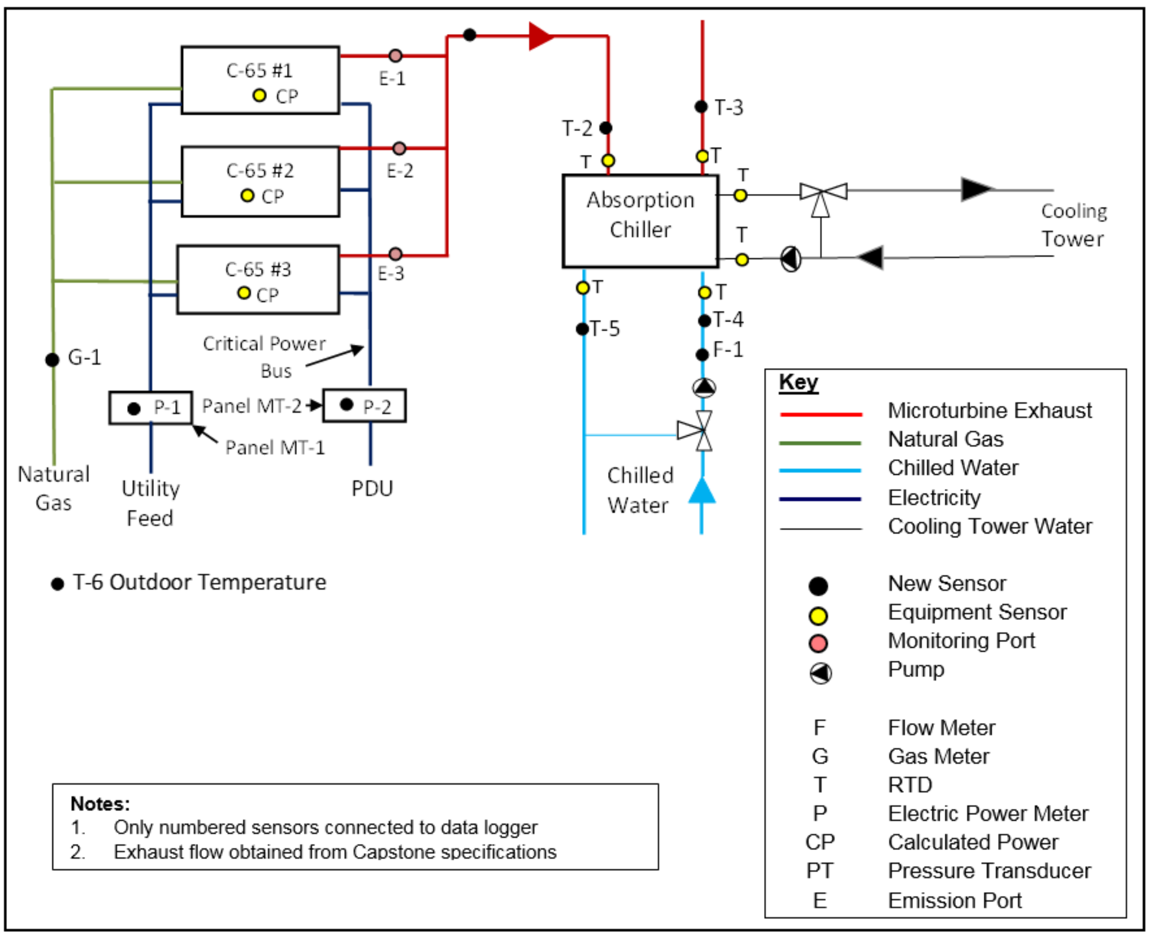
CHAPTER 5: Demonstration Results

5.1 Instrumentation and Data Collection

During the demonstration phase, the following key performance parameters were logged and analyzed for the CHP Hybrid UPS system (see **Figure 20** for instrumentation diagram):

- Fuel Usage
- Electric production and efficiency
- Overall CHP efficiency
- Absorption chiller output and coefficient of performance (COP)
- System availability
- NOx and CO emissions

Figure 20: Instrumentation Schematic

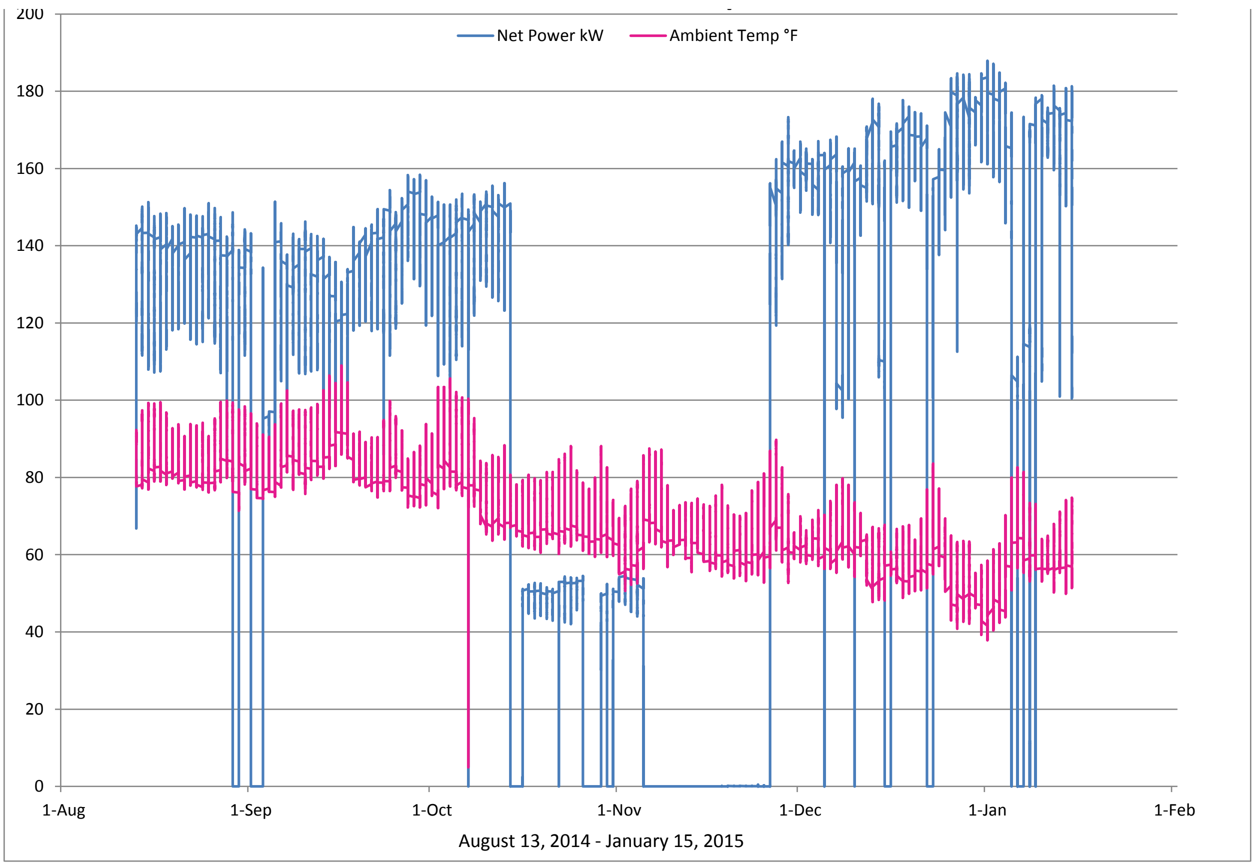


Source: DE Solutions

5.2 Performance Results

Figure 21 shows the net power output from the CHP Hybrid UPS system. Microturbine capacity decreases with increasing temperature, and this trend is observed in **Figure 21**, which shows the impact of diurnal temperature changes and seasonal temperature changes (warmer months and cooler months). On October 9, the ambient temperature sensor was relocated to the turbine inlet to improve the accuracy of measuring the turbine inlet conditions. Ambient temperatures taken prior to October 9 were adjusted +5 °F to reflect sample temperature differences between the two locations. As displayed, net power output hovered around 140 kW for the three microturbines during the warmer months (August, September, and October), and increased to 160 – 170 kW in the cooler months (December and January). During November, hardware repairs were being implemented to the CHP Hybrid UPS system, and the reduced power output shown in **Figure 21** is a result of one or more turbines being off-line.

Figure 21: Net Power Output

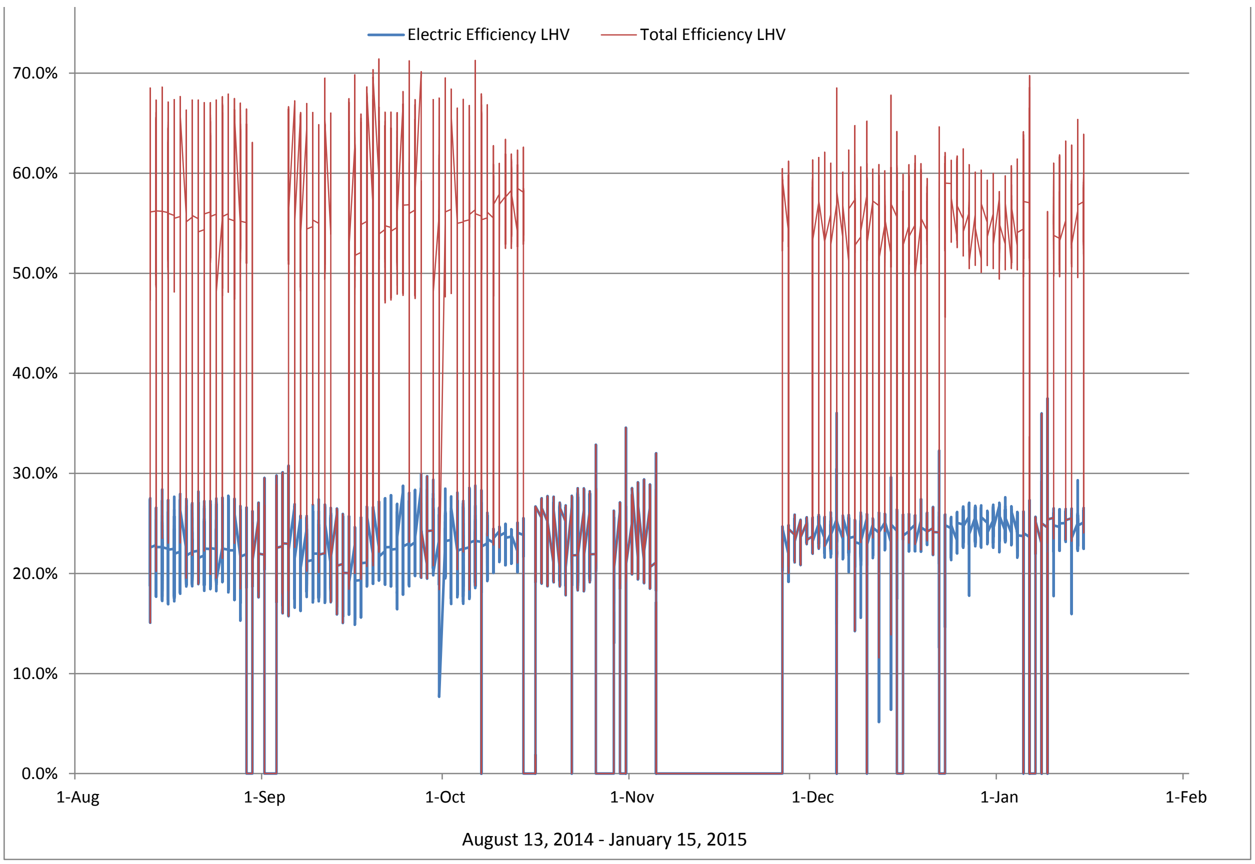


Source: DE Solutions

The two main parasitic electric loads are the natural gas compressors (5.5 kW for each microturbine) and losses across the isolation transformers (estimated at 5% of the gross electrical output from the microturbines). The power data in **Figure 21** is expressed as net power, and does not include these parasitic loads. Another potential parasitic load is the condenser water pump and cooling tower fan for the double effect absorber. If the displaced chiller was electric, the absorption chiller would have a somewhat higher parasitic power requirement. For the Monterey Park data center, however, the displaced chiller during evenings and weekends is a single effect absorption chiller, which requires ancillary power, rather than the double effect Thermax absorber used in the CHP Hybrid UPS system. For purposes of this analysis, the incremental parasitic load of the condenser water pump and the cooling tower fan required for the CHP Hybrid UPS system was assumed to be negligible.

Figure 22 shows the electric efficiency and overall efficiency of the CHP system. As illustrated, the chiller suffered many early-morning shutdowns due to unacceptably low cooling water (CW) temperatures. These shutdowns are represented by the sharp drops in the overall efficiency curve. This problem was remedied in early October by connecting the CW temperature control valve to a new controller that had better control capability. On October 9, the gas meter, which had previously been set to measure Therms, was reset to measure standard cubic feet (SCF) to provide higher resolution and better accuracy. This change exaggerated data swings in some data recorded during August, September and early October.

Figure 22: Electric and Overall Efficiency

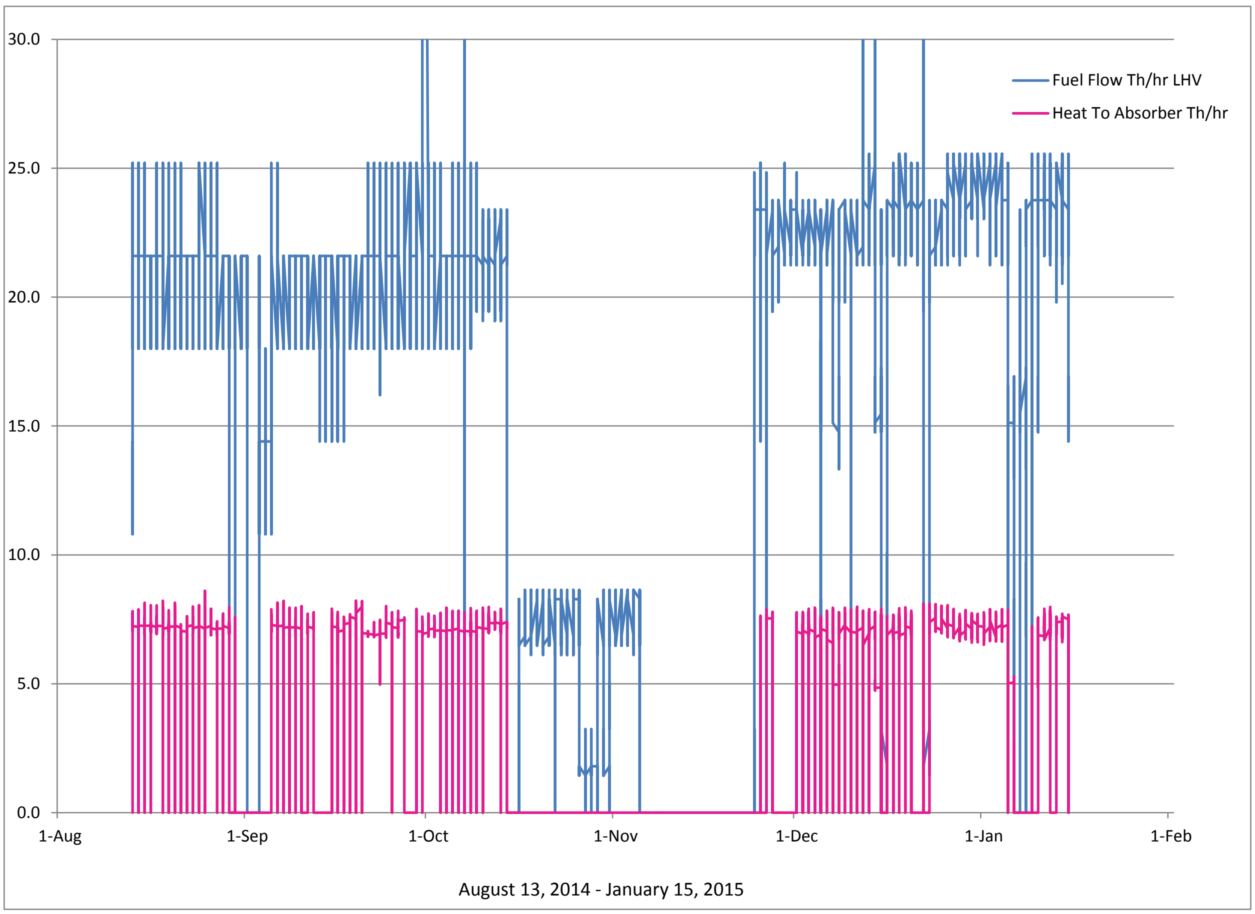


Source: DE Solutions

The data in **Figure 22** show that the net electric efficiency typically ranged from 20 – 26 percent (excluding microturbine shutdowns), and the overall efficiency typically ranged from 54 – 60 percent (excluding chiller shutdowns). The data anomaly in November occurred due to system repairs. This anomaly for November is evident in all data charts presented in this chapter.

Figure 23 shows the natural gas fuel flow for all three microturbines and the amount of thermal energy extracted from the microturbine exhaust stream across the Thermax absorption chiller. This figure shows several events – noted by sharp drops in fuel flow – where one, two, or all three of the microturbines were intentionally taken out of service, or in some cases, shut down for unintended purposes. When all three microturbines were operating, the fuel flow was typically near 22 therms/hr (2.2 MMBtu/hr, LHV) during the warmer months (August, September and October), and near 24 therms/hr (2.4 MMBtu/hr, LHV) during the cooler months (December and January).

Figure 23: Fuel Flow and Recovered Exhaust Heat



Source: DE Solutions

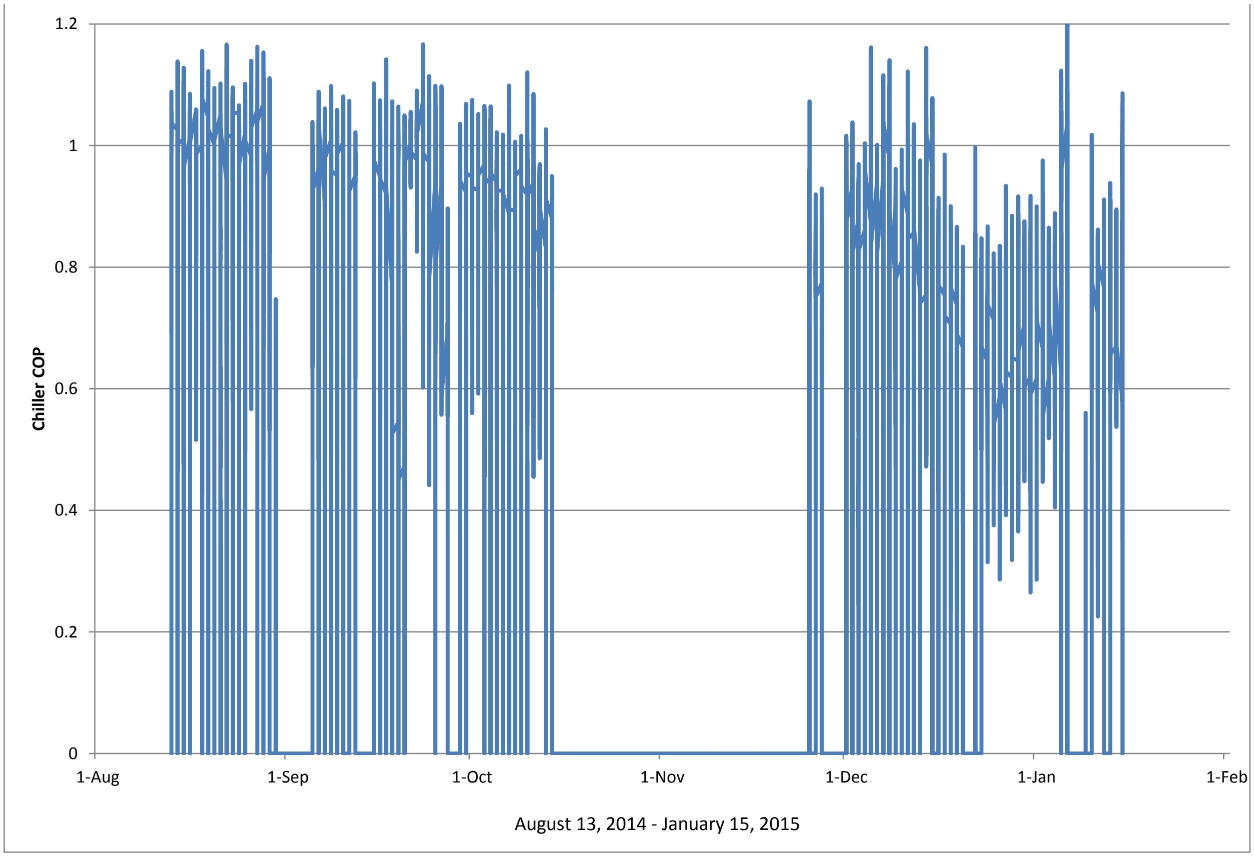
Figure 24 shows the chilled water output (tons) and the temperature of the chilled water (°F). When the chiller was operating with all three microturbines running, the chilled water production typically varied between 50 and 60 tons. The output was greater during the August through October time period compared to the December through January time period. In the warmer months, the capacity was near 60 tons, but dropped closer to 50 tons in the cooler months.

Figure 24: Chilled Water Production

Source: DE Solutions

Figure 25 shows the chiller Coefficient of Performance (COP). The COP followed a similar trend as the capacity. In the warmer months (August – October), the COP exceeded 1.0, but in the cooler months (December – January) the COP drifted down to a range of 0.8 - 0.9.

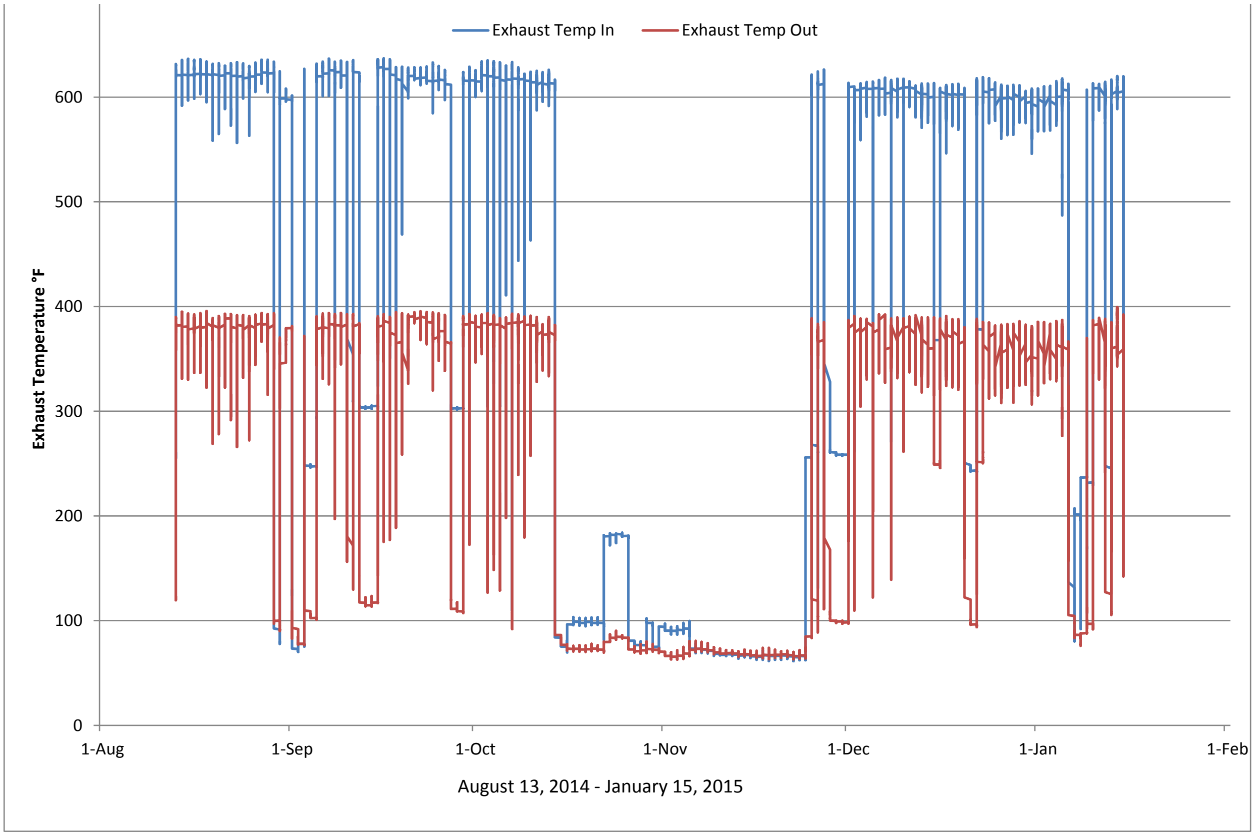
Figure 25: Chiller Coefficient of Performance (COP)



Source: DE Solutions

Figure 26 shows the inlet and outlet exhaust temperatures for the absorption chiller. The temperatures remained relatively constant over the monitoring period, but exhibited modest diurnal variation along with seasonal ambient temperature changes. During stable operation, the temperature drop of the exhaust stream remained close to 230 °F (620 °F in, 390 °F out).

Figure 26: Exhaust Temperature In and Out of Chiller

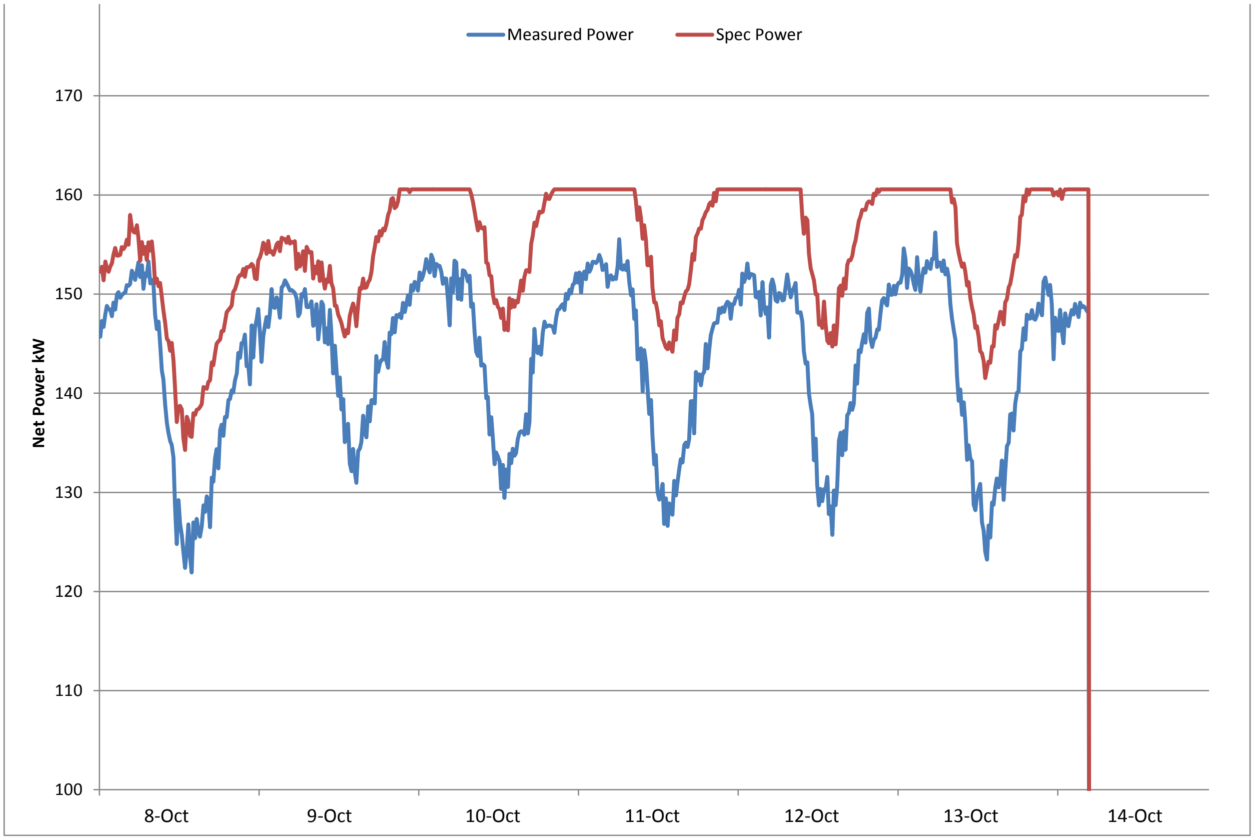


Source: DE Solutions

Figure 27 compares the net power output measurements against specifications supplied by Regatta Solutions. A number of factors affect the net power output, including the compressor power, efficiency of isolation transformers, ambient temperature, elevation, and back pressure. Data provided by Regatta were used to calculate expected performance. The comparisons are shown over a relatively short time period (October 8-14). As shown, the measured power levels generally fell short of expectations by 1-10 percent over the seven days shown. Key de-rate assumptions for calculating expected performance are listed below:

- A back pressure of 8 inches of water was assumed
- Monterey Park elevation of 384′ was used, resulting in a de-rate of about 1 kW per MT
- Fuel gas compressor power consumption was estimated at 5.5 kW by Regatta
- A 5% loss in the isolation transformers was assumed

Figure 27: Net Power – Measured Compared to Specifications

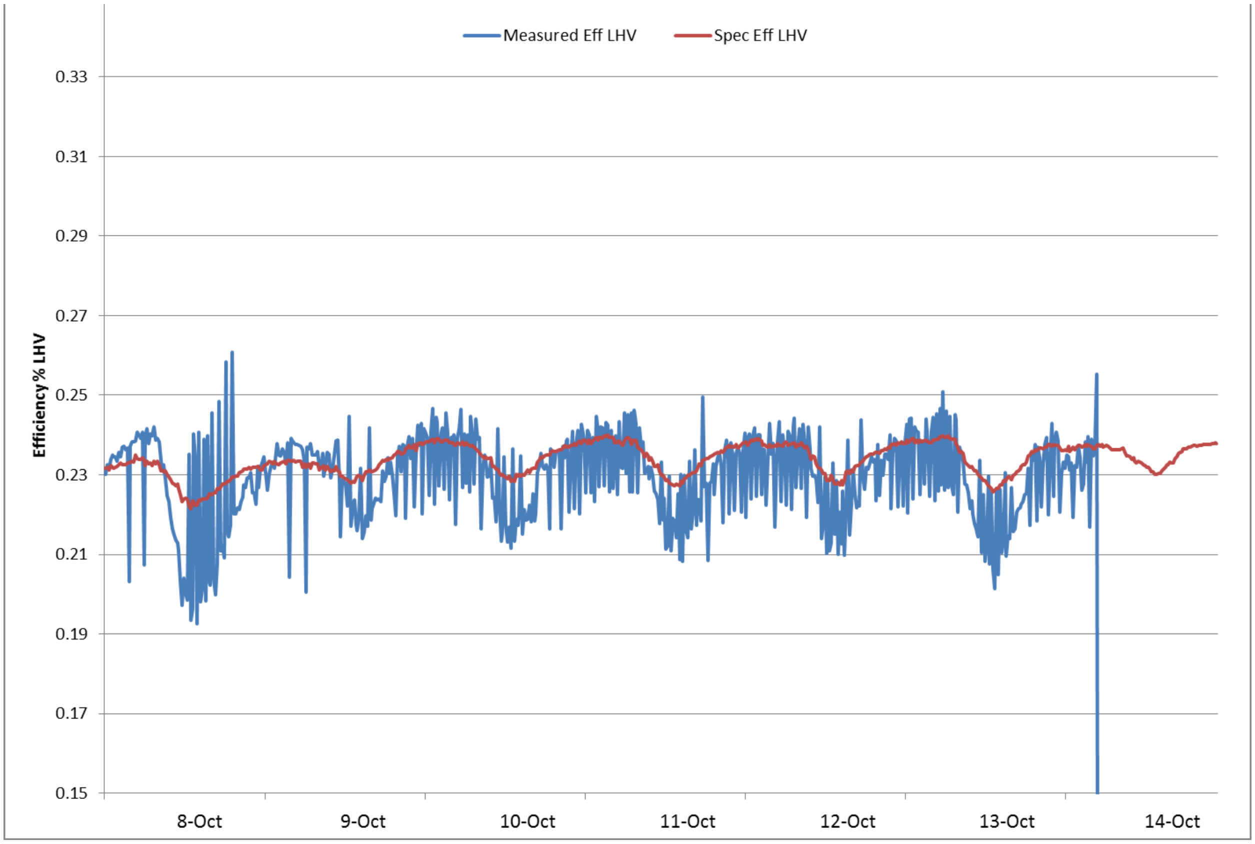


Source: DE Solutions

Figure 28 compares measured and expected (i.e., manufacturer specifications) microturbine efficiency using the same de-rate factors discussed in the preceding paragraph. As shown, the specified nominal data intersected with many of the measured values, but in general, the measured data fell below specified nominal efficiency expectations. Capstone's published variation in efficiency is +/- 2 percentage points, and the published variation in power output is +/- 3 kW for ambient temperatures above ISO conditions.[12]

[12] Capstone Turbine Corporation, *C65 & C65 ICHP MicroTurbine*, web link, accessed February 2015.

Figure 28: Measured and Specified Microturbine Efficiency



Source: DE Solutions

5.4 Emissions

Two emissions tests were completed. The first was completed by SoCalGas personnel on January 12, and the second was completed by the South Coast Air Quality Management District (SCAQMD) on January 15. The results of the two tests are shown in **Table 7**.

Table 7: Emission Test Results

Emission Type	Permit Limit (ppm, 15% O_2)	Test Date	Results (ppm, 15% O_2)		
			D32 (Unit #1)	D36 (Unit #2)	D37 (Unit #3)
NOx	9.0	12 Jan 2015	2.10	2.08	0.45
		15 Jan 2015	3.00	3.35	3.37
CO	10.0	12 Jan 2015	6.58	0.10	2.45
		15 Jan 2015	14.40	0.62	4.46

On January 12, the three microturbines all had emission levels below the 9 ppm NOx permit level, and the 10 ppm CO permit level. NOx emissions ranged from 0.45 (Unit #3) to 2.10 ppm (Unit #1), and CO emissions ranged from 0.10 (Unit #2) to 6.58 ppm (Unit #1). On January 15, all three microturbines had NOx emission levels below 9 ppm, but one microturbine (Unit #1) had CO emissions above 10 ppm. On January 15, NOx emissions ranged from 3.00 (Unit #1) to 3.37 (Unit #3), and CO emissions ranged from 0.62 (Unit #2) to 14.40 (Unit #1).

Unit #1 was taken out of service on January 15 because the CO level exceeded the 10 ppm permit level. As of February 2015, Capstone was planning to repair this microturbine, with the expectation that it would be returned to service in compliance with the SCAQMD air quality permit. As of February 2015, the CHP Hybrid UPS system continued to operate with two microturbines, producing electricity and chilled water.

One of the performance metrics established for this project was to compare NOx emissions from the CHP Hybrid UPS system to NOx emissions from the electric grid. This comparison needs to include the electric power generated from the microturbines and the offset electric load attributed to the absorption chiller. A summary of the total reduced electric load from the CHP Hybrid UPS is shown in **Table 8**. The reduced electric demand at the Monterey Park data center site is 211 kW. Using an estimate of 5 percent for transmission and distribution (T&D) losses, the reduction in demand for electric power at the point of generation is 222 kW.

Table 8: Reduced Electric Load from CHP Hybrid UPS

Reduced Electricity from Microturbines	(kW)	155
Offset Electricity for Chilled Water	(kW)	39
Avoided Loss from Conventional UPS	(kW)	17
Total On-site Reduction in Electric Demand	(kW)	211
Electric Grid T&D Losses	(%)	5%
Total Reduction in Demand for Grid Power (measured at grid generation plant)	**(kW)**	**222**

The reduction in NOx emissions from the CHP Hybrid UPS system is summarized in **Table 9**, which shows a reduction of 66 percent. The NOx emissions for the electric grid are based on values reported by EPA for California (see **Appendix D** for details).

Table 9: Reduced NOx Emissions from CHP Hybrid UPS

Description		**Hybrid UPS**	**Conventional**
Power from Microturbines	(kW)	155	---
Power from Utility Generation Plant	(kW)	---	222
NOx Emissions Rate	(lbs/MWh)	0.1968	0.4047
	(lbs/hr)	0.030	0.090
Reduction with CHP Hybrid UPS			**66%**

As shown in **Table 9**, the NOx emission rate for grid electricity is 0.4047 lbs/MWh. This value is based on EPA data from the 9th Edition of eGRID (more details in **Appendix D**). When the proposal for this project was prepared in 2012, a higher NOx rate of 0.62 lbs/MWh was used for grid electricity. If this higher grid value of 0.62 lb/MWh is used, the NOx reduction from the CHP Hybrid UPS system is 78 percent.

5.5 Summary

A summary of key performance results is provided in **Table 10**. This table also shows the performance results compared to the goals established for the demonstration.

Table 10: Performance Results

Metric	Goal	Measured Results		Comparison to Goal [1, 2]
		Range	Average	
Natural Gas Consumption	---	2.2-2.4 MMBtu/hr (LHV)	2.3 MMBtu/hr (LHV)	---
Electrical Conversion Efficiency	---	20-26% (LHV)	23% (LHV)	---
CHP Efficiency	66% [3]	---	52%	-22%
	59% [4]	54-60%	57%	-5%
Electric Power	174 kW	140-170 kW	155 kW	-11%
Chilled Water	77 tons	50 – 60 tons	55 tons	-29%
NOx Emissions	Reduce by 80% [5]	---	66%	-18%

Notes:
Comparison based on average result.
Differences may occur due to rounding.
Based on electric power and chilled water production.
Based on electric power and thermal energy extracted from microturbine exhaust stream.
Compared to grid.

CHAPTER 6: Technology Transfer and Production Readiness

6.1 Technology Transfer Plan

6.1.1 Overview

The new component in the demonstration project is the Capstone Hybrid Uninterruptible Power Supply (UPS) microturbine. Other major components include a direct exhaust fired Thermax absorption chiller and normal electrical and piping installation components that are available today in the market. The Capstone Hybrid UPS microturbine offers an alternative to traditional ways of protecting critical loads, such as those in data centers, health facilities, or continuous industrial processes.

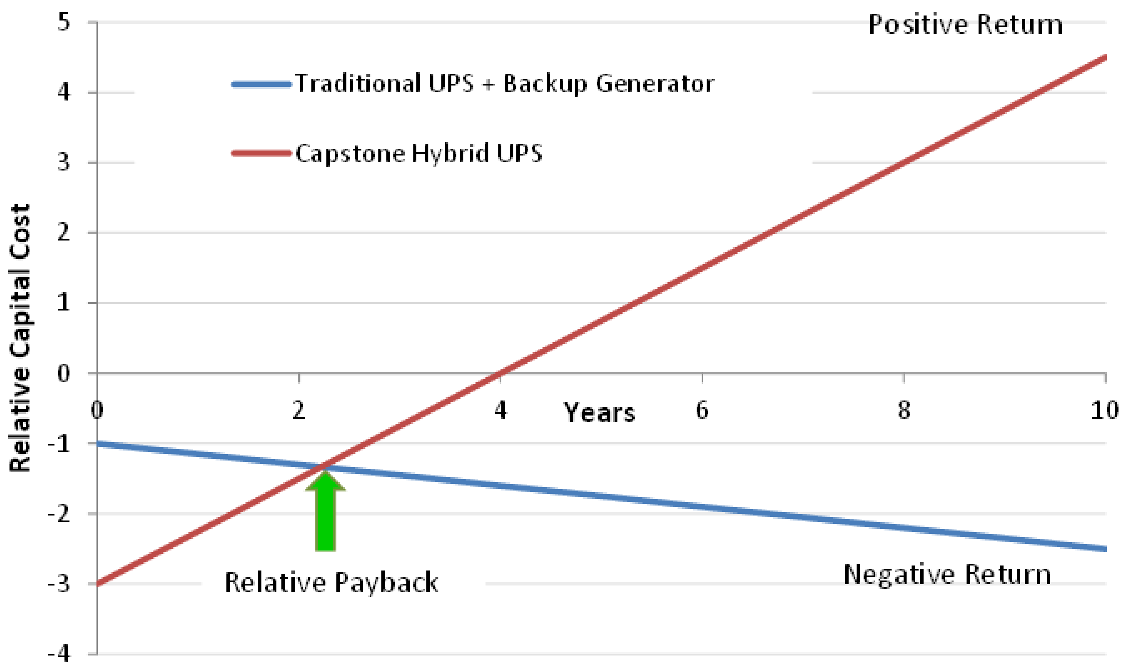
The global market for UPS systems above 50kVA is estimated to be $2.6 billion per year, with about $1.1 billion between 50 and 200kVA. Major suppliers in this three phase UPS market are Schneider (APC), Eaton (Exide PowerWare), Emerson (Liebert), and GE. The traditional generator sets that support these UPS systems for extended utility outages are from Caterpillar, Cummins, Kohler, and other well-established manufacturers. It will take a strong marketing and selling effort, along with successful customer installations, to make inroads into this conservative market. The technology transfer plan outlined below explains how Capstone intends to enter this market.

The traditional UPS plus backup generator (genset) solution serves the intended purpose well, and customers invest in this equipment as a means to insure their overall business performance against inevitable utility power problems. However, as a capital investment, there is no direct financial return. UPS systems are not 100 percent efficient, so there is an ongoing loss of energy going to the critical load, with its associated electric utility cost. Likewise, the backup diesel generators must be maintained and operated periodically to confirm their readiness but do not normally generate power to offset electric utility costs. Therefore, both the UPS and backup generator set represent ongoing operating costs that must be accounted for during their entire lives. The Capstone Hybrid UPS provides the same level of continuous power protection to the critical loads, but has the additional capability to generate power efficiently and offset some of the customer's electric utility costs.

Figure 29 illustrates the cost of a traditional UPS with backup generator and the relative cost of a Capstone Hybrid UPS system. In this example, the traditional UPS and diesel genset have a relative initial capital cost of 1, and continue to experience yearly operating costs as indicated by the blue line. This traditional approach has a negative return on the initial investment. The Capstone Hybrid UPS solution requires a larger initial capital investment – in this case shown as three times the traditional UPS and genset solution. However, the savings in electric utility costs produces a positive cash flow shown by the red line, thereby generating a positive return. For this example, the payback on that investment is about four years. However, compared to the traditional solution shown by the blue line, the relative payback is closer to two years.

The ability for the Capstone Hybrid UPS solution to pay for itself over time is the key differentiating value proposition.

Figure 29: Example Payback Comparison



Source: Capstone

While there may be a predicted financial return for a given installation, customers will not adopt this new technology if they are not convinced that it is at least as reliable as the traditional solution of a UPS and backup genset. The demonstration of this technology at the Monterey Park data center has provided valuable operating experience under real world conditions that will be used to confirm reliable performance to protect critical loads.

The technology transfer plan is to target potential customers where CHP economics make it viable. However, the primary sales message must be that the Capstone Hybrid UPS solution will provide equal or better protection than traditional solutions. The following elements will need to be perfected to support the value proposition and overcome objections in an extremely conservative market:

- Target Audience and Sales Plan – Selling into the datacenter market involves several important decision makers, including Information Technology (IT) professionals, facility personnel, and managers and executives with profit and loss (P&L) responsibility.
- Distribution and Service Support – Capstone sells products through a distribution channel that also has responsibility for local service support. Regatta is Capstone's distributor for California.

- Availability Calculation and Demonstration – Capstone has already generated some example availability calculations that show equal or better performance of the Hybrid UPS solution compared with traditional UPS and genset solutions. This needs to be augmented by a growing database of actual performance in real world applications.
- Economic Evaluation Tool – Capstone has an economic calculator to estimate savings for potential projects. Sources of savings come from efficient production of electricity as well as avoided costs of traditional equipment.
- Promotion and Presentation Material – An overview presentation of the features and benefits of the Capstone Hybrid UPS system has been put together, along with an application guide and user manuals. Several trade shows and conferences have been identified as the target audience, and case studies (including this CEC demonstration project) will be produced for successful projects. White papers and case studies will also be used to highlight successful projects.

6.1.2 Target Markets and Audience

The Capstone Hybrid UPS microturbines can be deployed in a variety of end user applications where continuity of power is critical. This includes data centers, as well as certain hospital loads and continuous process loads. Most of these types of loads are traditionally protected by UPS and backup gensets. However, there are expected to be a few applications where the Hybrid UPS microturbine is the only viable solution. To assist with marketing and sales efforts, a UPS market research report will be obtained to help quantify end user types and help target the right audience to call on. Initial market research data suggest that the total market for UPS systems greater than 50kVA is about $2.6 billion per year, and between 50kVA and 200kVa is about $1.1 billion per year.

A primary market will, of course, be data centers. Selling into the data center market involves several important decision makers and influencers. Data center technology is going through transformations that include:

- Cloud computing versus dedicated company computing resources
- Colocation or outsourced services versus in-house datacenters
- Data center consolidation versus multiple local data centers within a business
- Increased concern over data security
- Expansion of mobile applications
- Increased video and data visualization content
- Increased temperature capability of equipment, requiring less cooling

The general trend seems to be that the size of new data centers is increasing, and outsourcing or colocation of equipment is increasing. It may be advantageous to also focus on markets where the critical loads are more closely tied to the customer’s main business facilities; for example hospitals, airports, telecommunications, and continuous industrial processes. Some additional market research will help target which customers to focus on.

Several of the team members on this CEC project have in-depth experience related to the critical power market. They include Steve Acevedo, President of Regatta, and Mike Fluegeman, one of the Principals of PlanNet. Interviews with each of them will be conducted to gain their insights into which markets would benefit most from the Capstone Hybrid UPS solution and identify who the key industry decision makers and influencers are so we are targeting the right people with the right message .

6.1.3 Distribution and Service Support

Capstone uses a network of distributors to both sell and service its microturbine products. Most of these distributors also provide auxiliary equipment to complete typical projects, such as the absorption chiller used in this CEC project. Regatta is the local distributor in California, and has worked as part of this project team to provide the microturbines and Thermax absorption chiller, and to help with installation and commissioning of the overall system as the project's general contractor. Regatta is also responsible for ongoing service support, and has worked directly with Capstone Application Engineers to resolve some of the unique issues that came up during the installation and commissioning of the hardware for this CEC project.

As part of the technology transfer plan, select Capstone distributors will be trained in both the sales and service aspects of the Hybrid UPS product. Lessons learned from this CEC project will be included so that future projects benefit from our experience. In addition to Regatta, key US distributors are E-Finity, RSP, and Horizon Power Systems.

6.2 Production Readiness Plan

6.2.1 Overview

The Capstone Hybrid UPS microturbine was developed as an extension of the current production C65 microturbine, and uses the same basic sub-components with unique operating software. This means that the major production processes, tooling, assembly fixtures, and vendor supply structure are already in place. The basic C65 microturbine design has been in production since 2000, and is Capstone's highest volume product. There are only a few unique sheet metal and electrical connector components which are available through Capstone's existing vendor network with lead times consistent with the normal delivery times anticipated for the C65 Hybrid UPS microturbine. In fact, the three microturbines provided for this CEC project were manufactured using the same production assembly processes and personnel as the standard C65 microturbines. Capstone's production facilities are also ISO 9001 and ISO 14001 certified.

The only part of the build process that has not been integrated into the existing Capstone C65 production facility is final system testing. To be completely tested as a system, the C65 Hybrid UPS requires a fuel source as well as simultaneous connections to a three phase utility grid, a three phase load, and an external DC supply (battery pack). Current automated production test facilities do not have a large enough DC connection to support full power testing. The three units for this PIER project were each manually tested in Capstone's engineering lab, which has the required capability.

The production plan for the C65 Hybrid UPS is to utilize the existing engineering lab equipment for manual testing until sales volumes justify the capital expense to add production DC capacity and associated automated test capability. Capstone's current production capacity for all microturbines is estimated to be 2,000 units per year. Production of all models in fiscal year 2014 was 671 microturbine units, so there is sufficient capacity for substantial growth without additional capital investment. Estimated practical capacity for manual engineering lab testing of the C65 Hybrid UPS is 50 units per year. Investment in additional equipment will be revisited when incoming orders approach this level.

The C65 Hybrid UPS microturbine has also been thoroughly type tested and is certified to UL 2200 (Standard for Stationary Engine Generator Assemblies), UL 1741 (Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources), and UL1998 (Standard for Software in Programmable Components).

The C65 Hybrid UPS product is ready for full commercialization

6.2.3 Projected Cost and Selling Price

Since the major hardware components in the C65 Hybrid UPS are already in full production, the cost structure is well known and the vendor support structure is established. Proposed product pricing was developed using documented costs as well as market value calculations. Two market value calculations were used to establish a target selling price:

- Comparison to traditional UPS and backup diesel genset
- Comparison to traditional UP and standard Capstone products

Comparison to Traditional UPS and Backup Diesel Genset

Initial price levels were generated based on comparing a Hybrid UPS system to a solution that includes traditional UPS systems, backup diesel generators, and associated equipment. This type of comparison was included in the original project proposal and is also described in the May 2013 Performance Modeling Report as well as the December 2014 Technology Transfer Plan. Capstone has developed a software program to estimate the Hybrid UPS value proposition for potential projects, and Table 6 in the May 2013 Performance Modeling Report provides example outputs from this program.

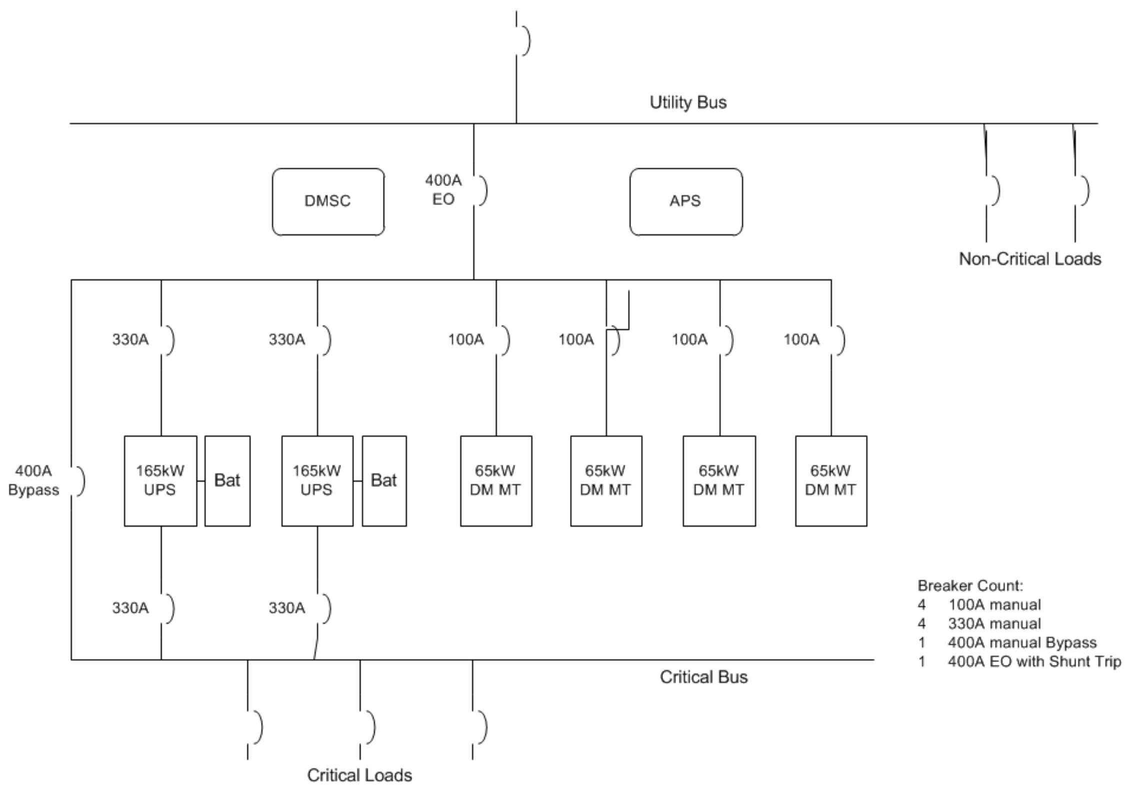
Comparison to Traditional UPS and Standard Capstone Products

In 2014, Capstone also did another market value calculation by comparing two project alternatives: one consisting of standard C65 microturbines and traditional UPS systems and a second using several C65 Hybrid UPS systems.

One of the advantages of the C65 Hybrid UPS microturbine compared to using a standard microturbine plus separate UPS system is that there is less "balance of plant" equipment required to complete an installation. **Figure 30** shows an example installation using four C65 standard "Dual Mode" microturbines and two traditional UPS systems that together provide a

CHP system, backup generation, and uninterrupted power for a critical load. The C65 microturbines are installed in an "n + 1" configuration such that the protected load can be no more than three times the capacity of a single microturbine. Since the microturbines have some de-rating based on ambient temperature, elevation, and other installation factors, the capacity of the microturbines was assumed to be 55 kW for this analysis. This means that the protected critical load should be no more than 165 kW. To achieve a similar level of availability for the traditional UPS system, two 165 kW units were considered for the analysis. In **Figure 30**, a Capstone Dual Mode System Controller (DMSC) and Advanced Power Server (APS) are shown, and are required to control the four C65 microturbines and operate the 400A electrically operated breaker to isolate the system from the utility bus during a grid disturbance.

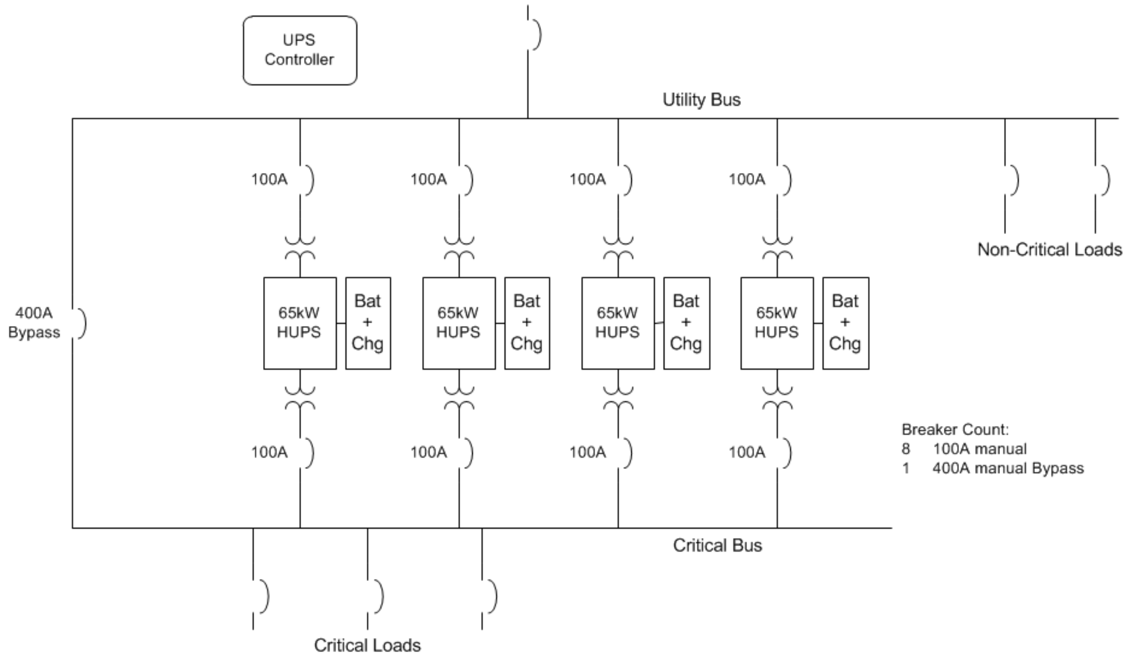
Figure 30: Example Installation using C65 Microturbines with Traditional UPS



Source: Capstone

Figure 31 shows an example of how that same critical load could be protected using four C65 Hybrid UPS microturbines. In this case, only the Capstone Hybrid UPS Controller (UPS Controller) is required, and no electrically-operated circuit breaker is needed to isolate the utility bus from the input to the traditional UPS systems. Note that since there are fewer pieces of equipment, overall better system availability should be the result.

Figure 31: Example Installation using C65 Hybrid UPS Microturbines



Source: Capstone

Estimated pricing for the microturbines and traditional UPS, as well as this ancillary and circuit protection equipment, was included in the comparative analysis. The result is a proposed selling price for the C65 Hybrid UPS that provides financial incentives for the customer versus a more traditional approach, and at the same time maintains internal Capstone margins at or above those for the existing C65 products.

The selling price resulting from this second evaluation is actually lower than the initial pricing based on comparisons to a traditional UPS and backup diesel genset. This improves the overall Capstone Hybrid UPS value proposition.

6.2.4 Product Support Documentation

In addition to preparing the C65 Hybrid UPS product for full production capability and establishing cost and selling price, customer documentation has been developed to assist with proper application and customer use of the product.

Application Guide

An application guide has been created to define the operating characteristics of the C65 Hybrid UPS microturbine system. This guide includes information to help size the microturbine system, coordinate it with external protective devices, and integrate it with a new or existing battery system.

User Manuals

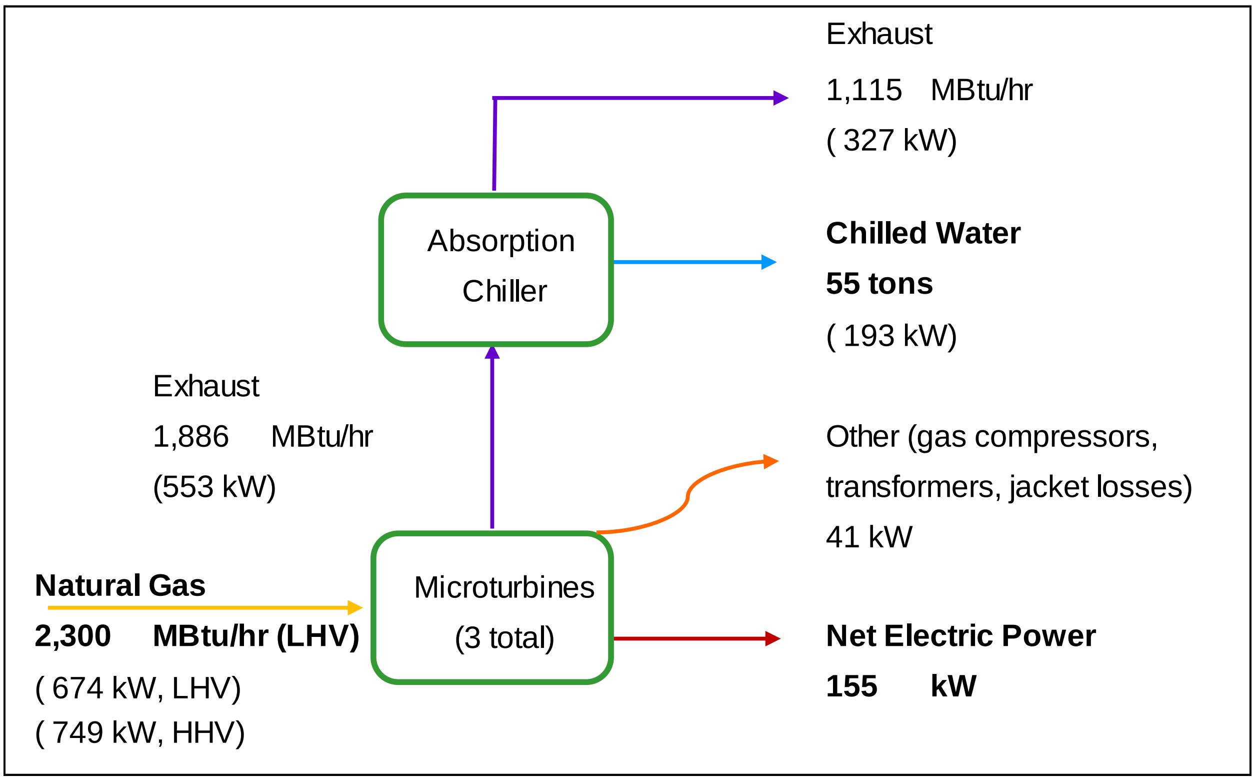
User manuals have been created for both the C65 Hybrid UPS microturbine itself as well as the Hybrid UPS Controller, which is the master device used to operate a group of microturbines.

CHAPTER 7:
Economic Results and Market Size

7.1 Comparison between CHP Hybrid UPS and Conventional UPS

The energy balance for the CHP Hybrid UPS system based on observed demonstration results at the Monterey Park demonstration site is shown in **Figure 32**. This figure shows that the system as demonstrated typically produced 55 tons of chilled water and 155 kW of net electric power, while consuming 2.3 MMBtu/hr of natural gas. The values shown in **Figure 32** represent average values. Variations in key performance parameters such as chilled water production and electric power output are discussed in Chapter 5.

Figure 32: Energy Balance Based on Actual Results



Source: ICF

The economics for the CHP Hybrid UPS system shown in **Figure 32** were evaluated for two operating scenarios:

- Scenario #1 – Continuous operation (8,760 hours/yr)
- Scenario #2 – Operation for 3,915 hours/yr corresponding to mid-peak (MP) and on-peak (OP) electricity rate periods as defined by the electric tariff that applies to this facility. This tariff is Time-of Use Schedule No. 8 (TOU-8) from Southern California Edison (SCE).

For Scenario #1, the effective average electricity rate was estimated to be 11.4 ¢/kWh, and for Scenario #2, the effective average electricity rate was estimated to be 18.3 ¢/kWh. These effective average electricity rates are based on TOU-8 as applied to the hourly operating schedules for both scenarios. Additional input variables (e.g., cost of natural gas, standby charges, and O&M costs) are shown in **Table 11** along with the results. Based on these input values, the operating cost for the CHP Hybrid UPS is $19.98/hr in Scenario #1 (continuous operation), and $21.97 in Scenario #2 (MP/OP operation).

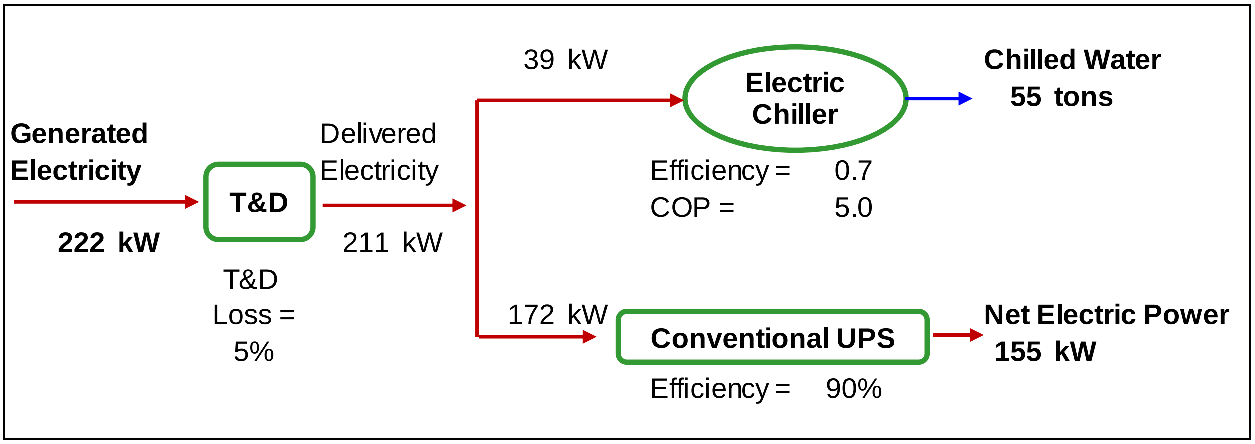
Table 11: Economic Results for CHP Hybrid UPS System

Description		**Scenario #1**	**Scenario #2**
Operating Hours and Energy Rates			
Annual Usage	(hrs/yr)	8,760	3,915
Natural Gas Rate	($/MMBtu)	$5.00	$5.00
Electricity Rate (average)	(cents/kWh)	11.4	18.3
Standby Charges	Non-bypass (cent/kWh)	1.008	1.008
	Capacity Charge ($/kW/month)	$7.59	$7.59
Fuel Cost			
Natural Gas Consumption	(MBtu/hr, LHV)	2,300	2,300
	(MBtu/hr, HHV)	2,555	2,555
Cost	($/hr)	$12.78	$12.78
Operation & Maintenance Cost			
Maintenance Cost	(cents/kWh)	2.6	2.6
	($/hr)	$4.03	$4.03
Unavoidable Electricity Charges			
Standby Charges	Non-bypass ($/hr)	$1.56	$1.56
	Capacity Charge ($/hr)	$1.61	$3.61
Net Operating Cost			
Total	**($/hr)**	**$19.98**	**$21.97**

The economics for the CHP Hybrid UPS were compared against a typical data center without CHP. This type of operation is shown in **Figure 33**, and is based on using an electric chiller to meet the data center space cooling requirement. Both the CHP Hybrid UPS and the conventional system (UPS plus electric chiller) deliver 55 tons of chilled water and 155 kW of power. For the conventional system, the electric chiller is estimated to operate with an efficiency of 0.7 kW/ton. In a conventional data center, power is routed through the UPS system at all times. Electricity is lost due to charging and discharging the batteries in a conventional UPS, and in this economic analysis, the efficiency for a conventional UPS system is estimated at 90 percent.

The economic results for the conventional data center (i.e., no CHP) are shown in **Table 12**. As indicated, the operating cost for the conventional data center is $24.95/hr in Scenario #1 (continuous operation), and $39.49/hr in Scenario #2 (MP/OP operation).

Figure 33: Energy Balance for Data Center with Conventional UPS and Electric Chiller



Source: ICF

Table 12: Economics for Conventional UPS

Description		Scenario #1	Scenario #2
Electricity Cost			
Electric Demand	(kW)	211	211
Cost	($/hr)	$24.02	$38.56
Operation & Maintenance			
Maintenance (chiller and UPS)	(cents/kWh)	0.6	0.6
	($/hr)	$0.93	$0.93
Net Operating Cost			
Total	**($/hr)**	**$24.95**	**$39.49**

The economics for the CHP Hybrid UPS and the conventional data center are summarized in **Table 13**. As shown, the cost savings with the CHP Hybrid UPS are estimated to be 20 percent for Scenario #1 (continuous operation), and 44 percent for Scenario #2 (MP/OP operation).

Table 13: Reduction in Cost with CHP Hybrid UPS

Description	Scenario #1		Scenario #2	
	CHP Hybrid	Conventional	CHP Hybrid	Conventional
Hourly Costs				
Natural Gas	$12.78	---	$12.78	---
Electricity	---	$24.02	---	$38.56
O&M	$4.03	$0.93	$4.03	$0.93
Standby	$3.17	---	$5.17	---
TOTAL [1]	**$19.98**	**$24.95**	**$21.97**	**$39.49**
Reduction with CHP Hybrid UPS Compared to Conventional UPS				
	Scenario #1		Scenario #2	
Hourly ($/hr)	$4.97		$17.52	
Annual ($/yr)	$43,567		$68,586	
Percentage [1]	20% *($4.97 / $24.95)*		44% *($17.52 / $39.49)*	

Note: 1) Differences may occur due to rounding.

7.2 Market Size

Data centers range in size from small "server" closets that contain only a few servers, to enterprise class facilities that may contain over a thousand servers. As a point of reference, the Monterey Park data center, which is a relatively large facility, showed a steady electric load of 800 to 1,000 kW (see **Figure 3**). As discussed in Section 1.1, data centers in California are estimated to collectively consume 5.2 billion kWh of electricity each year. If an average data center is assumed to have a load of 500 kW (about half of the Monterey Park data center), then there are approximately 1,200 data centers in California.[13]

The estimate of 1,200 centers is a rough approximation assuming that the average data center load is 500 kW. There is a wide range of data center capacities, and clearly there are many data centers that are too small for installing a system such as the CHP Hybrid UPS. However, this number highlights that the market is large, and significant opportunities exist for installing the CHP Hybrid UPS technology.

A conservative market impact projection was developed based on assuming that 50 CHP Hybrid UPS systems are installed, each with a capacity of 500 kW (electric power plus cooling). The performance specifications for each 500 kW system were scaled up based on the actual performance results obtained in the Monterey Park demonstration (specification shown in **Table 14**). The CHP systems were assumed to operate during on-peak and mid-peak time periods, corresponding to Scenario #2 (3,915 hrs/yr). The impact of installing these 50 systems is

[13] 1,198 data centers calculated based on 5.2 billion kWh used by all data centers in California, 500 kW load per data center, and 8,760 hrs/yr of operation

estimated to save nearly 98,000 MWh of electricity each year, and reduce electric demand by 25 MW. At 15.3 ¢/kWh, the CHP Hybrid UPS technology will help these data centers collectively save nearly $15 million each year.[14]

Table 14: Performance Specifications for 500 kW CHP Hybrid UPS System

Description		Grid Load Reduction with CHP Hybrid UPS System (kW)	
		211	500
Scaling Factor		1.00	2.37
Operating Schedule	(hrs / yr)	3,915	3,915
Cost Savings	($ / yr)	$68,586	$162,740
Electricity Savings	(kWh / yr)	824,978	1,957,500

Table 15: Impact of Installing 50 CHP Hybrid UPS Systems

Description		Value
Number of Data Centers in California		1,198
Average Load	(kW)	500
Market Penetration of CHP Hybrid UPS		4.2
Number of Data Centers that Adopt		50
Cost Savings for Each Site	($ / yr)	$162,740
Electricity Savings for Each Site	MWh/yr	1,958
Electricity Savings for All Sites	MWh/yr	97,875
	MW	25

[14] Energy Information Administration, average cost of electricity for all sectors in California reported, web link, accessed February 2015.

GLOSSARY

Term	Definition
AC	Alternating Current
BOP	Balance of Plan
Btu	British Thermal Unit
CARB	California Air Resource Board
CEC	California Energy Commission
CHP	Combined Heat and Power
DC	Direct Current
DG	Distributed Generation
HHV	Higher heating value
HUPS	Hybrid Uninterruptible Power Supply
kW	Kilowatt
kWh	Kilowatt-hr
LHV	Lower heating value
MBtu	Thousand Btu
MMBtu	Million Btu
MP	Mid-peak
M&V	Measurement and Verification
MW	Megawatt
MWh	Megawatt-hour
OP	On-peak
PIER	Public Interest Energy Research
RD&D	Research, Development, and Demonstration
SCAQMD	South Coast Air Quality Management District
SoCal Edison or SCE	Southern California Edison

SoCalGas or SCG	Southern California Gas Company
TOU	Time-of-use
UPS	Uninterruptible Power Supply

APPENDIX A:
Conceptual Design Performance Estimate

Capstone modeled the expected performance of the CHP Hybrid UPS system using site specific conditions at the Monterey Park data center location. The results are shown in **Table 16** and **Figure 34**. Notes from these modeling results include:

- A "gas pack" or "fuel gas booster" is a small gas compressor that increases the natural gas pressure from the supply pressure to a pressure high enough to inject it into the combustion chamber of the microturbine.
- The nominal net electrical output from the microturbine is 65 kW at ISO conditions, but it drops off when the ambient temperature rises above 63 °F.
- Derating factors include elevation, inlet pressure drop, and exhaust pressure drop. In addition, the gas pack represents a parasitic load, as well as the losses in the external isolation transformers associated with the Hybrid UPS model.
- Net Electrical output at ISO conditions with the above adjustments is 58 kW, or 174 kW for the three units.
- The nominal cooling capacity of the Thermax chiller is about 25.6 tons per microturbine using a COP of 1.2 (77 tons for three microturbines) for ISO conditions, and remains about constant for higher temperatures. This is due to the counteracting exhaust conditions from the microturbine where temperatures increase but mass flow decreases as ambient temperatures increase.

Table 16. Conceptual Design – Estimated Performance

Microturbine Information			Units
Capstone Product	C65		English
Catalog Number	65R-HD4-BU00		
kW Nominal Rating	65		
Fuel Type	LP Natural Gas	Requires Gas Pack	
Configuration	Stand Alone		
Heat Recovery Module	No		
Certification/Emissions	UL		

Site Information

Site Elevation	381	Feet

Parasitic Loads

Fuel Gas Booster	4.0	kW (from selection above)
Customer Load	3.0	kW (if any)
Total Parasitic Load	7.0	kW

Inlet & Exhaust Restrictions

Inlet Pressure Drop	0	inches WC
Exhaust Backpressure	5	inches WC

Cogeneration (Cooling) Direct Exhaust

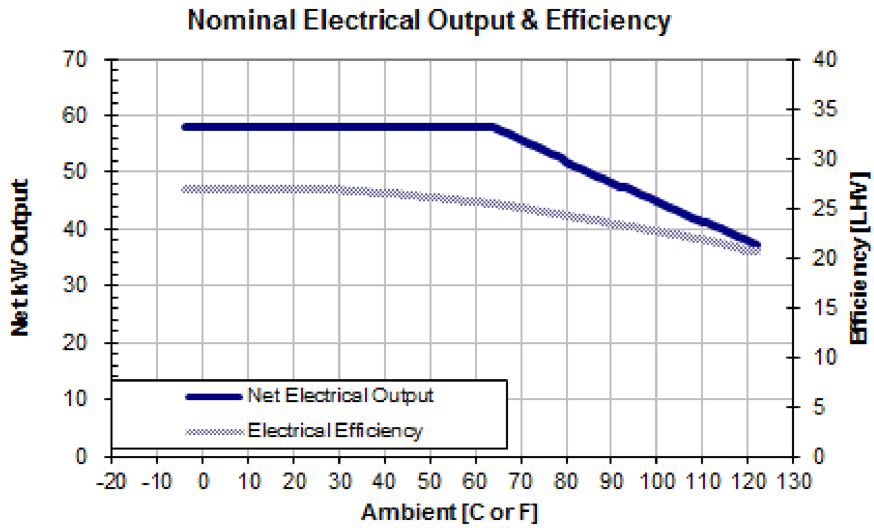
HRM or Direct Exhaust?	Direct Exhaust	
Coefficient of Performance	1.20	
Chiller Exhaust Outlet Temp	350	°F
Water Flow	40.0	gallons/min

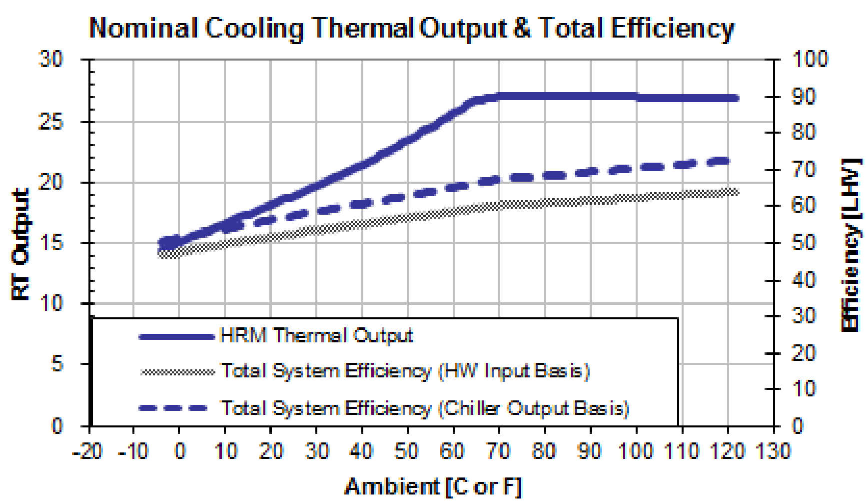
Nominal Performance for Selected Ambient Temperature

	Ambient	59.0	°F
Electrical Output	Power	58.0	kW
	Efficiency	25.6	% [LHV]
Cooling Output	Power	25.4	RT
		89.5	kW
	Efficiency	58.5	% [LHV] based on Heat Input
		65.0	% [LHV] based on Chiller Output

Source: Capstone

Figure 34. Conceptual Design – Estimated Performance Charts



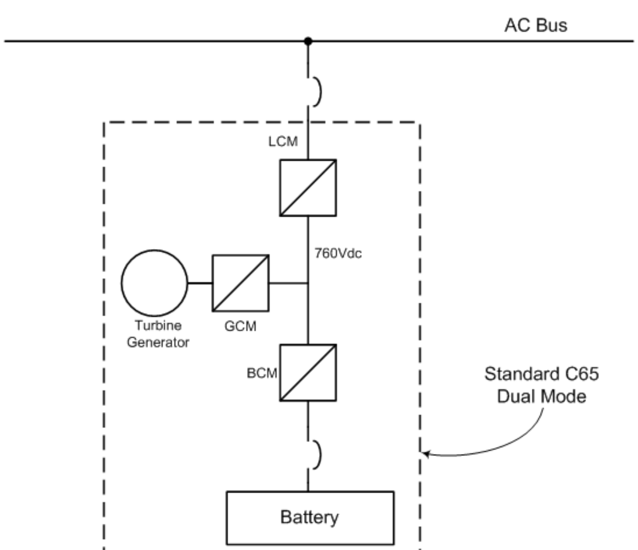


Source: Capstone

APPENDIX B:
CHP Hybrid UPS Details

Figure 35 shows a simple system schematic for a standard C65 microturbine. The standard microturbine in **Figure 35** is able to operate in parallel with a utility grid (grid connect mode) or provide power to an islanded load (standalone mode), and is able to transfer between these two modes of operation. The LCM (Load Control Module) is a three phase IGBT-based inverter that is able to pass power either to or from the microturbine's internal 760Vdc bus. The software to control operation of the LCM acts either as a current source when operating in grid connect mode, or as a voltage source when providing power to a standalone load. Capstone calls this capability "Dual Mode"; meaning that the microturbine is able to quickly switch between these two modes as required. The microturbine generator produces high frequency AC because it is spinning at high speed (up to 96,000 rpm at full power). A GCM (Generator Control Module) is another IGBT-based inverter that converts that high frequency AC to the internal 760Vdc. The BCM (Battery Control Module) is a third IGBT-based converter that allows power to flow from a battery to and from the 760Vdc bus. All of these inverters are bi-directional, so power can flow either to or from the 760Vdc bus as required.

Figure 35. Simple C65 Microturbine Schematic

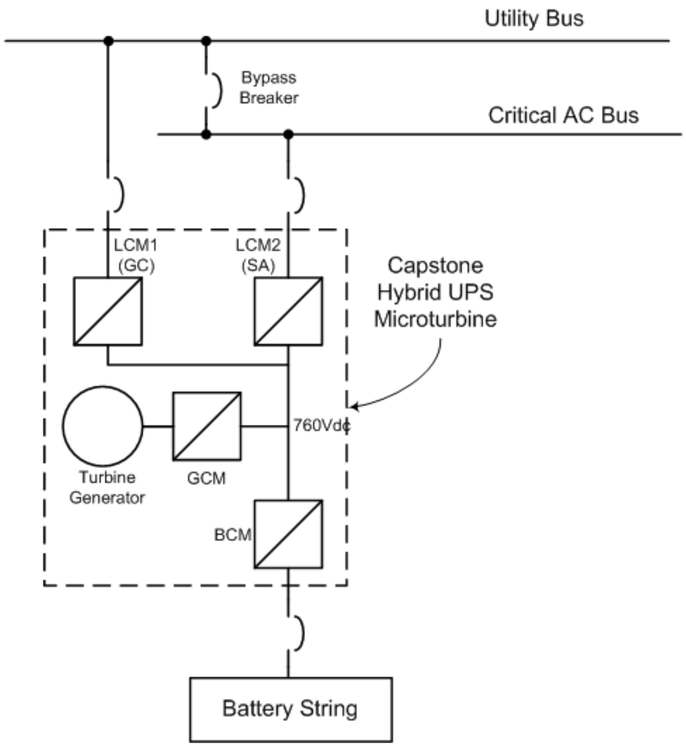


Source: Capstone

Figure 36 shows a simple schematic for the C65 Hybrid UPS microturbine. Note that in this configuration, there are two "LCM" inverters: one dedicated to operating in grid connect mode as a current source connected to incoming utility power (labeled LCM1 GC), and the second connected to a critical load acting in standalone mode as a voltage source (labeled LCM2 SA).

These are the same LCM constructions as in **Figure 35**, but with some software differences to allow operation in several new ways.

Figure 36. Simple C65 Hybrid UPS Schematic



Source: Capstone

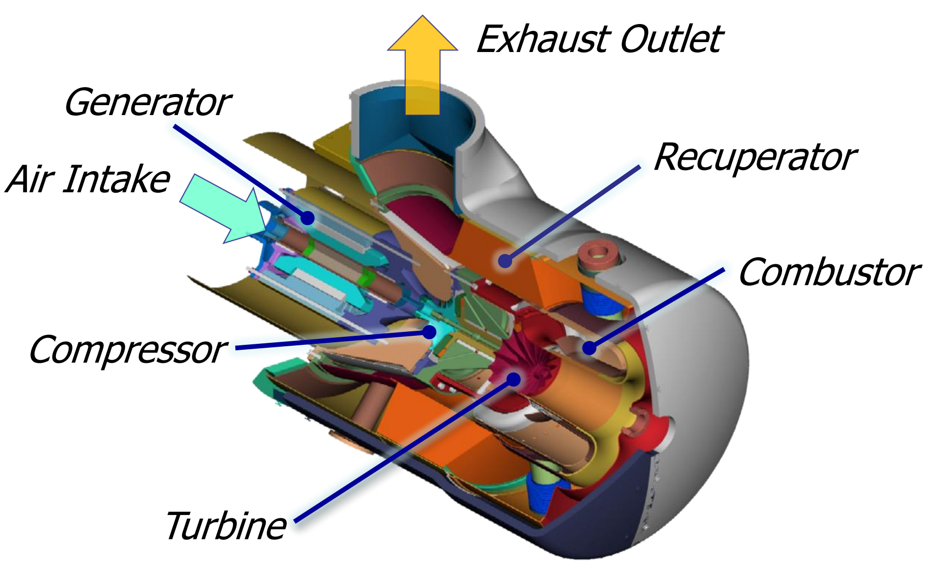
In normal UPS mode of operation, power can be fed from the Utility bus through LCM1 to the microturbine's internal 760Vdc bus, and then inverted back to power the critical AC bus through LCM2. This is exactly the same as a traditional "double conversion" UPS. However the turbine generator is also connected to the 760Vdc bus through its GCM. The turbine can be commanded to run, and can either provide more or less power than the critical load requires. This is because LCM1 will allow power flow either to or from the 760Vdc bus as needed to continue to support the critical load through LCM2. We call this "high efficiency" mode, since when the microturbine engine is running it can also provide exhaust energy for heating or chilling. This PIER project utilizes the exhaust for directly firing an absorption chiller. If the utility source has a voltage disturbance that goes outside of preset protective relay limits, or stops power altogether, the battery can provide power instantaneously to the 760Vdc bus through the BCM and continue to supply the critical load without interruption. Capstone calls this "Emergency" mode. If the turbine is not already running, the battery will also provide energy to start the engine. If the turbine is already running, the internal control software will adjust its power output to match the critical load.

You can see from the comparison of these two systems that the major hardware building blocks are the same, and the major development effort was to modify the control software to operate in UPS Normal, High Efficiency, and Emergency modes. A master control unit (Hybrid UPS Controller) was also developed to provide a convenient customer user interface to the system, and is based on an existing Capstone hardware platform.

During development testing, both individual batteries (meaning one per individual microturbine) and common battery (meaning one large battery connected to multiple microturbines) were successfully tested. For these test configurations, one of the DC bus legs was always solidly grounded. For this PIER project, it was decided to utilize an existing battery bank at the host site, which would provide valuable experience for future installations where the C65 Hybrid UPS would need to interface with existing UPS and battery systems. During initial commissioning, the team uncovered that the battery bank connected to one of the existing UPS units would not operate with a solidly grounded DC leg. To address this issue, Capstone developed a simple high resistance center-grounded filter that was added to each of the three microturbine DC connections, and the solid DC ground was removed. This has allowed operation with the existing battery bank and UPS system, and was tested under several load conditions to confirm battery voltages remained stable. This learning will be documented for future application, and the filter itself will be released as an accessory design when connection to an ungrounded battery bank is required.

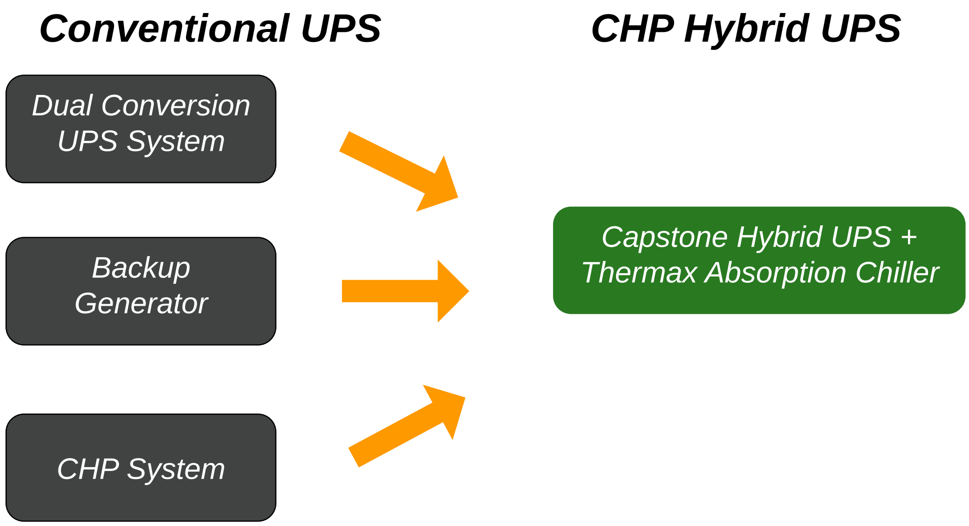
The following figures show key components of the Hybrid UPS system and operating modes:

Figure 37. Illustration of Capstone Microturbine



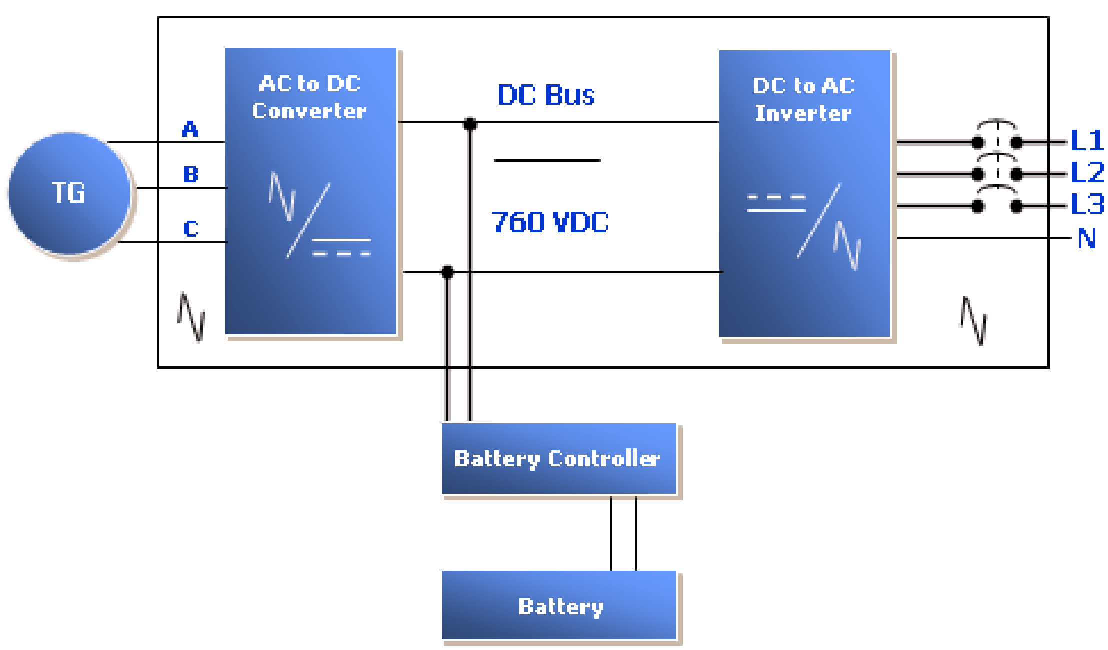
Source: Capstone

Figure 38. Comparison of Conventional UPS and CHP Hybrid UPS



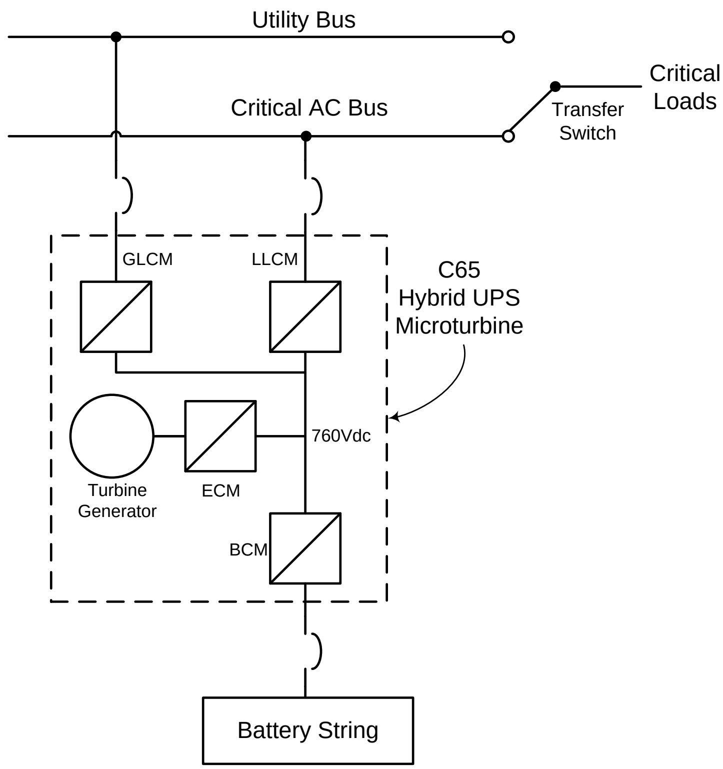
Source: Capstone

Figure 39. Inverter Based Electronics



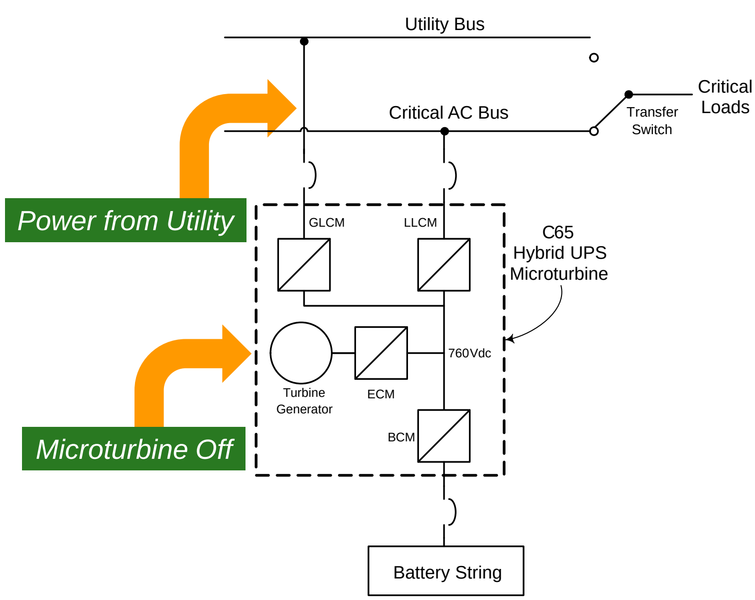
Source: Capstone

Figure 40. Hybrid UPS Solution



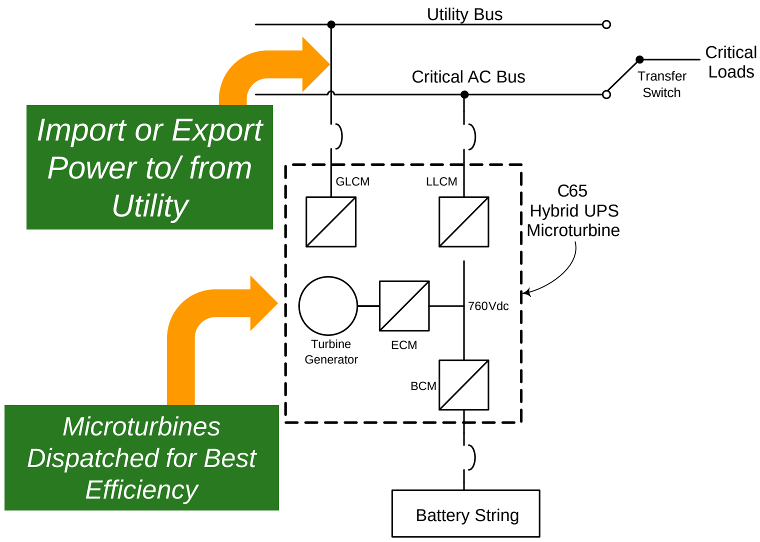
Source: Capstone

Figure 41. Standard UPS Mode (microturbines off)



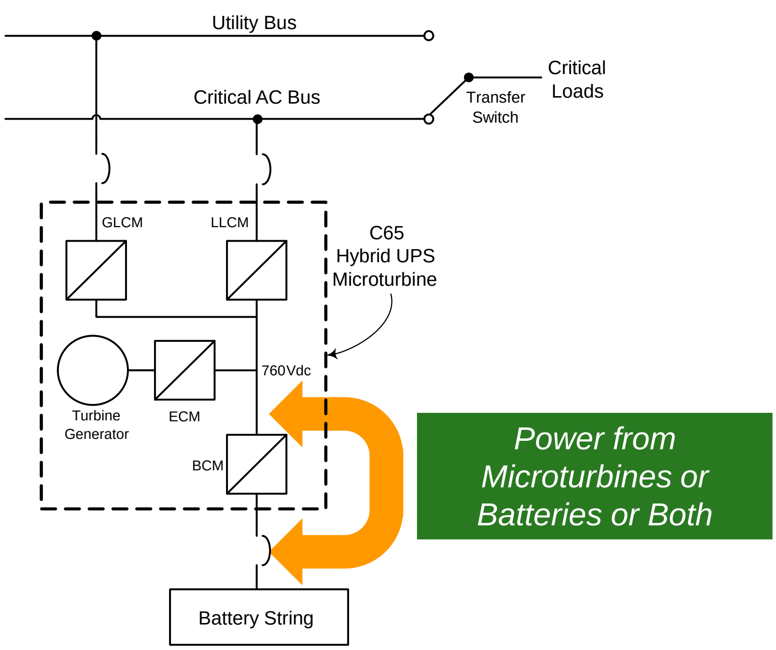
Source: Capstone

Figure 42. High Efficiency Mode (microturbines on, Thermax chiller operating)



Source: Capstone

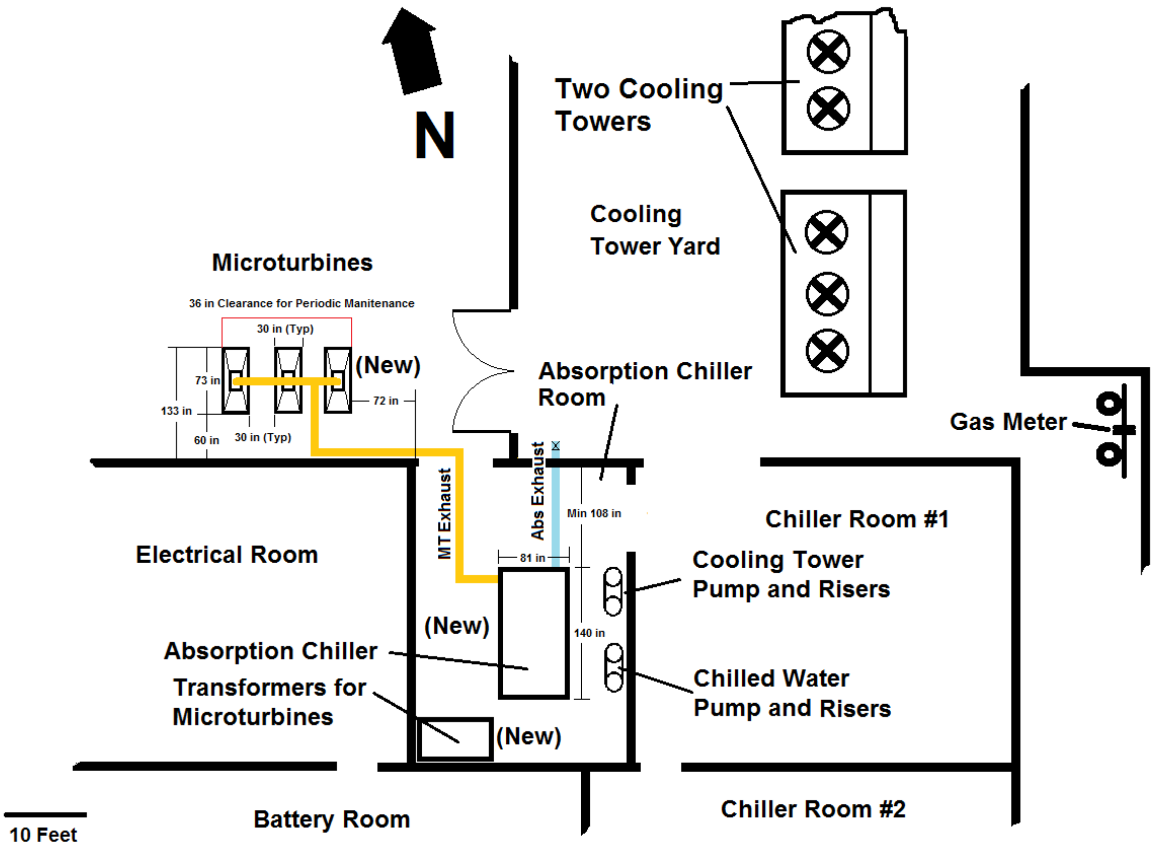
Figure 43. Emergency Backup Mode (batteries engaged, microturbines on)



Source: Capstone

APPENDIX C:
Site Plan

Figure 44. Scaled Site Plan



Source: ICF

APPENDIX D: NOx Emissions

Table 17. NOx Emissions Measured on January 15, 2015

Microturbine		Measured NOx Emissions			Electrical Conversion Efficiency		NOx (output basis)
Permit No.	Site Designation	ppm @ 15 percent O_2	ppm @ 0 percent O2	lb/MMBtu (input basis, HHV) [1]	LHV Basis [2, 3]	HHV Basis	lb/MWh
D32	Unit 1	3.00	10.6	0.0111	23.0	20.7percent	0.1822
D36	Unit 2	3.35	11.9	0.0123	23.0	20.7percent	0.2034
D37	Unit 3	3.37	11.9	0.0124	23.0	20.7percent	0.2046
---	**Average**	**---**	**---**	**---**	**---**	**---**	**0.1968**

Notes:

1) Conversion from ppm to lb/MMBtu based on EPA Method 19. Factor used is 1 lb NOx / MMBtu = 962 ppm of NOx (at 0 oxygen), web link.
2) Electrical conversion efficiency of 23 (LHV basis) is based on typical performance discussed in Chapter 5.
3) Ratio of lower heating value (LHV) to higher heating value (HHV) is 0.9.

Table 18. Electric Grid Emissions for California

Criteria Pollutant	Region	Emissions (lb / MWh)
NOx	CAMX / WECC	0.4047

Source: EPA, eGRID, 9th Edition, 2010 Data, web link.