CHP Case Studies – Saving Money and Increasing Security

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ABSTRACT

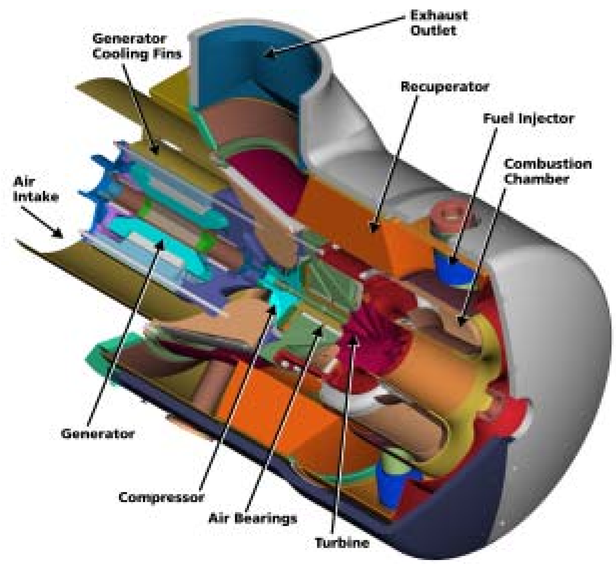
Microturbines are excellent power generators for use in combined heat and power (CHP) systems. Their low maintenance and clean exhaust make them a reliable choice for base load CHP applications. Integrating hot water heat recovery into the microturbine package has proven cost effective, and a growing number of commercial installations are saving money using this technology. Not only do microturbines provide this cost-saving performance day in and day out, but their value is further increased when the cost for traditional backup generation is eliminated. The examples sited in this paper are from the author's company, Capstone Turbine, but are intended to reflect the potential application of similar microturbine products.

MICROTURBINE TECHNOLOGY OVERVIEW

There is no formal definition for a "microturbine," however the common characteristics of today's products are simple radial compressor and radial turbine designs using a recuperator to preheat the combustion air for improved efficiency. Most designs use a single shaft onto which the radial compressor, radial turbine and generator are all coupled. This assembly is sometimes called the "turbo generator." Rotating speeds are extremely high, in the range of 45,000 to 100,000 revolutions per minute. The generator output is therefore high frequency alternating current. Figure 1 illustrates a microturbine turbo generator with annular construction recuperator.

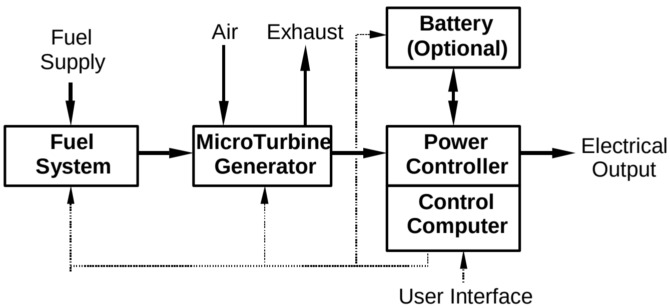
Power electronics are used to rectify this alternating current to direct current, then invert to the three-phase 50 or 60 Hertz power frequency. Insulated gate bipolar transistors (IGBT's) are commonly used, and the power electronics and controls are similar to technology used in uninterruptible power supplies and variable frequency motor drives. Integral computers control the conversion of power, operation of the turbo generator system, as well as provide convenient man-machine interface and remote communications. Because the designs are often so tightly integrated with the onboard computer, operator interface can be made both convenient and extremely powerful. Protective relay functions are also often built into the system, making microturbines extremely easy and safe to connect in parallel with an electric grid. Figure 2 provides a system diagram showing the key elements of such an electronically controlled microturbine system. One manufacturer uses a gearbox to transform the high-speed turbine output to a more traditional synchronous speed generator. In this case, synchronizing and protective relaying control is done using traditional separate control systems external to the microturbine.

Figure 1 Turbo Generator Engine



Microturbine turbo generators from most manufacturers are able to operate on a variety of fuel types: natural gas, biogas, diesel fuel, or propane. One of the characteristics of microturbines is that the fuel must be injected into the combustion chamber at relatively high pressure of three to five atmospheres. When using gaseous fuels, this requirement for fuel compression requires significant power, which must be considered part of the microturbine system when calculating net power output. Several manufacturers offer a natural gas compressor either internal to the microturbine package or directly powered and automatically controlled by the microturbine in order to simplify installation.

Figure 2. – Typical Microturbine System



Current production microturbines range in net power output from 28 to 250kW. The standard used by manufacturers for rating power and electrical efficiency for microturbines is at ISO ambient conditions of 15°C (59°F) and sea level. Electrical efficiencies relate to the lower heating value of the fuel (LHV), and are typically from the mid-twenty to low-thirty percent range, depending on fuel type and fuel compressor parasitic load. As with all Brayton cycle engines, the power and efficiency are both reduced with increased ambient temperature, resulting in performance de-rating curves, which can be obtained from the manufacturer for each specific microturbine.

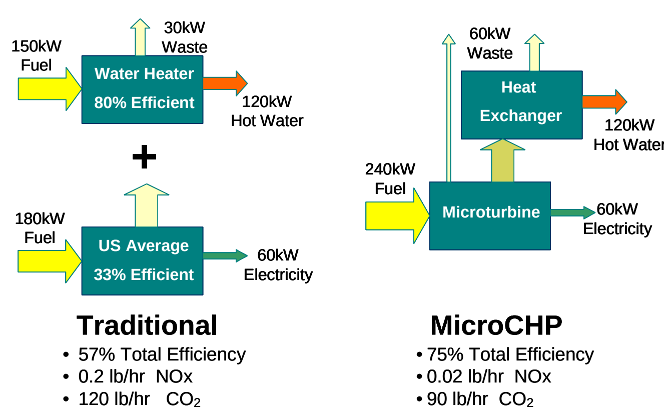
Microturbines do not have reciprocating parts that require frequent change of lubricants. Some microturbines even utilize air bearings and air cooling, thereby completely eliminating the need to change and dispose of hazardous liquid lubricants and coolants. In any case, microturbines are similar to major power plants, able to run for extended periods at full power output, and require little scheduled maintenance compared with traditional reciprocating engines of similar size. This makes them ideal for stationary prime power applications.

The combustion process in a microturbine is continuous and clean burning, similar to modern gas turbine power plants. Microturbine manufacturers have deployed state-of-the-art lean-burn combustion technology to control emissions without the need for expensive catalytic exhaust treatment equipment or chemicals. The leading microturbine manufacturers specify fewer than 9 parts per million (ppm) NOx (0.47 pounds per megawatt-hour) and similar emissions of CO at full power, and independent third parties have verified that emissions measurements are actually much lower. Because their exhaust is so clean, microturbines are relatively easy to site virtually anywhere. In Southern California, which has some of the strictest emissions standards in the world, most manufacturers have already deployed microturbines. In addition, the California Air Resources Board (CARB) set new emissions regulations for microturbines effective January 1, 2003, that are output based and must be measured over several real-world operating conditions. At least two microturbine manufacturers have now met this strict standard, and have had microturbine products certified to meet the CARB standard. Future standards, set to be imposed in 2007, will be even more stringent. This type of regulation is already facilitating installation of microturbines in California, and may become more widely accepted in all markets.

INTEGRATED CHP SYSTEMS

The benefits of combining the thermal and electrical outputs of a system are widely recognized. Extracting the exhaust energy that would otherwise be wasted increases the total system efficiency far beyond that of fossil-fueled utility power plants. This means more useful work from our limited natural resources, and less greenhouse gas emissions than using conventional energy conversion technologies. And since microturbines are already extremely clean burning, other exhaust emissions are reduced as well. Figure 3 provides an example comparing efficiency and emissions for traditional and microCHP systems with 60 kW electric output and 120 kW heat output. Note that total efficiency is significantly higher, greenhouse gas emissions (CO_2) are 25% less, and NOx emissions are an order of magnitude lower for the micro-CHP system shown. Reference emissions for the traditional system are extracted from published US Department of Energy data on efficiency and emissions from the average US fossil fuel power plant, according to US EPA data.

Figure 3. – Traditional vs MicroCHP System



These benefits of combined heat and power systems are significant for the environment and for energy conservation. National and state governments recognize the social values of such CHP systems, and often provide incentives to help develop new installations. For example, in California, the Public Utilities Commission provides up to 30% rebates for CHP installations that meet certain size and efficiency requirements; 40% if biogas fueled. The economic benefit of such microturbine-based CHP systems are becoming well accepted in the market, and example installations will be covered later in this paper.

To continue this adoption trend, however, microCHP systems must become even easier to apply and install. One example is the Capstone C60 Integrated CHP System (C60-ICHP), released in September 2003. It is, in many ways, similar to integrated CHP systems offered by Ingersoll-Rand and others. The Capstone C60-ICHP system was described in detail in a related AEE paper presented at Globalcon in Boston, Massachusetts March 24, 2004. Figure 4 shows the C60-ICHP System.

Figure 4. – C60 Integrated CHP System

CHP CASE STUDY #1 – RADISSON HOTEL

Two C60-ICHP systems are installed at the Radisson Hotel in Santa Maria, California. In this application, the hot water output is used for several different purposes. One use is for domestic hot water for the hotel guests. This thermal load is highest in the morning, and then increases again later in the day. A second use is for laundry service. This is highest during the working day. The third use is for building heat. This load is seasonal, and steady during the day when outside temperatures are low. Figure 5 shows the installation of these two C60-ICHP units at the hotel.

Figure 5. – Two C60-ICHPs at Radisson Santa Maria

The two C60-ICHP systems are set to operate in parallel with the electric grid, and Electric Priority mode is used. In this CHP mode, the electric power output for each microturbine is set at the desired level. For this Radisson hotel with 188 rooms, electric power is normally set for maximum from each microturbine during the day. This is below the building's peak electric demand, and power does not flow back into the electric utility grid. While the microturbines work to maintain their programmed electrical outputs, the exhaust diverters automatically adjust to accommodate the changing thermal requirements of the hotel. This example shows how the flexible control capabilities of the C60-ICHP allow simple integration with a building with changing thermal requirements.

The two C60-ICHP systems are set to operate 24 hours per day. The operating scheme was selected to match the thermal requirements of the hotel, provide the maximum electric energy, and reduce time-of-use demand charges from the local electric utility. This results in maximum financial benefit to the hotel, and helps to offload the utility when power is needed most by other customers. The hotel's electrical utility is PG&E, its gas utility is Sempra's SoCalGasCo. PowerHouse Energy supplied the ICHP systems to the hotel and managed the installation, system startup and continuous operation.

The ICHP application qualified for the state's PUC Self-Generation Incentive Program rebate of 30% on the total installed cost. The expected energy savings are very good, with a calculated average savings of about $5,528 a month or $66,336 per year. This savings to the hotel is net of natural gas, projected lifecycle maintenance costs, and project financing. Total installed cost was $185,000 (net of the PUC rebate), giving this project a respectable 32% IRR. The operating availability of the ICHP systems, including start up, commissioning, and service response time has been better than 95% to date.

CHP CASE STUDY #2 – INNS OF AMERICA

The Capstone microturbine installation at Inns of America in Carlsbad, California, was completed in August 2002 by California Power Partners (Calpwr). It included a Capstone C60 with fuel gas booster and separate hot water heat recovery module. Figure 6 shows the hotel with an inset photo of the 60 kW microturbine. As for the Radisson, this microCHP system provides both thermal and electric base load for this hotel. Energy savings were estimated at 40%. This lowered the daily per room energy cost by $4.00 – a significant portion of the hotel's profit margin.

Figure 6. –C60 CHP System at Inns of America

While this installation is saving the hotel owner money every day, there is a unique attribute that provided even more value than anyone envisioned when the decision to purchase this system was made. The hotel owner decided to purchase Capstone's dual mode version microturbine, with the capability to provide power even when the electric utility is not available. The logic was to avoid the cost of a traditional backup generator, thereby improving the economics of this project. Such traditional diesel backup generators are designed and permitted to operate only for short periods of time in case of a utility outage. But microturbines certified by the California Air Resources Board can operate continuously without the need for local air permits.

In October of 2003, Southern California was ravaged by multiple wildfires that lasted days and crippled the state with huge property and personal losses. Carlsbad, where the hotel is located, and the nearby San Diego region were especially hard hit. Power lines were shut down, and many homes and businesses. Figure 7 is a satellite picture of Southern California that shows the breadth of the fires' destruction.

During this time, the Inns of America lights remained on, powered by the Capstone 60kW microturbine. In support of the local community, the Inns donated a number of

Figure 7. – Satellite Photo of California Wild Fires

rooms for people who were displaced or otherwise in need. Local businesses began using the hotel's business center, and the Inns of America became an emergency base of operations for several groups. The result for the hotel was increased business and a strengthened relationship with the community – things that were never directly considered in their original decision to install a microCHP system.

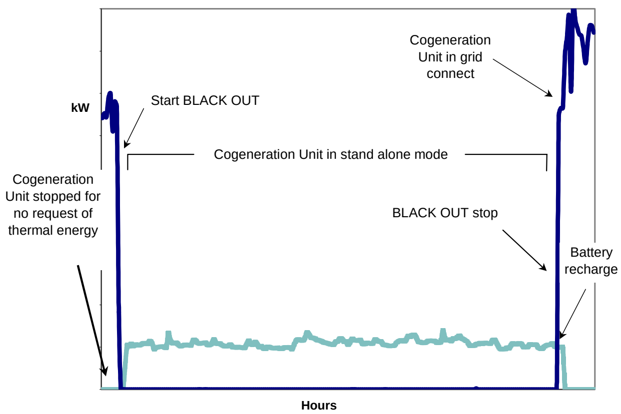
CHP CASE STUDY #3 – BAULI RESTAURANT

The US is not alone in facing extended power outages. On September 28, 2003 Italy faced a multi-hour power outage. The Bauli Grill restaurant in Verona had already installed a Capstone C60 microturbine-based CHP system with the help of the national electric utility. The primary driver for this installation was cost savings, made possible with the highly energy efficient CHP solution shown in figure 8.

Figure 8. – C60 CHP System at Bauli Restaurant

The Bauli Grill is a full service convenience restaurant located on the Autostrada, and operates 24 hours a day. At about 3:30 a.m., the utility power failed. The microCHP system was not operating at that time, as there was insufficient thermal load to make operation economical at that early hour. However, as soon as the outage occured, the Capstone C60 started up to provide power to critical loads in the restaurant. This continued until about 7:30 a.m. when utility power was restored. Figure 9 shows power data that was recorded by the electric utility, ENEL.

Figure 9. – Bauli Grill Power Outage



This roadside restaurant continued to stay open and serve travelers while virtually all of Italy was without power. Based on this demonstrated reliability and the good CHP economics, the owners of the Bauli Grill chain are now considering additional installations at their other locations.

EXPECT LONGER POWER OUTAGES

Southern California and Italy are not the only areas to be impacted by extended power outages. Whether due to natural disaster (as was the case of the Southern California wildfires), or the result of over-burdened utility grids (as was the case of the August 2003 Northeast blackout), power outages can last for many hours or even days.

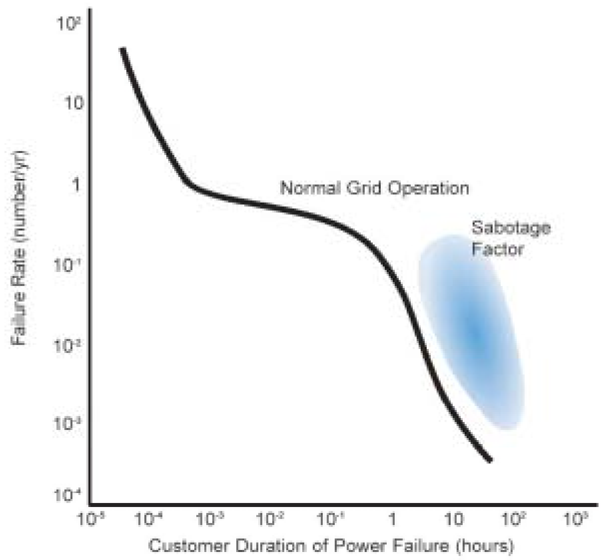
In fact, there is growing concern by many in the power industry that we face a threat of longer duration power outages in the future. In a whitepaper entitled *Critical Power* (ref www.digitalpowergroup.com), the authors describe the potential for sabotage to increase the duration of power outages many hours to days. Figure 10 compares this new sabotage factor to historical outage frequency and duration curves used to design high reliability power systems.

We can expect that security of power will become even more important to government and private industry, and the quickest way to achieve higher levels of security is through onsite power generation.

TRADITIONAL BACKUP IS NOT ENOUGH

Diesel backup generators are traditionally used to protect against extended utility power outages. However, they often fall short of expectations – especially during extended outages.

Figure 10. – Electric Grid Failures



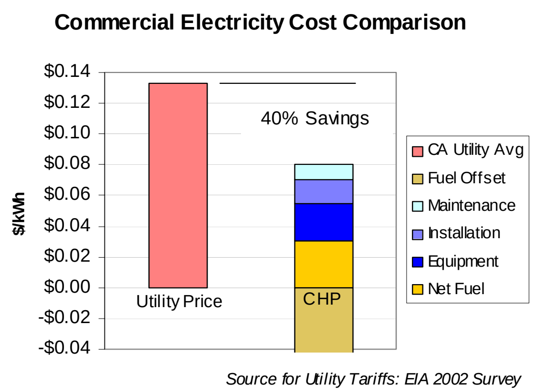
During the August 2003 Northeast blackout, about half of New York City's 58 hospitals suffered backup power failures. The reasons for this poor performance included inability to start, breakdown after starting, and lack of sufficient fuel to continue operation. The impact was exacerbated by the common practice of installing only one backup generator for critical loads. The *New York Daily News* described the resulting shuttling of patients from hospital to hospital in hopes of finding one with backup power "hospital hopscotch."

The *Wall Street Journal* reported some New York hotel operators with diesel backup generators limited the number of loads that were protected for fear that they would run out of fuel. And the industry's *Lodging* magazine reported that, like those at New York City hospitals, many backup generators could not be started or failed when presented with real-world conditions.

Solutions will include addressing problems with starting, extending fuel supply, and adding redundancy. Natural gas fired microCHP systems can cost-effectively address all these elements of good design practice. Since they run for extended periods *every* day (or continuously), the problems associated with infrequent starting are not an issue. For most outage scenarios, the natural gas supply remains available (in fact, several Capstone microturbines at a natural gas transmission plant in Ithaca, New York, kept the gas flowing throughout the outage).

Combining microturbines into a multipac system results in higher total system availability. And the best part is that a microCHP system pays for itself with energy savings. Figure 11 shows a sample calculation of how a hot water CHP system can result in 40% savings compared to purchasing power from a utility and sinking capital into a backup generator.

Figure 11. – Energy Savings Comparison



THE FUTURE IS EVEN MORE POWERFULL

The examples shown in this paper were all microCHP systems using hot water as the thermal load. As shown in the economics above, the savings can be dramatic where hot water thermal loads exist; such as in hotels, restaurants, schools, swimming pools and spas, and many industrial processes. There is a much larger potential market for cost-effective combined cooling, heating, and power systems (sometimes referred to as CCHP) or trigeneration.

Figure 12. –UTC Power's PureComfort 240M

United Technologies Corporation (UTC) recently introduced a dual-effect absorption chiller – with approximately twice the energy efficiency of single-effect chillers – that is able to directly accept the exhaust from four 60-kW microturbines. This product was developed with support from UTC's Carrier Corporation and the United Technologies Research Center, and is marketed through UTC Power. The first product is labeled "PureComfort 240M," and is offered as a complete trigeneration solution – including microturbines, chiller, and pre-engineered exhaust ducting and controls. Figure 12 shows the microturbines and exhaust ducting to the chiller during product development. UTC Power has received several orders for the PureComfort 240M, the first of which is scheduled for installation this summer.

Several examples of microturbine-driven combined cooling and power systems are now operating, using hot water driven absorption chillers and even direct-exhaust-fired chillers. As these combined cooling and power technologies continue to mature, the economic benefit will become viable for a significant number of commercial and industrial customers. The option to integrate backup functionality for these systems adds even more value for the increasing number of customers who are concerned about security of power. And since summertime load demands, and utility rates, double or triple in summer months, creating chilled water and air using heat energy instead of electric energy makes great sense.

CONCLUSION

Microturbines continue to find economic application in a growing market. Integration of hot water heat recovery, absorption chilling, and backup power functions makes for simple solutions that save money and increase power reliability, with the added social benefits of clean emissions, reduced greenhouse gas production, and more efficient use of our limited natural resources. The microCHP case studies in this paper are just a few examples of real commercial customers taking financial advantage of microturbine technology, and commercial microCCHP case studies are just around the corner.