Valuing the Reliability of Combined Heat and Power

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EPA Combined Heat and Power Partnership

The EPA CHP Partnership is a voluntary program that seeks to reduce the environmental impact of power generation by promoting the use of combined heat and power (CHP). CHP is an efficient, clean, and reliable approach to generating power and thermal energy from a single fuel source. CHP can increase operational efficiency and decrease energy costs, while reducing emissions of greenhouse gases that contribute to climate change. The Partnership works closely with energy users, the CHP industry, state and local governments, and other stakeholders to support the development of new CHP projects and promote their energy, environmental, and economic benefits.

The Partnership provides information about CHP technologies, incentives, emissions profiles, and many other resources on its Web site at: www.epa.gov/chp.

Valuing the Reliability of Combined Heat and Power (CHP)

Overview

Power reliability is a critical issue for many customers, representing a quantifiable business, safety, and health risk to their operations. These risks often compel customers to install back-up or emergency diesel generator sets, tying up significant capital in rarely used assets that require periodic maintenance and frequent testing. However, even these measures are not foolproof, as shown during the Northeast blackout of 2003, when half of New York City's 58 hospitals suffered failures in their back-up power generators.[1]

CHP can be a reliable and cost-effective alternative to installing unproductive back-up generators to provide protection against extended outages. A CHP system is typically selected for a facility due to its ability to reduce operating costs and overall emissions. However, power outage protection can also be designed into a CHP system that efficiently provides electricity and thermal energy to the site on a continuous basis. CHP systems can be configured in a number of ways to meet the specific reliability needs and risk profiles of various customers, and to offset the capital cost investment for traditional back-up power measures.

A key step for a customer considering a potential investment in CHP as a solution to reliability concerns is to identify and quantify the value of reliable power to their operations and compare these costs to those associated with configuring CHP to include outage protection.

Reliability Issues and Frequency

Reliability is often defined as how often and how long electric power service is interrupted. Service interruptions and variations in power quality can happen at any time. Although most grid outages are momentary occurrences that are generally brief and do not adversely impact anyone other than the most sensitive operations, an average facility can expect to experience an extended outage (lasting more than five minutes) every other year.[2]

In disaster situations, power outages can have dramatic effects. During the blackout of 2003, portions of the Midwest, Northeast, and Ontario, Canada were without power for up to four days in some locations. Total losses related to the power outage were estimated to top $10 billion, with more than 50 million people affected.

The cost of a service interruption varies by customer and is a function of the impact of the interruption on the customer's operations, revenues, and/or direct health and safety. As an example, Pacific Gas & Electric Company (PG&E) researched the estimated direct costs of outages to their customers (based on a combination of direct cost measures and willingness-to-pay indicators) and showed that the value of service can vary widely by customer class (Table 1).[3] PG&E estimated the total annual cost of power outages to its customers at $79 billion per year.[4]

[1] New York Times, August 16, 2003.
[2] Electric Power Research Institute (EPRI), *An Assessment of Distribution System Power/Quality: Volumes 1-3*, TR-106294 (V1, V2, V3), EPRI, Palo Alto, CA, 1995.
[3] California Energy Commission (CEC), *The Cost of Wildlife-Caused Power Outages to California's Economy*, Energy and Environmental Economics, CEC Report CEC-500-2005-030, February 2005.
[4] Kristina H. LaCommare and Joseph H. Eto, *Understanding the Cost of Power Interruptions to U.S. Electricity Consumers*, Lawrence Berkeley National Laboratory, September 2004.

Table 1. Estimated Direct Costs of Outages for PG&E Customers

Customer Class	$/kWh unserved
Industrial	$12.70 – $424.80
Commercial	$40.60 – $68.20
Agricultural	$11.50 – $11.70
Residential	$5.10 – $8.50

Power Sensitive Loads

For certain types of customers, reliability is a true business and operations issue, rather than merely an inconvenience. These customers cannot afford to be without power for more than a brief period without significant loss of revenue, critical data/information, operations, or even life.

Some particularly power sensitive customers include:

- Mission-critical computer systems
- Industrial processing companies
- High-tech manufacturing facilities and clean rooms
- Financial institutions
- Digital communication facilities (phone, television, satellite)
- Military operations
- Wastewater treatment facilities
- Hospitals and other health care facilities

Problems with Traditional Emergency Generators

There are at least five notable drawbacks to using diesel gen-sets, which are typically employed as back-up generators:

1. **Back-up diesel generators are rarely called to operate and might not start and run when needed.** Unless a facility keeps up with maintenance and frequent testing, emergency generators can fail to start on the rare occasions they are needed.

2. **Diesel fuel deliveries can be difficult or impossible to arrange during a widespread disaster.** During a major hurricane or regional blackout when a prolonged outage occurs, a diesel back-up system might have to shut down due to lack of fuel.

3. **Storing large quantities of fuel imposes high costs and risks of fuel leakage or fuel degradation.** Diesel fuel begins to chemically break down within 30 to 60 days of delivery and tends to absorb moisture from the air. These fuel quality issues can lead to unreliable engine operations and higher maintenance costs if fuel storage is used to hedge against potential shortages.

4. **Diesel engines used for back-up service typically have high emissions and are permitted for limited use.** Having limited permitted hours for operation makes it difficult to keep the engines in the proper state of readiness and prevents generator use for meeting general facility energy needs or reducing operating costs.

CHP as a Reliability Solution

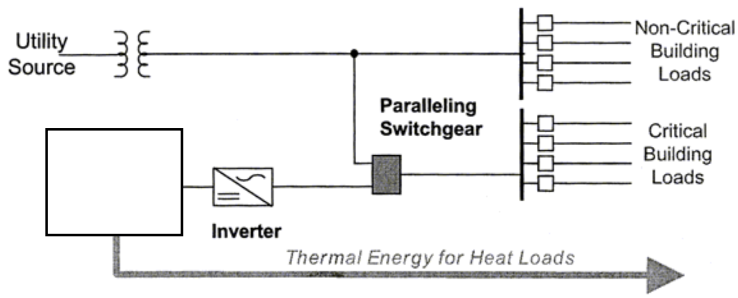
Rather than install a diesel back-up generator to provide outage protection, a facility can design capability into a CHP system that provides electric and thermal energy to the site on a continuous basis, resulting in daily operating cost savings (**Figure 1**). In this type of configuration, the CHP system would be sized, as normal, to meet the base load thermal and electricity needs of the facility. Supplemental power from the grid would serve the facility's peak power needs on a normal basis and would provide the entire facility's power when the CHP system is down for planned or unplanned maintenance. However, the CHP system would also be configured to maintain critical facility loads in the event of an extended grid outage. In order to operate during a utility system outage, the CHP system must have the following features:

1. **Black start capability.** The CHP system must have a battery-powered starting system.

2. **Generator capable of operating independently of the utility grid.** The CHP electric generator must be a synchronous generator, not an induction generator that requires the grid power signal for operation. High frequency generators (microturbines) or direct current (DC) generators (e.g., fuel cells) need to have inverter technology that can operate independently from the grid.

3. **System integration with load shedding.** The facility must match the size of the critical loads to the capacity of the CHP generator. These loads must be isolated from the rest of the facility's noncritical loads, which must be shut down during a grid system outage using appropriate switchgear and control logic. The critical load isolation approach can be manual or automatic and can be configured to incorporate dynamic prioritization of load matching to the CHP system capacity.

Figure 1. CHP System with Back-Up Responsibility for Critical Loads



The additional costs for switchgear and controls for a CHP system depend on the level of control and the speed with which the facility needs to have the CHP system pick up the critical loads in the case of a utility power outage. **Table 2** describes three levels of protection—manual, automatic, and seamless—and site-specific costs for reconfiguring the site wiring and control panels to isolate and serve the critical load. The level of back-up capability and control chosen for a CHP system will be directly tied to the value of reliability and risk of outages for the customer.

Manual control requires an operator to isolate the generator to the emergency circuits using manual transfer switches. An *automatic* transfer switch eliminates the need for operator intervention. The generator is switched to the emergency circuit automatically, a process in which the circuit is open for only a fraction of a second (5-10 cycles). *Seamless* transfer—most often integrated with a full uninterruptible power supply (UPS)—utilizes a more costly, closed transition, automatic transfer switch with bypass isolation. This switch is a "make-before-break" design that momentarily parallels the two circuits before switching. An isolation bypass switch allows removal of the automatic switching mechanism in the case of failure, with the ability to then manually switch the load.

Table 2. Control Costs for Generator Back-Up Capability[5]

Control Level	Time to Pick Up Load	Equipment Required	Capital Cost
Manual	Up to an hour	· Engine start · Manual transfer switch · Distribution switchgear	$20–$60 per kW
Automatic	5 to 10 cycles when running	· Engine start · Open transition automatic transfer switch · Distribution switchgear	$25–$105 per kW
Seamless	¼ to ½ cycle when running	· Engine start · Closed transition automatic transfer switch with bypass isolation · Distribution switchgear	$45–$170 per kW
Reconfiguring for Load Shedding	Not applicable	As needed by the site: · Design · Engineering · Rewiring · Added electrical panels, breakers, controls	$100–$500 per kW

Note: Cost range figures represent estimates for a 500 kW CHP system at the high end and a 3,000 kW CHP system at the low end. Cost estimates do not include recircuiting costs, which depend on site needs.

Estimating Costs of Outages

Traditionally, facilities have perceived that it is difficult to quantify the value of reliability to their operations; however, to justify the added costs of configuring a CHP system to provide stand-alone power, the value of reliability must be determined as a factor in the feasibility analysis. At least two different approaches can be used to estimate the value of reliability:

1. Estimate the direct costs of service interruptions based on experience. Customers pay for electricity based on the utility cost of service. While the cost of service determines the electric rates, the *value* of that service is different for each customer. When power delivery is disrupted, customers generally experience losses to their operations that are much greater than the cost of the electricity not delivered. The value of these losses can be referred to as the customer's value of service (VOS). VOS can be measured in terms of the *direct costs* of an outage. Power outages or service interruptions can impose direct costs on customers in a number of ways:

- Damaged plant equipment
- Spoiled or off-spec product
- Extra maintenance costs
- Cost for replacement or repair of failed components
- Loss of revenue due to downtime that cannot be made up
- Costs for idle labor
- Liability for safety/health

Some customers can determine their VOS—the direct costs of outages—by reviewing recent outage history and estimating an annualized cost of outages to their operations. One approach is to quantify the

[5] Adapted from: K. Darrow and M. Koplow, *Dual Fuel Retrofit Market Assessment*, Onsite Energy Corporation for Gas Research Institute, 1998. (Costs escalated at 3 percent per year for equipment and 6 percent per year for labor.)

direct cost impacts of momentary outages (less than 10 seconds) on either a dollars per incident or dollars per minute basis if the momentary outage results in an extended disruption at the facility, and to similarly quantify the direct cost impacts of extended outages (greater than 10 seconds) on a dollars per minute or dollars per hour basis. Estimates of typical annual values for the number of momentary outages and total time of extended outages can be determined by reviewing utility bills and/or facility records. The resulting cost value represents an annual direct operating cost that could be avoided with a properly configured CHP system and would be treated as operating savings in a CHP feasibility analysis. Dividing this total cost value by the number of unserved kWh (average power demand in kW times total annual outage time in hours) produces a value of service estimate similar to those included in **Table 1**.

Table 3 presents an example of how to quantify the cost of facility disruptions due to both momentary and long-term outages. The number of occurrences in this example is based on electric industry survey data[6]. The disruption caused by a particular type of outage is customer specific. In this example, even momentary outages cause extended disruption to plant operations (30 minutes), as would be the case where production is controlled by programmable logic controllers that need to be manually reset after an outage. The cost of an outage for this customer is estimated at $45,000 per hour of disruption based on operating history. Assuming an average plant power demand of 1,500 kW, the value of service is estimated to be $30/unserved kWh; this is towards the lower range of outage costs for industrial customers as shown in **Table 1**.

Table 3. Value of Service Direct Cost Estimation and CHP Value

Facility Outage Impacts			Annual Outages		Annual Cost	
Power Quality Disruptions	Outage Duration per Occurrence	Facility Disruption per Occurrence	Occurrences per Year	Total Annual Facility Disruption	Outage Cost per Hour*	Total Annual Costs
Momentary Interruptions	5.3 Seconds	0.5 Hours	2.5	1.3 Hours	$45,000	$56,250
Long-Duration Interruptions	60 Minutes	5.0 Hours	0.5	2.5 Hours	$45,000	$112,500
Total			3.0	3.8 Hours		$168,750
Unserved kWh per hour (based on 1,500 kW average demand)			1,500 kWh			
Customer's Estimated Value of Service (VOS), $/unserved kWh			$30 /unserved KWh			
Normalized Annual Outage Costs, $/kW-year			$113 $/kW-year			

* Outage costs per hour estimated based on facility data and include production losses, increased labor, product spoilage, etc.

2. Estimate the willingness-to-pay to avoid loss of service. Because outages occur infrequently at different times and last for different durations, it is sometimes difficult to determine the annualized cost of outages. In this situation, customers can use an alternative measure to estimate the value of reliability—their *willingness-to-pay* to avoid loss of service. If customers invest in back-up power generators, a second utility feed, power conditioning equipment, or UPS, these costs represent their willingness-to-pay to avoid an outage and therefore, represent an approximation of how much they value reliable electric service. The costs of these measures (e.g., the capital and maintenance costs of back-up generators) can be quantified and are important to consider as cost offsets in a CHP feasibility analysis.

As an example of how these cost offsets can impact CHP economics, **Table 4** provides an economic comparison of a hypothetical 1500 kW natural gas-fueled CHP system with and without the capability to provide back-up power to a site during grid power outages. The impact of enhanced reliability is calculated two different ways. The first method is based on a customer's specific calculations for the value of service and expected number of hours per year of facility disruption that could be avoided (**Table 3**) with a CHP system that includes back-up capability. For a customer with a VOS of $30/unserved kWh and an expected decrease in downtime of 3.75 hours/year, the internal rate of return for the CHP project example

[6] An Assessment of Distribution System Power Quality, Volumes 1-3, TR-106294-V1, V2, V3, EPRI, Palo Alto, CA, 1995.

increases from 12.2 percent for the standard CHP system to 17.5 percent for the system with back-up capabilities, and the net present value increases by a factor of four. The second approach, based on willingness to pay, is simply to take a capital cost credit for avoiding the cost of a diesel back up generator. A capital credit is taken for the back-up gen-set, controls, and switchgear that would not need to be installed at the site because back-up capability is integrated into the CHP system (note that the CHP system includes an additional capital cost for this capability, but the incremental capital cost is more than offset by credit from the displaced back-up gen-set). With the second method, the simple payback for the CHP system is reduced from 6.8 to 5.3 years and the internal rate of return is increased to 16.9 percent.

Table 4. CHP Value Comparison With and Without Back-Up Power Capability[7]

CHP System Components	Standard CHP (no off-grid reliability benefit)	CHP With Back-Up Capabilities – Direct Cost Measure	CHP With Back-Up Capabilities – Avoided Diesel Generator Measure
Generator Capacity (kW)	1500	1500	1500
CHP System Installed Cost, ($/kW)	$1,800	$1,800	$1,800
Added Controls and Switchgear Cost, ($/kW)	N/A	$175	$175
Typical Back-Up Gen-Set, Controls, and Switchgear, ($/kW)	N/A	Not valued directly	($550)
Total CHP System Capital Cost, ($/kW)	$1,800	$1,975	$1,425
Total CHP System Capital Cost, ($)	$2,700,000	$2,962,500	$2,137,500
Net Annual Energy Savings, ($)	$400,000	$400,000	$400,000
Decrease in Annual Outrage Time (hours/year)	0	3.8 hours	Not valued directly
Customer Value of Service ($/kW-year)	N/A	$113/kW-year	Not valued directly
Annual Decrease in Outage Costs	N/A	$168,750	Not valued directly
Total Annual Savings	$400,000	$568,750	$400,000
Payback	6.8 Years	5.2 Years	5.3 Years
Internal Rate of Return	12.2%	17.5%	16.9%
Net Present Value (at 10% discount)	$311,302	$1,239,507	$822,665

It should also be noted that a properly configured CHP system can provide better protection than a back-up generator because the CHP system reduces the time to pick up load (when it is running), and it provides a measure of voltage support that helps to protect the facility from momentary, as well as extended outages.

[7] Adapted from *The Role of Distributed Generation in Power Quality and Reliability*, Energy and Environmental Analysis, Inc. for New York State Energy Research & Development Administration. June 2004.