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Ensuring emergency power for critical municipal services with natural gas-fired combined heat and power (CHP) systems: A cost–benefit analysis of a preemptive strategy

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Abstract

Electric power failures in the aftermath of disasters cripple the delivery of critical emergency services. While emergency generators are available in some facilities, these systems are designed for short-term use and support limited functions. The substantial investment required to ensure emergency power for all critical services is difficult to justify because of the uncertainty associated with the likelihood and magnitude of future disasters. Investment evaluations change when a new source of emergency power is considered. This study evaluates the costs and benefits of a program to preemptively install new building-sited electric combined heat and power (CHP) generation technologies to ensure reliable long-term power for critical municipal services in hurricane-prone regions of the US. Three municipalities are selected for this analysis: Houston, Texas; Miami, Florida; and Charleston, South Carolina. Analysis indicates that costs of such a program can, in some cases, provide net energy bill savings regardless of the occurrence of a disaster.

Keywords: CHP; Distributed generation; Emergency power

1. Introduction

Emergency generators in disaster-prone areas are typically designed for short-term use for only the most vital municipal services. Post-disaster health care, shelter and public safety are extremely limited and in some cases virtually non-existent, largely due to electric system failures (US House of Representatives, 2006). Evaluating the future benefits of more extensive emergency power systems as part of a risk management process is difficult because of uncertainty associated with the likelihood and magnitude of future natural disasters. The expected benefit of additional investments in emergency generation equals the product of estimated benefits and the probability of occurrence. The probability of a disaster at any one specific location is exceedingly small, resulting in limited expected benefits. Consequently, existing emergency generation systems are typically determined by minimal requirements specified in existing health and safety codes.

Cost–benefit calculations for expanding municipal emergency power capabilities can change substantially, however, by considering a different source of emergency power available with new building-sited combined heat and power (CHP) electric generation (US Department of Energy, 2000, 2002). Instead of traditional emergency generator applications, these technologies are integrated in building energy systems to continuously provide some portion of a facility's electricity and thermal energy needs, including space heating, water heating and air conditioning. In the event of a power outage, these systems continue to operate, providing power for critical services. The economic benefit during normal daily operation helps offset some or all of their costs.

While CHP systems are widely recognized as useful for emergency power applications (Hordeski, 2005; Gulf Coast CHP Application Center, 2006), no analysis has been conducted to evaluate the costs and benefits of a program to preemptively install CHP systems to provide critical

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Table 1
Characteristics of three study locations

	Charleston	Houston	Miami
Mean January temperature, °C (°F)	8.8 (47.9)	11.0 (51.8)	20.1 (68.1)
Mean July temperature, °C (°F)	27.6 (81.7)	28.7 (83.6)	28.7 (83.7)
Population (2005)	106,712	2,016,582	386,417

Sources: Comparative Climatic Data, National Climatic Data Center, US National Oceanic and Atmospheric Administration, 2001, US Census Bureau, 2005.

emergency services for an entire municipality. Economics of CHP systems depend on (1) hourly energy use characteristics of critical service buildings, (2) CHP system characteristics and (3) electric and natural gas prices. Under the right circumstances, CHP systems can provide net economic savings over time, reducing the cost of expanding critical services emergency power systems.

This paper evaluates the costs and benefits of preemptive municipal disaster preparedness programs to provide minimum levels of CHP-generated electric power required for critical disaster management, safety, health and temporary shelter services during widespread and prolonged central electric system outages in hurricane-prone areas of the US.

Three municipalities are selected for this analysis: Houston, Texas; Miami, Florida; and Charleston, South Carolina. These locations are all in the "strike zone" of Caribbean-spawned hurricanes and each reflects different climate characteristics as indicated in Table 1.

Variations in hourly heating and cooling energy use help determine system configuration and energy cost savings that can occur with CHP systems. As indicated in Table 1, Miami has by far the warmest climate in the winter season (January). All three locations are characterized by warm summer seasons requiring substantial air conditioning. Municipalities range in size from Charleston, with a population of 106,712, to Houston, with over 2,000,000 inhabitants.

The remainder of this paper is organized as follows. The next section describes new CHP technologies and potential CHP economic advantages relative to emergency-only generators. Section 3 identifies critical service building facilities used in the analysis and describes the development of hourly electricity and natural gas load data required for CHP system design and economic analysis. The next section discusses CHP system design and economic analysis methodology. Analysis results are then presented, with the final section providing a summary of this research.

2. New building-sited combined heat and power technologies

Recent advances in CHP technologies provide building-sited electric generation that can serve both as an emergency source of electric power and as an integral component in meeting the daily energy needs of most commercial buildings. These CHP systems provide electricity and utilize waste heat from the generation process in existing building thermal applications such as space heating and domestic water heating. Thermal energy can also be used in an absorption refrigeration cycle to provide air conditioning and refrigeration. CHP systems, also referred to as cogeneration and distributed generation systems (DG), have been used for decades in large industrial plants and some large commercial complexes; however, recent technology extensions provide smaller, more economical units packaged with heat exchangers, remote monitoring and control capabilities and thermal applications such as absorption air conditioning. While these systems cost more than electric-only emergency generators, they can provide daily savings in energy costs that pay for part or all of the system over time.

Modern CHP systems include: (1) a prime mover, (2) heat exchangers, (3) end-use applications and (4) controls and monitoring systems. Natural gas engines are the most common prime mover; however, microturbines, fuel cells and sterling engines are also used. Heat exchangers transfer waste heat to useful thermal end-use applications. Controls and monitoring systems provide for offsite monitoring and continuous maintenance practices to limit unscheduled downtimes.

CHP systems with capacities as small as 6 kW are available (Aisin, 2006); one larger packaged system, the United Technologies PureComfort product, includes from four to six 60 kW microturbines with a double-effect absorption chiller/heaters in balanced electric–thermal designs (United Technologies, 2006). Manufacturer and installer-provided warranties along with the remote sensing and control capabilities of these systems allow building owners to take advantage of CHP technology with no onsite engineering expertise or maintenance responsibilities. CHP systems are being used in offices, restaurants, grocery stores, nursing homes, and other commercial and institutional buildings. Fewer than 5000 of the new smaller CHP systems have been installed in the US in the last 5 years (Jackson, 2005); however, a series of studies indicate that their market share could potentially reach as much as 20 percent of the US commercial, government and institutional sectors (US Department of Energy, 2000).

Table 2 shows a cost comparison between an electric-only emergency generator and a CHP system for a 5800 square meter (61,400 square foot) nursing home in Miami. Both systems provide the same generation capacity, 120 kW, providing approximately 54 percent of non-emergency electricity use for the entire facility or 100 percent electricity use in a system designed to support one-half of the facility during an emergency. The CHP system costs twice as much as the electric-only system; however, it provides daily energy cost savings that are not available with the electric-only system. This example includes a natural gas engine with 31.7 percent electric efficiency and the ability to use 48.7 percent of the natural gas input