

# A MULTIFACETED VIEW OF DISTRIBUTED GENERATION SYSTEMS AND THEIR IMPACTS

**Marcelo Algrain, Ph.D.**

Engineering Technical Steward

Electric Power Division

February 2014

**CATERPILLAR®**

# ABSTRACT

The term distributed generation (DG) encompasses a wide range of electric power generation sources – from a residential rooftop photovoltaic resource to a large wind farm.

Hence, the impact of DG varies significantly depending on the context with its neighboring utility. In parts of the world lacking major infrastructure, the impact of DG takes on major proportions. It creates oases of power fueling economic

growth, improving quality of life and enabling basic needs that most of us take for granted. In other cases, DG impact is not as dramatic, as it may be seamlessly integrated into the local utility, making its presence somewhat stealthy, although its absence could be highly noticeable.

The aim of this paper is to raise awareness on the diversity of issues associated with DG applications. To that end, several DG installations are reviewed here within.

# INTRODUCTION

DG is commonly defined as electric power generation facilities that are not directly connected to a bulk power transmission system<sup>1</sup>. It covers a multitude of energy sources, fuels and conversion methods to produce electricity through photovoltaic (PV) arrays, wind turbines, fuel cells, microturbines, liquid and gas-fueled reciprocating engines, etc.

Given the wide variety of sources, it is natural that specific impacts associated with DG would vary with type and application. However, there are many common threads on how DG benefits the customers it serves and society at large. This is demonstrated in this paper through several examples, giving testimonials of the positive impact these installations have.

# EXAMPLES

## Case 1 – Emergency/Temporary Power Application<sup>2</sup>

In mid-November 2007, the town of Chester, California, was preparing to undergo a 72-hour power shutdown. This was required to improve the service reliability in Chester after past sustained outages due to circuit configuration, condition and exposure.

For that reason, Pacific Gas and Electric (PG&E) would replace 41 power poles and their cross-arms on its Hamilton Branch transmission line. This line serves Chester with 1,652 electric meters within the community and accounts for a combined electrical demand in the range of 1.9 MW to 2.4 MW. Given PG&E's commitment to customer satisfaction, and to maintaining their service uptime percentage as high as possible, a prolonged outage was really not a viable option.

The solution was a temporary DG installation consisting of two 2 MW diesel generator sets operated through a parallel configuration with the PG&E power supply (see Figure 1). With this configuration, only two brief electrical clearances, totaling less than 30 seconds, were necessary. Over 2,378,880 outage minutes were avoided for PG&E customers.

Chester's lights remained on and the aging poles were replaced. PG&E avoided the combination of lost power sales during any outage, and the added expense and safety concerns of having to work crews around the clock for 72 hours to replace all the poles.



Figure 1: Cat® XQ2000 Power Modules in Chester

### Case 2 – Open-Market Price Hedging<sup>3</sup>

The volatility in the energy market was greatly affecting the power department budget in the city of Hurricane, Utah. Its population surged from 8,250 in 2000 to 12,084 in 2006 – an increase of 46.5 percent. That growth put stress on the municipal power system, operated by Hurricane City Power, especially in the summer when temperatures can exceed 110°F. This demand, coupled with high prices on the energy market, forced the city to dip into budgetary reserves to pay for power a few years in a row.

In order to diversify its electric supply options, Hurricane turned to natural gas generator sets. The city's new generator sets would have to meet Hurricane's needs – load following, summer peaking and open market price-hedging strategies. Hurricane also needed to boost end-of-line voltage and frequency for distribution system enhancement.

Over a period of three years, six Cat® G3520C natural gas generator sets with Cat oxidation catalysts were installed (see Figure 2). The catalysts lower emissions of carbon monoxide by 93% and decrease hydrocarbons by more than 40 percent, greatly reducing the generator sets' environmental impact. One of these units serves the nearby city of Washington and is used when supplemental power is needed there. The generator sets are rated at 1,940 kW at 1800 rpm, in 115°F temperature and at an elevation of 3,000 feet. They operate together with paralleling switchgear at 12,470 V. This power is connected directly to the adjacent substation's distribution buss.

### Case 3 – Combined Heat and Power and Standby Power for Hospital<sup>4</sup>

A cost-effective combined heat and power (CHP) and standby power generation package was required for the Norfolk and Norwich Hospital being built by Octagon Healthcare in the United Kingdom. In addition, tariff quality metering was necessary to qualify the CHP as eligible for payment under the Climate Change Levy "Good Quality CHP" scheme.

Rather than the usual basement plant room, a stand-alone energy center was built to give better access for servicing and supplies. The CHP system prime mover is a Cat G3516 lean burn gas engine. Heat is recovered from the engine exhaust, jacket water and oil cooler circuits, to provide 1314 kW. It used heat the returning medium-pressure hot water before it re-enters the boiler, so the CHP acts as lead boiler. When thermal demand is low, excess heat is dumped to a remote radiator. A Cat SR4 generator directly linked to the engine provides 400 volts at 50 Hz. This feeds a synchronizing

The reliability and cost-effectiveness of this power solution earned Hurricane City Power and Washington City Power a joint award in 2007 for the "Most Improved System of the Year" from the Utah Associated Municipal Power Systems (UAMPS). The city has been able to save as much as \$10,000 to \$12,000 a day because of its ability to react to market prices quickly, and run the generators instead of buying power on the market when the cost is high. In addition to cost savings for the city, the generator sets provide peak power production support and backup power in case of a citywide blackout. Three area blackouts have occurred in the three years since this system has been in place, and the generator sets have provided the power needed to get the city up and running when no outside power was available.



Figure 2: DG in Hurricane City Power Plant

circuit breaker inside a control panel, in turn connected to the hospital's HV line via a step-up transformer. The complete system is displayed on a graphical overview – a simple touch of the screen is all that is required for an operator to interact with the system.

The standby generation system comprises four 2250 kVA (1800 kW) Cat 3616B diesel generator sets guarding against utility failures. Generators work in an "n+1" configuration so that full coverage of the hospital power requirements continues if one set is unavailable, perhaps due to servicing at the time of power failure. The generators are connected to the hospital heating and ventilation power feed via an HV switchboard. Like the CHP system, the master control panel provides a graphical overview of the system. Restoration to utility power, once service has been deemed to be back to normal, is fully automatic. The system is tested monthly with a real disconnection from the utility supply.

**Case 4 – Landfill Applications<sup>5</sup>**

Landfill-gas-to-energy embodies the ideal solution to an environmental problem: it turns nuisance waste into a product with a practical use and economic value. It is an important and growing component of North America’s power generation mix. Generation from municipal solid waste and landfill gas is projected to increase to about 31 billion kilowatt-hours by 2025<sup>6</sup>. Although the U.S. leads in this category, landfill gas is globally available as the chart in figure 3 below illustrates<sup>7</sup>.

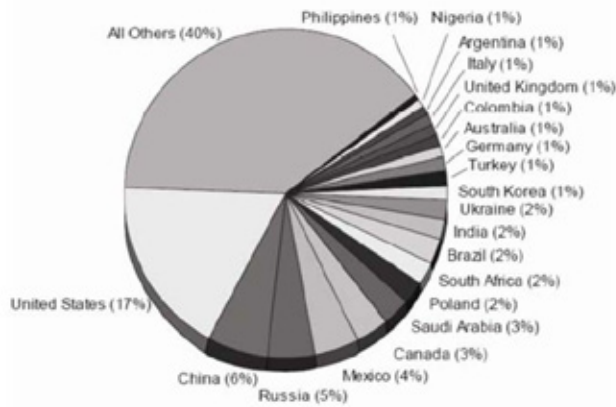


Figure 3: Estimated Global Landfill Methane Emissions (2005)

Landfill gas (LFG) is produced naturally as organic waste decomposes in landfills. LFG is composed of about 50 percent methane, about 50 percent carbon dioxide and small amounts of non-methane organic compounds. At most municipal solid waste landfills, the methane and carbon dioxide are destroyed in a gas collection and control system or utility flare. However, to use LFG as an alternative fuel, the gas is extracted from landfills using a series of wells and a vacuum system. Pipes



Figure 4: Landfill Gas Engine Generator Set

are inserted deep into the landfill to provide a point of release for the landfill gases. A slight vacuum is then applied in the pipe to draw the gases into and through it to a central point, where it can be processed and treated for use in generating electricity, replacing the need for conventional fossil fuels. The following pages provide a few examples from around the world of how LFG is used to produce electric power through engine generator sets (see Figure 4) in landfill configurations.

**Seneca Meadows Landfill, Seneca Falls, New York**

This energy system, owned by Innovative Energy Systems of Oakfield, New York, began operation in 1996 and has been expanded three times to its current 11.2 MW capacity. The system (see Figure 5) uses 14 Cat G3516 generator sets that have been modified for landfill use. Overall energy plant NO<sub>x</sub> emissions are compliant with local air quality standards.



Figure 5: Seneca Meadows Landfill, Seneca Falls, New York

**South East New Territories Landfill, Hong Kong**

This site operated by Green Valley Landfill Ltd., installed two Cat G3516 landfill generator sets in 1997. Each unit is rated at 970 kW, providing 1.9 MW of continuous power for the landfill infrastructure and an on-site wastewater treatment plant (see Figure 7). The units operate in parallel with the local utility, exporting excess power to the grid. The generator sets have oversized radiators to compensate for tropical heat and humidity.

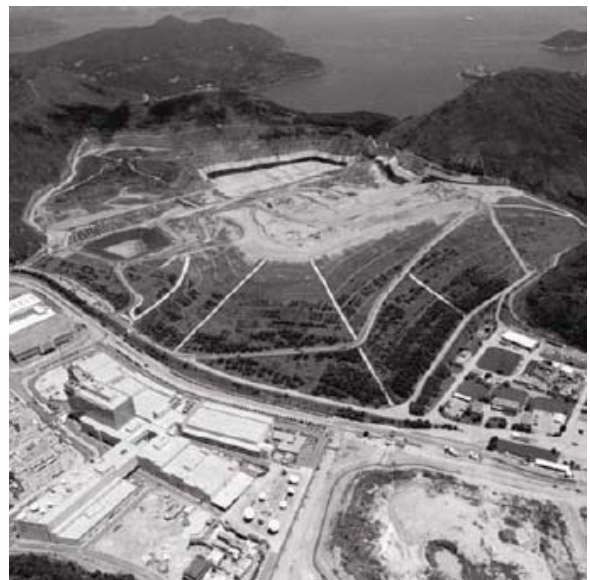


Figure 7: South East New Territories Landfill, Hong Kong

**Hartland Landfill in Victoria, British Columbia, Canada**

The landfill receives municipal solid waste from a population of roughly 400,000. Until the power generating system went online, the landfill gas had been flared. Independent power producer Maxim Power Corporation of Calgary, Alberta, installed the landfill-gas-to-energy system (see Figure 6). The electric energy output (continuous duty at 1.6 MW) is being sold to BC Hydro for that company's Green Power program.



Figure 6: Hartland Landfill, Victoria, British Columbia, Canada

**Case 5 – Biogas Applications<sup>8</sup>**

Biogas is produced through the natural anaerobic decomposition or fermentation of organic waste, such as manure, municipal solid waste, biodegradable waste or any other biodegradable feedstock within an anaerobic environment. Biogas consists primarily of methane (50-80 percent) and carbon dioxide (20-50 percent). Biogas can be extracted for commercial use from almost any of its sources. For example, some livestock farms or large feeder operations use a lagoon to store the manure generated by their livestock.

Instead of releasing the methane and carbon dioxide generated by the decomposition of this manure into the atmosphere, the methane can be extracted and burned at the farm in biogas-fueled boilers, heaters or other gas consuming devices, including gas engines. In addition to livestock farms, other agricultural operations afford opportunities for biogas productions.

For example, cassava-processing plants, which produce starch, are common in China, India and Indonesia and may utilize biogas for electric power. By tapping their biogas resources, these plants not only avoid the cost of purchasing heavy fuel oil and electricity but also reclaim valuable land that would otherwise have to be used to purify the factory's wastewater, and virtually eliminate odor and pest issues caused by large-scale decomposition of organic material.

As an example of this type of DG application, let us consider the Nong Rai Farm, in Rayong, Thailand. The farm partners with the CP Group, one of the largest food suppliers in Thailand, and runs a feeder operation for more than 30,000 hogs. Nong Rai Farm consumes approximately 200 kW of power for blowers, drying systems and other auxiliary needs associated with its operations. The manure produced by its hogs is piped into a digester pond (see Figure 8), where it generates biogas that is used to fuel the generator sets, which produce sufficient power for all of Nong Rai Farm's electric power requirements.



Figure 8: Buffer Tank and Digestion Process in Thailand

**Case 6 – Coal Mine Methane (CMM) Gas Applications<sup>9</sup>**

The anthropogenic release of methane ( $\text{CH}_4$ ) into the environment and its global warming potential continues to draw attention globally. Methane can be released into the atmosphere through sources where it naturally occurs: landfill decomposition, agriculture, gas and oil extraction systems, and coal mining activities. About 8 percent of total anthropogenic methane emissions come from coal mines<sup>10</sup>.

Globally, coal mines emit approximately 400 million metric tons or 28 billion cubic meters of carbon dioxide equivalent annually. This amount is equivalent to the consumption of 818 million barrels of oil or the carbon dioxide emissions of 64 million passenger cars. Between 1994 and 2005, U.S. emissions decreased by over 20 percent, in large part due to the coal mining industry's increased recovery and utilization of drained gas. China leads the world in coal mine methane with about 14 billion cubic meters of  $\text{CO}_2$  emitted annually – a 2004 measurement estimated nearly 200 million metric tons were emitted that year. Aside from the U.S. and China, other leading emitters include Ukraine, Australia, Russia and India.

Once methane is released into the atmosphere, it remains in it for approximately 15 years. It is a greenhouse gas with an estimated global warming potential of 21. This means that emissions of methane have an estimated effect on global warming equal to 21 times the effect of carbon dioxide. Implementing methods to use CMM instead of emitting it to the atmosphere will help mitigate global warming, improve mine safety and productivity, and generate revenues and cost savings.

There are several options currently available for CMM mitigation, including reciprocating gas engines, gas turbines, industrial boilers and furnaces, and chemical processing. Other technologies like catalytic systems and fuel cells are also being developed. Two examples of this type of DG application are described next, where CMM is sequestered and used as an alternative fuel for reciprocating gas engine generator sets. This is a mature and proven technology, highly effective for greenhouse gas mitigation.

**Appin and Tower Coal Seam Energy Project in Australia**

The Appin and Tower project (see Figure 9) is one of the largest coal seam gas energy systems in the world and one of the world's largest engine-generator installations of any kind. The Appin and Tower projects consume 600,000 m<sup>3</sup> of coal seam gas per day from two separate mines in New South Wales, Australia. Supplementing with natural gas when necessary, the Appin and Tower project uses more than 90 Cat G3516 lean burn generator sets, each of which produces 1,030 kW of continuous power. As of the summer of 2008, most units had completed over 80,000 hours of operation.



Figure 9: Appin and Tower Coal Seam Energy Project

**Sihe Mine in Jingcheng, Shanxi Province of China**

Sixty Cat G3520C generator sets with low energy fuel packages run on CMM at the Sihe mine in Jingcheng, Shanxi province of China (see Figure 10). The Cat G3520C operates at 1500 rpm with a continuous rating of 1,966 kW under standard operating conditions. An open combustion chamber design allows it to operate using low-pressure gas supplies of just 5 to 35 kPa (0.7 psi to 5 psi). The low boost pressure requirement reduces the installation cost of the fuel treatment systems often found in low-energy fuel environments.



Figure 10: Jingcheng CMM 120 MW Power Project

When fully commissioned, the 60 generator sets will produce over 108 MW of electric power. Additionally, the exhaust will be recovered and used to drive steam turbines to produce an additional 12 MW of electric power. The eventual production target is a combined 120 MW with jacket water heat recovery for hot water production. This project is the largest of its kind in the world.



# SUMMARY

The prevailing focus of this paper is DG systems based on engine-driven generator sets. However, in many instances, alternate DG technologies could have been used to achieve comparable results. Several DG applications have been presented, ranging from backup power to greenhouse gas mitigation systems. With such a widespread range of applications, it is undeniable that DG has a profound and positive impact on society. Some of these applications include power outage avoidance, keeping critical operations and life safety equipment running, providing a safety net

in volatile energy markets with wild price fluctuations, creating power from sustainable resources (landfill, biogas and coal seam gas), and mitigating the release of greenhouse gases, reducing their environmental impact and global warming effects. DG has become woven into the fabric of the electric power generation infrastructure. It diversifies the electric power generation portfolio, promotes economic growth in areas that otherwise would starve from lack of power and improves quality of life for those using it.

# REFERENCES

- <sup>1</sup> IEEE Standard 1547, "Standard for Interconnecting Distributed Resources with Electric Power Systems," published by IEEE, New York, New York, July, 2003.
- <sup>2</sup> Power Profile, "Pacific Gas and Electric Company," Caterpillar publication LEXE0012-00, October 2008.
- <sup>3</sup> Power Profile, "Hurricane City Power," Caterpillar publication LEXE8829-00, May 2008.
- <sup>4</sup> Power Profile, "Octagon Healthcare Limited," internal Caterpillar document.
- <sup>5</sup> Michael Devine, "Dealing with Landfill Fuel," internal Caterpillar document.
- <sup>6</sup> Annual Energy Outlook 2004 with Projections to 2025, U.S. Energy Information Administration, U.S. Department of Energy.
- <sup>7</sup> United States Environmental Protection Agency, "Global Anthropogenic Emissions of Non-CO<sub>2</sub> Greenhouse Gases 1990-2020," EPA Report 430-R-06-003. Retrieved August 7, 2008, from <http://www.epa.gov>.
- <sup>8</sup> John C.Y. Lee, et al., "Sustainable Application of Reciprocating Gas Engines Operating on Alternate Fuels," internal Caterpillar document.
- <sup>9</sup> John C.Y. Lee, et al., "Sustainable Application of Reciprocating Gas Engines Operating on Coal Mine Methane Gas," internal Caterpillar document.
- <sup>10</sup> United States Environmental Protection Agency, "Methane." Retrieved June 6, 2008, from EPA website <http://www.epa.gov/methane>.

# ACKNOWLEDGEMENTS

This paper leverages work from several people at Caterpillar. The author is particularly thankful to Mike Devine, John Lee, Thomas Teo, Peter Lau, Choon Hwa Tnay and Don Dentino.

## ABOUT

### About Caterpillar

For nearly 90 years, Caterpillar Inc. has been making sustainable progress possible and driving positive change on every continent. Customers turn to Caterpillar to help them develop infrastructure, energy and natural resource assets. With 2013 sales and revenues of \$55.656 billion, Caterpillar is the world's leading manufacturer of construction and mining equipment, diesel and natural gas engines, industrial gas turbines and diesel-electric locomotives. The company principally operates through its three product segments – Resource Industries, Construction Industries and Power Systems – and also provides financing and related services through its Financial Products segment. For more information, visit [caterpillar.com](http://caterpillar.com). To connect with us on social media, visit [caterpillar.com/social-media](http://caterpillar.com/social-media).

Diesel Solutions Center: [www.CatElectricPowerInfo.com](http://www.CatElectricPowerInfo.com)

Online Community: <https://caterpillar.lithium.com/t5/Electric-Power-Generation/ct-p/EPG>

Facebook: <http://www.facebook.com/Caterpillar.Electric.Power>

YouTube: <http://www.youtube.com/CatPowerGeneration>

**LEXE0077-01 February 2014**