

---

# Girding the Grid: How Utilities Reduce Costs and Boost Efficiency With Gas

**Michael A. Devine**

Electric Power, Caterpillar Inc.

## **ABSTRACT**

Low natural gas prices make gas-fueled distributed generation even more viable for peaking and power stability. Here's how to evaluate the economics of an installation.

## INTRODUCTION

Distributed generation has gained favor as utilities seek cost-effective ways to keep up with rising demand for power. The concept helps forestall construction of costly centralized power plants, and power used near the point of production limits stress on distribution and transmission systems.

Natural-gas-fueled reciprocating engine-generators have served well in distributed generation service, delivering reliable power, ease of service, and low life-cycle cost. Now, near-record-low natural gas prices in many countries make reciprocating engines even more attractive. When deployed for peaking support and other strategic purposes, they deliver high efficiency, increase the diversity of the power generating portfolio, protect power quality, and shield against market power price volatility. They also offer potential for profitable heat recovery in combined heat and power configurations.

All of these factors can help utilities improve their financial position, differentiate their service to customers, retain and attract commercial and industrial users, and support community economic growth. The key to using gas-fueled distributed generation is to deploy units strategically and dispatch them intelligently, with full understanding of market dynamics, daily and seasonal load profiles, and the relative costs of different generating resources.

## FOLLOWING THE MARKET

In spite of the economic slowdown that came with the 2008 recession, growth in electricity demand continues to outstrip supply, and utilities are challenged to meet that demand cost-effectively. Construction of new power plants and transmission lines impose huge costs, and often faces formidable social and political barriers. Distributed generation reduces or postpones investments in the electrical distribution network, becoming a significant part of the solution.

Gas engine-generators can be easily, quickly and cost-effectively deployed at strategic points in the distribution system either at utility substations or behind the meter at major industrial customers, typically in return for electric rate incentives. With the low exhaust emissions from a lean burn gas generator set, these gas units are relatively easy to permit even where air-quality regulations are strict.

The market factors favoring gas-fueled distributed generation largely boil down to two words: spark spread. The spark spread is the difference between the price received by a generator for electricity produced and the cost of the natural gas needed to produce that electricity. Spark spreads are calculated with the following equation:

$$\text{Spark spread (\$/MWh)} = \text{power price (\$/MWh)} - [\text{natural gas price (\$/mmBtu)} * \text{heat rate (mmBtu/MWh)}]$$

A key component of the spark spread equation is the heat rate, or measure of resource efficiency, of the generating unit itself. Though not included in the above calculation, all other costs (operation and maintenance, capital, and other financial costs) must be covered from the spark spread for the spread to be considered 'positive.'

Based on cost per equivalent unit of energy, commercial natural gas prices in North America are significantly lower than electricity prices, and projections show the gap increasing for the next two decades (Figure 1).<sup>1</sup>

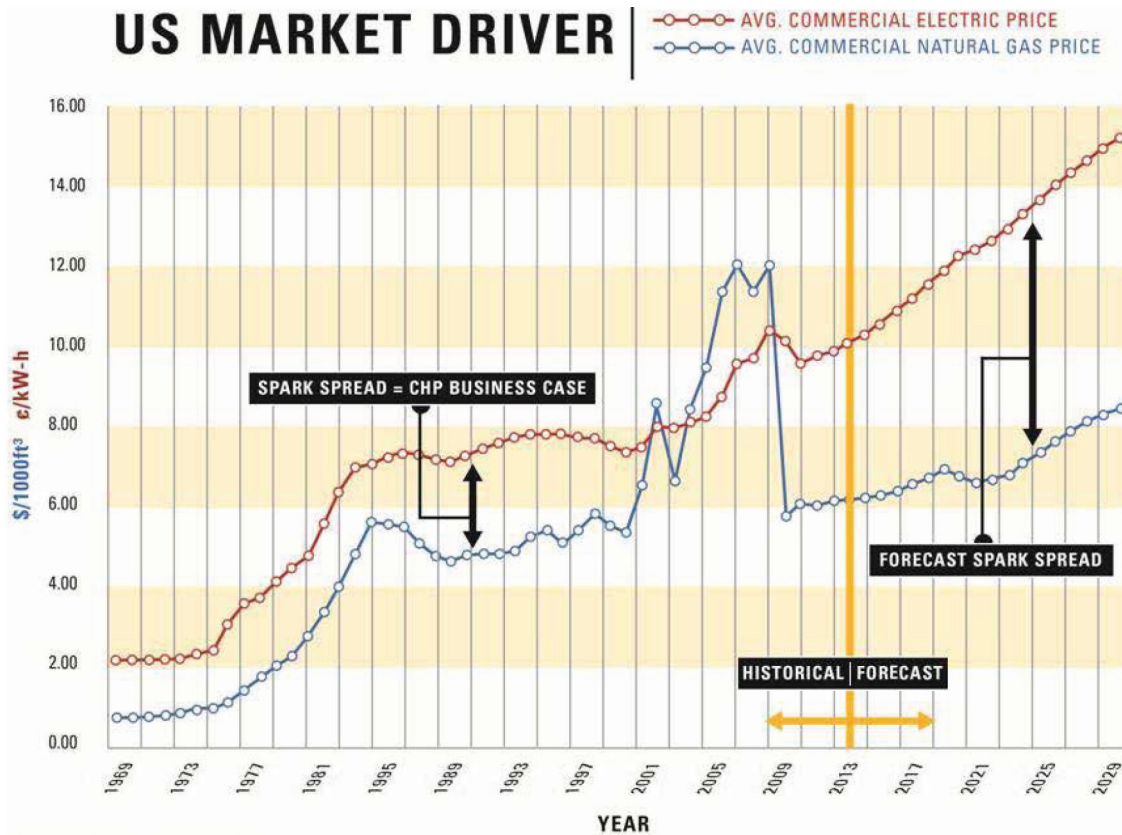


Figure 1: North America electricity and gas prices

The main reason for the favorable gas prices is that shale gas production through hydraulic fracturing (fracking) has dramatically increased the supply. Average wholesale natural gas prices in North America, for example, fell 31 percent in 2012<sup>2</sup>, and recent prices generally have ranged from \$3 to \$5/MMBtu – levels not seen since the early 1990s. Meanwhile, utility electricity prices have risen steadily and are projected to keep rising because of coal power plant retirements, the costs of transmission and distribution improvement, and other factors.

**Attractive technology**

As distributed power resources, engine-generators are inherently more efficient than centralized power plants. For example, a coal-fired power plant is typically 30 to 35 percent efficient, and line losses in long-distance transmission and distribution can mean net efficiencies at the point of use as low as 23 to 27 percent.

<sup>1</sup> U.S. Energy Information Administration

<sup>2</sup> Today in Energy, 2012 Brief: Average wholesale natural gas prices fell 31% in 2012, U.S. Energy Information Administration.

By comparison, a gas engine or turbine installation will deliver 35 to 46 percent electrical efficiency (based on the fuel source and fuel low heating value), and line losses are minimal if the power is used nearby. Advances in engine combustion and control technology continue to produce incremental efficiency gains. Other virtues of gas-fueled engine generators include:

- Proven reliability – up to 98 percent uptime with proper maintenance.
- Low installed cost per kW and low operating cost per kWh.
- Flexibility to add capacity in affordable increments to accommodate growth (installations of multiple units totaling 40 to 100 MW are fully feasible).
- Fast installation and commissioning – as short as few months for permanent installations and literally overnight with mobile packages for short-term needs, such as for emergencies or during central plant outages for repair or upgrade.

- Fast startup – when dispatched, it is not uncommon for gaseous fueled units to come online in just 15 to 30 seconds.
- Ability to follow loads – especially beneficial in peaking service.
- Potential for heat recovery, boosting total resource efficiency to as much as 90 percent, or even higher as demonstrated in Figure 2.
- Easy access to service – trained technicians are universally available.

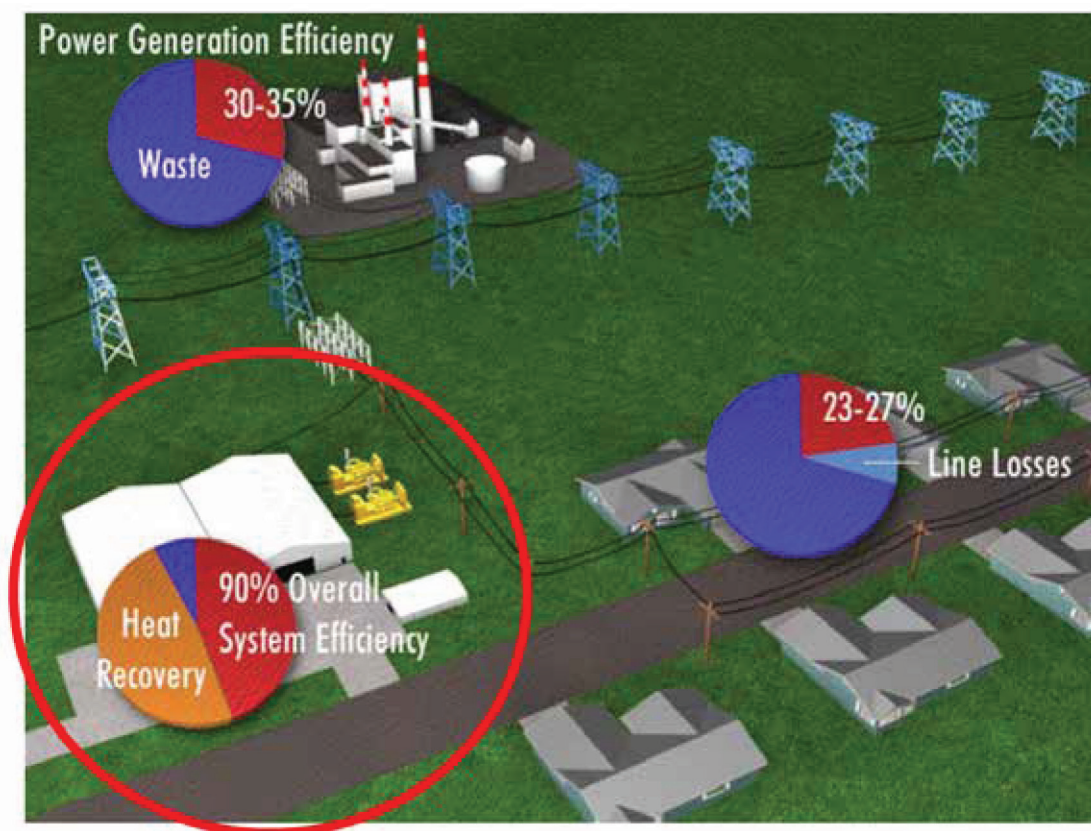


Figure 2: Electric Power Resource Efficiency

Distributed units have clear benefits beyond pure economics. Placed wisely, they can help shore up reliability in key sectors of the distribution system and help the system maintain uniform voltage – essential for customers operating sensitive electronic equipment and running precision manufacturing processes. Because they generate power at a predictable cost, they provide an effective hedge against volatile spot electric market prices.

When sited at customer facilities, distributed units also bring end users a source of standby power for an extra measure of reliability. That means a measure of insurance against process downtime, lost production, and their attendant costs. Benefits like these add significant value and can enable utilities to differentiate their services in what is otherwise a strictly price-driven commodity market. From a strengthened competitive position, utilities can more effectively retain major customers and attract new businesses and expansions to their territories.

### Evolving applications

Applications for distributed units have evolved significantly in the past 10 to 15 years. Historically, diesel-fueled generators were used for distributed power, operating for as few as 100 to 500 hours per year to help carry the highest daily and seasonal peaks. More recently, as air-quality regulations have grown stricter and as diesel fuel prices have risen, gas-fueled units have become a preferred generating source. Their lower owning and operating costs per kWh can allow them to operate economically for only a few hundred hours per year, or as continuous baseload units as the market price for electric power dictates.

For units hosted on customer sites, these extended hours help justify investment in equipment to recover heat from engine exhaust and coolant. This heat can serve a host of purposes: building space and water heating, air conditioning (by way of absorption chillers), desiccant dehumidification, and heat or cooling (or both) for a host of industrial processes. Heat recovery in turn improves economics so that it becomes cost-effective to operate the systems for up to 4,000 annual hours – essentially half the year – or even more. Figure 3 is a representation of this improved power generation availability due to the improved economics.

## PEAKING ECONOMICS vs. DAILY POWER

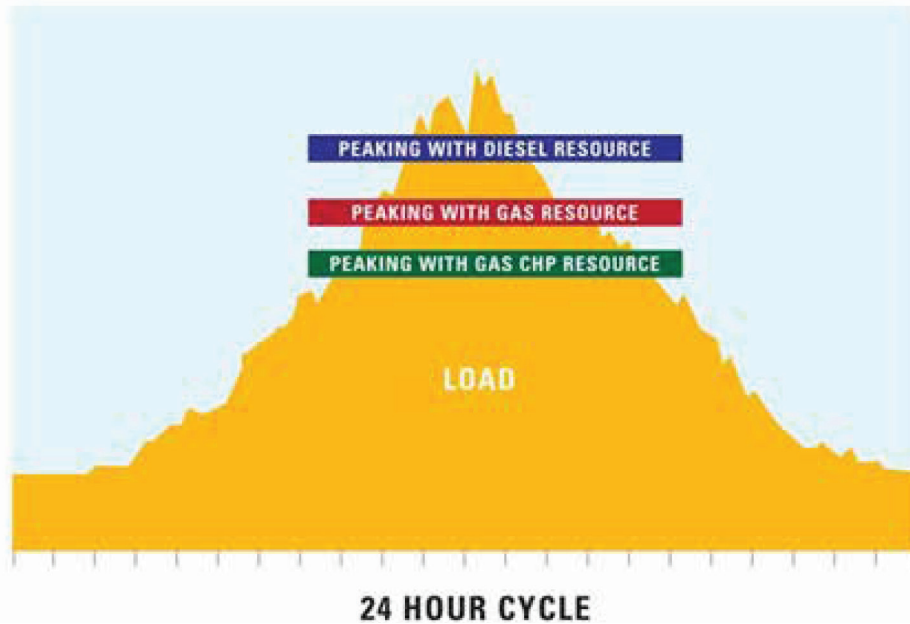


Figure 3: Peak shaving economics

### Assessing loads and costs

To define the optimum role for distributed generation, and to get the most value from it, it is essential to understand the dynamics of regional power markets and the utility's current and projected load profiles. 3D load graphs can help managers easily understand hourly, daily and seasonal load patterns. In the example annual load graph in Figure 4, the x-axis represents day of year, the y-axis represents the hour of the day, and the z-axis represents the demand on the system in megawatts.

### 3D Yearly Load Analysis

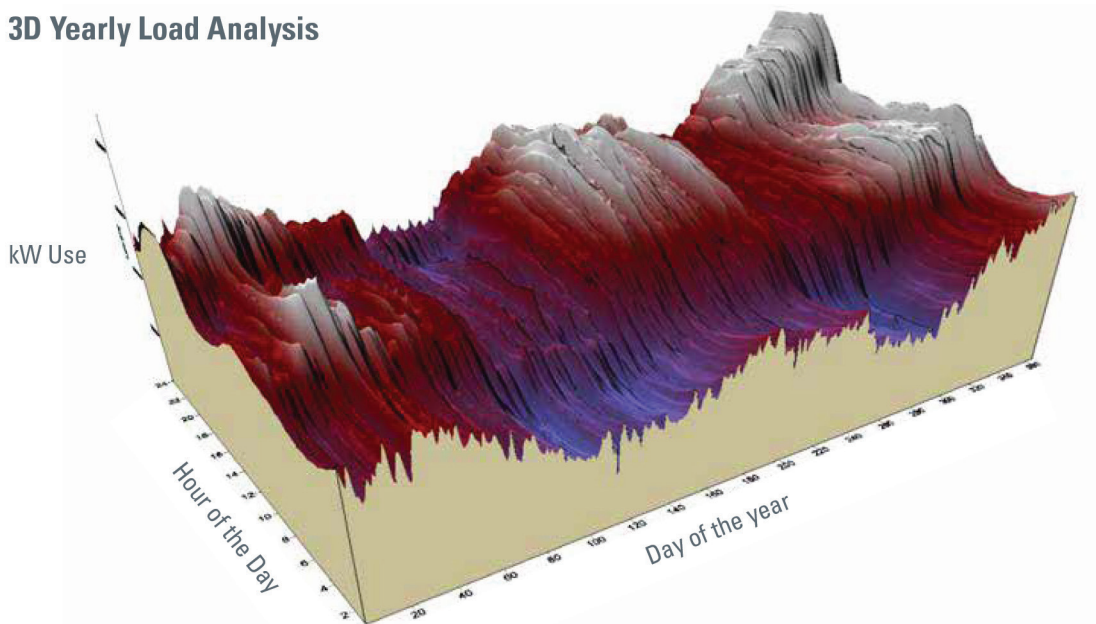


Figure 4: Annual utility load profile – Chart used with permission from Black Diamond Solutions Inc.

This graph shows visually what is happening on the system hour by hour, every day of the month, and every month of the year. Load patterns, most critically the peak load periods, become clear:

- Areas shaded blue represent periods of low usage – essentially base-load periods when the cost of energy is low.
- Areas shaded in red represent intermediate load periods. These loads are larger – usually 100 to 500 MW – and are typically fulfilled by large combustion turbines that run for relatively long periods at somewhat higher but still predictable operating cost.
- Areas shaded white represent the times of peak demand. In general, the higher the peak, the higher the per-kWh cost of energy. These are the periods in which distributed generation sources – like reciprocating engines – are most likely to come into play.

For a given utility, the timing and height of peaks depends on a variety of factors that include local climate and population patterns (e.g., seasonal versus year-round residency). Each utility, and often even regions within a utility service area, need to determine the load resources required to manage peaks.

Planning effectively means understanding not just today's demands but the projected demands several years into the future. Figure 5 presents a load graph for a utility covering five years, from 2006 through 2011. Comparing Hour 5 (during a low-demand period) to Hour 19 (during a peak period) shows a difference of 1.5 MW in 2006, but that difference increases to 3.5 MW by 2011. This indicates a peak load growing faster than the base load – an issue that needs to be addressed in resource planning.

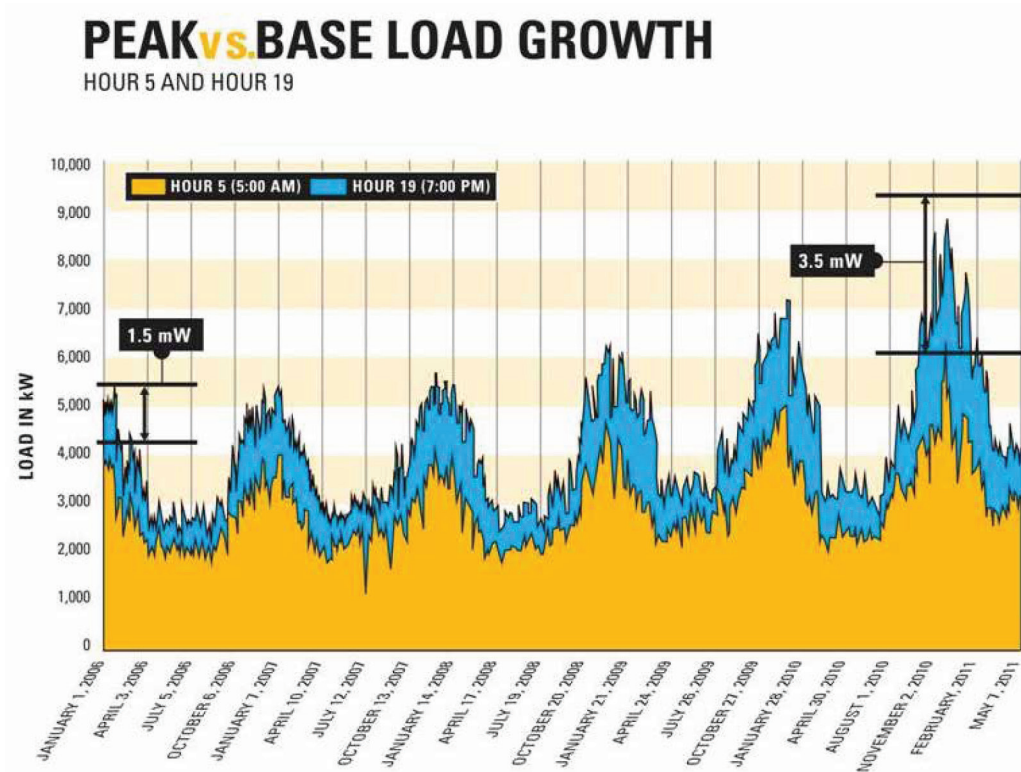


Figure 5: Peak vs. base load growth – Data for chart provided by Black Diamond Solutions Inc.

Whether for immediate or future purposes, a key question is whether to meet peaks by generating power or purchasing it on the market. The answer depends on a careful analysis of the costs of each option.

On the purchased power side, the key parameter is the total delivered price of the power. For illustration, assume a block purchase of 5 MW of capacity, covering 365 days a year around the clock. Assuming an energy price of \$55/MWh and a transmission charge of \$6/MWh, the total cost is \$61/MWh.

But if some of that energy will ultimately go unused, the unit cost increases. For example, if only half is actually sold to customers, the cost doubles to \$122/MWh. Of course, some of the energy can be sold back on the market, but likely not at the original purchase price. Assuming it is sold at \$35/MWh, the net cost for the purchased energy is now \$87/MWh. Of course, power for short-term peaks can be purchased on spot markets, but generally at much higher prices.

On the generation side, it is necessary to calculate the entire lifecycle cost per kW of the energy to be produced. This includes the installed cost of the unit and the facility to house it, plus the costs of fuel, operations, maintenance, periodic overhauls and repairs on the entire system. For the sake of comparison, the cost of power from a 2 MW gas-fueled generator set for intermediate and peak load service will range from \$55 to \$65/MWh, assuming a fuel price of \$5/MMBtu.

Of course, the cost of purchased energy rises with the height of the peak on the load graph, while the cost of generation remains fixed. Therefore, as the load curve ascends, the cost advantage of gas-fueled generation increases. That value increases further if transmission constraints limit capacity to import purchased power from the grid.

### Deploying resources

In the simplest terms, a plan for deploying resources means analyzing a five-year demand projection, comparing the resources available to meet the need, and deciding how best to accommodate demand growth – most likely with some combination of power purchases and power generation. Key questions to answer include:

- What power purchase agreements are in place and what are their durations? On their expiration, would another similar contract be available at a suitable price?
- What is the cost for transmission of the energy from the point of generation to the point of use?
- What generation resources are in place? What are their individual and combined capacities?

In this analysis, it is essential to review the load profile projection and understand the daily and seasonal peaks. On the load graph in Figure 6, for example, red dots indicate periods when peak demand growth is greatest. One high-growth area is in the early morning hours where base load power probably can be purchased at an attractive price. Of more concern is the fast-growing peak between hours 15 and 20 during June, July and August. There, demand is growing at peak times on the grid when energy is most expensive. This is the kind of peak that can lend itself well to on-site generation at a predictable cost with a resource such as gas-fueled reciprocating engines.

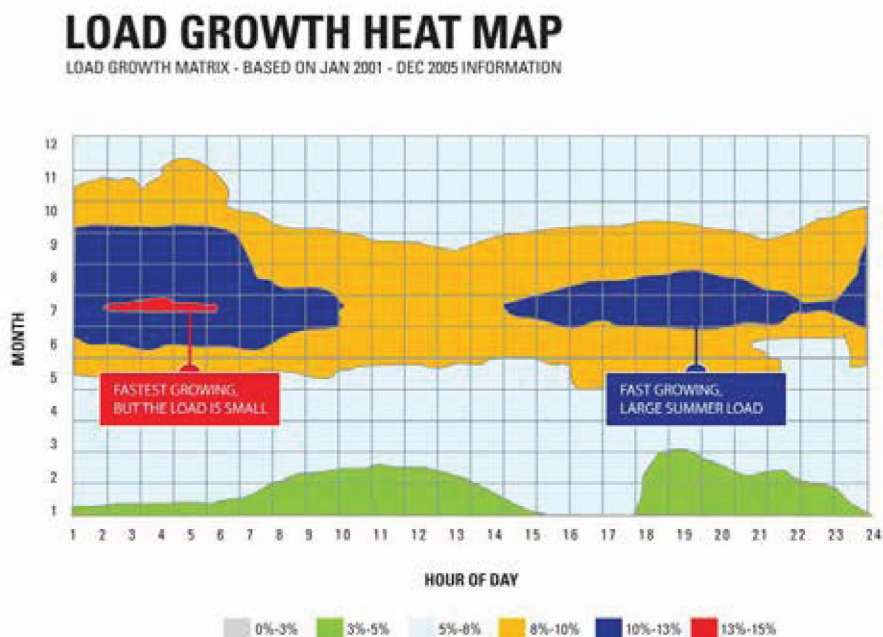


Figure 6: Load growth heat map – Data for Chart provided by Black Diamond Solutions Inc.

Resource planning includes assigning to each generation source a strike price – the cost per MWh to put the resource online. In general, a peaking resource would be dispatched anytime the cost of purchased power exceeds the strike price. In turn, the unit would be shut down when the purchased power cost falls below the strike price. For gas engine-generator sets, equipment dealers can provide a reliable estimate of the strike price based on the specific unit, local fuel price, altitude, ambient conditions, and other factors.

The next step is to stack resources from lowest to highest price – lowest-cost base load resources at the bottom and highest-cost peaking units at the top. Having multiple units available at different strike prices makes it possible to deliver power in the most cost-effective way in conformity with the actual load profile for any given hour or day. The idea is to find the mix of purchased power and self-generating resources that deliver customers the greatest energy security at the optimum cost.

### **Fulfilling short-term needs**

Gas engine-generator technology also can play a role in utility contingency or emergency planning: Contracted or rented gas-fueled power units are increasingly available. This concept enables utilities to deploy reliable power wherever it is needed, whether to shore up a weak area on the grid, provide seasonal peaking capacity, or respond to an emergency or natural disaster – all without the long-term costs of ownership and without carrying the assets on the balance sheet. Mobile rental units in capacities to 2 MW or larger can be deployed on utility-owner or customer sites for easy permitting. Installation is extremely fast – multiple units with combined capacity of 50 MW or more can be delivered and connected in seven days, versus seven months for a permanent gas turbine power station.

Units come as complete packages that include technologies grid paralleling controls, protective relays, circuit breakers, cooling systems, sound-attenuated enclosures, exhaust silencers, and emissions control devices as required.

A variety of financial models are available, including complete monthly or full-rental-term pricing that incorporates scheduled and unscheduled maintenance, technical support and repairs. Ancillary equipment and services can be included. Rental units can be reserved through equipment dealers under a contingency planning model where the utility receives the right of first refusal for access to equipment in case of catastrophic events.

### **Reliable and economical technology**

Advancing technology makes reciprocating engine-generator sets all the more appealing as distributed resources. The latest units develop high power output in footprints up to 50 percent smaller than in the past, fitting easily in small engine rooms or in containerized power plants. They use a variety of digital microprocessor-based monitoring and control technologies that include:

- Air/fuel ratio control based on charge air density, maintaining NO<sub>x</sub> emissions within the tightest available tolerance under all ambient and load conditions.
- Air/fuel ratio control based upon Total Electronic Management (TEM) systems that optimize generator set performance, measuring each cylinder's temperature and adjusting combustion to minimize fuel consumption, limit emissions, and prevent detonation. Systems can control functions beyond the engine itself, such as radiator motors, electrical breakers and systems, cogeneration equipment.
- Detonation sensing by individual cylinder with automated control to retard timing as a complete engine or by cylinder if detonation occurs.
- Low-pressure fuel system (0.5 to 5 psi (0.35-35 kPa)) that eliminates the need for fuel compression skids.

In more recent years, an alternative approach to engine selection has emerged: Instead of users purchasing units off the shelf, a manufacturer customizes the equipment to fit the specific application. In this model, the user provides a sample of the fuel, describes the site ambient conditions and altitude, and specifies the application and key operating objectives (top fuel economy, lowest emissions, block loading capability, and others). The manufacturer then designs a gas engine-generator system to fit those criteria.

The customized units come with further advances in engine technology that expand the limits of engine control and reach new heights of efficiency – up to 46 percent electrical efficiency in generator sets alone and up to 90 percent total plant efficiency in combined heat and power service. These include:

**Miller Cycle** This adjustment in the combustion cycle by itself increases fuel efficiency by about one percentage point.

**Ignition Advances** Prechamber spark plugs with optimized geometry, coupled with high-energy ignition, enables engines to operate on an extremely lean fuel mixture without lean misfire, sustaining high power output and low emissions over long life spans.

**Extended Maintenance Intervals** Intervals for spark plug replacement and oil changes can reach 4,000 hours – some six months of continuous operation, or more than double the interval expected with traditional technology. It is not uncommon for cylinder head overhaul intervals to reach 32,000 hours, and major overhaul intervals 64,000 to 80,000 hours. Costs are further reduced by lowering oil consumption by as much as half, a savings of 500 gallons (1,892 liters), which translates to \$10,000 per year on a 20-cylinder engine-generator rated at 2 MW.



## CONCLUSION

Today's utility operations can benefit greatly from the flexibility to deploy distributed generating resources. Natural-gas-fueled generator sets can fulfill that role admirably. When deployed strategically, they providing economic and reliability benefits to the utility and customers alike, while enabling utilities to differentiate their services and gain a stronger position in competitive markets.

**LET'S DO THE WORK.™**

LEXE0622-02 August 2013

© 2019 Caterpillar. All Rights Reserved. CAT, CATERPILLAR, LET'S DO THE WORK, their respective logos, "Caterpillar Yellow", the "Power Edge" and Cat "Modern Hex" trade dress as well as corporate and product identity used herein, are trademarks of Caterpillar and may not be used without permission.

