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DG Technologies: Microturbines, Fuel Cells, and Stirling Engines

Distributed generation (DG) promises many potential benefits, including peak shaving, price hedging, fuel switching, improved power quality and reliability, increased efficiency, and improved environmental performance. A number of technologies provide DG capabilities in sizes ranging from a few kilowatts (kW) to 10 megawatts (MW) or more. This topic covers some of the more common options: microturbines, fuel cells, and Stirling engines. We offer more in-depth information on Reciprocating Engine Generators elsewhere.

WHAT ARE THE OPTIONS?

this section

The major small-scale DG options are summarized in **Table 1**.

Table 1: Options for distributed generation

There are significant differences in cost, performance, and commercial readiness among DG technologies.

Technology	Size range	Electrical efficiency LHV (%)	Waste-heat quality	Current equipment cost ($/kW)
Reciprocating engine	1–5,000+ kW	25–45	High	500–1,000
Industrial gas turbine	500 kW–multi MW	15–35	High	400–650
Microturbine	30–1,000 kW	25–30	High	500–1,000
Fuel cell	Several watts to 3,000+ kW	30–60	MCFC, SOFC-high, PAFC-medium, PEM-low	1,000–5,000[a]
Stirling engine	Hundreds of watts and up	10–30	Medium	1,200–7,000[b]
Photovoltaics	1 kW and up	10–20	NA	6,000

Notes: kW = kilowatt; LHV = lower heating value; MCFC = molten carbonate fuel cell; MW = megawatt; NA = not applicable; PAFC = phosphoric acid fuel cell; PEM = proton exchange membrane; SOFC = solid oxide fuel cell.
a. Variance in price difference comes from the multiple fuel cell types as well as the various applications.
b. Variance in price comes primarily from the application; stationary Stirling engines are on the lower end of the range, whereas solar dish setups represent the high end of the range.

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Industrial Gas Turbines

Derived from jet engine technology, industrial gas turbines for DG use range in size from 50 kW to tens of megawatts. They are particularly suitable for large cogeneration applications where high-temperature steam is needed. Emissions are lower than those of reciprocating engines, and nitrogen oxide (NO_x) emission-control technology is available to reduce emissions even further. Other advantages over reciprocating engines are that these gas turbines require less maintenance, are lighter, and take up less space. On the other hand, for units under 2 MW, electrical efficiency is lower than for reciprocating engines, and the gas turbines take longer to ramp up and shut down.

Microturbines

Microturbines became commercially available in 1998. Initially, they had a slightly higher first cost than reciprocating engines, but that difference has disappeared. Microturbines are currently the most cost-effective alternative to reciprocating engines for small-scale generation (**Figure 1**). Microturbines operate on the same basic thermodynamic principle—the Brayton cycle—as their larger cousin, the conventional gas turbine. Though they initially offered much lower power than gas turbines, microturbines now offer power output up to 1 MW.

Figure 1: Microturbines

Microturbines have emerged as a viable alternative to reciprocating engines. Some models have just one moving part, so they have lower maintenance requirements than reciprocating engines. They also produce far fewer emissions than reciprocating engines. Two 60-kilowatt microturbines from Capstone Turbine are shown here.

Courtesy: Capstone Turbine

Microturbines have far fewer moving parts than reciprocating engines, and in some cases only one moving part, so they have the potential for longer lifetimes with lower maintenance requirements. They also produce much lower emissions than comparable reciprocating engines, and their waste heat can be used for heating and cooling applications to bring total efficiencies up to 80 percent or more.

Microturbines have several advantages for niche applications and can run off of a variety of fuels like diesel, propane, and kerosene. They are good at handling low-quality gases, such as “sour gas” at oil and gas resource recovery sites, and biogas from landfills, wastewater treatment plants, and agricultural livestock operations. Also, their exhaust gas stream is clean enough and hot enough to be used directly in greenhouses (the carbon dioxide boosts plant growth) or in industries with drying processes such as brick, grain, or

chemical drying.

Fuel Cells

Although the market for fuel cells is still in the development phase, there are more than 2,500 fuel cell units operating throughout the world. Fuel cells use chemical reactions rather than combustion to produce both electricity and thermal energy. Because there is no combustion, harmful emissions are extremely low—the only byproduct of hydrogen fuel cell electricity generation is pure water and heat. Most fuel cells currently derive the hydrogen from another fuel, using a “reformer” that is either integrated inside the unit or placed right next to it. This does create pollutants, such as trace amounts of NOx, although the process is still cleaner than combustion. The reforming process also produces carbon dioxide, although again, a smaller amount than would be produced by most other fossil-fueled DG technologies.

Noise from fuel cells is low compared with other DG technologies, and it generally only comes from air blowers and water pumps in the cooling module. The use of rejected (waste) heat from a fuel cell system can boost thermal efficiency to 80 percent or higher.

There are several different types of fuel cells, classified by the type of electrolyte material they use—phosphoric acid (PAFC), proton exchange membrane (PEM), solid oxide (SOFC), and molten carbonate (MCFC).

Phosphoric acid. The first commercially available product, introduced in 1992, was the PC 25 phosphoric acid fuel cell from UTC Fuel Cells, a unit of United Technologies. Since then, more than 75 MW of PAFC capacity has been installed worldwide. Phosphoric acid fuel cells, which operate at 300° to 400° Fahrenheit (F), have proven to be reliable and can achieve thermal efficiencies up to 85 percent when reject heat is used for space heating or steam generation. The downsides are that their electrical efficiency is about 10 percentage points less than solid oxide or molten carbonate fuel cells, and their purchase price is still relatively high, with costs around $2,500/kW.

Proton exchange membrane. More than a dozen companies are developing PEM fuel cells for applications ranging from powering forklifts and buses to backup power for remote cell phone towers. Most stationary PEM fuel cells will have capacities under 10 kW. The efficiency of PEMs is lower than that of solid oxide and molten carbonate fuel cells, but due to lower operating temperatures (less than 212°F), PEMs are able to ramp up quickly and match a changing load. Because of these traits, PEMs are the type of fuel cells that most

car manufacturers are focusing on for automotive applications. However, the downside of PEM fuel cells' lower operating temperatures is the lack of efficient cogeneration.

Solid oxide. SOFCs are being developed in sizes ranging from 5 kW to multi-megawatts. A number of companies are active in this area—Bloom Energy has received a lot of press for its products, but others include United Technologies and Delphi. SOFCs have very high operating temperatures (around 1,400°F) and boast higher electrical efficiency than other fuel cell technologies. They also reject heat at a higher temperature, making the heat usable for a wider range of combined heat and power (CHP) applications, although because of the higher electrical efficiencies and waste heat temperatures, manufacturers have been slow to employ CHP applications. A downside to SOFCs is that they can't ramp up or down as quickly as PEM fuel cells due to the high operating temperatures.

Molten carbonate. MCFCs are commercially available from FuelCell Energy in sizes ranging from 300 kW to 3 MW. As with SOFCs, MCFCs have very high operating temperatures (around 1,200°F) and therefore produce higher-quality heat and are more efficient than PEM fuel cells or other DG technologies. However, they can't ramp up or down as quickly.

Stirling Engines

Stirling engines operate like an external combustion engine, in which heat outside the engine is applied to a working fluid to convert heat energy into mechanical work. They offer the potential for low maintenance and low levels of emissions. Stirling engines are used in a variety of applications. They can be small generators, running on standard fuels like diesel, or they can be stationary power generators fueled by biofuels, like the 45-kW PowerUnit from Stirling Biopower (**Figure 2**).

Figure 2: Stirling engines

Stirling engines fueled by biofuels with combined heating and power systems made by Stirling Biopower are being sold to commercial and industrial customers in the United States.

Courtesy: Stirling Biopower

Because Stirling engines can accept heat from any source, they can be combined with solar collectors to create cleaner versions of the technology. Two companies, Cool Energy and Stirling Engine Systems (SES), have designed solar collection systems to power the engine with solar energy. Cool Energy's system uses solar thermal collectors to capture solar energy, feeding that energy into its proprietary engine that uses Stirling principles. Another application is concentrated solar power (CSP), in which solar dish systems are designed to reflect sunlight directly into Stirling engines as the heat source. Sandia National Laboratories, in collaboration with SES, has aided in the development of these systems, which are currently available for commercial applications from SES and other companies like Infinia. These dish-engine units can achieve peak capacities up to 25 kW and convert solar energy to electricity with an efficiency just over 30 percent. For comparison, typical photovoltaic (PV) systems today have an efficiency of 10 to 20 percent. Like all solar electric systems, the application of CSP is constrained by the availability of sunlight and space for the collectors.

The prices of Stirling engines vary considerably depending on the size of the engine and the application. Traditional stationary units begin at around $1,000/kW, whereas the newer CSP applications will cost several thousand dollars per kW.

HOW TO MAKE THE BEST CHOICE

this section

Consider the impact on power quality and reliability. The power quality and reliability markets for DG are already quite large—more than 14 gigawatts of reciprocating-engine generators sized between 10 kW and 2 MW are sold worldwide each year into these markets. DG was

once only of interest to equipment manufacturers, their dealer networks, and specific third-party companies. Now, regulated utilities, their unregulated subsidiaries, and independent companies are starting to use DG in service offerings that provide enhanced power reliability and quality. At the same time, end users are deploying increasingly sophisticated automated control systems and data storage technologies that need premium power to ensure the quality and integrity of their processes.

Match the engine to heating and cooling applications. Most of the DG technologies described here produce heat that can be harvested to create CHP systems, thereby greatly improving the economics of DG projects. Reciprocating engines, microturbines, fuel cells, and Stirling engines produce heat that can readily be used for water and space heating. Waste heat from solid oxide fuel cells is hot enough to serve as input to a gas turbine for the generation of electricity. In addition, it can be used in high-temperature industrial processes or to meet steam needs. The waste heat from these DG technologies could also be used to power an absorption chiller.

DG installers typically recommend that CHP systems be sized to appropriately meet a facility's thermal load rather than its electric load. This method provides the opportunity to meet both heating and electrical needs with the possibility of selling any excess electricity back to the grid. Vendors also say that facilities that have a simultaneous electric and thermal demand for at least 4,000 hours per year are better candidates for CHP, although the economics for buildings with 2,000 hours of demand per year can still sometimes work.

Consider new technologies in areas with strict requirements on air emissions. Although emissions from reciprocating engines are being reduced as technologies improve, other options still produce fewer emissions. Solar dishes with Stirling engines and PV systems are the cleanest of all, and fuel cells are also quite clean. Microturbines also offer lower emissions than comparably sized reciprocating engines.

Look for grants and incentives. At the federal, state, local, and utility levels, there are a number of grants and incentives available for DG technologies, especially the cleaner technologies like fuel cells and PV. A partial list of available grants and incentives is available online at www.dsireusa.org.

WHAT'S ON THE HORIZON?

this section

Numerous companies are pouring research and development funds into DG technologies. In the coming years, look for refinements in reciprocating engines, an increasing number of sites using microturbines, and the mass commercialization of products from the manufacturers of fuel cells. Developers of Stirling solar dish systems are also working on new materials and techniques that would make them less expensive and more efficient.

WHO ARE THE MANUFACTURERS?

this section

The following is a sampling of companies that offer commercial or very-near-commercial DG products. It is not meant to be a comprehensive list.

Industrial gas turbines

- GE Power Systems
- Pratt & Whitney
- Rolls-Royce
- Solar Turbines (a division of Caterpillar)
- Vericor

Microturbines

- Bowman
- Calnetix Power Solutions
- Capstone Turbine

Fuel cells

- Bloom Energy
- Doosan Fuel Cell America (previously ClearEdge Power)

- FuelCell Energy
- Ballard
- Plug Power

Stirling engines

- Qnergy
- Stirling Biopower
- Whisper Tech
- Cool Energy

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