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Distributed Utilities

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Distributed utilities (sometimes referred to as DU) is the current term used in describing distributed generation and storage devices operating separately and in parallel with the utility grid. In most cases, these devices are small in comparison to traditional utility base or peaking generation, but can range up to several megawatts. For the purposes of this section, DU will be limited to devices 5 MW and below applied at either the secondary voltage level, 120 V single phase to 480 V three phase, and at the medium voltage level, 2.4 kV to 25 kV, although many of the issues discussed would apply to the larger units as well.

In this section, we will give an overview of the different issues associated with DU, including available technologies, interfacing, a short discussion on economics and possible regulatory treatment, applications, and some practical examples. Emerging technologies discussed will include fuel cells, microturbines, and small turbines. A brief discussion of storage technologies is also included. Interfacing issues include general protection, overcurrent protection, islanding issues, communication and control, voltage regulation, frequency control, fault detection, safety issues, and synchronization. In the applications section, deferred investment, demand reduction, peak shaving, ancillary services, reliability, and power quality will be discussed. Economics and possible regulatory treatment will be discussed briefly.

7.1 Available Technologies

Many of the "new" technologies have been around for several years, but the relative cost per kilowatt of small generators compared to conventional power plants has made their use limited. Utility rules and interconnect requirements have also limited the use of small generators and storage devices to mostly emergency, standby, and power quality applications. The prospect of deregulation has changed all that. Utilities are no longer assured that they can recover the costs of large base generation plants, and stranded investment of transmission and distribution facilities is a subject of debate. This, coupled with improvements in the cost and reliability of DU technologies, has opened an emerging market for small power plants. In the near future, these new technologies should be competitive with conventional plants, providing high reliability with less investment risk. Some of the technologies are listed below. All of the energy storage devices and many of the small emerging generation devices are inverter/converter

Technology	Size	Fuel Sources	AC Interface Type	Applications
Fuel Cells	.5Kw– Larger units With Stacking	Natural Gas Hydrogen Petroleum Products	Inverter type	Continuous
Microturbines	10Kw-100Kw Larger sizes	Natural Gas Petroleum Products	Inverter type	Continuous Standby
Batteries	.1Kw-2Mw+	Storage	Inverter type	PQ, Peaking
Flywheel	>.1Kw-.5Kw	Storage	Inverter type	PQ, Peaking
PV	>.1Kw-1Kw	Sunlight	Inverter type	Peaking
Gas Turbine	10Kw–5Mw+	Natural Gas Petroleum Products	Rotary type	Continuous, Peaking Standby

FIGURE 7.1 Distributed generation technology chart.

based. Figure 7.1 is a listing of different technologies, their size ranges, fuel sources, and AC interface type, and most likely applications.

7.2 Fuel Cells

Fuel cell technology has been around since its invention by William Grove in 1839. From the 1960s to the present, fuel cells have been the power source used for space flight missions. Unlike other generation technologies, fuel cells act like continuously fueled batteries, producing direct current (DC) by using an electrochemical process. The basic design of all fuel cells consists of an anode, electrolyte, and cathode. Hydrogen or a hydrogen-rich fuel gas is passed over the anode, and oxygen or air is passed over the cathode. A chemical combination then takes place producing a constant supply of electrons (DC current) with by-products of water, carbon dioxide, and heat. The DC power can be used directly or it can be fed to a power conditioner and converted to AC power (see Fig. 7.2).

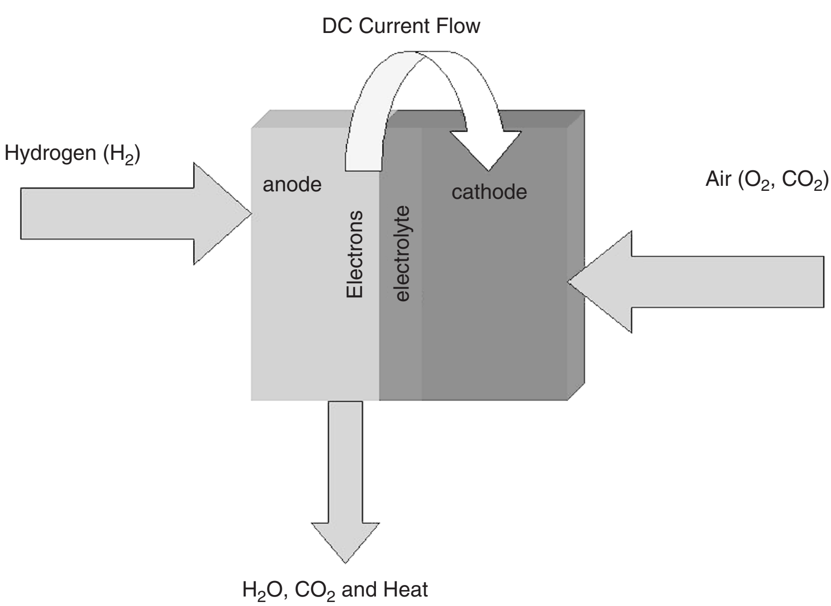

FIGURE 7.2 Basic fuel cell operation.

	PAFC	MCFC	SOFC	PEMFC
Electrolyte	Phosphoric acid	Molten carbonate salt	Ceramic	Polymer
Operating Temperature	375°F (190°C)	1200°F (650°C)	1830°F (1000°C)	175°F (80°C)
Fuels	Hydrogen (H_2)	H_2/CO	$H_2/CO_2/CH_4$	H_2
	Reformate	Reformate	Reformate	Reformate
Reforming	External	External	External	External
Oxidant	O_2/Air	CO_2/O_2/Air	O_2/Air	O_2/Air
Efficiency (HHV)	40–50%	50–60%	45–55%	40–50%

FIGURE 7.3 Comparison of fuel cell types. (From DoD Website, www.dodfuelcell.com/fcdescriptions.html.)

Most of the present technologies have a fuel reformer or processor that can take most hydrocarbon-based fuels, separate out the hydrogen, and produce high-quality power with negligible emissions. This would include gasoline, natural gas, coal, methanol, light oil, or even landfill gas. In addition, fuel cells can be more efficient than conventional generators. Theoretically they can obtain efficiencies as high as 85% when the excess heat produced in the reaction is used in a combined cycle mode. These features, along with relative size and weight, have also made the fuel cell attractive to the automotive industry as an alternative to battery power for electric vehicles. The major differences in fuel cell technology concern the electrolyte composition. The major types are the Proton Exchange Membrane Fuel Cell (PEFC) also called the PEM, the Phosphoric Acid Fuel Cell (PAFC), the Molten Carbonate Fuel Cell (MCFC), and the Solid Oxide Fuel Cell (SOFC) (Fig. 7.3).

Fuel cell power plants can come in sizes ranging from a few watts to several megawatts with stacking. The main disadvantage to the fuel cell is the initial high cost of installation. With the interest in efficient and environmentally friendly generation, coupled with the automotive interest in an EV alternative power source, improvements in the technology and lower costs are expected. As with all new technologies, volume of sales should also lower the unit price.

7.3 Microturbines

Experiments with microturbine technology have been around for many decades, with the earliest attempts of wide-scale applications being targeted at the automotive and transportation markets. These experiments later expanded into markets associated with military and commercial aircraft and mobile systems. Microturbines are typically defined as systems with an output power rating of between 10 kW up to a few hundred kilowatts. As shown in Fig. 7.4, these systems are usually a single-shaft design with compressor, turbine, and generator all on the common shaft, although some companies are engineering dual-shaft systems. Like the large combustion turbines, the microturbines are Brayton Cycle systems, and will usually have a recuperator in the system.

The recuperator is incorporated as a means of increasing efficiency by taking the hot turbine exhaust through a heavy (and relatively expensive) metallic heat exchanger and transferring the heat to the input air, which is also passed through parallel ducts of the recuperator. This increase in inlet air temperature helps reduce the amount of fuel needed to raise the temperature of the gaseous mixture during combustion to levels required for total expansion in the turbine. A recuperated Brayton Cycle microturbine can operate at efficiencies of approximately 30%, while these aeroderivative systems operating without a recuperator would have efficiencies in the mid-teens.

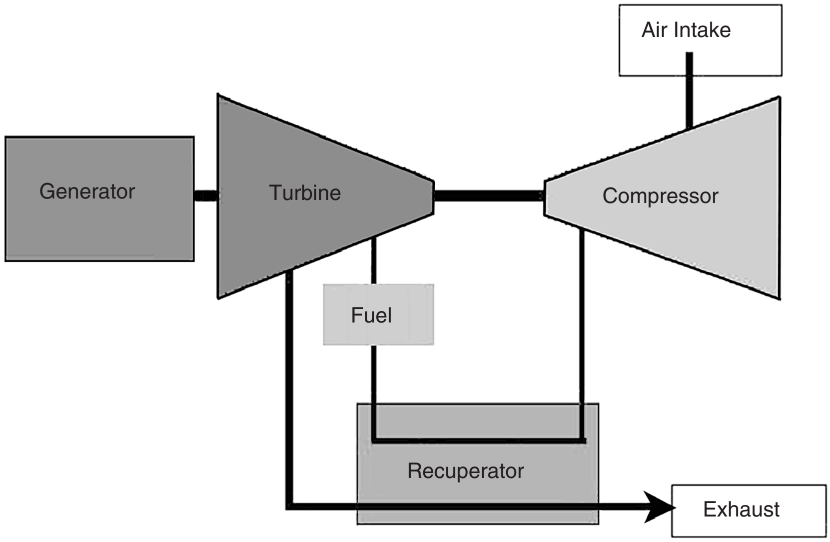

FIGURE 7.4 Turbine block diagram configuration with recuperator.

Another requirement of microturbine systems is that the shaft must spin at very high speeds, in excess of 50,000 RPM and in some cases doubling that rate, due to the low inertia of the shaft and connected components. This high speed is used to keep the weight of the system low and increase the power density over other generating technologies. Although many of the microturbines are touted as having only a single moving part, there are numerous ancillary devices required that do incorporate moving parts such as cooling fans, fuel compressors, and pumps.

Since the turbine requires extremely high speeds for optimal performance, the generator cannot operate as a synchronous generator. Typical microturbines have a permanent magnet motor/generator incorporated onto the shaft of the system. The high rotational speed gives an AC output in excess of 1000 Hz, depending on the number of poles and actual rotational speed of the microturbine. This high-frequency AC source is rectified, forming a common DC bus voltage that is then converted to a 60-Hz AC output by an onboard inverter.

The onboard electronics are also used to start the microturbine, either in a stand-alone mode or in grid parallel applications. Typically, the utility voltage will be rectified and the electronics are used to convert this DC voltage into a variable frequency AC source. This variable frequency drive will power the permanent magnet motor/generator (which is operating as a motor), and will ramp the turbine speed up to a preset RPM, a point where stabile combustion and control can be maintained. Once this preset speed is obtained and stabile combustion is taking place, the drive shuts down and the turbine speed increases until the operating point is maintained and the system operates as a generator. The time from a "Shaft Stop" to full load condition is anywhere from 30 sec to 3 min, depending on manufacturer recommendations and experiences.

Although things are in the early stages of commercialization of the microturbine products, there are cost targets that have been announced from all of the major manufacturers of these products. The early market entry price of these systems is in excess of $600 per kW, more than comparably sized units of alternative generation technologies, but all of the major suppliers have indicated that costs will fall as the number of units being put into the field increases.

The microturbine family has a very good environmental rating, due to natural gas being a primary choice for fuel and the inherent operating characteristics, which puts these units at an advantage over diesel generation systems.

7.4 Combustion Turbines

There are two basic types of combustion turbines (CTs) other than the microturbines: the heavy frame industrial turbines and the aeroderivative turbines. The heavy frame systems are derived from similar models that were steam turbine designs. As can be identified from the name, they are of very heavy construction. The aeroderivative systems have a design history from the air flight industry, and are of a much lighter and higher speed design. These types of turbines, although similar in operation, do have some significant design differences in areas other than physical size. These include areas such as turbine design, combustion areas, rotational speed, and air flows.

Although these units were not originally designed as a "distributed generation" technology, but more so for central station and large co-generation applications, the technology is beginning to economically produce units with ratings in the hundreds of kilowatts and single-digit megawatts. These turbines operate as Brayton Cycle systems and are capable of operating with various fuel sources. Most applications of the turbines as distributed generation will operate on either natural gas or fuel oil. The operating characteristics between the two systems can best be described in tabular form as shown in Fig. 7.5.

The combustion turbine unit consists of three major mechanical components: a compressor, a combustor, and a turbine. The compressor takes the input air and compresses it, which will increase the temperature and decrease the volume per the Brayton Cycle. The fuel is then added and the combustion takes place in the combustor, which increases both the temperature and volume of the gaseous mixture, but leaves the pressure as a constant. This gas is then expanded through the turbine where the power is extracted through the decrease in pressure and temperature and the increase in volume.

If efficiency is the driving concern, and the capital required for the increased efficiency is available, the Brayton Cycle systems can have either co-generation systems, heat recovery steam generators, or simple recuperators added to the combustion turbine unit. Other equipment modifications and improvements can be incorporated into these types of combustion turbines such as multistage turbines with fuel re-injection, inter-cooler between multistage compressors, and steam/water injection.

Typical heat rates for simple cycle combustion turbines vary across manufacturers, but are in a range from 11,000 to 20,000 BTU/kWh. However, these numbers decrease as recuperation and co-generation are added. CTs typically have a starting reliability in the 99% range and operating reliability approaching 98%. The operating environment has a major effect on the performance of combustion turbines. The elevation at which the CT is operating has a degradation factor of around 3.5% per 1000 ft of increased elevation and the ambient temperature has a similar degradation per 10° increase.

Figure 7.6 shows a block diagram of a simple cycle combustion turbine with a recuperator (left) and a combustion turbine with multistage turbine and fuel re-injection (right).

	Heavy Frame	Aeroderivative
Size (Same General Rating)	Large	Compact
Shaft Speed	Synchronous	Higher Speed (coupled through a gear box)
Air Flow	High (lower compression)	Lower (high compression)
Start-up Time	15 Minutes	2-3 minutes

FIGURE 7.5 Basic combustion turbine operating characteristics.

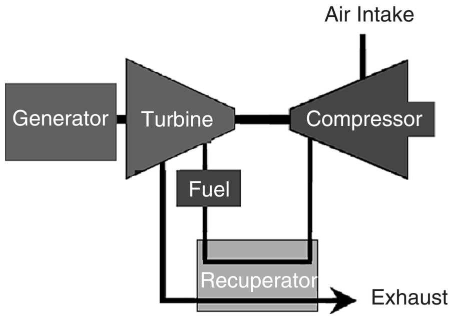

FIGURE 7.6 Basic combustion turbine designs.

7.5 Storage Technologies

Storage technologies include batteries, flywheels, ultra-capacitors, and to some extent photovoltaics. Most of these technologies are best suited for power quality and reliability enhancement applications, due to their relative energy storage capabilities and power density characteristics, although some large battery installations could be used for peak shaving. All of the storage technologies have a power electronic converter interface and can be used in conjunction with other DU technologies to provide "seamless" transitions when power quality is a requirement.

7.6 Interface Issues

A whole chapter could be written just about interface issues, but this discussion will touch on the highlights. Most of the issues revolve around safety and quality of service. We will discuss some general guidelines and the general utility requirements and include examples of different considerations. In addition to the interface issues, the DU installation must also provide self-protection to prevent short circuit or other damage to the unit. Self-protection will not be discussed here. The most important issues are listed in Table 7.1.

In addition to the interface issues identified in Table 7.1, there are also operating limits that must be considered. These are listed in Table 7.2.

TABLE 7.1 Interface Issues

Issue	Definition	Concern
Automatic reclosing	Utility circuit breakers can test the line after a fault.	If a generator is still connected to the system, it may not be in synchronization, thus damaging the generator or causing another trip.
Faults	Short circuit condition on the utility system.	Generator may contribute additional current to the fault, causing a miss operation of relay equipment.
Islanding	A condition where a portion of the system continues to operate isolated from the utility system.	Power quality, safety, and protection may be compromised in addition to possible synchronization problems.
Protection	Relays, instrument transformers, circuit breakers.	Devices must be utility grade rather than industrial grade for better accuracy. Devices must also be maintained on a regular schedule by trained technicians.
Communication	Devices necessary for utility control during emergency conditions.	Without control of the devices, islanding and other undesirable operation of devices.

TABLE 7.2 Operating Limits

1. Voltage—The operating range for voltage must maintain a level of $\pm 15\%$ of nominal for service voltage (ANSI C84.1), and have a means of automatic separation if the level gets out of the acceptable range within a specified time.
2. Flicker—Flicker must be within the limits as specified by the connecting utility. Methods of controlling flicker are discussed in IEEE Std. 519-1992, 10.5.
3. Frequency—Frequency must be maintained within ± 0.5 Hz of 60 Hz and have an automatic means of disconnecting if this is not maintained. If the system is small and isolated, there might be a larger frequency window. Larger units may require an adjustable frequency range to allow for clock synchronizaton.
4. Power factor—The power factor should be within 0.85 lagging or leading for normal operation. Some systems that are designed for compensation may operate outside these limits.
5. Harmonics—Both voltage and current harmonics must comply with the values for generators as specified in IEEE Std. 519-1992 for both total and individual harmonics.

Utility requirements vary but generally depend on the application of a distributed source. If the unit is being used strictly for emergency operation, open transition peak shaving, or any other stand-alone type operation, the interface requirements are usually fairly simple, since the units will not be operating in parallel with the utility system. When parallel operation is anticipated or required, the interface requirements become more complex. Protection, safety, power quality, and system coordination become issues that must be addressed. In the case of parallel operation, there are generally three major factors that determine the degree of protection required. These would include the size and type of the generation, the location on the system, and how the installation will operate (one-way vs. two-way). Generator sizes are generally classified as:

Large: Greater than 3 MVA or possibility of "islanding" a portion of the system
Small: Between large and extremely small
Extremely small: Generation less than 100 kVA

Location on the system and individual system characteristics determine impedance of a distribution line, which in turn determines the available fault current and other load characteristics that influence "islanding" and make circuit protection an issue. This will be discussed in more detail later.

The type of operation is the other main issue and is one of the main determinants in the amount of protection required. One-way power flow where power will not flow back into the utility has a fairly simple interface, but is dependent on the other two factors, while two-way interfaces can be quite complex. An example is shown in Fig. 7.7. Smaller generators and "line-commutated" units would have less stringent requirements. Commutation methods will be discussed later. Reciprocating engines such as diesel and turbines with mass, and "self-commutating" units which could include microturbines and fuel cells, would require more stringent control packages due to their islanding and reverse power capabilities.

Most of the new developing technologies are inverter based and there are efforts now in IEEE to revise the old Standard P929 *Recommended Practice for Utility Interface of Photovoltaic (PV) Systems* to include other inverter-based devices. The standards committee is looking at the issues with inverter-based devices in an effort to develop a standard interface design that will simplify and reduce the cost, while not sacrificing the safety and operational concerns. Inverter interfaces generally fall into two classes: line-commutated inverters and self-commutated inverters.

7.6.1 Line-Commutated Inverters

These inverters require a switching signal from the line voltage in order to operate. Therefore, they will cease operation if the line signal, i.e., utility voltage, is abnormal or interrupted. These are not as popular today for single-phase devices due to the filtering elements required to meet the harmonic distortion requirements, but are appearing in some of the three-phase devices where phase cancellation minimizes the use of the additional components.

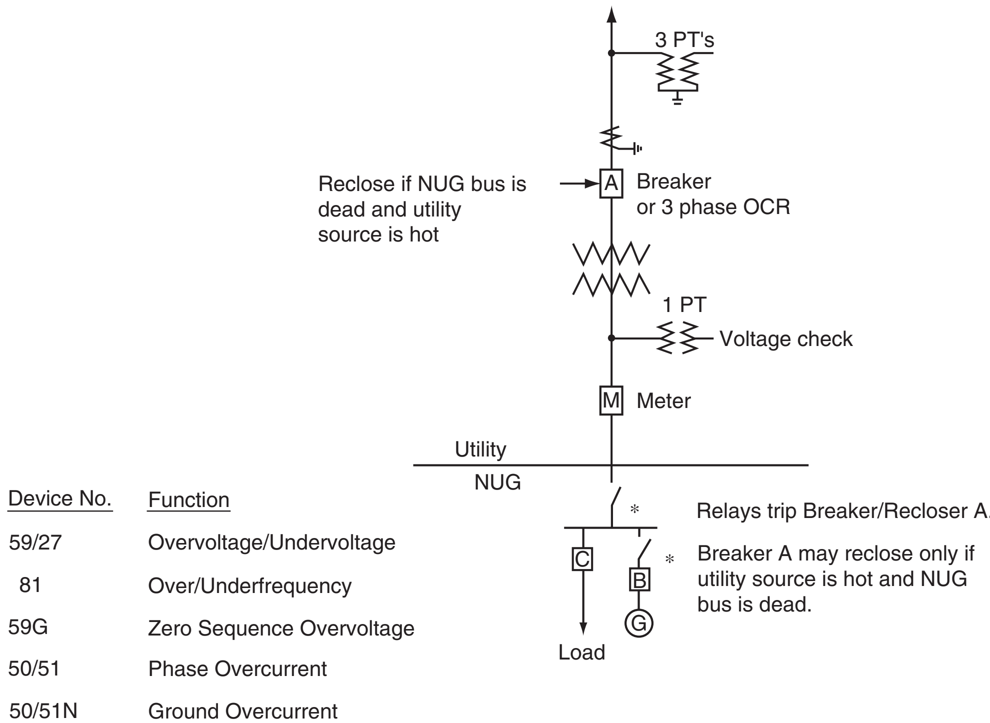

FIGURE 7.7 Example of large generator interface requirements for distribution. (From *Georgia Power Bulletin*, 18–8, generator interface requirements.)

7.6.2 Self-Commutated Inverters

These inverters, as implied by the name, are self-commutating. All stand-alone units are self-commutated, but not all self-commutated inverters are stand-alone. They can be designed as either voltage or current sources and most that are now being designed to be connected to the utility system are designed to be current sources. These units still use the utility voltage signal as a comparison and produce current at that voltage and frequency. A great deal of effort has gone into the development of non-islanding inverters that are of this type.

7.7 Applications

Applications vary and will become more diverse as utilities unbundle. Listed below are some examples of the most likely.

7.7.1 Ancillary Services

Ancillary services support the basic electrical services and are essential for the reliability and operation of the electric power system. The electrical services that are supported include generating capacity, energy supply, and the power delivery system. FERC requires six ancillary services, including system control, regulation (frequency), contingency reserves (both spinning and supplemental), voltage control, and energy imbalance. In addition, load following, backup supply, network stability, system "black-start", loss replacement, and dynamic scheduling are necessary for the operation of the system. Utilities have been performing these functions for decades, but as vertically integrated regulated monopoly organizations. As these begin to disappear, and a new structure with multiple competing parties emerges, distributed utilities might be able to supply several of these.

The distributed utilities providing these services could be owned by the former traditional utility, customers, or third-party brokers, depending on the application. The main obstacles to this approach are aggregation and communication when dealing with many small resources rather than large central station sources.

7.7.2 "Traditional Utility" Applications

Traditional utilities may find the use of DU a practical way to solve loading and reliability problems if each case is evaluated on a stand-alone individual basis. Deferring investment is one likely way that DU can be applied. In many areas, substations and lines have seasonal peaks that are substantially higher than the rest of the year. In these cases, the traditional approach has been to increase the capacity to meet the demand. Based on the individual situation, delaying the upgrade for 2 to 5 years with a DU system could be a more economical solution. This would be especially true if different areas had different seasonal peaks and the DU system was portable, thus deferring two upgrades. DU could also be used instead of conventional facilities when backup feeds are required or to improve reliability or power quality.

In addition, peak shaving and generation reserve could be provided with strategically placed DU systems that take advantage of reducing system losses as well as offsetting base generation. Again, these have to be evaluated on an individual case basis and not a system average basis as is done in many economic studies. The type of technology used will depend on the particular requirements. In general, storage devices such as flywheels and batteries are better for power quality applications due to their fast response time, in many cases half a cycle. Generation devices are better suited for applications that require more than 30 min of supply, such as backup systems, alternate feeds, peak shaving, and demand deferrals. Generation sources can also be used instead of conventional facilities in certain cases.

7.7.3 Customer Applications

Individual customers with special requirements may find DU technologies that meet their needs. Customers who require "enhanced" power quality and reliability of service already utilize UPS systems with battery backup to condition the power to sensitive equipment, and many hospitals, waste treatment plants, and other emergency services providers have emergency backup systems supplied by standby generator systems. As barriers go down and technologies improve, customer-sited DU facilities could provide many of the ancillary services as well as sell excess power into the grid. Fuel cell and even diesel generators could be especially attractive for customers with requirements of heat and steam. Many of the fuel cell technologies are now looking at the residential market with small units that would be connected to the grid but supply the additional requirements for customers with special power quality needs.

7.7.4 Third-Party Service Providers

Third-party service providers could provide all the services listed above for the utilities and customers, in addition to selling power across the grid. In many cases, an end user does not have the expertise to operate and maintain generation systems and would prefer to purchase the services.

7.8 Conclusions

Disbursed generation will be a part of the distribution utility system of the future. Economics, regulatory requirements, and technology improvements will determine the speed at which they are integrated.

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