Whitaker, Jerry C. “Standby Power Systems”
Jerry C. Whitaker
Boca Raton: CRC Press LLC, 1999
8.1 Introduction

When utility company power problems are discussed, most people immediately think of blackouts. The lights go out, and everything stops. With the facility down and in the dark, there is nothing to do but sit and wait until the utility company finds the problem and corrects it. This process generally takes only a few minutes. There are times, however, when it can take hours. In some remote locations, it can even take days.

Blackouts are, without a doubt, the most troublesome utility company problem that a facility will have to deal with. Statistics show that power failures are, generally speaking, a rare occurrence in most areas of the country. They are also short in duration. Studies have shown that 50 percent of blackouts last 6 s or less, and 35 percent are less than 11 min long. These failure rates usually are not cause for concern to commercial users, except where computer-based operations, transportation control systems, medical facilities, and communications sites are concerned.

When continuity of operation is critical, redundancy must be carried throughout the system. The site never should depend upon one critical path for ac power. For example, if the facility is fed by a single step-down transformer, a lightning flash or other catastrophic event could result in a transformer failure that would bring down the entire site. A replacement could take days or even weeks.

8.1.1 Blackout Effects

A facility that is down for even 5 min can suffer a significant loss of productivity or data that may take hours or days to rebuild. A blackout affecting a transportation or medical center could be life-threatening. Coupled with this threat is the possibility of extended power-service loss due to severe storm conditions. Many broadcast and
communications relay sites are located in remote, rural areas or on mountaintops. Neither of these kinds of locations are well-known for their power reliability. It is not uncommon in mountainous areas for utility company service to be out for extended periods after a major storm. Few operators are willing to take such risks with their business. Most choose to install standby power systems at appropriate points in the equipment chain.

The cost of standby power for a facility can be substantial, and an examination of the possible alternatives should be conducted before any decision on equipment is made. Management must clearly define the direct and indirect costs and weigh them appropriately. Include the following items in the cost-vs.-risk analysis:

- Standby power-system equipment purchase and installation cost.
- Exposure of the system to utility company power failure.
- Alternative operating methods available to the facility.
- Direct and indirect costs of lost uptime because of blackout conditions.

A distinction must be made between emergency and standby power sources. Strictly speaking, emergency systems supply circuits legally designated as being essential for safety to life and property. Standby power systems are used to protect a facility against the loss of productivity resulting from a utility company power outage.

### 8.2 Standby Power Options

To ensure the continuity of ac power, many commercial/industrial facilities depend upon either two separate utility services or one utility service plus on-site generation. Because of the growing complexity of electrical systems, attention must be given to power-supply reliability.

The engine-generator shown in Figure 8.1 is the classic standby power system. An automatic transfer switch monitors the ac voltage coming from the utility company line for power failure conditions. Upon detection of an outage for a predetermined period of time (generally 1 to 10 s), the standby generator is started; after the generator is up to speed, the load is transferred from the utility to the local generator. Upon return of the utility feed, the load is switched back, and the generator is stopped. This basic type of system is used widely in industry and provides economic protection against prolonged power outages (5 min or more).

The transfer device shown in Figure 8.1 is a contactor-type, break-before-make unit. By replacing the simple transfer device shown with an automatic overlap (static) transfer switch, as shown in Figure 8.2, additional functionality can be gained. As described in Section 5.3.4, the overlap transfer switch permits the on-site generator to be synchronized with the load, making a clean switch from one energy source to another. This functionality offers the following benefits:
Figure 8.1 The classic standby power system using an engine-generator set. This system protects a facility from prolonged utility company power failures.

Figure 8.2 The use of a static transfer switch to transfer the load from the utility company to the on-site generator.
Switching back to the utility feed from the generator can be accomplished without interruption in service. The load can be cleanly switched from the utility to the generator in anticipation of utility line problems (such as an approaching severe storm). The load can be switched to and from the generator to accomplish load shedding objectives (discussed later in this chapter).

**Dual Feeder System**

In some areas, usually metropolitan centers, two utility company power drops can be brought into a facility as a means of providing a source of standby power. As shown in Figure 8.3, two separate utility service drops—from separate power-distribution systems—are brought into the plant, and an automatic transfer switch changes the load to the backup line in the event of a main-line failure. The dual feeder system provides an advantage over the auxiliary diesel arrangement in that power transfer from main to standby can be made in a fraction of a second if a static transfer switch is used. Time delays are involved in the diesel generator system that limit its usefulness to power failures lasting more than several minutes.

The dual feeder system of protection is based on the assumption that each of the service drops brought into the facility is routed via different paths. This being the case, the likelihood of a failure on both power lines simultaneously is remote. The

---

**Figure 8.3** The dual utility feeder system of ac power loss protection. An automatic transfer switch changes the load from the main utility line to the standby line in the event of a power interruption.
dual feeder system will not, however, protect against area-wide power failures, which can occur from time to time.

The dual feeder system is limited primarily to urban areas. Rural or mountainous regions generally are not equipped for dual redundant utility company operation. Even in urban areas, the cost of bringing a second power line into a facility can be high, particularly if special lines must be installed for the feed. If two separate utility services are available at or near the site, redundant feeds generally will be less expensive than engine-driven generators of equivalent capacity.

Figure 8.4 illustrates a dual feeder system that utilizes both utility inputs simultaneously at the facility. Notice that during normal operation, both ac lines feed loads, and the “tie” circuit breaker is open. In the event of a loss of either line, the circuit-breaker switches reconfigure the load to place the entire facility on the single remaining ac feed. Switching is performed automatically; manual control is provided in the event of a planned shutdown on one of the lines.

Figure 8.4 A dual utility feeder system with interlocked circuit breakers.
8.2.1 Peak Power Shaving

Figure 8.5 illustrates the use of a backup diesel generator for both standby power and peak power shaving applications. Commercial power customers often can realize substantial savings on utility company bills by reducing their energy demand during certain hours of the day. An automatic overlap transfer switch is used to change the load from the utility company system to the local diesel generator. The changeover is accomplished by a static transfer switch that does not disturb the operation of load equipment. This application of a standby generator can provide financial return to the facility, whether or not the unit is ever needed to carry the load through a commercial power failure.

8.2.2 Advanced System Protection

A more sophisticated power-control system is shown in Figure 8.6, where a dual feeder supply is coupled with a motor-generator set to provide clean, undisturbed ac power to the load. The m-g set will smooth over the transition from the main utility feed to the standby, often making a commercial power failure unnoticed by on-site personnel. As discussed in Section 5.2, a conventional m-g typically will give up to 0.5 s of power fail ride-through, more than enough to accomplish a transfer from one utility feed to the other. This standby power system is further refined in the
application illustrated in Figure 8.7, where a diesel generator has been added to the system. With the automatic overlap transfer switch shown at the generator output, this arrangement also can be used for peak demand power shaving.

Figure 8.8 shows a simplified schematic diagram of a 220 kW UPS system utilizing dual utility company feed lines, a 750 kVA gas-engine generator, and five dc-driven motor-generator sets with a 20-min battery supply at full load. The five m-g sets operate in parallel. Each is rated for 100 kW output. Only three are needed to power the load, but four are on-line at any given time. The fifth machine provides redundancy in the event of a failure or for scheduled maintenance work. The batteries are always on-line under a slight charge across the 270 V dc bus. Two separate natural-gas lines, buried along different land routes, supply the gas engine. Local gas storage capacity also is provided.

8.2.3 Choosing a Generator

Engine-generator sets are available for power levels ranging from less than 1 kVA to several thousand kVA or more. Machines also can be paralleled to provide greater
capacity. Engine-generator sets typically are classified by the type of power plant used:

- **Diesel.** Advantages: rugged and dependable, low fuel costs, low fire and/or explosion hazard. Disadvantages: somewhat more costly than other engines, heavier in smaller sizes.

- **Natural and liquefied petroleum gas.** Advantages: quick starting after long shutdown periods, long life, low maintenance. Disadvantage: availability of natural gas during area-wide power failure subject to question.

- **Gasoline.** Advantages: rapid starting, low initial cost. Disadvantages: greater hazard associated with storing and handling gasoline, generally shorter mean time between overhaul.

- **Gas turbine.** Advantages: smaller and lighter than piston engines of comparable horsepower, rooftop installations practical, rapid response to load changes. Disadvantages: longer time required to start and reach operating speed, sensitive to high input air temperature.
The type of power plant chosen usually is determined primarily by the environment in which the system will be operated and by the cost of ownership. For example, a standby generator located in an urban area office complex may be best suited to the use of an engine powered by natural gas, because of the problems inherent in storing large amounts of fuel. State or local building codes can place expensive restrictions on fuel-storage tanks and make the use of a gasoline- or diesel-powered engine
impractical. The use of propane usually is restricted to rural areas. The availability of propane during periods of bad weather (when most power failures occur) also must be considered.

The generator rating for a standby power system should be chosen carefully and should take into consideration the anticipated future growth of the plant. It is good practice to install a standby power system rated for at least 25 percent greater output than the current peak facility load. This headroom gives a margin of safety for the standby equipment and allows for future expansion of the facility without overloading the system.

An engine-driven standby generator typically incorporates automatic starting controls, a battery charger, and automatic transfer switch. (See Figure 8.9.) Control circuits monitor the utility supply and start the engine when there is a failure or a sustained voltage drop on the ac supply. The switch transfers the load as soon as the generator reaches operating voltage and frequency. Upon restoration of the utility supply, the switch returns the load and initiates engine shutdown. The automatic transfer switch must meet demanding requirements, including:

- Carrying the full rated current continuously
- Withstanding fault currents without contact separation
- Handling high inrush currents
- Withstanding many interruptions at full load without damage

The nature of most power outages requires a sophisticated monitoring system for the engine-generator set. Most power failures occur during periods of bad weather. Most standby generators are unattended. More often than not, the standby system will start, run, and shut down without any human intervention or supervision. For reliable operation, the monitoring system must check the status of the machine continually to ensure that all parameters are within normal limits. Time-delay periods usually are provided by the controller that require an outage to last from 5 to 10 s before the generator is started and the load is transferred. This prevents false starts that needlessly exercise the system. A time delay of 5 to 30 min usually is allowed between the restoration of utility power and return of the load. This delay permits the utility ac lines to stabilize before the load is reapplied.

The transfer of motor loads may require special consideration, depending upon the size and type of motors used at a plant. If the residual voltage of the motor is out of phase with the power source to which the motor is being transferred, serious damage can result to the motor. Excessive current draw also may trip overcurrent protective devices. Motors above 50 hp with relatively high load inertia in relation to torque requirements, such as flywheels and fans, may require special controls. Restart time delays are a common solution.

Automatic starting and synchronizing controls are used for multiple-engine-generator installations. The output of two or three smaller units can be combined to feed the load. This capability offers additional protection for the facility in the event of a
failure in any one machine. As the load at the facility increases, additional engine-generator systems can be installed on the standby power bus.

8.2.3.1 Generator Types

Generators for standby power applications can be induction or synchronous machines. Most engine-generator systems in use today are of the synchronous type because of the versatility, reliability, and capability of operating independently that this approach provides [2]. Most modern synchronous generators are of the revolving field alternator design. Essentially, this means that the armature windings are held stationary and the field is rotated. Therefore, generated power can be taken directly from the stationary armature windings. Revolving armature alternators are less popular because the generated output power must be derived via slip rings and brushes.

The exact value of the ac voltage produced by a synchronous machine is controlled by varying the current in the dc field windings, while frequency is controlled by the speed of rotation. Power output is controlled by the torque applied to the gen-
erator shaft by the driving engine. In this manner, the synchronous generator offers precise control over the power it can produce.

Practically all modern synchronous generators use a brushless exciter. The exciter is a small ac generator on the main shaft; the ac voltage produced is rectified by a 3-phase rotating rectifier assembly also on the shaft. The dc voltage thus obtained is applied to the main generator field, which is also on the main shaft. A voltage regulator is provided to control the exciter field current, and in this manner, the field voltage can be precisely controlled, resulting in a stable output voltage.

The frequency of the ac current produced is dependent on two factors: the number of poles built into the machine, and the speed of rotation (rpm). Because the output frequency must normally be maintained within strict limits (60 Hz or 50 Hz), control of the generator speed is essential. This is accomplished by providing precise rpm control of the prime mover, which is performed by a governor.

There are many types of governors; however, for auxiliary power applications, the isochronous governor is normally selected. The isochronous governor controls the speed of the engine so that it remains constant from no-load to full load, assuring a constant ac power output frequency from the generator. A modern system consists of two primary components: an electronic speed control and an actuator that adjusts the speed of the engine. The electronic speed control senses the speed of the machine and provides a feedback signal to the mechanical/hydraulic actuator, which in turn positions the engine throttle or fuel control to maintain accurate engine rpm.

The National Electrical Code provides guidance for safe and proper installation of on-site engine-generator systems. Local codes may vary and must be reviewed during early design stages.

### 8.2.4 UPS Systems

An uninterruptible power system is an elegant solution to power outage concerns. The output of the UPS inverter can be a sine wave or pseudo sine wave. (See Section 5.3.2.) When shopping for a UPS system, consider the following:

- Power reserve capacity for future growth of the facility.
- Inverter current surge capability (if the system will be driving inductive loads, such as motors).
- Output voltage and frequency stability over time and with varying loads.
- Required battery supply voltage and current. Battery costs vary greatly, depending upon the type of units needed.
- Type of UPS system (forward-transfer type or reverse-transfer type) required by the particular application. Some sensitive loads may not tolerate even brief interruptions of the ac power source.
• Inverter efficiency at typical load levels. Some inverters have good efficiency ratings when loaded at 90 percent of capacity, but poor efficiency when lightly loaded.

• Size and environmental requirements of the UPS system. High-power UPS equipment requires a large amount of space for the inverter/control equipment and batteries. Battery banks often require special ventilation and ambient temperature control.

### 8.2.5 Standby Power-System Noise

Noise produced by backup power systems can be a serious problem if not addressed properly. Standby generators, motor-generator sets, and UPS systems produce noise that can disturb building occupants and irritate neighbors and/or landlords.

The noise associated with electrical generation usually is related to the drive mechanism, most commonly an internal combustion engine. The amplitude of the noise produced is directly related to the size of the engine-generator set. First consider whether noise reduction is a necessity. Many building owners have elected to tolerate the noise produced by a standby power generator because its use is limited to emergency situations. During a crisis, when the normal source of power is unavailable, most people will tolerate noise associated with a standby generator.

If the decision is made that building occupants can live with the noise of the generator, care must be taken in scheduling the required testing and exercising of the unit. Whether testing occurs monthly or weekly, it should be done on a regular schedule.

If it has been determined that the noise should be controlled, or at least minimized, the easiest way to achieve this objective is to physically separate the machine from occupied areas. This may be easier said than done. Because engine noise is predominantly low-frequency in character, walls and floor/ceiling construction used to contain the noise must be massive. Lightweight construction, even though it may involve several layers of resiliently mounted drywall, is ineffective in reducing low-frequency noise. Exhaust noise is a major component of engine noise but, fortunately, it is easier to control. When selecting an engine-generator set, select the highest-quality exhaust muffler available. Such units often are identified as “hospital-grade” mufflers.

Engine-generator sets also produce significant vibration. The machine should be mounted securely to a slab-on-grade or an isolated basement floor, or it should be installed on vibration isolation mounts. Such mounts usually are specified by the manufacturer.

Because a UPS system or motor-generator set is a source of continuous power, it must run continuously. Noise must be adequately controlled. Physical separation is the easiest and most effective method of shielding occupied areas from noise. Enclosure of UPS equipment usually is required, but noise control is significantly easier than for an engine-generator because of the lower noise levels involved. Nevertheless, the low-frequency 120 Hz fundamental of a UPS system is difficult to contain.
adequately; massive constructions may be necessary. Vibration control also is required for most UPS and m-g gear.

### 8.2.6 Batteries

Batteries are the lifeblood of most UPS systems. Important characteristics include the following:

- **Charge capacity**—how long the battery will operate the UPS.
- **Weight.**
- **Charging characteristics.**
- **Durability/ruggedness.**

Additional features that add to the utility of the battery include:

- **Built-in status/temperature/charge indicator and/or data output port.**
- **Built-in over-temperature/over-current protection with auto-reset capabilities.**
- **Environmental friendliness.**

The last point deserves some attention. Many battery types must be recycled or disposed of through some prescribed means. Proper disposal of a battery at the end of its useful life is, thus, an important consideration. Be sure to check the original packaging for disposal instructions. Failure to follow the proper procedures could have serious consequences.

Research has brought about a number of different battery chemistries, each offering distinct advantages. Today’s most common and promising rechargeable chemistries include the following:

- **Nickel cadmium (NiCd)**—used for portable radios, cellular phones, video cameras, laptop computers, and power tools. NiCds have good load characteristics, are economically priced, and are simple to use.
- **Lithium ion (Li-Ion)**—now commonly available and typically used for video cameras. This battery promises to replace some NiCds for high energy-density applications.
- **Sealed lead acid (SLA)**—used for uninterruptible power systems, video cameras, and other demanding applications where the energy-to-weight ratio is not critical and low battery cost is desirable.
- **Nickel metal hydride (NiMH)**—used for cellular phones, video cameras, and laptop computers where high energy is of importance and cost is secondary.
- **Lithium polymer (Li-Polymer)**—when commercially available, this battery will have the highest energy density and lowest self-discharge of common battery types, but its load characteristics will likely only suit low current applications.
• **Reusable alkaline**—used for light duty applications. Because of its low self-discharge, this battery is suitable for portable entertainment devices and other non-critical appliances that are used occasionally.

No single battery offers all the answers; rather, each chemistry is based on a number of compromises.

A battery, of course, is only as good as its charger. Common attributes for the current generation of charging systems include quick-charge capability and automatic battery condition analysis and subsequent *intelligent* charging.

### 8.2.6.1 Terms

The following terms are commonly used to specify and characterize batteries:

- **Energy density.** The storage capacity of a battery measured in *watt-hours per kilogram* (Wh/kg).
- **Cycle life.** The typical number of charge-discharge cycles for a given battery before the capacity decreases from the nominal 100 percent to approximately 80 percent, depending upon the application.
- **Fast-charge time.** The time required to fully charge an empty battery.
- **Self-discharge.** The discharge rate when the battery is not in use.
- **Cell voltage.** The output voltage of the basic battery element. The cell voltage multiplied by the number of cells provides the battery terminal voltage.
- **Load current.** The maximum recommended current the battery can provide.
- **Current rate.** The C-rate is a unit by which charge and discharge times are scaled. If discharged at 1C, a 100 Ah battery provides a current of 100 A; if discharged at 0.5C, the available current is 50 A.
- **Exercise requirement.** This parameter indicates the frequency that the battery needs to be exercised to achieve maximum service life.

### 8.2.6.2 Sealed Lead-Acid Battery

The lead-acid battery is a commonly used chemistry. The *flooded* version is found in automobiles and large UPS battery banks. Most smaller, portable systems use the *sealed* version, also referred to as *gelcell* or SLA.

The lead-acid chemistry is commonly used when high power is required, weight is not critical, and cost must be kept low [3]. The typical current range of a medium-sized SLA device is 2 Ah to 50 Ah. Because of its minimal maintenance requirements and predictable storage characteristics, the SLA has found wide acceptance in the UPS industry, especially for *point-of-application* systems.

The SLA is not subject to memory. No harm is done by leaving the battery on float charge for a prolonged time. On the negative side, the SLA does not lend itself well to fast charging. Typical charge times are 8 to 16 hours. The SLA must always...
be stored in a charged state because a discharged SLA will sulphate. If left discharged, a recharge may be difficult or even impossible.

Unlike the common NiCd, the SLA prefers a shallow discharge. A full discharge reduces the number of times the battery can be recharged, similar to a mechanical device that wears down when placed under stress. In fact, each discharge-charge cycle reduces (slightly) the storage capacity of the battery. This wear-down characteristic also applies to other chemistries, including the NiMH.

The charge algorithm of the SLA differs from that of other batteries in that a voltage-limit rather than current-limit is used. Typically, a multi-stage charger applies three charge stages consisting of a constant-current charge, topping-charge, and float-charge. (See Figure 8.10.) During the constant-current stage, the battery charges to 70 percent in about five hours; the remaining 30 percent is completed by the topping-charge. The slow topping-charge, lasting another five hours, is essential for the performance of the battery. If not provided, the SLA eventually loses the ability to accept a full charge and the storage capacity of the battery is reduced. The third stage is the float-charge that compensates for self-discharge after the battery has been fully charged.

During the “constant current charge,” the SLA battery is charged at a high current, limited by the charger itself. After the voltage limit is reached, the topping charge begins and the current starts to gradually decrease. Full-charge is reached when the current drops to a preset level or reaches a low-end plateau.

The proper setting of the cell voltage limit is critical and is related to the conditions under which the battery is charged. A typical voltage limit range is from 2.30

Figure 8.10 The charge states of an SLA battery. (From [3]. Used with permission.)
V to 2.45 V. If a slow charge is acceptable, or if the room temperature can exceed
30°C (86°F), the recommended voltage limit is 2.35 V/cell. If a faster charge is
required and the room temperature remains below 30°C, 2.40 or 2.45 V/cell can be
used. Table 8.1 compares the advantages and disadvantages of the different voltage
settings.

### Table 8.1 Recommended Charge Voltage Limit for the SLA Battery (After [3].)

<table>
<thead>
<tr>
<th>Voltage Setting</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.30 V to 2.35 V/cell</td>
<td>Maximum service life; battery remains cool on charge; battery can be charged at ambient temperature exceeding 30°C (86°F).</td>
<td>Slow charge time; capacity readings may be low and inconsistent. Produces under-charge condition that can cause sulphation and capacity loss if the battery is not periodically cycled.</td>
</tr>
<tr>
<td>2.40 V to 2.45 V/cell</td>
<td>Faster charge times; higher and more consistent capacity readings; less subject to damage because of under-charge condition.</td>
<td>Battery life may be reduced because of elevated battery temperature while charging. A hot battery may fail to reach the cell voltage limit, causing harmful over-charge.</td>
</tr>
</tbody>
</table>

8.3 Fault Tolerance as a Design Objective

To achieve high levels of power system reliability—with the ultimate goal being 24-hour-per-day availability, 365 days per year—some form of power system redundancy is required, regardless of how reliable the individual power system components may be [4]. Redundancy, if properly implemented, also provides power distribution flexibility. By providing more than one path for power flow to the load, the key elements of a system can be shifted from one device or branch to another as required for load balancing, system renovations or alterations, or equipment failure isolation. Redundancy also provides a level of fault tolerance. Fault tolerance can be divided into three basic categories:

- Rapid recovery from failures
- Protection against “slow” power system failures, where there is enough warning of the condition to allow intervention
- Protection against “fast” power system failures, where no warning of the power failure is given

As with many corrective and preventive measures, the increasing costs must be weighed against the benefits.

For example, recent developments in large UPS system technologies have provided the capability to operate two independent UPS systems in parallel, either
momentarily or continuously. The ability to momentarily connect two UPS systems allows critical loads to be transferred from one UPS system to the other without placing the UPS systems in bypass, thereby maintaining continuous UPS protection of the loads. Continuous paralleling of the two UPS systems, on the other hand, can be used to create a single redundant UPS system from two otherwise nonredundant systems when multiple UPS modules are out of service (because of failures or maintenance). Figure 8.11 illustrates one such implementation.

8.3.1 Critical System Bus

Many facilities do not require the operation of all equipment during a power outage. Rather than use one large standby power system, key pieces of equipment can be protected with small, dedicated, uninterruptible power systems. Small UPS units are available with built-in battery supplies for computer systems and other hardware. If cost prohibits the installation of a system-wide standby power supply (using generator or solid-state UPS technologies), consider establishing a critical load bus that is connected to a UPS system or generator via an automatic transfer switch. This separate power supply is used to provide ac to critical loads, thus keeping the protected systems up and running. The concept is illustrated in Figure 8.12. Unnecessary loads are dropped in the event of a power failure.

A standby system built on the critical load principle can be a cost-effective answer to the power-failure threat. The first step in implementing a critical load bus is to accurately determine the power requirements for the most important equipment. Typical power consumption figures can be found in most equipment instruction manuals. If the data is not listed or available from the manufacturer, it can be measured using a wattmeter.

When planning a critical load bus, be certain to identify accurately which loads are critical, and which can be dropped in the event of a commercial power failure. If air conditioning is interrupted but the computer equipment at a large data processing center continues to run, temperatures will rise quickly to the point at which system components may be damaged or the hardware automatically shuts down. It may not be necessary to require cooling fans, chillers, and heat-exchange pumps to run without interruption. However, any outage should be less than 1 to 2 min in duration. Air-cooled computer systems can usually tolerate 5 to 10 min of cooling interruption.

8.3.2 Power Distribution Options

There are essentially 12 building blocks that form what can be described as an assured, reliable, clean power source for computer systems, peripherals, and other critical loads [5]. They are:

- Utility and service entry (step-down transformer, main disconnect, and panelboard, switchboard, or switchgear)
Figure 8.11 Power distribution system featuring redundancy and high reliability. Of particular interest is the ability to parallel UPS systems as required by operational conditions. (After [4].)

- Lightning protection
- Power bus
- Facility power distribution
- Grounding
Figure 8.12 An application of the critical-load power bus concept. In the event of a power failure, all equipment necessary for continued operation is powered by the UPS equipment. Noncritical loads are dropped until commercial ac returns.

- Power conditioning equipment
- Critical load air-conditioning
- Frequency converter (if required)

© 1999 CRC Press LLC
• Batteries for dc backup power
• Emergency engine-generator
• Critical load power distribution network
• Emergency readiness planning

A power system to support a critical load cannot be said to be reliable unless all these components are operating as intended, not only during normal operation, but especially during an emergency.

It is easy to become complacent during periods when everything is functioning properly, because this is the usual mode of operation. An absence of contingency plans for dealing with an emergency situation, and a lack of understanding of how the entire system works, thus, can lead to catastrophic shutdowns when an emergency situation arises. Proper training, and periodic reinforcing, is an essential component of a reliable system.

8.3.3 Plant Configuration

There are any number of hardware configurations that will provide redundancy and reliability for a critical load. Each situation is unique and requires an individual assessment of the options and—more importantly—the risks. The realities of economics dictate that cost is always a factor. Through proper design, however, the expense usually can be held within an acceptable range.

*Design for reliability* begins at the utility service entrance [5]. The common arrangement shown in Figure 8.13 is vulnerable to interruptions from faults at the transformer and associated switching devices in the circuit. Furthermore, service entrance maintenance would require a plant shutdown. In Figure 8.14, redundancy has been provided that will prevent the loss of power should one of the devices in the line fail. Because the two transformers are located in separate physical enclosures, maintenance can be performed on one leg without dropping power to the facility.

Of equal importance is the method of distributing power within a facility to achieve maximum reliability. This task is more difficult when dealing with a campus-type facility or a process or manufacturing plant, where—instead of being concentrated in a single room or floor—the critical loads may be in a number of distant locations. Figure 8.15 illustrates power distribution through the facility using a simple radial system. An incoming line supplies the main and line feeders via a service entrance transformer. This system is suitable for a single building or a small process plant. It is simple, reliable, and lowest in cost. However, such a system must be shut down for routine maintenance, and it is vulnerable to single-point failure. Figure 8.16 illustrates a distributed and redundant power distribution system that permits transferring loads as required to patch around a fault condition. This configuration also allows portions of the system to be de-energized for maintenance or upgrades without dropping the entire facility. Note the loop arrangement and associated
switches that permit optimum flexibility during normal and fault operating conditions.

**Figure 8.13** Simplified service entrance system. *(From [5]. Used with permission.)*

**Figure 8.14** Fault-tolerant service entrance system. *(From [5]. Used with permission.)*
8.4 The Efficient Use of Energy

Utility company power bills are usually a large part of the operating expenses of a facility. To reduce the amount of money spent each month on electricity, engineers must understand the billing methods used by the utility. Saving energy is more complicated than simply turning off unnecessary lights. The amount of money that can be saved through a well-planned energy conservation effort is often substantial. Reductions of 20 percent are not uncommon, depending upon the facility layout and the extent of energy conservation efforts already under way. Regardless of any monetary savings that might be realized from a power-use-reduction program, the items discussed here should be considered for any well-run facility.
The rate structures of utility companies vary widely from one area of the country to another. Some generalizations can be made, however, with respect to the basic rate-determining factors. The four primary parameters used to determine a customer's bill are:

- Energy usage
- Peak demand
- Load factor
- Power factor

These items often can be controlled, to some extent, by the customer.

### 8.4.1 Energy Usage

The kilowatthour (kWh) usage of a facility can be reduced by turning off loads such as heating and air conditioning systems, lights, and office equipment when they are not needed. The installation of timers, photocells, or sophisticated computer-controlled energy-management systems can make substantial reductions in facility kWh demand each month. Common sense will dictate the conservation measures applicable to a particular situation. Obvious items include reducing the length of time high-power equipment is in operation, setting heating and cooling thermostats for reason-
able levels, keeping office equipment turned off during the night, and avoiding excessive amounts of indoor or outdoor lighting.

Although energy conservation measures should be taken in every area of facility operation, the greatest savings generally can be found where the largest energy users are located. Transmitter plants, large machinery, and process drying equipment consume a huge amount of power, so particular attention should be given to such hardware. Consider the following:

- Use the waste heat from equipment at the site for other purposes, if practical. In the case of high-power RF generators or transmitters, room heating can be accomplished with a logic-controlled power amplifier exhaust-air recycling system.
- Have a knowledgeable consultant plan the air conditioning and heating system at the facility for efficient operation.
- Check thermostat settings on a regular basis, and consider installing time-controlled thermostats.
- Inspect outdoor-lighting photocells regularly for proper operation.
- Examine carefully the efficiency of high-power equipment used at the facility. New designs may offer substantial savings in energy costs.

The efficiency of large power loads, such as mainframe computers, transmitters, or industrial RF heaters, is an item of critical importance to energy conservation efforts. Most systems available today are significantly more efficient than their counterparts of just 10 years ago. Plant management often can find economic justification for updating or replacing an older system on the power savings alone. In virtually any facility, energy conservation can best be accomplished through careful selection of equipment, thoughtful system design, and conscientious maintenance practices.

### 8.4.1.1 Peak Demand

Conserving energy is a big part of the power bill reduction equation, but it is not the whole story. The peak demand of the customer load is an important criterion in the utility company’s calculation of rate structures. The peak demand figure is a measure of the maximum load placed on the utility company system by a customer during a predetermined billing cycle. The measured quantities may be kilowatts, kilovolt-amperes, or both. Time intervals used for this measurement range from 15 to 60 min. Billing cycles may be annual or semiannual. Figure 8.17 shows an example of varying peak demand.

If a facility operated at basically the same power consumption level from one hour to the next and one day to the next, the utility company could predict accurately the demand of the load, and then size its equipment (including the allocation of energy reserves) for only the amount of power actually needed. For the example shown in the figure, however, the utility company must size its equipment (includ-
ing allocated energy reserves) for the peak demand. The area between the peak demand and the actual usage is the margin of inefficiency that the customer forces upon the utility. The peak demand factor is a method used by utility companies to assess penalties for such operation, thereby encouraging the customer to approach a more efficient state of operation (from the utility's viewpoint).

Load shedding is a term used to describe the practice of trimming peak power demand to reduce high-demand penalties. The goal of load shedding is to schedule the operation of nonessential equipment so as to provide a uniform power load to the utility company, and thereby a better kWh rate. Nearly any operation has certain electric loads that can be rescheduled on a permanent basis or deferred as power demand increases during the day. Figure 8.18 illustrates the results of a load-shedding program. This more efficient operation has a lower overall peak demand and a higher average demand.

Peak demand reduction efforts can cover a wide range of possibilities. It would be unwise from an energy standpoint, for example, to test high-power standby equipment on a summer afternoon, when air conditioning units may be in full operation. Morning or evening hours would be a better choice, when the air conditioning

Figure 8.17 The charted power consumption of a facility not practicing energy-management techniques. Note the inefficiency that the utility company must absorb when faced with a load such as this.
is off and the demand of office equipment is reduced. Each operation is unique and requires an individual assessment of load-shedding options.

An automated power-demand controller provides an effective method of managing peak demand. A controller can analyze the options available and switch loads as needed to maintain a relatively constant power demand from the utility company. Such systems are programmed to recognize which loads have priority and which loads are nonessential. Power demand then is automatically adjusted by the system, based upon the rate schedule of the utility company. Many computerized demand control systems also provide the customer a printout of the demand profile of the plant, further helping managers analyze and reduce power costs. Figure 8.19 shows one such printout. Note that both energy demand and the costs for that energy are provided.

### 8.4.1.2 Load Factor

The load factor on an electric utility company bill is a product of the peak demand and energy usage. It usually is calculated and applied to the customer's bill each month. Reducing either the peak demand or energy usage levels, or both, will decrease this added cost factor. Reducing power factor penalties also will help to reduce load factor charges.
8.4.1.3 Power Factor

Power factor charges are the result of heavy inductive loading of the utility company system. A poor PF will result in excessive losses along utility company feeder lines because more current is required to supply a particular load with a low PF than

Figure 8.19 Printout of a facility power profile: (a) billing demand in kW, (b) cost in dollars per hour, (c) demand in kvar. (After [6].)
would be demanded if the load had a PF close to unity. (The technical aspects of power factor are discussed in Section 1.9.) The power factor charge is a penalty that customers pay for the extra current needed to magnetize motors and other inductive loads. This magnetizing current does not show up on the service drop wattmeter. It is, instead, measured separately or prorated as an additional charge to the customer. The power factor penalty sometimes can be reduced through the addition of on-site PF correction capacitors.

Power factor meters are available for measurement of a given load. It is usually less expensive in the long run, however, to hire a local electrical contractor to conduct a PF survey and recommend correction methods. Possible sources of PF problems include transmitters, blowers, air conditioners, heating equipment, and fluorescent and high-intensity discharge lighting-fixture ballasts.

In this section, we have only touched the surface of the power conservation issue. Interested readers are referred to [6] for a detailed discussion of energy-saving options and case histories.

8.5 Plant Maintenance

Maintenance of the facility electrical system is a key part of any serious energy-management effort. Perform the following steps on a regular basis:

- Measure the current drawn on distribution cables. Document the measurements so that a history of power demand can be compiled.
- Check terminal and splice connections to make sure they are tight.
- Check power-system cables for excessive heating.
- Check cables for insulation problems.
- Clean switchboard and circuit-breaker panels.
- Measure the phase-to-phase load balance at the utility service entrance. Load imbalance can result in inefficient use of ac power.
- Measure and chart the power factor of the load.

Develop and post a simplified one-line schematic of the entire power network as well as other building systems, including heating, air conditioning, security, and alarm functions. A mimic board is helpful in this process. Construct the mimic board control panel so that it depicts the entire ac power-distribution system. The board should have active indicators that show what loads or circuit breakers are turned on or off, what functions have been disabled, and key operating parameters, including input voltage, load current, and total kVA demand. Safety considerations require that machinery not be activated from the mimic board. Permit machinery to be energized only at the apparatus. As an alternative, remote control of machines can be provided, if a remote/local control switch is provided at the apparatus.
Environmental control systems should be monitored closely. Air conditioning, heating, and ventilation systems often represent a significant portion of the power load of a facility. Computer-based data-logging equipment with process control capability can be of considerable help in monitoring the condition of the equipment. The logger can be programmed to record all pertinent values periodically, and to report abnormal conditions.

8.5.1 Switchgear Maintenance

All too often, ac power switchgear is installed at a facility and forgotten—until a problem occurs. A careless approach to regular inspection and cleaning of switchgear has resulted in numerous failures, including destructive fires. The most serious fault in any switchgear assembly is arcing involving the main power bus. Protective devices often fail to open, or open only after a considerable delay. The arcing damage to busbars and enclosures can be significant. Fire often ensues, compounding the damage.

Moisture, combined with dust and dirt, is the greatest deteriorating factor insofar as insulation is concerned. Dust and/or moisture are thought to account for as much as half of switchgear failures. Initial leakage paths across the surface of bus supports result in flashover and sustained arcing. Contact overheating is another common cause of switchgear failure. Improper circuit-breaker installation or loose connections can result in localized overheating and arcing.

An arcing fault is destructive because of the high temperatures present (more than 6000°F). An arc is not a stationary event. Because of the ionization of gases and the presence of vaporized metal, an arc can travel along bare busbars, spreading the damage and sometimes bypassing open circuit breakers. It has been observed that most faults in three-phase systems involve all phases. The initial fault that triggers the event may involve only one phase, but because of the traveling nature of an arc, damage quickly spreads to the other lines.

Preventing switchgear failure is a complicated discipline, but consider the following general guidelines:

- Install insulated busbars for both medium-voltage and low-voltage switchgear. Each phase of the bus and all connections should be enclosed completely by insulation with electrical, mechanical, thermal, and flame-retardant characteristics suitable for the application.

- Establish a comprehensive preventive maintenance program for the facility. Keep all switchboard hardware clean from dust and dirt. Periodically check connection points for physical integrity.

- Maintain control over environmental conditions. Switchgear exposed to contaminants, corrosive gases, moist air, or high ambient temperatures may be subject to catastrophic failure. Conditions favorable to moisture condensation are particularly perilous, especially when dust and dirt are present.
Accurately select overcurrent trip settings, and check them on a regular basis. Adjust the trip points of protection devices to be as low as possible, consistent with reliable operation.

Divide switchgear into compartments that isolate different circuit elements. Consider adding vertical barriers to bus compartments to prevent the spread of arcing and fire.

Install ground-fault protection devices at appropriate points in the power-distribution system.

Adhere to all applicable building codes.

8.5.2 Ground-System Maintenance

Out of sight, out of mind does not—or, at least, should not—apply to a facility ground system. Grounding is a crucial element in achieving reliable operation of electronic equipment. If a ground system has been buried for 10 years or more, it is due for a complete inspection. If the system has been in place longer than 15 years, it is probably due for replacement. Soil conditions vary widely across the country, but few areas have soil that permits a ground system to last more than 15 years.

The method of construction and bonding of the ground network also can play a significant role in the ultimate life expectancy of the system. For example, ground conductors secured only by mechanical means (screws and bolts, crimping, and rivets) can quickly break down when exposed to even mild soil conditions. Unless silver-soldered or bonded using an exothermic method, such connections soon will be useless for all practical purposes.

The inspection process involves uncovering portions of the ground system to check for evidence of failure. Pay particular attention to interconnection points, where the greatest potential for problems exists. In some cases, a good metal detector will help identify portions of the ground system. It will not, however, identify breaks in the system. Portions of the ground system still will need to be uncovered to complete the inspection. Accurate documentation of the placement of ground-system components will aid the inspection effort greatly.

Check any buried mechanical connections carefully. Bolts that have been buried for many years may be severely deteriorated. Carefully remove several bolts, and inspect their condition. If a bolt is severely oxidized, it may twist off as it is removed. After uncovering representative portions of the ground system, document the condition of the ground through notes and photographs. These will serve as a reference point for future observation. The photos in Figure 8.20 illustrate some of the problems that can occur with an aging ground system. Note that many of the problems experienced with the system shown in the photographs resulted from improper installation of components in the first place.
Figure 8.20 Ground system inspection: (a) Even though a buried copper strap may appear undamaged, give it a pull to be sure. This strap came apart with little effort. (b) Acidic soil conditions created holes in this ground screen. (c) Small pieces of copper strap were used in this ground system to attach radials to the ground screen around the base of a tower. Proper installation procedures would have incorporated a solid piece of strap around the perimeter of the screen for such connections.
8.6 References


8.7 Bibliography


