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Uninterruptible Power Supplies

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With the proliferation of electronic loads such as computers, the incidence of power quality-related problems is growing. As a result, the uninterruptible power supply (UPS) market has grown significantly in the last few years. What follows is an overview of UPS functions and descriptions of common types of UPSs and backup power sources.

16.1 UPS Functions

The primary purpose of a UPS is to provide conditioned, continuous power to its load. Another UPS function that is of growing importance in today's market is system integration, or the ability to communicate over a network to facilitate the monitoring and orderly shutdown of loads.

Power Conditioning

A UPS provides continuous, regulated power to its load, under all conditions of the utility power line. Unlike other types of power conditioning equipment, a UPS provides power during outages. Typically, a UPS will provide backup power for 10 or 15 min, although longer times are possible with large battery strings or a DC generator.

A UPS will also correct for high- and low-voltage events, known as surges and sags. This regulation is provided either electronically or by a tapped transformer or a ferroresonant transformer.

Normal mode, or line-to-line, transients are prevented from reaching the load. This is accomplished either with filter components, or in a double conversion UPS, by converting the AC to DC and then back to AC. There is quite some variation in the ability of UPS systems to protect the load from common mode, or line-to-ground, transients. Safety agency requirements preclude most forms of common mode transient protection. The best common mode transient suppression is achieved with an isolation transformer. Some UPSs have isolation transformers and some do not.

System Integration

The industrial electronics environment is very similar to the typical office LAN/WAN environment when it comes to using a UPS to provide power protection for industrial-grade PCs, PLCs and other equipment that make use of any form of microprocessor control.

The fact that a UPS only provides a finite amount of battery backup during an extended power outage should encourage us to take certain precautions to prevent the corruption and loss of data once the UPS reaches a point where it can no longer support the load equipment.

Certain methods may be used to communicate to the load equipment when a power outage has occurred and, in extreme cases, when a low battery condition exists. The load equipment should be configured to react to critical UPS conditions by saving data and preparing the system for a safe shutdown. Creating this "communication" between UPS and the load equipment is called UPS integration. There are several ways that the UPS can be integrated. These methods may be classified into three integration categories:

Basic
Enhanced
Network

No matter what integration methodology is utilized, four items are required to integrate the UPS. First, the UPS must have a communication port. Second, the equipment being protected must also have a communication port. Third, some medium (cabling) must be used to connect the two together. Finally, some form of software must be used to monitor the UPS and provide the appropriate actions relevant to specific UPS conditions.

Basic

The first and most common integration method communicates the status of the UPS via contact closures. Typically, normally open or normally closed relay contacts are used to signal two UPS conditions to the load equipment. These conditions are "AC Failure" and "Low Battery." An "AC Failure" should be signaled by the UPS whenever a power failure condition exists for more than 5 sec. The "Low Battery" signal exists when a minimum of 2 min of battery runtime remains to support the load. However, most UPS manufacturers allow this setpoint to be programmed by the user to allow more time to shutdown the system.

In most cases, the software to monitor the UPS is provided as a part of the computer's operating system. The UPS manufacturer typically provides the cable and appropriate setup information required to connect the two together.

Note that UPS manufacturers often substitute open-collector type circuits in place of actual relays, to provide the UPS signals. Users should pay close attention to this detail if they choose to build their own interface cable, since current is only allowed to pass in one direction through an open-collector circuit.

Enhanced

To provide more than just the basic UPS status information, many UPS manufacturers have chosen to offer RS232 and other forms of serial communication that allow real-time UPS data to be monitored by software running on the load equipment. Instead of knowing only that a power failure has occurred or that a low battery condition exists, the user may now know how much calculated runtime is available and the measured battery voltage at any given time. Other data values are typically available that represent the input and output voltage, percent of full load, UPS temperature, as well as many others.

Since the way this UPS data is presented is usually proprietary, the UPS manufacturer most often supplies the software to run on the protected load. Because the software is capable of monitoring real time data from the UPS, a GUI (graphical user interface) is typically used to portray the data using easy-to-read digital displays and historical graphs.

Network

The size and complexity of today's local and wide area networks has led to an increase in the use of network management tools to monitor and control network devices. The Simple Network Management Protocol (SNMP) has become the de facto standard for network management and is backed by many network management software products including SunNet Manager, HP-Open View, IBM's Netview/6000, and Novell's NMS.

Today, many UPS manufacturers offer software or a software/hardware combination that effectively makes the UPS a network peripheral. In some cases an internal or external network adapter is provided that through its own microprocessor and associated components effectively translates proprietary UPS data and commands into a format that is compatible with the SNMP standards set forth by a working group of the Internet Engineering Task Force (IETF). This group recently adopted a standard database of UPS-related information, called a Management Information Base (MIB), for all UPS products. The official IETF document that describes this MIB is RFC-1628, which is available on the Internet.

The SNMP-capable UPS provides three basic functions when communicating with a network management station. It responds to "get" requests by replying back to the management console with a value corresponding to the requested MIB variable. It responds to "set" requests by allowing the UPS configuration to be changed by the management console. And it broadcasts unsolicited alarm "traps" to the network management console alerting the network administrator to the existence of potential power problems.

The UPS in an industrial environment presents a new challenge to the integrator due to the existence of many different industrial network protocols. In some cases, many of the same protocols exist that are present in the office LAN environment, but they are often joined by such protocols as SP50 and PROFIBus, which are adaptations of Field Bus. Other industrial control protocols include FIP (Factory Instrumentation Protocol), MAP (Manufacturing Automation Protocol), and Echelon's LonTalk. UPS manufacturers have not yet built in direct connections to these industrial networks. In some cases, protocol adapters are available that translate the RS232 information from the UPS into the required network protocol. Future developments from UPS vendors may enhance and simplify the UPS connectivity in the industrial environment.

16.2 Static UPS Topologies

A static UPS is one that relies on power electronics, rather than a motor generator, to provide power to the load. Most UPSs today are of this type.

There are several basic UPS topologies, each of which has its advantages and disadvantages. The terms "on-line UPS" and "off-line UPS" have commonly been used to describe some UPS topologies. Unfortunately, UPS manufacturers have not been able to agree on the meanings of these terms, leading to confusion among users. Terms which are more descriptive of the differences between various topologies are double-conversion UPS, line-interactive UPS, and standby power supply.

Double-Conversion UPS

A double-conversion UPS (Fig. 16.1) first rectifies incoming AC line to a DC voltage, then inverts that DC voltage to provide an AC output. During normal operation, the rectifier is providing current to charge the batteries and also to the inverter. The inverter supports the load and provides regulation of the output voltage and frequency. In the event that line is lost or deviates from the specified input voltage

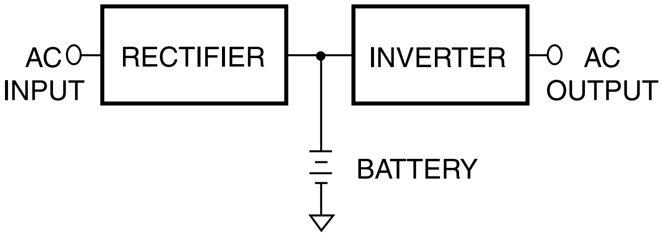

FIGURE 16.1 Double-conversion UPS. There is no disruption in output power when the UPS transfers from its line source to battery power, because the inverter is always operating.

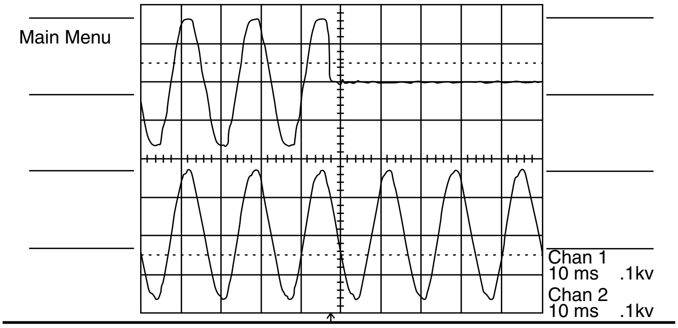

FIGURE 16.2 Typical double-conversion UPS response to a power disturbance. Top trace: AC input; bottom trace: AC output. (Courtesy of National Power Laboratory of Best Power, a unit of General Signal.)

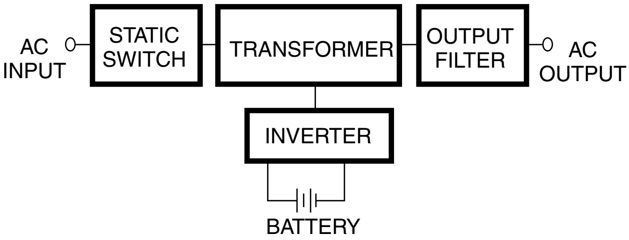

FIGURE 16.3 Typical line-interactive UPS.

and frequency tolerances, the inverter uses the batteries as an energy source and operates until the batteries are depleted or line is restored. (See Fig. 16.2 for typical response.)

Some double-conversion UPS have an automatic bypass switch. This switch connects the load to the AC source in the event of a UPS failure. It may also be used to help support a temporary overload that the inverter cannot support alone.

Traditionally, phase-controlled thyristor rectifiers have been used in double conversion UPSs. These rectifiers cause distortion of the input current and voltage waveforms. Distorted current waveforms can cause excess neutral currents in the building wiring, and distorted voltage waveforms can cause problems in other equipment on the same circuit. Some newer rectifier designs use pulse width modulation (PWM) techniques to reduce waveform distortion. These techniques can result in harmonic distortion levels of 5% or less.

Line-Interactive UPS

In normal operation (Fig.16.3), the AC input passes through a filter or transformer to the load. The inverter is normally not supporting the entire load, but may be used to buck or boost the line voltage, or even fill in “notches” of the incoming line voltage waveform on a subcycle basis. It is this ability of the inverter to interact with line that gives the line-interactive UPS its name. The inverter does not support the load unless there is a power outage, or the AC input falls outside the specified voltage and frequency tolerances. (See Fig. 16.4 for typical response.)

The key to a line-interactive unit is its ability to respond to line disturbances quickly. This is necessary to ensure that power is supplied continuously to the load. Some energy is stored in the magnetics and output filter, which can support the load for a short time. The static switch must open quickly and the inverter become active before that energy is lost to the load.

Voltage regulation during line operation may be achieved by phase-controlling the inverter, by using a tapped transformer, or by using a ferroresonant transformer.

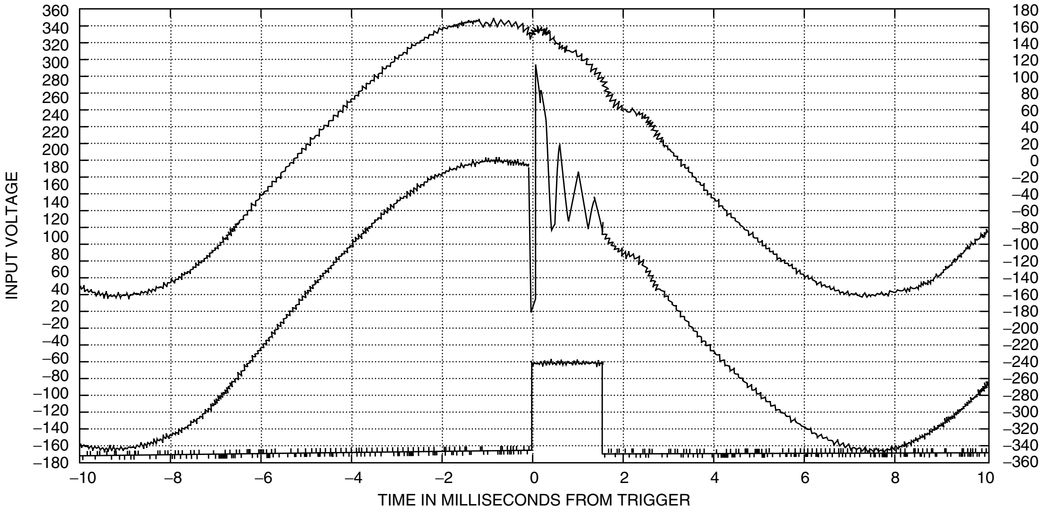

FIGURE 16.4 Typical response of a line-interactive UPS to a power disturbance. Top: AC output (right scale); middle: AC input (left scale); bottom: inverter active signal (no scale). (Courtesy of Best Power, a unit of General Signal.)

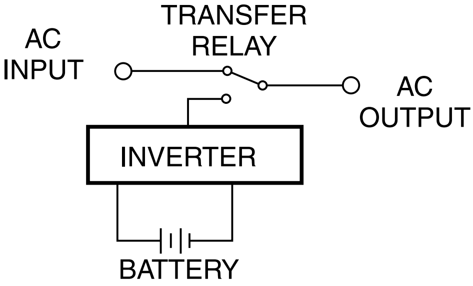

FIGURE 16.5 Standby power supply.

Line-interactive UPSs do not themselves cause harmonic distortions on the utility line. However, they may or may not pass harmonic load currents to the input. Ferroresonant-based units correct the current harmonic distortion of the load and present a near-sinusoidal current waveform to the utility line. Other line-interactive units provide little harmonic correction. This is of diminishing importance as computer power supplies are being redesigned to reduce the harmonic currents they cause, to meet the requirements of standards such as IEC 555-2.

Standby Power Supplies

Standby power supplies (SPS) (Fig. 16.5) are not properly called UPS because they do not provide continuous power to the load. A standby power supply is similar to a line interactive UPS in that the inverter is not normally supporting the load. However, when the load is transferred from line to inverter, an interruption in power occurs due to the break time of the transfer switch. Typically this switching device is an electromechanical relay and takes several milliseconds to open or close. The minimum operation on inverter is usually several seconds, as compared to the subcycle control possible with a line-interactive UPS. (See Fig. 16.6 for typical SPS response.)

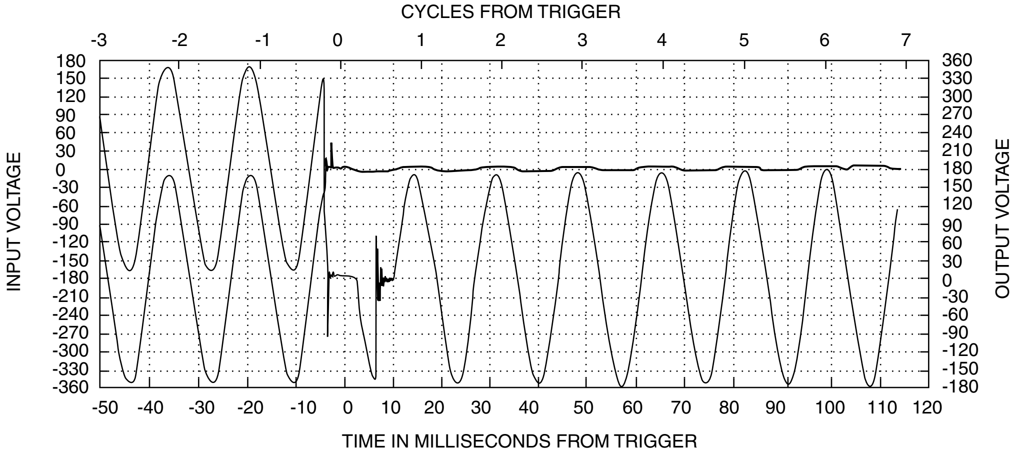

FIGURE 16.6 Standby power supply response to power disturbance. Top trace: AC input; bottom trace: AC output. (Courtesy of National Power Laboratory of Best Power, a unit of General Signal.)

Standby power supplies are typically low-cost products and provide minimum levels of voltage regulation and line conditioning. They usually provide square wave or stepped-square wave outputs on inverter, rather than the sinewave outputs provided by most double-conversion and line-interactive products. They are most appropriately used in less critical applications, where power interruptions several milliseconds in duration and voltage fluctuations can be tolerated.

16.3 The Rotary UPS

The earliest form of UPS is the rotating, or rotary, UPS. Motor and generator combinations have provided uninterruptible power since circa 1950. These early systems offered excellent isolation and fairly good overall performance. They consist of little more than a DC motor coupled to an AC generator. Rectified line normally powers the DC motor. Power switch-over to batteries occurs when the utility (line) fails. Due to the inertia of the rotating mass, switch-over times on the order of 0.3 sec are typical. In practicality, however, the decay in frequency is usually more of a problem than the decay in voltage. To remedy this problem, a supplemental flywheel increases the inherent ride-through to 1 sec or longer. Thus, large mechanical contactors are acceptable to make the power transfer from line to battery. However, modern systems use power semiconductors to do the switching. The mechanical coupling between motor and generator can be either direct, where the components share a common shaft, or by belt. Belt drives, while less efficient, do allow for different speeds between the motor and the generator. Rotary UPSs are currently available in sizes from 35 kVA up to 1000 kVA.

As have other forms of UPSs, the rotary UPS has continued to evolve. Most rotary UPSs today use AC induction motors instead of the DC motor, as AC motors do not require brush maintenance. A typical modern system rectifies and controls incoming AC to charge batteries. The batteries then power a simple three-phase inverter. This inverter, which requires no commutation or voltage-regulation circuitry, drives the induction motor. An added benefit is that this system requires no flywheel for energy storage, as there is no transfer time from line to battery power. Figure 16.7 depicts the block diagram of a typical rotary UPS.

Some of the newer rotating UPSs combine the motor and generator on one stator, and apply a DC field to the rotor. This scheme makes a very compact and cost-effective system. Other advances include the introduction of a “pole-writing” generator. In this topology, there are no pole windings as such. The poles of the generator write on a ferrite stator with varying position and frequency, depending on the speed of the rotor. Pickup coils read these poles and use them to produce the AC output, much as a tape recorder records a signal, then plays it back. This design can give as much as 15 sec of ride-through. Frequency and voltage stability are excellent.

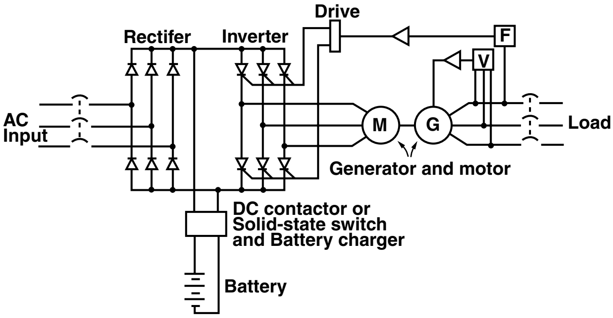

FIGURE 16.7 Typical rotary UPS.

A recent entry is a line-interactive rotary UPS. The line-interactive rotary UPS uses a normally free-spinning unloaded synchronous motor, with an additional motor or engine used for backup power. The synchronous motor has an overexcited field connected to a tapped line inductor. The motor acts as a synchronous capacitor, thereby providing power factor correction. When power fails, the mass of the synchronous motor powers the load until the engine comes up to speed and can assume the load.

Advantages of rotating UPSs include unmatched isolation, and the ability to use many different sources of energy. Single- or three-phase AC power, or power from a turbine or diesel engine can provide rotation. Reliability is excellent, with a demonstrable MTBF that exceeds 10^6 hours. High thermal inertia means that the UPS can sustain very heavy overloads for a short period of time. The units are efficient, with typical efficiencies running from 84 to 88%. Some newer designs can exceed 90% efficiency. For example, a 500 kVA Uniblock demonstrates an efficiency of over 94% at load. As with all rotary UPSs, the rotating mass offers a degree of frequency stability as well as immunity to small load fluctuations.

Disadvantages include an inherent difficulty in starting the system into high-surge loads. It is difficult to make a completely redundant system, and some maintenance, such as bearing replacement, will require shutdown. Rotary UPSs usually cannot start from the inverter, requiring a secondary motor to start rotation.

The rotary UPS is a very practicable system for any application requiring a medium- to high-powered premium UPS system that is reliable and cost-effective.

16.4 Alternate AC and DC Sources

Most UPSs use utility line for the AC source and batteries for the DC source. Batteries are a critical but often misunderstood component that bear further mention. Some installations use alternate power sources that are described below.

Batteries

Both flooded and valve-regulated lead acid (VRLA) batteries are commonly used in UPS applications. Wet cell batteries require maintenance of the electrolyte level and special precautions to prevent build-up of hydrogen gas. VRLA batteries have become increasingly popular in the last few years because of their relative ease of installation and maintenance.

All batteries require some maintenance. Battery terminals and connections should be checked for cleanliness and tightness. The batteries should be discharged periodically to test for battery capacity. End of life is usually defined as a 20% loss of the specified battery capacity at the desired discharge rate.

Battery life may be degraded by several factors, the greatest of which is battery temperature. Battery life is typically reduced by 50% for every 10°C increase in its temperature. Note that the battery temperature may be significantly higher than the ambient temperature of the room, especially if the battery is in an enclosure. Other factors affecting life include the charging method, the number of discharge cycles, the depth of discharge, the rate of discharge, and the ripple voltage across the battery terminals.

Battery storage life is also temperature dependent. Batteries experience a self-discharge at a rate that increases with temperature. This self-discharge is in addition to any current drain the UPS may have when it is off. UPS batteries should be charged upon receipt and every 6 months of storage after that, or more often if the storage temperature exceeds 25°C. If a battery is stored longer than this without being recharged, then a phenomenon called sulfation will occur. Sulfation is the formation of lead sulfate on the battery plates. This lead sulfate is an insulator and causes a loss of battery capacity. Many battery users have stored their batteries for long periods of time, only to find that at installation those batteries have no useful capacity at all. Most of the lost capacity can be recovered by exercising the batteries with repeated charge/discharge cycles, preferably at a high charge rate.

DC Generators

Direct current (DC) power generation has developed over the years to become a viable replacement for batteries in a variety of applications. These applications range from remote island power, such as railroad signal and switching, to uninterruptible power system backup and even lighting applications. Anywhere batteries are traditionally used, a DC generator can be installed to reduce the battery requirement or work in conjunction with alternate power sources such as solar.

To a great extent, the DC generator of today has changed from the days of maintenance-intensive brushes and commutators to highly efficient rectified systems. Now, instead of relying on the brush and commutator to perform the rectification process, AC alternators and diodes are used to produce near-"battery quality" DC power. Reduced maintenance requirements through elimination of brushes, commutators, and slip rings are a few of the obvious advantages of a solid-state rectified system. High frequency alternators and rectifier assemblies provide years of reliable service in less floor space than traditional AC generators or batteries.

Applications such as railroad switch and signal locations are examples of the versatility of DC power generation. Traditionally signal maintenance staff would replace a discharged battery with a recharged battery every few days. This was required to keep the trains rolling by properly signaling the track's availability. Even at sites where solar power sources were utilized, dark days could force increased signal maintenance due to low battery conditions. DC power generation has successfully demonstrated long term battery backup and cooperation with other alternate energy sources. Some railroad applications have adopted a "cycling duty" system to maintain signal integrity. By allowing the battery to discharge or the solar charger to operate, a DC generator can be used to automatically start and recharge the battery when required. This reduces the site maintenance requirement to about twice a year.

UPS backup applications for DC generation have also proven viable alternatives to large strings of batteries. By installing a "minimum" battery, most short-term power outages can be supported. For the long duration power outages, DC power generation can be used. DC power generation generally requires only a connection to the two battery terminals for the system to operate. Through these two battery connections the battery condition is monitored and the DC power generator will start and run automatically to provide long-term reliable DC power to the UPS inverter. Using the DC generator topology, oversized AC generators are not required. Generally the AC generator manufacturers recommend oversizing the generator to reduce the power factor induced by many UPS installations. With a DC generator, the induced power factor problem is not possible.

DC power generation has even grown into the lighting arena. By using a DC power source for floor lighting, HID bulb life is increased substantially. In some cases, this increase can be tenfold. Lighting manufacturers have doubled their lamp warranties due to DC power. In conjunction with these installations, DC power users have discovered the many utility rebates and rate credits available for peak-shaving with DC power generators. Generator run times as low as 50 hours per year can qualify for utility power reduction programs.

Telecommunications applications such as remote offices and cellular radio sites also enjoy the reliability of DC power generation. Even the information superhighway is powered by DC generators, bringing the benefits of the new technology to your doorstep.

Figure 16.8 shows two examples of DC generators available for operation with UPSs.

FIGURE 16.8 DC generators available for operation with UPSs. (Courtesy of Best Power Technology, Inc.)

Superconducting Magnetic Energy Storage

Superconducting magnetic energy storage (SMES) systems are relative newcomers to the field of backup power systems. SMES systems store DC energy in a superconducting magnetic coil. The niobium-titanium coil is cooled by liquid helium to 4.2 K or by superfluid helium to 1.8 K.

SMES units are used to provide large amounts of power for short durations. This is useful in industrial applications where even momentary power disturbances can cause expensive equipment downtime and production losses. Commercially available units store 0.3 to 1 kW-hour and are rated for 0.75 to 1.5 MW.

A complete SMES system is functionally the same as a traditional UPS with a more conventional DC storage element. AC line is fed to the load under normal operating conditions. A line fault detector monitors the AC line, and if line is unacceptable, disconnects line from the load. The magnetic storage element provides DC power to an inverter, which in turn supports the load. When acceptable line returns, the load is transferred back to the line source.

SMES has several advantages over batteries. The expected life of a SMES unit is claimed to be as long as 30 years, compared to 10 years or less for batteries. A SMES can be recharged completely in several minutes and the charge-discharge cycle can be repeated thousands of times without degrading the magnet.

AC Generators

What of extended autonomy, where utility may be out for hours at a time? For many applications where the AC line quality is unimportant, the AC generator is still a viable alternative for extended-run applications. With the potentially unlimited runtimes obtainable, the AC generator is certainly attractive. But with today's more sensitive loads, the AC generator may not be the best solution. It is well known in the industry that the AC generator suffers from poor regulation, and unless the unit is very large in comparison to the load, will also exhibit poor frequency stability. So, many users will run a hybrid combination of the AC generator and UPS to power critical loads for prolonged times.

A generator has its own set of maintenance issues. Aside from fuel, oil, and water requirements, the engine must be run periodically to maintain a degree of readiness. Any engine, especially a gasoline engine, must be run occasionally to keep moving parts lubricated, and fuel must be treated against the formation of varnish or bacterial growth, which can restrict fuel flow. Generators are usually kept outside, so shelters must be built and, in many areas, cold-weather starting packages must also be used.

Sometimes, compatibility problems between AC generators and UPSs occur. Double-conversion is usually the most trouble-free of the different topologies of UPSs when used with an AC generator. As the name implies, the power for the double-conversion UPS is converted twice—once from AC to DC (for the batteries) and then from DC back to AC. This scheme assures that no matter what is happening on the input, the output can be controlled precisely. A line-interactive or single-conversion UPS that typically passes line through to the output must incorporate design features to accommodate AC generator operation. The primary trade-off is the desensitization of the UPS to the fluctuating inputs. Often, generator outputs are far from sinusoidal and rather unstable, so the voltage window in which the UPS stays on utility power must be widened. The out-of-frequency window must also be widened, and the tracking capabilities of the phase-locked-loop must be increased. If these alterations are not taken, protracted inverter runs result, depleting the batteries and thus negating the purpose of the AC generator. Needless to say, the output reflects these widened windows. As most modern UPSs can be adjusted to function with an AC generator, the user must assess the impacts of the somewhat diminished performance. The vast majority of loads will function acceptably.

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