Kinetic Power Cell Technology

Battery-Free Back-Up Power Supply

CATERPILLAR®

Finding answers to the power reliability challenge

Abstract

Even for those unaffected by the August 14, 2003, blackout in the northeastern United States and southern Canada, the incident underscored the need for a reliable backup power supply for commercial and industrial applications. Even when the electricity is on, the voltage dips, sags and surges that occur frequently can damage the sensitive computer equipment that is part of virtually every business enterprise in the United States today.[1] According to a study by the Electrical Research Institute on recurring U.S. energy problems, more than 90 percent of manufacturing facilities will experience utility voltage sags greater than 20 percent from nominal. The study goes on to say that reliability and power quality limitations cost the U.S. economy more than $30 billion each year.[2] This comes not only from lost sales, but also from irretrievable production time, an unusable batch or run of materials, damage to machinery and the inability to transfer information from one site to another.

The traditional solution to power reliability issues is a lead-acid battery uninterruptible power supply (UPS).[3] However, these systems have proven unreliable for a variety of reasons. Although the batteries are typically warranted for 20 years *pro rata*, they actually must be replaced every four to five years because the more they are used, the faster they wear out. Leaks and spills are common, creating a risk to workers' safety and potential damage to the environment. Battery UPS systems also require a large amount of floor space to house a dedicated air conditioning system, eyewash stations and a separate battery room. Installation and maintenance are expensive due to the requisite spill containment systems, special floor coating and the myriad of tests that must be conducted. Even when maintenance is performed appropriately, there is no way of knowing if an aging battery will survive a full discharge.

Cat® UPS features Kinetic Power Cell Technology, which makes batteries unnecessary and significantly improves backup reliability. All the maintenance issues and environmental hazards of a battery-powered system are eliminated, lowering the cost of installation and upkeep. A smaller footprint means less space is taken away from critical missions. The Cat UPS system was designed to withstand high temperatures and high-density particulate matter so it is ideal for any setting — from call centers to paper mills. The integration of Kinetic Power Cell Technology provides total, immediate and continuing protection from transient spikes, dips, sags and complete outages.[3]

Introduction

Although continuous electrical power can be taken for granted in contemporary business life, an unbroken supply cannot always be depended on. This fact was driven home by the widespread blackout in parts of the northeastern United States and southern Canada on August 14, 2003. While the total loss in power that affected approximately 50 million people has been attributed, at least on first inspection, to a random occurrence in one part of the power grid, sags, dips and complete outages can be attributed to a variety of causes. An Electric Power Research Institute (EPRI) study on recurring U.S. energy problems found that **more than 90 percent of manufacturing facilities will experience utility voltage sags greater than 20 percent from nominal.** The study also states there will be more than 30 dips of over 10 percent per year.[2]

Adding to the problem is the unpredictable nature of power outages. In the United States there is a significant variation in the number of complete blackouts by region:

- ▲ Areas with high Kuronic rates (lightning strikes) experience more naturally caused power losses than areas with lower incidences of thunderstorms.

- ▲ Industries that are at the end of long feeder routes are at higher risk for outages than facilities that are closely coupled to electrical substations.

- ▲ Buildings in older parts of a city or suburb might experience higher failure rates due to equipment aging or poor maintenance.

Even before the August 14th blackout, it was clear that the electrical power infrastructure was in need of upgrades. The complexity of the U.S. grids means that even a small glitch in a local supply station, if not attended to in time, can cause an outage affecting millions of customers. In its Power Delivery Infrastructure Challenge, EPRI states, "The existing radial, electromechanically controlled grid needs to be transformed into an electronically controlled, smart electricity network in order to handle the escalating demands of competitive markets in terms of scale, transactional complexity, anti-power quality…. **These reliability and power quality limitations already cost the U.S. economy more than $30 billion each year.** The upgraded system is not a luxury, nor even an option for the future. Rather, it is imperative to build productivity and ensure global competitiveness in the $8+ trillion U.S. economy." Unfortunately, the program to update the U.S. electricity delivery system is on a 50-year plan, leaving American businesses with distinct limitations due to the lack of its reliability.[2]

The globalization of the American economy has created a lower tolerance for power delivery problems. Competition with manufacturers around the world has pushed even the smaller production facilities in the U.S. to attempt to increase factory productivity by relying on ever-increasing levels of automation and computerized control of processes, communication and materials flow. Thus, a full array of electronic equipment is now commonplace on the factory floor.[1]

Unfortunately, most of the computerized tools that enhance competitiveness are vulnerable to the same power quality issues that have threatened more traditional computer applications while being subjected to additional environmental factors — including temperature extremes, high airborne particulate density and more frequent electricity dips and sags. As processes become more precise, and as more and more sensitive electronic equipment is used to control manufacturing machinery, the issue of power quality problems increases.

What's at Risk

Some processes cannot tolerate an electrical disturbance without loss of a batch or run of materials. For example, in the semiconductor industry, certain diffusion steps are so critical that an incorrect temperature or loss of a timer can turn an entire production lot into very expensive scrap. Also, in certain serially integrated extrusion processes, power failure results in both a lost batch of finished product and serious equipment damage as machines can become choked with raw material if a heating function fails or a motor controller trips off-line. In many applications, these motor controllers are found in continuously running processes, such as paper mills, where many are used on a single production line. Tripping one adjustable speed drive or non-sequential tripping of the total motor population can cause a huge increase in waste materials and the need for significant human involvement to get the process back in operation.

There is more than one approach to alleviating such quality issues. First, there is a growing trend toward providing multiple sources of electrical power to an entire operation. Electrical feeders from two or more substations might be used, or electricity might be generated locally by engine-generators or co-generation plants. In other instances, manufacturers have placed small uninterruptible power supply (UPS) on the controls portion of numerically controlled machines or installed energy storage devices on the DC bus of the motor controllers. Often, diesel generators are used, but they are not always well coordinated with total power needs and are usually put in use only after a plant experiences an unexpected shutdown. Until recently, there was no well designed and integrated solution for the industrial market that would provide reliable protection for any type of equipment and keep the factory running through a power loss.

The Unreliability of Batteries

Contemporary UPSs provide both power conditioning and a source of temporary electricity for periods when the principal electrical source has been compromised or lost. It is common to include a short-term energy source in or as a part of the UPS system. This source of energy is generally assembled as an in-series string of lead-acid batteries.[3] Unfortunately, these batteries have many undesirable traits, most notably including:

- ▲ The more they are used, the faster they wear out. A typical lead-acid battery is exhausted after 250 complete discharges. Even though they are typically warranted for 20 years *pro rata*, they are routinely changed out about every four to five years.

- ▲ Lead-acid batteries can be unreliable. Seismic events, post-seal problems, corrosion and case swelling due to excessive sulphation can all cause leaks, and regardless of maintenance or repeated load testing, there is no way of knowing if an aging battery will survive a full load discharge.

- ▲ A significant amount of maintenance is required for lead-acid batteries to come close to the predicted mean time between failure (MTBF). Unfortunately, this stored-energy failure rate (1/MTBF) can be significant because most available UPSs use 10 or more 12-volt batteries in series, causing string failure rate to be multiples of the individual battery failure rate.

- ▲ Installation of battery systems can be expensive. They require spill containment systems, hydrogen monitoring, epoxy acid resistant floor coating, eyewashes and a completely separate battery room. In addition, there are dozens, if not hundreds, of costly copper connections and DC cable runs, as well as separate air conditioning with high air exchange to meet explosion codes.

- ▲ Battery systems require a large amount of floor space. For example, a 240 kW (300 KVA) array requires 120 square feet of space due to the need for a separate battery room, eyewash station, spill dike and neutralizing supply room.

- ▲ UPS battery strings must be kept at or near 77 degrees Fahrenheit to balance performance and life expectancy. For every 10 degrees above 77 degrees, this is cut in half. For example, at 87 degrees, a 10-year battery quickly becomes a 5-year battery, and at 97 degrees it becomes a 2.5-year battery. For temperatures below 77 degrees, life expectancy is extended, but expected performance — measured by protection time — drops below what is necessary to complete the mission.

- ▲ Spill containment and neutralization for lead-acid batteries are major issues, as are explosive hydrogen generation, potential catastrophic burndown, and safety issues from extensive, exposed high-voltage terminations and DC power, which cannot be shut off in certain short circuit conditions.

There is no question that the benefits of having stored energy on hand in an attempt to ride out a power outage have been proven. However, the most popular solution — batteries — is also one with many problems. In fact, a major user of UPS systems analyzed all the service actions on his UPS configuration over an extended period and found that **the battery string alone caused over 90 percent of these forced actions.**

The Cat UPS with Kinetic Power Cell Technology

Caterpillar® has addressed all these problems by eliminating batteries from its UPS. Instead, the company has integrated Kinetic Power Cell Technology into the system to provide a value-optimized power quality solution. The Cat UPS has been closely matched to the operating characteristics of a true high-efficiency line-interactive UPS. Unification between the UPS system and the engine-generator permits support through any power disturbance or outage from sub-cycle to blackouts. The multi-mega-joule Kinetic Power Cell Technology supplies energy for all quality deficiencies, depending on the load profile and the system chosen. For all outages or disturbances beyond that stored energy capacity, the engine-generator is brought on-line and continues to supply electricity through the on-board UPS for as long as there is fuel for the engine.

The robust Cat UPS system has been specifically designed for the harsh environment of a factory floor or service equipment room. It incorporates total protection from transient over-voltages, dips and sags to total power outages — with no time constraints. System benefits include:

- ▲ A useful service life in excess of 20 years with minimal maintenance.
- ▲ The rugged Kinetic Power Cell Technology eliminates all battery reliability issues.
- ▲ Maintenance for a Cat UPS consists of changing bearings once every two to three years.
- ▲ Only 11 square feet of space are required for the Cat UPS system, saving valuable space for plant operations.
- ▲ The Cat UPS is impervious to high cycling or temperatures under 105 degrees.
- ▲ Eliminating batteries from the system does away with environmental and safety issues.
- ▲ The additional installation costs associated with lead-acid batteries are avoided with the Cat UPS.

Technical Information for the Cat UPS with Kinetic Power Cell Technology

Voltage Transients

The Cat UPS was designed as a true line-interactive topology because, when the entire protection package is considered, it represents the best solution. The inverter is continuously operational and constantly monitors the quality of input power. Any transient over-voltage is attenuated by two actions. First, there are high-energy transient-voltage surge suppressors (TVSS) and large line-isolating inductors on the input. Second, there are redundant surge suppressors on the inverter terminals' output. Both of these assemblies are designed to meet ANSI C-62.41-1991 standards for high-energy (6kV @ 3kA), high-exposure transients. In addition, some energy is also harmlessly transferred to the DC capacitors through the inverter.

Because of these transient reduction techniques, a stiff 6,000-volt peak on the input will be reduced to a harmless voltage deviation on the output. This level of transient protection is consistent with a typical double-conversion UPS.

Voltage Sags

The EPRI report on power disturbances points out that a majority of system problems are voltage sags of 10 to 30 percent below nominal, and they last from 3 to 30 cycles in duration. These are the kind of disturbances that cause adjustable speed drive (ASD) controlled processes to be momentarily interrupted or permanently tripped off-line. The Cat UPS system senses the beginning of a voltage sag and immediately begins to take energy from the integrated Kinetic Power Cell to sustain the desired output voltage. In the worst case of a 30-cycle, 30 percent dip, followed by a controlled walk-in back to normal operation, a draw of less than 10 percent of the total stored energy is consumed. Recovery of the power used, following the 30 percent dip, is extremely rapid: The Kinetic Power Cell is back to its full charged state within 20 seconds. Unlike the battery energy storage used in a conventional double-conversion UPS, the Kinetic Power Cell has no restrictions on the number of energy discharge cycles and has no significant wear-out mechanism based on the number of discharges. The Kinetic Power Cell also has a much broader operating temperature range than the lead-acid battery. Installations on factory floors can be completed without the air-conditioning required for batteries.

Voltage Surges

The inverter has input voltage sense ranges, which can be easily tailored through software for the customer's specific requirements. The range of acceptable voltage on the input of the UPS determines when the system takes energy from the Kinetic Power Cell and when the engine-generator is started. There is a quick response range to take action for dips, and there is a slower response range that gives alternate responses to sags and surges. For electrical input that temporarily exceeds these programmable acceptability ranges, energy is either taken seamlessly from the Kinetic Power Cell on a temporary basis or from the engine-generator for longer periods. The UPS output voltage is always within the desired range for any disturbance time.

Power Loss

The Kinetic Power Cell supplies short duration energy needs from single cycle to 12.5 seconds (at 100 percent load). For all outages in excess of the Kinetic Power Cell storage time, a diesel-generator can be used as a preferred standby source. To achieve high reliability with the engine-generator, an optional redundant stiff-power function that uses energy from the Kinetic Power Cell for 24VDC engine-generator starting power was added to the design of the Cat UPS.

Using an engine-generator for protection times in the realm of the Kinetic Power Cell is an excellent application for a diesel engine. All engine manufacturers recommend running engines for at least 30 minutes under load at least once every two weeks to maximize engine life. The Cat UPS generally cycles the engine enough times that a separate maintenance-only program is unnecessary. By examining the EPRI regional outage data, complete power failures occur, on average, less than once a month. By allowing additional engine starts during the month as part of the normal system operation, Caterpillar has integrated diesel-run maintenance into regular protection events.

Generator Interface

Because there is an increasing trend to install engine-generators to ensure continuous power availability, the Cat UPS allows a more cost-effective solution than a typical battery-based, double-conversion UPS with a separate engine-generator. Because this is a Caterpillar product, all of the generator-UPS interface problems have been eliminated. This insures the generator is sized appropriately for the application, and interface controls are available for reliable coordination.

Frequency Limitations and Efficiency

The line-interactive UPS technology of this new product provides customers with operating efficiencies (typically 98 percent) that are significantly higher than double-conversion UPS (92 to 94 percent fully loaded), therefore lowering life cycle costs significantly. However, a characteristic of the line-interactive technology is that there is no frequency isolation from input to output. This is not an issue while operating from the utility because it has to be extremely frequency stable to maintain a connected grid. Minor frequency deviations (>0.1 percent) can cause the entire grid to begin collapsing if it is not addressed by the utility infrastructure. Larger frequency deviations typically come from free-running engine-generators or small co-generation plants. Although their base frequency stability is acceptable with all known industrial, commercial and IT loads, large cycling loads can cause frequency swings, especially on improperly sized generators.

Caterpillar addressed this in two ways: First, the static inverter of the Cat UPS and the generator are sized for totally compatibility. Second, the UPS senses any transient or in-rush current load change and uses kinetic energy to prevent the transient from impacting the frequency presented to the load. In effect, the Cat UPS acts as a large filter between the engine-generator and the load. When a load transient occurs that could result in a line frequency disturbance, the UPS detects it and intervenes, providing a stable operating frequency to the load at a maximum tolerance of ± 1.0 Hz. This is the same tolerance that a double-conversion UPS is typically set for to track an engine-generator. Double-conversion UPSs advertise a very stable run frequency (typically ± 0.1 Hz). However, these UPS systems also track the frequency of a connected generator to ± 1.0 Hz. This is done to keep synchronized with the source so, if the UPS fails, the load can be switched to the generator via the bypass and remain in phase with the generator. The Cat UPS system operates with the same frequency limits as a double-conversion UPS and, like the double-conversion, can be software configured for tighter requirements.

Fault-Clearing Capability

Experience has shown that industrial venues have many more internal branch breaker operations than either commercial or IT arenas. This is mainly due to a higher opportunity for machine operator error and dynamic machine failures. To maximize availability of the entire enterprise, the UPS system must be able to provide circuit breaker or fuse fault-clearing energy without degrading the output power to the point that other critical loads are compromised. The Cat UPS has a better chance of successfully clearing a branch breaker than a double-conversion UPS. The double-conversion system typically senses a fault-based overload and immediately transfers it to bypass to provide the maximum amount of fault-clearing current. The Cat UPS system is already connected to the utility and does not need to shift the load through a static switch. Therefore, the probability of failure of the static switch must be considered in the evaluation of the double-conversion UPS fault-clearing action.

Output Voltage Total Harmonic Distortion

Under normal operation, the UPS output voltage distortion is a reflection of the UPS input source voltage. Because manufacturing plants typically have a stiff low-impedance power distribution connection that is sized for growth, sine wave distortion is generally characterized by transient events such as dips, sags and surges. Under worst case continuous conditions, non-linear loads from uncorrected low power-factor motor controllers typically cause a voltage distortion up to 8 percent. The isolating inductors of the line-interactive UPS add a small amount to this level of distortion but it typically remains below 10 percent for most applications.

Input Current Total Harmonic Distortion

Most double-conversion UPSs use a 6-pulse rectifier on the input. This controlled rectifier has a characteristic input current distortion of 28 to 30 percent regardless of the non-linearity of the load. Even in the presence of a unity power factor load (all real power), the UPS will continue to draw 28 to 30 percent non-linear current from the source. Manufacturers of the double-conversion solution offer passive input filters that will reduce this distortion down to 10 percent. Unfortunately, these filters can cause system problems, especially when the UPS is lightly loaded. They can circulate large reactive currents to an engine-generator, particularly if there is any question of instability between the UPS and generator controls. They can also cause a "fast response" generator output voltage to go extremely high if the UPS load appears as a capacitive impedance. The capacitors in the filter can also cause certain types of motors to "self-excite" and continue to run even after utility power has been lost, causing an out-of-control safety risk.

In contrast, the line-interactive inverter of the Cat UPS system normally passes the load current distortion through to the source. However, because the industry trend is rapidly moving toward power factor-corrected loads, the typical distortion that the Cat UPS system places back on the utility is typically less than the standard double-conversion UPS.

Life Cycle Costs

One of the major benefits of the Cat UPS system is its operating efficiency. As mentioned above, most double-conversion UPSs have efficiencies in the range of 92 to 94 percent (full load). At half load, the double-conversion UPS efficiency can drop as low as 87 percent. Cat UPS system operates at 98 percent, which includes the necessary power to maintain its fully charged state. A simple examination of the operating costs reveals that at $0.07 per kW/hr., a three-percentage point difference in efficiency results in a savings of $46,000 in electricity costs and another $46,000 in cooling costs over a 10-year period. These savings could easily pay for another manufacturing machine tool or finance other existing business needs. Add to this value the replacement cost of a typical conventional UPS lead-acid battery — which will have worn out once or twice in the same time period. This easily makes a Cat UPS a much wiser and more economical choice.

"Technical Brief #19: True Line Interactive UPS Topology," IntelliPower, Inc., 2002.

[1] "Flywheels for Electric Utility Energy Storage," Electric Power Research Institute (EPRI), TR 108889, December 1999.

[2] "An Assessment of Distribution System Power Quality," EPRI, TR 106249, May 1996.

[3] "Performance Testing of Flywheel-Based Uninterruptible Power Supply Report," EPRI, 1004444, July 2002.