IT White Paper

PROTECTING CRITICAL SYSTEMS DURING UTILITY OUTAGES: THE ROLE OF UPS TOPOLOGY

SUMMARY

The year 2003 may well be remembered as the year of the blackout. And not just for the major outage that occurred in the eastern half of the United States in August. In Europe, a single downed line in Switzerland caused a widespread blackout that left virtually all of Italy without power for as long as 18 hours. And, in late September, Hurricane Isabel caused extended outages in the mid-Atlantic region, including Washington DC.

This has increased the attention on the power grid and its vulnerabilities. Some of this attention may result in actions that ultimately improve the reliability of electrical power, but the grid is complex and it will take a massive investment and many years to create significant improvements in power reliability. Until then, the onus is on the private sector to protect business critical systems from interruptions in utility power—and the dramatic fluctuations in power quality that often precede them.

An important part of that protection is the Uninterruptible Power Supply (UPS) system. In short term outages the UPS system provides backup power to mask the outage. During long-term outages the UPS ensures systems are shut down properly or, in situations where a generator is available, the UPS ensures the protected loads continue to receive stable, regulated power throughout the outage. UPS systems also perform an equally valuable function by protecting equipment from fluctuations in power quality.

How the UPS handles incoming power – the UPS topology – determines how effective the UPS can be in shielding sensitive electronics from power fluctuations. It also determines how frequently the UPS has to go to battery to protect the load, impacting battery life and performance.

In 1999, the IEC, released standards to ensure consistency in how UPS topologies are identified. The IEC defined three types of UPS:
- Passive Standby
- Line Interactive
- Double Conversion

There are substantive differences in how each of these three topologies handles incoming power and these differences have a direct impact on UPS performance. Double conversion systems provide the highest level of protection. The double conversion topology more effectively isolates the load from power problems, including frequency transients and input AC source faults, does not have to go to battery as frequently, and is better able to handle the sags and surges that occur during transition to generator power. Consequently, double conversion UPS systems are better able to handle the extreme conditions that occur before, during and after a power outage.

Trouble on the Grid

At 3:32 P.M. on August 14, an overheating electrical transmission line sagged into a tree just outside Cleveland, Ohio. The failure of that single line may have triggered a chain of events that left more than 50 million people without power in the largest blackout in the history of the United States.

According to the theory from independent consultants at Cambridge Energy Research Associates, the line failure in Cleveland caused more power to be drawn from southern Ohio to meet the demand in the north. This sharp increase in demand caused the utility that serves southern Ohio to disconnect from the grid to protect its equipment and customers.

To meet the demand in northern Ohio, power flowed up from Indiana and through Michigan. But this unexpected shift in power caused lines in Michigan to overload and fail, shutting down plants and disrupting the flow of power from Michigan into Ontario.

Energy that had been flowing into Ontario then had to change direction and travel back into Michigan, exasperating problems there. Ontario, in turn, attempted to meet its demand from New York, causing New York to shut itself off from Ontario, creating excess power surging across the grid in New York. These surges shut down more plants and caused the blackout to spread.

These events caused massive fluctuations in the quality of power being delivered to business and industry immediately prior to the blackout, wreaking havoc with systems that were not adequately protected.

What is perhaps most alarming about this chain of events is how inevitable they seem in retrospect. The way the grid is designed, and power is shared, a problem in one area can easily create a ripple effect that has the potential to create significant power problems across a wide region.

And the U.S. is not alone in this vulnerability. Europe has suffered from a number of similar, if less lengthy events this year. Italy experienced a nationwide blackout in late September that left 55 million Italians without power for as long as 18 hours. In this case, the problem began when a tree branch fell on power lines in Switzerland, causing a disruption that moved through France, which provides Italy with its major source of electricity. Scandinavia also had its largest outage in twenty years in 2003, when southern Sweden and eastern Denmark went black, affecting up to five million people.

Add to that problems from Hurricane Isabel, which left large parts of the U.S. mid-Atlantic in the dark for as long as a week and it becomes clear that, for now, outages must be accepted as a "fact of life."

This is a reality few organizations can afford to ignore, particularly considering the ever-increasing dependence on digital systems. The loss of power can shut down everything from telephone switches to police communication networks to the electrically actuated valves and pumps that move water, oil, and gas.

In short, blackouts no longer just "cripple" a business. Today they can cause complete paralysis over a very widespread area.

The only way an organization can be sure it is protected from the damage and downtime caused by power outages and other anomalies is to systematically identify critical systems and ensure the appropriate level of protection is provided for each system as close to the system as possible. The UPS is a key component in this protection strategy.

And, blackouts represent only one of the threats to critical system availability. The majority of power problems still originate internally, rather than externally.

The only way an organization can be sure it is protected from the damage and downtime caused by power outages and other anomalies is to systematically identify critical systems and ensure the appropriate level of protection is provided for each system as close to the system as possible. The UPS is a key component in this protection strategy. And the topology of the UPS determines, to a large extent, how it will handle day-to-day aberrations as well as how it will perform in the extreme conditions that exist before, during and after a blackout.

Defining UPS Topologies

The topology of a UPS system refers to the internal design of the system. This determines the relationship between the UPS and incoming utility power. A variety of terms have been used to define UPS topologies and the precise meaning of some of these terms has become muddied over the years as they were applied to product designs that didn't fit the generally accepted definition.

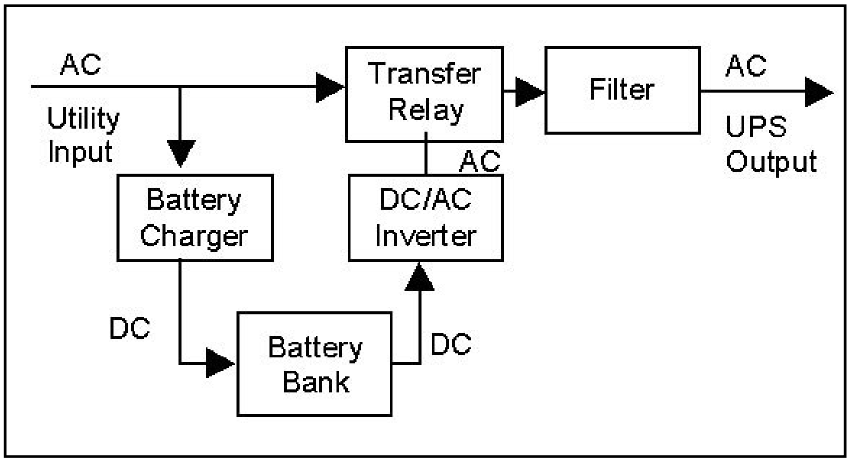

Figure 1. Passive standby topology.

Consequently, the International Electrotechnical Commission (IEC), the leading global organization that prepares and publishes international standards for all electrical, electronic and related technologies, addressed the issue to provide clarity and consistency. In 1999, the IEC issued its standard 62040-3 covering UPS topologies. This has become the accepted standard for defining UPS topology and performance. It defines three types of UPS topology:

- Passive Standby
- Line-Interactive
- Double Conversion

<u>Passive Standby</u>

Passive Standby is the term the IEC adopted to more accurately describe the topology that has traditionally been referred to as "offline." The IEC defines passive standby as follows:

> In normal mode of operation, the load is supplied with AC input power via the UPS switch. When the AC input supply is out of UPS preset tolerances, the unit enters stored energy mode of operation [battery power] by activating the inverter, and the load is transferred to the inverter directly or via the UPS switch. The battery-inverter combination maintains continuity of load power for the duration of the stored

> energy time or until an acceptable AC input supply returns to within UPS preset tolerances and the load is transferred back

This is a relatively inexpensive UPS to produce, but due to limitations in how it conditions incoming power, is typically limited to applications that are not mission critical and are smaller than 3 kVA.

Line Interactive

Line interactive systems utilize a transformer or inductor between the utility power source and the load to correct or filter some variations in input power. The IEC defines the operation of a line interactive system as follows:

> In normal mode of operation, the load is supplied with conditioned power via a parallel connection of the AC input and the UPS inverter. The inverter or the power interface is operating to provide output voltage conditioning and/or battery charging. The output frequency is dependent upon the AC input frequency. When the AC input supply voltage is out of the UPS preset tolerances, the inverter and the battery maintain continuity of load power in stored energy mode of operation and the power interface disconnects the AC input supply to prevent back feed from the inverter. The unit runs in stored energy mode for the duration of the stored energy time or until the AC input supply returns within UPS design tolerances, whichever occurs sooner. In the event of a UPS functional unit failure, the load may be transferred to bypass.

This topology provides some degree of power conditioning, but does not effectively isolate the load from major power problems, such as input frequency transients and certain types of input faults. In addition, it is much more dependent on battery power for conditioning than a double conversion topology

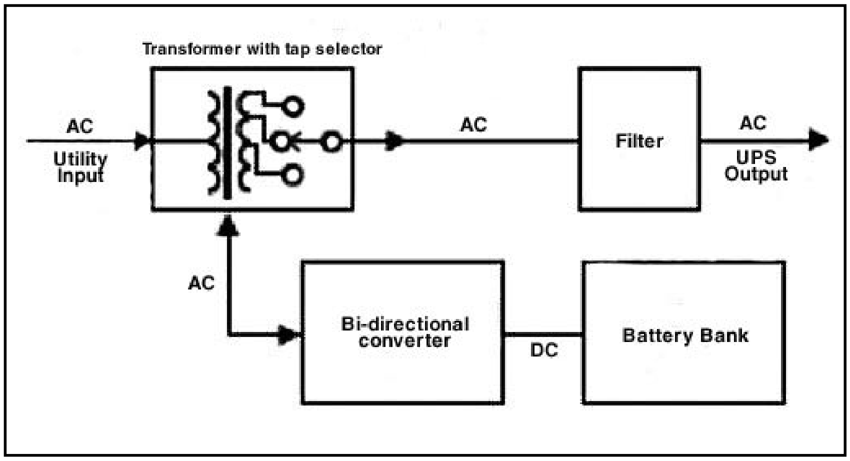

Figure 2. Line Interactive topology.

Double Conversion

What was traditionally referred to as an "online" topology was redefined by the IEC as a double conversion UPS to more accurately distinguish between this topology and the line interactive approach, which some manufacturers tried to label as "online." The IEC defines the double conversion topology as follows:

> In normal mode of operation, the load is continuously supplied by the rectifier/inverter combination. When

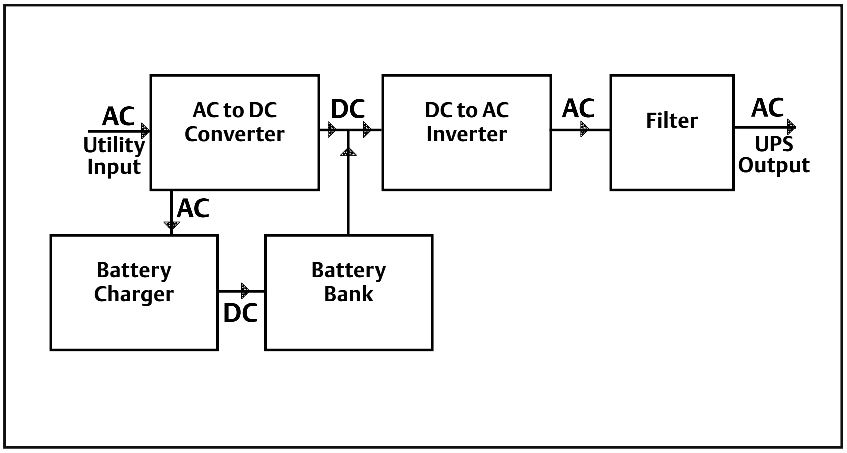

Figure 3. Double conversion topology.

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the AC input supply is out of UPS preset tolerances, the unit enters stored energy mode of operation, where the battery/inverter combination continues to support the load for the duration of the stored energy time, or until the AC input returns to UPS design tolerances, whichever is sooner. In the event of a rectifier/inverter failure or the load current becoming excessive, either transiently or continuously, the unit enters bypass mode where the load is temporarily supplied via the bypass line from primary or secondary power.

Because of the isolation and degree of power conditioning this topology delivers, it is preferred for applications that have low tolerance for downtime and those that utilize redundant UPS systems and a backup generator. It is sometimes referred to as "online double conversion" because many people still know this topology by the term that was commonly used for it prior to the creation of the IEC standards.

Topology and UPS Performance

There are significant differences in performance between each of these topologies. The passive standby topology provides limited, if any, power conditioning capabilities and is generally used only in non-critical desktop applications.

The line interactive topology does provide some degree of power conditioning and consequently has been promoted as a solution for mission critical applications by some UPS manufacturers. However, the difference between a line interactive and double conversion system is as significant as the difference between a passive standby and line interactive system. The double conversion system provides significantly greater protection.

The advantages of the double conversion configuration include.

- The critical load is completely isolated from the incoming AC input power.
- The critical load is always being supplied by the output inverter, which is always being supplied from the internal DC bus. When input power fails, there is no transitional sag in the output voltage because the inverter is already operating from DC.
- Fluctuations in input voltage and frequency don't affect the load, since the rectifier is only making DC power to feed the DC bus. This gives the double conversion UPS the ability to operate indefinitely at full load and even recharge its batteries with input volt-

ages of 15% below nominal. It can continue to operate, without discharging the batteries, through voltage sags of 20% below nominal. Likewise if input frequency is fluctuating in and out of specification, the rectifier will continue to make DC power and the output inverter will continue to make 60 Hz power without using the battery.

- The double-conversion UPS is inherently dual-input, meaning that it has separate inputs for the rectifier and bypass circuits. Single-input models are available if required but dual-input UPS products are incrementally more fault-tolerant.
- A true double-conversion UPS can be used in a dual-bus power system, where the UPS will sync to the designated reference source in all operating modes: on utility, on batteries, or while on backup generator.
- A fault on the input line causes the UPS to go to battery power, but the UPS rectifier will not allow power from the DC bus to flow upstream.
- The double-conversion UPS eliminates problems with generator compatibility that can occur with line interactive systems. When supporting power from a generator, line interactive systems may switch to battery every time other loads on the generator are started as this causes the generator's output frequency to vary, which these systems sense as an interruption. This can significantly shorten battery life. They may also experience problems when the UPS load is transitioned to the generator as the generator voltage and frequency sags during the transition. This causes the UPS to go back to battery operation. Soon thereafter, the UPS senses stable generator output, transfers the load back to the generator, then transfers back to battery operation when generator output dips again.

The lack of these capabilities in other topologies results in a weaker solution, particularly in times of extreme stress, such as a blackout. And, these weaknesses are often transparent to the end user – until the UPS fails to perform as expected and equipment shuts down unexpectedly or gets seriously damaged.

There is a place for other topologies – Liebert manufactures all three types of UPS system – but they should not be used to protect mission critical systems.

Real-World Experience

The large-scale blackout that affected the Eastern and Midwestern United States in August 2003 served as a real-world test of UPS systems under extreme conditions. Following are four examples of the problems that existed during the blackout and how various UPS topologies handled them.

NLX Corporation

NLX is an internationally recognized provider of simulation and training simulators. Simulators developed by NLX are used by the U.S. Army to test avionics equipment and provide visual imagery for crews using the simulators.

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NLX was testing new systems when the power disturbances caused by the blackout hit their facility in upstate New York. Reacting to the huge disturbances, the local utility islanded itself from the regional grid. This kept the power on, but resulted in extremely erratic power for about 90 minutes. The first clue that problems were occurring came when the metal halide lights in the facility shut down because of low voltages.

Matt Wightman, an electrical engineer at NLX, checked the readings on the facility's main UPS, a 50 kVA Liebert Npower. Matt observed incoming voltages ranging from 130V to 260V – dramatic deviations from the 208V nominal. He also observed frequency variations from 52 to 80 cycles per second. Despite these fluctuations, the test equipment protected by the Liebert Npower rode through the disturbances without a problem. The Npower not only isolated the equipment from the disturbances, but also provided consistent power quality throughout the episode, only going to battery for several seconds the entire time. The Liebert-protected systems continued to perform testing until the test protocol was shut down because of the possibility of an extended blackout.

By contrast, a small number of PCs were protected by non-Liebert, passive standby UPS systems. These UPS systems all suffered either premature shut down due to battery failure or catastrophic failures. These failures allowed bad power to reach the computers, causing irreparable damage. Power supplies burned up in five of the computers and one motherboard caught fire.

As a result, NLX is re-evaluating its power protection systems and increasing its dependence on the Liebert Npower system. "We need to have all our critical systems protected by the Liebert system," said Wightman. "This event showed us just how important the added protection of a double conversion system can be. I think the performance of the Liebert UPS impressed everyone who realizes its capability."

New York Stock Exchange

Fortunately for the New York Stock Exchange, the blackout hit shortly after trading had ceased for the day on August 14, 2003. But that didn't mean the Exchange could afford to lose power to its critical systems, which hold transactional data from the day's trading. Like many organizations with zero tolerance for downtime, The New York Stock Exchange relies on Liebert UPSs to protect critical systems. But unlike other organizations with high availability requirements, the Exchange is unable to keep a generator on-site due to environmental restrictions. Consequently, a diesel generator had to be trucked into the Exchange to provide power during the blackout. Critical systems were kept up and running on UPS battery power while the generators were in transport. The UPS systems then managed a seamless transition to generator power and, when power was restored, back to utility power. According to Robert Britz, president of the New York Stock Exchange: "The UPS systems operated as they should, which helped the Exchange conduct business without interruption and, thereby, fulfill our obligation to America's 85 million investors."

Batteries in the line interactive UPSs did not have the capacity to support the connected load while the back-up generators were started and stabilized; many shut down well before their rated back-up time and dropped critical loads unexpectedly.

Equinix

Equinix is the leading global provider of network-neutral data centers and Internet exchange services for enterprises, content companies and network services providers. The company maintains data centers in Secaucus, N.J., and Newark, N.J. Like all of the company's facilities, these centers are designed for zero downtime. And they experienced zero downtime during the blackout, thanks in part to Liebert double conversion UPS systems. According to Margie Backaus, chief business officer at Equinix, "We had zero interruptions. Absolutely none."

Time-Warner

Time Warner's operations in Manhattan were in the heart of the area most affected by the blackout. The data center at this location manages a number of complex content delivery services, both locally and nationally, including Road Runner high-speed cable modem service, video-on-demand, and commercial insertion servers that place local, regional and national commercials on dozens of cable channels.

For Time Warner, data center downtime translates directly into lost revenue.

Time-Warner uses both room-scale and rack-scale UPS systems at its Manhattan facility. The rack-scale systems include Liebert GXT UPStations, a double conversion UPS, and non-Liebert, line interactive systems. The blackout highlighted significant performance differences between the Liebert and non-Liebert systems, including:

- Batteries in the line interactive UPSs did not have the capacity to support the connected load while the back-up generators were started and stabilized; many shut down well before their rated back-up time and dropped critical loads unexpectedly.
- The line interactive UPS units were unable to support start-up on exhausted batteries. When the utility restarted with "dirty" power, the line interactive UPSs attempted to go to their already-spent batteries, causing the units to shut down unexpectedly and drop the load.
- After the blackout, the incoming power lost its neutral and voltage jumped to 150 on one pole and dropped to 90 on the other. The line interactive UPSs let this anomaly through, destroying the power supplies on seven servers.

The Liebert double conversion GXT UPStations performed flawlessly throughout these conditions. None of the disturbances – including the loss of neutral – affected the output power from the Liebert systems.

"Battery maintenance has been an ongoing problem with the line interactive systems because of the frequency that these systems have to go to battery," said Scott Widney, IT manager at Time Warner. "It is a problem we have lived with until now by stockpiling extra batteries on site. But seeing the performance of the Liebert systems has convinced me that all of our critical systems need to be protected by double conversion UPS systems."

Four Steps to Better Protection

In light of the reliability problems with the grid, it is likely there will be a repeat of the situation that created the events these organizations had to deal with. Consequently, many organizations are re-evaluating their disaster recovery systems and processes. Following is a four-step process for conducting a systematic audit of power protection systems.

1. ***Are the right systems protected?***
   Virtually every organization has some degree of protection for critical systems in the data center. However, when the costs of a widespread, extended blackout are calculated, many organizations discover just how far their networks have spread beyond the corporate data center. Today, business critical systems are as likely to be located on the plant floor, in distribution centers or in remote offices, as in the data center. Many of these systems lack the protection their importance to the business warrants.

2. ***Do systems have the right level of protection?***
   Regarding the type of protection for each system, consider the UPS topology, whether or not a generator is required and the degree of redundancy in the power protection system.

   Business critical systems need to be protected by a double conversion UPS system. An audit of UPS topologies should be conducted to ensure all critical systems are protected by a true double conversion system.

   Some organizations may also re-evaluate the feasibility of a generator in light of the costs of the blackout. If a generator is to be added to an existing power system, ensure compatibility between the existing UPS and the generator. Line interactive systems can perform poorly when used with a generator because they are overly sensitive to frequency changes that occur when new loads are started on generator power.

   Finally, the level of redundancy built into the power system should be evaluated. Dual-bus systems provide redundancy across the entire power path, including redundant backup generators. Organizations with a dual-bus system in place were able to overcome the failure of any single component in the system, including a generator.

If a generator is to be added to an existing power system, ensure compatibility between the existing UPS and the generator. Line interactive systems can perform poorly when used with a generator because they are overly sensitive to frequency changes that occur when new loads are started on generator power.

3. ***How well did the systems that are in place perform before, during and after the event?***
   How well did existing systems handle the extreme fluctuations in power quality that preceded the blackout itself? Was facility-level surge protection adequate to protect critical systems from damage? Was the UPS able to provide adequate power conditioning to protect systems and data prior to and during the blackout? Any damage to protected systems that occurred is likely the result of the failure of the UPS system to isolate the load from incoming power

quality problems. During the blackout, was battery capacity adequate to provide a controlled shutdown or transition to backup power? Was the transition to backup power accomplished smoothly?

4. ***Is a service strategy in place to ensure equipment is properly maintained?*** One of the most common problems reported during blackouts involve generator failure. The New York Daily News reported that about half of that city's 58 hospitals had generator problems during the August 2003 blackout. Increased emphasis on service may have prevented many of these failures. Look for a service organization that can coordinate UPS and generator maintenance into a single program. In addition, poor battery maintenance can contribute to problems. Battery maintenance can be complicated by having too many small UPS systems in operation, as opposed to fewer, larger systems.

Ensuring all critical systems are protected by a true double conversion UPS is one of the most important steps an organization can take to minimize the financial impact of the next blackout.

Conclusion

Future blackouts are probably unavoidable considering the complexity and interdependency of the power grid. However, organizations can minimize the lost revenue, equipment damage and downtime associated with blackouts through increased attention to critical system protection.

Double conversion UPS systems have proven their ability to provide the protection required before, during and after extended outages. They deliver consistent power quality to the load, despite wide swings in voltage and frequency, provide more effective use of batteries and operate more reliably in conjunction with a generator. Ensuring all critical systems are protected by a true double conversion UPS is one of the most important steps an organization can take to minimize the financial impact of the next blackout.

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