Which UPS is Right for the Job?

A Dell Technical White Paper

Dell

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Abstract

Traditionally, office managers, IT managers, and facilities managers could choose from three UPS topologies: standby, line-interactive, and double-conversion (online)—offering widely varying levels of efficiency, performance, and protection.

Until recently, selecting a UPS configuration was a matter of compromise. Standby and line-interactive UPSs offered highest efficiency, but they sacrificed level of protection because they didn’t go through the double power conversion process. Online UPSs offered highest protection, but only about 91–93 percent of incoming power actually was available for powering equipment; the rest was used or wasted by the UPS.

Dell has eliminated that tradeoff between efficiency and protection. Dell high-efficiency online UPSs use an industry-leading multi-mode technology that enables the UPS to operate at 98-percent efficiency or better under normal utility conditions. The UPS continually monitors incoming power and balances the need for efficiency with the need for premium protection, to match the conditions of the moment. Even a few percentage points of gain in UPS efficiency translate into big savings in energy costs.

This white paper describes how various UPS topologies work, and looks at the impact of operating mode on five key elements of UPS performance:

- Maintaining output voltage within tolerances
- Transferring among modes without affecting the protected equipment
- Transitioning gracefully to and from generator power
- Reliability and availability
- Energy efficiency

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Introduction

Which uninterruptible power system (UPS) design is right for protecting your office, retail location, local area network or data processing systems? The answer depends on a combination of factors that have been influenced by industry trends and technology advances—and complicated by marketing hype.

At its most basic level, a UPS performs two primary and complementary functions:

- *Conditioning incoming power* to smooth out the sags and spikes that are all too common on the public utility grid and other primary sources of power
- *Providing ride-through power* as a temporary power replacement during for sags or short-term outages (say, five minutes to an hour) by dynamically selecting and drawing power from the utility grid, batteries, backup generators, and other available sources

UPSs provide these services to meet the requirements of the power supply units in electronics as set forth by industry standards and specifications. However, there are differences in the degree of protection they provide and the way they provide it. Three different UPS topologies are commonly available today:

- **Standby UPSs** allow electronics to run off utility power until the UPS detects a problem, at which point the UPS switches to battery power to protect against sags, surges, or outages.
- **Line-interactive UPSs** regulate voltage by boosting input utility voltage up or moderating (bucking) it down as necessary before allowing it to pass to the protected equipment or resorting to battery power.
- **Double-conversion UPSs** isolate equipment from raw utility power—converting power from AC to DC and back to AC again—to deliver the cleanest power and highest protection.

Dell High-Efficiency Online UPSs offer the best of line-interactive and double-conversion topologies. These UPSs operate in high-efficiency mode unless power conditions warrant a switch to the higher protective level of double-conversion mode.

Although other topologies, including ferroresonant and rotary designs, are available for specific purposes such as industrial or harsh environments, this paper discusses the typical static UPS topologies used in most business environments.

Which design is right for your application? The way a manufacturer designs a product to these topologies can have a significant effect on overall power performance, equipment uptime, and total cost of ownership. This white paper provides an objective view of key to consider when selecting the best UPS internal design for your requirements.

UPS Topologies

UPS topologies can be classified into two basic design categories: double-conversion and single-conversion.

Double-conversion UPS systems process power twice. An input rectifier processes AC to DC, which then feeds into an output inverter that processes the DC back to AC power to send to the protected equipment. In normal operation, the UPS is always double-processing power through this combination of rectifier and inverter.

If the AC input supply is out of predefined limits, the rectifier turns off and the UPS draws current from the battery. Battery power passes through the output inverter and on to the equipment. The UPS stays on battery power until the AC input returns to normal tolerances (or until the battery runs out, whichever is sooner).

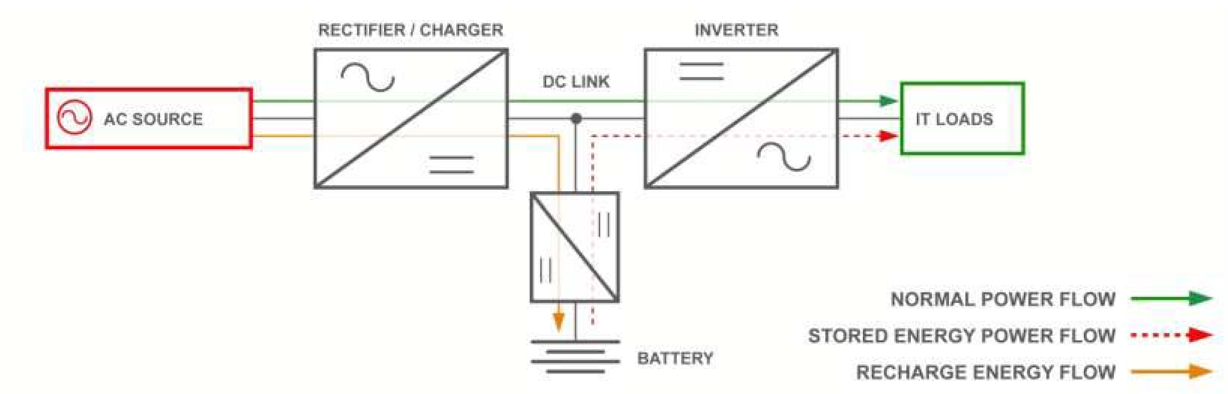

Figure 1. Internal Design of a Typical Double-Conversion UPS

Single-conversion UPS systems use the incoming utility AC power to supply the required AC to the output loads in normal operation. Some systems use inductors or transformers to regulate output voltage. These designs also include some type of battery charging circuit to ensure the battery is fully charged.

If the AC input supply is out of predefined limits, the UPS engages its inverter. (In some designs, the inverter is always on, but without load, for faster synchronization). The inverter draws current from the battery, and then disconnects the AC input supply to prevent backfeed from the inverter into the utility. The UPS stays on battery power until the AC input returns to normal tolerances (or until battery power is depleted, whichever is sooner).

Two of the most popular single-conversion designs are the *line-interactive* and *standby* systems, which, in the past, were typically used in applications with lower power requirements. Line-interactive systems usually have a wider input voltage range than standby systems and can regulate voltage to within acceptable limits through the power interface without using the battery. Standby power systems simply pass incoming AC power to the connected equipment and switch to battery power when necessary. Some standby UPS designs incorporate transformers or other devices to provide limited power conditioning as well.

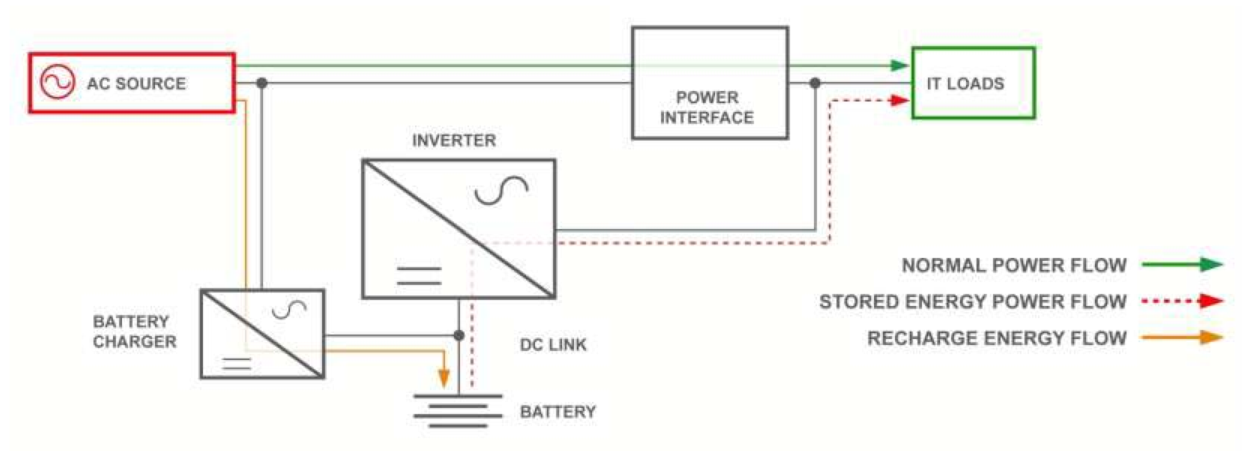

Figure 2. Internal Design of a Single-Conversion Design—Line-Interactive UPS

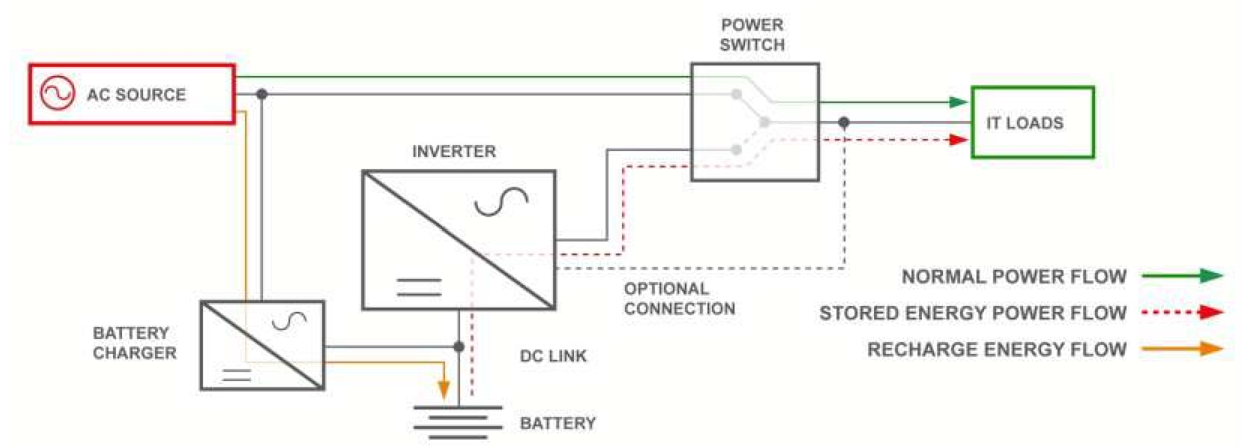

Figure 3. Internal Design of a Single-Conversion Design—Standby UPS

Dell High-Efficiency Online UPSs combine the best of single- and double-conversion technologies to provide the benefits of each. Whenever the UPS's high-speed line-detection circuitry senses a change in condition, the system automatically changes modes:

- **Normal conditions**: When power conditions are within acceptable limits, the multi-mode UPS operates as a high-efficiency, energy-saving system—while also providing surge protection.
- **Erratic power or fleeting disturbances**: If AC input power falls outside of preset tolerances for line-interactive mode, the system switches to double-conversion mode. The UPS processes incoming power through a rectifier and inverter, completely isolating equipment from disturbances in the incoming AC source.
- **Power outage or sustained power anomalies**: If the AC input power is outside the tolerances of the double-conversion rectifier (or the power goes out altogether), the UPS uses the battery to supply energy to keep the output loads operating. When the generator comes online and supplies backup AC power, the UPS uses double-conversion mode until the generator has stabilized sufficiently to safely switch back into high-efficiency mode.

Dell High-Efficiency Online UPSs provide exactly the level of power protection needed under the conditions of the moment.

With energy costs continuing to rise, the efficiency gains of this strategy are substantial. An organization with even a modest number of servers can significantly reduce utility bills without compromising data center performance or reliability.

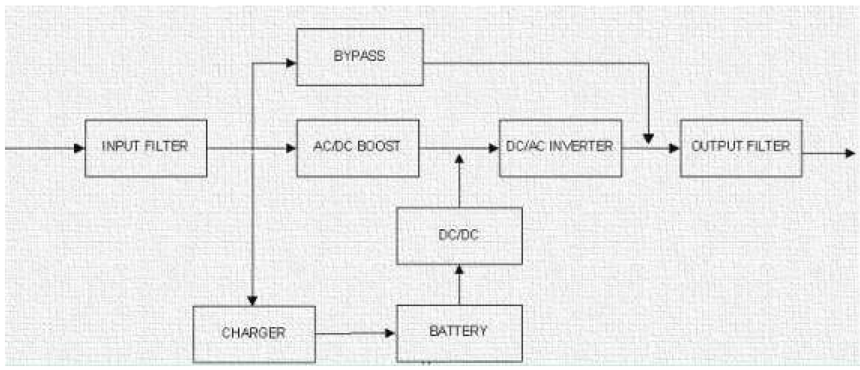

Figure 4. Internal Design of a Dell High-Efficiency Online UPS

How does UPS design and operating mode affect performance?

The key objective of the UPS is to ensure that the power supplied to the protected equipment remains within the specifications of the equipment's power supply unit under all input AC conditions, including generator operation. Let's take a look at how different designs fare on the key criteria:

- Maintaining output voltage within tolerances
- Transferring among modes without affecting electronic equipment
- Transitioning gracefully to and from generator power

Maintaining output voltage within tolerances

For most IT equipment—such as servers, storage systems and network devices—UPS output voltage must remain within the acceptable zone specified by the Information Technology Industry Council (ITIC) curve, under all input power conditions.

Input voltage to the power supply unit (PSU) is shown on the vertical axis. The horizontal axis represents the duration of input voltage events (in AC cycles up to 10,000 cycles, about 28 minutes). The ITIC curve—more of a stair-step than a curve, actually—shows the acceptable input voltage envelope for a typical PSU design for IT equipment.

The UPS must ensure that voltage to the PSU is not in the prohibited range above the acceptable zone, since voltage in that range could damage the IT equipment. Voltages below the threshold could cause the PSU to shut down or exhibit erratic behavior.

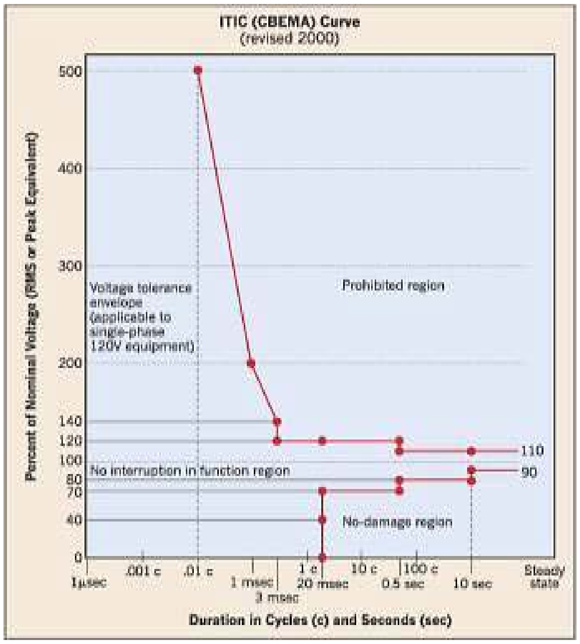

Figure 5. **(Right) The ITIC (CBEMA) Curve Shows Power Tolerances for IT**

Managing high-frequency transients and intense spikes

Almost all system designs provide some surge suppression to protect against high-frequency transients and intense spikes, such as from lightning or from damage to the facility's power plant.

- **Most small standby and line-interactive systems** use some form of transient clamping device such as metal oxide varistors (MOVs) that shunt excess energy to ground or—if the energy level is too high—self destruct to absorb the overvoltage or transient hit. Since most UPSs of this type are small, designed to be located close to the equipment being protected, they may have only a minimal number of these clamping devices.
- **Traditional double-conversion UPSs** operating in normal mode process power through an AC-to-DC-to-AC conversion process to prevent damaging input conditions from passing through the UPS to the connected load equipment. (However, if the UPS is in bypass mode, as during system maintenance or a system fault, damaging input impulses would pass through the UPS bypass to the loads.)
- **Dell High-Efficiency Online UPSs** have sophisticated sensing circuitry to detect power problems and apply highest protection to the loads, thereby isolating input transients from the loads. Even in high-efficiency mode, the connected load is protected from transient events. One way or the other, the equipment is protected from intense surges and strikes.

Whichever UPS design is used, it is still recommended to have surge protection at the utility entrance, to protect the UPS input monitoring circuitry and to provide surge protection on the electrical circuits and equipment that do not have UPS protection.

Managing more moderate out-of-range voltage conditions

The various UPS designs differ in how they handle less extreme voltage conditions, such as under- or over-voltage conditions:

- A **standby UPS** supplies the equipment with acceptable power to meet this specification as long as the input voltage is within predefined UPS tolerances. However, this band of normal operations is typically narrow (±10 percent of the ITIC curve) so the UPS must resort to batteries frequently, and this can reduce battery runtime and service life. Some standby systems allow a wider input voltage window which helps conserve the battery, but could cause lock-up or sporadic operational issues with the connected equipment.

  Furthermore, most standby UPSs deliver output power shaped like a square or step-square wave. Dell systems must have true sine-wave power, so standby UPSs are not appropriate for use with Dell systems.

- A **line-interactive UPS** supplies power within ITIC specifications as long as its input voltage is within preset UPS tolerances. However, a typical line-interactive system can provide some voltage regulation using a tap changing transformer or a buck/boost circuit. Thus, a line-interactive system doesn't have to resort to batteries as often as a standby system, although it may use some battery power to support the transition between normal mode and voltage regulation mode. Dell's line-interactive UPSs do not use battery power while transitioning to buck/boost mode of operation, thereby reducing battery use.

- A **double-conversion UPS** typically provides output voltage tightly regulated to within a few percentage points of nominal under a wide range of input power conditions. Compared to other topologies, a double-conversion UPS uses batteries less often and for less time. That can translate into longer battery runtime and service life. Many of today's double-conversion UPSs are intelligent enough to support a wider input acceptance window if the UPS is less than 100percent loaded—reducing battery use even more.

- **Dell High-Efficiency Online UPSs** supply power within ITIC specifications when input voltage is within preset UPS tolerances. When the input AC voltage is outside this range, the UPS automatically uses double-conversion mode to regulate the output to the ITIC specification. As a result, battery usage duration and frequency is similar to the double-conversion UPS, and in some instances may even be lower.

As the Figure 6 shows, all the UPS designs meet input voltage requirements even for sensitive IT equipment as defined by ITIC. The key difference is how the UPS achieves that result, which has a great influence on the frequency and duration of demands on the battery. Battery demands are highest for standby UPSs and lowest for Dell High-Efficiency Online UPSs.

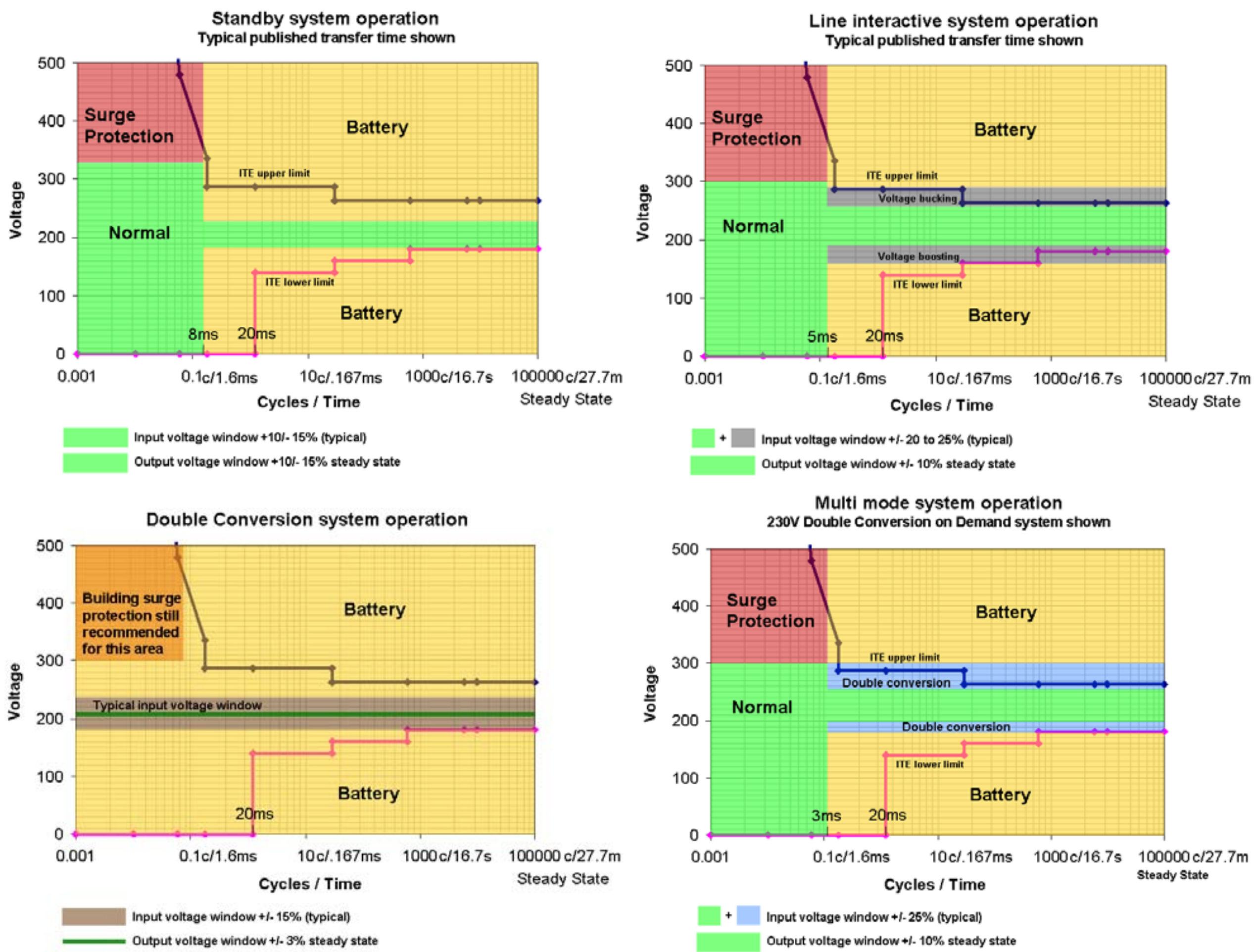

Figure 6. **Performance of Various UPS Designs Related to the ITIC Curve**

Transferring among modes without affecting protected equipment

By industry standards, power supply units inside servers and storage devices are designed to store enough energy to maintain the device during approximately 12 milliseconds (ms) of power interruption. This is known as "hold-up" time. That means the device can withstand brief interruptions in power while a UPS transitions between modes of operation, such as from normal operating mode to battery and back again.

However, transfer time should actually be much faster than 12 ms, because the longer the PSU goes without power, the larger the in-rush current it will draw when it receives power again. In-rush could exceed the current handling capacity of the UPS and cause it to shut down.

- **Standby UPSs** switch to battery mode in 5–12 ms (8 ms typical). Standby systems typically use a fast acting mechanical relay for the power switch, which extends the length of time before the transfer to battery can be made.

  Most power supplies can tolerate this interruption. However, when transfer time is greater than 5 ms, the in-rush current may exceed the capability of the UPS inverter and cause connected equipment to reset, resulting in data corruption or shut-down. If the standby system allows output voltage to dip more than 10 percent below nominal current (say, below

108V on a 120V system), the PSU is likely to be in a state where it is pulling higher than normal current. For this reason, a prolonged loss of output increases the odds that the PSU will shut down.

Another concern about using standby systems for highly critical servers is the issue of output voltage waveform while on battery power. Many standby systems create square-wave or modified sine-wave output, which today's power factor-corrected power supplies may not be able to handle. If this is the case, the power supply may shut down once battery operation commences. For this reason, standby UPSs are not appropriate for use with Dell servers.

- **Line-interactive UPSs** switch to battery mode with a typical transfer time of 3–8 ms (5 ms typical), which is within acceptable limits for most power supplies. Some PSUs can exhibit in-rush currents exceeding 400 percent if the transfer time is longer than 5 ms; the UPS inverter may have problems supporting this high current requirement.
- **Double-conversion UPSs** begin drawing current from the battery with zero interruption (transfer time) in output power. There is, therefore, no risk of the transfer causing any in-rush.
- **Dell High-Efficiency Online UPSs** typically switch to battery mode in 3–6 ms, well within the lowest portion of the in-rush curve of a typical PSU. The subsequent in-rush current is less than 200 percent of normal peak currents—easily handled by the battery and inverter for short periods.

Transitioning gracefully to and from generator power

For some installations, you have to know how the UPS handles the transfer to backup generator during extended utility power outages. The transition is not always smooth, since the generator may have unstable voltage and frequency during start-up and warm-up periods.

The UPS must be able to handle generator output aberrations as the generator and its loads go through initial ramp-up to full operation. If this is not conditioned by the UPS, the unstable power can result in data corruption or shut-down of connected equipment. The UPS should make as few as possible transfers to and from battery operation, so there is a lower chance of disruption in output power and less stress on the batteries.

Standby and **line-interactive UPSs** must first quantify the source and then synchronize the inverter to this source before switching the load over to the generator. These designs are also tend to switch back to battery operation if generator frequency or voltage deviates even slightly.

Dell Online and High-Efficiency Online UPSs ensure that even if the generator experiences unstable output voltage or frequency as the generator warms up (or due to other loads cycling on and off the generator) the UPS continues to operate on the rectifier, rather than switching to battery operation. Since the input rectifier is used to process AC to DC, these UPSs have the shortest period on battery power.

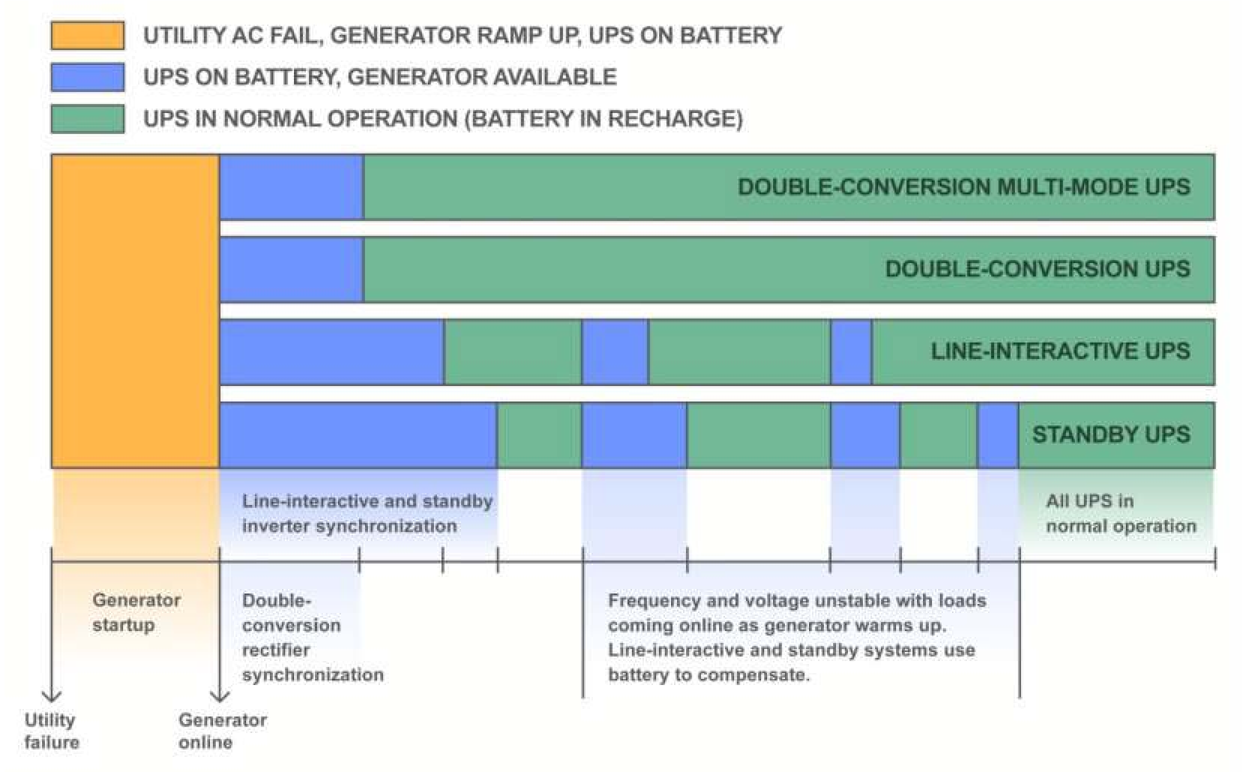

Figure 7. How Different UPS Designs Handle Generator Start-Up

NOTE: Standby and line-interactive UPSs tend to revert frequently to battery during this process.

How does UPS design affect reliability?

The availability of a UPS configuration depends on several factors:

Multiple power paths

A *standby UPS* typically has two power paths, but a single power switch serves them both. A failure in the power switch will cause the protected equipment to lose power.

A *line-interactive UPS* has two power paths, but without a shared power interface. If the power interface fails, this UPS could still operate in battery mode long enough to transfer to generator power, or gracefully to shut down connected equipment.

Dell Online and *High-Efficiency Online UPSs* have two power paths—from utility/generator and battery sources—plus an electronic system bypass that is used to bypass failed components or to synchronize the system to a mechanical bypass system to perform planned maintenance. An automated maintenance bypass system ensures uninterrupted transfers during UPS servicing.

Redundancy through paralleling

You can increase reliability and availability by deploying multiple UPS systems to work together. In a parallel configuration, multiple UPSs feed a common output bus which then supplies power to the protected equipment. If any UPS should fail, the others are sized to take over the load.

Because of the added costs of manufacturing systems that can be paralleled, this capability is reserved for larger, high-cost UPSs.

Battery health

The UPS design dictates the frequency of battery usage for any given power grid condition—which in turn affects battery runtime and service life. Battery drain is lowest in double-conversion and high-efficiency double-conversion with multi-mode designs. Dell UPSs use multi-stage charging techniques that offer a battery rest period, significantly extending battery service life compared to conventional trickle or float charging methods.

How does UPS topology affect energy efficiency?

The more efficient the UPS, the less utility power you have to buy to run your business. And since most of the lost power is dissipated as heat, the more efficient the UPS, the less you pay in air-conditioning or other cooling systems to remove that heat.

This is a particular concern for organizations fielding data centers. When overall data center infrastructure efficiency (DCiE) is high, cooling costs might only equal 50 percent of spending on energy to power the IT equipment. When energy efficiency is poor, it could cost almost as much to cool the data center as it does to run the equipment—as much as 80 to 100 percent of the cost of powering the IT equipment, according to industry studies. So it’s no surprise that organizations are taking a close look at the efficiency of their power protection systems.

Efficiency is profoundly influenced by UPS design or operating mode. Single-conversion (*standby* and *line-interactive*) UPSs are more energy-efficient than *double-conversion* UPSs because there is no power conversion from AC to DC and then back to AC. Dell High-Efficiency Online UPSs achieve very high efficiency because they only use the less efficient double-conversion mode when necessary, and operate as an energy-saving system the rest of the time.

Even small increases in UPS efficiency can quickly translate significant savings in utility bills. Higher UPS efficiency also provides more battery runtime for the same battery capacity and produces cooler operating conditions within the UPS environment, which in turn extends the service life of components.

Closing thoughts

In the past, the popular assumption was that for important applications where unplanned downtime was unacceptable, the only UPS choice was one that operated solely in double-conversion mode. The UPS provided premium protection, but at a cost. The continuous double-conversion processing made these UPSs less efficient than single-conversion designs.

Dell now offers viable and remarkably cost-effective new choices with UPSs that combine the best of single- and double-conversion topologies: exceptional efficiency plus the high protective level of double-conversion operation.

With a more efficient allocation of power, you not only reduce utility bills and total operating cost, but also achieve more with available backup power and cooling systems—delaying the point where those systems would have to be upgraded to support business expansion.

So, which UPS topology is right for your organization? Where there once was only one “right” answer, Dell now offers effective choices specifically designed to deliver premium protection at minimum operating cost.