EVALUATION OF ECO MODE IN UNINTERRUPTIBLE POWER SUPPLY SYSTEMS

EDITORS:

George Navarro, Eaton

Brad Thrash, GE Digital Energy

CONTRIBUTORS:

Lynn Simmons, Dell

John Collins, Eaton

David Loucks, Eaton

Dusty Becker, Emerson Network Power

Bill Campbell, Emerson Network Power

Harry Handlin, GE Digital Energy

Andrew Lynch, Gexpro

Pam Lembke, IBM

Shaun Harris, Microsoft

Stephen McCluer Schneider Electric

Jim Spitaels, Schneider Electric

Keith Klesner, The Uptime Institute

Executive Summary

The Green Grid Association, a non-profit, open industry consortium working to improve the resource efficiency of information technology (IT) and data centers throughout the world, developed this white paper to provide data center owners, operators, and designers with an evaluation of uninterruptible power supply (UPS) Eco Mode operation. The Eco Mode feature can improve data center efficiency and power usage effectiveness (PUE™) when appropriately designed and deployed. In fact, The Green Grid Data Center Maturity Model (DCMM) identifies UPS Eco Mode deployment as one of its energy savings recommendations. This white paper explores in detail the application considerations for UPS Eco Mode performance and makes recommendations regarding other power distribution equipment (e.g., static switches) needed to ensure a reliable power system.

The deployment of UPS Eco Mode also requires an understanding of the power quality and ride-through requirements of modern IT power supplies in server, network and storage equipment. This white paper gives a perspective on the latest voltage and ride-through capabilities for modern IT power supplies. Because knowledge of the utility grid power quality is important to optimize UPS Eco Mode operation, The Green Grid also provides suggestions for evaluating utility grid power quality. In addition, the white paper discusses the energy efficiency gains and economic benefits of UPS Eco Mode, illustrated by examples of improvements for various types of data centers.

Table of Contents

I. Introduction

As energy costs rise and the desire to be "green" increases, the need for energy efficiency is becoming more prevalent. Data center operators are reviewing certain aspects of their data centers, including power distribution systems and, in particular, uninterruptible power supply (UPS) systems, to identify opportunities to boost efficiency.

Many options to incrementally improve power system efficiency are available to data center operators. These options typically involve either removing or moving components in the power path, changing an aspect of data center operations (such as raising the distribution voltage), or using more efficient components. The Green Grid Data Center Maturity Model (DCMM) includes specific recommendations on many of these potential efficiency improvements in the power system. (Please see Appendix E: Power Section of the Data Center Maturity Model (DCMM) for more information.)

This white paper addresses one of these efficiency improvement opportunities in depth: Eco Mode operation for three-phase, facility-scale UPSs. An alternating current (AC) UPS can have several modes of operation, of which one is so-called "Eco Mode." Different levels of efficiency and performance are achievable with the different modes. Typically, Eco Mode is the highest-efficiency mode. This white paper focuses on Eco Mode in data center–level, three-phase UPS systems; it does not address smaller, single-phase UPSs.

Operating in Eco Mode can improve efficiency and thus conserve energy. In order to deploy Eco Mode without compromising performance and reliability, one must have some knowledge of UPS technology and performance, critical power system configuration, IT power supply ride-through, and utility grid reliability. This white paper looks at each of these topics and their trade-offs, helping data center operators understand the basic concepts and prepare to deploy UPS Eco Mode as a Level I Best Practice. Figure 1 illustrates how an Eco Mode UPS fits into the DCMM.

Minimal/Nothing Done	Part Best Practice	Best Practice Today	Reasonable steps between		Visionary - 5 years away
Level 0	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Mid to low efficiency <90% for your usage pattern	90% Efficiency for your usage pattern	92% Efficiency for your usage pattern	94% Efficiency for your usage pattern	95% efficiency for your usage pattern	96% efficiency for your usage pattern
• Low efficiency power infrastructure and inefficient	• Eco Mode UPS if applicable to business type	• Consolidate transformers (use fewer series isolation	• Eco Mode UPS that works for all business types	• Move to higher IT load voltage, either AC or DC	• 100% of PSUs certified by 80Plus - greater than 80% at

Figure 1. Eco Mode UPS references in The Green Grid Data Center Maturity Model

In addition to The Green Grid referring to UPS Eco Mode deployment in its maturity model, several other key industry groups have recently mentioned using UPS Eco Mode. For example, the U.S. Environmental Protection Agency (EPA) identifies Eco Mode as one of the operating modes for efficiency improvements in its ENERGY STAR Uninterruptible Power Supplies specification.[1] Because of the continued industry and government focus on efficiency, the option to implement Eco Mode operation on UPSs is becoming more attractive. If data center operators understand both the mode and its trade-offs and thoroughly review the complete power system prior to implementation, they can take advantage of the energy savings benefits while minimizing risks.

II. UPS and Power System Terminology and Descriptions

UPS AND POWER SYSTEM TERMINOLOGY

Eco Mode is just one of the operating modes in a typical AC UPS. Eco Mode is also known by many other names, including “high efficiency mode,” “bypass mode,” and “multi-mode,” all of which carry an underlying meaning and portray a particular view of performance (some positive and some negative). Additionally, UPS vendors may have their own brand names for Eco Mode. This white paper’s authors and editors, who represent a cross-section of UPS vendors, have agreed to simplify the discussion by using the more historical term “Eco Mode” and supporting that term with the following definition:

- **Eco Mode:** One of several UPS modes of operation that can improve efficiency (conserve energy) but, depending on the UPS technology, can come with possible trade-offs in performance.

Appendix A. Summary List of UPS and Power System Terms and Definitions contains a list of the key UPS and power system terms used throughout this white paper to retain clarity in the discussion.

UPS DESCRIPTIONS

[1] www.energystar.gov/index.cfm?c=new_specs.uninterruptible_power_supplies

UPS performance can be described and categorized a multitude of ways. The Green Grid supports the International Electrotechnical Commission (IEC) standard 62040-3, Section 5.3.4 Classifications for UPS. It describes many possible operating modes, all of which will have only one of the following input dependency characteristics:

- **Voltage/frequency dependent (VFD):** The UPS output voltage and output frequency are identical to the input voltage and frequency from the AC source.
- **Voltage independent (VI):** The UPS provides a stable output voltage to the load[s], but its frequency is identical to the input AC source.
- **Voltage/frequency independent (VFI):** The UPS provides stable voltage and stable frequency to the connected loads independently of the input AC source. This is also referred to as a “double conversion UPS.”

Definitions for these IEC classifications can be found in Appendix A. Summary List of UPS and Power System Terms and Definitions.

The double conversion (or VFI) UPS topology is the most widely deployed in the data center; therefore, the remainder of the white paper concentrates on it. A double conversion UPS employs multiple operating modes, one of which may be Eco Mode. The double conversion UPS can, with the support of suitable controls, be designed and configured to include IEC classification VFD in its particular Eco Mode implementation.

IEC 62040-3 Edition 2 defines “normal mode” of UPS operation as the stable mode of operation that the UPS attains under the following conditions:

- AC input supply is within required tolerances and supplies the UPS
- The energy storage system remains charged or is under recharge
- The load is within the specified rating of the UPS
- The bypass is available and within specified tolerances (if applicable)

The EPA ENERGY STAR Uninterruptible Power Supplies specification development process added the following definitions for single-normal-mode or multiple-normal-mode UPSs:

- **Single-normal-mode UPS:** A UPS that functions within the parameters of only one set of input dependency characteristics, i.e., a UPS that functions only as VFI.
- **Multiple-normal-mode UPS:** A UPS that functions within the parameters of more than one set of input dependency characteristics, i.e., a UPS that can function as either VFI or VFD.

Figure 2 through Figure 6 represent various possible modes of the double conversion UPS. **Red** represents the power flow path. **Blue** indicates load power is not flowing. **Yellow** implies power is available. These diagrams show there are several types of UPSs available for use, offering different levels of protection and different dynamic output characteristics; Eco Mode is one such type (see Figure 3).

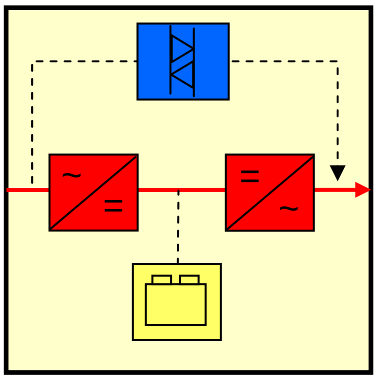


Figure 2. Double conversion, Normal Mode

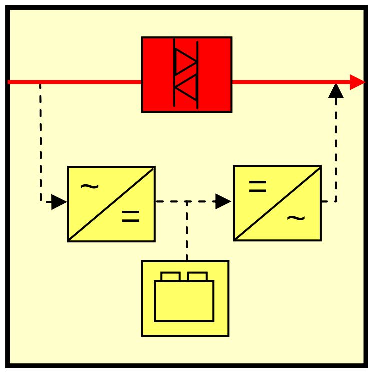


Figure 3. Double conversion, Eco Mode

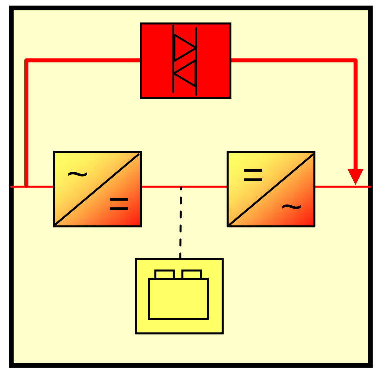


Figure 4. Double conversion, line interactive

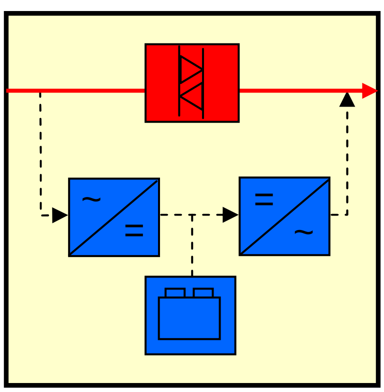


Figure 5. Double conversion, bypass

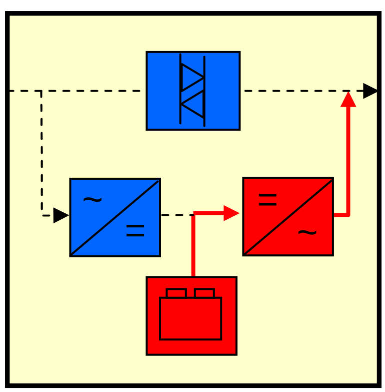


Figure 6. Double conversion, system on battery

III. Performance of Eco Mode

Key to any Eco Mode evaluation is the performance it affords the user and whether that performance can meet the data center's particular requirements. Table 1 shows the performance characteristics and tradeoffs for various modes of operation.

UPSs are described by the IEC standard 62040-3, Section 5.3.4 via the AC UPS output voltage dynamic performance; a UPS's performance in Eco Mode can be classified in a similar manner. Details as to how each Eco Mode internal bypass transfer mechanism is categorized in this regard also can be found in Table 1. Within this standard, the IEC defines characteristic codes for UPSs. The IEC characteristic code consists of several multiple-digit groups. The code's first three characters reflect the output dependency on input characteristics. Its second two characters are the output voltage waveform characteristics. Its last two or three characters represent the dynamic output performance of the UPS. To define types of UPSs for the purposes of this white paper, Table 1 shows a subset of the whole code. The row of "Normal IEC characteristic codes" in Table 1 shows the first digits of the third group of characters. Figure 7 through Figure 10 provide representational graphic figures for the various UPS internal bypass transfer mechanisms described in Table 1.

The following is a summary of the subset of classes defined in IEC 62040-3 and shown in Table 1:

- **Class 1:** Performance is required for sensitive critical loads.
- **Class 2:** Performance is accepted by most types of critical loads.
- **Class 3:** Performance is accepted by general-purpose IT loads.

Please refer to the IEC standard 62040-3 for more information.

Table 1. Performance characteristics and tradeoffs of Eco Mode transfer types

Eco Mode Transfer Mechanism Between Inverter and Bypass						
	Electro-Mechanical Transfer	**Static Switch**	**Grid-Connected**	**Line Interactive**	**Conventional Double Conversion**	**Battery Mode**
Graphic Figure	Figure 7 or 8	Figure 9 or 10	Figure 9 or 10	Figure 9 or 10	Figure 9 or 10	Figure 9 or 10
Normal IEC Characteristic Codes	VFD > Class 3 (exceeds recommended limits)	VFD Class 3	VFD Class 1-3 (varies by implement-	VI Class 1-3 (varies by implementation)	VFI Class 1-3 (varies by implementat-ion)	VFI Class 1-3 (varies by implementation)

Eco Mode Transfer Mechanism Between Inverter and Bypass						
	Electro-Mechanical Transfer	**Static Switch**	**Grid-Connected**	**Line Interactive**	**Conventional Double Conversion**	**Battery Mode**
(Section 5.3.4)			ation)			
Description	Electro-mechanical switch (such as contactors)	Double-throw static switch	Static switch is normally on, connecting the inverter output to the bypass; inverter is tracking the bypass voltage and frequency	Static switch is normally on; inverter is actively engaged in bypass voltage regulation	Output normally powered by inverter	Output normally powered by inverter
Inverter Control Electronics (Energized or De-energized)	Yes or No (either)	Yes or No (either)	Energized	Energized	Energized	Energized
Inverter Power Circuitry (Energized or De-energized)	Can be on or off (i.e., hot or cold standby)	Can be on or off (i.e., hot or cold standby)	Inverter is connected to the bypass (phase locked & operating), but inverter is not supplying power; inverter is instantly available if bypass is out of limits	Inverter is operating, connected to bypass, and doing bypass regulation	Energized	Energized
Momentary Interruption in Output Power During Transfer	4-30 cycles	0.5 - 3 cycles	0 - 0.25 cycle	0	0 - 0.25 cycle	0 - 0.25 cycle

Eco Mode Transfer Mechanism Between Inverter and Bypass						
	Electro-Mechanical Transfer	**Static Switch**	**Grid-Connected**	**Line Interactive**	**Conventional Double Conversion**	**Battery Mode**
Inverter Output: Bypass Voltage Tracking?	Yes or No (either)	Yes or No (either)	Yes	Yes	Yes	Yes
Inverter Output: Bypass Frequency Matching?	Yes or No (either)	Yes or No (either)	Yes	Yes	Yes	Yes
Inverter Output: Bypass Phase Matching?	Yes or No (either)	Yes or No (either)	Yes	Yes	Yes	Yes
Comments		Transfer times can be as low as 2-4 milliseconds under the right conditions	The static switch internal to the UPS needs to be gated off less than 2 milliseconds when bypass goes out of limits	Limited by how much surge/overload/ fault current can be provided at any given time	Inverter will synchronize with bypass provided the bypass source is within acceptable limits	Inverter will synchronize to bypass provided the bypass source is within acceptable limits

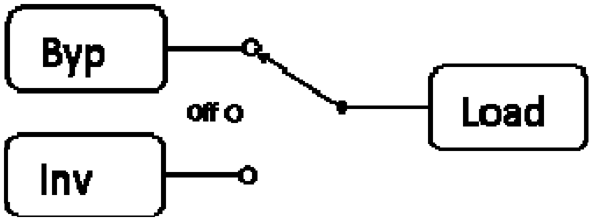


Figure 7. Basic electro-mechanical transfer switch; center-off requirement; no overlap capability

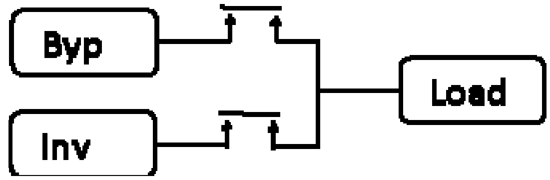


Figure 8. Electro-mechanical transfer switch; overlap capability. Inverter is capable of at least momentary paralleling.

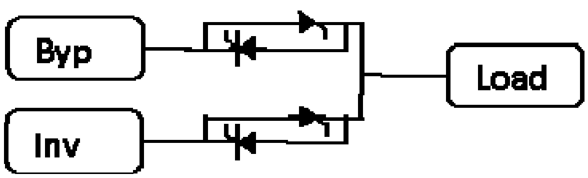


Figure 9. Static transfer switch overlap capability; two discrete paths. Similar performance to Fig 7. Inverter may be capable of continuous interactive operation.

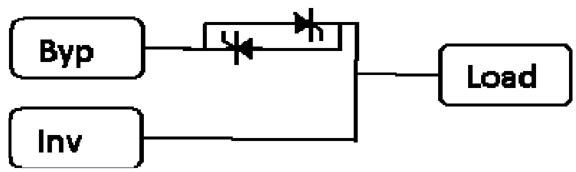


Figure 10. Static transfer switch overlap capability; inverter is second path. Inverter is capable of continuous interactive operation.

EFFECT OF TRANSFER TIME ON PERFORMANCE

For a UPS, transfer time is defined as the time that it takes the UPS to transfer the critical load from the output of the inverter to the alternate source, or back again. Included in Table 1, transfer time is one of the most salient performance characteristics for Eco Mode. It is important because it defines the amount of time (usually stated in milliseconds) that the load will be without power from the UPS output.

Not all Eco Mode designs are the same. Figure 7 through Figure 10 show the different Eco Mode transfer switch configuration implementations. As is shown, implementations vary widely, including everything from relatively fast static switches to the much slower mechanical transfer devices. This is not a complete indictment of Eco Mode as a viable power protection means. Instead, a specific transfer switch configuration is one data point to be understood and evaluated prior to implementation of Eco Mode. An evaluation should include transfers of the critical load between the two possible sources of power and in both directions:

- Transfer of the critical output load from the UPS inverter to the alternative source
- Transfer of the critical output load from alternative source back to the UPS inverter

Table 1 delineates the differences in transfer time performance between the implementation shown in the figures. It should be expected that with different implementations come transfer times that are wide-ranging; fastest is the 0 to 0.25 cycle and slowest is 500 milliseconds.

It should be noted that transfer time includes the time it takes for the logic to detect that the present power source is outside acceptable boundaries of power quality, followed by a momentary interruption in the power going to the critical load.

So how should Eco Mode transfer times be evaluated when it comes to installed information technology equipment (ITE)? By what benchmark or requirement should a data center operator review transfer time requirements?

There is currently no de facto standard for Eco Mode transfer times, although it can be argued that the IEC Standard for UPS may be applied. One tool used by the industry is a set of curves that describe the ITE input immunity, referred to below as "IT Equipment Disturbance Tolerance curves."

Figure 11 describes the basic curve and its regions of importance, the key being that the Eco Mode transfer must remain within the upper and lower boundaries of the "No Interruption of IT Equipment" region.

Figure 11 also provides a historical perspective that is worth noting and covers nearly 40 years of industry use. (See Appendix C: History of Ride-Through Time for more information.) These curves are the current industry guide; however, best design practices address transfer time from the perspective of the ITE power supply unit (PSU). (See Section IV: Deployment Considerations for Eco Mode for more information.)

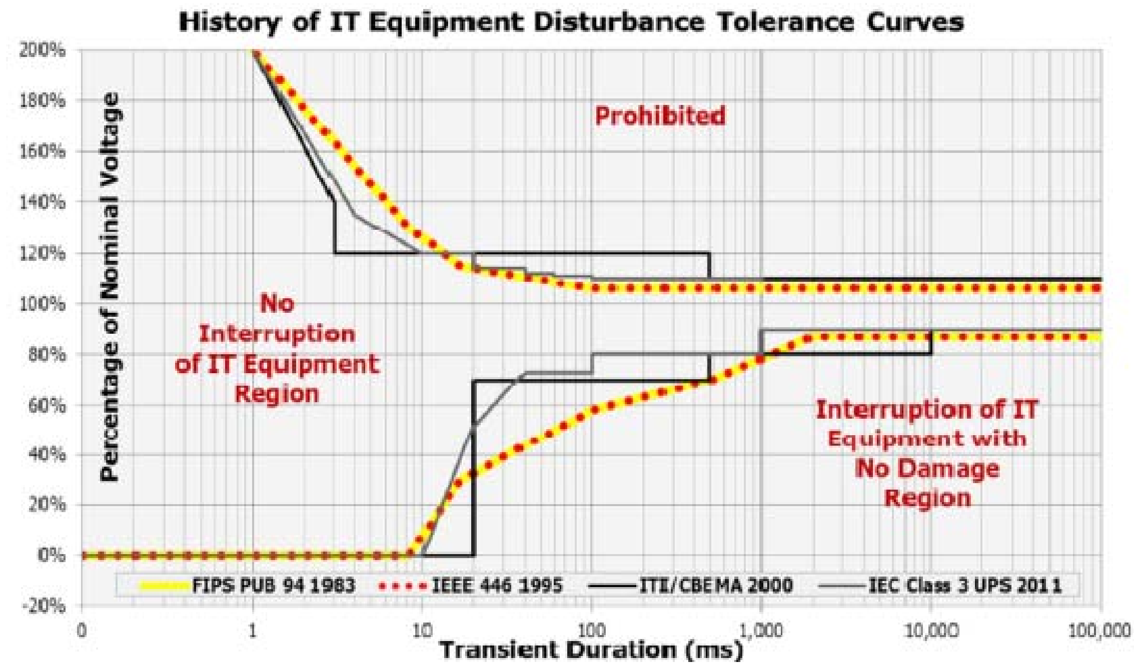


Figure 11. History of IT equipment disturbance tolerance curves

Using the tool another way, Figure 12 illustrates how the input disturbance tolerance curves can be used to evaluate Eco Mode UPS transfer times. For the purposes of discussion, the curves show two references: the ITIC/CBEMA 2000 curve and 2010 PSU curve. Overlain in the figure are transfer time performance curves for two examples of Eco Mode UPSs: Eco Mode UPS 1 and Eco Mode UPS 2. Note that Eco Mode UPS 1 remains well within the all-important “No Interruption” region while Eco Mode UPS 2 has the potential to result in interruptions to ITE. Eco Mode UPS performance can be wide-ranging and, like any other power system transfer performance, it should be evaluated with respect to ITE requirements. Again, this is not to indict the performance of Eco Mode UPS 2, since the acceptability of the transfer time afforded does depend on the reference curves (i.e., the applications). The line marked “2010 PSU” is addressed later in the white paper.

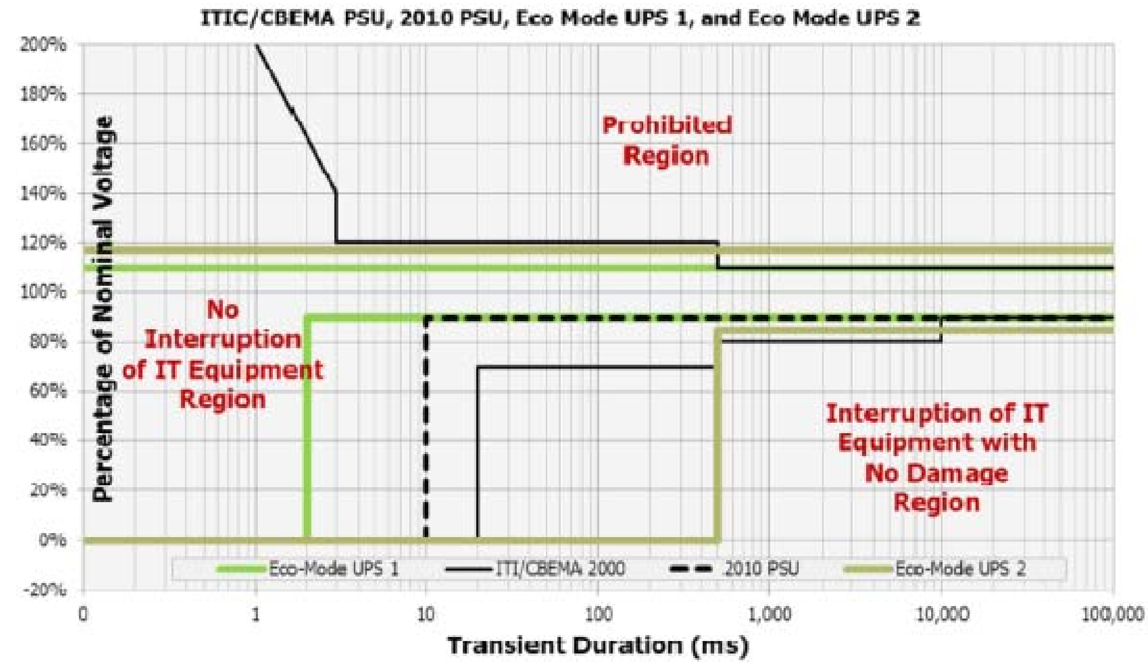


Figure 12. ITIC/CBEMA curves with The Green Grid additions

FAULT TOLERANCE PERFORMANCE OF ECO MODE

A UPS system operating in Eco Mode needs the ability to identify the difference between a low voltage caused by a fault and a low line voltage that would cause the UPS to transfer from mains power to inverter power. Each UPS supplier has its own method for identifying this difference. Therefore, not all Eco Modes operate the same way. If there is a fault, the UPS must be able to determine if the fault is “downstream” or “upstream.” However, to cover over-voltage conditions, external surge protection upstream of the UPS should be used for all systems, no matter if the UPS is operating in a normal mode or in an Eco Mode.

IV. Deployment Considerations for Eco Mode

The subject of downstream loads and their tolerance to upstream outages deserves detailed handling in any power system design or evaluation. This discussion uses the PSU that is built into the IT equipment and a downstream static transfer switch as examples.

IT EQUIPMENT POWER SUPPLY UNITS

One of the considerations to review prior to implementing Eco Mode is the design ride-through of the ITE power supply units. PSUs in ITE systems can store small amounts of energy in capacitors and thereby allow for a certain amount of ride-through time. Measured in milliseconds (ms), ride-through time is the length of time that the IT equipment can continue to function during a complete loss of power. Rated ride-through time is based on the single power supply at full load. The ride-through time of a PSU is a specific design criterion that is unique to each power supply, typically a value anywhere from 10 ms to 50 ms. For systems with dual power supplies, the load on each supply is typically cut in half. Dual power supplies (each operating at half load) increase the ride-through time by as much as 50% to 100% compared with a single power supply at full load. There is no need to keep the two power supplies synchronized.

Even though PSUs can draw current at a wide range of phase angles, the PSU test specification is based on the worst case phase angle. The rated ride-through time also is based on worst-case situations, such as 100% load with no redundancy.

After an outage, PSUs will recover any loss of energy due to an interruption within one or two cycles. An Eco Mode UPS will be required to supply the resultant transient inrush load current. This same current surge or inrush current may drop the power supply input voltage due to line impedance between the UPS and the PSU. Therefore, the shorter the Eco Mode UPS interruption, the less energy that must be recharged into the PSU capacitors following the transfer, resulting in less voltage drop at the input of the PSU.

As stated above, every PSU will have a different supported ride-through time. Prior to implementation, it is imperative to know the ride-through capabilities of every ITE PSU that will be powered by the UPS and to know the transfer time of the UPS operating in Eco Mode. For example, if an Eco Mode UPS has a transfer time of greater than 10 ms, and it is paired with IT equipment that has ride-through capabilities of only 10 ms, the UPS may not be able to support the IT equipment. Therefore, Eco Mode is not a solution that should be implemented in that data center.

Ride-through times in ITE PSUs have been shrinking. See Appendix C: History of Ride-Through Time for a review of the tolerance of downstream loads to upstream outages. Appendix C also provides a historical review of time versus voltage curves used by the industry to quantify the tolerance of IT load to input power disturbances. The information in Appendix C is helpful for keeping some of the following PSU and static transfer switch (STS) discussion points in perspective.

Current written standards vary on the required ride-through time for PSUs. Figure 12 compares the most commonly cited performance requirements for PSUs. The Green Grid recommends designing for the minimum transfer time or voltage immunity standard that all ITE should be able to meet. To identify the best minimum ride-through time, The Green Grid polled several ITE manufacturers for their PSUs' available ride-through times. While some equipment had a more extended ride-through, the lowest ride-through time identified for high-volume server power supplies was 10 ms. A voltage immunity standard is currently available that also supports this 10-ms minimum ride-through time; see standard 24 (EN55024) from CISPR (the special international committee on radio interference). Another similar standard is IEC 61000-6-1, 2005-03, which also includes a minimum of 10 ms.

In summary, it is important to compare output envelope capabilities of the UPS with the input envelope requirements of the power supply. Any interruption of UPS output must be shorter than what the PSU input can tolerate. If there are areas that do not agree, it is possible that Eco Mode cannot be used. For these cases, data center operators should consult the Eco Mode UPS vendors, particularly in light of the fact that certain Eco Modes can be adjusted to accommodate site and/or application requirements. It is up to the data center operators to determine what is important for their site and application.

V. Downstream Power Systems

Eco Mode carries the stigma of providing less protection when compared with double conversion. Because the transfer of the Eco Mode UPS from one operating mode to another may entail a momentary interruption and not all Eco Mode UPSs provide the same performance with regard to transfer times, the Eco Mode of choice must also meet the most demanding transfer times required by critical downstream loads, such as any surge protection or static transfer switches.

SURGE PROTECTION

The Eco Mode UPS is frequently viewed as providing no surge protection for downstream loads in the data center. While this may be true in some cases or for some Eco Mode types, it is not true for all types. Figure 13 below illustrates that an Eco Mode UPS can provide some degree of surge protection while delivering energy savings. Figure 13 provides additional detail beyond that of Figure 2 and Figure 3, as it shows rectifier input and inverter output filter capacitors remaining connected to both the UPS input and the UPS output. This capacitance, which can be substantial in size, absorbs the energy of an incoming surge and limits the peak amplitude of that surge.

Because not all Eco Mode UPSs are designed to work in this manner, data center operators need to evaluate what a specific UPS offers this configuration. That said, The Green Grid recommends standard surge suppression in the data center, as required; surge performance offered by any UPS should only be viewed as supplementary. It may be possible for the UPS vendor to provide surge suppression performance data to confirm that the surge performance matches data center equipment requirements both at the individual box and system levels.

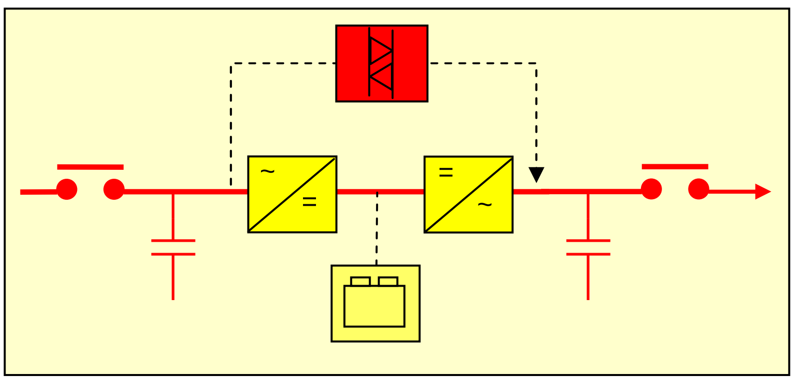


Figure 13. Eco Mode UPSs and surge protection

INTERNAL SITE POWER SYSTEM STUDY

Power quality disturbances may also be generated inside the data center facility. Therefore, an extended site power quality analysis should be performed on any data center because it is the most reliable way to measure power quality risk for any given site.

STATIC TRANSFER SWITCH COMPATIBILITY

Dual-corded ITE typically does not use static transfer switches. However, for data centers with ITE that uses static transfer switches, the following is a guide to implementation with Eco Mode. Today's STSs have transfer times of 4 ms to 6 ms, and their use in data center power systems is quite common. The STS may allow some disturbances to reach the load with the assumption that the load will naturally tolerate those disturbances—be they voltage sags, outages, or surges. Figure 14 below shows how a UPS, in this case an Eco Mode UPS (equipped with a static or mechanical internal transfer switch), is used to serve as the primary source that feeds the STS; the STS is, in effect, a downstream load to the Eco Mode UPS. As such, coordination of Eco Mode UPSs with the static transfer switches is critical. The following discussion, although not a complete coverage of Eco Mode UPS-to-STS compatibility, covers the major components experienced in practice.

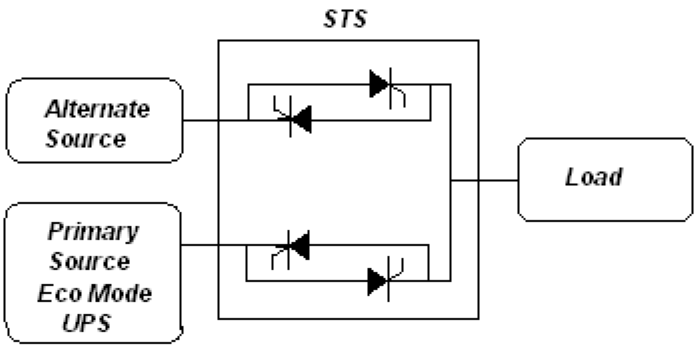


Figure 14. STS and Eco Mode UPS implementation

The STS continuously monitors the voltage, current, frequency, and phase of the primary and secondary sources, and it uses a number of power quality settings to form the basis of a decision to transfer from the preferred or primary source to the alternate or secondary source. What happens if the STS sees an interruption of several milliseconds caused by the UPS switching between Eco Mode and some other mode? In general, STS transfer settings must be compatible with the transfer characteristics of the particular Eco Mode UPS. Incompatibility issues can take many forms; the key is that these issues should never be triggered by normal Eco Mode transfers. While some STS settings are easily confirmed and analyzed without STS vendor involvement, other parameters may require review or discussion with the STS vendor. The Green Grid highly recommends Eco Mode UPS-to-STS compatibility testing. (The STS also contains parameters that form the basis of the transfer back to the primary source, although this white paper does not cover them. Please see Appendix D: Detailed Guide of Static Transfer Switch Parameters Important to Power System Performance.)

VI. Utility Reliability and UPS Eco Mode

UPS Eco Mode operation requires an acceptable level of utility power quality that is within the voltage tolerance of the ITE power supplies and the UPS Eco Mode voltage settings. When the utility power quality is outside the voltage tolerance, the UPS will transition to a more protective mode (VFI or VI) and the efficiency could be lower than expected. Understanding the quality of the utility power is important for deploying UPS Eco Mode in such a way that the data center will realize the expected energy efficiency improvements.

The EPA ENERGY STAR Uninterruptible Power Supplies specification draft comments discuss “multiple-normal-mode UPS,” as indicated in the EPA comments below:

> *“EPA received additional stakeholder comments on the inclusion and weighting of Multiple-normal-mode UPSs. After consideration of all stakeholder inputs, EPA has maintained the same position as in Draft 2 – Multiple normal-modes are one of several innovative strategies for realizing energy savings in UPS systems, but the amount of time these modes are used is still an open question.”*

DATA CENTER SITE UTILITY DATA

The best way to determine if facility power is good enough to operate a UPS in Eco Mode is to gather power quality data at the specific data center site. Most data center sites should have power quality metering devices at the utility service entrance. These power quality meters can be used to measure and track the incoming utility power for deploying UPS Eco Mode. Power quality meters can be programmed to track, over time, utility power quality disturbance events and duration relative to voltage immunity requirements. This white paper has already outlined a range of voltage immunity guidelines, including the historical ITIC and CBEMA curves, along with the tightest 2010 PSU requirement (see Figure 12). Data center operators can use these voltage immunity curves programmed inside a power quality meter to accurately track the number of power quality events that occur and the duration of these events outside their voltage immunity requirements. This site-specific information needed to guide the Eco Mode UPS application also can be obtained from a detailed power quality site survey from power quality companies and consulting firms. For green field data center sites where the data center (and the site metering) has not been built, the operator can ask the local utility to provide the utility power quality history (to millisecond resolution, if available – see more info in next section and figures in Appendix C: History of Ride-Through Time) at the closest metering point (e.g., distribution substation) to the proposed data center site.

U.S. UTILITY POWER QUALITY DATA

If no site-specific utility power quality data is obtainable, there is data available on the reliability of the U.S. utility grid that can help data center operators make a general determination on the amount of time UPS Eco Mode can operate. Utilities are required to report their utility power distribution reliability to various regulatory bodies, such as state public service commissions (PSCs). Called the Customer Average Interruption Duration Index (CAIDI) and System Average Interruption Duration Index (SAIDI), these public reliability metrics usually exclude events that last less than 1 minute and do not include power quality events of very short duration (subcycles) that could disrupt sensitive IT power supplies. For data centers, the number of events matters as much as the duration of the events.

The Electric Power Research Institute (EPRI) recognized the need to measure subcycle power quality events for mission-critical sites and that existing utility metrics (CAIDI, SAIDI) were not suitable, so it decided to use a system average RMS variation frequency index (SARFI) to measure utility power quality in the U.S. In 2003, EPRI worked with a number of U.S. utilities on measuring utility power quality using highly accurate metering at more than 200 utility distribution sites around the U.S. for a period of two years. EPRI compared this actual utility power quality data using the SARFI index to a variety of voltage immunity guidelines, including ITIC and CBEMA. Figure 15 summarizes the overall results as a three-dimensional plot of event duration (x axis), annual number of events (y axis), and voltage sag (z axis).

UPS Eco Mode operation requires an acceptable level of utility power quality that is within the voltage tolerance of the ITE power supplies and the UPS Eco Mode voltage settings.

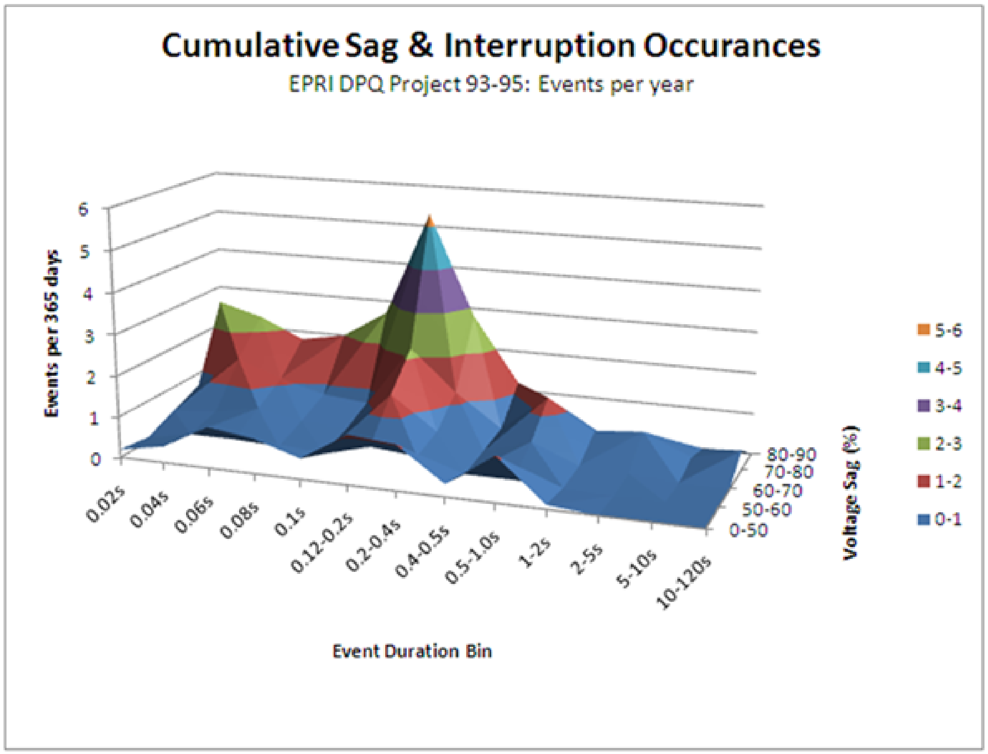


Figure 15. Findings from the EPRI study on U.S. utility power quality

The report released by EPRI following its study provides a good benchmark on U.S. utility reliability. The general conclusion is that U.S. utility power quality is reasonably reliable for deploying UPS Eco Mode. Based on the report's data, the U.S. utility grid averages about 25 events per year outside the ITIC curve and more than 95% of sites monitored had less than 52 events per year (or one pair of forced operating mode changes per week). As illustrated in Figure 15, most utility events are very short duration (less than 1 minute). Figure 16 shows the SARFI index compared to the ITIC curve. To put this in perspective, imagine that each utility event lasts 1 hour, which suggests that utility power quality would be outside the ITIC voltage immunity curve for about 25 hours per year (or less than 1% annually). A UPS could operate in Eco Mode as much as 99% of the year. Even if an average utility event lasted one full day, the UPS could still operate in Eco Mode more than 93% of the time.

	$SARFI_{ITIC}$
Minimum	0
CP5	3
CP50	19
Mean	25
CP95	52
Maximum	141

Figure 16. EPRI study statistics on number of voltage events per year outside the ITIC curve

ENERGY STAR FOR UPS

As part of its ENERGY STAR program, the EPA provides a 25% efficiency allowance to the manufacturer for the UPS Eco Mode capability, as calculated below in Equation 1, where Eff_1 is double conversion efficiency and Eff_2 is Eco Mode efficiency.

Equation 1 $$Eff_{AVG} = 0.75 \times Eff_1 + 0.25 \times Eff_2$$

The EPA weighting of 25% was primarily due to the question about the amount of time that the UPS is actually used in Eco Mode. The amount of time Eco Mode can be used is a function of input power quality from the utility grid, site power quality, and the end user's operating behavior.

"FREE COOLING" ANALOGY

There is a close conceptual relationship between UPS Eco Mode operation and the well-known "free cooling" operation that allows data centers to reduce energy consumption in their cooling systems when the outside ambient air temperature and humidity are within acceptable levels.

The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) provides guidance regarding the outside air ambient temperature and humidity ranges in which data centers can realize energy savings benefits from free cooling.[2] Free cooling has evolved to include free cooling maps[3] that help data

---

[2] ASHRAE TC 9.9. *2011 Thermal Guidelines for Data Processing Environments – Expanded Data Center Classes and Usage Guidance* (2011), http://goo.gl/Y0H8H

center operators understand geographic regions with weather patterns (temperature, humidity) that define typical hours per year in which conditions are acceptable for operating with free cooling.

As with external weather conditions, data center operators can make the most of available high-quality utility power to improve efficiency. In this case, rather than free cooling, it is "free power quality" that data centers can take advantage of, available when the UPS Eco Mode uses external utility power that is already in high-quality condition. Similar to free cooling, where the chiller is not used or is turned off when not needed, the UPS Eco Mode turns off the UPS rectifiers/inverters when the availability of "free power quality" makes them unnecessary.

VII. Economic Benefits of Eco Mode

The economic benefits of Eco Mode (VFD) operation also should be a component of any evaluation. Economic benefits are found in the efficiency gains of Eco Mode when compared with double conversion (VFI) normal mode and the occurrence of those gains at the majority of the load range. The Green Grid White Paper #16, *Quantitative Analysis of Power Distribution Configurations for Data Centers*,[4] looked specifically at the efficiency of components in the power distribution chain, including UPSs. Figure 17 below depicts efficiency curves from two UPSs. The red and blue curves show the efficiency of a UPS that offers an Eco Mode option; the blue curve represents the UPS in double conversion (VFI) normal mode and the red curve shows the same UPS in Eco Mode. The efficiency gains from using Eco Mode average about 4.3%. For comparison, the most efficient double conversion UPS from White Paper #16 is shown in green. This UPS does not offer an Eco Mode option. The efficiency gains from using the UPS with Eco Mode versus using the double conversion UPS with no Eco Mode average about 2%.

[3] www.thegreengrid.org/en/Global/Content/white-papers/WP46-UpdatedAirsideFreeCoolingMaps-TheImpactofASHRAE2011AllowableRanges

[4] www.thegreengrid.org/en/Global/Content/white-papers/Quantitative-Efficiency-Analysis

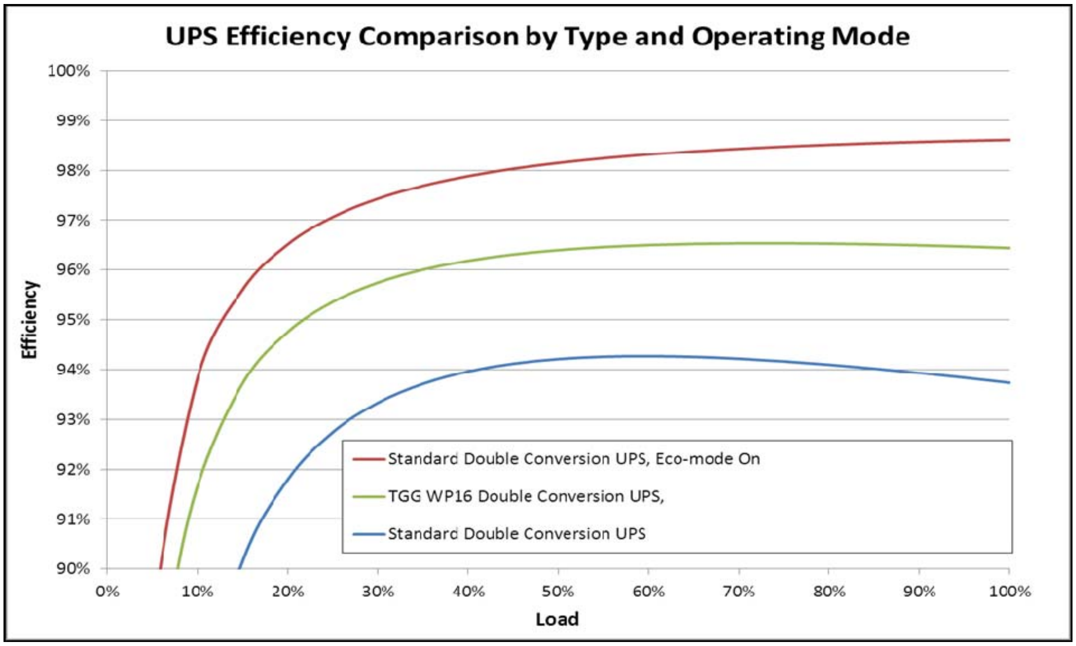


Figure 17. Double conversion UPS comparison

The Green Grid examined the impact on power usage effectiveness (PUE™) of UPS Eco Mode efficiency relative to UPS double conversion efficiency; its findings are summarized in Table 2. This summary assumed three types of data centers that vary based on their efficiency as measured by PUE, with the UPS operating in double conversion mode:

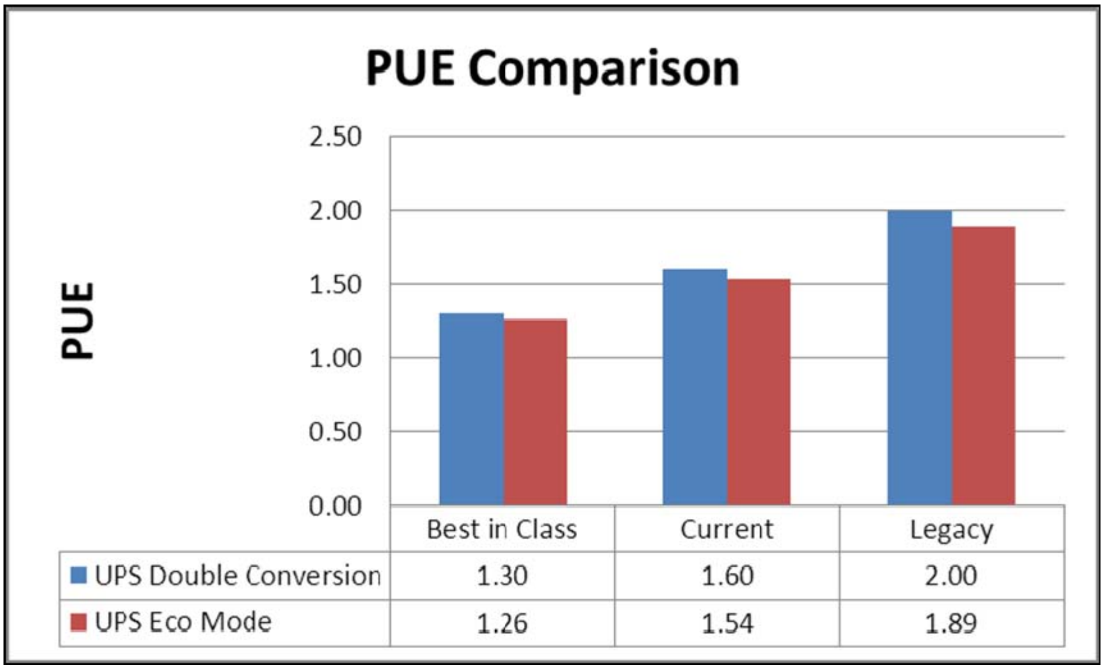
- "Best-in-class" PUE = 1.3
- "Current" PUE = 1.6
- "Legacy" PUE = 2.0

Table 2. Typical data center PUE and UPS efficiency

	Best in Class	Current	Legacy
UPS Eco Mode Efficiency	99.0%	98.0%	98.0%
UPS Efficiency (VFI)	96.0%	94.0%	92.0%
PUE Cooling Contribution	21.8%	48.5%	84.1%
Typical PUE	1.3	1.6	2.0

UPS inefficiencies generate heat in the data center, which is removed by the data center's cooling system. That heat removal is accounted for with the PUE cooling contribution. Tax credits or other incentives for improving a data center's PUE may be available for some areas; see www.dsireusa.org for more information.

Figure 18 estimates the improvement in PUE from turning on UPS Eco Mode in each typical data center; this improvement could range from 0.04 for a "best-in-class" data center to 0.11 for a legacy data center.



PUE Improvement	0.04	0.06	0.11

Figure 18. PUE improvement with UPS Eco Mode

The economic benefit of UPS Eco Mode measured as energy cost savings also can be estimated. These potential energy savings will vary with a range of factors, including UPS efficiency, cooling efficiency, power cost, operating hours, and IT load (in kilowatts [kW]). Using the three typical data center types described above, The Green Grid estimated the annual energy savings as a function of IT load (kW); Figure 19 represents a summary of the results. These energy savings ranged from less than $100,000/year savings for 1 megawatt (MW) IT load to almost $500,000 per year for 5 MW load in a legacy data center, based on the operating assumptions included in the lower portion of Figure 19.

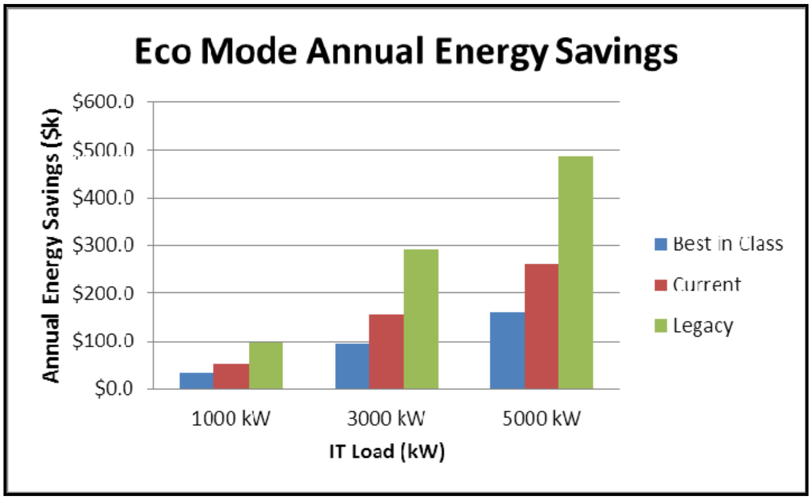


Figure 19. UPS Eco Mode annual energy savings for typical data centers

Assumptions	Value	
Operating Hours	8760	hours
Power Cost	$0.10	$/kw-hr
UPS Eco Mode Eff	98.0%	
Power cost escalation	5.00%	
Cost of Capital (Interest)	10.00%	

For a longer-term view, these annual energy savings can be converted into life cycle energy savings over a UPS's typical operating life (10 years) using a simple net present value (NPV) calculation. (See Figure 20.) Using the annual energy savings from the best-in-class data center, the NPV life cycle cost savings range from more than $20,000 for the 100 kilowatt IT load to almost $1.2 million savings for the 5 megawatt IT load over ten years.

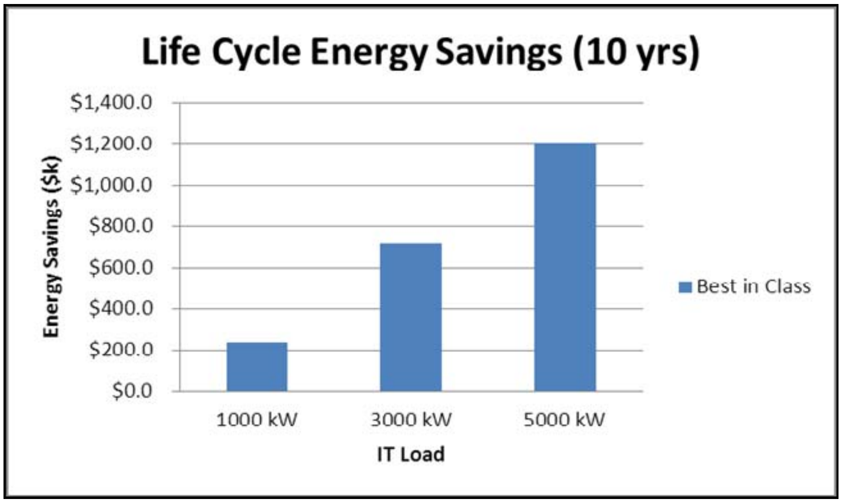


Figure 20. UPS Eco Mode life cycle energy savings for typical data centers

VIII. Summary and Recommendations

Eco Mode for UPSs has become a viable option to help increase energy efficiency and save costs in the data center. However, there are several points that data center operators need to consider prior to implementing it.

First, it is extremely important to match the switch-over time for an Eco Mode UPS to the power supply ride-through or static switch time. Not all Eco Mode UPSs may be initially tuned to meet this time requirement or able to meet it. Data center operators should analyze the power distribution within their data centers and consult their UPS manufacturers for information prior to implementing Eco Mode. All equipment must be tuned to work well together.

Second, UPS Eco Mode operation requires an acceptable level of utility power quality. It must be within the voltage tolerance of all equipment to keep the UPS operating in the most efficient range possible. Before many data centers will be able to move from Level 1 UPS Eco Mode implementation to Level 3 implementation in The Green Grid's Data Center Maturity Model, the following will need to take place:

- Voltage immunity curves should be updated to help all designers and operators by accounting for the shorter ride-through times now implemented in many servers.
- Users should identify their critical business types and the characteristics of their loads to determine the best implementation mode for their business.

- Periodic, in-depth power quality studies should be conducted so that the results can be studied by possible Eco Mode users.
- UPS manufacturers will need to continue to identify and implement advances in Eco Mode technology that can help close any gaps in current systems that prevent utilization of Eco Mode.

IX. References

1. International Electrotechnical Commission (IEC), *International Standard 62040-3 Edition 2* (2011) http://webstore.iec.ch/webstore/webstore.nsf/artnum/044928!opendocument.

2. The Green Grid, *Data Center Maturity Model* White Paper #36 (2011) www.thegreengrid.org/en/Global/Content/white-papers/DataCenterMaturityModel.

3. The Green Grid, *Quantitative Analysis of Power Distribution Configurations for Data Centers* White Paper #16 (2008) www.thegreengrid.org/en/Global/Content/white-papers/Quantitative-Efficiency-Analysis.

4. U.S. Environmental Protection Agency and the U.S. Department of Energy, *ENERGY STAR Uninterruptible Power Supplies – Version 1.0 Specification* (2012) www.energystar.gov/index.cfm?c=new_specs.uninterruptible_power_supplies.

X. About The Green Grid

The Green Grid Association is a non-profit, open industry consortium of end users, policy makers, technology providers, facility architects, and utility companies that works to improve the resource efficiency of information technology and data centers throughout the world. With its member organizations around the world, The Green Grid seeks to unite global industry efforts, create a common set of metrics, and develop technical resources and educational tools to further its goals. Additional information is available at www.thegreengrid.org.

Appendix A. Summary List of UPS and Power System Terms and Definitions

Eco Mode: One of several UPS modes of operation that can improve efficiency (conserve energy) but, depending on the UPS technology, can come with possible trade-offs in performance.

Transfer time: For an uninterruptible power supply (UPS), the time that it takes the UPS to transfer the critical load from the output of the inverter to the alternate source, or back again.

Ride-through time: For a power supply, the time a power supply can continue to supply an output power when input power is interrupted.

Power supply unit (PSU): A component of information technology equipment (ITE), such as a server, that provides direct current (DC) to other components within the ITE. It typically converts from one voltage to another and from one frequency to another (e.g., 120Vac/60 Hz from the mains distribution to 5Vdc at the printed circuit board level).

Uninterruptible power supply (UPS) system: An electrical apparatus that draws upon stored energy (typically a battery or a flywheel) to provide AC output power to a load when the input power source (typically mains power) fails. (Cf., a device that provides DC output to a load is termed a rectifier plant.)

Static transfer switch (STS): A transfer switch composed of two static switches. One static switch connects the AC load to the selected “PREFERRED” source. The second static switch stands ready to transfer the AC load directly to the “ALTERNATE” source if so desired. Each static switch contact is comprised of a pair of silicon controlled rectifiers (SCRs) connected in paralleled-opposing.

Table A1. UPS definition details

Term	Voltage & Frequency Dependent (VFD)	Voltage Independent (VI)	Voltage & Frequency Independent (VFI)
Definition	Output voltage and frequency are **dependent** on (i.e., identical to) the input	Output voltage is **independent** of the input; frequency is the same	Output voltage and frequency are **independent** of the input
Protects against	▪ Power outage	▪ Power outage ▪ Under/over voltage	▪ Power outage ▪ Under/over voltage ▪ Frequency variations
Typical efficiency/efficiency range		94-98% efficiency across typical load levels	88-98% efficiency across typical load levels
Topology example (from IEC standard)	Standby or grid-connected	Line interactive	Double conversion

Appendix B: IT Equipment Input Immunity Curves

Historically, uninterruptible power supply (UPS) transfer times were designed around two curves. The Computer Business Equipment Manufacturers Association (CBEMA) created the first, known as the "CBEMA curve," with a required ride through time of at least 8 ms   It was intended to characterize the power abnormalities that would likely be seen in an ITE environment.

For the second curve, the Information Technology Industry Council (ITIC) revamped the CBEMA curve. Commonly called the ITIC curve, it has a lower limit of 20 ms, which is greater than the older CBEMA curve. PSU manufacturers initially designed to this ride-through target.

While relevant at the time, the ITIC curve is now out-of-date for current ITE installations because it refers to a 20-ms cycle requirement and power supplies now may only have a ride-through time of 10 ms, half of what is listed on the ITIC curve.

The Green Grid is not aware of any planned updates to the ITIC curve at the time of this writing.

For ease of comparison, The Green Grid has put together four figures—Figures C1 through C4 in Appendix C: History of Ride-Through Time—that include several relevant pieces of information: the International Electrotechnical Commission (IEC) UPS class requirements, the ITIC curve, and The Green Grid's research on minimum ride-through time. These figures depict several combinations of UPS outputs and power supply ranges.

Appendix C: History of Ride-Through Time

Power supplies used to be very much oversized, based on worst-case system power plus some margin. Because of this, ride-through time was also higher; around 10 years ago, power supplies could have two to three cycles of ride-through time. For example, with previous PSU designs, a system might actually draw only 500 watts (W) of a 1,000-W power supply, so the ride-through time would be longer than what may have been specified; a user could assume that the specified ride-through time of 20 ms is actually double the spec, or 40 ms (i.e., close to 2.5 cycles at 60 Hz or 2 cycles at 50 Hz).

Over the years, ride-through time has slowly but steadily decreased while PSU utilization has increased. Driven by attempts to improve efficiency, today's power supply units have much less ride-through time; for example, a ride-through could be as low as 20 ms (about one cycle) and sometimes as low as 10 ms (or only about half a cycle). As vendors right-size their PSUs, users are limited to just what is specified as ride-through time—only 20 ms for example—and cannot depend on any more.

There are several additional reasons for decreasing times. First, line interactive UPSs are now able to detect a loss of utility and switch over in less than 10 ms, allowing power supply designers to decrease ride-through time. Also, since many data center installations were moving to double conversion UPSs, power supply manufacturers were able to move to a shorter cycle time.

Figures C1 through C4 below show that curves can vary based on a given voltage range, hence the effect on the PSU 2010 line.

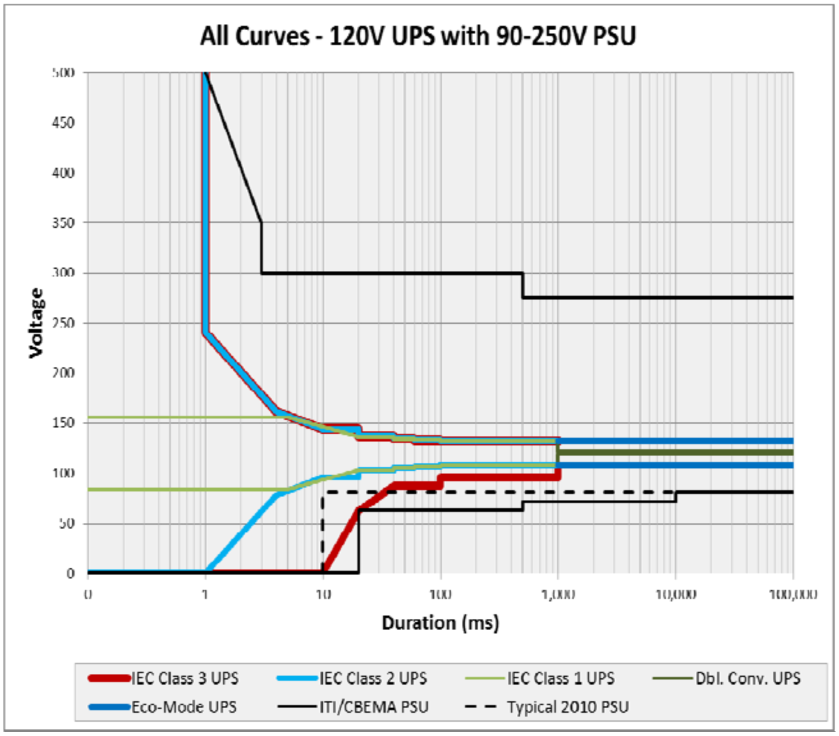


Figure C1. 120V UPS with 90-250V PSU

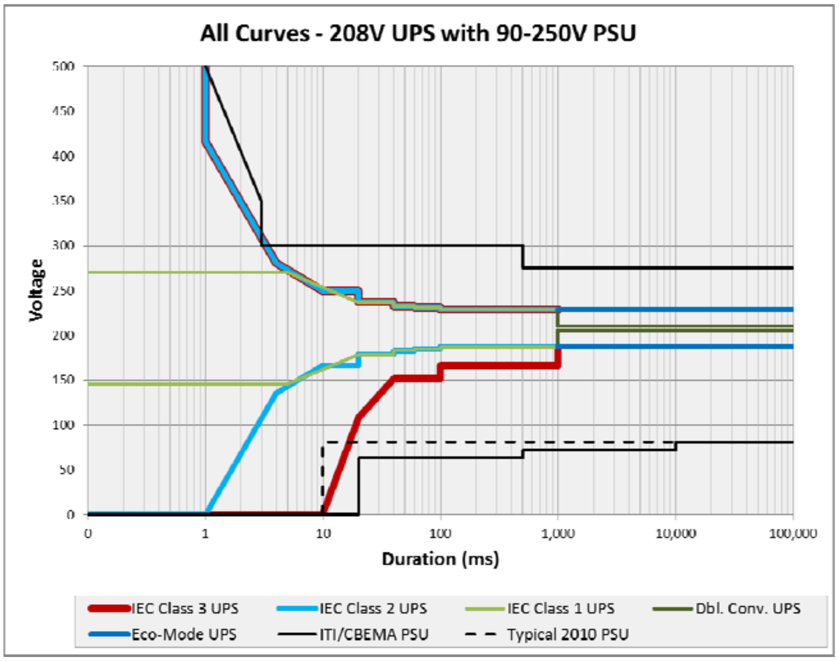


Figure C2. 208V UPS with 90-250V PSU

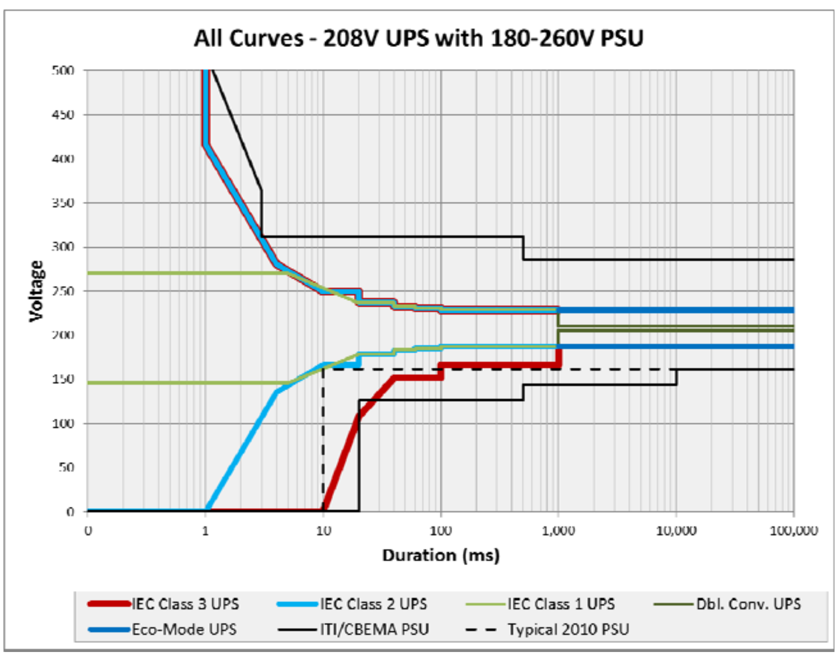


Figure C3. 208V UPS with 180-260V PSU

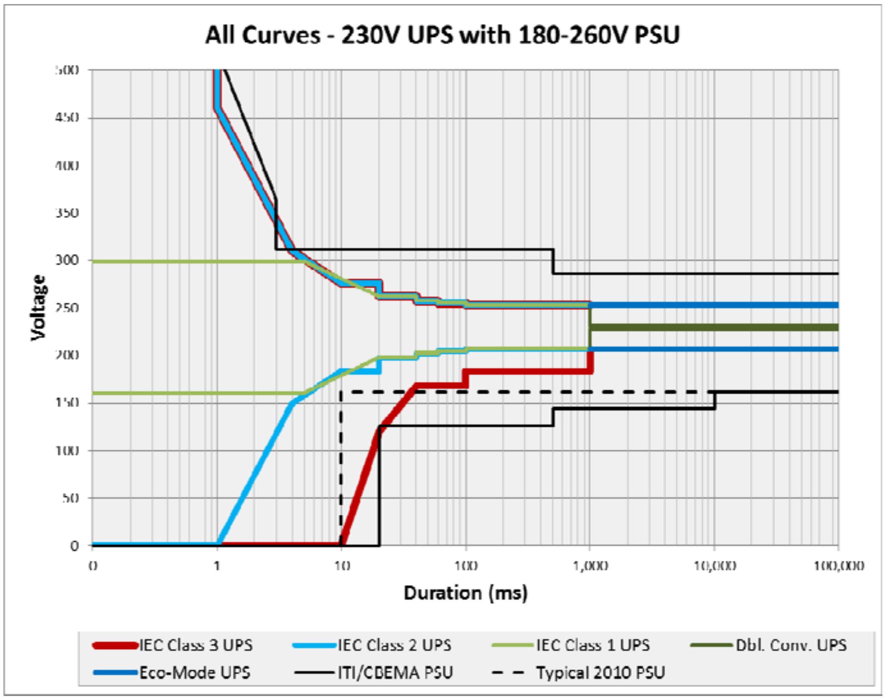


Figure C4. 230V UPS with 180-260V PSU

Appendix D: Detailed Guide of Static Transfer Switch Parameters Important to Power System Performance

A static transfer switch (STS) typically will transfer automatically to the “better” of two available power sources. Although all of the STS parameters are important to the power system performance, the most important user-adjustable set point is the voltage of the sources. Voltage set points are based on values in relation to the nominal voltage. Under-voltage (UV) refers to the amount of voltage or percentage below the nominal voltage. Over-voltage (OV) refers to the amount of voltage or percentage over the nominal voltage. The following is a summary of the typical STS voltage set points:

- **Fast UV setting (%):** If the voltage drops below this set percentage of the nominal voltage, the STS instantly transfers from the current source to the opposite source.
- **Slow UV setting (%):** If the voltage remains at this set percentage below the nominal voltage for the period of the slow detection delay, the STS transfers from the current source to the opposite source.
- **OV setting (%):** If the voltage exceeds this set percentage of the nominal voltage for the period of the OV detection delay, the STS transfers from the current source to the opposite source.

Note that the STS identifies the source voltage excursions as fast or slow depending on the amount of the voltage excursion. This approach is best explained by Figure D1 below, which shows a hypothetical source voltage (RMS) over time and the times at which the source voltage has deviated beyond the allowed tolerance. A source voltage that remains within the slow voltage window is considered a “good” source from a voltage standpoint. Voltage excursions above or below the slow window (slow OV or slow UV) may indicate that the source is degrading or experiencing a load transient, and, depending how long the aberration persists, the decision to transfer is delayed by a “SLOW DELAY” timer. For example, a site’s typical load transient duration may not initiate a transfer since the disturbance is substantially shorter than the transfer time delay.

The fast window levels are set out farther from the nominal voltage than the slow window on the premise that an excursion past this level will most likely start affecting the load quickly. In the case of voltage disturbances that exceed the fast window levels, transfer is immediately initiated, with only minimal delay as set by the “FAST DELAY” timer. The FAST DELAY timer determines the delay of transfer command due to the source exceeding the FAST over/under voltage set point, while the SLOW DELAY timer determines the delay of transfer command due to the source exceeding the SLOW over/under voltage set point.

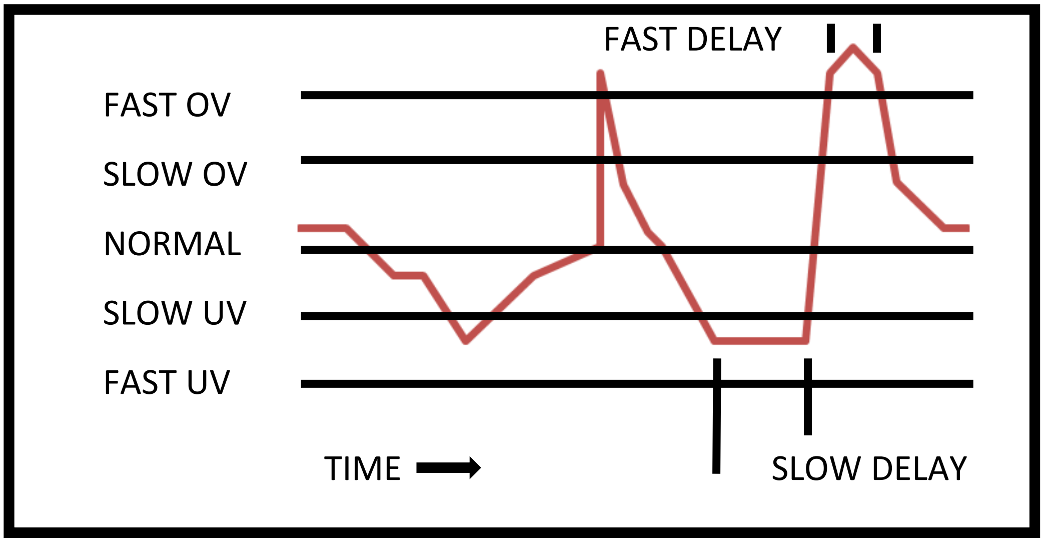


Figure D1. STS transfer times

Table D1 below shows typical STS factory and user settings. As noted above, some STS settings may require additional research. (Fast UV delay is not listed, but it can be as low as 1 ms.) A 1-ms fast UV setting will produce unneeded transfers in response to normal Eco Mode UPSs with transfer times greater than 1 ms; it is acknowledged that some of the fastest Eco Mode UPSs require a downstream STS fast UV delay of 2 ms to avoid unneeded STS transfers.

For voltage transfers, both the Eco Mode UPS and the STS need to operate without unnecessary transfers back and forth because of primary source operation close to one of the STS thresholds. The performance objective is to discourage unnecessary transfers or oscillating between the sources. As such, some level of hysteresis is required in the STS, in the form of voltage percentage either above or below, before it switches back to the other mode. Site configurations of external downstream static switches need to have some additional consideration for UPSs in Eco Mode. The static switch may see a load interruption and try to switch unexpectedly, or the STS may interpret a UPS Eco Mode-to-normal transfer as a load transient. Eco Mode plus static switch time must be coordinated so there is no unnecessary switching. Users can "desensitize" the static switch mode to make it compatible, as the factory default is not necessarily what is best for every scenario. Some level of qualification is needed for the STS; it should not be so short that when Eco Mode turns on, the static switch flips. The overarching objectives of a user's Eco Mode UPS and STS tests should be to:

1. Set up the Eco Mode UPS and STS so that they are compatible
2. Make sure STS and UPS transfer times are less than 10 ms

Source frequency is another quality-defining factor, which a user can adjust to fit site conditions. The over-frequency (OF) and under-frequency (UF) window is normally set to envelop the utility frequency deviation tolerance or the load's sensitivity requirements. Excursion beyond the OF/UF window normally will initiate an immediate transfer.

Table D1. Typical STS factory and user settings

Setting	Range	Factory Default	Additional Info
Fast UV (%)	-10 to -30% of nominal voltage rating	-20%	Set in increments of 1%
Slow UV (%)	-5 to -20%	-10%	Set in increments of 1%
Slow UV Detection Delay	1 to 60 cycles	5 cycles	Units: line cycle
OV Setting (%)	+5% to +20%	+10%	Set in increments of 1%
OV Detection Delay	1 to 255 cycles	3 cycles	Units: ¼ line cycle

ELEMENTS OF ANY ECO MODE-TO-STS COMPATIBILITY TEST REGIMENT

The Green Grid recommends that some level of testing be completed in order to confirm compatibility of an Eco Mode UPS with the downstream STS. As covered above, the STS contains any number of power quality parameters in its active monitoring of the power quality of the two sources. While a focused analysis and review of the parameters is most important, in an Eco Mode UPS and STS application, it is likely that the extent to which all of the STS parameters combine would remain uncertain without some level of testing. Any Eco Mode UPS-to-STS compatibility test regimen should include the bulleted elements below and should treat the Eco Mode UPS and STS as a system. (The same is true when applying a double conversion UPS to an STS.)

- Test the compatibility of the UPS and STS during a variety of simulated conditions while the UPS is operating in Eco Mode and Normal Mode, including:
    - Manually and automatically initiated transfers to and from Eco Mode
    - Load steps and other load transients, including overload
    - Eco Mode UPS input source disturbances, including outages, voltage sags, voltage surges, and frequency slew
    - System response to faults both at the load and at the UPS input source

In practice, the key evaluation is determining the STS detection times and the needed adjustments to key STS detection times. The extent to which those detection times need adjusting and the ease with which they can be adjusted depend on the Eco Mode UPS transfer characteristics and the STS design. As mentioned in the preceding discussion, one of the key STS settings to focus on is fast UV delay.

Appendix E: Power Section of the Data Center Maturity Model (DCMM)

The Green Grid's DCMM Power Section[5] includes the following recommendations regarding Eco Mode UPSs:

- **Level 1 (implementable for most data centers today):** Eco Mode UPS if applicable to business type
- **Level 3 (often a future step for most data centers):** Eco Mode UPS that works for all business types

This Eco Mode UPS white paper addresses Level 1.

[5] www.thegreengrid.org/Global/Content/Tools/~/media/Tools/DCMM%20-%20Power.ashx