WHITE PAPER

UPS Battery Backup Technologies and Power Quality Issues

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Abstract

The AV community is becoming more aware that a solid power foundation is necessary for their equipment to work properly, be available for their customers to use, and reduce costly service calls. Through the use of power monitoring devices, AV technicians are seeing firsthand that power quantity is not the same thing as power quality. Even if power is available, it may not be the low-distortion/low-noise 120 Volt/60 Hz sine wave we expect to be distributed within homes and commercial buildings.

Electrical Power is generated only milliseconds before it is used and travels through hundreds of miles of exposed transmission lines before it is distributed through a labyrinth of wires within a structure. Either at the power generation source or during the transmission and distribution process, disturbances such as Voltage Surges, Voltage Fluctuations, Noise, Neutral-Ground Voltages, Voltage Sags, Momentary or Long-term Dropouts and others are introduced. These disturbances affect electronic equipment in a variety of ways.

	Immediate End of Life	Premature End of Life	Lock-Ups/ Quality Issues
Voltage Surge	✓	✓	✓
Over Voltage	✓	✓	
Under Voltage		✓	✓
Noise			✓
N-G Voltages			✓
Voltage Sags		✓	✓
Power Loss			✓

Table 1 above breaks down the effects of power disturbances on electronic equipment into (3) categories. Immediate End of Life is defined as one single disturbance event permanently damaging a piece of equipment. This category is easy to visualize if you have ever witnessed a direct lightning strike. Premature End of Life is defined as a piece of electronic equipment not lasting to the end of its theoretical lifespan. Failure analysis techniques used in the electronics design industry can estimate how long an electronic product will last before one or more components are likely to fail. If products in the field do not last as long as their theoretical lifespan, this is referred to as Premature End of Life. While Lockups may not always be caused by damage to an internal component, they are still a nuisance to the end user because they render the electronic equipment useless until the equipment is power cycled or rebooted.

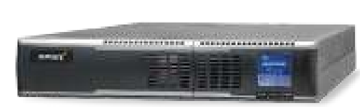
Other white papers in this series take a closer look into the sources of power disturbances and how improvements in power distribution wiring can solve these electrical problems. However, in some cases the improvements to the power distribution system are not feasible leaving few options for the AV professional to improve the power condition.

In this white paper, we will discuss the differences between Uninterruptable Power Supply (UPS) technologies, features to look for in UPS's, and how certain types of UPS's can be used not only for backup but can actually solve a variety of power quality issues.

1.0 UPS Basics

Traditionally, the UPS has been a tool to provide back-up electrical energy when the main power source (usually from the power utility) fails or is for some reason unavailable. When electrical power goes out, it is most likely due to a failure in the power transmission or distribution network.

The UPS sits between the power source and the electrical load. This could be a large, high capacity unit that is near the electrical service entry point to the structure, our could be a smaller, low capacity unit that is positioned at the point-of-use. A smaller UPS is plugged into an electrical receptacle, and the electrical load is then plugged into the UPS.



All UPS technologies have 3 basic building blocks in common:

- AC/DC Converter or Battery Charger
- DC Battery
- DC/AC Converter or Inverter

Inside all UPS's is a DC Battery used for energy storage. Electrical energy from the grid is AC or alternating current. AC power is somewhat easy to generate, but AC power cannot be stored. Remember that the AC power we use every day is generated at power plants across the world milliseconds before it is consumed.

In order to store electrical energy inside a UPS, the AC power from the grid is converted into DC or direct current and batteries inside the UPS are charged up to store the electrical energy. The AC to DC conversion is performed by an AC/DC Converter or Battery Charger.

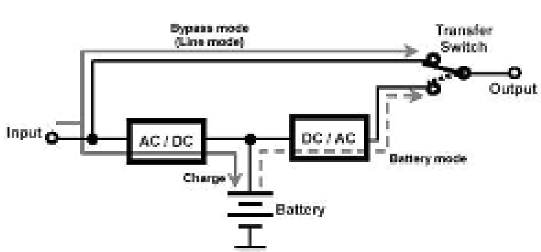
When the grid power is removed, the DC electrical energy inside the batteries is sent to a DC/AC Converter or Inverter which changes DC electrical energy back into AC electrical energy.

The above description is valid for all UPS sizes and technologies. All UPS's take AC energy from the grid, turn it into DC energy so it can be stored, then turns or inverts the stored DC energy back to AC energy when the grid voltage is not available.

However, there are different UPS technologies/topologies that accomplish this task.

2.0 UPS Technologies – Standby UPS

The most basic and least expensive UPS technology is the Standby UPS. In addition to the Battery Charger, Batteries, and Inverter that all UPS's contain, the Standby UPS also contains a Mechanical Relay. The Mechanical Relay is used to switch the OUTPUT between the grid voltage at the INPUT, and the DC/AC Converter or Inverter output.



During normal operation (normal level of grid voltage is present at the UPS's input) or Bypass Mode, the relay is in position to transfer the incoming grid voltage to the UPS output terminals. During this time, the Battery Charging circuit uses some of the incoming grid voltage to charge the batteries. Depending on the capacity of the batteries, the battery depletion level, and the designed charging current in the Battery Charger, it may take many hours to fully charge the UPS's internal batteries. (Note that during charging, the UPS is acting as a load on the branch circuit. This load should be taken into consideration when performing load calculations for your system).

When the grid voltage falls below a threshold or is cut completely, a circuit inside the UPS senses the low/no voltage condition and switches the relay to allow the AC output from the Inverter to be sent to the UPS output terminals.

On the surface, it seems like the Standby UPS is all one needs to provide backup AC energy when there is a problem with grid provided power. However, there are many drawbacks to Standby UPS technology:

- Slow Reaction to Voltage Fluctuations - Since a Mechanical Relay is used to connect the incoming grid voltage to the output of the UPS during normal operating mode, any transient voltage fluctuations such as voltage sags or voltage swells are passed right through to the connected electronic devices at the output of the UPS.

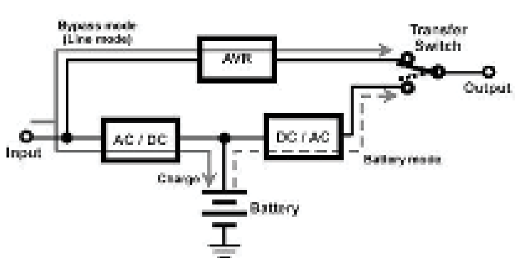
- Relay Switching Artifacts – A Mechanical Relay takes between 4mS-10mS to switch over to Inverter power once the incoming grid voltage is cut. Depending on the design of the connected electronic equipment, this amount of drop-out could be enough to turn OFF the equipment, which is what you are trying to prevent in using the UPS in the first place. In addition, most Standby UPS's do not make the switch at an AC zero-crossing. 120V AC voltage varies between +173V and -173V passing through 0V every half cycle. If the Mechanical Relay were to switch when the Inverter output voltage was at a peak, an instantaneous change from 0V to +173V would be seen by the connected electronic equipment. This instantaneous change is known as a transient and is a category of surge which is detrimental to the long-term health of your electronic equipment. Not switching at a zero crossing also allows Current Inrushes to be pulled by the electronic equipment.

- Inverter AC Output Quality – Since Standby UPS's are the low-cost options in the UPS world, costs are greatly reduced by not providing a true sine wave output when in backup mode. Look for descriptions such as "Square Wave", "Approximated Sine Wave", "Simulated Sine Wave", or "Step Wave" as a sign of a low quality, high harmonic distortion output voltage. Sensitive AV equipment such as control systems, DSP based devices, and high-performance audio/video gear may not work to their fullest potential when powered with this low-quality electrical power source.

- Limited Backup Time – Again, in order to cut costs, the Inverter section of Standby UPS's not only produce poor quality sine waves, they are sometimes designed with poor quality components making them unable to perform the DC to AC inversion for long periods of time. Therefore, many Standby UPS's do not have the ability to connect external battery extensions. Extra battery capacity means the possibility of a longer ON time, which creates more heat and a shorter life expectancy of the UPS.

3.0 UPS Technologies – Line Interactive UPS

As an improvement to the Standby UPS's an Automatic Voltage Regulator (AVR) is sometimes added to a Standby UPS making a new UPS category called Line Interactive UPS. It gets its name from the output interacting with the incoming grid voltage or LINE voltage during normal operation or bypass mode.



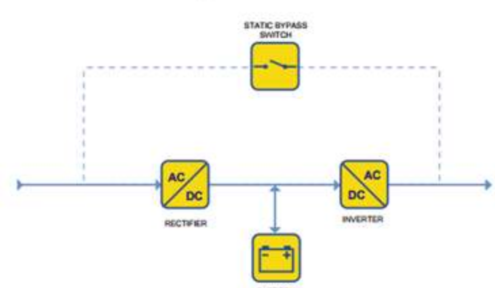
During normal operation, the AVR will make course adjustments to the incoming LINE voltage to output a voltage within a range of +/-10% of the nominal or target LINE voltage. This target output voltage range varies from manufacturer to manufacturer, but the overall goal is to adjust the output voltage to a level as close to NOMINAL as possible. The is usually accomplished by installing a Buck/Boost Transformer. A Buck/Boost Transformer is a special type of transformer that has multiple output taps. A 1:1 transformer has a single output tap. The circuit voltage goes in the primary windings, and the same circuit voltage is present at the output tap. In a Buck/Boost transformer, multiple output taps are provided for -20V, -10V, +10V, +20V in addition to the 1:1 tap that outputs the same voltage that is seen at the input.

A relay network is used to connect one of the taps to the UPS output. If the incoming grid voltage is, for example, 100V (which is down 20V from the target voltage of 120V in this example), the +20V tap of the Buck/Boost Transformer is chosen. If the incoming grid voltage is 130V, the -10V is chosen, all in order to set the output voltage as close to 120V as possible.

Since Line Interactive UPS's from some manufacturers are Standby UPS's with Buck/Boost AVRs added, the drawbacks of Line Interactive UPS's are the same as Standby UPS's. However, it should be noted that in the competitive UPS marketplace, some UPS manufacturers offer Line Interactive UPS's with higher quality inverters and faster switching capabilities. These products are an improvement over traditional Line Interactive UPS's in that during backup mode, the output is a true sine wave and not an approximated sine or square wave.

4.0 UPS Technologies – Double Conversion / Online UPS

Double Conversion / Online UPS's are a giant step above Line Interactive and Standby UPS technology. The name Double Conversion refers to the full-time operation of taking the incoming AC grid voltage, converting it into DC (to both charge the batteries and provide power to the Inverter section) and converting the DC back into AC voltage.



This AC->DC->AC function allows for two big advantages over other UPS technologies.

First, since high quality Inverters are used, precision voltage regulation can be achieved. Most Online UPS's can output a very low distortion true sine wave with +/-1% accuracy for both voltage and frequency with the input varying +/- 20%-25%. The acceptable input voltage range will vary by manufacturer. In addition, since the regulation is electronic, its reaction time to voltage fluctuations is instantaneous. This is a key difference that allows Double Conversion / Online UPS's to be used as a tool to cure voltage fluctuation issues in addition to its primary function of providing backup energy when grid voltage is down.

In fact, some system designers are including Double Conversion / Online UPSs in their designs for their voltage regulation attributes, and not necessarily for their power backup capabilities. In both commercial and residential applications, it is common that the customer or building manager is reluctant to improve the electrical service either for cost or feasibility reasons. In these cases, installing a Double Conversion / Online UPS in your AV equipment rack is less cost and has much less impact on the customer than upgrading the electrical service.

The second big advantage Online UPS's have over the other technologies is that there are no switching artifacts when switching to backup. Unlike the other technologies discussed above which use a mechanical relay to choose between grid voltage and inverter voltage, Online UPS's are always running off the Inverter. When the grid power to the AC/DC Converter is cut, the energy stored in the battery takes over seamlessly with no interruption in the AC output going to the connected equipment.

Double Conversion / Online UPS's pair well with generator backup systems. On-site generators are indispensable tools that provide long-term electrical energy when the grid or distribution system fails. However, they too have some drawbacks.

When the grid voltage is cut, an on-site generator takes 30 seconds or longer to detect the failure, start up and reach rated speed, then switch over to generator power through its transfer switch. This process can be not only a nuisance since every piece of equipment in the facility has lost power during this process, but at switchover a voltage transient is created which is harmful to all electronic equipment downstream of the generator. In addition, if the generator is not maintained properly, the quality of the generated sine wave may not be ideal.

Using a Double Conversion / Online UPS after an on-site generator's transfer switch ensures that all AV equipment stays ON and that no electrical disturbances are passed through during switch over to/from generator power.

An additional attribute to Double Conversion / Online UPS's is that since the Inverter stage is designed to be ON full-time, manufacturers provide the ability to add additional battery capacity which can greatly extend its backup time. On the other hand, since the Inverter circuitry is ON full-time and is most likely supplying large amounts of current (and thus creating heat), they usually include forced air fans to keep them cool. It is important that you include heat contributions of your UPS in your rack BTU calculations and position them in locations where fan noise will not be a problem.

5.0 Isolation Transformer

Some UPSs will include an Isolation Transformer on the AC output. The isolation transformer is usually positioned right before the UPS output so that it is in line in both bypass and backup mode. An isolation transformer not only galvanically isolates (transfers energy through magnetic coupling but has no physical electrical connection) the output from the rest of the electrical system, it also establishes a new NEUTRAL to GROUND bond or connection that eliminates any NEUTRAL to GROUND voltage or noise.

All electrical distribution systems within a structure after 1970 that conform to the National Electrical Code are required to have (3) wires connected to the receptacle: LINE, NEUTRAL, and GROUND. The LINE and NEUTRAL conductors are the pathways that allow current to flow to and from the electrical load. The GROUND conductor was added as a path for fault current to safely flow to ground in the event of an electrical short inside electrical load. Having this path for fault current greatly increases the likelihood that the circuit breaker will trip during a fault condition. At the breaker panel, NEUTRAL and GROUND are terminated to the same electrical buss bar, but at the receptacle, they are purposely separated. In situations where the wire runs are long (making them more resistive) and large currents are flowing through the NEUTRAL wire to and from the electrical loads, a voltage between NEUTRAL and GROUND can be measured at the receptacle. This NEUTRAL-GROUND voltage can cause lockups in sensitive microprocessor based electronic equipment.

Since NEUTRAL and GROUND are connected within the breaker panel, some are tempted to connect or bond NEUTRAL to GROUND at the receptacle in order to eliminate N-G voltages. However, this practice violates both UL and National Electrical Code standards. The only approved method for establishing a NEUTRAL to GROUND bond downstream of the breaker panel (and thus eliminating errant voltages and noise at the point of use) is to utilize an Isolation Transformer.

Using a UPS with an Isolation Transformer establishes and new N-G bond near the electronic equipment greatly reducing the electrical noise floor across all frequency bands that is powering your AV equipment. N-G AC voltage and electrical noise leads to lock ups in sensitive microprocessor based electronic equipment.

6.0 Specifying the correct UPS

The three main specifications that must be considered in choosing a UPS is the required Load Wattage, the available Supply Voltage, and the desired Backup Time.

The Load Wattage can be determined by looking at the power consumption of the equipment you intend to connect to the UPS. Alternatively, if all equipment is on a common power strip, a power meter can be utilized to measure the actual load. When using this method, measurements should be taken over time to reflective of the different modes of system operation that consume different amounts of electrical power.

The total wattage of all equipment (either calculated or measured) should fall below the maximum deliverable wattage of the UPS. A good rule is for the maximum wattage of the equipment to be 80% or less than the maximum deliverable wattage of the UPS.

Wattage rating of the UPS should not be confused with Volt-Amps or the VA rating of the UPS. The deliverable Wattage of a UPS is its VA rating multiplied by its Power Factor (PF). In many cases, the UPS manufacturer will list its deliverable Wattage in the table of specifications. The highest PF attainable is 1.0 meaning that a 1000VA UPS can deliver 1000 Watts. However, there are many UPS's on the market that have PF ratings well below 1.0. It is imperative that the Wattage rating be used to select a UPS and not its VA rating.

In addition to considering steady-state Load Wattage (or conversely Load Current), it is important to check how much Overload or Inrush Current that the UPS can supply. All electronic equipment pulls a large inrush current when turned ON, and this higher than normal current must be supported by the UPS, especially for Double Conversion / Online UPS as they are regenerating the power locally and is the full-time source of power to the electrical load.

Supply Voltage must also be considered when choosing a UPS. Since Wattage = Voltage x Current it is sometimes necessary to supply a higher voltage to the UPS in order to deliver the rated power. This is usually not a concern for Standby and Line Interactive UPSs as during normal operation, the input voltage is transferred to the output through a relay. So, for 120V output applications, the input voltage is also 120V. However, for Double Conversion / Online UPSs where the AC voltage is converted to DC, then back to AC full time, it is common on higher power UPSs to require a higher input voltage. In North America where most AV equipment works off of 120V, some Large Format UPSs will require 240V Split Phase (2 opposite 120V phases) or even 208V Three Phase as the input voltage in order to supply the rated power to the output. More sophisticated Large Format UPS systems will also incorporate an Isolation Transformer to allow for both 120V and 240V outputs simultaneously.

The Backup Time of a UPS is dependent on the actual Load Wattage being consumed by the connected equipment. In many cases, either a table or graph is provided by the UPS manufacturer showing the amount of up-time that can be expected as a function of the percentage of the maximum load. In general, one can expect anywhere from 3 to 5 minutes of backup time at full load with fully charged internal batteries. However, this varies from manufacturer to manufacturer. Backup time increases somewhat proportionally as the load current decreases.

Note that some UPSs have optional extension battery cabinets to increase the total backup time. The maximum number of cabinets allowed will vary depending on the quality of the inverter. Higher quality inverters are designed to stay ON at full power for longer periods of time, thus the manufacturer will allow more extension battery cabinets to be connected. The absence of extension battery cabinets as an option may be an indication of a cost-reduced inverter design that may not have longevity. This is usually the case with Standby and some Line Interactive designs.

Another consideration when choosing a UPS is its function when the batteries go bad. Batteries, no matter the technology, will eventually go bad. Some designs will turn OFF the AC output to indicate that the batteries are bad and not available to provide backup functionality. This can be a huge problem in AV applications where a system is down until a technician can be scheduled and dispatched to replace the batteries. Other manufacturers design the UPS to stay ON when the batteries go bad and will indicate the loss of backup functionality by either an audible alarm or through SNMP or other network communication protocol.

7.0 Installation Considerations and Positioning of a UPS in an Electrical Distribution System

In the AV community, the most common form factor for a UPS is the 19" rack mount version. This normally comes in a 2RU height if standard technology Valve Regulated Lead Acid (VRLA) batteries are used. Other battery technologies allow for 1RU designs with varying output wattage capabilities.

VRLA/19 Inch/2RU Models will range from as low as 600 Watts to around 3000 Watts. In general, 1500-Watt units and below can run off a standard 15A branch circuit, while units in the 2000- to 2200-Watt range will require a 20A branch circuit. Higher output wattages will require higher input power and may require a hardwired connection of either 120V or 208-240V at either 20 Amps or 30 Amps. These UPSs are installed in the equipment rack and depending on the electrical load of the rack, can provide backup for the entire rack.

Large Format or freestanding UPS designs are available for higher load wattage applications. These designs are usually hardwired (by a certified electrician) both on the input and output while some designs offer the option of a receptacle panel on the UPS itself. The output from a Large Format UPS is wired to a "critical load" circuit breaker panel separate from non-UPS backed loads. Branch circuits powering AV and other critical loads are then wired to this critical load breaker panel. While it is ideal to include Large Format UPS in the electrical system design from the start, it is quite common to install one in an existing electrical distribution system. UPS manufacturers should provide resources to assist you in adding a UPS to your system.

When UPS technology is used, the UPS is effectively now your power source, so some considerations should be made in advance in the event that the UPS fails. When standard INPUT/OUTPUT connectors (i.e. NEMA in North America or Schuko and others in Europe) are used on the UPS, bypassing the UPS is simple. The technician can simply unplug the electrical loads from the UPS and plug directly into the wall receptacle using a power strip. However, if the UPS is hardwired, bypassing the UPS will require an electrician to be scheduled which means a long period of downtime for your system. Therefore, it is strongly recommended that whenever a hardwired UPS is used, to include a Maintenance Bypass Switch. This will allow for quick and easy bypassing of the UPS by the service technician while the UPS is repaired. Note that if the input to the UPS is 208V-240V and the load devices are 120V, that a special bypass switch incorporating a step down transformer must be used.

8.0 UPS Maintenance

In most cases, a UPS is included in a system to provide backup when grid AC power is down. Therefore, one must rely on the UPS to be available 24/7/365. The most vulnerable component of a UPS system is the battery. As batteries charge and discharge, they lose their ability to store and deliver energy. In addition, battery life will decrease if in a higher temperature environment than they are rated for.

In mission critical applications where confidence that the UPS' backup functionality will always be available; service organizations will offer battery maintenance service as part of their managed service offerings. For instance, service organizations will use a 5-year expected life battery, but change them out on a 3- or 4-year rotation. This greatly increases confidence that the UPS will be able to provide backup power when called upon to do so.

9.0 Battery Technologies

By far, the most common battery formula used in UPS's is the Lead-Acid battery. One particular version, Valve-Regulated Lead Acid (VRLA), has many positive attributes for use in UPSs. It is very common and therefore easily obtained, relatively low in cost, and is maintenance free. However, one positive attribute that is often overlooked is that it is 99% recyclable.

The lifespan of VRLA batteries depends on how many times they are put through the charge-discharge cycle and the ambient temperature, but for normal, indoor UPS use, they should last about 3-4 years. VRLA batteries come in a variety of formulations. Some are designed for longer life or are rated for use in higher ambient temperature environments. One negative attribute of VRLA batteries is that their Energy Density is not as high as other technologies making them physically large and heavier.

Another battery technology becoming more popular in UPSs is Lithium Iron Phosphate or LiFePO. This battery formula is common in electric vehicles and whole-house energy storage systems. It is considerably more expensive than VRLA but has 4 times the energy density by volume than VRLA technology. This means that a LiFePO based systems can have the same backup time but with ¼ of the physical battery size. Other advantages LiFePO technology has over VRLA include a longer lifespan, a greater number of charge-discharge cycles, and require a shorter time to charge the battery to 100%. However, these last two attributes are not as important for most UPS applications in the AV space. Unlike automotive and whole-house applications in which the battery is partially or completely discharged on a daily basis, AV UPS batteries may get called into duty for the occasional power outage. And, there is usually plenty of time between outages to ensure a full charge on the batteries. Therefore, VRLA battery technology works well for most AV applications.

10.0 Conclusion

Power company and University Research studies estimate that failures and disturbances in our electrical power delivery system account for tens of billions of dollars in business downtime each year. While originally used only for providing backup power when grid power is unavailable, Double Conversion / Online UPSs are being used in AV systems for their precision voltage regulation capabilities as well providing continuous, transient free power during switch over in systems using a backup generator. Inclusion of Isolation Transformers in UPSs not only isolates your AV system from any upstream electrical pollution but re-establishes the NEUTRAL-GROUND bond for an almost immeasurable electrical noise floor. Precision voltage regulation and N-G noise/voltage elimination allows for systems to be available for their intended use, reduces the overall service burden on AV dealers, and greatly extends the life of today's sophisticated electronic equipment.