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POWERING HEALTH: UNINTERRUPTIBLE POWER SUPPLIES

Uninterruptible power supplies provide backup power, protecting equipment from damage in the event of grid power failure.

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POWERING HEALTH

This document is provided as part of USAID's Powering Health toolkit. Health-care facilities require electricity to maintain perishable supplies and power life-saving technologies. Energy is essential for preventing child and maternal deaths, controlling the HIV/AIDS epidemic, and combating infectious diseases and pandemics.

Reliable electricity can mean life or death for patients in developing country health-care facilities. However, many of these facilities have little or no access to reliable electricity. USAID supports partner countries in understanding the energy needs of their health-care facilities over the long term. This challenge requires local capacity for careful planning, a commitment to maintenance, and dedicated funding.

USAID uses its experience at the nexus of the health and energy sectors to help international development practitioners and health-care administrators design programs that meet the energy needs of health-care facilities. By applying international best practices and lessons learned, stakeholders can help ensure that health-care facilities are able to power standard appliances, such as lights, life-saving equipment, blood and medicine refrigerators, ventilators, laboratory diagnostic tools, and technology that monitors patients' vital signs.

INTRODUCTION

An uninterruptible power supply (UPS) is a type of device that powers equipment, nearly instantaneously, in the event of grid power failure, protecting the equipment from damage. UPS systems vary significantly in their design and functionality, affecting the amount of time they can power equipment, their ability to improve power quality, and their cost.

Data servers, computer systems, industrial settings, and laboratories commonly use UPS systems. Because a UPS protects equipment, it is appropriate for any situation where electrical loads may be sensitive to power loss or other power quality issues. For example, UPS systems are commonly used for computers and servers because power loss to these loads may result in loss of data or component damage.

Likewise, many types of medical and laboratory equipment are sensitive to interruptions in power supply or poor-quality power. For many health facilities in developing nations, grid power is unreliable or of poor quality, resulting in scheduled or unscheduled power loss for large portions of the day or fluctuations in grid voltage that may adversely affect equipment. In addition, power loss in hospitals and laboratories leads to downtime, affecting the quality and availability of critical services. Thus, health facilities often employ backup power systems to meet electrical loads in the case of power loss from the grid.

UPS systems serve two main purposes: (1) to provide backup power as quickly as possible in the event of power loss and (2) to offer some degree of protection from power quality issues that may damage equipment. UPS systems fulfill these goals to varying degrees depending on their design and features, which ultimately affect their costs.

Meeting power supply challenges at health facilities is important to ensuring quality health-care services. This paper provides a discussion of some of those challenges and an explanation of the appropriate uses of UPS systems and the differences between them and similar devices. Lessons learned and best practices regarding the use of UPS systems in health facilities with poor grid access are also presented.

TYPES OF UNINTERRUPTIBLE POWER SUPPLIES

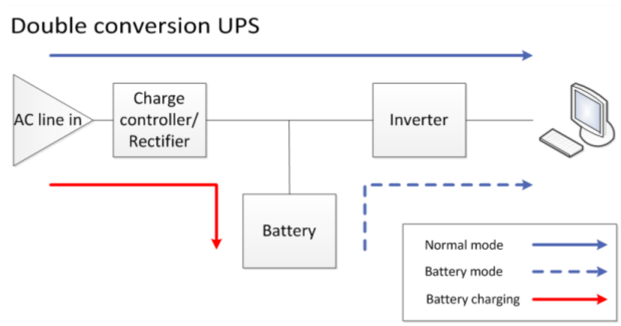
UPS systems provide a comprehensive, modular solution to protecting sensitive equipment from power supply problems. UPS systems and other similar equipment commonly address a variety of power quality issues. UPS systems come in several configurations that offer different levels of protection for a range of costs. Following is a brief description of each configuration, the power-quality issues it is built to solve, and a critique of its most important features.

DOUBLE CONVERSION OR ONLINE UPS

A double conversion or online UPS system provides full protection and electrical isolation from power quality issues and ensures an instantaneous source of backup power in the event of power loss from the grid.

This type of UPS offers the highest level of protection by fully isolating connected loads from grid power. Alternating current (AC) power from the grid is converted into direct current (DC) power before being converted back into AC power again. This AC power output has perfect voltage and frequency characteristics, therefore addressing all potential power quality issues. Furthermore, internal capacitors store energy throughout the conversion process, providing a seamless transition from grid to battery power.

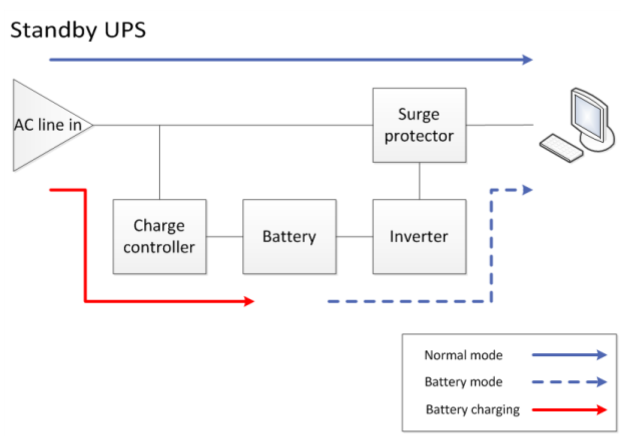
The basic configuration of a double conversion UPS is shown here. This figure presents the essential power conversion components, but a number of other components are involved in the process, including capacitors, transformers, and bypass circuits.



These systems cost more than either standby or line-interactive UPS systems but offer superior protection. A good deal of energy is lost through the double conversion process, however, so the efficiency of these systems is less than that of the other UPS options.

STANDBY OR OFF-LINE UPS

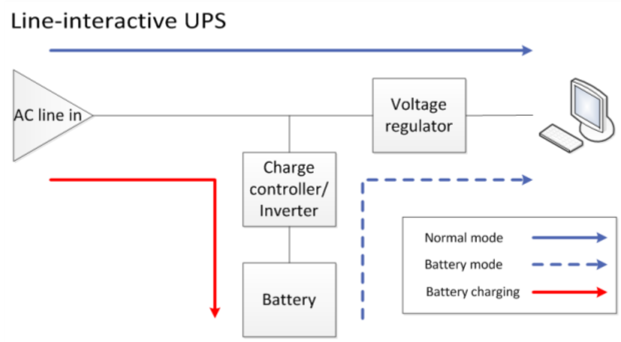
In a standby or off-line UPS system, the load is supplied power directly from the grid, with no power conditioning or protection other than basic surge protection or, in some cases, noise filtering. When grid power is lost, power is supplied from the system's internal battery.



This is the least expensive type of UPS system and provides the lowest level of protection. Furthermore, inexpensive models often produce a square wave rather than a perfect sine wave when converting DC battery power to AC power, which could be damaging over time to some sensitive equipment.

LINE-INTERACTIVE UPS

Line-interactive UPS systems offer another level of protection over the basic standby system. These systems provide a degree of power conditioning by regulating the voltage of the incoming grid power. This functionality does not provide perfect "clean" power or isolate loads from all power quality issues, but it does solve basic issues such as undervoltage and overvoltage, which can be common.



As the second-tier option for UPS systems, line-interactive UPS systems have all the functionality of a standby UPS plus some basic voltage regulation.

Each of these UPS technologies is designed to meet the power quality and backup supply needs of electronic equipment in a variety of applications. Generally, double conversion and line-interactive systems are geared toward business and industry, while standby units are intended for the average consumer computer system. The following table compares the three main types of UPS by their typical range of size, efficiency, and power-conditioning capabilities.

COMPARISON OF UPS TYPES

UPS TYPE	CAPACITY (kilovolt-ampere (kVA))	NORMAL MODE EFFICIENCY	TYPICAL POWER CONDITIONING
Standby	0.3–1.5	97–99 percent	Surges, Noise
Line-interactive	0.4–5	95–99 percent	Surges, Noise, Voltage
Double Conversion	0.7–20+	85–97 percent	Surges, Noise, Voltage, Harmonics, Frequency

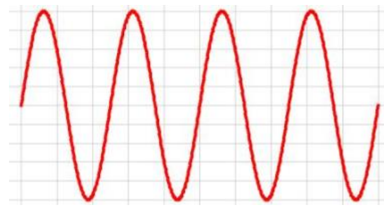
Another important distinction between UPS units is how they are integrated into a building circuit—at an outlet or hardwired. Outlet UPS systems plug into existing electrical outlets and, in turn, provide several on-unit outlets to supply supported loads. Hardwired units are wired directly into an electrical circuit; supported loads are plugged into existing outlets connected to that circuit. Outlet systems are typically of lower capacity. Hardwired systems are normally high capacity line-interactive or double conversion units.

Also note that high-end double conversion systems used in data centers and other energy intensive IT applications can have a system capacity of many megawatts (MW). These systems are typically designed and built to purpose; thus, there is no limit to the size and cost of such systems.

The challenge of selecting the right system to meet the demands of a health-care environment is understanding which features are necessary and which are not. These considerations are discussed in the following sections.

POWER QUALITY ISSUES

Power quality refers to the adequacy of a power supply in terms of voltage, frequency, and waveform characteristics. Electrical equipment is designed to use electrical power with certain characteristics such as 12 or 24 volts or, when designed for AC power, 50 or 60 hertz (Hz) frequency. Similarly, power supplied by the grid, or some other source such as a generator or battery bank, is intended to meet a certain voltage level or frequency.



Most power systems, including the grid, operate on AC power as opposed to DC power. AC electrical power is represented by a sine wave, where the current regularly changes direction. The rate of this change in direction is the current's frequency, which is typically 50 or 60 Hz (50 or 60 changes per second).

Electrical equipment is designed to consume power with particular voltage and frequency characteristics, in the form of a perfect sine wave. Power supplies, however, are never perfect, and there are inevitably variations in the voltage, frequency, and waveform of AC electricity. For most common appliances and electrical devices, these variations are acceptable, but some medical and laboratory equipment are unable to tolerate less-than-perfect power due to their complex and sensitive circuitry. While not all power quality problems lead to immediate damage, cumulative effects over time will harm equipment or result in less efficient operation.

One of the major advantages of a double conversion UPS system is to provide perfect power to sensitive loads, like those often found in a health laboratory. Discussed below are a number of common power quality issues, including power loss, that health facilities must be prepared to address to ensure the safety of critical equipment.

POWER INTERRUPTION

A power loss can last anywhere from milliseconds to days, depending on the cause of the interruption. In the event of loss of grid power, many health facilities have some backup power source, typically a generator. Although backup power may be available, it will not be instantaneous, resulting in a brief period of loss of power. Furthermore, generator start-up often produces a spike in voltage. UPS systems protect equipment against such threats, smoothing out the transition from grid to backup power.

VOLTAGE SAG/UNDERVOLTAGE

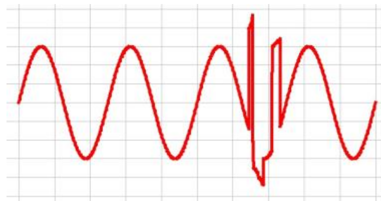
Voltage sag is a decrease in the utility power voltage lasting as long as one minute. This power problem can adversely affect sensitive electronic loads. UPS systems or voltage regulators are needed to address voltage sags.

VOLTAGE SWELL/OVERVOLTAGE

Voltage swell is the opposite of voltage sag; it is an increase in the utility power voltage lasting as long as one minute. Similar to voltage sag, swells can be destructive to sensitive electronic equipment.

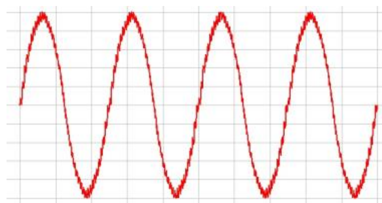
VOLTAGE TRANSIENT/SPIKE/SURGE

A voltage transient is a short, sudden, and sometimes extreme, change in voltage or current. Lightning strikes and other issues in grid operation can cause these types of problems. Sensitive electronics may be damaged, and data loss may result. UPS systems, as well as basic surge protectors, insulate equipment from transients.



NOISE

Noise is characterized as unwanted, random signals in the power supply. Noise is often caused by the equipment connected to an electrical circuit. In most cases, noise is unavoidable, as it is not due to malfunctions but rather anomalies in the way electronic components operate.



HARMONIC DISTORTION

Harmonic distortions are alterations to a pure sine wave. Such distortions are due to nonlinear loads. Computer power supplies are a common cause as well as lighting ballasts and variable speed drives, such as those found on high-efficiency air conditioners. Harmonic distortions can cause overheating of equipment and wiring and efficiency losses.

UPS TERMS

When selecting an appropriate UPS system for health facility applications, it is useful to have a basic understanding of the common terms and features that may be encountered when researching UPS products.

RUNTIME

Runtime is the amount of time the UPS can operate loads on battery power. This depends on the size of battery included with the unit and the availability of battery extension to increase runtime. This figure may range from a couple of minutes to several hours and is usually reported at both full and half load. A lower load results in longer runtime and, as a general rule of thumb, a UPS battery at half load will run three times longer than at full load.

AUTOMATIC DATA NETWORK SHUT DOWN

A useful option when powering servers or computers is automatic data network shutdown. This function automatically shuts down computer equipment safely through the installed operating system, ensuring that all data is saved before the UPS battery runtime is complete.

BATTERY EXTENSIONS

Many UPS systems allow for battery extensions, which are external battery packs that can be connected to the UPS to increase the system's runtime. These battery packs are offered by the UPS manufacturer, so it is important to understand which battery pack models are compatible with the UPS and to ensure that enough battery extensions can be added to meet equipment runtime needs.

DATA PORT

Many UPS systems offer some way to interface, or connect, with other equipment, such as computer or other power equipment. These connections usually come in the form of a USB, RS-232, or other data port. This functionality can be beneficial, for instance, in reporting UPS alarms or other operating data to a central point and in monitoring the performance of the UPS systems.

BYPASS SWITCH

A bypass switch provides a direct connection between the input and output lines of a UPS, circumventing the system's internal components. This feature is important in case the UPS fails or runs out of battery power and is unable to supply any power at all to connected loads. No backup power or power conditioning is available when in bypass mode.

An automatic bypass switch will move connected loads to normal grid or generator power automatically when the UPS fails. A manual bypass switch is used for maintenance purposes, when components need to be repaired or replaced.

DELTA CONVERSION

A delta conversion is a particular form of online UPS that does not perform full double conversion when connected to the grid. Rather than using a rectifier and an inverter, a delta conversion UPS utilizes a transformer and an inverter to produce "clean" power for connected loads, resulting in greater efficiency. Such systems match all of the abilities of a traditional online or double conversion UPS while also being able to do power factor corrections, all with greater efficiency.

EMI/RFI NOISE FILTERING

Electromagnetic interference (EMI)/radio-frequency interference (RFI) noise filtering removes uncontrolled frequency variations common in facility wiring. Noise is generated by other loads on the same distribution system, such as an air conditioner, or from the incoming power grid. Because noise can be damaging to sensitive medical equipment, this feature should be considered important for any health facility UPS system. All double conversion UPS systems filter noise; for standby or line-interactive UPS systems, it is important to ensure that this option is included.

TRANSFER TIME

Transfer time is the amount of time, in milliseconds, that it takes for the UPS to switch from grid to battery mode—the amount of time connected loads will see an interruption in power. For off-line and line-interactive units, transfer times typically range from 4 to 25 milliseconds. Online UPS units should have an instantaneous transfer time, as their internal capacitors allow for in-line energy storage.

COLD START OPERATION

Turning on a UPS before being plugged into the AC line is called cold starting. Under this operation, the UPS will run on battery power only. This function can be useful if a UPS needs to be added during a power outage or to ensure that the battery is working properly.

HOT SWAPPABLE BATTERIES

Hot swapping allows a UPS battery to be replaced without disconnecting the UPS or its connected loads from AC power. If a battery requires replacement, it can be hot swapped without any equipment downtime. If a UPS is not hot swappable, the system should be disconnected before battery replacement.

BATTERY RECHARGE RATE

Battery recharge rate is typically described as the number of hours to complete recharge. If power outages are too long or too frequent to provide adequate time for battery recharging, the life of the battery will decrease and the effectiveness of the UPS will be compromised due to inadequate capacity. External battery packs and a separate battery charger allow for the battery to be recharged more quickly if necessary.

VOLTAGE TRANSFER SET POINTS

In all types of UPS systems, loads are transferred to battery mode if the incoming voltage goes above or below specific set points. In the case of standby and line-interactive UPS systems, this acceptable voltage range is fairly narrow, as these systems have no other mode of protecting against harmful voltage variations. Double conversion units have a built-in capacity for voltage regulation during normal operating mode; a double conversion unit will only transfer to battery power when the incoming voltage is beyond its ability to correct.

EFFICIENCY

The power conditioning processes inside UPS systems inevitably lead to energy losses, even in standby systems with minimal capabilities. UPS systems typically have efficiencies between 85 and 99 percent, with increased efficiency as the connected load reaches the system's capacity.

REDUNDANCY

Because UPS systems are so important to protecting critical loads against power failure, it is common practice to use redundant, or extra, systems in case a UPS fails or needs to be serviced. Redundancy is an important issue in large-scale UPS applications, such as data servers, where UPS systems are networked together to backup large loads. In a typical medical or laboratory setting, UPS systems are not networked.

NUMBER OF OUTLETS

In outlet-type UPS systems, pieces of equipment directly plug into the unit itself. For these units, it is important to ensure that an adequate number of outlets is available to support all connected equipment. Large UPS systems are hardwired into the electrical circuit, so existing wall outlets are protected.

SIZING AND SELECTION

Given the range of options for backup power and power quality equipment, selecting the most appropriate choice for a health-care facility requires a careful examination of the facility's loads, power supply, and energy management capacity. Important questions to consider include the following:

- How large are the sensitive equipment loads compared to the total facility load?
- Which power supply issues does the facility face—quality, availability, both?
- What resources are available to manage and maintain energy equipment?

In order to address these questions and develop a cost-effective energy system to meet facility needs, USAID's Powering Health toolkit describes a four-step approach, focused on analyzing energy supply and demand, identifying appropriate use of technology, and ensuring energy system sustainability through management and maintenance. The toolkit also includes Energy Audit and Load Calculation and System Optimization tools to assist in the process.

LOAD CHARACTERIZATION

With regard to UPS systems in particular, contact and no-contact loads is an essential concept. Health-care facility loads can be characterized in one of three ways: non-critical loads, contact critical loads, and no-contact critical loads.

Each type of load places different requirements on the backup power system. Non-critical loads do not require battery backup power but should be supplied by a diesel generator when grid power is unavailable. Contact critical loads can be directly supplied by grid and generator power but require battery backup in the event that this primary power is disrupted. No-contact critical loads should always be isolated from grid or diesel power due to fluctuations or spikes in voltage that can occur. They should be supplied solely and constantly by a double conversion UPS or other source of clean power that acts as a buffer between the sensitive equipment and the unreliable primary power source.

KIM DOMPTAIL / USAID

These different load categories can be characterized by their backup power and power quality needs, which, in turn, point to suitable power supply equipment. These considerations are outlined in the following table.

BACKUP POWER NEEDS FOR LOAD CATEGORIES			
	NON-CRITICAL LOADS	CONTACT LOADS	NO-CONTACT LOADS
Example Equipment	Air conditioners, low-priority area lighting, TVs	Priority area lighting, cold chain refrigerators, incubators, centrifuges	Data servers and computers, emergency lighting, blood analyzers, microscopes, fire suppression equipment
High-Quality Power	Preferable	Preferable	Required
Emergency Power Transfer Time	Transfer not required	10 seconds or less	Instantaneous
Autonomy/Runtime (Backup Power Time)	No backup required	Variable, from a few minutes to an hour	Variable, enough for the longest power outage
System Reliability	N/A	99 percent	>99 percent
Monitoring	Not necessary	Not necessary	Recommended
Power Supply Equipment Options	Automatic voltage regulator, surge protector	Standby UPS, line-interactive UPS, contact battery/inverter system	Double conversion UPS, no-contact battery/inverter system

The first step in selecting an appropriate backup power or power quality technology is to understand the size of the current facility load, identifying contact and no-contact loads. This process begins with an energy audit to inventory, categorize (*i.e.*, non-critical, contact, no-contact), and quantify all existing loads as well as their operating hours. Also, as in step two of the approach, future additions or changes in facility loads should be considered before going ahead with system sizing.

USAID's Powering Health toolkit provides resources to aid in conducting an energy audit and obtaining load estimates.

POWER SUPPLY CHARACTERIZATION

UPS systems are recommended for any sensitive electronic equipment that may be damaged in the event of power loss or other power anomalies, even when grid power is reliable. While UPS systems are important regardless of the level of power quality a facility receives, an assessment of power quality is useful in determining the size, configuration, runtime, and additional features of the UPS system.

There are a number of power quality tests available, designed to quantify issues such as harmonic distortion, power factor, frequency variation, and voltage variation. In determining UPS requirements at a health facility, the two most important power quality indicators will be grid availability and voltage variation.

Understanding these two factors and quantifying the facility's critical loads are necessary when choosing the correct type and size of UPS system. The length of power outages will point to the amount of battery runtime necessary to power equipment until the grid or generator is restored, while the frequency of outages may affect the battery's charging and could necessitate additional replacement batteries. Voltage variation will point to the correct UPS system type (off-line, line-interactive, online) based on the level of grid isolation needed to provide good quality power.

An assessment of grid availability is mostly based on past experience. Interviews with facility personnel, logs of generator runtime, or in some cases utility data, will be useful in evaluating the extent of grid availability. Administrators and technicians should have a good idea of how frequently, and for how long, power outages occur. In some cases, power is supplied on a schedule, meaning that grid loss is frequent and predictable.

Assessing voltage variation requires on-site measurement. Grid power entering the facility should be recorded over a period of at least a couple of hours, with longer measurement times providing greater confidence in the assessment. A data logger is hooked up to the laboratory circuit in order to capture current, power demand, and voltage across all three phases.

Logged data can then be analyzed using computer software or spreadsheets. In this analysis, voltage within each phase, and between phases, is compared to identify overvoltage, undervoltage, and other variations. Voltage data yields minimum, maximum, and average values for each phase; these values should not vary more than 2 percent for any one phase or between phases.

BATTERY CONSIDERATIONS

UPS systems transfer to battery mode when power is lost or a voltage set point is crossed. Selecting a UPS that is appropriate to the grid power conditions at the facility is therefore important. If data logging shows frequent voltage swings, a UPS should be chosen that has some form of automatic voltage regulation, such as a double conversion unit or many line-interactive units; otherwise, the UPS will frequently switch to battery power, lowering its lifespan.

Depth of discharge is difficult to control, as the UPS will operate in battery mode until grid or generator power is restored. However, this too can be managed by correctly sizing the UPS and selecting an appropriate runtime capacity. Reducing the load on the UPS will increase runtime, lowering the depth of discharge on the battery over short periods. This can also be accomplished by adding external battery packs. The required runtime should be determined based on the typical length of grid or generator power loss.

SIZING

Like a battery bank or any other energy system, the process for sizing a UPS system begins with a calculation of the supported load. In the case of UPS systems, the supported load may be a single piece of equipment, several pieces of related equipment, or one or more electrical circuits. UPS units are usually classified by their output capacity range in volt-amperes (VA), e.g., 350–750 VA or 10–40 kilovolt-amperes (kVA). Therefore, loads should be measured or calculated based on specified or nameplate capacity of various equipment in kVA.

A UPS with a capacity range that covers the supported load should be selected, with some greater capacity if additional loads are expected in the future. It is also common to slightly oversize a UPS system just to ensure enough capacity for all connected loads; a general rule of thumb when oversizing is to add an additional 10 percent of the load to the system capacity.

Another important consideration regarding UPS system size is the effect on the facility power load. UPS systems have power consumption beyond that of their connected loads. Due to inefficiencies in power conversion and battery charging, UPS systems will add to the overall system load. The exact efficiency of any given system will vary depending on its type, quality, and features. Double conversion systems have the lowest efficiency due to losses from the double conversion process.

It is worth considering efficiency when comparing UPS systems, but battery charging is generally not included in reported operating efficiencies. Charging efficiency will play a greater or lesser role depending on the frequency of battery use. As a general rule of thumb, expect a conservative 20 percent increase in power load due to the UPS.

MAINTENANCE

The maintenance required for UPS systems is generally low. Battery health is the greatest concern in ensuring the overall effectiveness of a UPS system. Confidence in the UPS system's ability to provide necessary runtime depends on good battery maintenance. Maintaining UPS batteries entails periodic cleaning and testing as well as proper replacement at the end of the battery's life.

Most UPS systems use low maintenance, sealed lead-acid or lithium-ion batteries. These batteries require simple types of preventative maintenance such as confirming that terminal connections are tight and removing corrosion.

It is also important to check battery health from time to time to ensure that sufficient capacity is available to backup loads. UPS systems connected to monitoring software continuously track information on the state of charge and other parameters indicating battery health and performance. Smaller UPS systems typically provide a "test" button that when pressed will perform a deep discharge/recharge of the battery as a matter of routine maintenance.

UPS batteries have a life of about 3 to 5 years. Actual battery life depends greatly on operating and environmental conditions like the frequency and depth of discharge and the ambient temperature. These factors can be managed through proper sizing and selection.