Uninterruptible Power System – Operation & Maintenance

Whitham D. Reeve

1. Introduction

The *uninterruptible power system*, or UPS, is an important accessory in any observatory. The UPS is a backup ac source that supplies power to station equipment when the primary ac power source fails or otherwise exceeds preset operating thresholds. Other names are *uninterruptible power supply* and uninterruptible power source. One of the main reasons for having a UPS is to prevent corruption of station PC programs or hard drives or network attached storage (NAS) caused by short electric utility outages or transients. A station PC equipped with a UPS generally will have better data collection reliability and continuity over the long term compared to one without a UPS.

The typical UPS used in residential and small business applications (the so-called small office, home office, SOHO) is an integrated package of filters and surge protection, one or more 12 V batteries, battery charger, inverter, and load transfer switch (figure 1). Depending on the UPS rating and load, the batteries provide backup time (runtime) from a few minutes to a few hours. The batteries are a consumable component of the UPS and eventually require replacement. This article focuses on common UPSs rated between about 500 and 1500 volt-amperes. After briefly discussing power quality and typical UPS features (sections 2 and 3), this article covers UPS maintenance including battery replacement (section 4), battery characteristics and testing (sections 5 and 6) and UPS operating costs (section 7).

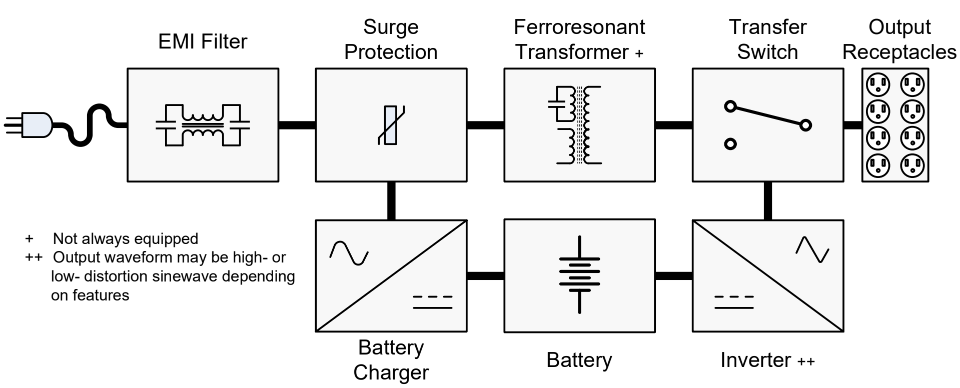

Figure 1 ~ UPS conceptual block diagram showing basic functions contained in a typical UPS designed to back up a PC and other loads. The ferroresonant transformer, if equipped, provides voltage regulation to reduce sags and swells on the output without switching to the battery and inverter. Image © 2019 W. Reeve

2. Power Quality

Modern UPSs are designed to protect against degradation in power quality, not just simple interruptions. The primary power source most often is the electric utility service, and any number of detrimental conditions can exist on it. These conditions are categorized according to their voltage magnitude and duration and include very short duration voltage variations called *transients*, longer duration under- and over-voltages called *sags* and *swells* and long duration under-voltage conditions called *brownouts* and *blackouts*. Over-voltages are often called *surges*.

The IEEE Recommended Practice for Monitoring Electric Power Quality [IEEE-1159] precisely defines many power quality terms, making it easier to analyze and mitigate problems that may occur. This is only one of many power quality standards issued by the Institute of Electrical and Electronics Engineers, International Electrotechnical Commission (IEC) and other organizations.

Transients can cause problems ranging from malfunction to damage and include computer or receiver lockup or power supply failure. Most severe transients are caused by nearby lightning strikes but also can be caused by electric utility distribution line-slap during storms or other events. Transients caused by load switching – simply turning a light or motor on or off – usually are less severe but still may cause problems especially where wiring quality is poor. Residential heat pumps, air conditioners and furnace motors also are sources of transients.

Voltage sags and swells are voltage variations exceeding 10% that last from ½ cycle of the powerline frequency (8.3 ms at 60 Hz) to 1 min and are the most common power quality problem. A swell can occur when a large load is disconnected and may be accompanied by a transient. A sag can occur when a large load is connected and usually is more troublesome in terms of PC or receiver malfunction.

As a point of practical reference, the Information Technology Industry Council (ITIC) has developed a curve showing the voltage-duration tolerance of, among other things, power supplies used in personal computers and other information technology equipment (figure 2).

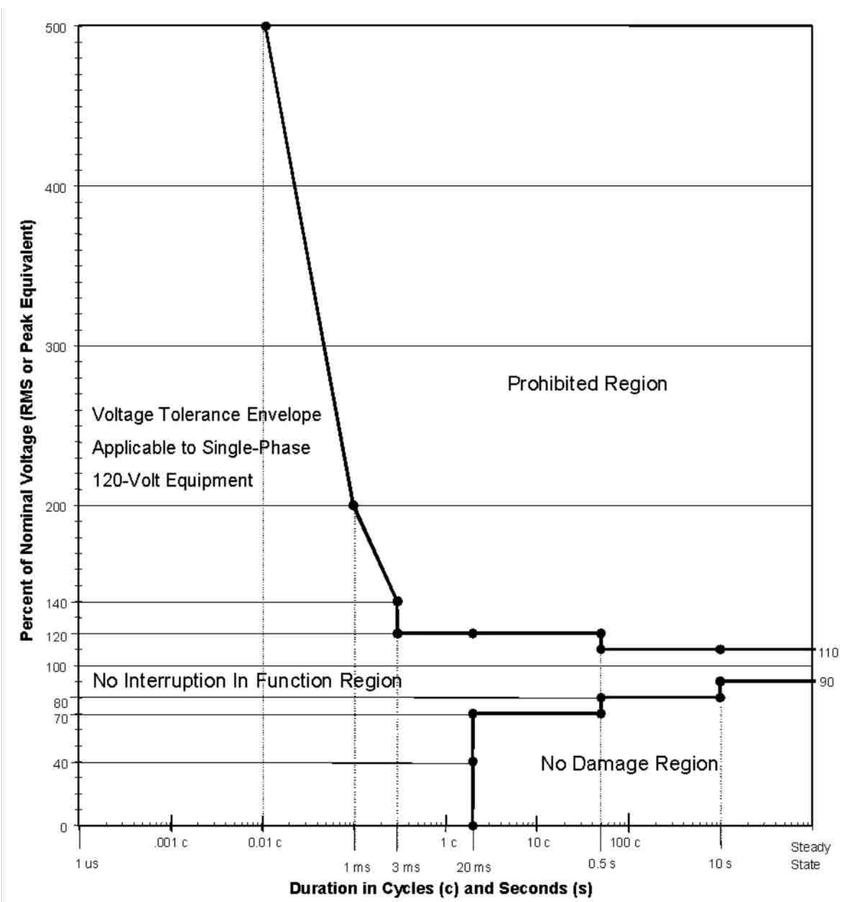

Figure 2 ~ Information Technology Industry Council (ITIC), formerly Computer and Business Equipment Manufacturers Association (CBEMA), voltage-duration tolerance curve. The curve is an aid to both electric utility service providers and computer and business equipment power supply manufacturers. The curve's vertical scale indicates the equipment input voltage as a percentage of a 120 V base and its horizontal scale indicates the duration in cycles (c) and seconds (ms and s). The solid line defines the separation between *functional* on the left and *prohibited* and *no damage* regions on the right. For example, equipment should be able to tolerate 200%, or 240 V, for no more than 1 ms and 500%, or 600 V, for no more than 0.01 cycles, or 0.17 ms at 60 Hz. Similarly, equipment should function normally with a voltage dip to 40%, or 48 V, lasting no more than 20 ms, or 1.2 cycles at 60 Hz. Image source: {ITIC}

3. UPS Operational Features

A UPS monitors the voltage at the receptacle into which it is plugged. In the USA, the receptacle voltage and frequency are nominally 120 Vac and 60 Hz, and the UPS *typically* intervenes when the voltage drops below 90 Vac or exceeds 140 Vac. These voltage setpoints represent a range of –25% to +17% with respect to the nominal voltage and are adjustable in many UPS models through the UPS monitoring software (see below). Examination of the ITIC voltage-duration curve indicates that these voltage setpoints are quite wide compared to the desired nominal variations of ±10% (108 to 132 Vac). Specific site experience and requirements may point toward the wider range. The important points are to prevent damage from higher voltages and to prevent excessive UPS switching due to lower voltages while ensuring the connected equipment functions normally. Because it monitors the voltage on one point of a branch circuit, the UPS can be affected by poor wiring in that or upstream circuits.

Many UPSs are equipped with a display that shows operational details such as voltage and frequency and remaining battery time during discharge (figure 3). Most UPSs provide an audible alarm when they detect an electrical event that exceeds preset thresholds, and if a display exists, the UPS may have basic user diagnostic features.

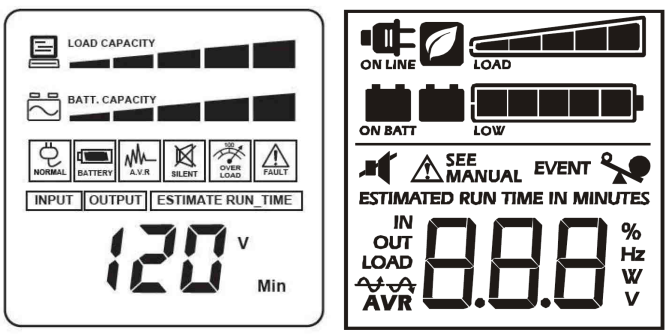

Figure 3 ~UPS displays for CyberPower (left) and APC (right) UPS brands. Load and battery capacity is indicated by a low-resolution bar graph. Voltage, power and frequency are indicated numerically and status is indicated by icons. Image sources: CyberPower and APC user manuals.

A typical UPS may be setup for *autonomous* or *control* modes. In autonomous mode, the UPS simply switches to its batteries when failure conditions are met and operates until either the failure condition stops or the batteries discharge completely. When the batteries are completely discharged, the UPS simply shuts off as do the loads connected to it. Complete battery discharge is equivalent to pulling the plug on any connected equipment such as a PC. If the PC is writing data at this time, the data or program may be corrupted.

A UPS equipped with a communications and control port can connect to a PC for a control mode. Nowadays, this most often is a USB port but older PCs used an EIA-232 serial port. UPS software (figure 4) on the PC gathers and logs information from the UPS and can command a controlled shutdown of the PC before the batteries are completely discharged.

The control mode is preferred to the autonomous mode because it prevents possible corruption of the PC at end of battery discharge. Sometimes a recalcitrant program running on the PC may prevent orderly shutdown but the control mode significantly reduces the possibility of problems. The control mode generally requires that the PC and UPS be located within about 3 m of each other due to USB cable length limitations but work-arounds are available.

Most UPSs used in residential and small business applications do not generate a low distortion (sometimes called "pure") sinewave output waveform during battery operation. Instead, an output waveform is generated that has a highly distorted squarewave-like appearance (figure 5). UPS manufacturers call these high distortion output waveforms "simulated", "approximated", "modified" or "step-approximated sinewave". UPSs that generate a low distortion sinewave output cost about 40% more and usually are larger and heavier for a given power rating.

Anything other than a low distortion sinewave means significant powerline harmonics on the UPS output. Some load equipment is very sensitive to the presence of powerline harmonics and will not work properly when the UPS is operating from its battery. Equipment that could malfunction when powered by a distorted UPS output waveform often is discovered during the first electric utility outage after installation of the UPS.

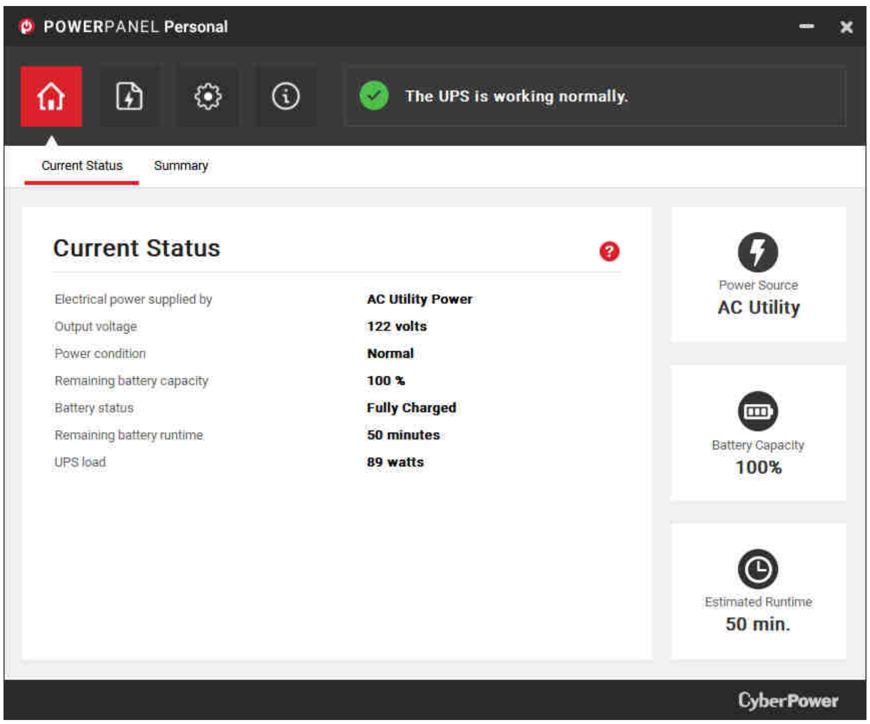

Figure 4 ~ UPS software status and configuration software. Shown here is the POWERPanel Personal software used with the CyberPower UPS; it is typical of the software supplied with a UPS. It runs as a Windows service and loads automatically when the PC starts. By default, it is configured to shutdown the PC 5 min before the batteries are completely discharged, but it requires a USB connection to the PC for this to work. It also can be configured to send an email whenever a power event occurs and to schedule PC start and stop, among other functions.

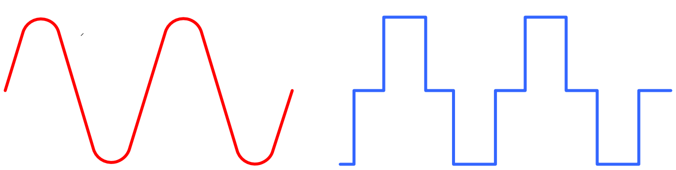

Figure 5 ~ UPS output waveforms. Left: Low distortion sinewave. Right: High distortion simulated sinewave. Both have the same fundamental powerline frequency but the distorted waveform has high harmonic content. Image © 2019 W. Reeve

A UPS is rated according to its operating voltage and capacity in terms of apparent power (volt-amperes, VA) and real power (watts, W). The volt-amperes rating determines the number of amperes that can be drawn from the UPS at its rated voltage whereas the wattage rating determines the amount of real power that it can deliver. The two ratings are related by the load power factor (PF), which typically is 0.6. For example, if the rating of a UPS is 1000 VA and 0.6 PF, the maximum real load that it can serve is 600 W.

In most USA residential and small business environments, the wall receptacle rating is 15 A but the maximum allowable continuous load is 80% of rating, or 12 A. The receptacles on UPS equipment generally have the same rating. Where the load power factor is 1.0, for example, a resistive load such as an electric heater or incandescent lamps, the 12 A current is equivalent to a maximum load of 1440 W at 120 V. A load power factor of 0.6 which applies to lightly loaded motors and most switch-mode power supplies including PC power supplies, equates to a maximum real power load on the receptacle of only 864 W. Different lighting technologies (incandescent, compact fluorescent, light emitting diode, and so on) have different power factors. Modern name-brand LED lamps generally are 0.7 or higher.

All UPSs use batteries for energy storage and these are recharged automatically when the primary source power returns after an outage. Recharge times range from 8 to 12 h for a fully discharged battery. During discharge, the battery runtime depends on the UPS rating, its battery capacity and the connected load. The relationship between rating, load and runtime is nonlinear (figure 6). To aid in sizing, UPS manufacturers provide a runtime calculator with plots and tabular data on their websites, for example, see {CyberPower} (table 1). A fully loaded UPS typically provides only a very short runtime measured in minutes.

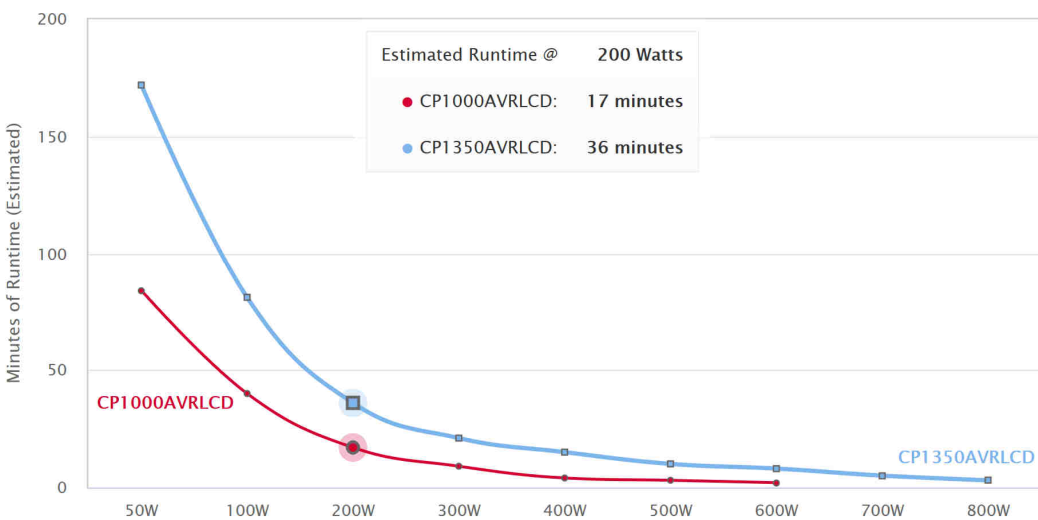

Figure 6 ~ Comparative plots of the estimated battery runtime for the CyberPower models CP1350AVRLCD and CP1000AVRLCD UPS. The larger unit is rated 1350 VA/815 W and provides a runtime of 36 min when the load is 200 W or 25% of capacity. Note the nonlinear nature of the curves. Image source: {CyberPower}

Table 1 ~ Battery runtime data for the CyberPower model CP1350AVRLCD rated 1350 VA/815 W
Load and runtime data source: {CyberPower}

Load (W)	Runtime (min)	Fraction of load rating (%)
50	172	6.1
100	81	12.3
200	36	24.5
300	21	36.8
400	15	49.0
500	10	61.4
600	8	73.6
700	5	85.9
800	3	98.2

Depending on the operating system and open application programs, PC shut-down can require perhaps 15 seconds up to about two minutes. Where there are frequent short outages or other power problems, it is not good practice to shut down the PC with every power hit, assuming it is setup in control mode. Therefore, where most outages last more than a few minutes, the UPS is loaded to only a fraction of its rated capacity, say 10 to 20% or no more than 50%, to allow it to operate through these outages without triggering a PC shutdown. In any case, it also is not good practice to load a UPS to more than 80% of its rating.

Most UPSs include two sets of output receptacles – one set for loads the require both battery backup and surge protection and another set for surge protection only. A common operational problem involves inadvertently plugging loads that require battery backup into the wrong receptacles, which usually is discovered during the first power outage after installation.

All modern UPSs have built-in filtering to reduce electromagnetic interference (EMI). I occasionally hear anecdotes about EMI from UPSs but have never seen any credible reports. If interference exists, it may indicate a UPS internal problem or poor branch circuit wiring. Such interference, if it exists at all, is either conducted or radiated. Conducted interference might be mitigated by placing several ferrite beads on the UPS power leads or using an EMI filter made for the purpose (for example, see {OnFilter}). Radiated interference normally is more difficult to eliminate and the only solution may be disconnecting the UPS altogether or replacing it with a different model.

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4. Battery Characteristics

Batteries are a consumable part of a UPS and are worth discussing in more detail. Most residential and small business UPSs use multi-cell, sealed lead-acid (SLA) batteries that produce a nominal open-circuit voltage of slightly more than 2 V per cell (VPC) when fully charged. Various names are used for these types of batteries including absorbed glass mat (AGM), valve-regulated lead-acid (VRLA) and maintenance-free. The latter name indicates the batteries do not require regular electrolyte maintenance as do vented lead- acid (VLA, or flooded) batteries. The battery capacity rating will be printed on its nameplate in amp-hours (Ah) or watts (W). These ratings are based on the time required to reach a specified *end-of-discharge* (EOD) voltage, also called *final voltage*, while under a specified load at a specified ambient temperature. Battery ratings usually are given at 20 or 25 °C.

UPSs used for residential and small business applications typically use one or two 12 V batteries depending on the UPS rating. If two batteries are used, they most often are connected in series for a 24 V total voltage. Individual battery capacity ratings usually are in the 7 to 9 Ah range. The total capacity of two identical series-connected batteries is the same as the capacity of an individual battery. For example, the total capacity of two 8 Ah batteries connected in series is 8 Ah. The battery capacity rating is controlled by complicated nonlinear electro-chemical processes. Therefore, a battery rated to discharge at a given current in 20 h to some voltage will not have the same capacity if discharged at a higher current in 10 h to that same voltage.

Ratings based on amp-hours often use a 20 h discharge time to 1.75 VPC EOD voltage (10.5 V for a 12 V battery) at 25 °C. Two examples are the Kung Long WP7.2-12, which is rated 7.2 Ah and the Powersonic PS-1290, which is rated 9 Ah. UPS batteries rated in watts typically are designed for relatively high currents and fast discharge times by increasing the amount of lead in the internal plates.

Battery wattage ratings usually are based on watts per cell at 25 °C, 1.30 VPC EOD voltage and 15 min discharge time. For example, the B.B. Batteries model SH1228W is a 12 V sealed lead-acid battery rated 28 W per cell. This battery has six cells and will deliver 168 W when it is discharged to 7.8 V in 15 min. The SH1228W is the same physical size as both the PS-1290 and WP7.2-12. The weights are 2.20 kg for the SH1228W, 2.72 kg for the PS-1290 and 2.39 kg for the WP7.2-12. One would expect a battery rated in watts to weigh more than a dimensionally identical battery rated at a 20 h discharge rate but not so in this case.

A battery will have more capacity at a higher ambient temperature but shorter life due to more energetic chemical reactions. Conversely, the same battery will have less capacity at a lower temperature but longer life. Battery capacity also depends on the end-of-discharge voltage. For any given battery, its capacity in amp-hours will be less for a higher EOD voltage (say, 11.0 V instead of 10.5 V) and more for a lower EOD voltage (say, 10.0 V instead of 10.5 V). Of course, a lower EOD voltage means nothing if the connected load does not work at that voltage.

Battery life usually is defined as the time required for the battery discharge capacity to be reduced to a specified percentage of its rated capacity. For example, if a battery is rated 8 Ah and end-of-life is defined as 80%, that battery will be considered at end-of-life when its fully charged capacity in service has decreased to 6.4 Ah. A lead-acid battery operates by consuming itself over time and frequent discharge-recharge cycles and high temperatures wear it out much faster. Even if the battery is never discharged, it eventually will lose capacity and require replacement.

Different industries use different conditions or percentages for battery life. For residential and small business applications, the end-of-life condition is met when the UPS batteries no longer provide the required reserve time. For some users, this could correspond to 50% of rating. However, 80% is more typical and provides some allowance for the more rapid reduction in capacity as batteries age and wear out. A more thorough discussion of lead-acid batteries may be found in [Reeve06].

For reference, the type of terminal on a battery (figure 7) depends on their anticipated service. Smaller batteries with light-duty discharge requirements commonly use the F1 terminal. The larger batteries used in residential and small business UPS applications most often use the F2 terminal. Batteries that are still larger use bolted connections.

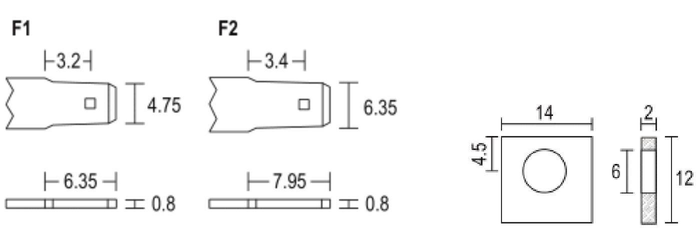

Figure 7 ~ Terminals on batteries used in typical residential and small business UPS equipment. The F1 and F2 on the left are push-on types often a known by a tradename *Faston*. Their non-metric width dimensions are 3/16 and 1/4 in. The F2 is most common. The right-hand terminal requires a bolted connection.

Battery replacement costs represent roughly 1/4 to 1/2 the cost of a new UPS. There are many battery brands but some brands are undoubtedly made by the same manufacturer to slightly different specifications or at least different labeling. It is not necessary to replace batteries with those purchased from the UPS original equipment manufacturer (OEM), and the replacements need not be exactly the same brand and model as originally used in a UPS. However, replacements must meet certain criteria, which are discussed in the next section. Generally, sealed lead-acid batteries have no extraordinary shipping restrictions, but they can be expensive to ship because of their high mass density. It is worth shopping around for replacements. Remember two important battery replacement rules:

1) It is false economics to replace a used battery with another used battery, euphemistically called “refurbished”, that was bought at a high discount. The only truly refurbished battery is one in which the case was opened, the plates replaced, the case resealed and the battery fully tested;
2) Never mix used and new batteries except on a temporary basis (for instance, to temporarily recover from a battery failure until new replacements are available).

If spare batteries are kept handy, they should be periodically connected to a charger. Battery datasheets recommend proper float voltage, and inexpensive battery chargers made for sealed lead-acid batteries are readily available. A spare UPS also should be periodically connected to an ac power source so its batteries can be recharged. If batteries are allowed to completely self-discharge, and left sitting for any significant length of time in that condition, they may be damaged due to lead sulfate build-up on the plates. Self-discharge rates of sealed lead-acid batteries are in the neighborhood of 3% per month. Manufacturers of the types of batteries used in UPSs recommend that batteries not be left to self-discharge for more than 6 months at normal room temperature and much less if the ambient temperature is elevated.

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5. UPS Maintenance

The typical UPS requires no regular maintenance except occasional dusting, testing and battery replacement. The batteries used in a typical UPS have a useful life between 3 and 7 yr depending on the ambient temperature and number of discharge-recharge cycles. Many UPSs have a basic functional self-test that may be initiated either from a built-in control panel or associated software, but this usually does not test battery capacity or backup time. When a UPS fails to do its job in service, the cause almost always is reduction in battery capacity due to age or, less often, complete battery failure.

Four pieces of information are needed for battery replacement: 1) Battery capacity; 2) Battery voltage; 3) Battery terminal type; and 4) Battery physical dimensions. Of these, 2), 3) and 4) are the most important because a battery with the correct voltage, terminals and dimensions most likely will have the required capacity. Batteries with the same dimensions, voltage and terminals often are available with slightly different capacities. In this case, the larger capacity should be selected.

One of the potential problems with replacing batteries is their dimensions. Because many batteries have similar but not identical dimensions it is easy to purchase the wrong ones. This problem is made worse with online ordering because of the sometimes-inaccurate or inadequate data that is posted. A difference of only 0.1 in (2 or 3 mm) in any dimension can prevent a new battery from fitting in the battery compartment of the UPS. It is well worth the small extra effort to confirm all dimensions before ordering. Datasheets that show dimensions are readily available for all name-brands. Brands or models for which datasheets are not available should be avoided.

The several UPSs discussed here are rated between 1000 and 1350 VA. All use a pair of 12 V batteries connected in series and all have a similar physical configuration with the battery compartment at the front of the main enclosure. To remove the batteries for testing or to replace them, it is first necessary to take the UPS out of service by turning it off and completely disconnecting it from the primary power source and all loads. The next step is to remove the front panel to access the battery compartment (figure 8.a).

The batteries in all my UPSs are held together on three sides by a tough, clear, flexible plastic sheet wrapped around and stuck to the batteries with reusable adhesive (figure 8.b). The battery string is disconnected and tabs on the plastic sheet are then used to pull the batteries out of the compartment. If the batteries are difficult to remove because they are bloated due to lead sulfate buildup, there is no sense in testing them and they should be replaced. Similarly, if there is any leakage or corrosion, the batteries should be replaced and internal UPS and wiring damage should be investigated. This may require complete disassembly of the UPS.

Figure 8 ~ Battery replacement details. (a) Upper-left: The connectorized front panel has been removed and is sitting to the left of the main enclosure. (b) Upper-right: A flexible clear plastic wrapper has adhesive on one side and holds the two batteries to the partition. (c) Lower-left: A hollow plastic partition with a wiring compartment separates the two batteries. One new battery has been connected. The batteries are placed with their terminals at opposite ends of the partition, reducing the chance for a short-circuit. (d) Lower-right: After reassembly of the batteries and reconnection, the front panel is ready for installation. The green printed circuit board on the front panel includes a pushbutton control and display. This view clearly shows one of the tabs on the clear plastic sheet that holds the batteries and partition together. Images © 2019 W. Reeve

The clear plastic sheet holds the batteries to a plastic partition such that their terminals face the partition but at opposite ends. Now, slowly and carefully peel the plastic sheet away from the batteries and the partition (a heat gun on low heat helps). Put the plastic sheet aside for later reuse and remove the connectorized jumper wires from the batteries. It is advisable to take notes or photographs of the configuration to ensure trouble-free reassembly. The battery jumpers are inside the plastic partition (figure 8.c) and have push-on terminals that match the batteries. Once disassembled, the old batteries may be tested as described in the next section. Even small batteries can supply dangerous short-circuit currents, so care is required in their handling.

To reassemble, place the new batteries (or existing batteries if they tested good) and partition together while reconnecting the jumpers. When everything is aligned properly, reapply the plastic sheet to hold the batteries and partition together (this is easier with three or four hands but can be done with two). The battery assembly is then slid back into the compartment and reconnected (figure 8.d). The front panel is replaced in position as a final step. The whole battery replacement process requires about 15-20 min. After a brief test by connecting the UPS to the primary power source and turning it on to verify its operation, the UPS may be reinstalled.

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6. Battery Testing

All batteries tested as described in this section are 12 V (6 cells), have F2 terminals, and have the same dimensions but slightly different amp-hour ratings: 7.2 Ah, 8 Ah and 9 Ah. The brands originally used in my UPSs include B.B. Battery, Kung Long and Powersonic. The Powersonic PS-1290 F2 (9 Ah) was used to replace the batteries in one UPS and Duracell Ultra SLA12-9F2 (9 Ah) and SLA12-8F2 (8 Ah) replaced the others.

Batteries may be tested in-place by connecting a known load to the UPS output and then disconnecting the UPS input from the primary power source. A stop-watch can be used to time the battery discharge until the UPS shuts off. Many UPSs display the estimated remaining discharge time but this probably is an estimate based on new batteries and not accurate for old batteries. The advantages of a live test are its simplicity, no test equipment is required and the test is under actual operating conditions. If the desired runtime is achieved, the UPS may be put back into service (the batteries will automatically recharge). If not, the batteries can be replaced as previously described. A more formal test involves removing the batteries and discharge testing them with a device made for the purpose as described below.

The following electrical measurements were produced by the Computerized Battery Analyzer, model CBA-II and CBA-IV, from West Mountain Radio {CBA} (figure 9). The CBA-II is an older unit, about 13 years. It worked flawlessly until I accidentally reversed the leads when connecting it to a battery and damaged it beyond economical repair. Both the CBA-II and CBA-IV are controlled through a USB interface and both have temperature measurement capability (temperature measurements were not made during these tests).

I have the Pro version of the CBA software, which allows various testing modes. However, I used only the constant current discharge mode available in the Standard version. This mode applies a constant current to the battery while the battery voltage is logged and plotted (figure 10). The constant current discharge is run until the preset end-of-discharged voltage is reached. All tests discussed here used 10.5 V EOD voltage, equivalent to 1.75 VPC for the 6 cell, 12 V batteries.

The UPS batteries used for these tests were B.B. Battery models SH1228W and SH1228Ws, both rated 28 W to 1.30 VPC, and Kung Long Batteries model WP7.2-12, rated 7.2 Ah to 1.75 VPC. All of these batteries were 5 to 7 yr old and removed in fully charged condition from several different UPSs during routine maintenance. The batteries were tested within 24 h of removal at a temperature of 20 °C.

Figure 9 ~ West Mountain Radio CBA-II battery analyzer (right) connected to a 12 V battery for a discharge test. CBA-II dimensions are 90 W x 75 D x 77 H mm. The analyzer and its regularly updated software can be used with numerous battery technologies. The analyzer connects to a PC through a USB 2.0 port (far right in image). The CBA-II is equipped with PowerPole connectors on a short input cable. Any number of adapter cables can be shop-built for various terminations. In this case, a 14 AWG adapter cable was built with push-on connectors matching the F2 battery terminals. The CBA-II is a 2nd generation analyzer and is rated the higher of 40 A or 150 W at up to 48 V. The latest model is the 4th generation CBA-IV. Image © 2019 W. Reeve

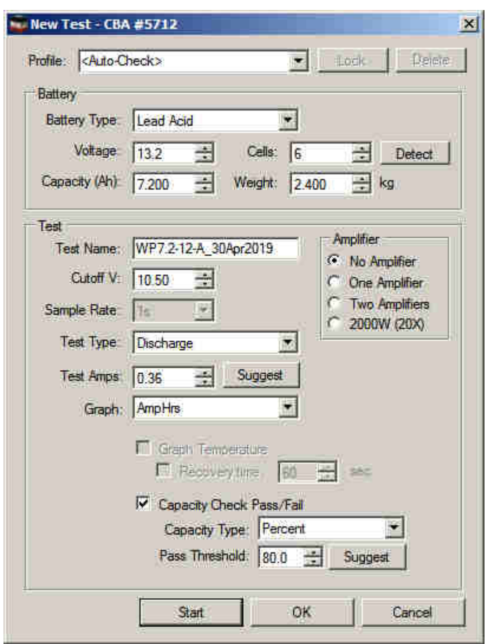

Figure 10 ~ Screenshot of the battery analyzer software setup window, which specifies all pertinent details for discharging the battery and logging the measurements. In this image, the WP7.2-12 battery (indicated along with the date in *Test Name*) is to be tested with 0.36 A discharge current (*Test Amps*) and a target of 80% nameplate capacity (*Pass Threshold*) to 10.5 V discharge cutoff voltage (*Cutoff V*). The battery voltage 13.2 V (*Voltage*) and six cells (*Cells*) are default values for Lead Acid batteries (*Battery Type*) but can be changed to any practical value. When the *Start* button is pressed, a real-time plot is produced of the battery voltage and number of amp-hours as the battery discharges. These plots may be saved as a CBA-II .bt2 file, which can be loaded later directly into the software, comma separated variable .csv file, and a portable network graphics .png image file. Multiple tests can be plotted on a single chart.

Some model SH1228W batteries tested good under assumed discharge conditions (figure 11). The model SH1228Ws batteries showed clear failure conditions (figure 12) so just for fun one of the batteries in the set was tested further. It was recharged for about 15 h, tested, recharged for another 72 h and tested again (figure 13). Its condition degraded with each test. The CBA-IV was used to test two new fully charged PS-1290 batteries (figure 14).

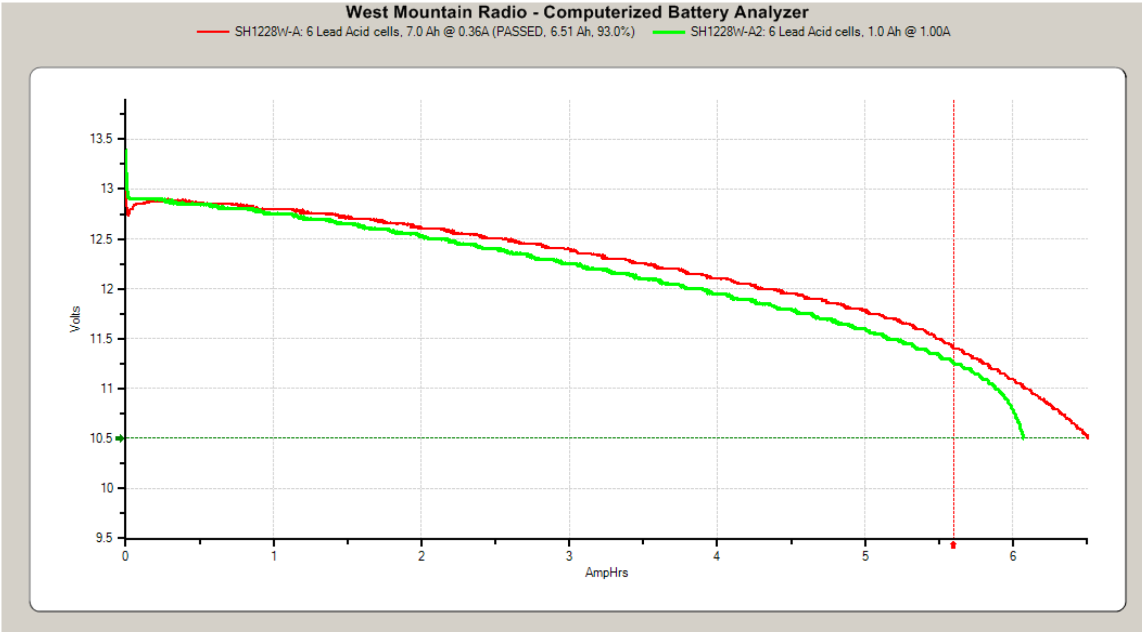

Figure 11 ~ Battery performance plot for the B.B. Batteries model SH1228W batteries. The batteries were discharged with constant current of 0.36 A to 10.5 V final voltage (1.75 VPC EOD) shown on the left vertical scale. The final voltage is indicated by a faint green horizontal line. The horizontal scale shows the cumulative amp-hours discharged from the battery and for constant current discharge is similar to a time scale. For example, a current of 0.36 A for 2.78 h represents a 1 Ah discharge. The discharge current is based on a 20 h discharge rate assuming 7 Ah equivalent capacity. The red and green traces are for the two batteries removed from one UPS that are believed to be 5 years old. The red vertical line is set at 80% of the assumed capacity, or 5.6 Ah, and both batteries passed this discharge cutoff. Note that if the assumed battery capacity is 8 Ah, the discharge current would be set slightly higher (to 0.4 A) and the discharged cutoff would be 6.4 Ah. In this case, the batteries may fail.

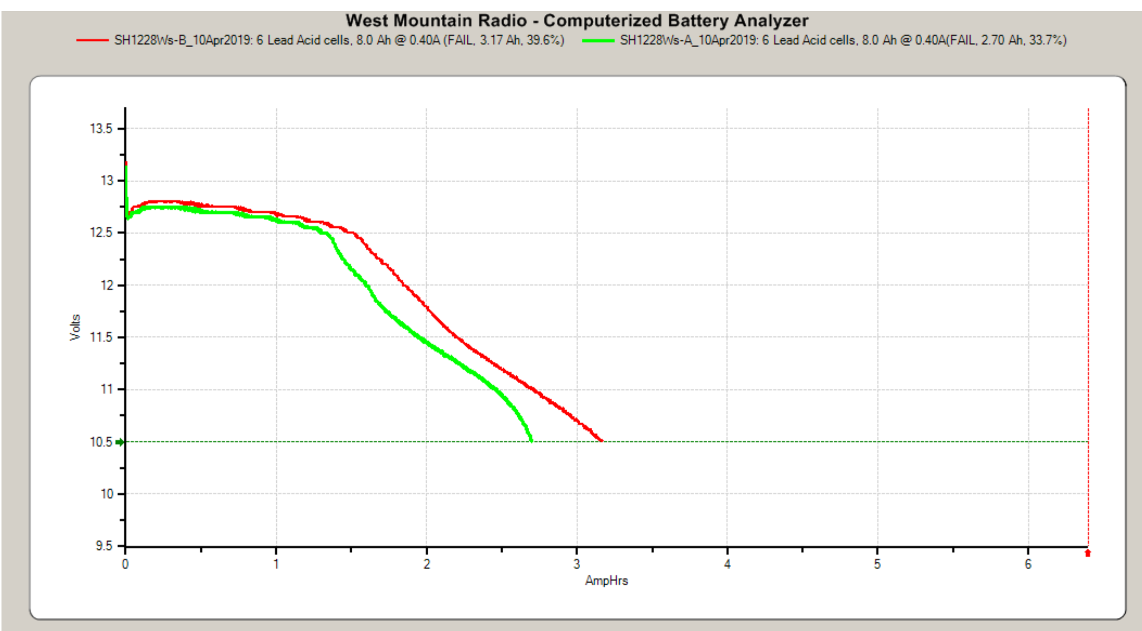

Figure 12 ~ Battery performance plot for the B.B. Batteries SH1228Ws batteries. These batteries have the same wattage rating and dimensions as the SH1228W shown previously but are believed to be older. The batteries were assumed to have an equivalent amp-hour rating of 8 Ah for these tests, so they were discharged with constant current of 0.40 A to 10.5 V final voltage. The red vertical line is set at 80% of the assumed capacity, or 6.4 Ah. Both batteries failed this discharge cutoff by a large margin and were tested further as shown in the next figure.

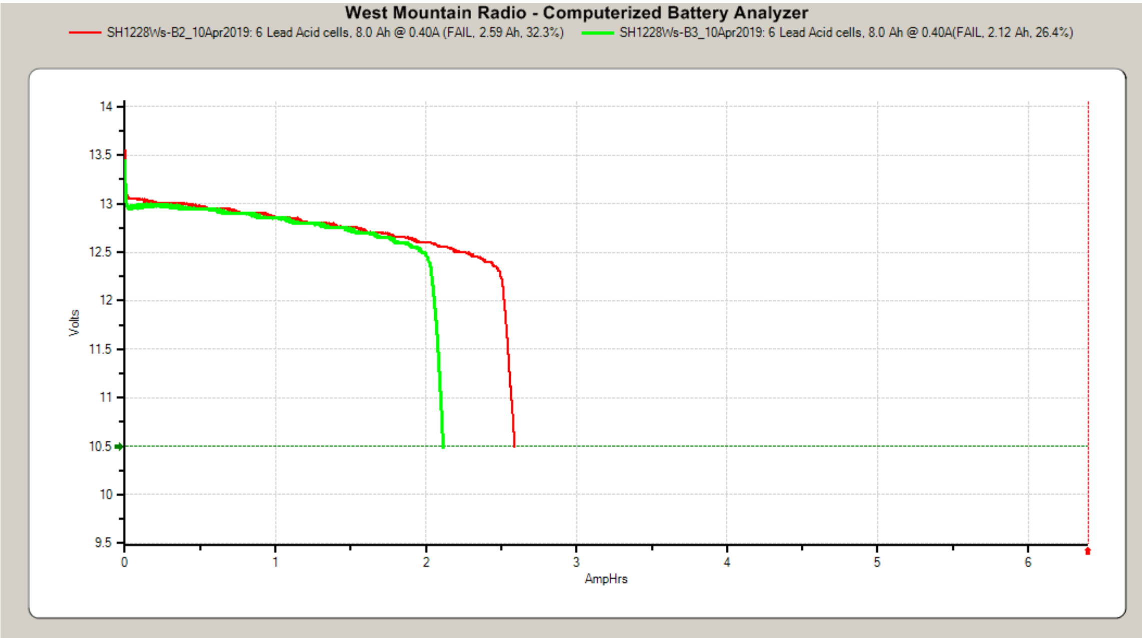

Figure 13 ~ Battery performance plot for the SH1228Ws battery shown by the red trace in the previous plot except for two more recharge/discharge cycles. The battery was recharged for about 15 h and then discharged (red trace). This was followed by 72 h recharge and another discharge (green trace). The batteries clearly fail all tests and are scheduled for recycling.

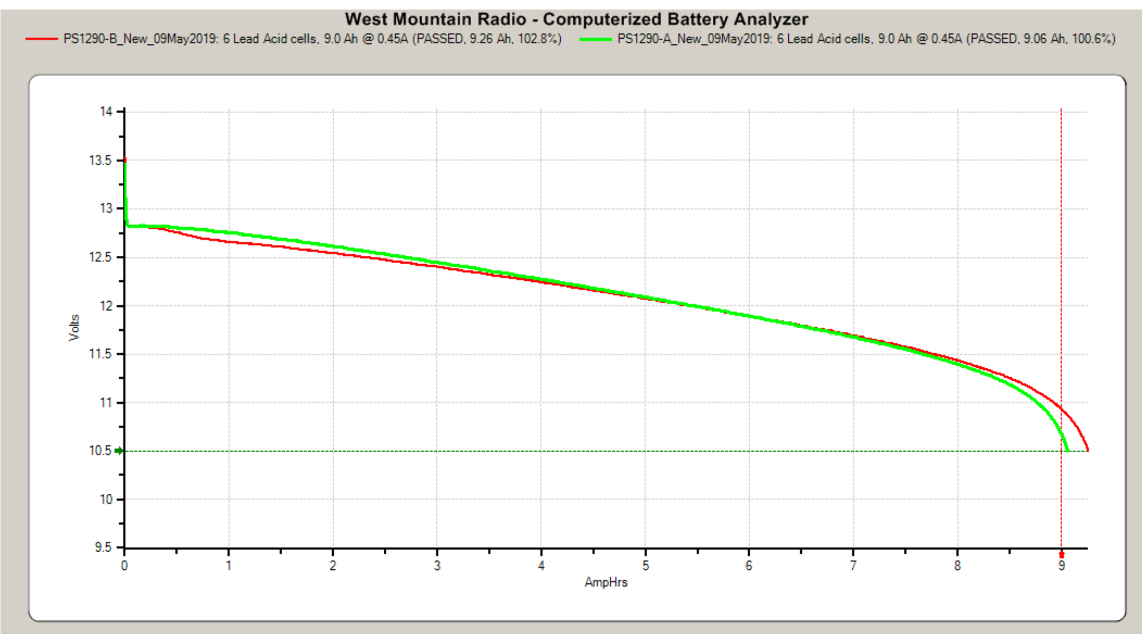

Figure 14 ~ Battery performance plot for two new Powersonic PS-1290 batteries. Both batteries were fully charged for at least 24 h before the discharge tests. The nameplate capacity is 9 Ah to 1.75 VPC at the 20 h rate, so the discharge current was set to 0.45 A and discharge cutoff to 10.5 V. Because the batteries were new, the red vertical pass/fail line was set to

100%, or 9 Ah. Both batteries passed the tests, one with a few percent extra capacity (red trace). The other battery (green trace) had been discharged and recharged once before the test shown here.

Close examination of the discharge plots for the older batteries show a voltage dip and small recovery at the very beginning of the discharge; this is called the *coup de fouet*, or *whiplash*, and is common to lead-acid batteries when discharged. This effect indicates lead sulfate build-up on the battery plates and is less apparent in new batteries. Studies have shown that the magnitude of the dip correlates well to the amount of capacity loss as batteries age.

All batteries were immediately recharged after each test so they would not sit in a discharged condition (figure 15). The test durations ranged from about 5 h for the older batteries because they discharged faster to more than 20 h for the new ones. No attempt was made to "rejuvenate" the older batteries with the voodoo devices advertised for that purpose because any "improvement" in battery condition generally is short-lived.

Battery testing is only meaningful if it is started with a full charge. This means the batteries should be charged until only a small current is necessary to maintain full charge. It should be noted that new batteries may not reach their maximum capacity until they have been in service for up to a year but usually within a few months.

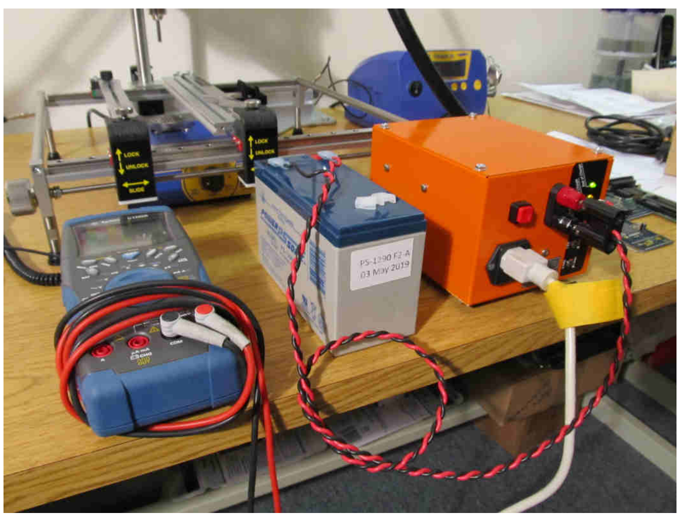

Figure 15 ~ Battery charging between discharge sessions. The (orange) shop-built charger on the right provides a relatively high initial charge current (up to 1 A) to the battery in the middle. When the battery voltage rises and acceptance current drops to a preset threshold, indicating full charge, the charger automatically switches to a float mode. This mode provides a regulated float voltage of 13.66 V (2.28 VPC). The datasheet for the battery shown recommends a float voltage between 13.5 and 13.8 V at 20 °C, and says "When held at this voltage, the battery will seek its own current level and maintain itself in a fully charged condition." The charger has state indicators (LEDs) but no meters, so the DMM on the left is used to occasionally check the battery voltage. Image © 2019 W. Reeve

7. Operating Costs

At least three life cycle costs are associated with operating a UPS – battery replacement costs, electricity costs and UPS disposal costs. Battery replacement costs include not only the cost of the new batteries but the cost of recycling the old ones. Many battery vendors exchange new batteries for the old ones but usually charge for recycling. Hazardous materials recyclers also accept old batteries for a fee. Recycling fees can range from 10 to 50% (or even more) of the costs of new batteries.

A UPS is not 100% efficient and will use some electricity while simply plugged into the primary power source. Some of this is used by the charger to compensate for internal battery losses during float charge, and some is used to power the internal control electronics. To determine the magnitude of these costs, a P3 International

P4460 *Kill A Watt EZ* power meter was used to measure the power consumption of two UPSs with no connected load (table 2).

Table 2 ~ UPS measurements with no external load using P4460 power meter. Costs are first-order estimates, see text. The incremental electricity rate ($0.197/kWh) applies to residential service at Anchorage, Alaska.

Parameter	**UPS No. 1**	**UPS No. 2**
Manufacturer	CyberPower	CyberPower
Model	CST1350AVRLCD	CST135XLU
Rating at 120 Vac	1350 VA/815 W	1350 VA/815 W
Total test time	189 h	138 h
Energy use during test period	1.22 kWh	0.89 kWh
Apparent load	6 VA	8 VA
Real load	4 W	6 W
Input current	0.05 A	0.07 A
Power factor	0.6	0.71
Costs (rounded) at $0.197/kWh	$0.19/week, $0.85/month, $10.85/yr	$0.19/week, $0.85/month, $10.35/yr

The power meter was connected between the UPS and a lab receptacle. Both UPSs had two new, fully charged batteries. The measured load was quite low. The power meter accuracy is not specified at such low levels and its resolution is fairly coarse. Therefore, I also measured the UPS no-load current with an Intertek UNI-T UT210E clamp-on ammeter (3% accuracy) and it read about 30 – 40% higher than the power meter. The power meter current error probably translates to wattage and cost errors but I made no attempt to determine them.

There may be hazardous or recyclable materials in a UPS in addition to the batteries. If so, there likely will be a disposal charge when the UPS reaches end of life; however, these disposal costs may be far enough in the future that the present worth of the future disposal charge is not significant. Recyclers may charge a flat fee or a fee based on weight.

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8. Conclusions

The uninterruptible power system can provide power backup to a PC when the observatory primary power source fails and, thus, helps improve data reliability and continuity. Generally, the only significant maintenance needed on a name-brand UPS is battery replacement after 3 to 7 yr of use. Batteries may be tested using a computerized battery analyzer or any method that provides a controlled discharge. If necessary, battery replacement is easy and cost effective, but recycling costs do add to the overall UPS operating costs.

If the UPS batteries require replacement, two important rules are

1) It is false economics to replace a used battery with another used battery, euphemistically called "refurbished", that was bought at a high discount. The only truly refurbished battery is one in which the case was opened, the plates replaced, the case resealed and the battery fully tested;
2) Never mix used and new batteries except on a temporary basis (for instance, to temporarily recover from a battery failure until new replacements are available).

9. References and Weblinks

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