UNINTERRUPTIBLE POWER SUPPLY
BATTERY ACCEPTANCE/CAPACITY TEST PROCEDURE

Developed for BATTCON97
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1. Scope

This procedure supplements existing industry standards and is intended to provide the user with the *minimum recommended* acceptance/capacity test procedures for Uninterruptible Power Supply (UPS) batteries. Additionally, this procedure describes two different methods of loading a UPS battery during an acceptance/capacity test. Both methods are technically correct and will be discussed later in this procedure. It is the user's responsibility to determine which test method is the most technically correct for their respective UPS installation.

2. Definitions

Acceptance Test. A constant load capacity test conducted on a new battery installation to determine that the battery meets specifications or manufacturer's ratings.

Capacity Test. A constant load discharge of a battery to designated terminal voltage.

Battery Terminal Voltage. Overall or total battery voltage measured at the battery terminals.

End Voltage. End of discharge voltage.

Valve Regulated Lead-Acid Cell. A lead-acid cell that is normally sealed via a pressure relief/regulating valve. The gaseous products of electrolysis are normally contained within the cell and recombine to form water.

Flooded Cell. A lead-acid cell in which the gaseous products of electrolysis and evaporation are allowed to escape to the atmosphere as they are generated.

3. References

[1] ANSI/IEEE 450-1995, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Large lead Storage Batteries for Generating Stations and Substations.

[2] ANSI/IEEE 484-1996, IEEE Recommended Practice for Installation Design and Installation of Large Lead Storage Batteries for Generating Stations and Substations.

Note: While the IEEE Standards listed above were written primarily for generating stations and substations, the information and practices contained in these Standards are applicable to UPS lead-acid battery installations. As new standards are developed and published, portions of this procedure may need to be revised to comply with the new standards.

4. Purpose

Capacity testing is a very important part of a comprehensive battery maintenance program. Regularly scheduled capacity testing is a key part of IEEE/ANSI Standard 450-1995, which specifies minimum acceptable standards for maintenance of large lead acid storage batteries.

Capacity testing serves three main purposes. First, capacity testing determines the actual capacity of the battery. Second, capacity testing determines if the battery can support the connected load for the specified time. Third, capacity testing will reveal internal conduction path problems that cannot be detected by other means.

5. Definition

5.1 **General:** A capacity test is basically a constant load discharge of the battery to a specified end voltage. The time required for the battery voltage to drop to the specified end voltage is then compared with the battery manufacturer's discharge curve to determine the capacity of the battery. The following paragraphs detail items of paramount importance when conducting capacity tests.

5.2 **Continuous Monitoring:** All battery parameters require continuous monitoring. Continuous monitoring of individual cell voltages and overall battery voltage is required to detect problems such as high conduction path resistance, low cell voltage or cell reversal and alarming or terminating the test, as appropriate, on out-of-tolerance conditions.

5.3 **Load Control:** Maintaining a constant discharge load throughout the test despite changes in battery voltage. This requires an intelligent or "smart" load unit that can automatically parallel additional load elements to maintain a constant load as the battery voltage drops during the discharge.

5.4 **Data Logging:** Automatic data logging should record any change in each monitored parameter providing a complete record of events and irrefutable data.

5.5 **Automatic Test Execution:** This removes the largest and most uncontrollable testing variable, the human element, thus insuring test repeatability and accurate results.

6. Safety Considerations

6.1 **General:** Personnel safety is of supreme importance! Batteries are inherently dangerous devices presenting risks of injury and/or death from electrocution, explosion, fire, and chemical burns. All flooded cells contain explosive concentrations of hydrogen and oxygen gas. Individual cells of relatively small size can produce high short circuit currents, (in the area of 1000 to 5000 amps). Larger cells can produce short circuit currents in excess of 10,000 amps. Cell short circuits caused by maintenance personnel can result in severe injury and/or death from fire, explosion, and chemical burns. The electrolyte in lead-acid cells is dilute sulfuric acid. Skin exposure to lead-acid battery electrolyte will generally cause only minor burns if not promptly treated, however, exposure to the eyes, and/or mucous membranes will cause severe debilitating burns without immediate first aid.

6.2 **Safety Rules:** The following safety rules must be stringently followed:

(1) Do not lay any tools or materials, (nuts, bolts, intercell connectors, etc.), on top of the cells.

(2) No smoking, open flame or other ignition sources are permitted in the vicinity of the battery.

(3) When possible, explosion resistant vent caps, (flame arresters), must be installed in the cell vents.

(4) All hand tools must be electrically insulated. Tools may be insulated with electrical tape and/or insulating shrink wrap tubing. When insulating tools, insulate every possible surface that can be insulated while still allowing proper use of the tool. ***NOTE: Don't be stingy with the electrical tape. Your safety depends on it!***

(5) Safety glasses and face shields are the minimum required personnel safety equipment.

(6) Batteries used in some UPS systems are intentionally grounded. In grounded DC systems all cell posts are electrically live with respect to earth ground. High voltage UPS battery systems pose a significant electrocution hazard. Personnel should always be isolated from earth ground when working on grounded DC systems.

7. Initial Conditions

7.1 **General**. The following initial conditions *must* be met prior to commencing an acceptance test. Failure to meet these initial conditions will result in invalid test results and the possibility of the battery failing the acceptance test.

7.2 **Installation Inspection**. Inspect the battery and insure that is installed in accordance with IEEE 484-1996.

NOTE: If the test to be performed is a capacity test conducted with the battery in the "as found" condition, proceed to step (9).

(1) Insure that all intercell connections are installed in accordance with the battery manufacturer's instructions.

(2) Insure that all intercell connection resistances have been measured and recorded.

(3) Insure that all intercell connection resistances are under the battery manufacture's ceiling value and that there are no resistances more than 10% or five microhms, whichever is greater, above the average intercell connection resistance.

(4) Insure that all battery cabling is properly supported. *Cable connections should not strain the cell posts!* Improperly supported cables can cause premature post seal failure, high resistance connections and bent or broken cell posts.

(5) Insure that all inter-tier/row cable resistances are under the battery manufacture's ceiling value. Like cable connection resistances should be no more than 10% or five microhms, whichever is greater, above the average cable connection resistance for similar connections.

(6) Insure the battery has received a freshening charge in accordance with the battery manufacturer's instructions and IEEE/ANSI Std. 484-1996.

(7) Review the initial specific gravity and cell voltage readings, taken 72 hours after the termination of the freshening charge, and insure that all voltage and gravity readings are within the battery manufacturer's specified limits.

(8) If more than thirty days has elapsed between the termination of the freshening charge and initiation of the acceptance test, an equalization charge is required. If required, the equalization charge should be accomplished in accordance with the battery manufacturer's instructions. After termination of the equalization charge, allow the cell voltages and specific gravities to stabilize on float charge for at least 72 hours, but not more than thirty days before proceeding with the acceptance test.

(9) Measure and record all cell voltages and specific gravities. Correct all specific gravity readings for temperature and level and record the corrected values. *NOTE: A temperature compensating digital hydrometer is strongly recommended for specific gravity measurements.*

(10) Measure and record the electrolyte temperature of at least 10% of all cells and calculate the average electrolyte temperature. Note: On Valve Regulated cells, measure the temperature of the negative posts. During oxygen recombination the negative plates and post will be slightly warmer then the positives.

(11) Measure and record the float voltages of all cells.

8. Test Methods

8.1 **General.** There are two industry accepted methods of applying load to a UPS battery during an acceptance/capacity test. Each method has its particular advantages; however, both methods, when properly executed, will accurately measure battery capacity. Regardless of the loading method used, the following battery parameters ***MUST*** be monitored during the discharge test:

(1) Individual cell voltages. This measurement must include the voltage drop across each cell's associated intercell connector.

(2) Battery terminal voltage, (overall battery voltage).

(3) Battery discharge current.

The above-mentioned parameters should be monitored on intervals not exceeding thirty seconds.

8.2 **D.C. Load Bank(s).** In this method, computer controlled load bank(s) are used to directly load the battery independent of the UPS. This requires that the battery be removed from service. The UPS, depending upon its design, may be able to remain in service as a power conditioner. This type of test is generally the most repeatable and controllable method of loading a battery; however, it can be expensive in terms of equipment cost. A major consideration and possible limiting factor when using computer controlled D.C. load banks are locating them near the battery and dissipating the heat from the load banks.

8.2.1 **Discharge Rate.** The discharge rate should be equal to the battery's design reserve time to an end voltage equal to the UPS "D.C. Under Voltage Shutdown Level." This information is then compared with the battery manufacturer's discharge tables/curves to determine the correct load to place on the battery at 77°F. initial average electrolyte temperature.

8.2.2 **Temperature Compensation.** Batteries produce electrical energy by means of an electrochemical reaction and the speed of that reaction directly affects battery performance. The speed of the electrochemical reaction is directly affected by electrolyte temperature; therefore, battery performance must be corrected to a standard temperature. The standard temperature for batteries of U.S. manufacture is 77°F.

Battery performance data published for cells of U.S. manufacture is only valid when the electrolyte temperature is 77°F. If the electrolyte temperature is other than 77°F. the discharge load is normally adjusted, up or down, for temperature prior to starting a discharge test. A temperature correction factor table may be found in IEEE Std. 450-1995. The temperature correction factors published in IEEE 450-1995 are only valid for nominal 1.215 specific gravity cells. Additionally, these temperature correction factors are only valid at the eight-hour discharge rate. Since UPS battery discharge rates are normally in the ten to thirty minute ranges and many UPS batteries have nominal specific gravities higher that 1.215, the battery manufacturer should be consulted to obtain the correct temperature correction factor.

8.3 **Inverter Loading.** In this method, an A.C. load is placed on the output of the UPS and then input power to the UPS is removed causing the battery to discharge into the UPS inverter. This type of test requires that the UPS be removed from service and isolated from the critical load. The major advantages of this type test are that it is an excellent functional test of the UPS, since it simulates worst case operating conditions, and the comparatively lower cost of the load equipment. Standard A.C. load banks can be used in lieu of computer controlled D.C. load banks.

8.3.1 **Discharge Rate**. When loading a battery through the inverter section of a UPS, it is not normally possible to accurately set or specify the discharge load on the battery. This is because of variances in individual inverter efficiencies. Therefore, the inverter should be loaded to its maximum rated output current via an A.C. load bank(s). The actual load placed on the battery will not be known until the test starts. Since the load placed on the battery in this type of test cannot normally be accurately set or specified prior to starting the test, temperature compensation of the discharge load is not possible. When the initial average electrolyte temperature is other than 77°F, the test results must be corrected for temperature. This will be explained later in the section on calculating capacity.

8.3.2 **Emergency Test Termination**. The user must determine how to remove the load from the battery safely and quickly if an unsafe condition occurs during the test, (over heated connection, cell polarity reversal, etc.).

9. Procedure

9.1 **D.C. Load Bank(s).**

(1) Isolate the battery from the UPS system.

(2) Connect data logging/control instrumentation to the battery.

(3) Connect D.C. load units to the battery.

CAUTION: Care should be exercised in the positioning of air cooled load units as the heat dissipated during the test may trigger the building fire alarm system. If the facility is equipped with an automatic fire suppression system, consideration should be given to inhibiting the automatic activation of the fire suppression system during the discharge test.

(4) Using the average initial electrolyte temperature, from step 7.2.10, select the proper temperature correction factor and temperature compensate the discharge load.

(5) Apply the load to the battery. The load must be maintained at the specified level throughout the test until the battery terminal voltage drops below the specified end voltage.

NOTE: Capacity tests are not stopped after reaching a specified discharge time. Capacity tests are only terminated when the battery terminal voltage drops below the specified end voltage. Example: End voltage per cell times the number of cells in series equals the battery terminal end voltage, 1.67 (per cell end voltage) x 180 (cells in series) = 300.6 (battery terminal end voltage). The capacity test would terminate when the battery terminal voltage dropped below 300.6 VDC.

(6) Check for over heated connections during the test. If the temperature rise across any connection becomes unacceptable, terminate the test.

NOTE: High resistance connections appear as low voltage cells during the test. This is because the cell voltage measurements include the voltage drop across the cell's associated intercell connector. Normally, (but not always), a cell showing low voltage during the first thirty to sixty seconds of a capacity test is not truly a low voltage cell but rather a high resistance connection.

(7) If the voltage of any cell approaches polarity reversal, (less than one volt), terminate the test.

CAUTION: Cells should not be allowed to go into polarity reversal as this causes irreparable damage to the cell and can pose a safety hazard.

(8) At the conclusion of the test, record the elapsed test time, disconnect all test equipment, and return the battery to service.

CAUTION: Care should be exercised when returning the battery to service. If this battery serves a static UPS that is still supplying power to the critical load, closing the battery breaker may cause a momentary under voltage condition on the output of the UPS. This may adversely affect the critical load and/or cause the UPS to transfer to the "Bypass" or alternate power source.

CAUTION: UPS systems that are lightly loaded and have no "Battery Charge Current Limit" may supply recharge currents high enough to cause a significant increase in battery temperature. This may cause the battery to enter a "Thermal Runaway" condition that can destroy the battery and pose a fire safety hazard. Valve Regulated Lead-Acid cells are more prone to thermal runaway than flooded cells. The electrolyte temperature of flooded cells should not exceed 110°F. and, the electrolyte temperature of Valve Regulated Lead-Acid cells should not exceed 95°F. to prevent thermal runaway during battery recharge.

9.2 **Inverter Loading.**

(1) Isolate the UPS from the critical load.

(2) Connect A.C. load unit(s) to the inverter/UPS output.

CAUTION: Care should be exercised in the positioning of air cooled load units as the heat dissipated during the test may trigger the building fire alarm system. If the facility is equipped with an automatic fire suppression system, consideration should be given to inhibiting the automatic activation of the fire suppression system during the discharge test.

(3) Connect data logging/control instrumentation to the battery and start data logging.

NOTE: It is imperative that battery discharge current be monitored and recorded during the test. The preferred method for monitoring discharge current is via a D.C. shunt. A properly sized D.C. shunt is normally far more accurate than clamp-on D.C. ammeters. Many UPS systems have an internal D.C. shunt for monitoring battery charge/discharge current.

(4) Apply maximum A.C. load to the inverter.

(5) Open the A.C. input feeder breaker to the UPS simulating an input power failure. This will cause the battery to discharge into the inverter. Continue the discharge until UPS trips for "D.C. Under Voltage" or the battery terminal voltage drops below the specified end voltage. The UPS may trip for "D.C. Under Voltage" at a battery terminal voltage that is different from the specified battery terminal end voltage. It is the user's responsibility to insure the battery is not over discharged because of a faulty "D.C. Under Voltage Trip" circuit.

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(6) Check for over heated connections during the test. If the temperature rise across any connection becomes unacceptable, terminate the test.

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(7) If the voltage of any cell approaches polarity reversal, (less than one volt), terminate the test.

***CAUTION**: Cells should not be allowed to go into polarity reversal as this causes irreparable damage to the cell and can pose a safety hazard.*

(8) At the conclusion of the test, record the elapsed test time, disconnect all test equipment, and return the battery to service.

***CAUTION**: UPS systems that are lightly loaded and have no "Battery Charge Current Limit" may supply recharge currents high enough to cause a significant increase in battery temperature. This may cause the battery to enter a "Thermal Runaway" condition that can destroy the battery and pose a significant fire safety hazard. Valve Regulated Lead-Acid cells are more prone to thermal runaway than flooded cells. The electrolyte temperature of flooded cells should not exceed 110°F. and, the electrolyte temperature of Valve Regulated Lead-Acid cells should not exceed 95°F. to prevent thermal runaway during battery recharge.*

10. Capacity Calculations

10.1 **D.C. Load Bank(s).** The capacity calculation for this test method is very simple. Divide the actual test time, (how long the test actually ran), by the specified test time, (how long should the battery have lasted), and then multiply the product by one hundred. The equation is shown below:

$$\%\ \text{capacity at } 77°\text{F} = \frac{T_a}{T_s} \times 100$$

where:
T_a = actual test time
T_s = specified test time

10.2 **Inverter Loading.** Capacity calculations for this test method are generally more complex because the actual discharge load is not known nor can the load be temperature corrected to 77°F prior to test initiation.

10.2.1 **Constant Power Capacity Calculations.**

(1) Determine the kilowatt loading of the battery by multiplying the current readings by the voltage readings. All the kilowatt calculations should be approximately the same.

(2) If the initial average electrolyte temperature is other than 77°F the calculation must be corrected for temperature. To correct the calculation for temperature, multiply the total battery kilowatt loading, (from the previous step), by the appropriate temperature correction factor, (see 8.2.2).

(3) Determine the kilowatts per cell by dividing the total temperature corrected battery kilowatt loading, (from the previous step), by the number of cells in the battery.

(4) Determine the average per cell end voltage by dividing the actual battery terminal end voltage by the number of cells in series.

(5) Compare the temperature corrected kilowatts per cell, (from step (3) above), and the average per cell end voltage, (from step (4) above), to the battery manufacturer's per cell kilowatt chart to determine the specified test time, (how long the battery should have lasted).

(6) Calculate the battery capacity by dividing the actual test time, (how long the test actually ran), by the specified test time, (from step 5 above), and then multiply the product by one hundred. The equation is shown below:

$$\% \text{ capacity at } 77°\text{F} = \frac{T_a}{T_s} \times 100$$

where:
T_a = actual test time
T_s = specified test time

EXAMPLE: Battery manufacturer "A" cell model XYZ-37, 180 cells in series.

Total battery kilowatt loading from step (1) above: 580KW

Initial average electrolyte temperature from 7.2.(10): 67°F

Temperature correction factor from IEEE 450-1995 and confirmed by the battery manufacturer, (see paragraph 8.2.2): 1.064

Total temperature corrected battery kilowatt loading from step (2) above: 580KW x 1.064 = 617KW

Temperature corrected kilowatts per cell from step (3) above:

$$\frac{617\text{KW}}{180} = 3.427 \text{ KW per cell}$$

Battery terminal voltage at end of test: 300.6

Average per cell end voltage from step 4 above:

$$\frac{300.6}{180} = 1.67 \text{ Volts per cell}$$

Specified test time from the battery manufacturer's data sheet, (step 5 above): 13 minutes

Actual test time: 12.5 minutes

Capacity calculation: $\frac{12.5}{13} \times 100 = 96.2\%$ capacity

10.3 **Weak Cells**. Analyze the test data to determine if there are any weak cells in the battery. A weak cell is any cell with a capacity 10% or more below the battery capacity. Individual cell capacity can be determined by substituting the time that the cell voltage fell below the specified end voltage for "T_a" in the capacity formula.

10.4 **Defective Cells**. Analyze the test data to determine if there are any defective cells in the battery. A defective cell is any cell with a capacity of 80% or less. Individual cell capacity can be determined by substituting the time that the cell voltage fell below the specified end voltage for "T_a" in the capacity formula.

11. Battery Replacement Criteria

The industry accepted replacement criteria for rectangular pasted plate cells, (most stationary batteries), is to replace the battery when the measured capacity drops to 80% of the manufacture's rated capacity. This replacement criterion is valid for batteries sized in accordance with IEEE 485. Unfortunately, most UPS batteries are not sized in accordance with the spirit or intent of IEEE 485 and therefore may require replacement at higher capacities. When most UPS batteries are sized, no aging factor, temperature correction factor, or cable loss corrections are used. This means the battery will only support full rated UPS load when electrolyte temperature is 77°F or greater and the battery has more than 100% of rated capacity. In these instances, the UPS user must determine how much battery reserve time is required for their respective installation. This would then be used as the battery replacement criteria as long as the battery capacity was greater than 80%. All rectangular pasted plate lead-acid cells should be replaced when the measured capacity drops to 80% of the manufacturer's rated capacity regardless of connected load.

12. Test Frequency

12.1 **Short Duration Flooded Lead-Acid Cells:** Batteries comprised of flooded cells with a design discharge time of one-hour or less should receive annual capacity tests.

12.2 **Long Duration Flooded Lead-Acid Cells:** Batteries comprised of flooded cells with a design discharge time greater than one-hour should be tested according to the following schedule:

(1) Conduct an Acceptance Test upon installation.

(2) Conduct a Capacity Test after the battery has been in service for two years and every three years thereafter until the battery reaches 85% of its design life or shows signs of degradation.

(3) Conduct annual Capacity Tests on batteries that exceed 85% of their rated design life or show signs of degradation. Signs of degradation are a drop of capacity of 10% or more from the previous capacity test or when the capacity is less than 90% of the manufacturer's rated capacity.

12.2 **Valve Regulated Lead-Acid Cells:** Batteries comprised of Valve Regulated Lead-Acid Cells should receive annual capacity tests.