SUBSTATION SWITCHGEAR
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 substation switchgear battery systems. This procedure describes only Off-line testing using a computer control test system and a temporary battery.

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.

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 before 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. Temporary Battery

8.1 **Requirement for a Temporary Battery.** Substation switchgear batteries provide crucial control and safety functions. The primary purpose of a switchgear battery is to provide the energy to trip or open circuit interrupting devices, (circuit breakers, motor operated switches, etc.), during an electrical fault on the effected A.C. transmission/distribution line. Additionally, the battery is sized to operate the maximum number of circuit interrupting devices required to operate during a worse case fault scenario. Battery chargers should never be relied upon to operate the switchgear without a suitably sized battery connected. The control circuitry used in most battery chargers will not function properly without a battery connected to the charger output. Additionally, battery chargers that can maintain a regulated output without a battery connected should not be relied upon to operate the switchgear without a suitably sized battery connected because the A.C. input power to the charger may be interrupted during an electrical fault on the effected A.C. transmission/distribution line.

8.2 **Requirements of a Temporary Battery.**

(1) A temporary battery can utilize any of the conventional battery chemistries, (flooded lead-acid, valve regulated, nickel cadmium).

(2) The temporary battery must be voltage compatible with the battery to be tested.

(3) A temporary battery should be portable and capable of surviving the rigors of highway travel. Stationary batteries make poor temporary batteries because they are not designed to withstand the rigors of highway travel. Batteries designed for motive power or locomotive applications generally have more robust design and construction features making them ideal for a temporary battery. Additionally, some valve regulated lead-acid and nickel cadmium cell designs are suitable for temporary battery applications.

(4) A temporary battery ***MUST*** be able to supply the highest or worse case currents required by the switchgear to which the battery will be connected. Remember that temperatures below 77°F. reduce battery capacity.

NOTE: Automotive class batteries, (automobile starting batteries, deep cycle R.V. or trolling motor batteries, truck starting batteries, etc.), are not desirable for temporary battery use. This type battery has very thin plates that have a very short life in float operations. When used as a temporary battery, automotive class batteries should be limited to a maximum in service or float charge time of ninety days.

9. Discharge Rate

The discharge rate and time selection is based upon the battery's design duty cycle. First the duty cycle is compared with the battery manufacturer's discharge curves. A discharge rate is then selected which equals or slightly exceeds the battery's design duty cycle. The recommended discharge rate for lead-acid switchgear batteries is either the fifteen-minute or thirty-minute discharge rate to an end voltage of 1.75 volts per cell.

10. 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. The battery manufacturer should be consulted to obtain the correct temperature correction factor.

11. Test Procedure

11.1 **General.** 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.

11.2 **Procedure.**

(1) Insure the battery has received an equalization charge at least three days, but no more than thirty days, before the test. ***NOTE: An equalization charge is not required if the battery is being tested in the "as found" condition.***

(2) Measure and record the specific gravity of all cells except Valve Regulated and/or Nickel Cadmium, (NiCad), cells.

(3) Measure and record the electrolyte temperature of at least 10% of the cells and calculate the average temperature. *NOTE: Negative post temperatures are substituted for electrolyte temperatures on valve regulated cells.*

(4) Measure and record cell float voltages.

(5) Parallel portable battery plant with station battery.

(6) Isolate the station battery from the DC system.

(7). Connect test equipment to battery.

(8) Apply the temperature correction factor to discharge load and program test equipment.

(9) Initiate the capacity test. 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, 1.75 (per cell end voltage) x 60 (cells in series) = 105.0 VDC (battery terminal end voltage). The capacity test would end when the battery terminal voltage dropped below 105.0 VDC.

(10) Check for over heated connections during the test. Pause, or terminate if necessary, the test if the temperature rise across any connection becomes unacceptable. The test pause time should be kept to less than 10% of the specified test time.

NOTE: High resistance connections will show 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 a high resistance connection.

(11) If the voltage of any cell approaches polarity reversal, (less than one volt), pause the test, jumper around the cell, and resume the test to the new end voltage. The test pause time should be no more than 10% of the specified test time.

CAUTION: *Isolate the cell to be jumpered before connecting the jumper. Do not short circuit the cell being jumpered.*

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.*

(12) At the conclusion of the test, record the elapsed test time, disconnect all test equipment.

(13) Match the battery and DC bus voltages. This can be accomplished by either raising the battery voltage to match the DC bus or by lowering the DC bus to match the battery. Raising the battery voltage will require a separate charger and sufficient time to recharge the battery. Lowering the DC bus voltage will require that the battery charger be turned off or turned down.

NOTE: The battery voltage will normally recover to nominal open circuit voltage within 30 minutes of test termination.

(14) Reconnect the battery to the DC bus when the voltages match. The allowable voltage difference is a local determination; however, a voltage difference of 5.0 VDC or less is normally considered acceptable.

(15) Monitor the initial recharge and, if necessary, adjust the charger current limit and output voltage levels.

(16) Disconnect portable battery plant.

12. Data Analysis

12.1 **Capacity Calculation.** 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

12.2 **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.

12.3 **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.

13. 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.

14. Test Frequency

14.1 **Flooded Lead-Acid Cells.** Batteries consisting of flooded cells should be tested according to the following schedule, (IEEE/ANSI Std. 450-1995), when the battery installation design complies with IEEE/ANSI Std. 484-1996. Batteries subjected to extreme temperatures should receive annual capacity tests.

(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.

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