CENTRAL TELEPHONE OFFICE BATTERY PLANT
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 Central Telephone Office battery plants. Additionally, this procedure describes two different methods of loading a Central Telephone Office battery plant during a capacity test. Both methods are technically correct and will be discussed later in this procedure. It is the user's responsibility to determine the appropriate test method for their respective installation. This procedure requires the use of automated battery capacity test equipment but does not endorse or require a specific manufacturer or model of test equipment.

2. Definitions

Acceptance Test: A constant load capacity test conducted on a new battery installation to determine that the battery meets purchase specifications and/or manufacturers' 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 Central Telephone Office 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 telephone switching systems are intentionally grounded. In grounded DC systems all cell posts are electrically live with respect to earth ground. 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 / capacity 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 Central Telephone Office battery plant 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 **Off-Line, (Isolated Battery), Testing:** This is technically the best and safest test method; however, it is time consuming and costly. Off-line testing is the most repeatable and controllable method of capacity testing a battery and when properly executed will reveal every performance related problem in the battery. This test method requires that the battery be electrically isolated from the DC bus. Isolating the battery to be tested is relatively simple in offices with two or more batteries in parallel. Small single battery offices require the use of a temporary battery. Consideration should be given to the reduced battery plant reserve time when one battery is isolated from the DC bus. In offices with standby generators the reduced reserve time has little consequence; however, when an alternate power source is not available, the reduction in battery plant reserve time requires serious consideration. Reconnecting the tested battery to the DC bus in an on-line central telephone office requires matching the voltages of the incoming battery and the DC bus. Failure to match the voltages will generate voltage transients that may affect the telephone switching equipment.

8.2.1 **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.). Automated test equipment can be programmed to stop a test automatically if an unsafe condition develops.

8.2.2 **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. Then a discharge rate is selected which equals or slightly exceeds the battery's design duty cycle. Most central office battery plants are designed for an eight-hour reserve time. An eight-hour test is both time consuming and removes an excessive amount of energy from the battery. Testing at the three-hour discharge rate will produce nearly identical results to an eight-hour test and remove significantly less energy from the battery plant. The end voltage used for an off-line test should be the same as the low voltage shut down level of the connected telephone switching equipment. This is normally 42.0 VDC or 1.75 volts per cell.

8.3 **On-Line Testing:** This test method loads the entire battery plant using normal office load and supplemental DC load bank(s). On-line testing is a realistic and cost-effective method of determining total battery plant capacity and individual battery string capacity. On-line testing will also reveal weak points in the DC distribution system that might not be otherwise detected. In this test method the battery plant is discharged to an end voltage that is safely above the DC low voltage limit of the connected telephone switching equipment. On-line testing ***REQUIRES*** the use of automated test equipment and a central or *"master"* DC shunt for measuring the total office load. The major advantages of this type test are that it is an excellent functional test of the battery plant and DC distribution system. It simulates, under controlled conditions, near worst case operating conditions, and it significantly reduces the cost of capacity testing as an entire battery plant can be tested at once. The major limitation of On-line testing is that it can be difficult to determine individual battery string capacity, especially when dissimilar model cells are connected in parallel or when the capacity of one string is significantly lower than the other string(s). In such case, the results of On-line testing will reveal total battery plant capacity and indicate that additional Off-lines tests are necessary to fully define all battery problems.

8.3.1 **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.). The automated test equipment can be programmed to remove the additional test load automatically; however, the rectifiers must be manually started to stop the battery plant discharge.

8.3.2 **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. Then a discharge rate is selected which equals or slightly exceeds the battery's design duty cycle. Most central office battery plants are designed for eight hour reserve time. An eight-hour test is both time consuming and removes an excessive amount of energy from the battery. Testing at the three-hour discharge rate will produce nearly identical results to an eight-hour test and remove significantly less energy from the battery plant. The end voltage used for an on-line test must be low enough to be realistic yet high enough to prevent failure of the telephone switching equipment. An end voltage of 1.86 volts per cell is recommended as this provides an end of test voltage of 44.64 VDC at the DC bus. Virtually all electro-mechanical and digital switching equipment in use in the U.S.A. will operate satisfactorily at this voltage. In some instances higher end voltages may be required or lower end voltages may be used. The use of end voltages higher than 1.86 volts per cell may produce deceptive or inaccurate test results because of the initial voltage drop.

8.4 **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 is found in IEEE/ANSI Std. 450-1995.

9. Procedure

9.1 **Off-Line Testing:**

(1) Isolate the battery from the DC bus.

CAUTION: *Batteries used in telephone switching systems are intentionally grounded. In grounded DC systems all cell posts are electrically live with respect to earth ground. Personnel should always be isolated from earth ground when working on grounded DC systems.*

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

(3) Connect D.C. load unit(s) 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 from IEEE/ANSI Std. 450-1995 and temperature compensate the discharge load.

(5) Program the battery test equipment.

(6) 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, 1.75 (per cell end voltage) x 24 (cells in series) = 42.0 VDC (battery terminal end voltage). The capacity test would terminate when the battery terminal voltage dropped below 42.0 VDC.

(7) 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 rather a high resistance connection.

(7) 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 kept to less 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.*

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

(9) 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 rectifiers be turned off or turned down.

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

(10) Reconnect the battery to the DC bus when the voltages match. The allowable voltage difference is a local determination; however, a voltage difference of 0.1 VDC or less is normally considered acceptable.

9.2 **On-Line Testing:**

(1) Connect data logging/control instrumentation to the battery and the "master" station shunt. The "master" shunt is normally located in the main DC power distribution panel.

(2) Connect D.C. load unit(s) to the load side of the "master' shunt and the “master” or main ground bus. The load unit(s) is connected as if it were an additional piece of telephone switch equipment.

CAUTION: *the load unit(s) should not connect to the DC system via an auxiliary ground bus or equipment ground cables.*

CAUTION: *the load unit(s) should not connect to the DC system via over current protection devices already serving telephone switch equipment.*

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) Using the average initial electrolyte temperature, from step 7.2.(10), select the proper temperature correction factor from IEEE/ANSI Std. 450-1995 and temperature compensate the discharge load.

(4) Program the battery test equipment.

(5) Begin the test by simultaneously turning off the rectifiers and commanding the test equipment to begin the test. The test equipment is sensing system load and will automatically increase the total system load to the programmed level. The test equipment is capable of responding to and correcting for any change in load from telephone switch equipment.

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, 1.86 (per cell end voltage) x 24 (cells in series) = 44.64 VDC (battery terminal end voltage). The capacity test would terminate when the battery terminal voltage dropped below 44.64 VDC.

(6) Measure and record the individual battery discharge currents, (assuming the test is being conduct on an office with two or more parallel batteries), at five minutes into the test and every fifteen to thirty minutes thereafter until test conclusion. Battery discharge currents should be measured with a hall effect type DC clamp-on ammeter.

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

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 rather a high resistance connection.

(8) If the voltage of any cell approaches polarity reversal, (less than one volt), stop the test. The test equipment can be programmed to remove the additional load applied by the load unit(s) automatically if this condition occurs; however, the rectifiers must be manually started to stop the battery discharge.

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.

(9) Continue the discharge until the DC bus voltage decreases to the specified end voltage. Terminate the test when the DC bus voltage drops below the specified end voltage. The test equipment can be programmed to automatically remove the additional load applied by the load unit(s) when the specified end voltage is exceeded; however, the rectifiers must be manually started to stop the battery discharge.

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

10. Capacity Calculations

10.1 **Off-Line, (Isolated Battery), Testing:** 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:

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

where
T_a = actual test time
T_s = specified test time

10.2 **On-Line Testing:**. Battery plant capacity is calculated using the formula shown in paragraph 10.1. Individual battery capacity calculations use the same formula if the total system load was equally divided across like parallel batteries. Capacity calculations are generally more complex if the load was not evenly divided or if dissimilar batteries are connected in parallel. When this occurs it is first necessary to calculate the average discharge load from the data collected in step 9.2(6). Then divide the average load by the number of positive plates in one cell to reduce the load down to amps per positive plate. This is then compared with the battery manufacturer's discharge curves to determine how long the battery should have supported this load to the specified end voltage. This new time then becomes the specified test time used in the capacity formula from paragraph 10.1. *NOTE: This method of capacity calculation will only provide an approximation of individual battery string 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 is calculated 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. To determine individual cell capacity, substitute 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.

12. Test Frequency

12.1 **Flooded Lead-Acid Cells:** Batteries consisting of flooded cells 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 five 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 consisting of Valve Regulated Lead-Acid Cells should receive annual capacity tests.