Predicting Battery Performance Using Internal Cell Resistance

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INTRODUCTION

Predicting whether a battery system will perform its intended backup mission or not is a major challenge faced by all battery users. There are very few battery users today who have absolute confidence in their backup system. Ask any UPS or Telco operations manager if he or she would dare test a system by deliberately disconnecting primary AC power!

The lack of confidence in battery systems has grown considerably since the introduction of VRLA batteries. These maintenance-free wonders, promising 20 year life, have caught many a user by surprise, typically failing in three to four years, and rarely lasting more than six years.

TEST SOLUTIONS

With today's technology, there is no reason why anyone should not have full confidence in their systems. There are both test equipment and procedures available to accurately determine how a battery is going to perform during an emergency. Unfortunately, though, a lot of battery users perceive performance testing as both complicated and expensive.

Load Testing

The most reliable test to prove a battery's ability to perform is to load test the entire string. This test should be performed with automated test equipment that can log data on all the individual cells while subjecting them to a load current that matches the normal operating load. Such a load test performs a 100% integrity check and will identify any problems that exist with either the cells or the external conductance path.

Resistance Testing

A new test, based on looking at a cell's internal resistance, is proving to be a very reliable indicator of state of health and should offer a cost-effective supplement/replacement solution to load testing.

The internal resistance of a cell is closely related to its capacity and can, therefore, be used to predict the cell's performance during a discharge. Even though there is a close correlation between a battery cell's internal resistance and its capacity, it is not completely linear. The resistance measurement is, therefore, not used as a direct indicator of capacity, but, rather, as a warning indicator that signals if a cell has deteriorated to a level that will affect the operating integrity of the system.

Field testing on all types of batteries has proven that, if a cell's internal resistance increases to more than 25% above its known good base line value, that cell will fail a capacity test.

UNDERSTANDING CELL RESISTANCE

To understand why cell resistance is a good indicator of a cell's state of health, it is important to know:

* What a battery looks like internally.

* How resistance measurements are made.

* What parameters influence a cell's resistance.

* What cell problems can be detected.

Internal Battery Parameters

The total conductance path through a cell includes the metallic or ohmic path, as well as the path that is involved electrochemically, as illustrated in Figure 1.

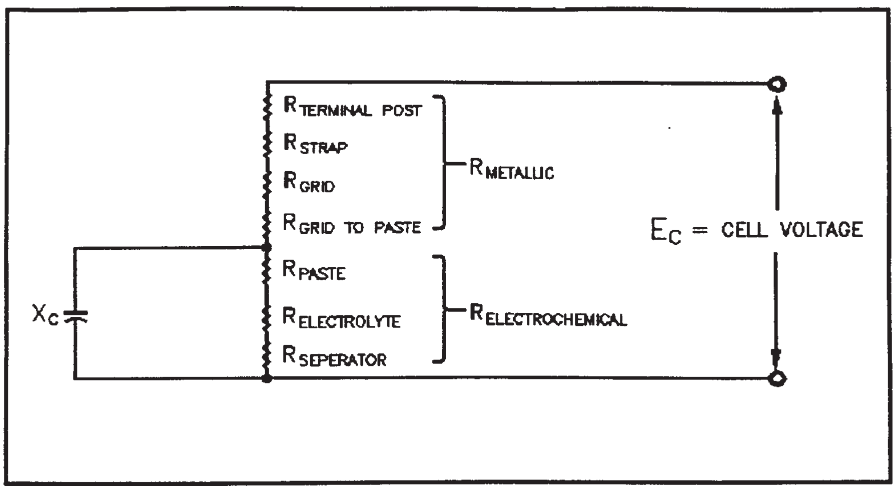

Figure 1: Simplified Model of a Lead-Acid Cell.

The ohmic path includes the resistance of the terminal posts, the strap, the grid structure, and the grid to paste connection. The electrochemical path includes the paste, electrolyte, and the separators. The capacitor C_P is the result of all the parallel plates with a dielectric between them. Capacitor value is a substantial 1.3 to 1.7 farad per 100 ampere hours of battery rating, depending on battery design. The inductance of the battery has been ignored, since its effect is negligible for the frequency range used by today's battery instruments.

Looking closer at the equivalent circuit, it is obvious that the capacitive reactance (X_C) effectively shunts R_E (the electrochemical part of the path), masking the changes that may take place in this part of the path. This part of the path includes the paste and the electrolyte, which is where the energy is stored.

The resistance of the internal circuit path is what influences the capacity/performance of a cell and is, therefore, the important parameter that needs to be measured.

How Measurements Are Made

Instruments presently available use either an AC current injection method or a momentary load test (DC measurement). AC injection instruments, better known as impedance or conductance meters, apply a test signal through the battery and then measure the resulting AC voltage and current. The impedance reading V/I varies with the frequency or the value of capacitive reactance X_C, which in turn lowers electrochemical resistance R_E.

The problem with AC measurements is that they are susceptible to charger ripple currents and other noise sources. Some instruments cannot be used while the battery is on-line (i.e., connected to the charger and load in a normal full float operation). A particularly bad choice of test current frequency is 60Hz in the United States and 50Hz in the majority of the rest of the world, since this is the primary charge ripple and noise source frequency. It is not uncommon to have RMS ripple currents in excess of 30A flowing through large UPS batteries.

The DC load test instruments, which measure resistance, subject the battery to a momentary load current and then measure the instantaneous change in battery terminal voltage. Figure 2 shows what happens when a battery is subjected to a load for a few seconds. The instantaneous drop when the load is applied, or the instantaneous voltage recovery when the load is removed, is due to the internal resistance.

A resistance meter, such as the Albércorp Cellcorder, reads the current and cell voltage just prior to removal of load and then measures the recovered cell voltage. The resultant resistance is simply Rcell = V/I. Present day A/D converters can effectively measure the DC values while totally ignoring any AC signals flowing through the battery at the same time; thus, this type of instrument is capable of operating on-line even in high noise environments.

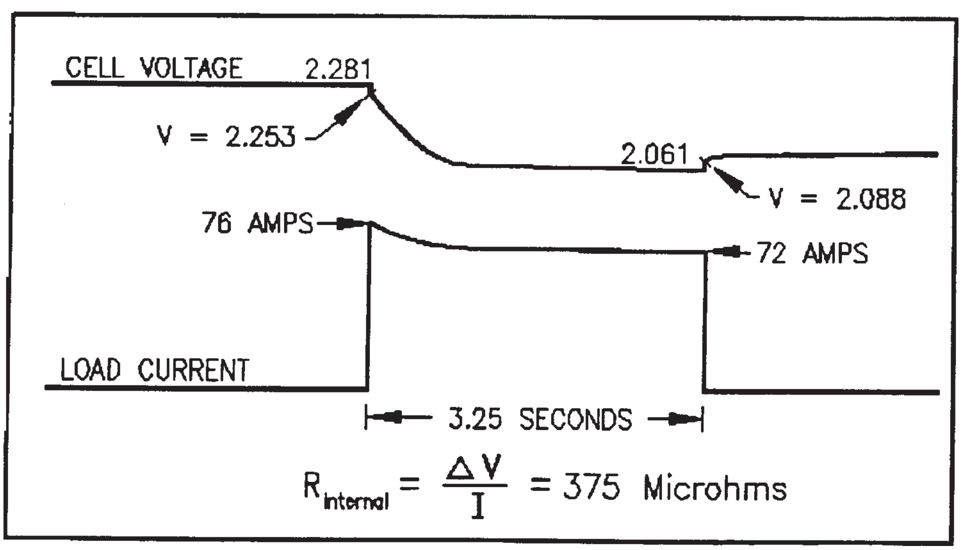

Figure 2: Typical Load Response of a 340Ah Plante Cell.

What Parameters Affect Cell Resistance?

The following more common factors have an effect on a cell's internal resistance:

Corrosion - As the grids and straps corrode, the metallic path is reduced and the internal resistance increases.

Grid Growth - Grid growth associated with corrosion/battery aging causes the active material (paste) to break loose from the grid structure, leading to a high resistance connection problem.

Sulfation - As part of the active material converts to lead sulfate, the paste resistance increases.

Dry Out - This condition, which is unique to VRLA cells, eventually causes a complete break in the conduction path between adjacent grids.

Manufacturing - Manufacturing defects, such as bad lead burns and pasting problems, cause high metallic resistance and capacity problems.

State of Charge - From a fully equalized condition, all the way to 20% partially discharged, there is very little effect on a cell's internal resistance. Lab testing that deliberately removed 20% of the stored energy at a slow rate showed less than 3% change in resistance.

Temperature - High temperatures up to 102°F have very little effect on resistance (less than 2%). Low temperatures do have some effect on resistance, but it is minimal until the electrolyte gets below 65°F.

What Problems Can Be Detected

Almost all cell problems that influence a cell's ability to perform can be detected. The problems can be divided into metallic and electrochemical problems. Figures 3, 4 and 5 clearly illustrate the impact on a cell's performance for each of these problems.

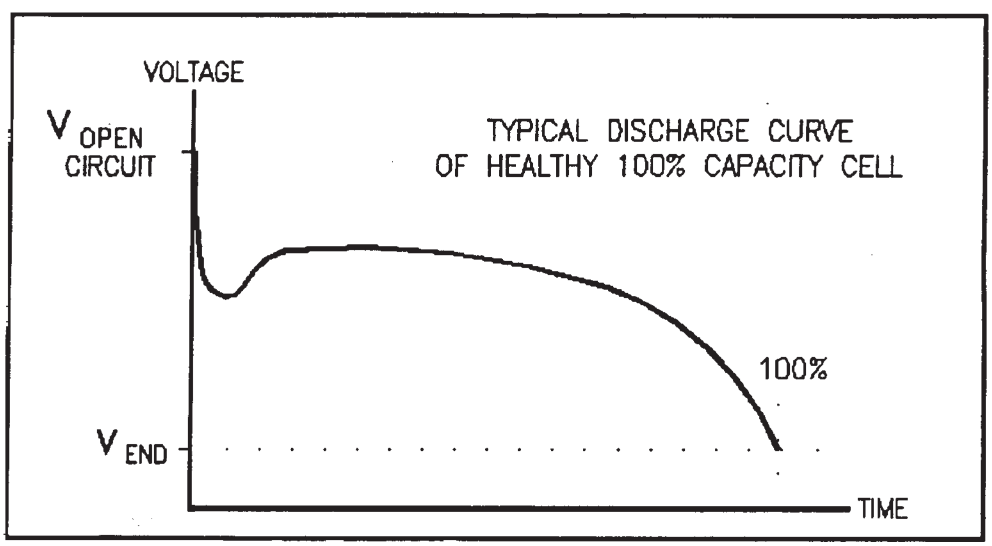

Figure 3: Typical Discharge Curve - Healthy Cell.

The typical discharge curve of a battery is shown in Figure 3 above. Note that there is an instantaneous voltage drop, due to the internal resistance of the battery, followed by an exponential voltage decay and subsequent recovery, known as the ‘coup de fouet’ phenomena, before the voltage stabilizes. Once the voltage stabilizes, it is sustained by the electrochemical reaction which, as mentioned above, is fueled by the available active material and acid.

Figure 4 shows the same battery tested at the same rate, but with a higher internal metallic resistance path. (Assume a bad lead burn between strap and grids or bad internal connection between two adjacent cells in a six volt module.) This figure clearly shows the loss of capacity due to a high internal metallic resistance. The higher the discharge current, the higher the internal voltage drop and the lower the capacity.

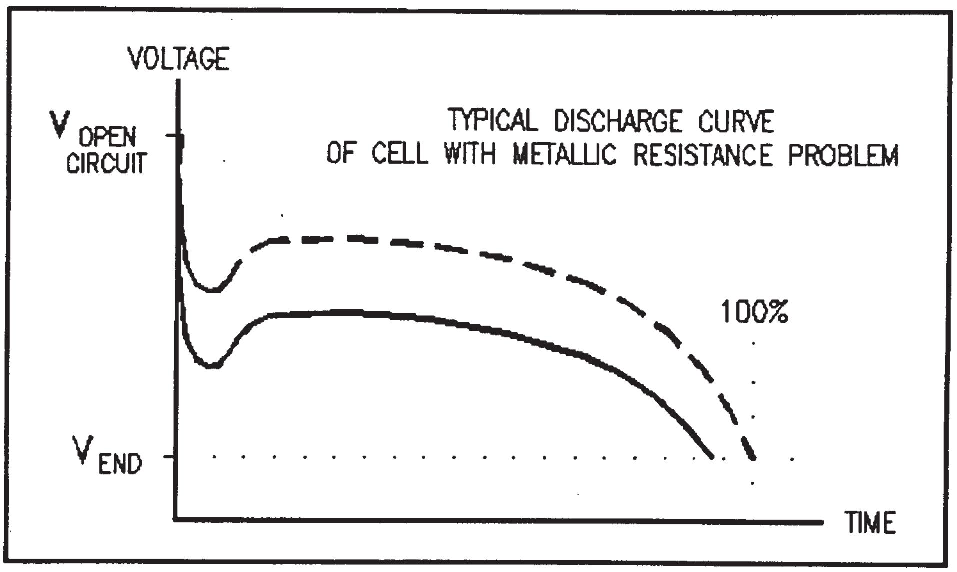

Figure 4: Typical Discharge Curve - Metallic Resistance Problem.

Figure 5 shows the same battery as Figure 3, but with a problem in the electrochemical path (paste, electrolyte or separator problems). This figure also shows a loss of capacity, since the fuel supply has been affected. Note, however, that there is very little initial voltage depression due to this problem.

The metallic resistance problems are potentially the most dangerous, since these can lead to a cell explosion during a discharge. This type of problem will also lead to an instantaneous drop or total interruption of the bus voltage, causing a system shutdown without any warning.

The electrochemical problems affect a cell’s capacity and, therefore, the system reserve time. The resistance of the paste and electrolyte constitutes a small percent of the total resistance. This means that it takes a substantial change in this part of the path before it significantly impacts the overall resistance.

Fortunately, in reality, as a battery ages, both the paste and paste-to-grid resistance increase at the same time; therefore, the normal aging problems can be readily detected.

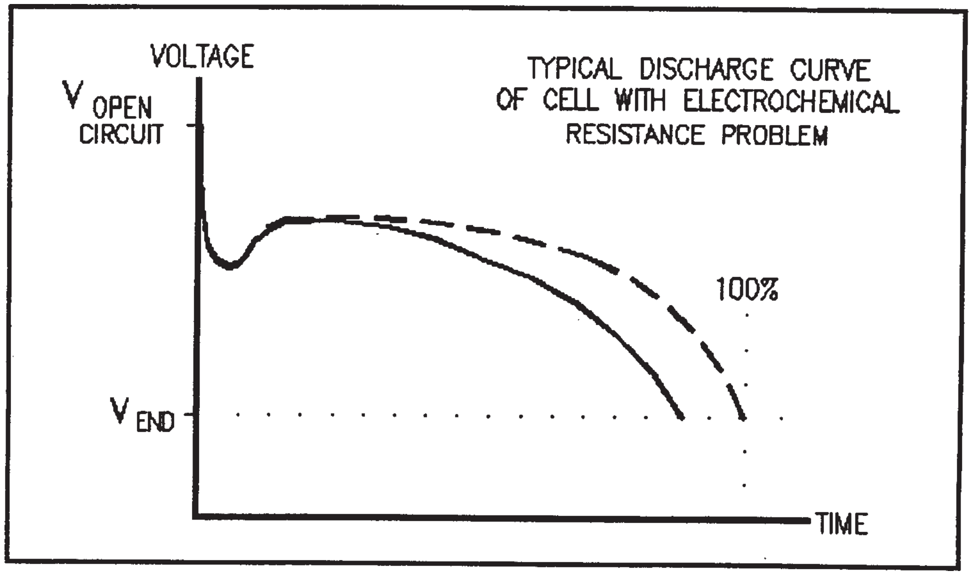

Figure 5: Typical Discharge Curve - Electrochemical Resistance Problem.

FIELD EXPERIENCES

Albércorp is presently compiling test data from many test equipment users and will issue a report on their findings. The results so far show that any cell whose internal resistance has risen by more than 25% above base line will not pass a standard capacity test. This has been confirmed in all cases so far. Results also show that flooded cells deteriorate uniformly as a group, whereas VRLA cells vary significantly from cell to cell. It is not uncommon to see resistance spreads from 0% to 100% above base line for a three to four year old battery string.

HOW CELL RESISTANCE MEASUREMENTS FIT INTO A MAINTENANCE PROGRAM

When a cell's resistance level indicates a potential capacity problem, one of the following options must be exercised:

1. Replace the cell and/or the entire string without any further testing.

2. Capacity test the cell using a single cell tester and then base the replacement criteria on whether the cell's capacity is above or below 80%.

3. Capacity test the entire string and replace cells below 80% of nameplate-rated capacity. Note that, if two or more cells fail the test, consideration should be given to replacing the entire string.

Which option should be chosen depends on economic and system reliability considerations. If reliability is the main consideration, then option #3 should be chosen. Option #1 may be the most economical, especially in small applications and where short life VRLA's are involved.

Our Specific Recommendations for Resistance and Capacity Testing

* Capacity test all new battery strings following installation as part of the final Acceptance Test.

* Resistance test all flooded cells annually and VRLA cells quarterly.

* Establish base line values (value of known good 100% capacity cell) for all battery types used. Albércorp maintains a database of base line numbers that it makes available to its customers.

* Replace all cells, without any further testing, that have a resistance 50% or greater than base line value. Single cell capacity test all cells whose resistance is between 20% to 50% greater than base line.

* Capacity test all batteries over 12 to 15 years of age and take action as follows:

1. Replace if less than 80% of capacity.
2. Retest annually if less than 90% of capacity.
3. Retest in three years if greater than 90% of capacity.