WHEN "GOOD" IS TOO GOOD

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Abstract

When can "good" become too good? This paper briefly discusses the history of transmission and distribution station battery maintenance practices at American Electric Power and the changes made in response to NERC PRC-005. It also discusses one area of weakness found after years of what was thought to be a solid maintenance program. Mitigation steps to prevent a repeat of the same mistake are then addressed.

Introduction

The introduction of NERC PRC-005 standards had an impact on the station maintenance practices within American Electric Power. Uniformity was needed around all aspects of testing, including the test set, testing method, and results analysis. Every step can be made to ensure compliance. But sometimes assumptions can creep in, and when combined with too narrow of a focus, what is considered a good test result can actually be "too good."

AEP Station DC Supply Maintenance Practices

American Electric Power (AEP) maintains more than 3,000 transmission and distribution substations in 11 states: Virginia, West Virginia, Tennessee, Kentucky, Ohio, Indiana, Michigan, Louisiana, Arkansas, Oklahoma, and Texas. Supplying switching and back-up power for these stations is over 3,800 stationary battery systems. Of these batteries systems, over 60% are NERC applicable. With the introduction of DC supply testing requirements in NERC PRC-005, the AEP station field group responded by developing a uniform testing procedure.

Prior to this point, there did not exist a uniform standard of testing for all regions of AEP. Each area had developed and maintained their own standards and practices for several years. Most areas had been performing some type of annual, internal ohmic testing, with some areas even doing bi-annual internal ohmic testing. Also, there was no uniform test set being used. Different manufacturers were being used in different areas, producing a variety of test values. Most areas had been routinely testing every jar, not testing individual cells. And no one was testing the intercell connections.

Though there did exist much diversity on test equipment and practices, all areas had standardized upon stationary vented lead-acid batteries (VLA's) for substation application. This is the current standard for station DC supply for AEP and will be for the foreseeable future. For VLA batteries, the NERC standard PRC-005 requires utilities to verify (determine that the component is functioning correctly) 6 different aspects of the DC supply system and inspect (examine for signs of component failure or performance degradation) 4 others, with different maintenance intervals. If any of those 10 aspects are missed during a maintenance interval, a potential violation occurs. The PRC-005 standard's table for VLA batteries is shown below in Figure 1.

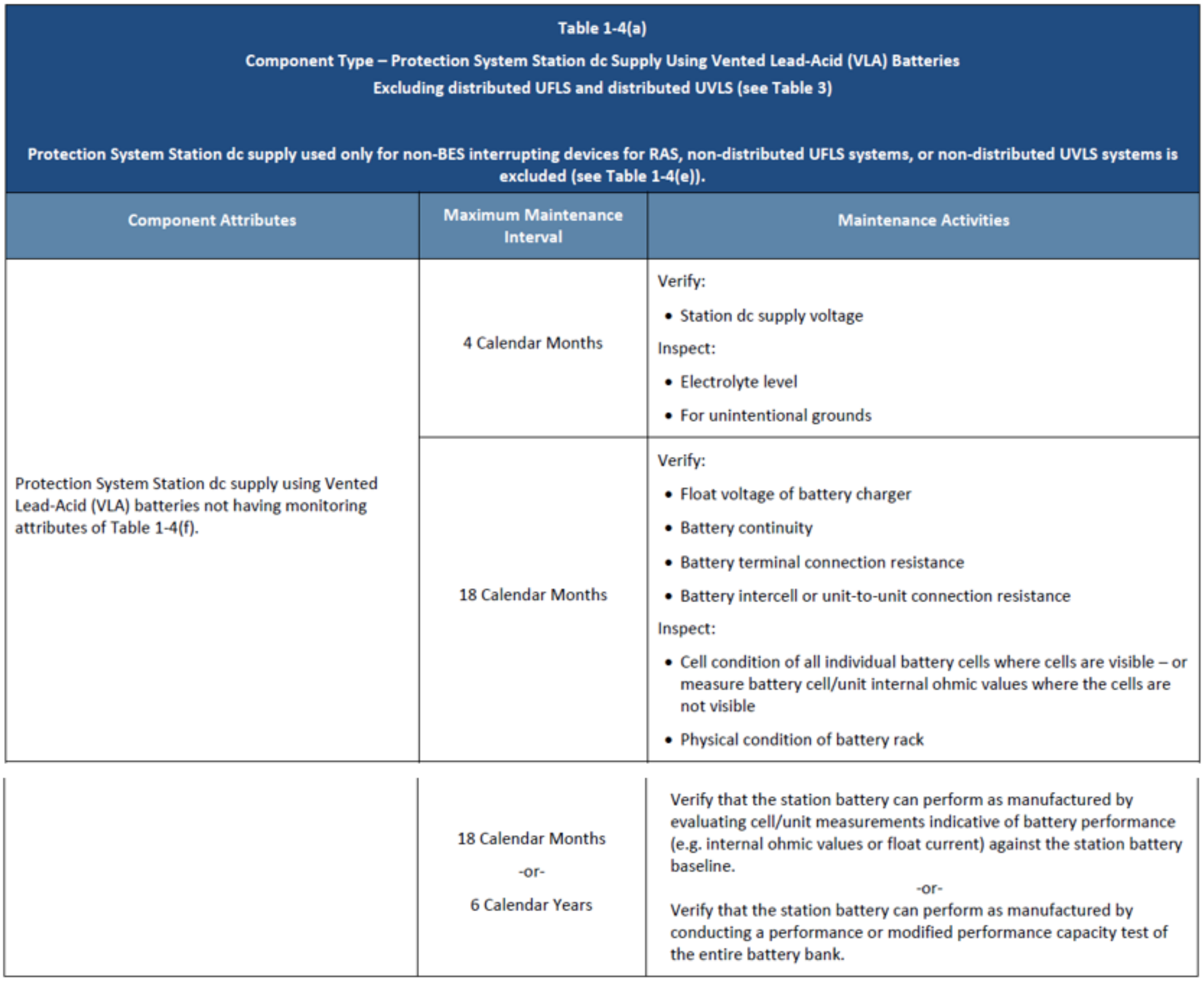


Table 1-4(a)

Component Type – Protection System Station dc Supply Using Vented Lead-Acid (VLA) Batteries
Excluding distributed UFLS and distributed UVLS (see Table 3)

Protection System Station dc supply used only for non-BES interrupting devices for RAS, non-distributed UFLS systems, or non-distributed UVLS systems is excluded (see Table 1-4(e)).

Component Attributes	Maximum Maintenance Interval	Maintenance Activities
Protection System Station dc supply using Vented Lead-Acid (VLA) batteries not having monitoring attributes of Table 1-4(f).	4 Calendar Months	Verify: • Station dc supply voltage Inspect: • Electrolyte level • For unintentional grounds
	18 Calendar Months	Verify: • Float voltage of battery charger • Battery continuity • Battery terminal connection resistance • Battery intercell or unit-to-unit connection resistance Inspect: • Cell condition of all individual battery cells where cells are visible – or measure battery cell/unit internal ohmic values where the cells are not visible • Physical condition of battery rack
	18 Calendar Months -or- 6 Calendar Years	Verify that the station battery can perform as manufactured by evaluating cell/unit measurements indicative of battery performance (e.g. internal ohmic values or float current) against the station battery baseline. -or- Verify that the station battery can perform as manufactured by conducting a performance or modified performance capacity test of the entire battery bank.

Figure 1. PRC-005-6 VLA Maintenance Requirements

For AEP stations, part of the NERC standard is met through bi-monthly checks of the substation and DC supply system. The remainder of the standard is completed through annual detailed maintenance, which includes an internal ohmic test.

Response to PRC-005

To guard against the possibility of missing a required maintenance cycle, AEP chose to maintain a shorter maintenance interval window than the NERC standard required. The 4 calendar month tasks are accomplished every 2 months, and the 18 calendar month tasks are done annually. This matched the maintenance cycles that were already being used in most areas, and has been the practice since 2012.

To guard against missing potential DC supply deficiencies, AEP instituted a layered approach in analyzing test results. The person in the field (the station servicer), at the station testing, is the first layer of defense. They can check their test results before they leave the station (or even mid-test) and retest as needed to verify any bad results. The expectation is placed upon the servicer to examine the test results before they leave the station.

The second layer is an internally created program that analyzes each test result and flags areas of concern. The final layer is the local field engineer who reviews the results, looks for deficiencies, analyzes trends, and makes the final decision on any problems. A field engineer may analyze test results for multiple servicers, having as few as a couple dozen to over 100 batteries, depending upon the area and current workforce make-up. For uniformity, these maintenance practices were applied to all stations, at all voltage levels, whether they were NERC applicable or not.

Standardization

To meet the NERC PRC-005-2 requirements when they were first introduced, AEP began a process of standardization. The first step in standardization was to agree upon a test set. Multiple manufacturers were asked to make presentations to a mix of field and engineering staff. The pros and cons of each were weighed, looking not only at what the field employees preferred but also what the majority of field employees were already using. Choosing a test set that the majority of field employees were already using would help to maximize the acceptance of new testing standards and gain the maximum amount of buy-in from the field.

Once a test set was chosen, the funds were obtained to buy a new tester for every servicer and regular battery tester. New standards on the maintenance, testing, and commissioning of batteries (some of which are discussed above) were then written. Then the new test sets were individually handed out to the station servicers (who perform DC supply maintenance and testing) after they had received training on the new testing procedures. This all occurred over the course of 2012.

AEP transmission currently has 5 different DC supply standards, addressing topics such as safety and commissioning, with one standard alone dedicated to detailed, internal ohmic battery testing. Station servicers also receive a quick reference sheet which reminds them of expected test values and what constitutes a failed cell and intercell connector.

Test Criteria

When the reported cell conductance is less than 70% of the expected internal ohmic value, it is considered to be in a Warning state. If it tests below 60% of the expected internal ohmic value, it is considered failed. Once a battery cell is determined to be failed, the field has a course of action it is expected to take, the response time of which is dependent upon the level of failure. Immediate corrective actions can include the simple step of installing a jumper around a failed cell (and lowering the float voltage by the appropriate amount) or installing a battery cart.

The resistance values of intercell connectors are expected to be within a range of values all in micro-Ohms. After obtaining hundreds of recorded test results as a guide, it was determined that any intercell connector over 100 micro-Ohms would be considered in a warning state. An intercell connector in a warning state would require extra maintenance, which could include re-checking the tightness of the intercell connections or removing the intercell connector, cleaning the connections, and reapplying the connector.

These standard maintenance practices have been in force since they were first introduced in 2012. A DC Supply working group, consisting of the field engineers who review the tests results and members of the equipment standards team, was created. The field engineers are expected to review and maintain the testing practices for their area. The working group provides a way for the field engineers and other field personnel to ask questions and bring up any problems they might be experiencing. Through this working group, AEP maintains a feedback loop with the field.

How “Good” Became Too Good

In the final quarter of 2018, a new field engineer was hired within an area of AEP. As he was to become the battery test reviewer for his area, he received training on the proper testing procedure, how to review test results, and how to upload the results to AEP transmissions database system. As he began to review the test results for his area, he noticed an unusual trend in some results. He noticed that for certain batteries, the intercell connector test results were very low. In these tests, all the intercell connector resistances were less than 10 micro-Ohms, with most having a resistance value of 1 micro-Ohm.

This concerned the field engineer because the majority of the intercell test values he reviewed ranged between 20 and 80 micro-Ohms. He consulted his supervisor, who had trained him on reviewing battery test results, about these low values. The supervisor confirmed that those values were abnormally low. Particularly alarming was the high number of intercell connections with only 1 micro-Ohm of resistance.

The supervisor conducted an investigation and found those test results all tied back to one individual station servicer. The supervisor spoke with the servicer and inquired upon his test procedures. The servicer was also asked to demonstrate his test procedure, whereupon it became clear the reason for the low intercell connector test values.

Figure 2 below shows the initial stage of testing a battery cell. The test probes are placed on the positive and negative posts of the cell. This performs the internal ohmic test, from which the internal conductance and resistance is derived. Next, the servicer leaves the red probe on the positive post of the cell and moves the black probe to the positive post of the next cell, as shown in Figure 3. The test set then performs the intercell resistance test.

Figure 2. A cell conductance (internal ohmic) test

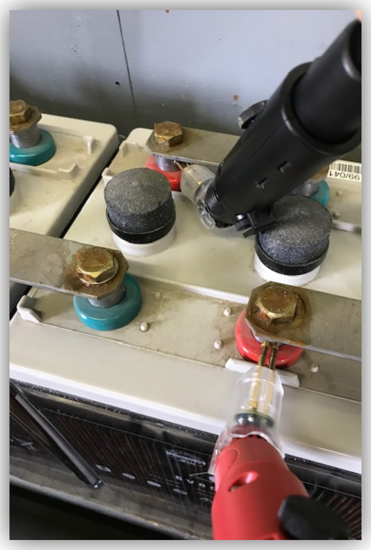


Figure 3. An intercell connection test

The intercell resistance is a calculated value. The tested resistance found during the internal cell test is subtracted from the resistance found during the intercell connector test. What remains should the resistance of the intercell connector.

However, this particular servicer was performing his intercell connector tests as shown in Figure 4. As can be seen, the servicer performed the intercell connection resistance test with the black test probe on top of the intercell connector, instead of on the positive post of the next cell. This resulted in an entire connection point not being tested (Figure 5).

Figure 4. The incorrect intercell connection test

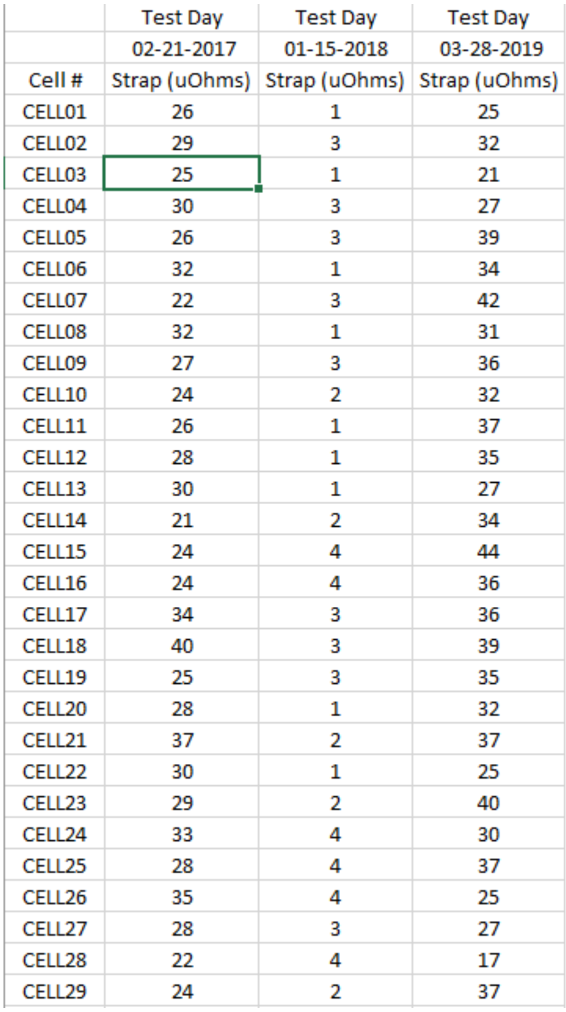
Figure 5. The intercell connection point NOT tested

Follow-up conversations with this servicer revealed that he had received the initial training on how to perform the tests on the battery when the new procedure, with the new test set, was instituted in 2012. He was adamant that he believed he was testing the batteries correctly, according to how he had been taught, and was shocked to learn that he was performing the tests wrong.

The Net Results

The net result of this servicer's incorrect test procedure was that the intercell connection resistance was not tested. In fact, for every connector of every cell of every battery of every year that this servicer tested batteries, these connection points were not tested. Ultimately this meant that for every NERC applicable battery the servicer tested, multiple violations had potentially occurred.

Figure 6 below shows an example of an incorrect test that was performed in 2018, discovered during the internal regional audit. The servicer who performed the 2018 test was different from the person who performed the 2017 and 2019 tests. This test was included in a NERC self-report.



	Test Day 02-21-2017 Strap (uOhms)	Test Day 01-15-2018 Strap (uOhms)	Test Day 03-28-2019 Strap (uOhms)
Cell #			
CELL01	26	1	25
CELL02	29	3	32
CELL03	25	1	21
CELL04	30	3	27
CELL05	26	3	39
CELL06	32	1	34
CELL07	22	3	42
CELL08	32	1	31
CELL09	27	3	36
CELL10	24	2	32
CELL11	26	1	37
CELL12	28	1	35
CELL13	30	1	27
CELL14	21	2	34
CELL15	24	4	44
CELL16	24	4	36
CELL17	34	3	36
CELL18	40	3	39
CELL19	25	3	35
CELL20	28	1	32
CELL21	37	2	37
CELL22	30	1	25
CELL23	29	2	40
CELL24	33	4	30
CELL25	28	4	37
CELL26	35	4	25
CELL27	28	3	27
CELL28	22	4	17
CELL29	24	2	37

Figure 6. Comparison of Intercell Connection Test Results

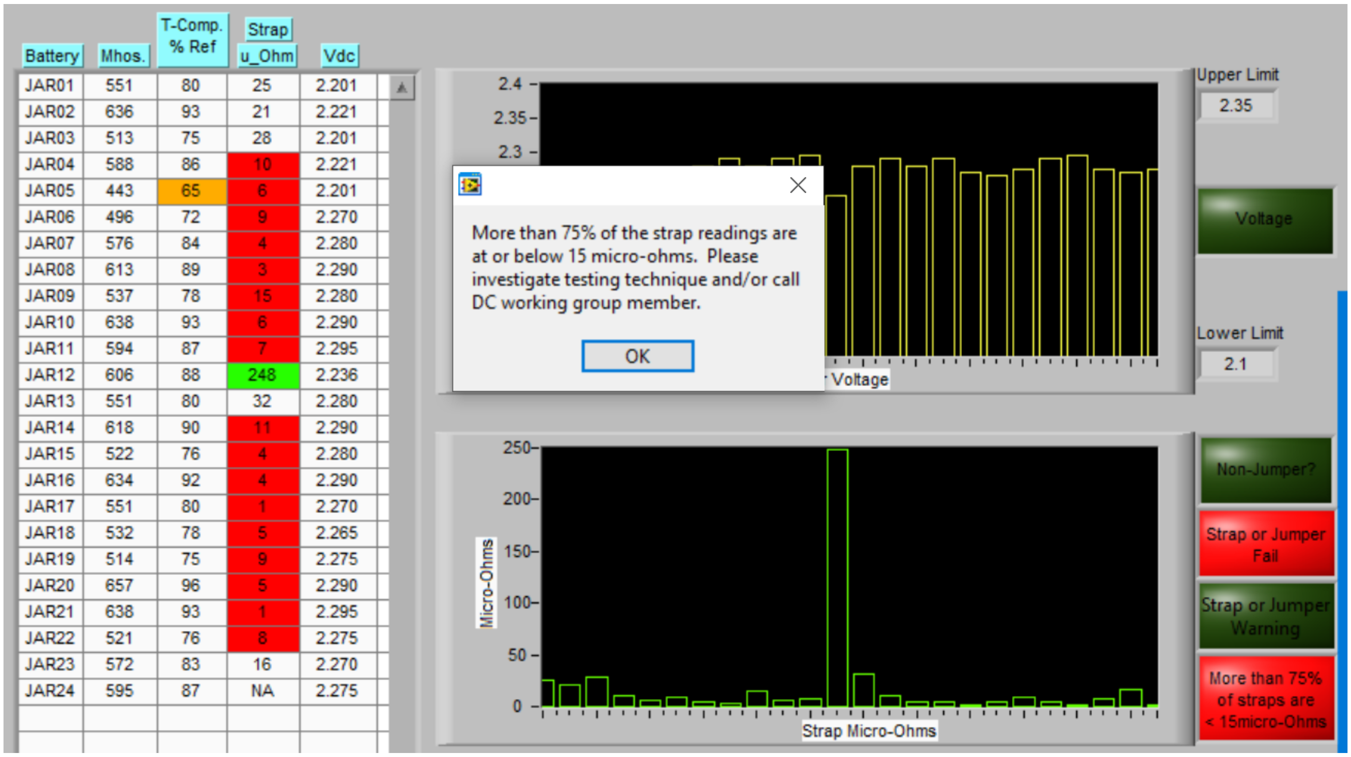
Why were these test results only being investigated now? This field servicer had been performing the test incorrectly for a number of years. Why had no one seen this problem earlier? The previous field engineer for that area, who had reviewed the test results for the previous years admitted to seeing the low intercell connection resistance values. However, he was taught only to be concerned with resistance values that were too high. There was never any indication that low resistances could indicate a problem, so he never believed there was any concern. According to the criteria he was given for evaluating intercell connections, the results were “good.”

Mitigation

Immediately, the local supervision had every battery re-tested using the correct procedure. These tests did verify that the intercell connections were not at the Warning level. The supervisor over this region also looked at other test values to determine what other batteries at other substations might have been affected. Since this servicer was one of the more experienced persons in the field, he had been used to train newer employees for a number of years. It was feared that his incorrect testing procedure may have been taught to others. There were other batteries of concern, and all suspicious batteries were retested within the next few months.

Next, there was a concern if any other servicer in other regions of AEP were also incorrectly performing the intercell resistance test. A report was created to run inside of AEP's database to look for other batteries with similarly low intercell connection values. Any consistent, suspicious values were investigated, with the local field engineers interviewing the servicers to determine what method of testing was being used. This report was then set up to run on a quarterly basis to look for any future incorrect test procedures going forward.

The software that automatically evaluates the test data was modified to include a flag for low intercell connections. Figure 6 shows an example of a battery string with low intercell connector values that has been flagged. If found, the reviewer would have to comment on if a problem actually existed. Also, all field engineers were trained on this incident and made aware of appropriate test values.



Battery	Mhos.	T-Comp. % Ref	Strap u_Ohm	Vdc
JAR01	551	80	25	2.201
JAR02	636	93	21	2.221
JAR03	513	75	28	2.201
JAR04	588	86	10	2.221
JAR05	443	65	6	2.201
JAR06	496	72	9	2.270
JAR07	576	84	4	2.280
JAR08	613	89	3	2.290
JAR09	537	78	15	2.280
JAR10	638	93	6	2.290
JAR11	594	87	7	2.295
JAR12	606	88	248	2.236
JAR13	551	80	32	2.280
JAR14	618	90	11	2.290
JAR15	522	76	4	2.280
JAR16	634	92	4	2.290
JAR17	551	80	1	2.270
JAR18	532	78	5	2.265
JAR19	514	75	9	2.275
JAR20	657	96	5	2.290
JAR21	638	93	1	2.295
JAR22	521	76	8	2.275
JAR23	572	83	16	2.270
JAR24	595	87	NA	2.275

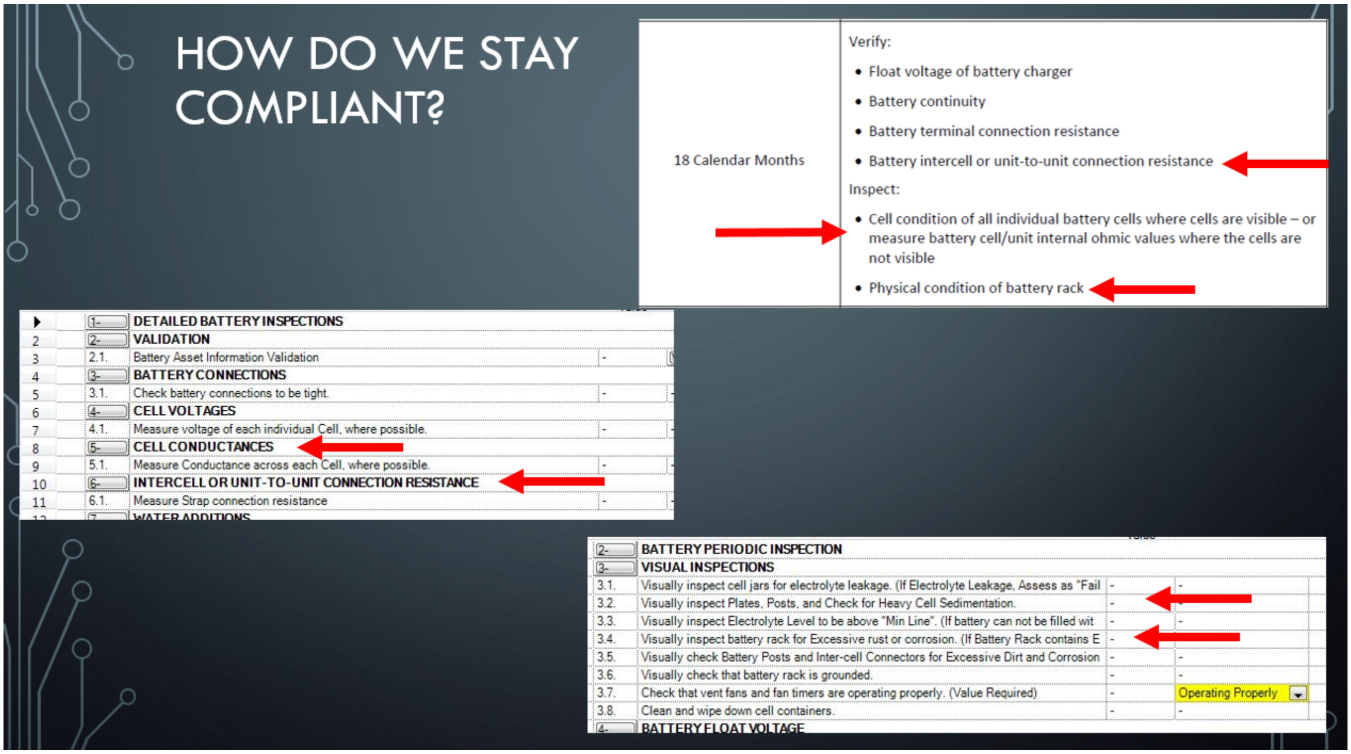
More than 75% of the strap readings are at or below 15 micro-ohms. Please investigate testing technique and/or call DC working group member.

Upper Limit: 2.35

Lower Limit: 2.1

Figure 6. An example of low intercell connectors being flagged

During 2019, all servicers and field engineers were trained on this incident and on the correct testing procedure. A video was also created and shared with all the servicers showing the correct testing procedure. Figure 7 shows an example of the training, discussing how the servicer's testing helps the company stay compliant with NERC standards. All appropriate battery policy and procedure documents were updated to show the expected test value range, noting that consistently low test values could be indicative of an incorrect test procedure and should be verified.



HOW DO WE STAY COMPLIANT?

18 Calendar Months	Verify: • Float voltage of battery charger • Battery continuity • Battery terminal connection resistance • Battery intercell or unit-to-unit connection resistance Inspect: • Cell condition of all individual battery cells where cells are visible – or measure battery cell/unit internal ohmic values where the cells are not visible • Physical condition of battery rack

▶	1-	**DETAILED BATTERY INSPECTIONS**		
2	2-	**VALIDATION**		
3	2.1.	Battery Asset Information Validation	-	
4	3-	**BATTERY CONNECTIONS**		
5	3.1.	Check battery connections to be tight.	-	-
6	4-	**CELL VOLTAGES**		
7	4.1.	Measure voltage of each individual Cell, where possible.	-	-
8	5-	**CELL CONDUCTANCES**		
9	5.1.	Measure Conductance across each Cell, where possible.	-	-
10	6-	**INTERCELL OR UNIT-TO-UNIT CONNECTION RESISTANCE**		
11	6.1.	Measure Strap connection resistance	-	-
	7-	**WATER ADDITIONS**		

2-	**BATTERY PERIODIC INSPECTION**		
3-	**VISUAL INSPECTIONS**		
3.1.	Visually inspect cell jars for electrolyte leakage. (If Electrolyte Leakage, Assess as "Fail	-	-
3.2.	Visually inspect Plates, Posts, and Check for Heavy Cell Sedimentation.	-	-
3.3.	Visually inspect Electrolyte Level to be above "Min Line". (If battery can not be filled wit	-	-
3.4.	Visually inspect battery rack for Excessive rust or corrosion. (If Battery Rack contains E	-	
3.5.	Visually check Battery Posts and Inter-cell Connectors for Excessive Dirt and Corrosion	-	-
3.6.	Visually check that battery rack is grounded.	-	-
3.7.	Check that vent fans and fan timers are operating properly. (Value Required)	-	Operating Properly
3.8.	Clean and wipe down cell containers.	-	-
4-	**BATTERY FLOAT VOLTAGE**		

Figure 7. A slide from field training on staying complaint

Summary

Future steps are always being looked at to prevent this particular incident from happening again. Options that have been discussed include annual "refresher" training, either conducted locally or pre-recorded and viewed online. The latest quarterly report run in March of 2021 shows the last suspicious test was performed in October of 2019. For now, it seems the mitigation steps taken have proven successful.

A number of lessons were learned from this experience. The first lesson was to not be too narrowly focused. The standards created only looking for test values in one-direction: too high. The question should have been asked if test results the other way (too low) were encountered, what could they indicate? At the very least, the discussion should have taken place, with some imagination being used to discuss the possibility and its impact.

Another lesson learned is that the importance of gaining a fresh perspective cannot be overlooked. For nearly six years, a problem was missed. One set of new eyes pointed out a problem that can now be clearly seen.

A final lesson learned was a familiar one about making assumptions. It was assumed that this servicer, because he had been taught how to properly test and had been provided with a procedure document (with pictures) on how to test, was testing the batteries correctly. And he was, in every aspect save one. Assumptions are not safe. The servicers, especially new ones, should be audited to verify that proper procedures are being followed.