Extending the Service Life of 2-Volt VRLA Cells with a Catalyst Rehydration Procedure
(A telecommunication operator perspective)

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Abstract

TELUS is Canada's fastest-growing national telecommunications company, with $12.0 billion of annual revenue and 13.7 million customer connections. TELUS provides a wide range of communications products and services, including wireless, data, Internet protocol (IP), voice, television, entertainment and video, and is Canada's largest healthcare IT provider.

With ~1,200 absorbed glass mat (AGM), 2 volt valve regulated lead acid (VRLA) battery strings in the network, premature failure of AGM VRLA is an important budget pressure for TELUS.

Partnering with Anderson's Electronics, Inc. (AEI), TELUS proceeded to add catalysts and rehydrate over two hundred and forty (240) strings of AGM 2V VRLA batteries, between four and eleven years of age. With improvement of Ohmic readings for 90% of the targeted strings, coupled to a relatively low cost and risk for the network, the procedure was found to be a good method to extend the life of the batteries, allowing TELUS to fuel its passion for growth. This document presents the failure mechanisms we believe are affecting our VRLA batteries, the procedure to extend the batteries' useful life, and TELUS experience in applying the procedure to a large battery population installed in a large geographical area.

Introduction

Originally introduced to the TELUS network in the 1990's, the absorbed glass mat (AGM), 2 volt valve regulated lead acid (VRLA) batteries were sold as a higher energy density option to the standard vented lead acid (VLA) batteries. Because VRLA did not require watering, they were also marketed as a maintenance free battery, and suppliers claimed that they would have useful lives similar to the VLA equivalents.

Approximately 25 years later, TELUS considers that AGM VRLA technology has evolved to be an appropriate solution for higher energy density applications. However, AGM 2V VRLA consistently fail to meet the promised design/service life, causing the organization to question the use of VRLA as part of critical facility design solution.

The author acknowledges that one must be careful in describing the failure mechanisms for AGM 2V VRLA batteries because, although chemistries are similar, they cannot be assumed to be the same for all products. Failure mechanisms described herein were observed within the TELUS network. The reader should understand that the author does not represent himself to be a battery expert, and the failure descriptions contained herein are meant to provide context for the decision of proceeding with the procedure of adding catalysts and rehydrating a large number of VRLA strings in the TELUS network.

Over the years TELUS has been forced to replace AGM 2V VRLA batteries prematurely from their network due to cracked jars, poor Ohmic results, and batteries failing to meet their expected reserve times. The replacements were done well before the marketed useful/design lives and were believed to be the result of cell dry-out. This failure mechanism occurs over time as the VRLA cell fails to recombine the hydrogen and oxygen produced by the constant float charge applied to the battery string.

The early replacement is quite a challenge for TELUS because it channels investments that would have otherwise been directed to growth into replacing batteries. Early failures threaten the reliability of the services delivered to our customers and delay the introduction of new platforms.

In 2002, Peter J. DeMar presented "Restoring Capacity and Extending Useful Life In VRLA AGM Batteries through the Process of Rehydration and Catalyst Installation" at Battcon [1]. His results appeared to demonstrate that the introduction of a catalyst and the addition of water could yield the following benefits:

1) Reducing float current, which equates to less water loss.
2) Reduced positive plate growth, which helps reduce mechanical jar damage.
3) Capacity is restored as the water wicks back into the glass mat and increases the surface area available for the chemical reactions.

After early work with the addition of catalysts and rehydration of VRLA cells in 2007, TELUS elected to rehydrate approximately 240 strings between four and eleven years of age.

By investing ~ 8% of the total replacement cost of the VRLA batteries, TELUS was able to improve the Ohmic readings and delay the end of life for most of the selected VRLA batteries. Batteries with excessive positive plate growth and mechanical jar damage could not be rehydrated and had to be replaced. Once mechanical jar failure occurs, the compression within the cell is lost and capacity cannot be restored. Electrolyte released as a result of the mechanical jar failure poses a risk to personnel, service, the environment and the TELUS brand. For those reasons, means of reducing or reversing cell dry-out are desirable.

The procedure is relatively low cost and non-intrusive which makes it a perfect fit for critical facilities such as the ones operated by TELUS.

It is well understood that the addition of the catalyst and rehydration will not reverse positive plate growth; however, the team observed that batteries equipped with a catalyst from the factory seemed to have significantly less positive plate growth than other cells of similar age not equipped with a catalyst.

Based on the results and the observations, the team recommends that catalysts be added before any signs of positive plate growth appear.

Premature Capacity Loss

Essentially, lead acid batteries are controlled chemical reactions placed into containers. Overall system performance is the result of design decisions made by the manufacturers based on manufacturability and market demand. Competing chemical reactions are kept balanced, but complete equilibrium is difficult to achieve. In order to ensure proper performance, customers must understand and respect the manufacturers' recommendations in regards to the environmental conditions, the charging regiments, and maintenance procedures, otherwise Premature Capacity Loss (PCL) or failure of the battery may result.

Capacity failures observed for the 2V AGM VRLA batteries installed in the TELUS network correspond to the failure descriptions documented in IEEE Std 1188a-2014 C.8.1.[2] According to our understanding of the aforementioned document, AGM VRLA batteries have a finite useful life, and failure at the end of that useful life is inevitable. The challenge for telecommunication operators such as TELUS is finding methods to delay irreversible failures, reverse the ones that are reversible and, ultimately, eliminate Premature Capacity Loss.

In general, 2V AGM VRLA batteries are removed from the TELUS infrastructure by year 10 to 12. The Premature Capacity Loss observed appeared to be linked to what IEEE Std 1188a-2014 C.8.1.[2] describes to be negative self-discharge and cell dry-out.

After confirming proper settings on the battery chargers to prevent overcharging or undercharging based on temperature, TELUS elected to focus on methods that could help extend the useful life of the batteries installed in our network.

Cell Dry Out

Cell Dry Out is not initially visible because it is internal to the cell. It is a process where the water contained in the cell is lost over time. Figure 1 shows a simple illustration to help conceptualize cell dry-out.

Figure 1. Simplified way to think about cell dry-out.

Essentially, dry-out is the result of the lemon drying out and the nickel/dime losing contact with the pulp/juice of the lemon. As contact is lost, so is capacity. A similar phenomenon occurs in the 2V AGM VRLA; as water is lost in the cell, the contact between the plates is reduced and capacity is lost.

In TELUS experience, water is lost in 2V AGM VRLA batteries when:

1) The hydrogen and oxygen fail to recombine fully within the cell.
2) When part of the electrolyte solution is expelled from the cell due to higher internal pressures or valve assembly failures.
3) When part of the electrolyte solution leaks out from the jar due to the mechanical failure of the jar.

The effects of negative self-discharge and cell dry-out observed most often by TELUS are:

1) A degradation of Ohmic readings (higher internal resistance or lower conductance).
2) An increase of float current.
3) Damage to the jar as the positive post pushes the cover outward.

Visible effects of negative plate self-discharge (Positive Plate Growth)

In order to perform correctly, electrochemical reactions within the VRLA cells must be kept in relative equilibrium. The negative plates in VRLA batteries have a tendency to self-discharge to combat this natural tendency. The batteries must be placed under constant float charge, which tends to corrode the positive plates, which results in Positive Plate Growth (PPG) and becomes noticeable when the positive plates apply pressure to the jar, distorting it as shown in the middle picture of Figure 2.

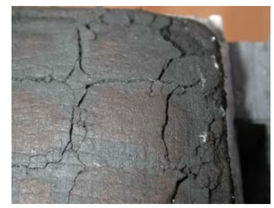
Normal battery without apparent traces of PPG.	PPG is deforming the case and pushing the terminals forward.	Positive grid becomes larger over time causing the grid to pull away from the active material.
		

Figure 2. Pictures of PPG compared to normal batteries.

The rate at which the positive plate grows is governed by the amount of float current accepted by the cell. The amount of float current accepted by the cell is governed by the rate at which the cell self-discharges, so it follows that reducing self-discharge is desirable.

Self-discharge results from impurities in the negative active material. An accepted method to reduce self-discharge is to increase the purity of the negative active material. In TELUS experience, this approach has practical limits because obtaining and maintaining high purity throughout the manufacturing process is very expensive. The pure lead used in these types of products tends to be very soft and has mechanical limits that prevent the construction of the large plates, such as the ones used in long duration telecommunication batteries.

If it is impractical to produce large AGM 2V VRLA batteries with extremely high purity, negative active material, customers such as TELUS must look for methods of dealing with some level of impurities in the negative of their large AGM 2V VRLA batteries.

What is a Catalyst?

Originally introduced in 1998, the catalyst (Figure 3) helps reduce negative plate self-discharge, reducing float current and thus also helping reduce positive plate growth.

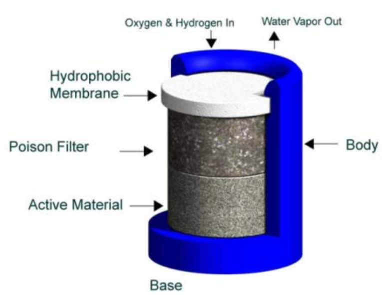


Figure 3. Catalyst representations and the impact of catalyst addition to VRLA cells. [4]

As the cell self-discharges, hydrogen is produced. Water (H_2O) is lost when that hydrogen (H_2) fails to recombine with the oxygen (O) contained in the cell. The catalyst helps recombine the hydrogen and oxygen in the cell to reduce water loss. By reducing the amount of oxygen present in the cell, there is less to react with the negative plates and self-discharge is then reduced.

The rate at which dry-out occurs is dependent on the battery construction and the environment in which it is installed. It is TELUS' experience that chemistries and manufacturing processes are in constant evolution, and product performance improvements are to be expected. The effects of these improvements are hard to evaluate because, in most cases, only time will tell.

During the rehydration project, the team found that batteries that were equipped with catalysts from the factory (Figure 4B) appeared to have fewer visible signs of positive plate growth than the ones not equipped with catalysts (Figure 4A).

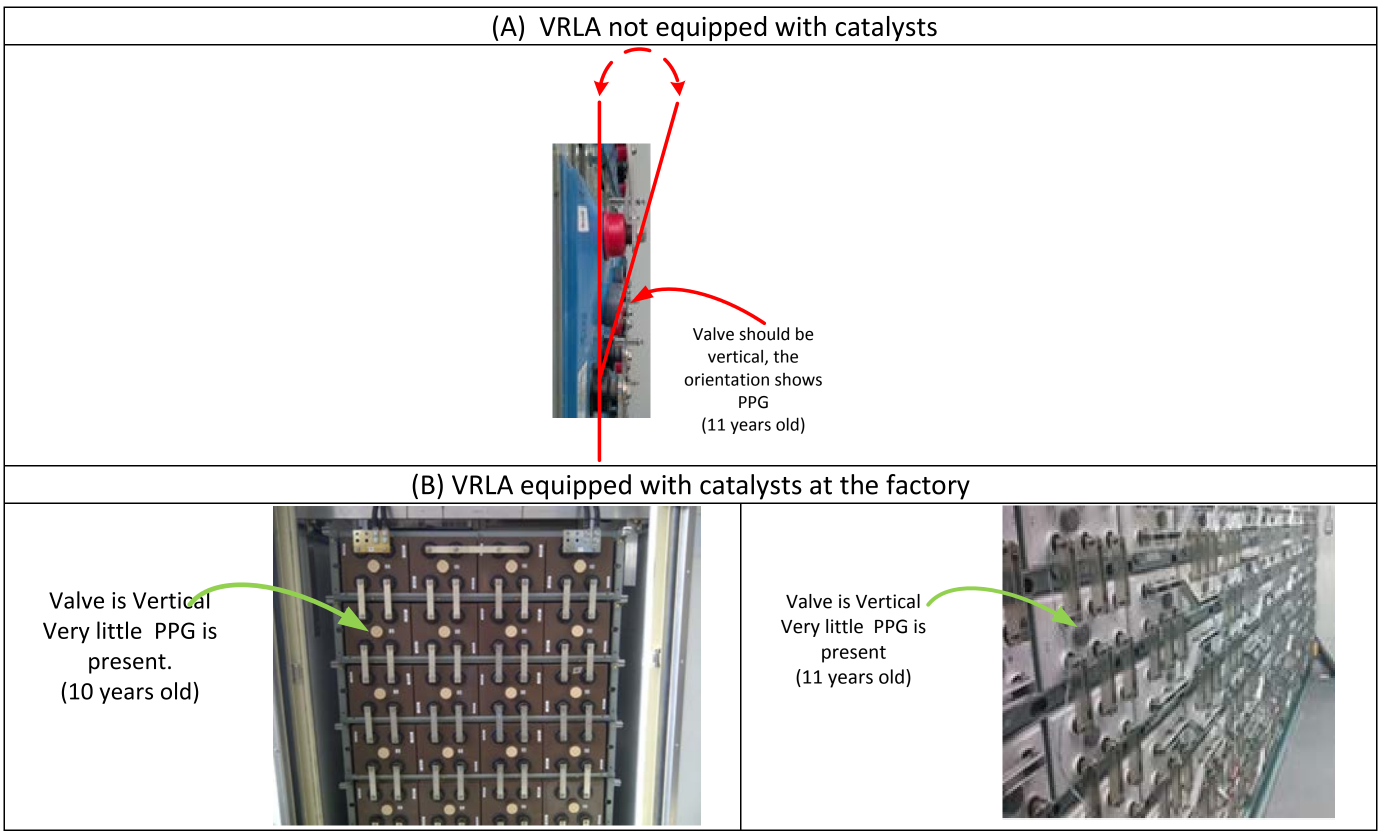


Figure 4. Comparison of PPG based on presence of catalyst from the factory.

The point of interest in Figure 4B is that even though the batteries equipped with a catalyst at the factory are not from the same manufacturer and may have slightly different chemistries, the addition of the catalyst appears to have reduced the visible signs of positive plate growth. The observations warrant consideration for further investigations at TELUS.

Based on the team's observations and because the majority of the 2V AGM VRLA batteries replaced at TELUS are replaced due to Premature Capacity Loss due to cell dry-out, it appears desirable to include a catalyst on a go forward basis, even with the new chemistries, to attain the marketed useful life.

What is rehydration?

Rehydration is a process where distilled water is added to the VRLA through the valve assembly opening. The intent is to re-establish the contact between the AGM and the plates that was lost as a result of cell dry out. Water addition is done based on the Ohmic measurements in order to prevent over watering.

What is the procedure?

The installation of catalysts and rehydration of AGM 2V VRLA is considered to be non-intrusive. The battery string can remain in service during the procedure and will provide energy in the event of a discharge. The procedure is made up of seven sequential steps:

1) Visual inspection

    Inspect the batteries to ensure it can be re-hydrated. The technician looks for signs of electrolyte leaks or excessive signs of bulging, which would indicate positive plate growth. If the mechanical integrity of the jar is compromised, the procedure is cancelled and the cells must be replaced.

2) Pressure test

    Following visual inspection, valve assemblies are removed and air pressure is applied to the jar. The cell must stay pressurized to prove the mechanical integrity of the jar. If pressure is lost, the case may be damaged and no water will be added. However, a catalyst valve assembly can still be installed.

3) Ohmic readings

    Proceed to record Ohmic values to determine the state of dry-out. These values are then used to determine the quantity of distilled water to be added to each cell.

4) Water addition

    Based on the results of the Ohmic tests, add distilled water to the jar. The quantity of water to be added must be controlled.

5) Installation of Catalysts

    Following water addition, install and torque the Catalyst Valve Assembly into the cell.

6) Ohmic tests

    Perform Ohmic tests to validate that contact between the AGM and the plates is being re-established.

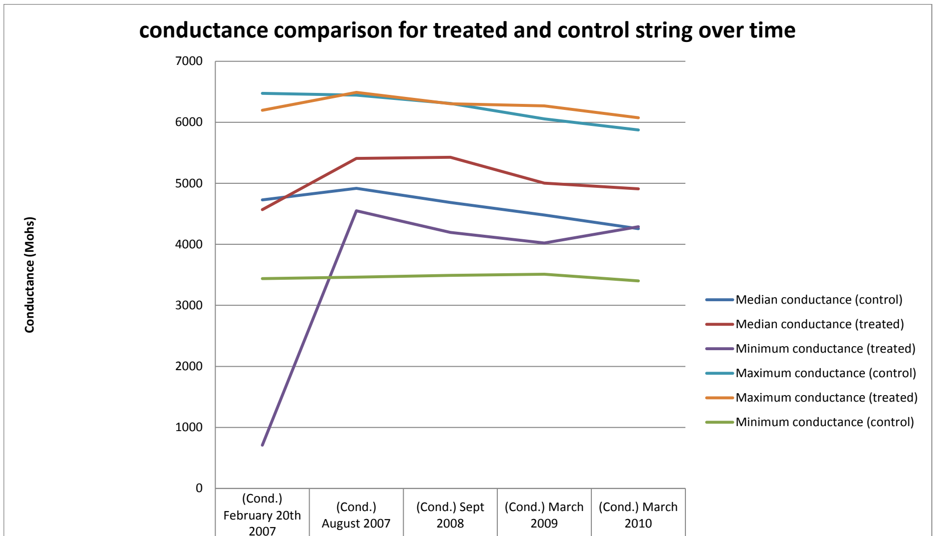
7) Monitor Ohmic readings and plan next rehydration cycle.

For additional information regarding the addition of catalyst and rehydration of AGM 2V VRLA, please refer to IEEE Std 1188a-2014 Annex C[2]

Initial tests at TELUS site

In 2007, two battery strings were selected for a comparative test. Both strings were manufactured in 2001 by the same supplier and installed in the same location. String 2 was rehydrated with the procedure documented in this paper; String 1 was not and used as a control. String 2 was selected as the pre-procedure Ohmic readings yielded lower conductance values.

Figure 5 shows conductance readings over time for both the treated and control strings. Improvement is shown by an increase in conductance. For TELUS, a battery which fails to meet 60% of the published conductance reference is considered to be failed and must be replaced.



	(Cond.) February 20th 2007	(Cond.) August 2007	(Cond.) Sept 2008	(Cond.) March 2009	(Cond.) March 2010
Median conductance (control)	4729	4918	4686.5	4480	4256.5
Median conductance (treated)	4569	5409	5427.5	5001.5	4909
Minimum conductance (treated)	709	4549	4195	4021	4289
Maximum conductance (control)	6475	6445	6309	6055	5875
Maximum conductance (treated)	6198	6490	6304	6270	6073
Minimum conductance (control)	3439	3461	3492	3509	3401

Figure 5. Comparison of conductance for treated and control strings over time.

Figure 5 shows that minimum conductance for the treated string was brought back to levels above 60% of reference, allowing the string to remain in the network for an extra three years. The treated string also consistently showed better median conductance than the control string. For the better jars, the conductance improvement was only marginally better than the control best jars.

Based on our test results and the ones published by Peter J. DeMar in his 2008 Battcon paper, [3] the decision was made to rehydrate more than 240 batteries aged 4 to 11 in the network. The population rehydrated is shown in Figure 6.

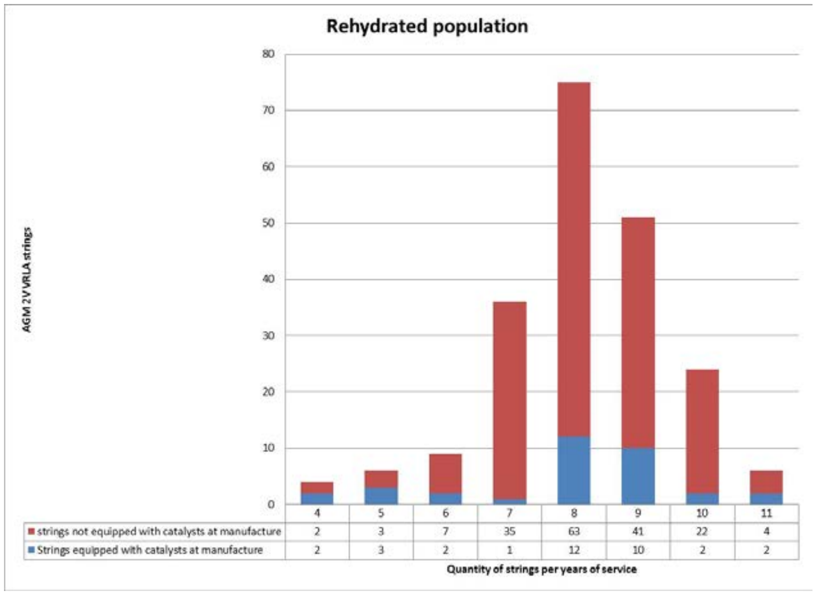


Figure 6. Rehydrated population.

A total of 240 battery strings were selected for rehydration and catalyst addition. Out of those, 218 were rehydrated, and 22 were too far gone with positive plate growth and could not be saved.

During the rehydration procedure, the team noticed that batteries equipped with catalysts at the manufacturer appeared to have fewer visual signs of positive plate growth. The rehydration and catalyst addition improvements are recorded in Figure 7.

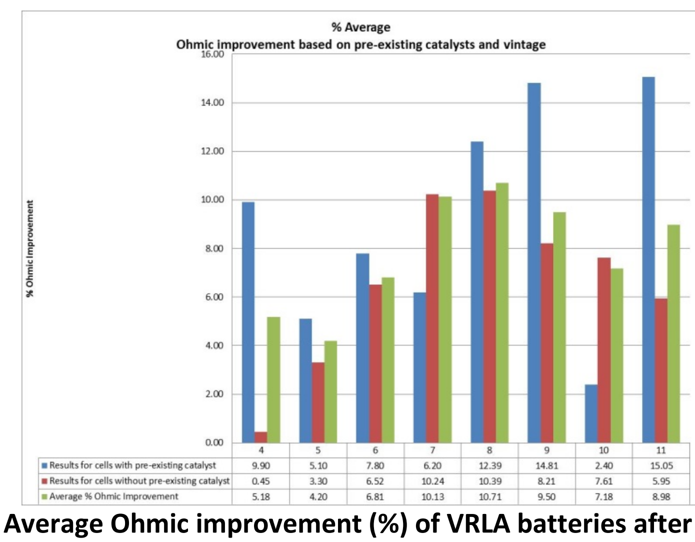


Figure 7. Average Ohmic improvement (%) of VRLA batteries after treatment.

Figure 7 shows that batteries equipped with catalysts from the factory seem to have better improvements than the ones without catalysts. The hypothesis is that, with a catalyst installed at the time of manufacture, positive plate corrosion would be less advanced, and the mechanical separation between the grid and the active material would be smaller. With rehydration conducted in the field, conductance was greatly improved. Further investigation for batteries of age 7 and 10 is required, as they seem to buck the trend.

Impacts

Financially, approximately 90% of the battery population could be rehydrated and equipped with catalysts. On average, we spent approximately 8% of the total value of the asset and extended their useful lives by ~3 years based on the TELUS test site and Peter J. DeMar 2008 Battcon paper [3].

Battery replacement cannot be completely avoided, However, the benefits of rehydrating cells and adding the catalyst compared to premature replacement are listed in Table 1.

Table 1. Benefits of rehydration and catalyst addition compared to premature battery replacement.

Considerations	Rehydration and Catalyst addition	Premature replacement
Capital Intensity	~8%	100%*
Execution time /string	2 hours	40 hours
Capacity restored	Observed 30%	100%**
Projected useful life	~3 (due to reduced PPG)	? (depends on the battery)
Potential network risk of the procedure	Very Low (Non-intrusive)	Low

* Cost may be lower based on pro-rated value of the product being replaced. In most cases, the logistic costs associated with the battery replacements usually outweigh the value returned by the manufacturer.

** This assumes that batteries are fully charged when shipped and installed.

The decision to proceed with catalyst addition and rehydration is driven by economics. Some remote locations may require premature replacement because the capacity restored is not sufficient or the logistic costs of getting to site exceed the projected three years benefit.

For most sites, rehydration and catalyst addition is a quick, non-intrusive method to restore capacity and allow investments to be re-directed to other priorities to support our passion for growth.

We successfully rehydrated 90% of the battery strings we intended to. The battery strings that were not rehydrated had to be replaced, as the mechanical damage to the batteries was excessive.

Discussion of the results

Based on the observations made by the team, it appears that batteries equipped with catalysts at the factory tend to have less visible positive plate growth and generally show better improvements than cells of similar age not equipped with a catalyst.

Capacity testing will need to be performed in 2015 to provide further information regarding the ability of the cells equipped with a catalyst at the factory to retain capacity when compared to the cells where a catalyst was added in the field.

TELUS recognizes that the relationship between Ohmic tests to the actual capacity of the battery cell is not well defined. The Ohmic results are affected by the state of recombination in the cell, Ohmic tests can be used to recognize bad cells but it is not possible to use Ohmic tests to determine the amount of reserve left in a cell that has been tagged as bad. For this reason, TELUS will be exploring methods to perform short cycled discharge tests to obtain better data relative to capacity of the rehydrated cells over time.

Conclusions

Based on the data collected and TELUS experience, we are able to conclude the following:

1) Battery rehydration with the addition of a catalyst is a non-intrusive, relatively inexpensive method to extend the life of 2V AGM VRLA batteries.
2) Batteries equipped with a catalyst from the factory show fewer signs of positive plate growth than other batteries of the same vintage not equipped with the catalyst. It appears that having the catalyst added early will help batteries age more gracefully.
3) The addition of a catalyst and rehydration can improve the Ohmic readings and reverse cell dry out but it cannot reverse positive plate growth. For that reason, it is advisable to proceed with catalyst addition early on to reduce positive plate growth.
4) The operator must find a method to document the procedure within their inventory system to prevent premature battery replacements.

References

[1] Peter J. DeMar. "Restoring Capacity and Extending Useful Life In VRLA AGM Batteries through the Process of Rehydration and Catalyst Installation." http://www.battcon.com/PapersFinal2002/DeMarPaper2002.pdf, March 10, 2014.

[2] IEEE Recommended Practice For Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications, Amendment 1: Updated VRLA Maintenance Considerations

[3] Peter J. DeMar. "Report on the Long Term Results of Battery Capacity Recovery Processes for VRLA Cells." http://www.battcon.com/PapersFinal2008/DeMarPaper2008PROOF_7.pdf, March 10, 2014.

[4] Harold Vanasse, Philadelphia Scientific.