# BATTERY IMPEDANCE MONITORING...AN ADDED DIMENSION

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## ABSTRACT

The last line of defense against critical power loss has historically been the DC battery. Conscientious planned maintenance insured the availability of that battery. Today the last line of defense has shifted to yet another layer; intelligent battery validation systems. These surveillance devices coupled with quality software, a personal computer and a phone line, provide the predictive capability once enjoyed by manual surveillance techniques. The duty of these validation systems goes beyond reporting a failure but must include warning and alarm capability for impending battery system failure. The following illustrates such a system and highlights two examples of fault identification using battery validation equipment. For discussion purposes, we will concentrate on valve regulated or sealed type batteries since they offer the most critical maintenance issues to date.

## Introduction ... Surveillance Criteria

Any battery surveillance system must provide the minimum data to the end user:

- Battery terminal voltage
- Ambient Temperature
- AC power outage alarm

A quality battery surveillance system should provide an additional level of data to the end user:

- All the above
- Pilot cell temperature
- Cell or jar level voltages while on float
- Cell performance (voltage) during a discharge event

A quality battery validation system should provide yet another level of data to the end user:

- All the above
- Multi pilot cell temperatures
- Internal cell or jar impedance values
- Connection strap resistance
- Alarm conditions for high impedance occurrences
- Trend reporting software to illustrate impending battery problems

## Impedance Testing

The measurement used to predict most valve regulated lead acid (VRLA) battery failures today is impedance. An ac perturbation is placed onto the battery system such that an identifiable current of frequency and magnitude flows and impresses a resultant ac voltage drop across the cells under test.[i] [ii] This frequency should be selected so as to ignore reactive influences at the sub-Hz region and the $>10^3$ Hz regions. Selective filtering extracts the signal from the ever present plethora of system electrical noise and a calculation is performed.

The impedance vector is stored as data, along with the individual dc float voltages, and, if within acceptable pre-programmed limits, the alarms remain silent. Once the threshold is breached the predictive characteristics of the battery validation system forewarns the user of impending problems with his battery system.

### The Circuit

The generic representation of a battery circuit is illustrated as Figure 1. The metallic resistance incorporating terminal post, strap, grid and grid paste is represented as Rm. Ra is the resistance of the electrochemical path comprising the electrolyte and separator. The capacitance of the parallel plates is represented by Cb and roughly measures 1.3 to 1.7 Farads per 100Ah of capacity. This in turn is shunted by a non-linear resistance contributed by the contact resistance of plate to electrolyte. Although more sophisticated models exist, this illustration will suffice as reference material for the following discussion.

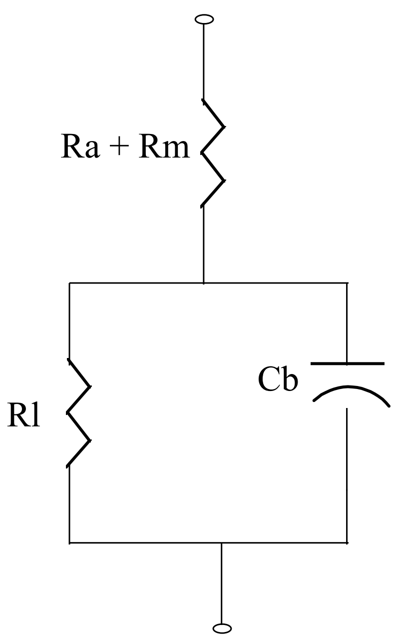


**Figure 1 Model Battery Circuit**

## VRLA Failure Mechanisms

The focus of this paper is to represent trend analysis data with identifiable failure mechanisms. Since the VRLA cells are opaque, normal surveillance practices are no longer practical and identifying failure mechanisms is after the fact. When flooded cells were the installed favorite, the maintenance technician realized when the electrolyte level was diminished, simply by looking at the fluid level in the jar. If this loss of electrolyte was left uncorrected, exposed plates would oxidize and become unusable surface area for energy transfer. This failure mechanism is currently identified as dry out in VRLA cells. Dry out may occur for several reasons:

1) Improper float charging will generate internal heat which in turn will create pressure buildup. Once this pressure exceeds the battery manufacturer's designed limits, the valve or vent opens until the pressure is relieved. This opening of the valve exposes the sealed cell to the atmosphere. Hydrogen is usually released and air is allowed to enter. Since this is done near the area of recombination, water is evacuated as well. Continuous operation under these conditions leads to gradual water loss and eventual capacity loss.

2) Excessive ambient temperature operation

3) Failure of the valve to close properly

4) Evaporation of water through the jar material[iii]

An additional concern for VRLA product is the internal deterioration of strap to post and internal connections between cells in multi-cell jars. Depending on alloys used, these metallic parts are subject to similar corrosion processes as the plates. It is not unusual to cut open a failed jar and see the post to strap connection completely dissolved. If there was some sort of strap or intercell connection corrosion taking place outside the normal process for flooded cells, the technician would be able to determine its extent with a flashlight and a good visual inspection. Once again, this preclusion of test leads to most VRLA battery system failures. The manned surveillance of today's UPS batteries will be replaced by automated systems for two reasons.

1) Visual inspection is no longer practical as mentioned and manual diagnostic techniques are formidable when dealing with large substation battery systems using multiple strings. Maintenance crews once dedicated to battery validation are now responsible for the entire substation maintenance.

2) The transition from good cell to bad cell is much more rapid with the VRLA cell and the required frequency of manual surveillance would be cost prohibitive. Flooded

cells provide more subtle transitions from full capacity to borderline. Unless an established trend analysis is maintained, these variations may go unnoticed.

## Impedance Trends and Cell Dry Out

Dryout is basically water loss. Water loss is primarily caused by two secondary reactions that occur:[iv]

1) Hydrogen evolution at the negative electrode and
2) Corrosion of the positive grid

Both electrochemical reactions consume a portion of the (over)charge current and result in water loss. This water loss reduces the electrolyte volume which in turn leads to increased internal resistance.(Ra of Figure 1) Water loss also increases the acid concentration of the cell which leads to more rapid sulphation of the negative. Loss of active material in contact with the electrolyte increases resistance as well. (Rl of Figure 1) I refer you to the paper written by Dr. Berndt of Varta Battery and of which I have just paraphrased. He and his associates have gone into greater detail from a battery manufacturer's viewpoint and serves as a reference for this paper.

The problem of water loss is not fatal if the symptom can be identified within a reasonable time frame. The key is to identify this failure mode early and act upon it before the cell is sulphated beyond reclamation. The recent announced procedure of re-watering VRLA cells has lowered the internal resistance of VRLA cells and it is expected to extend the product life. Unfortunately, this re-hydration process is still experimental and the degree of life expectancy after the process is not yet understood.

Correlative data is offered as Figure 2. This particular UPS battery installation was comprised of 132, 12-volt VRLA modules arranged in 4 parallel strings. Battery validation systems were installed at all UPS locations. For purposes of discussion, this system will be identified as #6 and the system later discussed under corrosion failures as #7. Out of the 132 jars involved, 25 were eventually replaced with similar problems. Unit #9 is representative of the 25 replaced.

Figure 2 shows a steady rise in impedance of unit 9, Site 6, between the dates October 27, 1994 and April 20, 1995. Since the jar impedance value passed through the set alarm point of the battery validation system in November of 1994, a surveillance was established by maintenance personnel to determine when the unit should be replaced. Load tests were performed using a CNI 1000C test set and the unit capacity report is offered as Table 1. The unit reached its low voltage cutoff and the test terminated. The tested jar was replaced and sent to the manufacturer for teardown.

| Time | Voltage | Current | Power | Ah | Wh |
|---|---|---|---|---|---|
| 0:00:10 | 11.44 | 85.3 | 976 | 0.2 | 2 |
| 0:00:30 | 11.48 | 85.1 | 977 | 0.7 | 8 |
| 0:01:00 | 11.48 | 85.1 | 978 | 1.4 | 16 |
| 0:01:30 | 11.38 | 85.9 | 978 | 2.1 | 24 |
| 0:02:00 | 10.66 | 91.5 | 976 | 2.8 | 32 |
| 0:02:03 | 10.46 | 93.0 | 974 | 2.8 | 32 |

**Table 1 Discharge Data (15 minute rate) - Unit 9**

Factory personnel performed an autopsy of Unit #9 and data indicated that a faulty valve mechanism allowed water to evaporate and consequently, the jar exhibited dryout.

Since the subject string was being monitored weekly and was in alarm prior to actual replacement, impedance data was used to develop a trend analysis in the hope that a better understanding of the correlation of impedance and cell failure could be established. An impedance signature or behavior trend was expected so that predictive capabilities would be determined. The equation for the trend analysis is shown in the graph area of Figure 2. The coefficient of x (slope) is rather insignificant when compared to a corrosion problem as illustrated later by Figures 4 and 5. This impedance data reveals that a degree of observance is required in order to identify dryout conditions.

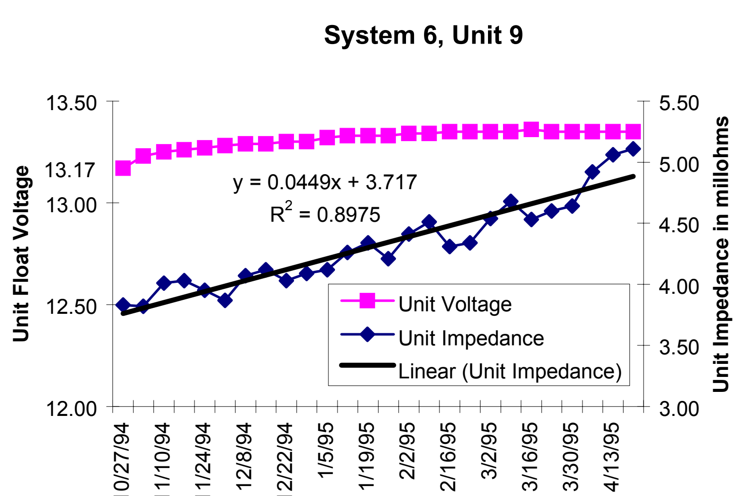

**Figure 2 - Cell Dryout Data**

## Impedance Trends and Internal Corrosion

The effects of corrosion of the internal connection path can be much more subtle until the point of failure. Figure 3 illustrates two possible cell interconnect failure mechanisms. The upper or cross sectional fault will exhibit a high impedance quicker than the lower representation. The lower, lateral corrosion example will mask the increase in impedance by generating a parallel current path until a full fracture occurs. Figure 4 shows the impedance life of a particular VRLA cell which failed due to negative bus strap corrosion. From October 27, 1994 until February 16, 1995 the impedance values showed a higher than average impedance value but nothing indicating a trend upward. After the February 16 data, the impedance data turns upward leaving only 3 weeks to remove the unit prior to the unit approaching open circuit.

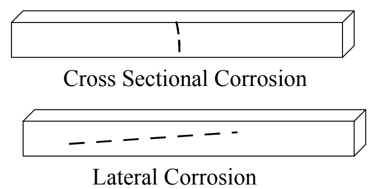


**Figure 3 - Internal Corrosion Forms**

Initial impedance readings grouped this module with those in the upper value distribution. Not all of these modules exhibited this failure mechanism. Several factors influence the impedance of a cell, manufacturing processes being one variation. Improper burns or welds and damaged separators will create an offset in the impedance value. However, the unit may pass an acceptance test and produce rated capacity but as the duty cycle lengthens, heat will buildup and the recombination process can further deteriorate internal bus connections.

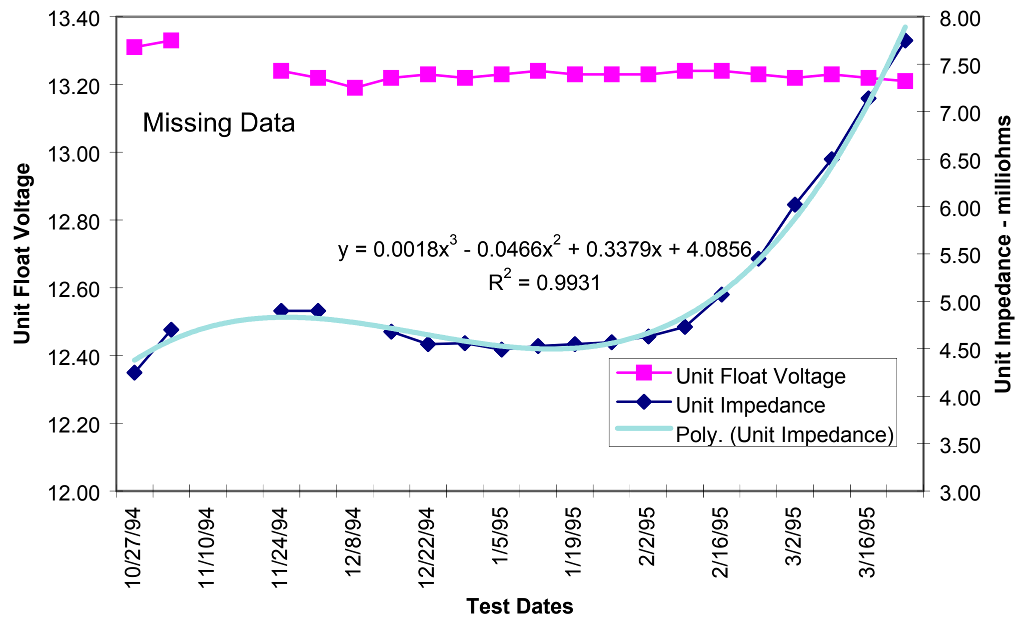


**Figure 4 - Internal Bus Corrosion - Unit 72**

Once again, impedance data from the battery validation system was used to analyze a confirmed jar failure. As mentioned above, the negative strap separated from the internal cell connection causing a cross sectional fracture. An attempt to create an equation covering the entire length of duty cycle forced a polynomial curve fit (Figure 4). The third order coefficient is subject to much debate, however the second order coefficient resembles that of the dryout condition. As to what use this information generates, remains to be seen through further study but if we isolate on the "period of imminent demise" we extract some useful information.

Figure 5 shows this "period of imminent demise" expanded and isolated from the previous data. Providing a regression line from the first suspect datum (January 19, 1995) until its removal date (March 23, 1995) we arrive at a slope coefficient larger by an order of magnitude ( 0.366) with a similar offset value of 3.628 as the dryout candidate.

## Conclusion

Only by using a dedicated battery impedance monitor, can you accurately discover fault trends in time to schedule maintenance and not suffer dc system failures. Looking at the representative

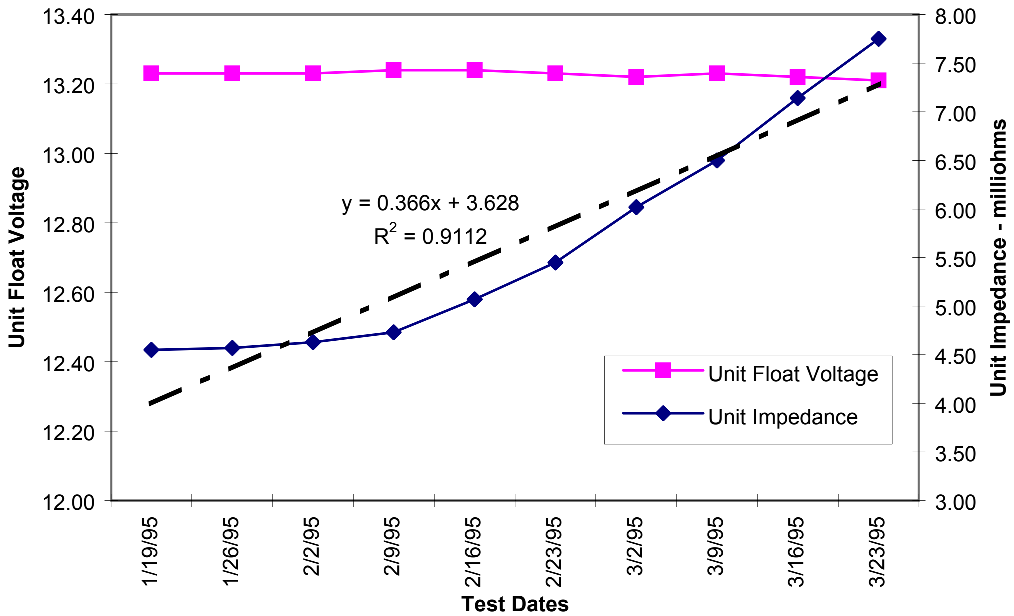


**Figure 5 - Unit 72, Expanded Time Frame**

voltage curves provides no concrete information until the unit is well into a state of non-performance. By providing a moving average of several measurement periods, the impedance slope coefficient can be calculated and used as a barometer for cell health and perhaps function as a dynamic alarm condition. It has been shown that the impedance test methods can provide the necessary information for predictive maintenance but the amount of data required prohibits this exercise by manual diagnostic methods.

## Discussion

The BTECH S3 is shipped from the factory with impedance alarm levels set at 15 percent. We feel that this provides additional time for the user to first determine the problem and then schedule the maintenance required. In the aforementioned case of intercell connection corrosion, the period of imminent demise is short; requiring an early warning. This contradicts recent IEEE recommended practice VRLA documents (PARs 1187, 1188 and 1189) and the telecommunication VRLA standard from the T1E1 group. Those recommended alarm levels are 30 percent for the IEEE documents whereas the telecommunication offering has not yet settled on an alarm percentage. Monitoring at the single cell level may predict failure mechanisms at the 30 % level however, a majority of VRLA applications are serviced by multi-cell modules. To accurately predict embedded cell health, a lower alarm level is appropriate.


## Acknowledgments

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[iv] D.Berndt, E. Meissner, W. Rusch, Aging Effects in Valve-Regulated Lead-Acid Batteries, Proceedings Intelec 1993 , S.22.B pp 139-145