CAVEAT EMPTOR: DOES YOUR BATTERY MANAGEMENT PLAN ACTUALLY MEET YOUR REQUIREMENTS?

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ABSTRACT

Risk mitigation is a fundamental part of today's business, and a lot of money is spent annually on the monitoring and maintenance of battery systems in order to reduce their potential for failure. The surprising thing is that very few customers ever question the value or interpretation of the parameters that are being used to report on the condition of the battery.

For many users, this can mean that the risk of battery failure may be much higher than they understood from the description of the product or services they were sold.

INTRODUCTION

Battery reliability should be a fundamental part of risk mitigation, so why are the users willing to contract for maintenance services based on price or personal relationships rather than an evaluation of the methodology used by the contractor?

The answer is relatively simple. The IEEE Guides and Recommended practices that most vendors use to validate their service offerings are, by design, generic and provide no ranking with respect to the recommended parameters that should be measured.

Also, should the user look for guidance from technical papers published by any of the battery related conferences and seminars, they will find that the majority of papers where the value of a specific measurement parameter is discussed are often written with an underlying commercial bias.

If an organization is to achieve the Holy Grail of "five nines" reliability or 99.999% availability from their standby power system, they need some way to measure the effectiveness of their battery management to ensure that the battery system will not fail when required.

This paper will propose establishing a Vulnerability Index that will define the risk of battery failure. The index will be a simple numerical value that can be calculated from the ranking of those battery parameters that are recognized to have value and the various service elements offered as part of the battery maintenance contract. A battery system on which no maintenance is carried out will have a Vulnerability Index of 100, then the value of the rankings allocated to the parameters being measured and the services selected will be subtracted from 100 to give us the final Index value.

DEFINING THE PARAMETERS

To get started, we need to identify the parameters that should be measured, and it is logical to use those listed in IEEE 1491-2005, Guide for Selection and Use of Battery Monitoring Equipment in Stationary Applications. There are a total of 16 different parameters listed in IEEE 1491 but many of those are, in fact, operational values of the same basic parameter, so the list to be measured has been reduced to the following.

- Voltage
- Coup de Fouet
- Current
- AC ripple current
- Temperature
- Specific gravity
- Ohmic value

Each parameter will be assessed on its ability to:

- Identify a failed cell / unit or battery
- Estimate loss of capacity of the battery

- Predict the failure of a cell / unit or battery
- Forecast time to replacement of the battery

As already noted, within each of the primary parameters there are a number of subparameters, some of which can contribute to the battery assessment. Where this occurs, each of these will be separately assessed as to their ability to contribute to the four basic requirements.

In order to eliminate subjective bias, a simple scale of 0 – 2 will be used to define the value of a specific parameter and its ability to reduce the risk of failure. The grade will be applied as follows:

0	No Value
1	Contributes when evaluated with another parameter
2	Can be used as a stand alone indication

Table 1

Voltage

Voltages, whether at the battery, string, midpoint or cell level, are by far the most common parameters measured and recorded, but what do they really mean?

Battery or String Voltage Evaluating the voltage of an open circuit battery is accepted as a good indication of the battery's State of Charge (SOC); however, very few batteries are operated at open circuit, so measuring the voltage in that operating mode is seldom an option. The majority of batteries are kept fully charged by applying a continuous float voltage, the value of which is determined by the charging equipment to which the battery is attached, and it is the charging voltage that is most commonly recorded. The problem is, when a battery is in float mode, with the voltage controlled by the charger, the Battery or String voltages will have no value in identifying either a failed or failing battery.

However, floating the battery at the correct voltage is an important element in achieving the projected design life, so recording and averaging the float voltage over time will provide one of the parameters required to estimate end of life. The value of the Battery or String Voltage during discharge, whether scheduled or unscheduled, can also provide valuable data as to the overall condition of the battery at the time of discharge, but, without a record of the individual cell voltages, there is limited ability to predict a subsequent failure.

Using the battery or string voltage as a static parameter is limited in its diagnostic capability but it provides a record of the voltage at which the battery was operated and, therefore, has relevance in the end of life calculation. Under discharge conditions, its value is considerably greater and can identify a battery that failed and will provide a clear indication of loss of capacity. If the loss of capacity can be correlated with other parameters, such as float current or ohmic value, a reasonable prediction as to end of life can be achieved.

Parameter	Identify	Capacity	Predict	End of Life
Battery/String Voltage Float Mode	0	0	0	1
Battery/String Voltage During Discharge	1	1	1	1

Table 2

The assessment of the individual Cell/Unit Voltages is much more complex; each cell has an optimum voltage at which it should be charged, based on chemistry and design. On batteries where multiple cells in series are charged at the recommended charge voltage, variations across cells will occur but they should be within acceptable limits until one or more of the cells deteriorate. At that time, the voltage on these cells will change but, because of the fixed charging voltage, the voltage on the other cells will also change, and it is not until a cell has deteriorated badly will the voltage change be sufficient to indicate it is outside manufacturer's limits.

The graph in Figure 1 demonstrates this delay in the voltage response. The unit voltage did not drop below the user preset limit until 09/03/2007 but, in Figure 2, the rise in impedance shows that the unit had in fact failed open on 08/22/2007, some 12 days before the voltage drop provided an alarm indication.

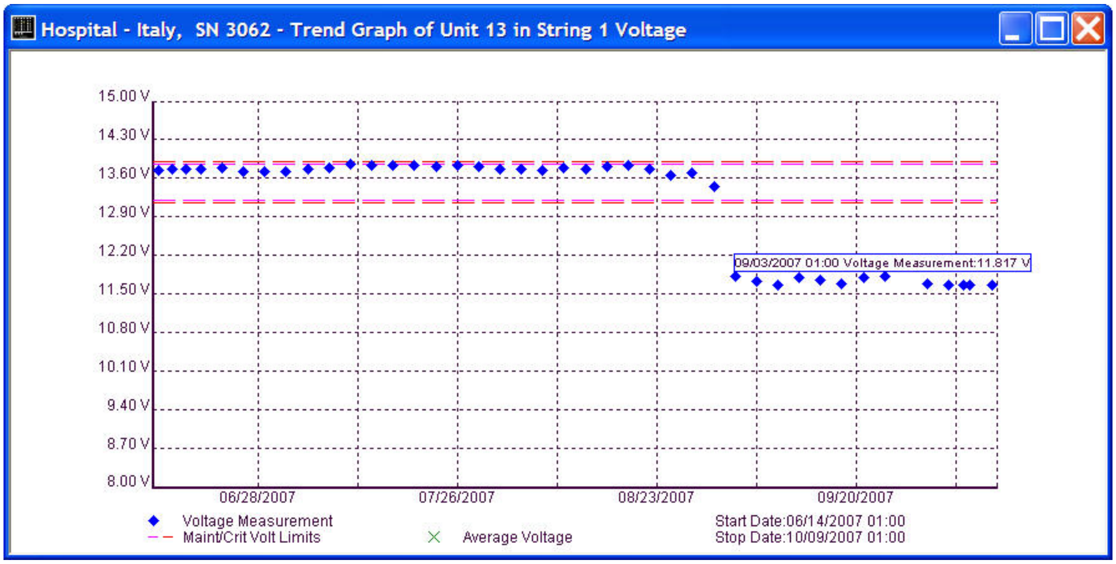


Figure 1

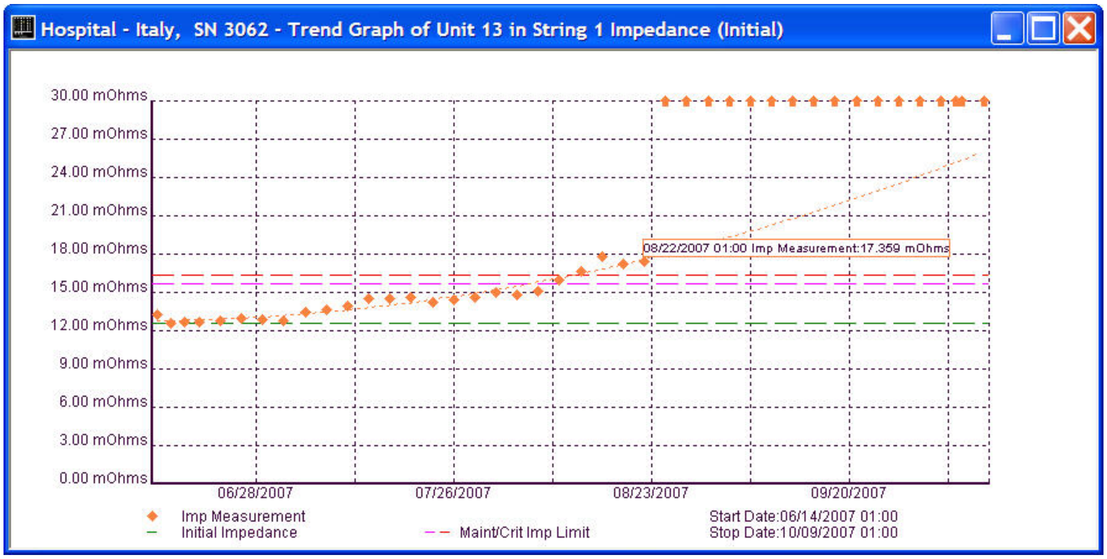


Figure 2

Philip Symons, in a 2004 Battcon Paper[1], provides a good insight into the behavior of cell/units in series connected battery strings and highlights the need to understand the behavior of the individual cell/units during charging and discharging.

The individual cell voltages can provide even more information if the data is collected and time stamped during a discharge and subsequent recharge. The voltage response of a cell to both discharge and recharge will clearly identify those cells in which the electrochemical reaction is responding differently than in the other cells. While this may not immediately have a bearing on the ability of the battery to meet specification, it may, over time, affect the operation of the other cells.

Parameter	Identify	Capacity	Predict	End of Life
Cell Voltage Float Mode	2	0	1	1
Cell Voltage During Discharge / Recharge	1	1	1	1

Table 3

Coup de Fouet

It is generally accepted that a full discharge at a rate appropriate to the type of battery is the only true validation of the battery's capacity. The problem is that it is an expensive and time consuming process which, if carried out on a regular basis, will accelerate the demise of a failing cell and ultimately shorten the life of the battery.

To this end, there have been a number of studies carried out to evaluate using the condition known as Coup de Fouet. The objective was to see if the depth of the initial voltage drop would relate the battery's SOH (State Of Health). In one study[2] under controlled load conditions, with batteries that had been subjected to accelerated aging and batteries that were normally aged in the field, there did appear to be a direct correlation between the trough voltage and SOH. But the authors add a warning that "The technique shows some dependency on battery design" and "For other failure modes, the correlation of coup de fouet voltage and deliverable capacity may not be linear."

This reflects that the batteries tested appear to have only had age related loss of capacity and may not exhibit the same behavior if the cell was losing capacity for a different reason. Because of this and the fact that the value of the trough voltage also varies with load means that using this parameter on a operational systems has substantial limitation but, if the necessary analysis capability is in place, it can provide supporting data in respect of capacity and end of life.

Parameter	Identify	Capacity	Predict	End of Life
Coup de Fouet Voltage Dip	1	1	0	1

Table 4

Partial Discharge

In an attempt to reduce the cost of scheduled test discharges, there are advocates that promote the use of a partial discharge using the system load, as an alternative guide to the battery's SOH (State of Health). Like the Coup de Fouet, this technique has limitations due to the behavior of a cell/unit under certain failure modes.

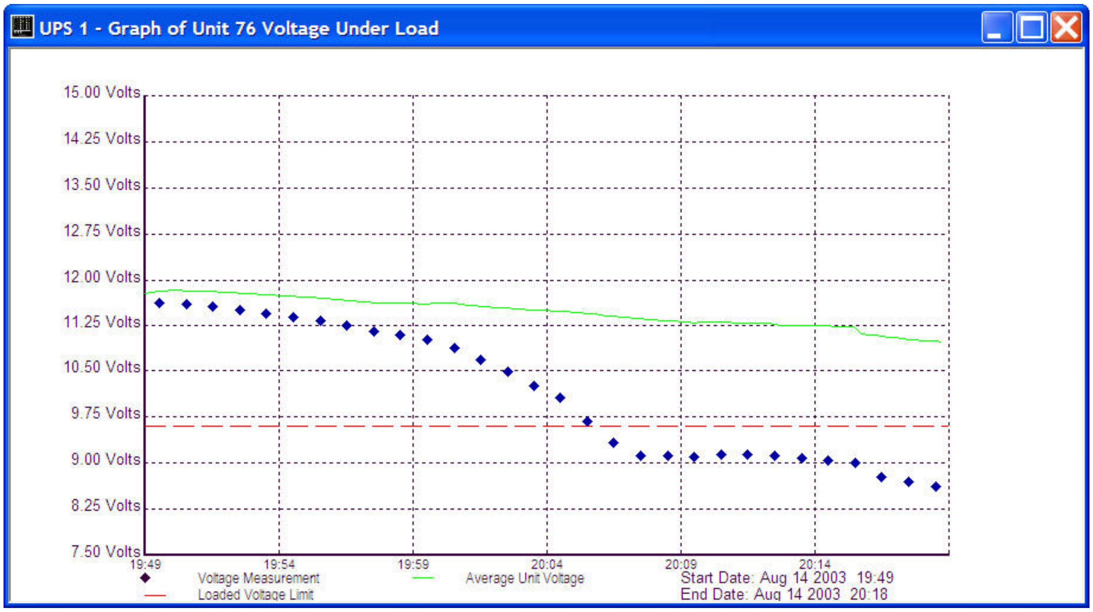


Figure 3

This is clearly demonstrated in Figure 3 and 4. Both units were in the same battery during the same discharge. In Figure 3, the discharge graph for Unit 76 starts below the average voltage for the other units in the battery and continues to decay at a faster rate, which is what would be expected from a failing unit. The graph for Unit 6 in Figure 4, however, shows the voltage following the average for a large part of the discharge before it starts to decay, a characteristic that would not be detected on a partial discharge.

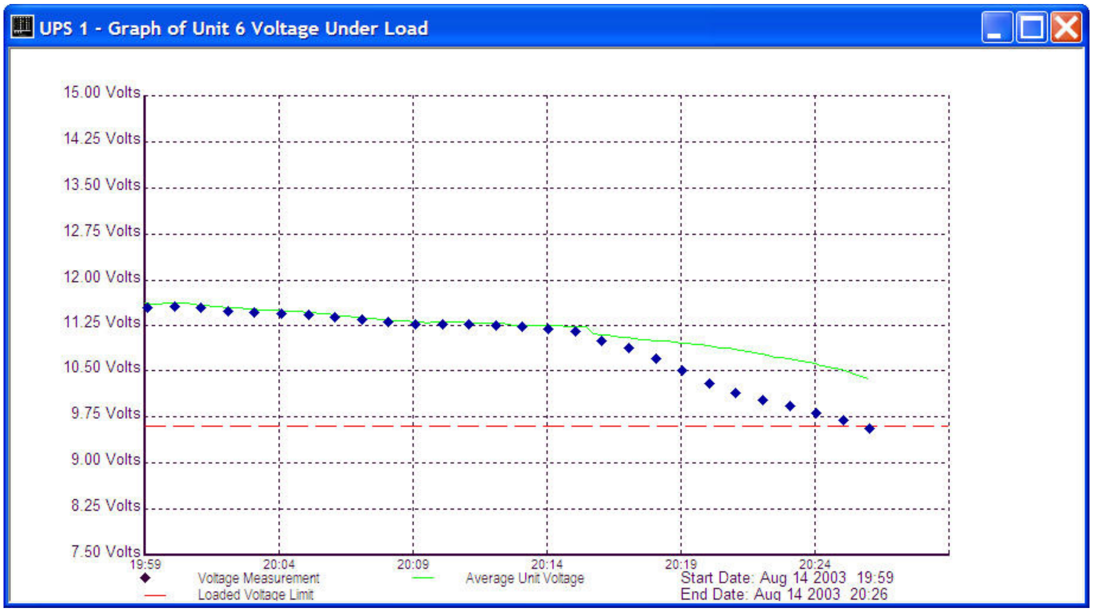


Figure 4

In order to differentiate the effectiveness of a full discharge against a partial, the following operational parameter has been added.

Parameter	Identify	Capacity	Predict	End of Life
Full Discharge	2	2	2	2

Table 5

Battery Current

DC Current flow within a battery is an intrinsic part of the electrochemical process on which a lead acid battery operates, and the measurement of that current provides valuable data during all phases of a battery's operation. During the discharge cycle on a single string, the value of the current is dependant on the load applied and is required to normalize the battery voltage readings when calculating the anticipated run time. In many applications where there are parallel strings of identical cells, only the overall battery current is measured in order to save costs. This can be very shortsighted; measuring the current at the string level will ensure that any imbalance in the current between individual strings can be identified, a clear indication of problems with the lower current string. This will also apply to variations in recharge current in the individual strings at the end of the discharge when a cell may have been damaged by being over discharged. The predominant mode of operation for a standby battery is under float conditions, and there have been papers from as long ago as 1994 demonstrating the ability of float current to identify SOC[3]. The number of users who have implemented float current monitoring has been very small. This is due to the complexities of measuring, with accuracy and at reasonable cost, the low levels of float current with a sensor that also has to be subjected to a high current discharge/recharge cycle. There are now a number of products in development or recently released that should accelerate the use of float current as a management tool.

Battery current by itself will not indicate or predict failure of a battery or an individual cell/unit; however, when integrated with other parameters, it will provide valuable insight to the battery's operational viability.

Parameter	Identify	Capacity	Predict	End of Life
Discharge / Recharge Current	1	1	0	0
Float Current	2	1	1	1

Table 6

AC Ripple Current

Hypothetically, a battery that is being charged by a DC source should have no AC current flowing in the circuit but that is unfortunately not the case. Often, due to the design of the charging source and the nature of the load applied to the battery, considerable levels of AC current can flow in a battery string. This is particularly true with a UPS where the battery acts as a filter between the rectifier and the inverter. While there is validity to the idea of using the AC Voltage developed across the cell/unit by this ripple current to establish the impedance of the battery, there are challenges to the practical implementation of such a system, as outlined in the 2008 Battcon paper from Zbigniew Noworolski[4]. This, however, should not preclude the measurement of AC current, as Mark H. Townsend[5], a UPS Applications Engineer from General Electric, pointed out in a Battcon 2007 presentation that a steady increase in the AC current flowing through a battery could indicate the failure of components within the UPS itself, and identification of the problem may limit potential damage to the battery.

The key to using any AC based data is to understand the limitations of the existing measurement practices. In a Tech Support document from C&D DYNASTY Division[6], it is suggested that measuring the AC voltage across a cell/unit can be used as a troubleshooting tool. The problem is that, although they point out the values obtained will not necessarily correlate with the ohmic values from the specialty battery test systems. There are companies that continue to use the technique and the values obtained to discount the values and trending data from the more sophisticated equipment.

At this time, the value of the data that can be obtained is somewhat limited simply because there are too many variables in the data collected to utilize simple trending as a means to identify failing cells/units

Parameter	Identify	Capacity	Predict	End of Life
AC Current	1	0	1	0
AC Voltage across the Cell / Unit	1	0	0	0

Table 7

Temperature

The temperature of a battery is affected by a number of factors. During both discharge and recharge, heat is generated due to the internal resistance of the battery. During a discharge, the potential rise in temperature will be limited by the energy available in the battery and the endothermic electrochemical reaction, though, in the majority of cases, the heat gain from the I^2R losses will exceed the effect of the endothermic cooling with a limited rise in battery temperature. This is not the case when a battery is recharging, now the temperature rise is supported by the exothermic chemical reaction and the recharge current is limited only by the charging source. The temperature of the individual cell/units is also very dependant on the physical configuration of the battery and the environmental controls at the battery's location.

Corrosion is a primary reason for battery failure, and the rate at which it occurs and, hence, battery life is dependant on the ambient temperature in which the battery is operated. For example, if the battery is operated continuously in an ambient temperature of 94°F, 17° above 77°F, then the anticipated life of the battery will be halved.

The recording of both ambient and pilot cell temperatures will provide a record from which the user can detect changes in the relationship between the two temperatures and float current, which may indicate a change in battery chemistry. Monitoring of the temperature of the individual cells will give an even more detailed picture.

Parameter	Identify	Capacity	Predict	End of Life
Ambient Temperature	0	1	1	1
Cell/Unit Temperatures	1	1	1	1

Table 8

Specific Gravity

Of all the parameters discussed in this paper, SG (Specific Gravity) is the one that is not applicable to all lead acid based batteries. A long standing parameter for flooded cells, it cannot be measured on an AGM or gelled cell. The objective of measuring the SG of the sulphuric acid in a flooded cell is to establish the SOC by comparing the value measured with the original value.

Although electronic, hand held testers and permanently installed sensors are available, replacing the manually intensive use of a hydrometer, the measurement and recording of SG is no longer considered as important as it once was.

Parameter	Identify	Capacity	Predict	End of Life
Specific Gravity	0	1	1	1

Table 9

Ohmic Value

There is general consensus that one of the more consistent ways to determine a battery's condition is to measure and trend the change in ohmic value of an individual Cell/Unit. Ohmic value can be measured by passing either an AC or DC current through the battery, and the value of the response can be reported in milliohms representing resistance or impedance and siemens as an indication of conductance.

There have been many papers and articles published describing the benefits and limitations of the different methodologies that the manufacturers of battery testers use to measure the ohmic value of a battery and, in the interest of fairness, the assessment of this parameter will be based on the validity of ohmic measurement rather than the differing characteristics of the individual products. There is, however, one word of warning; the values obtained by the different products are not directly comparable, and the most accurate results are obtained by trending the values obtained over a period of time using the same methodology.

Parameter	Identify	Capacity	Predict	End of Life
Ohmic value	2	1	1	1

Table 10

ANALYSIS

Now that the individual battery parameters have been graded, a review of the results will clearly demonstrate that only a few of the parameters that can be measured have the ability to stand alone in judgment without the support of other parameters, and those that can either need the battery to have been subjected to a discharge /recharge cycle or have been perturbed as part of an ohmic measurement sequence. For all the other parameters, it is the relationship between them and how that evolves over time in response to the changes in the battery chemistry that holds the key to identifying a potential failure condition.

Obviously, then, the analysis of the data collected is the key to reducing risk and, while it is possible to do this analysis manually, the best results are obtained when software developed specifically for battery evaluation is used.

There are two basic analysis functions that can be applied to the data:

- Limit Alarms – Indicates when any of the measured parameter e.g. battery voltage, cell/unit voltage, temperature, or ohmic value has exceeded a user set value. Limit alarms, by definition, are intended to identify an impending failure within the battery but, in order to minimize spurious or false alarms, the limits are often set such that, by the time the alarm is activated, the battery or cell has failed and the user is already at risk. The drop in Unit voltage, as shown in Figure 1, clearly demonstrates this as it would not have alarmed until it dropped below the lower red line on the graph.
- Trend Analysis – Trend analysis will identify any divergence in the relationships between the measured parameters, as a result of changes to the environmental conditions or variances in the electrochemical activity within the individual cells/units. This form of analysis is more discriminating than limit based alarms in that in can identify the rate of change in a parameters value resulting in the ability to detect a failing cell/unit or to predict the time scale within which the battery will require replacement.

Both types of analysis are required in order to get maximum benefit from the data collected. This is reflected in the calculation of the Vulnerability Index by simply excluding the parameter values allocated to Predicting Failure, Estimating Capacity and Forecasting End of Life if trend analysis is not selected. In the unlikely event that Limit Alarms are not included in the analysis, then the values allocated to Identifying a Failure are excluded.

Scheduling

Other than evaluating the battery, unit or cell voltages during a discharge, all the other analysis requires data gathered over an extended period and, as with all analysis, the more data you have the more accurate the results. Therefore, the frequency with which the data is collected is an important factor in minimizing the risk of failure.

Typical maintenance contracts are based on the inspection schedules contained in IEEE 450-2002 Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications and IEEE 1188-2005 Recommended Practice for Maintenance, Testing and Replacement of Valve Regulated Lead-Acid (VRLA) Batteries for Stationary Applications. Although both documents recommend monthly, quarterly, semiannual and annual inspections due to cost, the majority of maintenance contracts eliminate the monthly inspections. The problem with that is the propensity of a lead acid battery to fail outside the planned maintenance schedule. With a quarterly maintenance schedule, a battery may have actually failed and the user would be unaware. The following graph from archived data clearly demonstrate this.

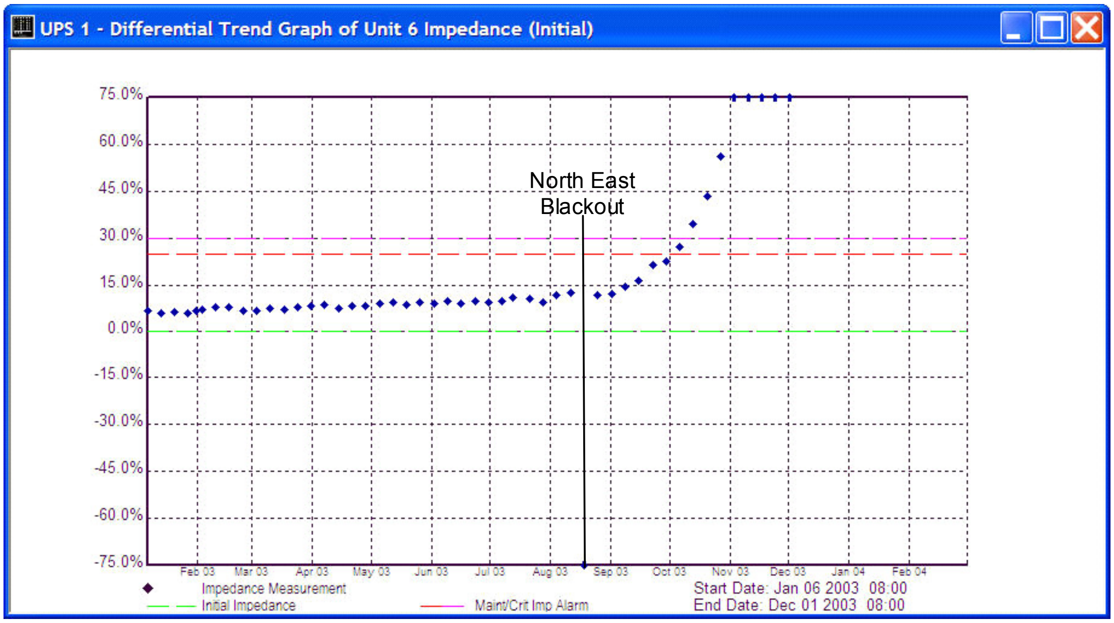


Figure 5

The graph in Figure 5 shows the impedance plot for unit 6 in a UPS located in New York City before and after the Northeast Blackout. Over the two plus years that the battery had been installed, the impedance of unit 6 had risen by just under 15%, well within the normally accepted limit of 30%. After the deep discharge on August 14th, the unit appeared to recover, and the following two scheduled reads were normal. Had this battery been inspected after the discharge, the battery technician would have been justified in giving this unit a clean bill of health? The situation changed after week three at that point the impedance started to rise rapidly and the unit went open circuit within two months, well before the next inspection was scheduled.

Obviously, the more frequently the data is collected, the quicker a failing battery will be identified, so there has to be an adjustment to the ranking of a parameter based on the frequency at which the data is collected.

If we are to accept that any battery which is not inspected at least once a year is the most vulnerable and one which is being monitored in real time is the least, then a simple multiplier between 0-1 referenced to time will provide a reasonable correction factor.

While it would be simplest to apply the multiplier to the total of all the rankings selected, it would not reflect the overall value of the different parameters, so the following rules will apply.

No correction will be applied to the ranking of parameters where the data is obtained during a discharge or recharge cycle.

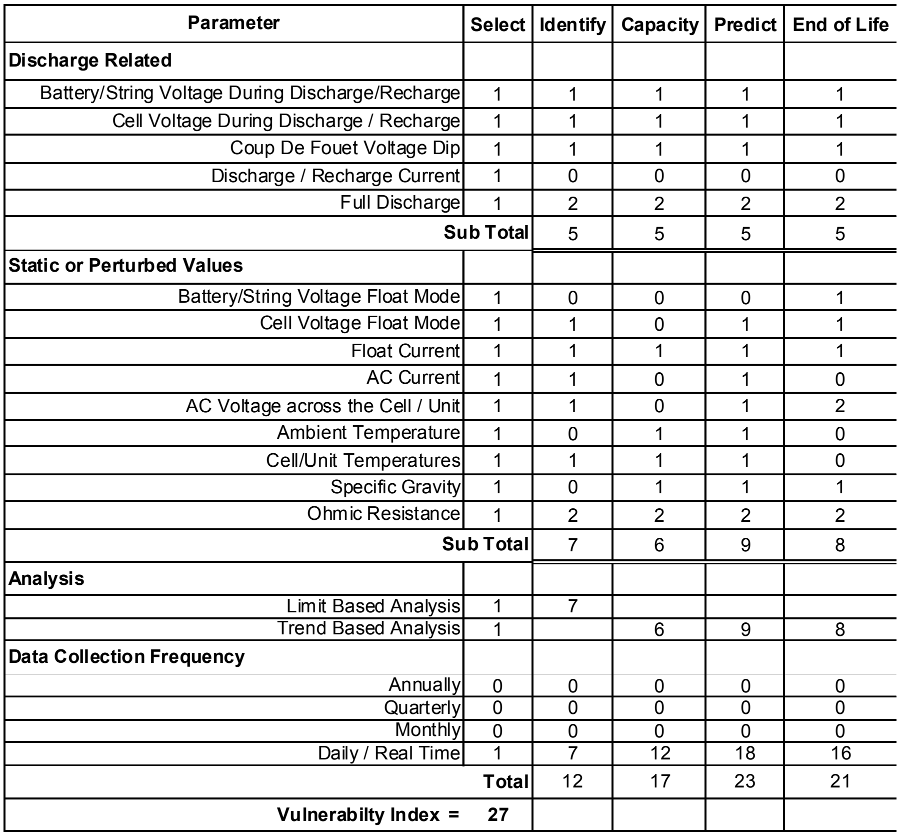
The rankings applied to parameters, with reference to identifying the failure of a battery or a cell/unit using limit based alarms, will be multiplied directly by the multiplier to reduce their value based on the number of times that they can applied during the year.

Data Collection Frequency	Multiplier
Annually	0.1
Quarterly	0.25
Monthly	0.916
Daily/Real-time	1

Table 11

The other rankings, which all apply to prediction, will have a multiplier with a base of 1 plus the appropriate frequency multiplier, i.e. Quarterly = 1 + 0.25 giving a 1.25 multiplier. This represents the increase in the accuracy of the prediction algorithms based on the volume of data available for analysis.

The spreadsheet shown in Figure 6 shows how the calculation of the index would work based on the ranking, analysis and frequency of data collection. The spreadsheet works by placing a 1 in the "Select" column of each parameter selected for measurement and repeating the process to select the level of analysis and the frequency at which the data is being collected. With all parameters measured, fully analyzed and recorded in real time, the Vulnerability Index is determined to be 27.



Parameter	Select	Identify	Capacity	Predict	End of Life
Discharge Related					
Battery/String Voltage During Discharge/Recharge	1	1	1	1	1
Cell Voltage During Discharge / Recharge	1	1	1	1	1
Coup De Fouet Voltage Dip	1	1	1	1	1
Discharge / Recharge Current	1	0	0	0	0
Full Discharge	1	2	2	2	2
Sub Total		5	5	5	5
Static or Perturbed Values					
Battery/String Voltage Float Mode	1	0	0	0	1
Cell Voltage Float Mode	1	1	0	1	1
Float Current	1	1	1	1	1
AC Current	1	1	0	1	0
AC Voltage across the Cell / Unit	1	1	0	1	2
Ambient Temperature	1	0	1	1	0
Cell/Unit Temperatures	1	1	1	1	0
Specific Gravity	1	0	1	1	1
Ohmic Resistance	1	2	2	2	2
Sub Total		7	6	9	8
Analysis					
Limit Based Analysis	1	7			
Trend Based Analysis	1		6	9	8
Data Collection Frequency					
Annually	0	0	0	0	0
Quarterly	0	0	0	0	0
Monthly	0	0	0	0	0
Daily / Real Time	1	7	12	18	16
Total		12	17	23	21
Vulnerabilty Index =	**27**				

Figure 6

The reason why this number is not lower is simply because identifying the failed or failing battery doesn't eliminate the risk, the identified cell/unit has to be replaced before the risk is removed, and the time between identification and repair is an important element in reducing risk. As a result, there are a number of additional design and operational factors that impact the assessment of risk.

Redundancy

One of these factors is the level of redundancy within the battery system. In a location where the power system has limited or no redundancy, maintenance, and that includes battery change out, is only possible during a planned service outage. So, on systems where there is the potential for an operational delay to the replacement of a compromised cell/unit, then the vulnerability index has to be raised. To do that, the overall index at this point will be multiplied by the same multiplier that is applied to limit based systems on a monthly data collection schedule.

Redundancy	Multiplier
No Redundancy	0.916
N+1	1

Table 12

On systems where there is redundancy, the operations staff will typically allow concurrent maintenance so cell/unit replacement can be done on demand and there is no change to the Index.

The next part of the vulnerability assessment has nothing to do with the physical battery or its configuration, but has everything to do with the relationship between the service provider and the end user. If we are to truly reduce the vulnerability of a battery to failure, then the relationship between the two has to be one of mutual trust. The user has to understand the importance of replacing the compromised units in a timely manner, and it is the vendor's responsibility to ensure that all work is carried out in accordance with the original agreement.

Replacement Authorization

In view of the risk attached to having a compromised battery, it would seem logical to have the authorization in place to replace the failed units but, in many cases, even if the cell/unit is still under warranty, the labor to replace it may well not have been budgeted and requires a separate requisition and approval process. This could add weeks if not months to the replacement cycle. The ability to structure preauthorized replacement will be dependant on the bureaucracy within the user company and is allocated as a user defined value as shown in Table 13 and may well be predicated on whether the failure is actual or predicted.

The availability and location of spare cells/units is also a determining factor; if they are not immediately available, then a delay will occur. The multipliers as shown in Table 14 work the same way as those used to correct for data collection frequency.

Replacement Authorization	Value
Pre Authorized Replacement On Failure User Defined 1-5	5
Pre Authorized Replacement On Prediction User Defined 1-5	5

Table 13

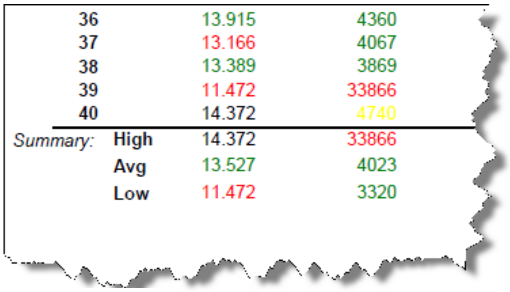
Replacement Availability	Multiplier
Replacement Cells Requisition Required	0.916
Replacement Cells/Units held Vendor	0.981
Replacement Cells/Units held on Site	1

Table 14

Data Presentation

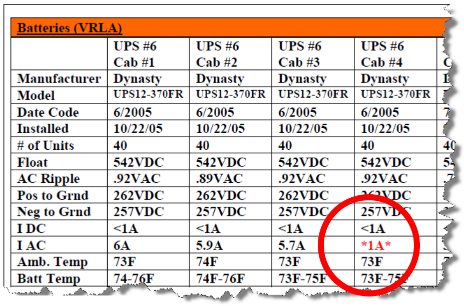
Another factor is the way in which the information is provided to the user. Clear and concise presentation of the battery's condition is essential and as it cannot be assumed that the user will fully understand the relevance of the data being presented a detailed description of the risk and its potential impact is required in any report submitted.

To demonstrate why this is important here are some extracts from a service report that the user requested a second opinion on. The maintenance report covered five UPS with flooded cells and two with VRLA units in cabinets. When reviewing the maintenance report, the following observations were made on cabinet 4 of UPS 6. Figure 7a shows the ohmic value of unit 39 to be 33,000 milliohms, way above the more typical reading in the 4,000 milliohm range and in a range where it is reasonable to assume that the battery may be close to open circuit. This conclusion is further supported by the measurement of ripple current shown in Figure 7b, where the current in that string is very low in comparison with the other strings. This unit is a component of a four string, nonredundant battery configuration and based on the UPS manufacturer's data sheet for the battery configuration, four cabinets would give about 13 minutes in the event of a power failure. If unit 39 went open circuit



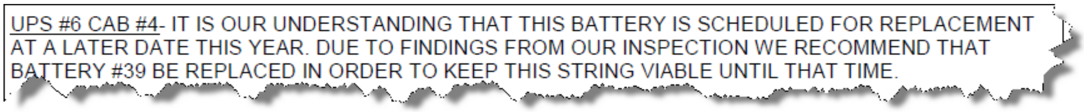
	36	13.915	4360
	37	13.166	4067
	38	13.389	3869
	39	11.472	33866
	40	14.372	4740
Summary:	High	14.372	33866
	Avg	13.527	4023
	Low	11.472	3320

Figure 7a



Batteries (VRLA)	UPS #6 Cab #1	UPS #6 Cab #2	UPS #6 Cab #3	UPS #6 Cab #4
Manufacturer	Dynasty	Dynasty	Dynasty	Dynasty
Model	UPS12-370FR	UPS12-370FR	UPS12-370FR	UPS12-370FR
Date Code	6/2005	6/2005	6/2005	6/2005
Installed	10/22/05	10/22/05	10/22/05	10/22/05
# of Units	40	40	40	40
Float	542VDC	542VDC	542VDC	542VDC
AC Ripple	.92VAC	.89VAC	.92VAC	.92VAC
Pos to Grnd	262VDC	262VDC	262VDC	262VDC
Neg to Grnd	257VDC	257VDC	257VDC	257VDC
I DC	<1A	<1A	<1A	<1A
I AC	6A	5.9A	5.7A	*1A*
Amb. Temp	73F	74F	73F	73F
Batt Temp	74-76F	74F-76F	73F-75F	73F-75F

Figure 7b



UPS #6 CAB #4- IT IS OUR UNDERSTANDING THAT THIS BATTERY IS SCHEDULED FOR REPLACEMENT AT A LATER DATE THIS YEAR. DUE TO FINDINGS FROM OUR INSPECTION WE RECOMMEND THAT BATTERY #39 BE REPLACED IN ORDER TO KEEP THIS STRING VIABLE UNTIL THAT TIME.

Figure 7c

and cabinet 4 failed, the remaining three cabinets would give about 7 minutes at full load. In this case, the situation would not have been that bad as the UPS wasn't fully loaded.

The problem is that although both these items were highlighted in separate parts of the report, the recommendations shown in Figure 7c simply recommended replacement and made no reference to the risk of a cabinet failure or the fact that the run time would be compromised.

As the user had asked for a second opinion, it might be assumed that they were aware of the potential problem and that in fact the report was adequate, but in fact they were questioning a second recommendation within the report that all the flooded cells be equalized to see if the low SG readings on some cells could be improved and they were concerned that it could damage the 10 year old battery.

Data Presentation	Value
Clarity of Data	1-5

Table 15

As any judgment about the presentation of data is somewhat subjective, a ranking from 1 – 5 can be entered by the user depending on the perceived value of the reporting format of the service provider or that of the analysis software.

Vendor Competency

The last and probably the most important factor is the competency of the vendor; here, the user has to apply a rating of between 1 and 5 based on previous experience or on references obtained.

Vendor Assessment	Value
Vendor Competency	1-5

Table 16

Parameter	Select	Identify	Capacity	Predict	End of Life
Discharge Related					
Battery/String Voltage Discharge/Recharge	1	1	1	1	1
Cell Voltage Discharge / Recharge	1	1	1	1	1
Coup De Fouet Voltage Dip	1	1	1	0	1
Discharge / Recharge Current	1	1	1	0	0
Full Discharge	1	2	2	2	2
	Sub Total	6	6	4	5
Static or Perturbed Values					
Battery/String Voltage Float Mode	1	0	0	0	1
Cell Voltage Float Mode	1	1	0	1	1
Float Current	1	1	1	1	1
AC Current	1	1	0	1	0
AC Voltage across the Cell / Unit	1	1	0	1	1
Ambient Temperature	1	0	1	1	1
Cell/Unit Temperatures	1	1	1	1	1
Specific Gravity	1	0	1	1	1
Ohmic Resistance	1	2	2	2	2
	Sub Total	7	6	9	9
Analysis					
Limit Based Analysis	1	7			
Trend Based Analysis	1		6	9	9
Data Collection Frequency					
Annually	0	0	0	0	0
Quarterly	0	0	0	0	0
Monthly	0	0	0	0	0
Daily / Real Time	1	7	12	18	18
	Sub Total	13	18	22	23
Power System Configuration					
Non Redundant	0	0			
n+1	1	76			
Customer / Vendor Relationship					
Replacement Cells Requisition Required	0	0			
Replacement Cells/Units held by Vendor	0	0			
Replacement Cells/Units held On Site	1	76			
Pre Authorized Replacement On Failure 1-5		5			
Pre Authorized Replacement On Prediction 1-5		5			
Clarity in Documentation 1-5		5			
Competency of Vendor Staff 1-5		5			
Vulnerability Index =	**4**				

Figure 8

The final spreadsheet is shown in Figure 8 and, even if we do everything listed, we are still left with a Vulnerability Index of 4, and that is because no matter what you do with a battery, there will always be some potential for failure, including human error.

Now that we have the Index, how can it be used when evaluating a power system for its contribution to achieving “five nines” 99.999% system availability rating?

Five Nines

The term “five nines” availability, when used in the context of an IT infrastructure, reflects the loss of service to the end-user for no longer than five minutes and fifteen seconds in any one year and that includes both software and hardware. In practical terms, this means that there can be no failures, as the human response to any problem will probably take longer than that.

This is supported by the Uptime Institute, which has developed a guide to the infrastructure requirements necessary to achieve various levels of availability. In their White Paper, “Tier Classifications Define Site Infrastructure Performance,”[7] they state that a fully duplicated infrastructure, which they have designated Tier 4, can only consistently achieve 99.99% availability, and this is based on operational data gathered over a ten year period and not a statistical calculation. In support of using co-generation as the primary power source for both Tier 3 and Tier 4 locations, they also state that “Disruptions to the Utility Power are not considered a failure, but rather an expected operational condition for which the site must be prepared.”

In this context, the potential impact of a battery on system availability due to Utility failure is during the period from when the battery is recognized to be compromised in its ability to support the load until the point at which it can again support the load. This correlates well with the methodology used to establish the Vulnerability Index; in fact, from a practical point of view, the Index value could well be interpreted as the number of days in a year when the power system is at risk of failure during a Utility outage.

CONCLUSIONS

The importance of a standby power system within an organization is a function of regulatory requirements or business continuity requirements. This paper has been an attempt to put a value on the different products and services that comprise the battery management of that power system and to give users a tool by which they can understand, in a practical way, the level of risk of battery failure under that battery management plan. As with any proposal that requires subjective assessment, there will be many who disagree with the conclusions reached but, if it generates a debate, then the objectives will have been achieved.

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