How to Achieve "Five Nines" Availability from a Lead Acid Battery's Perspective

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Abstract

The term "Five Nines" is used to indicate that the Uptime or availability of a service is greater than 99.999% over a year. In practical terms, this equates to a downtime of no more than 5.26 minutes in any one year. The term is most closely associated with data centers, and, regrettably, the battery's reputation in that industry is not too good. In the most recent Ponemon study into the cost of data center outages sponsored by Vertiv, UPS Failure ranked up there with hacking as the most common reason for data center downtime. Although not broken out in this latest report, the previous reports in 2010 and 2013 identified UPS battery failure as the top root cause of UPS related unplanned outages.

This paper will look at the life of the battery from when it leaves the manufacturer, till it is sent to the recycler. It will initially examine each step from selection to commissioning, to determine whether some of the subsequent failures are due to the choice of battery and way it is transported, installed, and placed in service.

Once the battery is in service, the current management practices and software will be reviewed to determine if they can consistently identify a battery deterioration early enough to ensure remedial action can be taken before the battery fails. With the growing use of Machine Learning software to analyze performance data, the potential to use this to improve battery analysis will also be investigated. But simply identifying these potential points of failure is not enough, the way in which the information is presented to the user must be in a format that is understood by persons who are not battery experts. Multiple trend graphs and limit based analysis without identifying the level of risk to the supported service is no longer sufficient.

Typically, when the battery reaches end of life, it is replaced by the same model, but is that the best way to improve reliability, or should the accrued data be used to select a battery that may be better suited to the application and the operating environment? Battery reliability can be improved, but what this paper will demonstrate is that improvements are needed at every stage in the battery's life if it is to be achieved.

Introduction

From a data center operations perspective, to achieve "Five Nines" level of service availability requires removing all single points of failure from the computer systems which provides that service. Usually, this is achieved by implementing redundancy and establishing the methods and procedures to ensure the early detection of any failures within those redundant systems.

To enable that level of availability, the reliability of the supporting infrastructure also becomes a critical factor and, more specifically, the availability of electricity on which all these systems are totally dependent.

When one examines the configuration of any power system specifically designed to provide that uninterrupted power, it becomes very apparent that within that power system, the final defense against loss of service is a battery.

Battery Reliability

Unfortunately, of all the parts of a standby power system, the battery is not perceived to be the most reliable component. There are many reasons why batteries can fail, and contrary to popular opinion most of these are not the responsibility of the battery manufacturer. From the point at which they are shipped until they are replaced and recycled, the management of that battery by the user or their nominated representatives is the key to determining the actual service life of the battery.

Battery System Design

Interestingly, the ability of that battery to meet its anticipated life is often determined at the system design stage before it ever leaves the factory. While the basic lead acid battery is still the same as the original Gaston Planté design, there are now many models of batteries designed to meet specific requirements; high rate discharge, cycling applications, and high temperature are only a few examples. From the outside, they may look the same, but internally they can be very different. So, the first step in improving reliability should be to ensure that the correct battery is selected to suit the application, the location, and the environment.

Because of the drive to increase data center efficiency, the recommended range of the operating temperature has been extended from 20-25^{o}C to 18-27^{o}C; this may not seem a lot but, depending on the location of the UPS and the airflow in the room, the battery temperatures in the cabinets could now be in the 30-35^{o}C region, greatly reducing battery life.

Sizing the battery is also an important factor. A lot of UPS specifications are now asking for runtimes of less than ten minutes and the battery manufacturers are responding with battery models to meet that requirement. The problem is from an availability perspective it means that a single failing unit within the battery can reduce the runtime below that required for a generator to start and come online. Probably not a good idea.

Shipping

Individual battery units are both heavy and fragile at the same time. The battery manufacturers take great care in getting the batteries shipped to the point of distribution often with their own specialized carrier. From that point on, the situation deteriorates and there is no guarantee that the batteries will not have been dropped or mishandled in some way before they arrive at the point of installation. Some damage will be obvious: damaged pallets and packing material are a clear indication that the shipment has been mishandled and should be rejected. The bigger challenge is to identify those batteries that have been dropped and may have suffered internal damage. While this damage may show up in a commissioning discharge, it may also be a simple crack that corrodes in service and becomes a fuse when the load is applied. The best solution is to request that the batteries are shipped with “Drop & Tell” indicators on each pallet. Set to a “G” force acceptable to the battery manufacturer, it should then be stipulated in the order that any pallet on which the indicator is activated will be returned.

Installation

Location

This is another minefield in the path to battery reliability. The battery is so often the stepchild in the planning and space allocation for a standby power system. Space is expensive and large battery systems take up a lot of room. VLA batteries on open racks are often located in areas where they must be installed on three tier racks, or broken into smaller sub racks separated with long interconnects. None of this is conducive to ensuring that the individual units are charged equally. Access to the install location can also be a challenge. Doors not wide enough to accept a pallet will require the battery units be unpacked and hand carried to the installation location. Buildings with floor loading restrictions may require the batteries to be installed in a basement with no elevator. Manhandling individual units down stairs on a hand truck adds yet another opportunity for damage.

Installation Practices

Battery installation is often carried out by the battery supplier before the other components of the power system are in place, or are available for connection. Under these circumstances, at least one link on each battery string must be left out. This is to ensure that it doesn't become an inadvertent welding machine for the uninitiated installer who follows. Even if it doesn't catch fire, a short circuit across the battery for any period of time will do nothing to improve its long-term reliability. It may cost more to return to the site, but it pays for itself by limiting the potential of a catastrophic event.

Human Interaction

From the point at which the battery is delivered until it is decommissioned, there will be a requirement for human interaction with the battery and all associated equipment. Each time this occurs, there is a risk to both the personnel involved, and the operational availability of the battery. Working with a battery system exposes personnel to mechanical, chemical, and electrical hazards. To comply with OSHA requirements, all personnel that work on a battery, from installation to decommissioning, must be trained in the functions they are carrying out. The owner of the battery is responsible for ensuring that all personnel have the required Personal Protective Equipment (PPE), and that all safety related equipment required is in place and operable. Human error is also high on the list of reasons for data center down time.

Commissioning

Every time a battery is installed, whether in a new system or as a replacement battery for an existing system, it should go through a commissioning process. This will ensure that the battery has been installed correctly, it is being charged correctly and has been discharged to verify the initial capacity of the battery, and identify any failing cells/units due to infant mortality or damage. A failure to do so can reduce the life of the battery.

Battery Management

Once the battery is installed and tested, the next step in improving the battery's availability starts. Unlike some other components in the standby power system, the battery has a finite life and starts to deteriorate as soon as the electrolyte is added. This means that to ensure that the battery will meet its design life maintenance is required, and contrary to popular belief VRLA batteries are not "Maintenance Free"

Recommended Practices

Since the lead acid battery was introduced, the maintenance methods have changed very little. They continue to be based on routine parameter measurement, and visual inspections to identify potential problems, along with the occasional discharge to verify capacity. In the past, these functions were carried out by experienced battery technicians who monitored the small changes in their measured values, and used the visual inspections to accurately assess the condition of the battery, and determine when and if a discharge test or battery replacement was required. As the number of batteries in standby service increased, and the quantity of knowledgeable technicians decreased, there was a need to establish some form of maintenance and assessment standards. A Stationary Battery Committee was established by the IEEE PES to create a set of recommended practices to codify these methods and practices of battery maintenance. The subsequent documents were based on the traditional practices, but established a time-based maintenance program with a schedule of onsite inspections, data collection requirements and routine discharge tests to determine the battery's serviceability.

VRLA Batteries

In the 1970's, the VRLA battery was developed with the objective of supplying a battery that would eliminate the need to check electrolyte levels and reduce the requirement for maintenance visits to remote sites. Unfortunately, this new battery also removed two of the parameters used as part of the recommended maintenance schedule for VLA batteries, Specific Gravity, and the ability to visually inspect the condition of the plates. To compensate for that, a new parameter was identified, measuring the internal impedance of the battery. This resulted in development of portable instruments which could measure this parameter using a number of different methods, and reporting it as either resistance, impedance or conductance. To show no favoritism to a specific technology or product, the resultant value is referred to in all IEEE documents as the ohmic value of the cell or unit. Subsequently, a new set of recommended practices were introduced for the new batteries and they followed the format of the earlier documents but with the introduction of the ohmic value as a new parameter to be measured and analyzed.

Ohmic Values

The next challenge was to determine how a change to the ohmic value reflected the ability of the battery to support the load in the event of a discharge. Typically, limit based analysis was used for all the other measured parameters based on the battery manufacturer's recommended upper and lower limits. So, continuing that format, a change in value of an ohmic reading from an initial value established at installation was considered to be an indication of a deteriorating battery. The question was, what is the relevant change in ohmic value that would represent a 20% loss of capacity traditionally accepted as end of life for a lead acid battery? At the time, a major battery manufacturer suggested that a 30% rise, subsequently revised to 50%, was a reasonable indication that the battery had reached end of life.

While a change in an ohmic value clearly indicates a change in the response of the individual units being measured, it does not always correlate to loss of capacity. This has led the relevance of ohmic measurement to be discounted by some, but even a small change in the value can indicate the potential to fail if the battery was placed under load. In a 240 cell UPS battery, it only takes one cell to go open circuit to make the capacity of the other 239 cells irrelevant.

Current analysis methodology

Over the last 25 years, monitoring products have been introduced and placed in service which automate most of the data collection process. This has been providing a considerable amount of data and trend analysis of individual data points that can help to provide an indication of potential failure. But the consensus is still that it has to reach a specific value before it is considered for replacement, and this is not the way to achieve "Five Nines" availability.

Another requirement if we are to improve the availability of the battery is to report the battery's condition in a way that clearly identifies the impact of the battery status on the operational viability of the standby power system. This is not the situation today; the software used to analyze the collected data, whether manually or with an online monitor, is proprietary to the manufacturer of the product. Thus, the data used is limited to that collected by the product and does not consider factors such as the operating environment or the load on the power system. Therefore, most of the generated maintenance reports only identify the cells or units that currently are outside of the predetermined limits and recommend their replacements.

In many cases, the first report that the battery has a problem is after the unit has already failed, and that obviously does not achieve the objective of close to 100% availability. If we want to achieve that objective, then it's time to rethink how we analyze the data and how we report it.

User Interface

To understand what information the analysis is required to produce, we need to understand what the end user is looking for in the report. It is also necessary to consider the format in which the analysis is presented to ensure it is fully understood.

From an operational perspective, the requirement is to understand the risk of battery failure in the event of a power outage. To do that, any potential points of failure within the battery system should be identified, and their impact on the viability of the battery under current operating conditions must be determined. This requires that the real-time load, not the design load, must be known so the ability of the battery to achieve the required run time can be assessed.

The locations of the potential points of failure within the battery are also important. For example, a multi string battery supporting a UPS loaded at under 40% capacity with all the identified units located in one string does not represent the same risk as the same UPS at 80% capacity with the potential points of failure spread across all strings.

What is needed is a way to correlate the levels of change in the relevant battery parameters into a value that defines the risk associated with any of the identified potential points of failure. From those values, a chart can be produced that will identify the risk potential at each level and the number of units involved. This is a different approach to how the information is presented today, but sending a quarterly report that identifies cells 28, 42 60 and 92 as being 50 percent over their initial ohmic values does not satisfy today's requirements.

Limit based analysis

This is the way most battery data is analyzed today, and because most of the parameters measured as part of a maintenance plan, reflect the current operating conditions they are analyzed using the manufacturers recommended limit settings. Any small changes in those parameter values are typically ignored when the data is reviewed so they don't actually contribute to the analysis process.
Because the ohmic readings are the one parameter that does change as the battery deteriorates, it has become the key value used to determine a battery's condition outside a discharge test.

The change of an ohmic value clearly indicates the cell's reaction to the test current stimulation and, when it exceeds the preset limits, there is a high risk of failure if placed under load.

But there are always other cells that have deviated from the average as they age and are nowhere near the preset limits, yet they also can fail during a discharge test. Clearly, they are also potential points of failure and should have a level of risk assigned but how should that be done.

Next generation analysis

One of the most interesting areas of computer science today is the work being done in what is referred to as machine learning. This is the ability of a computer to teach itself to recognize patterns in large volumes of data and is now being used to identify and predict everything from engine failure in flight to cancer. If you have sufficient data including up to the point at which the level of deterioration is conventionally detected, then the software can identify small changes in the parameters measured that can then be associated with the identified problem. If a consistent pattern is established within the volume of data collected, this can then be used to take proactive corrective action before the problem becomes apparent using existing analysis methods.

In many ways, this approach is very close to how those original battery technicians worked. They collected and mentally analyzed an amazing amount of data by simply observing the battery and a few measured parameters. Yes, they maintained records, recording the same data that is collected today, but their judgment about a battery's condition wasn't based on the written record. It was on the minor changes to the individual units that differentiated them from the other units in the battery, that provided them the information they required.

Rather than looking at specific parameters and evaluating them individually, perhaps it's time to learn from the past, but use a more modern methodology.

Relationship rather than a defined value

If we are to apply the concepts of artificial intelligence in battery analysis, clearly measuring and analyzing individual parameters in isolation is not the way to go. What is needed is a greater understanding about the relationship between the individual parameters under all operating conditions. Changes in ambient temperature and the charging voltage are known to change the value of the other measured parameters, and that relationship is reasonably well understood. What has not been examined in detail is the change in those relationships as a cell starts to fail. What does happen as the ohmic value rises? because the amount the value has risen does not always relate to the potential for failure. Is it possible or even probable that the change in the relationship of the ohmic value with the other parameters will be different, depending on the reason for that rise in ohmic value? At the moment, this level of analysis is not possible because the proprietary software supplied with the monitoring hardware does not store the data collected at the granularity required.

Basically we need more data to do this level of analysis.

Age as a risk factor

Another factor in assessing risk must be the age of the battery. There are a number of factors that directly impact the potential life of a battery, primarily temperature, charging voltage, number of discharges, and the average depth of these discharges. These are parameters that are always measured and recorded by a battery monitoring system, yet the reduction in life that they can represent is not a value that is calculated and reported.

By doing that calculation and comparing it to the time since installation, a more accurate indication of potential life will be available. An older battery with a projected loss of capacity and several identified potential points of failure will have more risk attached to its ability to support the required runtime than the same number of potential points of failure would in a new battery.

Battery Replacement

All batteries will eventually have to be replaced, and the basis on which the replacement is selected is just as important as the original selection. If the level of data acquired is sufficient, the actual operating conditions and the battery response can be compared to the original battery's specification. From that, it can be determined if the original selection was correct or a battery with different characteristics is required. This is important because without that evaluation the technical requirements that justified the original selection are often ignored, and the replacement is determined by the lowest bidder.

Conclusions

There is no question that if steps were taken to manage or eliminate some of the problem areas identified in this paper there would be an overall improvement in battery reliability. But to make the breakthrough required to achieve that elusive “Five Nines” availability, the battery industry must rethink its zealous adherence to limit based analysis and work together to embrace the idea of using artificial intelligence. It is clearly the way that reliability analysis is going and eventually will be the predominant method used to predict the level of risk that a battery will fail. It’s not as if it hasn’t been done before; all that is required is to create an electronic version of the original battery technician.

References

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