



**THE EFFECT OF REGULAR, SKILLED
PREVENTIVE MAINTENANCE AND
REMOTE MONITORING ON CRITICAL
POWER SYSTEM RELIABILITY**

Executive Summary

Vertiv™ has long promoted the need for a comprehensive preventive maintenance (PM) program, the single most important activity to maximize the reliability of uninterruptible power supply (UPS) units and the battery systems upon which they depend.

While most organizations intuitively understand the necessity of a good UPS and battery PM program, the value of PM has never been adequately quantified in a manner that could help guide decisions about PM frequency or skill level of the service provider. The industry-wide lack of statistical support for PM can be attributed to an absence of data from which meaningful statistics could be compiled.

To confirm the importance of PM and provide insight into the impact of frequency on reliability, Vertiv analyzed data collected by its service organization, which maintains the most extensive database of service-related events for large UPS systems and battery systems in the industry. The data covered 185 million operating hours for more than 5,000 three-phase UPS units, and more than 450 million operating hours for more than 24,000 strings of batteries. The UPS analysis factored in both electrical failure and service-related human error, while the battery analysis allowed the impact of UPS system downtime due to bad batteries to be factored into the calculations.

For the UPS analysis, Vertiv enlisted a contractor with a doctorate in mathematics to help develop a mathematical model that takes the unit-related outages that occurred on these systems and accurately projects the impact of PM on UPS reliability. These calculations indicate that the UPS mean time between failures (MTBF) for units that received two PM service events a year is 23 times higher than a machine with no PM service events per year. At the expected levels of service error attributed to a Vertiv Services, factory-trained technician, UPS reliability continued to steadily increase up to 19 PM visits per year. The final conclusion of the real-world analysis and mathematical model re-affirmed the long-held industry belief that an increase in the number of PM visits substantially increases system reliability.

For the battery analysis, Vertiv gathered the data of battery-related outages that occurred on UPS systems and then projected the impact of adding monitoring services to the units. These calculations led to two main conclusions:

1. To date, there have been zero system outages due to bad batteries on systems where the batteries have been professionally maintained and remotely monitored.
2. A customer using the Albér® monitoring equipment to monitor their battery strings on site increases the MTBF by more than double when compared to preventive maintenance alone.

The conclusion of this analysis re-affirmed that proactive battery maintenance and remote monitoring service increases the reliability of the units the batteries support.

Introduction

As organizations become increasingly dependent on data center systems, there is a need for greater reliability in the critical power system. For many organizations, the IT infrastructure has evolved into an interdependent business-critical network that includes data, applications, storage, servers, and networking. A power failure at any point along the network can impact the entire operation and have serious consequences for the business.

In most cases, the ability to keep critical systems running through power outages, utility spikes, and other unforeseeable power issues is dependent on the reliability of the UPS system. However, the UPS system is only as reliable as the batteries that support it.

The Need for Preventive Maintenance

Overall, UPS systems are designed to offer the utmost reliability and performance at an affordable price. While only a very small fraction of the Liebert® UPS installed base has ever experienced a unit-related output failure, failures do occur.

For UPS systems, factors such as application, installation design, real-world operating conditions, and maintenance practices can impact reliability and performance of UPS systems. Virtually all systems contain life-limited components that need to be replaced according to the manufacturer's specifications. The reliability of a system only lasts as long as the shortest component life in the unit, and in many cases, that component is a battery.

For UPS systems, minor irregularities in incoming power cause energy to be drawn from the batteries. And as batteries are discharged, its current backup capacity diminishes. Other problems such as high temperatures, corrosion, cracks, and dryouts can cause the lifetime of a battery string to be shortened even further.

One way end users can further minimize unit-related failures is to institute a comprehensive PM program that is implemented by technicians trained by the original equipment manufacturer (OEM). When correctly implemented, PM visits ensure maximum reliability of data center equipment by providing systematic inspections, detection and correction of incipient failures, either before they occur or before they develop into major defects that result in costly downtime. Typical PM programs include inspections, tests, measurements, adjustments, parts replacement, and housekeeping practices.

Mean Time Between Failures

While established engineering practices support the need for PM, Vertiv™ recognized the need for an in-depth analysis that organizations focused on the bottom line could use to help shape their PM policies and practices. The analysis conducted by Vertiv is the first in the industry that conclusively quantifies the change in system reliability due to the level of PM activity on Liebert equipment. Vertiv has one of the largest installed bases of any large UPS manufacturer and one of the most extensive databases of UPS service events in the industry. Field-observed MTBF is a robust measure of reliability that uses the number and types of failures that products actually experience in real applications to assess system behavior. It serves as a reliable parameter for the mathematical model in this analysis.

Two key statistics are incorporated into MTBF, cumulative operating hours and number of unit-related failures. They are used to calculate average reliability across all units in a given population.

In general, a higher MTBF number, stated in hours, indicates a more reliable unit. For example, a UPS unit with a MTBF of two million hours is more reliable than a unit with a MTBF of one million hours.

$$\text{MTBF} = \left[\frac{\text{cumulative operating hours}}{\text{number of outages} + 1} \right]$$

Figure 1: Calculating mean time between failures

The cumulative operating hours metric is calculated according to the number of hours in a given month multiplied by the number of machines that were under contract with Vertiv in that same month. A machine was counted "under contract" if the contract terms were still active on the last day of that given month.

UPS Analysis

The number of outages used in the analysis is a subset of all failures experienced by systems in the population. This subset only includes unit-related failures, because there are many different causes for failures, ranging from someone pushing the Emergency Power Off button, to batteries reaching the end of discharge. Many of these causes can be attributed to human error, not the reliability of the UPS system. To control human error, any failures that are not

unit-related were removed from the initial analysis of MTBF. Each outage counted in the analysis consisted of a loss of the critical bus and was caused by a error of some internal UPS mechanism. The mathematical model will include the contribution of errors committed by the service engineer, as described later in this paper.

The analysis began by tabulating data covering more than 185 million cumulative operating hours. Also tabulated were the number of unit-related outages for the 5,000-unit sample of Liebert® three-phase UPS units having a service contract within a defined 76-month period. Once gathered, the sample was broken into groups according to the number of PM visits written into the contract for a 12-month period.

When the MTBF calculations were complete, the data in each group were checked for validity to ensure efficacy in the sample, and only those numbers that were theoretically and statistically valid were used as a basis for the mathematical model.

The observed MTBF for the “no PM” group was found to be unreliable. First, the “no PM” group consisted of units under a PM contract for emergency service only, meaning the unit did not have a regularly-scheduled maintenance agreement with Vertiv™. However, it is possible that these units had a maintenance agreement with a third-party vendor or had sporadic maintenance on a time and materials basis from Vertiv. In fact, further analysis suggests that some maintenance is occurring to a majority of the “no PM” group at some point in the life of the machine.

Also, it is inaccurate to state that a unit will continue to function properly with no outside intervention after the life span expiration of certain life-limited components, such as capacitors and fans. To adjust for these inaccuracies the mathematical model was used to more accurately project the MTBF of a unit with no human intervention.

The MTBF for the groups containing three or more PM events per year was also deemed unstable and not robust enough for the basis of any statistical inferences. The main reason for this mathematical instability is that none of these units experienced any outages during the test period. The real-world experience of no failures for any machine receiving three or more PM visits is substantial evidence for the need for PM, but for the mathematical model these numbers were too unstable.

This instability stems from two major factors. First, if one machine in the sample had a failure the corresponding MTBF would automatically be cut in half. Second, the number of units that receive three or more PM events a year is substantially smaller than the group having one or two PM events per year. If you put both of these factors together the MTBF for the units that received three or more PM events a year turns out to be a measure of cumulative operating hours for a small group of units, not an MTBF calculation.

Out of the more than 185 million operating hours in the analysis, more than 90 percent were in the group having one or two PM events. It was found that the MTBF figures for one and two PM visits per year were reliable. The data were then placed in a two-parameter Weibull probability distribution that projected MTBF rates based on a yearly PM frequency. The Weibull probability distribution, a widely used mathematical construct, is used as a basis for the mathematical model and allows the impact of component aging to be considered in the analysis. The ability to adjust for aging and other variables allows the Weibull distribution to better represent reality than data estimates that are not substantiated.

For example, Vertiv has no information about a piece of equipment that has never had a service event, but the Weibull probability distribution can take the reliable data for the group having one or two PM events and project a more realistic MTBF figure for the “no PM” group. For the mathematical model, a two-parameter Weibull probability distribution is used to model the time between unit-related outages versus the number of annual PM visits. The major inputs for this model include the real-world MTBF metrics for units having one and two PM visits per year along with the measure of service-related error labeled “PM safety.”

$$\text{PM safety} = 1 - \left[\frac{\text{number of technician caused outages}}{\text{number of PM visits}} \right]$$

Figure 2: Calculating the preventive maintenance safety factor

PM safety can be thought of as the probability of completing a PM visit without incurring any service-related human error. The PM safety factor used, 0.99998, is derived from real-world Vertiv quality assurance data and shows that, on average, with a Vertiv technician, more than 5,000 service events can occur without service-related human error (see Figure 4).

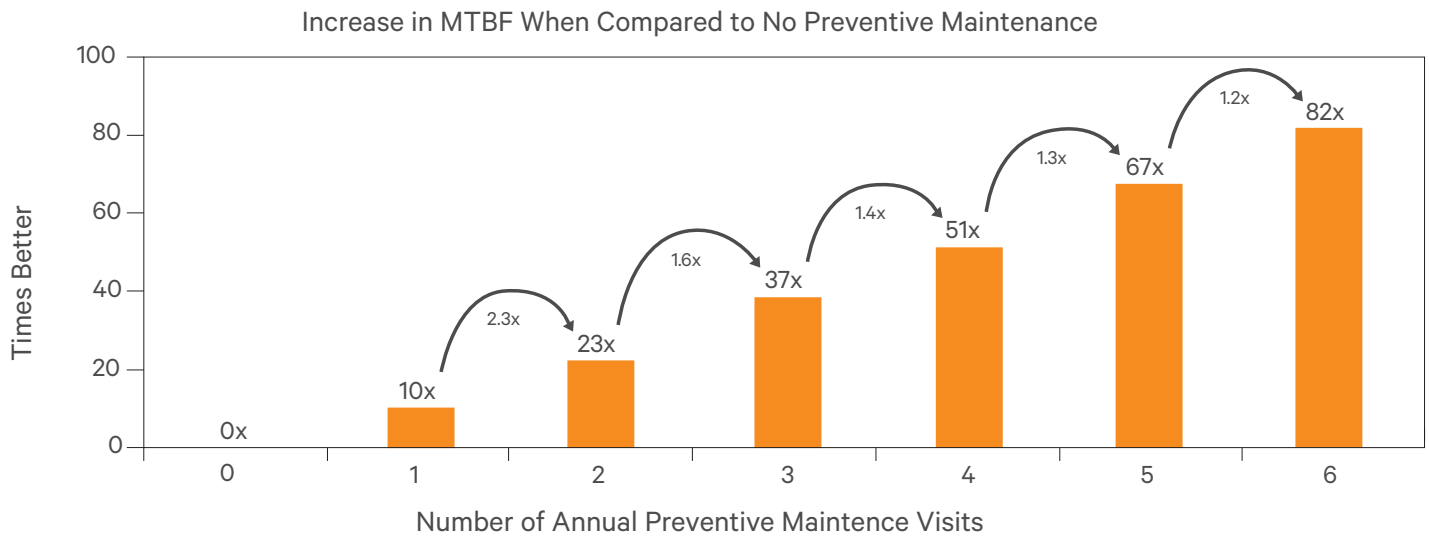


Figure 3: An increase in the number of annual preventive maintenance visits increases the MTBF.

The outcome of the model can be seen in Figure 3, which depicts the expected MTBF figures projected up to six PM events per year. The mathematical model incorporated real-world Vertiv™ data to arrive at Figure 3. The MTBF estimate for the “no PM” group is substantially lower than the observed MTBF for units with emergency service only contracts with Vertiv Services, but is in line with the lifespan of components that must be replaced.

There is a substantial increase in MTBF from zero to six PM visits per year. When projected out farther than six PM visits, the MTBF begins to level off around 19 PM visits per year and then slowly declines at higher levels of maintenance. This decline after a large number of PM visits can be attributed to the fact that every service event introduces the possibility of service-related human error.

The PM safety factor for Vertiv trained technicians is extremely high. It has been calculated to be one technician-caused failure for every 5,000 PM events. This high level of quality service stems from the fact that all technicians are continuously trained to be current with new procedures, equipment, designs, and other changes that have been made. Also, each technician uses the OEM-specified testing equipment, which accurately collects Liebert® equipment data within the specified limits of the calibration procedures. Therefore, it can be concluded that the risk of human error is minimal when Vertiv personnel access the system.

It is reasonable to assume that a technician who has not been properly trained and certified on Liebert equipment will have a higher error rate than a Vertiv technician. Also, without the manufacturer’s specified testing equipment, it is reasonable

to assume that data collection and settings may be inaccurate, or not within the specified limits of the calibration procedures. In an effort to take these training and quality standards into account, different PM safety factors are compared in Figure 4. A Vertiv technician with a PM safety factor of 0.99998 will have gains in unit reliability up to 19 PM service events a year, after which there are diminishing returns.

The reliability of the UPS unit theoretically increases up to 19 PM events per year, but realistically, Vertiv would not recommend this high level of maintenance activity. Instead, two or more maintenance events per year will substantially increase unit reliability. For a non-factory-trained technician with a higher error rate (or one technician-caused failure for every 100 PM events), the unit reliability will only increase to one PM visit a year before realizing diminishing returns. This shows that an increase in PM events will increase reliability only if the technician completing the work has a very low error rate. Figure 4 illustrates the solid relationship between proper training and MTBF.

Battery Analysis

Realizing the need for metrics to understand the impact of PM and remote monitoring services on battery strings, Vertiv conducted a second analysis using four groups, customers with the following attributes: no battery maintenance or monitoring; battery maintenance only; on-site battery monitoring; and battery maintenance and remote monitoring together, conducted by a reliable systems expert.

The study conducted by Vertiv™ quantifies the change in system reliability due to the presence of maintenance and/or monitoring on the battery systems.

The analysis began by gathering data on more than 700 million cumulative operating hours covering service contracts from a defined 41-month period. Over that same period, the number of system outages due to bad batteries was also collected.

Using the above data sets, outages were compared against the respective product set. Once complete, there were several significant findings regarding the importance of both maintenance and monitoring (see Figure 5 for study findings).

First, Vertiv found that preventive maintenance on battery strings increased the availability of the entire system, and that customers without preventive maintenance were vulnerable to down units. For example, an analysis of customers who did not have battery maintenance or monitoring in place found that 37 percent of all down units were due to bad batteries.

Second, the study found that customers who had an Albér® battery monitoring system installed at their site had a reduced rate of outages due to bad batteries. While outages did still occur, the incidents were isolated to cases where customers were either not watching their system, or they did

not know how to properly analyze the data provided by the monitor. This indicates the need for experts to correctly monitor the alarm data and properly maintain a system.

The study also found an increased MTBF between regular battery service contracts and those with a battery monitoring appliance installed at their site. The MTBF of a site with an Albér unit more than doubled the MTBF when compared to a site without. This indicates that the addition of a battery monitoring device installed at a customer site and monitored by the customer will also increase the availability of those battery systems.

Lastly, and perhaps most importantly, the study found that customers who had both battery maintenance and remote monitoring, had not experienced any outages due to bad batteries over the span of three and a half years. This demonstrates the increased reliability of equipment when professionals are monitoring systems around the clock and utilizing highly skilled technicians for PM services.

Since there were no outages at any site with both expert preventive maintenance and remote monitoring together, there was no significant MTBF. The number generated could only be the cumulative number of hours that the battery strings were continuously running. However, the analysis confirmed that monthly preventive maintenance and monitoring on battery systems can significantly decrease the percentage of down units.

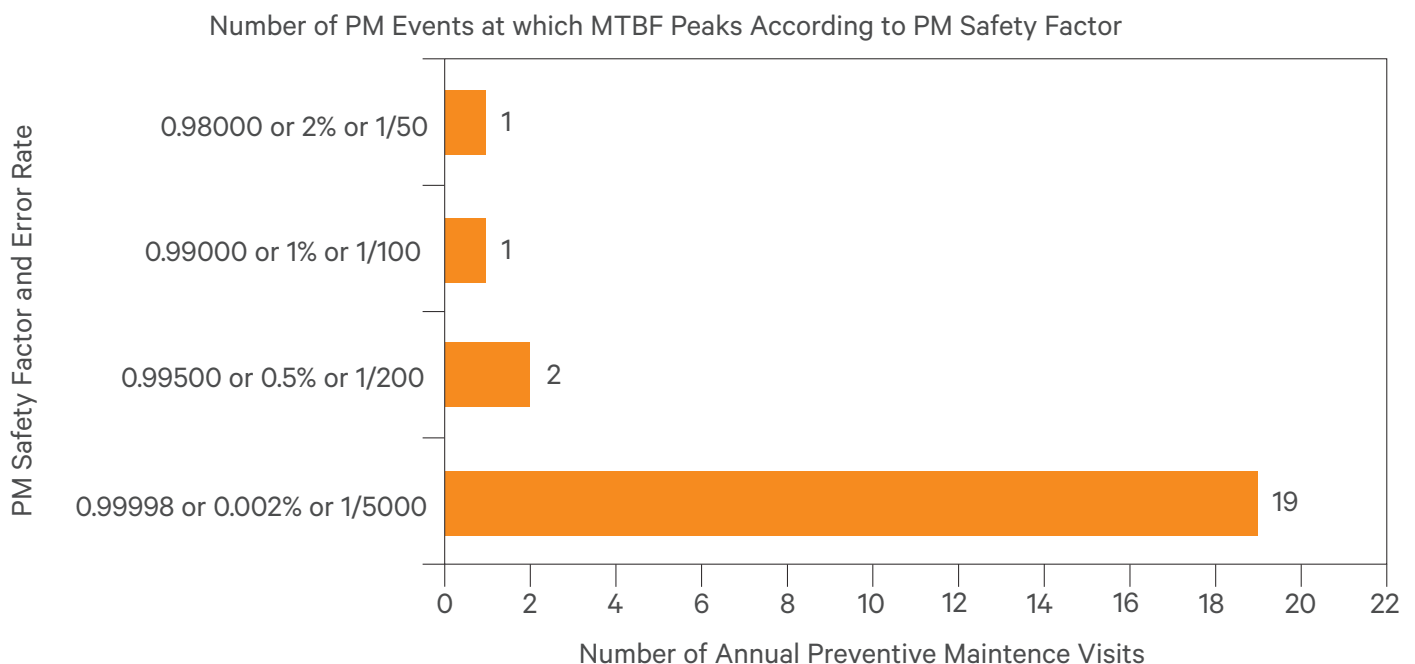


Figure 4: Factory-trained and certified technicians with a PM safety factor of 0.99998 could provide gains in unit reliability up to 19 PM service events a year, after which there are diminishing returns.

Battery MTBF Example

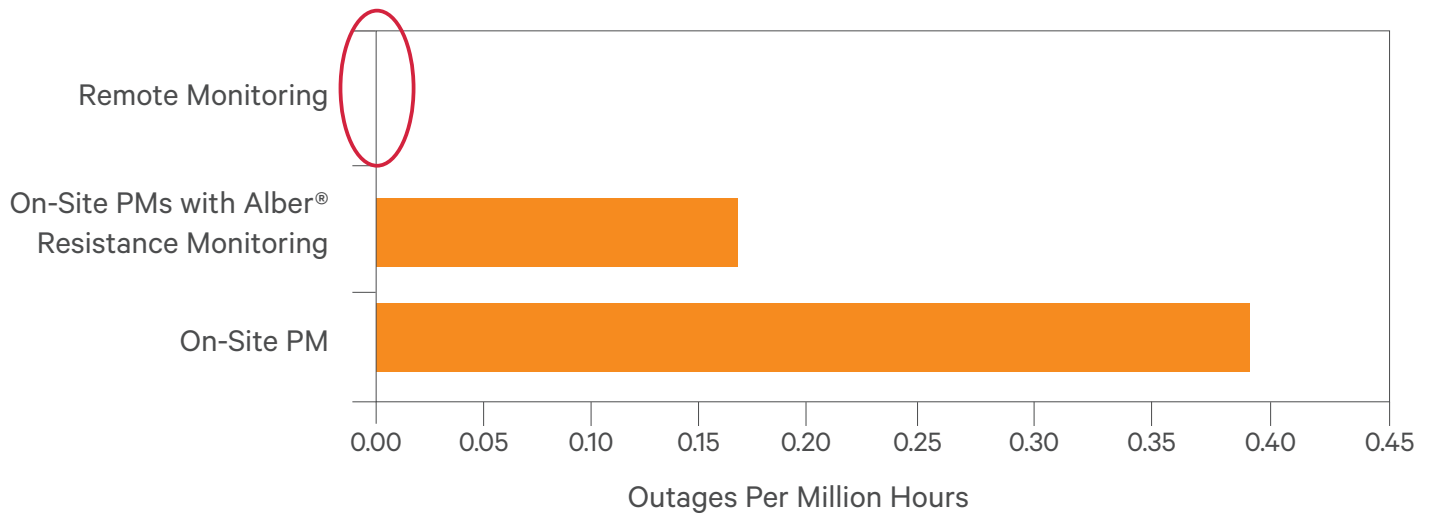


Figure 5: Systems with maintenance alone show high reliability. Systems monitored by on-site personnel have significantly longer runtime before a failure than maintenance alone. And maintenance and remote monitoring, together, conducted by technical experts have experienced no outages due to bad batteries.

Conclusion

This analysis of service data for UPS and battery systems is a preliminary look at the connection between PM and system reliability. It does not lend itself to all-encompassing conclusions. Instead, the interpretation is straightforward and specific. The number of preventive maintenance visits and the technician's level of training have a substantial impact on system availability, and preventive maintenance paired with monitoring substantially increases battery availability.

The research supports a recommendation of at least two UPS PM visits per year, along with implementing monthly battery maintenance and a monitoring program. Depending on the cost of downtime for a particular application, a high return on investment can be realized in many cases by increasing PM frequency and/or monitoring.

