The Effect of Regular, Skilled Preventive Maintenance on Critical Power System Reliability

Liebert ®

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Executive Summary

Emerson Network Power has long promoted the need for a comprehensive Preventive Maintenance (PM) program to maximize the reliability and performance of the Uninterruptible Power Supply (UPS) systems on which organizations depend to keep critical systems running.

While most organizations intuitively understand the necessity of a good UPS 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, Emerson Network Power analyzed data collected by its service organization, which maintains the most extensive database of service related events for Large UPS systems in the data center support services industry. The data covered 185 million operating hours for more than 5,000 three-phase UPS units. The analysis allowed the impact of both electrical failure and service related human error to be factored into the calculations.

Emerson enlisted a Ph.D. level mathematician 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 Liebert trained and certified service engineer, UPS reliability continued to steadily increase up to 19 PM visits per year. The final conclusion of the real-world analysis and mathematical model reaffirmed the long-held industry belief that an increase in the number of PM visits substantially increases system reliability.

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. 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. Factors such as application, installation design, real-world operating conditions, and maintenance practices can impact the 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. The Liebert design philosophy addresses this issue by reducing the number of parts that need to be replaced, thus decreasing the chance of a failure.

One way end users can further minimize unit-related failures is to institute a comprehensive PM program that is implemented by original equipment manufacturer (OEM) trained and certified technicians. 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.

While established engineering practices support the need for PM, Emerson Network Power recognized the need for an in-depth analysis that bottom-line driven organizations could use to help shape their PM policies and practices. The analysis conducted by Emerson Network Power is the first in the industry that quantifies the change in system reliability due to the level of PM activity on Liebert equipment. Liebert Services, a division of Emerson Network Power, has one of the largest installed bases of any Large UPS manufacturer and one of the most extensive databases of UPS service events and installations in the industry.

Field observed Mean Time Between Failures (MTBF) is a robust measure of reliability that uses the number and types of failures that products actually experience in real applications. Mean Time Between Failures is an industry recognized measure of system behavior and serves as a reliable parameter for the mathematical model in this analysis.

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In general, a higher MTBF number, stated in hours, indicates a more reliable unit. For example, a UPS unit with a MTBF of 2 million hours is more reliable than a unit with a MTBF of 1 million hours. Two key statistics are incorporated into MTBF, cumulative operating hours and number of unit-related failures, to calculate average reliability across all units in a given population.

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

Figure 1. Calculating Mean Time Between Failure (MTBF)

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 Emerson's Services group 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.

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 user personnel error, not the reliability of the UPS system. To control for user personnel 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 buss and was caused by a failure 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 and number of unit-related outages for the 5,000 unit described sample of Liebert three-phase UPS units with a service contract between October 2001 and February 2007. 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 for the sample of three-phase UPS units in the Liebert installed base, 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 contract for emergency service only, meaning the unit did not have a regularly scheduled maintenance agreement with Liebert Services. However, it is possible that these machines had a maintenance agreement with a third-party vendor or had sporadic maintenance on a time and materials basis from Liebert. 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. Any time a maintenance event occurs it substantially increases the reliability of the unit, which inflates the MTBF for the "no PM" group in this analysis. 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 were also deemed unstable and not robust enough upon which to base 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, and second, the number of units that receive three or more PM events a year is substantially smaller than the one PM and two PM per year groups. If you put both of these factors together the MTBF for the units that received three or more PM events a year turn 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 one or two PM groups. 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 PM frequency. The Weibull probability distribution, a widely used mathematical construct, is used as a basis for the mathematical model and allows the impact 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, Liebert Services 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 one PM and two PM groups and project more a 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 one and two PM visits per year along with the measure of service related error labeled "PM safety."

PM safety can be thought of as the probability of coming through a PM visit without incurring any human error. The PM Safety factor used, 0.99998, is derived from real-world Emerson Network Power quality assurance data.

$$PM\ Safety = 1 - \left[\frac{Number\ of\ CE\ caused\ outages}{Number\ of\ PM\ visits} \right]$$

Figure 2. Calculating the preventive maintenance safety factor

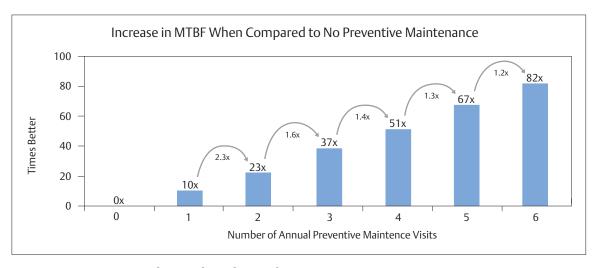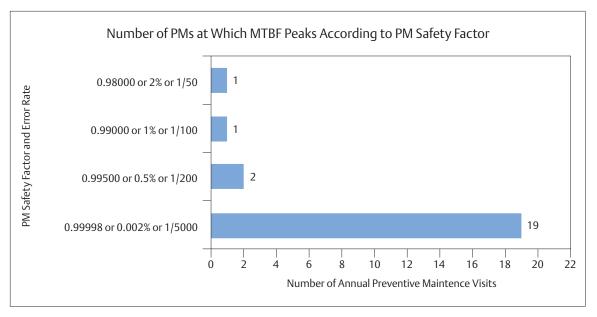## Increase in MTBF When Compared to No Preventive Maintenance

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 Emerson Network Power 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 Liebert 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 6 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 Emerson Network Power trained and certified Customer Engineers (CE) is extremely high, it has been calculated to be one CE caused failure for every 5,000 PM events. The high level of quality service from Liebert engineers stems from the fact that all Liebert CEs are continuously trained to be current with new procedures, equipment, designs and changes that have been made. Also, each Liebert CE 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 Liebert trained personnel access the system.

It is reasonable to assume that an engineer who has not been properly trained and certified on Liebert equipment will have a higher error rate than a Liebert trained CE. 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 Liebert trained and certified CE 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.

Number of PMs at Which MTBF Peaks According to PM Safety Factor

Figure 4. A Liebert trained and certified CE 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.

The reliability of the UPS unit theoretically increases up to 19 PM events per year but realistically Emerson 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-Liebert trained CE with a higher error rate, of one CE caused failure for every 100 PM events, the unit reliability will only increases to one PM visit a year before realizing diminishing returns. This shows that an increase in PM events will increase reliability only if the engineer completing the work has a very low error rate. Figure 4 illustrates the solid relationship between proper training and MTBF.

Conclusion

This analysis is a preliminary look at the connection between preventive maintenance and UPS system reliability for Liebert equipment. This analysis does not lend itself to all-encompassing conclusions; instead the interpretation is straightforward and specific: the number of preventive maintenance visits and the service engineer's level of training have a substantial impact on system reliability.

The research supports Emerson's recommendation of at least two PM visits per year, but also makes the case for more PM visits for data centers where downtime is unacceptable. Further work will be completed using this analysis as a basis to provide data center managers with tools such as the total cost of ownership and return on investment calculations. 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.

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