

Assessment Of Alternatives To Lead-Acid Substation Batteries

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Abstract

Emergency power in electric company substations, primarily lead-acid battery systems serving dc loads, plays a critical role in power system reliability. This paper uses survey results from approximately 50 power companies to describe existing design and maintenance practices for substation battery systems, reported operating problems, and potential interest in applying new energy storage technology solutions. The paper provides a snapshot of current practices and identifies areas for future research that will address utility concerns for reliability in substation emergency power systems. Future work will assess candidate technologies as alternatives to replace or supplement lead-acid batteries in hybrid systems for substation emergency power. Some of the candidate technologies being considered for substations include advanced batteries, electro-chemical capacitors, and fuel cells and hybrids of these or hybrids of lead acid.

BACKGROUND

Ongoing research into substation emergency power systems by EPRI and participating electric power delivery companies aims to improve design, performance, and maintenance of substation emergency power systems. This paper focuses on results of a survey to evaluate current practices in specifying, sizing, and maintaining substation batteries. The survey sample includes about 50 utilities, primarily in US, reporting on a total of 15,892 substations. This sample size is approximately 10% of substations with battery systems. The breakdown of substations based on primary voltage is shown in Figure 1. More than half of the substations in the respondents sample are in the voltage class of between 69 kV and 169 kV.

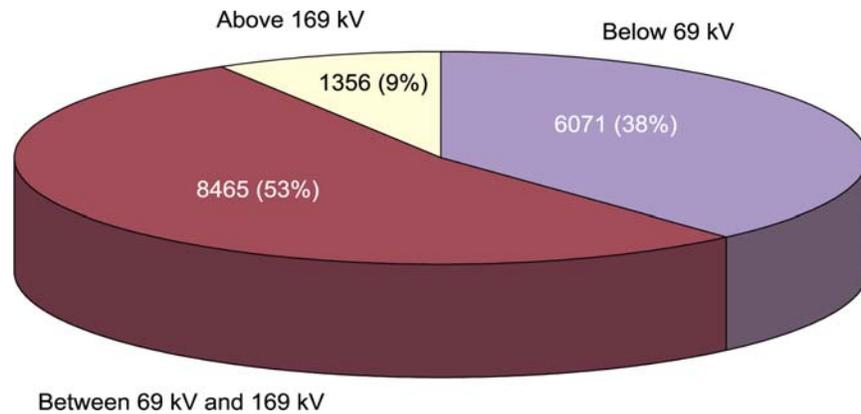


Figure 1. Distribution of Substations by Voltage Class

One of the key issues driving this work is changing characteristics of electrical loading in substations. For example new switches and breakers now use dc-electric motor actuators on emergency power instead of hydraulic and compressed air actuators (driven from normal ac power), and are controlled by electronic multifunction relays instead of discrete electromechanical relays. Also changing are the energy storage technology options, such as advanced nickel, zinc, and lithium batteries, electrochemical capacitors, and fuel cells, which may offer higher power or energy density than traditional lead-acid batteries.

Looking closer at the emergency load characteristics and new storage technologies can help optimize designs and match unique load requirements to performance capabilities of the substation emergency systems. For example some systems may be sized for end of discharge power needs and thus are oversized in bulk energy storage requirements. System maintenance and life may also see improvements with technology. For example, although relatively inexpensive and reliable, existing flooded lead-acid system performance can be difficult to monitor and load testing reduces life. If the

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charging current or ambient temperature levels are outside design limits battery life can be reduced. An unexpected failure can be disruptive and very costly to the utility and affected customers.

SPECIFICATION AND DESIGN PRACTICES

Approximately 83% of substations in the survey have some form energy storage system. This extrapolates to more than 100,000 substation battery installations in the US and represents a strategic investment for utilities. The back-up battery systems are typically drawn upon to provide power to circuit switching components and to power substation control equipment in times of AC power loss. In most cases utilities use banks of 100 to 400 AH, heavy-duty, usually flooded-electrolyte lead-acid batteries – though valve-regulated “sealed” designs are also employed – to serve critical dc loads in the 1 to 10 kW range. Nickel cadmium batteries (Nicads) have also been used, especially in warmer climates.

Based on the survey flooded, lead-acid batteries are used in 76% of the substations. Valve regulated (VLRA) are second most used at 14%, and NiCad are third, used primarily in hotter climates, accounting for 6% of substations. The others, 4% of substations, use flooded nickel, commercial UPS, deep cycle, and various other types of batteries. Recent utility research demonstrations in substations are looking at lithium, nickel-metal hydride, and zinc battery systems.

Generators may be a part on these emergency power systems, however most of the utilities in this survey did not use generators, and overall only about 2% of the stations reported having any on-site generators. Although inverters for ac communications equipment, and the rare propane back-up generator, can be found the survey showed that by far the largest single component in these emergency systems is the battery bank.

These battery-based emergency power systems are rated at 125Vdc (60 cells in a single series string about 64% of the time), 48Vdc (29%), 250 Vdc (4.3%), and 24Vdc in less than 2% of cases. Typically a 4 to 8-hour backup is required. However, a 100% redundant design criteria is also common, and about 40% of installations in the survey reported greater than 8 hours, up to 16-hours, of back up using 200 to 800 AH cells. Only about 15% of substations reported using more than one series-connected battery string.

The design loading for substation emergency back-up dc systems is quite small, generally a few watts per MW of substation capacity. This emergency loading varies depending on the substation capacity, number and type of circuit switches, and the related control devices. The largest loads are very intermittent, such as solenoid pull-in power, dc motor inrush and gear mechanisms for charging circuit breaker trip springs, and motorized switch movements. These operations are infrequent and have relatively short durations that fall in the range of 10 seconds or less. And the maximum design loading is a calculated worst case that is rarely, if ever, seen because of diversity in the operation of various substation loads.

Since the maximum loading on the back-up system is only relevant during ac power outages, the frequency of power outages is another design factor. For stations in the US the average total outage time per year is about 2 hours and the frequency of outages of all durations is 6, based on reported reliability indices. Note that these data exclude major events such as storms or blackouts. Therefore the maximum, and average load, as reported in Table 1 are expected to occur only about 2 hours per year. And the average load is estimated at 10 to 20 times less than the maximum design load.

Only the minimum load is expected to be a continuous dc load for operating indicator lights, sensors, and low power relays, is seen during both normal and emergency conditions.

Table 1 Design Loading based on Substation Voltage Class (note number of respondents is given)

Substation Voltage Class	Average (kVA)	Minimum (kVA)	Maximum (kVA)
Below 69 kV (based on 21 responding)	1.64	0.00	20.0
Between 69 kV and 169 kV (27 responses)	2.93	0.10	25.0
Above 169 kV (based on 21 responding)	8.49	0.10	160

In these substation systems the design life is typically 15 to 20 years. Field experience reported by 95% of respondents for flooded lead-acid batteries is that they meet or exceed this design life. In some cases, where 100% lead, Plante-type batteries are specified field experience has show greater than 30-year life. Reported field experience with VLRA were significantly less favorable and indicated that 20% lasted longer than 10 years, 60% 5-10 years, and 20% less than 5 years. Thus far we have not correlated battery life to specific maintenance practices and environment, although these factors are believed to be linked.

Other design factors not covered in the survey are type and rating of the battery chargers. Also the location of the battery, if collocated or separate from the control house, if the space is air-conditioned or heated, and the type of circuit protection, are likely factors in system performance. For example one design approach is to install batteries without fusing to avoid nuisances trips during emergencies. In this case the batteries are likely located in a separate building (not conditioned air) or enclosure to prevent a battery fault from jeopardizing other substation equipment.

MAINTENANCE PRACTICES

These systems require regular maintenance. Even so, based on survey inputs, maintenance practices vary quite a lot among utilities as shown in Figure 2. Although 45% of utilities provides maintenance every 2-6 months, more than half indicated higher or lower frequency of maintenance.

Maintenance procedures and the frequency it is carried out varied. The respondents were given six maintenance procedures and responded as to the frequency they are carried out:

- Visual inspection – All reported completing this inspection more than once a year and 64% reported more than 10 times/year.
- Specific gravity of pilot cell – 26% reported completing the check more often than 10 times/year, 42% less often than 4 times/year or as needed, and 32% reported never.
- Specific gravity of all cells – 72% completed this check 1 to 4 times/year, 6% as needed, and 22% reported never.
- Link resistance (Ductor) – 70% completed this measurement 1 to 4 times/year, 7% less than 1 time/year, and 23% reported never.
- Battery internal resistance – 81% completed the measurement 1 to 4 times/year, 3% < 1/year, and 16% reported never.
- Reading on-line condition monitor – 5% completed the reading greater than 10 times/year, 11% 1 to 4 times/year, and 84% reported never.

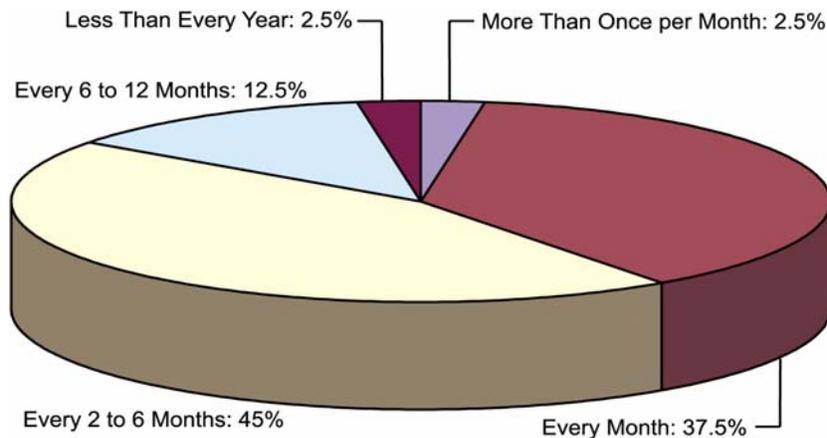


Figure 2 Frequencies of Substation Battery Maintenance Practices Among Utilities

Interviews with utilities indicate that most follow maintenance procedures that have been developed based on field experience and local conditions. Some also consider the IEEE recommended maintenance practices for both lead-acid (Std-450, 1995) and NiCad (Std-1106, 1995) batteries. Only 32% of the utilities responding are tracking the cost of maintenance for substation emergency power systems. And most felt that the cost of battery maintenance was not very significant relative to overall substation maintenance costs.

SATISFACTION WITH TODAY'S BACK UP SYSTEMS

Even with relatively low costs and satisfactory life in most battery systems, a key issue is the difficulty in predicting future performance and assuring reliable operation. Capacity tests are one way to determine battery condition. Of the utilities surveyed less than half, 44%, reported that they conduct capacity tests. The most common interval for a discharge capacity test was 3-6 years, testing all cells at once, and discharging to about 12% remaining capacity. We conclude that most substation battery systems are not tested until there is a power outage of significant duration.

Utility personnel attitudes toward existing back-up system performance and maintenance were addressed in several survey questions. Figure 3 shows the frequency of utility personnel response to the question: *What is the top three problems associated with maintaining substation emergency/backup power systems?*

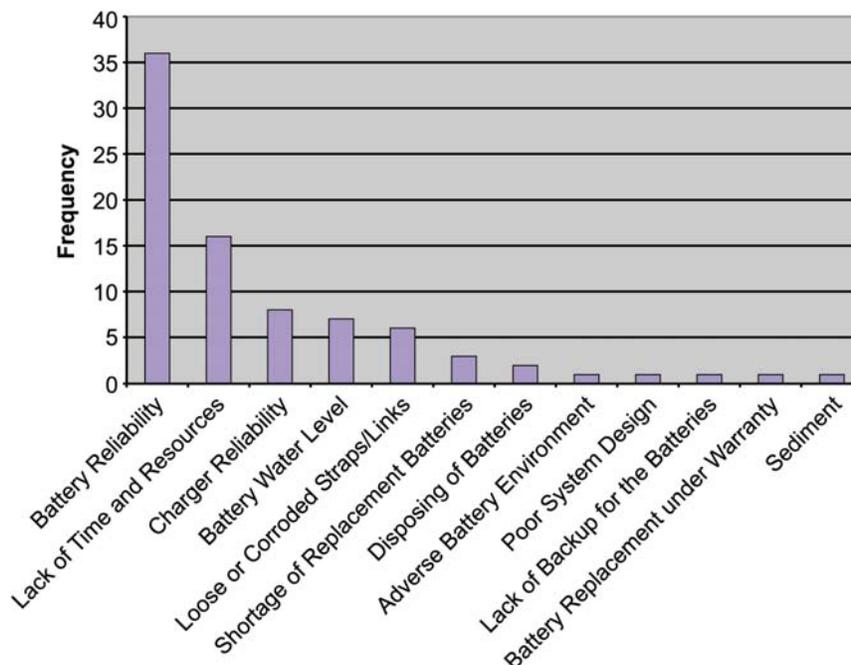


Figure 3 Utility Design and Maintenance Personnel Top Concerns for Substation Batteries

Clearly reliability is the main concern and the highest priority in maintaining substation batteries. Also of concern are lack of maintenance resources, problems with battery chargers, water levels and corroded connections.

During the recent Northeast Blackout, August 14, 2003, many substation battery systems were put to the test. In some cases the batteries were completely discharged for up to 20 and 30 hours. Voltage levels reached less than 50% of rated design. After this outage the most common problems reported in restoration of these systems were the inrush loading, tripping of the dc breaker, with shutdown or failure of the battery chargers. And overall the battery systems were not a significant factor in restoration. None of the utilities polled conducted additional load tests after the blackout.

OPPORTUNITIES FOR TECHNOLOGY IMPROVEMENTS

From this sample of substation systems the survey has focused on specification, design, and maintenance of the battery systems. Future work will investigate characteristics and trends in substation emergency loads and assess the potential for applying alternative energy storage technologies.

The survey indicated that capacity testing is not universally carried out and there are not a lot of battery condition monitors being used in substations. Approximately 85% of the substations are maintained without any kind of online monitoring. Most of the utilities interviewed expressed interest in better reliability prediction, real-time condition monitoring, and reliability-based maintenance.

Beyond condition monitoring, another opportunity is better matching the energy storage or alternative power technology with the substation loads. This belief has led to additional fieldwork to characterize substation dc loads. Many new options for emergency power (e.g., advanced batteries, electro-chemical capacitors, fuel cells, etc) are becoming available that may provide cost-effective alternatives to the traditional lead-acid battery. However to identify the potential for these options, and to convince substation engineers to try them a lot more design and application experience are needed.

As shown in Figure 4, when utilities were asked if interested in trying new technologies in substation emergency power systems there was moderate interest. This is despite the long-standing acceptance, and apparent success, of the flooded lead-acid battery.

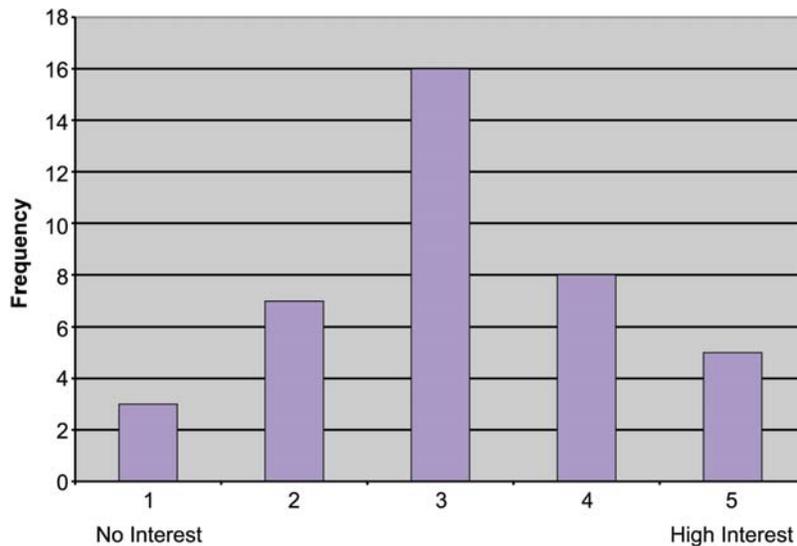


Figure 4 Interest in Trying Replacement or Hybrid Technologies for Substation Batteries.

To exploit any new technology options both the design best practices and the application engineering guidance will be needed. These should be based on the broad experience of many utilities as to what is working in the field. And good reports from actual field experience will be critical. For example, how to best match critical load requirements with the energy storage system capabilities is a key consideration. A better understanding of lifecycle costs and design practices is also needed to properly evaluate alternatives. Future work will address these needs.

CONCLUSIONS

Substation back-up power is a high priority and a major investment for utilities. Maintenance of these systems is a bigger concern than first cost. However most power companies do not track costs of emergency power system maintenance because these efforts are included in overall substation maintenance activities. The survey indicates that the main objective of utility battery system maintenance is to extend battery life and prevent unexpected failures. Clearly, battery reliability is the number one concern associated with maintaining a substation emergency/backup power system.

Utilities are generally satisfied with today's flooded lead-acid battery systems. Except for the occasional complaint about lack of resources, and the infrequent occurrence of premature failures, these systems are getting the job done. The flooded lead acid systems are lasting 15-20 years in 80% of applications and have out-performed newer technologies such as the VRLA batteries. Areas open for new energy storage technologies to out perform flooded LA are wider tolerance to ambient temperatures, more accurate means monitor capacity, and better match to substation load profiles.

Because of the high priority placed on substation emergency power the survey found utilities were generally open to look at new alternative technologies. However, even if a new technology is found that answers all the long-standing challenges in the design, operation, and maintenance of substation emergency power systems, we expect that acceptance of any new technology will take time and require many successful field trials.