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NUCLEAR ENERGY INSTITUTE

August 27, 2013

Mr. Jack R. Davis
Director
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: EA-12-049 Mitigating Strategies Resolution of Extended Battery Duty Cycles Generic Concern

Project Number: 689

Dear Mr. Davis:

Attached is the industry response to the NRC generic request for additional information regarding extended battery duty cycles originating from the staff review of the Mitigating Strategies Integrated Plan Reviews. The attached analysis demonstrates per NEI 12-06, Section 11.5, Item 1 that adequate DC power will be available to ensure successful implementation of a site's mitigating strategies. This response reflects NRC staff comments received during the Aug 20th 2013 public meeting. Ref: ML13224A383.

If you have any questions, please feel free to contact me.

Sincerely,

N. Pappas

Nicholas Pappas

Attachment

c: Mr. Eric E. Bowman, NRR/DPR/PGCB, NRC
Mr. Stewart N. Bailey, NRR/DSS/SSIB, NRC
Ms. Sheena A. Whaley, NRR/DSS/SNPB, NRC
Mr. Jeremy S. Bowen, NRR/DIRS/IPAB, NRC

Issue

In the NRC's April18, 2013 public meeting on "Mitigating Strategies Integrated Plan Review", the NRC raised the following issue:

> Several licensees have stated that their Class 1E station batteries can last beyond 8 hours. The Institute of Electrical and Electronics Engineers (IEEE) Standard 535-1986, "IEEE Standard for Qualification of Class 1E Lead Storage Batteries for Nuclear Power Generating Stations," as endorsed by Regulatory Guide 1.158, "Qualification of Safety-Related Lead Storage Batteries for Nuclear Power Plants," provides guidance for qualifying nuclear-grade batteries and describes a method acceptable to the NRC staff for complying with Commission regulations with regard to qualification of safety-related lead storage batteries for nuclear power plants.
>
> Identify the length of the duty cycle for which a vented lead-acid battery is qualified per IEEE Standard 535-2006.
>
> Discuss if there are any limitation(s) on the length of the duty cycle for a vented lead-acid battery, and please specify the technical bases (i.e., methodology, assumptions, and prerequisites) used to establish this.

Response

1) The industry does not believe IEEE 535 is applicable to beyond design basis events and battery qualification for an extended loss of ac power event is not intended.

2) Typically to extend the FLEX mission time of the batteries, stations are relying on timely load shedding of non-essential loads (including non-essential Class 1E loads) from the batteries. Engineering calculations are utilized to provide a reasonable engineering basis to demonstrate that the batteries will have sufficient FLEX mission time to maintain power to key instruments until deployment of on-site portable FLEX equipment. The actual FLEX battery mission time needed at a site is dependent upon the individual station FLEX strategies.

3) Existing station batteries are qualified to meet their design basis function throughout their qualified life. Current Technical Specification surveillance and safety-related maintenance practices ensure the station's safety-related batteries are maintained ready to perform their function when required.

4) The existing maintenance and surveillance programs are adequate to trend battery capacity and to ensure age-related or other degradation is addressed for station safety-

related batteries before the design basis capacity is challenged. An aging factor is included when sizing lead-acid batteries for design basis loads to allow time for replacement once degradation is detected/confirmed.

5) Based on the well-maintained condition of the safety-related batteries (as a result of existing maintenance and surveillance programs), the capacity of the batteries to carry design basis loads is known.

6) Load shedding is an established industry practice to extend battery mission time. Given the known capacity of nuclear plant station batteries, load shedding is a reasonable strategy to extend battery runtime during an ELAP to meet the FLEX battery mission time. Load shedding was explicitly identified in NEI 12-06, "Diverse and Flexible Coping Strategies (FLEX) Implementation Guide", Section 3 as a means to extend battery runtime.

7) IEEE 485, "Recommended Practice for Sizing Large Lead Storage Batteries for Generating Stations and Substations", methodology is the industry Standard for battery sizing, taking into account correction factors for aging, temperature, and design margin, with the certified manufacturer's discharge data. The IEEE 485 methodology has been proven over time in many nuclear station applications and is widely used by manufacturers, utilities, consultants, and others throughout the battery industry.

    a. Using the specific FLEX load profiles as design inputs, the effect of load shedding on the battery runtime can be evaluated using IEEE485.

    b. The aging correction factor is an integral part of IEEE 485 methodology to adjust the battery sizing for the proper end-of-service life condition (normally 80% of rated capacity).

    c. Testing a stationary battery to detect signs of degradation and/or when to replace the battery can be accomplished by testing the battery per IEEE 450. When degradation occurs or capacity approaches 80%, then cell replacement can be planned. This is current industry practice.

    d. The certified manufacturer's discharge data is supplied with the batteries and gives a range of discharge rates for various times and end voltages based on various factory tests. The discharge times typically range from 1 minute to several hours. This discharge data may be in a tabular form or a discharge characteristic curve as described in IEEE 485-2010, Annex F.

e. Certified discharge data load profiles similar to FLEX load profiles should now be available for most if not all station batteries which support the FLEX sizing calculations.

8) In terms of battery qualification, the same battery model can be qualified for a 2-hour duty cycle in one application and a 4-hour duty cycle in another. In addition to these qualified uses, this same model could also deliver capacity for an 8-hour duty cycle and longer runtimes if required. While it was not qualified for the longer runtimes, such a battery can perform in projected BDB functions consistent with the certified discharge data available.

9) The preliminary test results from on-going testing at Brookhaven National Laboratory (BNL) demonstrate performance during extended discharge runtimes is consistent with the above calculation methodologies. In addition, the BNL testing has not identified any new or unusual battery failure mechanisms associated with extended battery load durations.

Conclusions:

A. Additional battery qualification for FLEX load profiles is not required nor intended.

B. Following accepted industry guidance in calculating battery runtime for the projected BDB Extended Loss of AC Power (ELAP) event for the FLEX strategies, results in a defendable engineering basis for the calculated FLEX battery mission time. This FLEX battery mission time provides an engineering basis for establishing a mission time to install portable FLEX equipment in accordance with the station's FLEX strategies.

NRC Generic Concern on Extended Battery Duty Cycles
Industry White Paper Addendum – Engineering Analysis

This addendum to the Industry White Paper provides justification for use of the existing safety-related station batteries for extended duty cycles during Phase 1 of Order EA 12-049 Mitigating Strategies (FLEX Strategies). This response provides a reasonable engineering basis that battery calculations performed per IEEE 485 are sufficient to demonstrate that station batteries will meet the required coping time for the beyond design basis event.

This paper addresses the battery sizing methodology, the development and use of discharge test data/performance curves, and battery aging/failure mode issues identified in the July 23, 2013 NRC public meeting.

Battery Sizing Methodology

IEEE 485, Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications, provides the methodology for sizing batteries for safety-related and nonsafety-related applications in nuclear plants as well as in other stationary applications including nonnuclear generating facilities and substations. The methodology is based on a 1954 technical paper by E. A. Hoxie who performed extensive discharge testing to determine the performance of lead-acid batteries subjected to various load duty cycles. The IEEE 485 sizing method has been proven to accurately determine the battery capacity needed for a given load duty cycle.

One of the critical design inputs used in sizing analysis is discharge characteristic (rating) data. Each of the manufacturers of the existing station batteries used in nuclear plants provides performance discharge data to support the use of the IEEE 485 sizing method. This data is backed by manufacturer testing and includes the ratings data for extended discharges beyond 8 hour published discharge curves. Development of this discharge data is discussed in greater detail in the section below.

In addition to the discharge data input, the IEEE 485 methodology includes corrections/adjustments for several factors, including temperature, aging and design margin. The temperature factor corrects the calculation to the minimum expected electrolyte temperature for the event being examined. Electrolyte temperatures less than 77^0F reduce the available discharge capacity of the battery. Electrolyte temperatures greater than 77^0F increase the available capacity of the battery, however, no correction is normally made for the higher capacity. An aging correction factor of 1.25X is recommended by IEEE 485 which corresponds to the IEEE 450 recommendation for replacement when battery capacity drops to 80% of rated capacity. Aging will be discussed separately in regard to failure modes.

Design margin is recommended to allow for future load additions. All of these correction factors are applied to the base design or uncorrected cell size in the IEEE 485 sizing methodology.

Discharge Test Data/Performance Discharge Characteristic Curves

Battery discharge data in tabular form or plotted on performance discharge characteristic curves has always been a critical interface between the battery manufacturers and users. Annex F of IEEE 485-2010 provides a general discussion of the development and use of discharge curves. Pertinent parts of the F.1 Overview section are summarized below.

- "The actual methodology involves multiple discharges with multiple cells at a controlled temperature approximating 77^{0}F."
- "The average voltage versus time profile for each discharge is determined and then de-rated by a statistical measure, usually 2.6 or 3 sigma, to allow for manufacturing variability and thus assure 100% compliance to the products' nominal ratings."
- "The product ratings are then verified by testing on factory production strings against the proposed rates."

In discussions with the battery manufacturers it was learned that the discharge testing utilized both new and aged batteries.

In the past these curves were used routinely for manually sizing batteries for a wide variety of load duty cycles. More recently the curves have been supplemented by tabulated ratings data for convenient use with current sizing programs. In addition, now all the major battery manufacturers have battery sizing programs available on their websites that are based on the IEEE 485 methodology.

The operative concept in all of the above is the ratings used in the analysis are based on discharge testing._It is imperative for the future business of the manufacturers that the batteries continue to consistently perform within their discharge ratings.

After introduction of the passive design plants using 24 and 72 hour duty cycles, there was a significant increase in battery discharge testing by the manufacturers in anticipation of these new applications. Manufacturers of the existing 1E batteries have completed a significant amount of discharge testing to these longer duty cycles and have made this data available to prospective users. Extended discharge ratings out to 72 hours are available on the manufacturers web sites referenced below. In addition to this testing they have been involved in testing to support the extended SBO applications.

In summary, the discharge ratings data for the extended SBO duty cycles, bounding most if not all of the proposed FLEX station battery strategies, are available and are based on factory testing by the manufacturers as described in Annex F of IEEE 485-2010.

In October 2012 in support of the Brookhaven National Laboratory (BNL) confirmatory testing on extended SBO load profiles, the IEEE 485 sizing methodology was used to estimate the expected test runtimes. These estimates were simply done for planning purposes but they speak to this issue for two reasons. One, the discharge ratings data needed to perform the runtime calculations were available at that time; and two, preliminary test results appear to be within 3% on average of the calculated runtimes.

Battery Aging/Failure Modes

The IEEE 485 recommended Aging Factor of 1.25X discussed under Battery Sizing Methodology above provides a capacity correction for aging such that the battery will be able to carry its load at the end of expected service life when the battery capacity has dropped to 80% of rated. Trending of performance test results verifies the battery capacity is greater than this limit. Another aspect of aging involves the onset of degradation discussed in IEEE 450 when the capacity on a performance test drops more than 10% from the capacity on the previous performance test. In effect these two criteria in conjunction with the 5-year frequency of performance testing have provided a reasonable basis for trending aging over the service life of the battery on existing 1E and non-1E batteries.

Service tests are required on the 1E batteries to verify the batteries can meet their design basis duty cycle. They are not used for trending capacity with respect to aging. The discharge testing done by the manufacturers provides a reasonable basis that the batteries can satisfy the extended FLEX duty cycles for a beyond design basis event. Therefore, a service test using the extended duty cycle is not required.

Prior to the start of discharge testing to the longer durations of up to 72 hours, there were various concerns about new failure modes expressed across the industry. The potential failure modes for the longer duration duty cycles were focused on potential end of discharge and recharge issues once the discharge was completed, not during the bulk of the discharge cycle itself. Presentations were made at the IEEE Stationary Battery Committee meeting describing the issues and discussing compensatory actions. For example, concerns about over-discharge of individual cells at the end of the discharge can be addressed by using higher end of discharge voltages, which is typical for most plants already. Concerns about difficulty with recharge due to the batteries being deep discharged and left in that condition for several hours are addressed by using FLEX equipment to reenergize chargers to power dc loads and recharge the batteries. Accordingly, the potential failure modes mentioned would not be of concern in these events. Finally, these potential failure modes would not prevent the batteries from supporting the extended FLEX duty cycles.

Summary

- Manufacturers discharge testing, including tests performed on aged cells, was used to develop battery performance/discharge data/curves.
- Although typical published ratings data only included discharge times up to and including 8 hours, more recent testing has been completed on various discharge periods up to and including 72 hours.
- No new failure modes were identified during the extended battery discharge tests that affect battery performance during such discharge periods. Some potential concerns exist regarding battery recharging; however, those concerns are irrelevant for such a BDBE.
- Certified discharge ratings data is used by utilities to determine required battery sizes and to estimate battery runtimes using IEEE 485 methodology.
- Although the formal report has not yet been published, BNL testing has recently been completed that demonstrates extended battery discharge times can accurately be estimated using the IEEE 485 methodology.
- Technical Specification performance tests per IEEE 450 are done periodically to identify potential aging degradation and/or provide insights on the rate of aging degradation. Testing at different discharge rates is not required to identify aging degradation.

All licensees crediting the NEI white paper and this addendum for resolving the generic battery RAI will provide the equivalent of the following statement as part of their RAI response or next six month update as appropriate:

[Insert Licensee] confirms that the FLEX strategy station battery run-time was calculated in accordance with the IEEE-485 methodology using manufacturer discharge test data applicable to the licensee's FLEX strategy as outlined in the NEI white paper on Extended Battery Duty Cycles. The detailed licensee calculations, supporting vendor discharge test data, FLEX strategy battery load profile, and other inputs/initial conditions required by IEEE-485 [are or will] be available on the licensee's web portal for documents and calculations. The time margin between the calculated station battery run-time for the FLEX strategy and the expected deployment time for FLEX equipment to supply the dc loads is ["X"] hours.

The IEEE 485 Sizing process is illustrated in the example below.

Design Inputs:

1. Mfr. Name and Cell Model – C&D Model LCR-29
2. Discharge Data extracted from C&D website
3. 60 cells in battery with a minimum cell voltage of 1.75 volts per cell (VPC)
4. Minimum expected electrolyte temperature of 65 degree Fahrenheit
5. Aging Factor of 1.25 corresponding to end of service life capacity of 80%
6. Minimum Design Margin of 5% (1.05X)

Extended ELAP Duty Cycle:

NEI RES Battery Test Load Duty Cycle from NRC/BNL Testing is used in this example. Since the duration of the last step is not known until after the calculation is completed, it would be determined in an iterative fashion. However, in this case the calculation has been done and indicates a value of 1199 minutes.

Step Number	Load Amperes	Duration in Minutes
1	450	1
2	291	30
3	103	30
4	75	1199 *

Total duration in hours = **21**

Entering this load duty cycle and input data into the IEEE 485 worksheet requires discharge data values for 1260, 1259, 1229 and 1199 minutes for section 4 of the worksheet. These values are obtained from the C&D website and confirmed with them. The completed worksheet shows a calculated cell size summarized below.

Maximum Section Size	Random Size	Uncorrected Size	Temperature Correction Factor	Aging Factor	Design Margin	No. of Positive Plates Required
9.68	0	9.68	1.080	1.25	1.05	13.72

The LCR-29 model has a total of 29 plates or 14 positive plates which exceeds the number required. Total battery estimated runtime is 21 hours and includes all correction factors.

Bibliography:

1. IEEE 485 Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications

2. IEEE 450 Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications

3. C&D Battery Website: http://www.cdtechno.com/product/vla/vla_energy.html

4. Enersys Battery Website: http://www.enersysreservepower.com/productInfo.asp?brandID=35

5. Exide/GNB Battery Website: http://www.exide.com/us/en/product-solutions/network-power/product/gnb-flooded-classic-ncn.aspx

Battcon 2012 Paper on 72 hour discharge testing and recharge: http://www.battcon.com/PapersFinal2012/Kyle%20Floyd%20-%20Initial%20Test%20Results%20on%2080%25%20Service%20Test.pdf