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SIZING OF LARGE LEAD-ACID STORAGE BATTERIES

A. INTRODUCTION

This guide describes a method that the staff of the U.S. Nuclear Regulatory Commission (NRC) considers acceptable for use in complying with requirements and regulations on the criteria for the sizing of large lead-acid storage batteries for use in nuclear power plants. Specifically, the method described in this regulatory guide relates to requirements set forth in Title 10, Section 50.55a, "Codes and Standards," of the Code of Federal Regulations (10 CFR 50.55a), 10 CFR 50.63 (a)(2), "Loss of all alternating current power," and General Design Criteria (GDC) 1 and 17, as set forth in Appendix A, "General Design Criteria for Nuclear Power Plants," 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities." (Ref. 1):

- 10 CFR 50.55a(a)(1) requires that structures, systems, and components be designed, fabricated, erected, constructed, tested, and inspected to quality standards commensurate with the importance of the safety function to be performed.

- GDC 1, "Quality Standards and Records," requires that structures, systems, and components important to safety shall be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed.

- GDC 17, "Electric Power Systems," requires that an onsite electric power system and an offsite electric power system shall be provided to permit functioning of structures, systems, and components important to safety.

- 10 CFR 50.63(a)(2) requires that the reactor core and associated coolant, control, and protection systems, including station batteries and any other necessary support systems, must provide

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sufficient capacity and capability to ensure that the core is cooled and appropriate containment integrity is maintained in the event of a station blackout for the specified duration.

This regulatory guide endorses (with certain clarifying regulatory positions described in Section C of this guide) IEEE Std 485-1997, "IEEE Recommended Practice for Sizing of Lead-Acid Batteries for Stationary Applications." (Ref. 2)

The NRC issues regulatory guides to describe to the public methods that the staff considers acceptable for use in implementing specific parts of the agency's regulations, to explain techniques that the staff uses in evaluating specific problems or postulated accidents, and to provide guidance to applicants. Regulatory guides are not substitutes for regulations and compliance with them is not required.

This regulatory guide contains information collection requirements covered by 10 CFR Part 50 that the Office of Management and Budget (OMB) approved under OMB control number 3150-0011. The NRC may neither conduct nor sponsor, and a person is not required to respond to, an information collection request or requirement unless the requesting document displays a currently valid OMB control number.

B. DISCUSSION

10 CFR 50.55a(h)(2) and (3) require compliance with the requirements for safety systems in IEEE Std 603-1991, "IEEE Standard Criteria for Safety Systems for Nuclear Power Generating Stations" (Ref. 3) and the correction sheet dated January 30, 1995. The IEEE Std 603-1991 states that specific criteria unique to the Class 1E power systems are given in IEEE Std 308-1980, "IEEE Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations," (Ref. 4). Furthermore, the IEEE Std 308-1980 states that "each battery supply shall be capable of starting and operating its required steady-state and transient loads" and refers the reader to "IEEE Std 485-1978 for recommendations on sizing batteries." The IEEE Std 485-1978 is no longer available from the IEEE. However, wording of this section of the IEEE Std 308-2001, "IEEE Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations," (Ref. 5) is identical to that of the IEEE Std 308-1980 except that it references the IEEE Std 485-1997.

While the NRC has not previously endorsed the IEEE Std 485, several previous positions relate directly or indirectly to various versions of this standard. In addition to the references above to the IEEE Std 485-1978, the NRC staff has previously endorsed designs predicated on both the IEEE Std 485-1983 and the IEEE Std 485-1997. For example, NUREG-1431, "Standard Technical Specifications Westinghouse Plants" (Ref. 6); NUREG-1433, "Standard Technical Specifications General Electric Plants, BWR/4" (Ref. 7); and NUREG-1434, "Standard Technical Specifications General Electric Plants, BWR/6," (Ref. 8) all reference the IEEE Std 485-1983. On the other hand, NUREG-1793, "Final Safety Evaluation Report Related to Certification of the AP1000 Standard Design," issued in September 2004, states that among the "features of the AP1000, compared to currently operating reactors...[is]...increased battery capacity." While NUREG-1793 notes that a regulatory guide had not previously endorsed the IEEE Std 485-1997, it proceeds to state that the battery sizing, which was performed in accordance with the IEEE Std 485-1997, is considered acceptable. Additionally, Appendix A to NUREG/CR 6901, "Current State of Reliability Modeling Methodologies for Digital Systems and Their Acceptance Criteria for Nuclear Power Plant Assessments," issued in February 2006, references the IEEE Std 485-1997. More recently, Revision 3 to Section 8.3.2 of NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," issued in March 2007, states that "IEEE Std 485 provides a method acceptable to the staff for sizing stationary lead-acid batteries" and cites the IEEE Std 485-1997 as a reference.

The Battery Sizing Working Group of Standards Coordinating Committee 29 prepared the IEEE Std 485-1997, and the IEEE Standards Board approved it on March 20, 1997. The IEEE reviewed and affirmed the standard in 2003. The IEEE Std 485-1997 describes recommended methods for defining the direct current (dc) load and for sizing a lead-acid battery to supply that load. The IEEE Std 485-1997 is applicable to full-float stationary applications in which a battery charger normally maintains the battery in a fully charged state and provides power to the dc load. This standard is applicable to vented and valve-regulated lead-acid batteries, and also describes some factors relating to cell selection. However, consideration of battery types other than lead-acid is beyond the scope of the standard. Additionally, installation, maintenance, qualification, testing procedures, and design of the dc system and sizing of the battery charger(s) are also beyond the scope of this standard.

The IEEE Std 485-1978 is no longer available from the IEEE. A comparison with the current standard is also not available. The IEEE Std 485-1983, "IEEE Recommended Practice for Sizing Large Lead Storage Batteries for Generating Stations and Substations" (Ref. 12), addresses sizing of large lead storage batteries for generating stations and substations but does not mention valve-regulated lead-acid batteries. Subsequently, the IEEE Std 485-1997 was generalized for the sizing of lead-acid batteries for stationary applications. The later version explicitly states its applicability to both vented and valve-regulated lead-acid batteries. In addition, requirements (indicated by the verb "shall") in the previous version of the standard have been restated as recommendations (indicated by the verb "should") in IEEE Std 485-1997. A comparison of IEEE Std 485-1983 and IEEE Std 485-1997 is available from the IEEE. The IEEE Std 485-1997 also includes an additional instruction to consult with manufacturers on any limitations on paralleling two or more strings of cells. The 1997 edition updates a previous reference to the IEEE Std 484-1981 in IEEE Std 485-1983 to reference the IEEE Std 484-1996, "Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications." The 1981 edition of IEEE Std 484 is no longer in print, and the IEEE has since published a newer version of the standard, IEEE Std 484-2002 (Ref. 13) which the NRC endorsed in Revision 2 of Regulatory Guide 1.128, "Installation Design and Installation of Vented Lead-Acid Storage Batteries for Nuclear Power Plants" (Ref. 14), issued in February 2007.

The IEEE Std 450-2002, "IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications" (Ref. 15), which the NRC endorsed in Regulatory Guide 1.129, "Maintenance, Testing, and Replacement of Vented Lead-Acid Storage Batteries for Nuclear Power Plants," (Ref. 16) repeatedly refers to IEEE Std 485-1997 in its discussion of considerations related to battery sizing as it affects many of the various testing criteria, including acceptance tests, performance tests, service tests, and battery replacement criteria.

The sizing methodology provided by IEEE Std 485-1997 is essentially identical to that provided by IEEE Std 485-1983. The approach consists of first defining the load that the batteries will be required to support. To this end, the standard provides guidance on general considerations that should be included in defining the duty cycle; load classifications, including continuous, non-continuous, and momentary loads; and the construction of a duty-cycle diagram. Annex B to IEEE Std 485-1997 provides a method for converting constant power and constant resistance loads to constant current loads so that they can be correctly considered using the sizing methodology provided in the standard. The standard provides a brief summary of some factors that should be considered when selecting a cell design for a particular application. The IEEE Std 485-1997 refers the user to vendor literature and to the IEEE Std 1184-1994, "IEEE Guide for Batteries for Uninterruptible Power Supply Systems," (Ref. 17) in its discussion of cell selection considerations.

The standard provides a methodical and conservative procedure for determining the battery size required to deliver sufficient power to the previously determined load. In addition to the defined duty cycle, the approach considers other factors, including maximum system voltage, minimum system voltage, and various correction factors. The IEEE Std 485-1997 no longer includes a discussion on charging rate as a limiting factor in battery sizing and a qualification on total time span of the duty cycle, which appeared in the 1983 edition of the standard. The 1997 edition also slightly revised the consideration of minimum system voltage as a limiting factor to be more consistent with the cell-sizing worksheet incorporated by the method.

In addition to Annex B described above, the IEEE Std 485-1997 was also augmented with the following additional information:

- Section 7 discusses the potential need for calculating cell or battery terminal voltages at various times throughout the duty cycle.
- Annex C describes a method for calculating the cell/battery terminal voltage as a function of the duty cycle and provides two sample calculations, one using "fan" curves and one using "S" curves to describe the discharge characteristics of a given battery.
- Annex D provides a bibliography.

Annex A to IEEE Std 485-1997 provides battery- and cell-sizing examples. Included are example calculations that demonstrate how to properly select the number of cells, how the number of cells affects the required cell capacity, and how to use the cell-sizing worksheet to calculate the required cell size. However, Figure A.1 contains three typographical errors. In Section 4 of the figure, the positive values and the negative value for the Section 4 subtotal, "–800.2," are correct; however, the figure contains the following errors:

- The cell in Section 4, row 2, column 7 ("Neg Values"), is blank but should read "–640.2."
- The cell in Section 4, row 3, column 7 ("Neg Values"), currently reads "–40.2" but should read "0.0."
- The cell in Section 4, row 4, column 7 ("Neg Values"), is blank but should read "–160.0."

C. REGULATORY POSITION

Conformance with the procedures defined in IEEE-Std 485-1997 (reaffirmed in 2003) provides methods acceptable to the NRC staff for complying with the design requirements as set forth in (1) 10 CFR 50.55a(a)(1), (2) 10 CFR 50.55a(h)(2), (3) 10 CFR 50.55a(h)(3), (4) 10 CFR 50.63(a)(2), and (5) GDC 1 and 17 of Appendix A to 10 CFR Part 50 as they relate to the requirements for defining dc loads for all specified battery duty cycles and for sizing lead-acid batteries to supply that load for stationary battery applications in full-float operation for nuclear power plants, subject to the following stipulations:

1. Section 2, "References," which stipulates that this standard shall be used in conjunction with other IEEE standards, should be supplemented as follows:

   For nuclear power generating stations, the recommended practice should also be used in conjunction with other pertinent publications. The pertinent publications include the following IEEE standards:

   - IEEE Std 308-2001, "IEEE Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations," as endorsed by Regulatory Guide 1.32

- IEEE Std 535-2006, " IEEE Standard for Qualification of Class 1E Lead Storage Batteries for Nuclear Power Generating Stations"
- IEEE Std 344-1987, "IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations," as endorsed by Regulatory Guide 1.100
- IEEE Std 384-1992, "IEEE Standard Criteria for Independence of Class 1E Equipment and Circuits," as endorsed by Regulatory Guide 1.75
- IEEE Std 484-2002, "IEEE Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications," as endorsed by Regulatory Guide 1.128
- IEEE Std 450-2002, "IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Application," as endorsed by Regulatory Guide 1.129.

2. Annex A to IEEE Std 485-1997 is informative and provides sample sizing demonstrations. Unless otherwise stated in a regulatory position, endorsement of the IEEE Std 485-1997 does not include this annex. Figure A.1 has the following three typographical errors:

3. Annex B to IEEE Std 485-1997 is endorsed as an accepted method of converting constant power and constant resistance loads to constant current loads for purposes of defining the duty cycle for battery-sizing calculations.

   a. The cell in Section 4, row 2, column 7 ("Neg Values"), is blank but should read "–640.2."
   b. The cell in Section 4, row 3, column 7 ("Neg Values"), currently reads "–40.2" but should read "0.0."
   c. The cell in Section 4, row 4, column 7 ("Neg Values"), is blank but should read "–160.0."

4. Annex C to IEEE Std 485-1997 is informative and provides a method for estimating battery terminal voltage at various points in the battery duty cycle using manufacturer's typical discharge characteristics. Unless otherwise stated in a regulatory position, endorsement of the IEEE Std 485-1997 does not include this annex.

5. Annex D to IEEE Std 485-1997 is informative and provides the bibliography. Unless otherwise stated in a regulatory position, endorsement of the IEEE Std 485-1997 does not include this annex.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC's plans for using this regulatory guide. The NRC does not intend or approve any imposition or backfit in connection with its issuance.

In some cases, applicants or licensees may propose an alternative method or use a previously established acceptable alternative method for complying with specified portions of the NRC's regulations. Otherwise, the methods described in this guide will be used in evaluating compliance with the applicable regulations for license applications, license amendment applications, and amendment requests.

REFERENCES

1. U.S. *Code of Federal Regulations*, Title 10, Energy, Part 50, "Domestic Licensing of Production and Utilization Facilities," U.S. Nuclear Regulatory Commission, Washington, DC.

2. IEEE Std 485-1997, "IEEE Recommended Practice for Sizing of Lead-Acid Batteries for Stationary Applications," IEEE, Piscataway, NJ, September 1997.

3. IEEE Std. 603-1991, "IEEE Standard Criteria for Safety Systems for Nuclear Power Generating Stations," IEEE, Piscataway, NJ, December 1991.

4. IEEE Std 308-1980, "IEEE Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations," IEEE, Piscataway, NJ, October 1980.

5. IEEE Std 308-2001, "IEEE Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations," IEEE, Piscataway, NJ, March 2002.

6. NUREG-1431, "Standard Technical Specifications Westinghouse Plants," U.S. Nuclear Regulatory Commission, Washington, DC, June 2004.

7. NUREG-1433, "Standard Technical Specifications General Electric Plants, BWR/4," U.S. Nuclear Regulatory Commission, Washington, DC, June 2004.

8. NUREG-1434, "Standard Technical Specifications General Electric Plants, BWR/6," U.S. Nuclear Regulatory Commission, Washington, DC, June 2004.

9. NUREG-1793, "Final Safety Evaluation Report Related to Certification of the AP1000 Standard Design," U.S. Nuclear Regulatory Commission, Washington, DC, September 2004.

10. NUREG/CR 6901, "Current State of Reliability Modeling Methodologies for Digital Systems and Their Acceptance Criteria for Nuclear Power Plant Assessments," U.S. Nuclear Regulatory Commission, Washington, DC, February 2006.

11. NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," U.S. Nuclear Regulatory Commission, Washington, DC, March 2007.

12. IEEE Std 485-1983, "IEEE Recommended Practice for Sizing Large Lead Storage Batteries for Generating Stations and Substations," IEEE, Piscataway, NJ, June 1983.

13. IEEE Std 484-2002, "IEEE Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications," IEEE, Piscataway, NJ, February 2003.

14. Regulatory Guide 1.128, "Installation Design and Installation of Vented Lead-Acid Storage Batteries for Nuclear Power Plants," U.S. Nuclear Regulatory Commission, Washington, DC.

15. IEEE Std 450-2002, "IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications," IEEE, Piscataway, NJ, April 2003.

16. Regulatory Guide 1.129, "Maintenance, Testing, and Replacement of Vented Lead-Acid Storage Batteries for Nuclear Power Plants," U.S. Nuclear Regulatory Commission, Washington, DC.

17. IEEE Std 1184-1994, "IEEE Guide for Batteries for Uninterruptible Power Supply Systems," IEEE, Piscataway, NJ, June 1995.

18. IEEE Std 535-2006, "IEEE Standard for Qualification of Class 1E Lead Storage Batteries for Nuclear Power Generating Stations," IEEE, Piscataway, NJ, June 2007.

19. IEEE Std 344-1987, "IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations," IEEE, Piscataway, NJ, August 1987.

20. IEEE Std 384-1992, "IEEE Standard Criteria for Independence of Class 1E Equipment and Circuits," IEEE, Piscataway, NJ, June 1992.