

IEEE Recommended Practice for the Design of DC Auxiliary Power Systems for Generating Stations

Sponsor
**Energy Development & Power Generation Committee
of the
IEEE Power Engineering Society**

Approved December 3, 1992
IEEE Standards Board

Abstract: Guidance for the design of the dc auxiliary power systems for nuclear and large fossil-fueled power generating stations is provided. The components of the dc auxiliary power system, including lead storage batteries, static battery chargers, and distribution equipment, are addressed. Guidance for selecting the quantity and types of equipment, the equipment ratings, interconnections, instrumentation, control and protection is also provided.

Keywords: dc auxiliary power systems, fossil-fueled generating stations, nuclear generating stations

The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA
Copyright © 1993 by the Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 1993. Printed in the United States of America
ISBN 1-55937-283-4

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

IEEE Standards documents are developed within the Technical Committees of the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Board. Members of the committees serve voluntarily and without compensation. They are not necessarily members of the Institute. The standards developed within IEEE represent a consensus of the broad expertise on the subject within the Institute as well as those activities outside of IEEE that have expressed an interest in participating in the development of the standard.

Use of an IEEE Standard is wholly voluntary. The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of all concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason IEEE and the members of its technical committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration.

Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE Standards Board
445 Hoes Lane
P.O. Box 1331
Piscataway, NJ 08855-1331
USA

IEEE Standards documents are adopted by the Institute of Electrical and Electronics Engineers without regard to whether their adoption may involve patents on articles, materials, or processes. Such adoption does not assume any liability to any patent owner, nor does it assume any obligation whatever to parties adopting the standards documents.

Introduction

(This introduction is not a part of IEEE Std 946-1992, IEEE Recommended Practice for the Design of DC Auxiliary Power Systems for Generating Stations.)

DC auxiliary power systems play an ever-increasing role in generating station control and in providing backup power for emergencies. This recommended practice fulfills a need within the industry to provide common or standard practices for the design of dc systems. The design features described are applicable to all installations and system capacities.

This recommended practice may be used separately and, when combined with applicable portions of IEEE Std 308-1991, IEEE Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations (ANSI); IEEE Std 450-1987, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Large Lead Storage Batteries for Generating Stations and Substations; IEEE Std 484-1987, IEEE Recommended Practice for Installation Design and Installation of Large Lead Storage Batteries for Generating Stations and Substations (ANSI); IEEE Std 485-1983, IEEE Recommended Practice for Sizing Large Lead Storage Batteries for Generating Stations and Substations (ANSI); IEEE Std 535-1986, IEEE Standard for Qualification of Class 1E Lead Storage Batteries for Nuclear Power Generating Stations (ANSI); and IEEE Std 650-1990, IEEE Standard for Qualification of Class 1E Static Battery Chargers and Inverters for Nuclear Power Generating Station (ANSI), will provide the user with a general guide to designing, qualifying, maintaining, and testing dc systems (safety-related and non-safety-related).

In the 1992 IEEE style, notes in text are not a normative part of a standard. This standard makes an exception to that rule. In future revisions, this exception will not occur.

Participants

This recommended practice was prepared by the Task Force on DC Auxiliary Power, Station Design Subcommittee of the Energy Development and Power Generation Committee of the IEEE Power Engineering Society. The following is a list of the members on the Task Force:

B. G. Treece, *Chair*

M. D. Bowman
K. R. Caraway
P. L. Gogan
D. J. Jakubowski

R. A. Johnson
J. L. Knox
J. F. Montalbano

G. C. Seibert
C. F. Seyer
D. L. Smith*
K. W. Uhler

*Liaison Representative, SC-4 of Nuclear Power Engineering Committee.

Other individuals who have contributed review and comments are:

A. N. Pal

S. P. Martinovich

R. E. Miller

The following persons were on the balloting committee that approved this document for submission to the IEEE Standards Board:

I. B. Berezowsky
S. R. Brockschink
E. E. Chelotti
R. S. Coleman
M. L. Crenshaw
D. J. Damsker
G. Engmann
A. H. Ferber
W. W. Fields
D. I. Gorden

J. H. Gurney
T. J. Hammons
R. D. Handel
M. E. Jackowski
J. H. Jones
P. R. H. Landrieu
J. E. LeClair
G. L. Luri
J. T. Madill

O. S. Mazzoni
D. R. McCabe
G. R. Meloy
J. L. Mills
C. R. Pope
E. P. Rothong
J. E. Stoner, Jr.
R. E. Strasser
T. R. Whittemore
J.P. Whooley

When the IEEE Standards Board approved this standard on December 3, 1992, it had the following membership:

Marco W. Migliaro, *Chair*
Donald C. Loughry, *Vice Chair*
Andrew G. Salem, *Secretary*

Dennis Bodson
Paul L. Borrill
Clyde Camp
Donald C. Fleckenstein
Jay Forster*
David F. Franklin
Ramiro Garcia
Thomas L. Hannan

Donald N. Heirman
Ben C. Johnson
Walter J. Karplus
Ivor N. Knight
Joseph Koepfinger*
Irving Kolodny
D. N. “Jim” Logothetis
Lawrence V. McCall

T Don Michael*
John L. Rankine
Wallace S. Read
Ronald H. Reimer
Gary S. Robinson
Martin V. Schneider
Terrance R. Whittemore
Donald W. Zipse

*Member Emeritus

Also included are the following nonvoting IEEE Standards Board liaisons:

Satish K. Aggarwal
James Beall

Richard B. Engelman

David E. Soffrin
Stanley Warshaw

Rochelle L. Stern
IEEE Standards Project Editor

CLAUSE	PAGE
1. Scope	1
2. References	1
3. Definitions	2
4. General	2
4.1 Description and operation	2
4.2 Number of batteries	3
4.3 Number of chargers and distribution panels	3
4.4 System voltage considerations	3
4.5 Physical layout	4
5. Batteries	4
5.1 General description	4
5.2 Determination of battery duty cycles and battery size (capacity)	4
5.3 Installation design	5
5.4 Maintenance, testing, and replacement	5
5.5 Qualification	5
6. Battery chargers	5
6.1 General description	5
6.2 Determination of rated output	5
6.3 Sample calculations	6
6.4 Qualification	6
6.5 Output characteristics	6
7. Distribution system and equipment	6
7.1 Description and rating	6
7.2 Typical diagram	7
7.3 Voltage ratings for dc powered components	9
7.4 Instrumentation, controls, and alarms	10
7.5 Special dc loads	13
7.6 Design features to assist in battery testing	14
7.7 Cross-tie between buses	14
7.8 Qualification	15
7.9 Available short-circuit current	15
8. Spare equipment	16
9. Bibliography	16
Annex A Battery charger rating sample calculations (Informative)	18
Annex B Batteries, available short-circuit current—sample calculations (Informative)	20
Annex C Effect of grounds on the operation of dc auxiliary power systems (Informative)	24
Annex D Battery charger, short-circuit current contribution (Informative)	27

IEEE Recommended Practice for the Design of DC Auxiliary Power Systems for Generating Stations

1. Scope

This recommended practice provides guidance for the design of the dc auxiliary power systems for nuclear and non-nuclear power generating stations. The components of the dc auxiliary power system addressed by this recommended practice include lead storage batteries, static battery chargers, and distribution equipment. Guidance for selecting the quantity and types of equipment, the equipment ratings, interconnections, instrumentation, control and protection is also provided.

This recommended practice is intended for nuclear and large fossil-fueled generating stations. Each recommendation may or may not be appropriate for other generating facilities; e.g., combustion turbines, hydro, wind turbines, etc.

The ac power supply (to the chargers), the loads served by the dc systems, except as they influence the dc system design, and engine starting (cranking) battery systems are beyond the scope of this recommended practice.

2. References

This standard shall be used in conjunction with the following publications:

ANSI C37.16-1988, IEEE Standard for Low-Voltage Power Circuit Breakers and AC Power Circuit Protectors—Preferred Ratings, Related Requirements and Application Recommendations.¹

IEEE C37.90-1989, IEEE Standard for Relays and Relay Systems Associated with Electric Power Apparatus (ANSI).²

IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms.

IEEE Std 308-1991, IEEE Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations (ANSI).

¹ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

²IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

IEEE Std 336-1985 (Reaff 1991), IEEE Standard Installation, Inspection, and Testing Requirements for Power, Instrumentation, and Control Equipment at Nuclear Facilities (ANSI).

IEEE Std 383-1974 (Reaff 1992), IEEE Standard for Type Test of Class 1E Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations (ANSI).

IEEE Std 384-1981, IEEE Standard Criteria for Independence of Class 1E Equipment and Circuits (ANSI).

IEEE Std 450-1987, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Large Lead Storage Batteries for Generating Stations and Substations (ANSI).

IEEE Std 484-1987, IEEE Recommended Practice for Installation Design and Installation of Large Lead Storage Batteries for Generating Stations and Substations (Includes Supplement IEEE Std 484A-1984) (ANSI).

IEEE Std 485-1983, IEEE Recommended Practice for Sizing Large Lead Storage Batteries for Generating Stations and Substations (ANSI).

IEEE Std 535-1986, IEEE Standard for Qualification of Class 1E Lead Storage Batteries for Nuclear Power Generating Stations (ANSI).

IEEE Std 603-1991, IEEE Standard Criteria for Safety Systems for Nuclear Power Generating Stations (ANSI).

IEEE Std 627-1980 (Reaff 1991), IEEE Standard for Design Qualification of Safety System Equipment Used in Nuclear Power Generating Stations (ANSI).

IEEE Std 649-1991, IEEE Standard for Qualifying Class 1E Motor Control Centers for Nuclear Power Generating Stations (ANSI).

IEEE Std 650-1990, IEEE Standard for Qualification of Class 1E Static Battery Chargers and Inverters for Nuclear Power Generating Stations (ANSI).

NEMA MG 1-1978 (R 1981), Motors and Generators.³

NEMA PE 5-1983, Constant-Potential-Type Electric Utility (Semiconductor Static Converter) Battery Chargers.

3. Definitions

For definitions of terms used in this document, see IEEE Std 100-1992 and other referenced standards.

4. General

4.1 Description and operation

All power generating stations require dc auxiliary power systems to operate those dc components which must be available should a loss of ac power occur. Some examples of such components are auxiliary motors, circuit breakers, relays, solenoids, and inverters. The dc source(s) may be one common battery for both power and control or two separate batteries—one for power and another for control and instrumentation. Separate batteries are recommended for special services such as for engine (cranking) starting.

³NEMA publications are available from the National Electrical Manufacturers Association, 2101 L Street NW, Washington, DC 20037, USA.

In normal operation, the battery and charger(s) are both connected to the dc distribution bus and, therefore, operate as parallel sources to supply the connected loads. The charger, in addition to charging the battery, carries the normal continuous load. Chargers are typically provided with a current limiting circuit for overload protection. If overloaded, the charger output voltage will drop, causing all loads in excess of the charger rating to be supplied by the battery. In the event of: a) a failure of the ac power supply to the charger(s) or b) a charger failure (or the removal of the charger from service), the battery must supply all of the power required by the loads.

For nuclear applications, Non-Class 1E dc loads should not be connected to Class 1E dc power systems. Any exceptions (e.g., the Non-Class 1E load provides operational flexibility during accident mitigation such as access to an alternate heat sink) shall meet the independence requirements established in IEEE Std 384-1981.⁴ Thus, non-safety-related dc systems should generally be provided for applications such as switchyard control, turbine-generator auxiliaries, lighting, plant security, fire detection/suppression systems, etc. A dc system that performs a safety function shall meet the appropriate requirements of IEEE Std 603-1991 and IEEE Std 308-1991, and shall be qualified in accordance with IEEE Std 627-1980.

4.2 Number of batteries

As a minimum, one battery should be provided for each unit. If the auxiliaries (loads) of one unit are divided into two or more independent systems, then each independent system should be provided with a separate battery. If the maximum dc power requirements exceed the capacity of one battery, then the development of two independent systems should be considered. Cross-ties from other batteries may be provided, where appropriate (see 7.7).

For Class 1E nuclear applications, as a minimum, a separate battery shall be provided for each Engineered Safety Feature (ESF) Division in each unit in order to provide the required independence between redundant Class 1E power systems (see IEEE Std 308-1991). For increased operating flexibility in designs where the reactor protection system channels are dependent on dc, the number of safety-related batteries provided on each unit should equal the number of independent and redundant reactor protection system (instrumentation and control) channels. For example, in a unit with four reactor protection channels, four batteries should be provided. The rated capacity of each battery should be determined as described in 5.2 of this document.

4.3 Number of chargers and distribution panels

As a minimum, one battery charger and main distribution panel should be provided for each battery. Additional (spare or standby) chargers should be considered for increased operating flexibility and plant availability (see clause 8.)

4.4 System voltage considerations

The nominal voltages of 250, 125, 48, and 24 are generally utilized in station dc auxiliary power systems. The type, rating, cost, availability, and location of the connected equipment should be used to determine which nominal system voltage is appropriate for a specific application. Two hundred fifty (250) V systems are typically used to power motors for emergency pumps, large valve operators, and large inverters. One hundred twenty-five (125) V systems are typically used for control power for nest relay logic circuits and the closing and tripping of switchgear circuit breakers. Forty-eight (48) V or 24 V systems are typically used for specialized instrumentation.

For a given dc auxiliary power system, the connected equipment governs the maximum and minimum voltage operating limits. Standards such as ANSI C37.16-1988, IEEE C37.90-1989, and NEMA MG 1-1978 establish voltage limits for various equipment and relays (see 7.3). When the voltage limits for a given system are established, the size of the battery (number of cells and capacity) and the operating procedures should be established as outlined in IEEE Std 485-1983 and IEEE Std 450-1987, respectively.

⁴Information on references can be found in clause 2..

4.5 Physical layout

Consideration should be given to locating the equipment (i.e., battery, charger, and main distribution panel) as close together, and as near the center of the electrical load, as practical so as to minimize voltage drop and to accommodate maintenance and testing activities. If the ac auxiliary power system is separated into two or more independent divisions, with a dc auxiliary power system for each ac division, then the equipment and cables for each dc auxiliary power system division should be separated from the equipment and cable of the other division, to the same extent as employed for the ac system.

For Class 1E nuclear applications, the redundant equipment (including the cables) of the safety-related dc system shall be arranged to meet the physical separation requirements of IEEE Std 384-1981.

5. Batteries

5.1 General description

The station batteries are used to supply power to dc loads during the loss of all ac power sources.

5.2 Determination of battery duty cycles and battery size (capacity)

The determination of the battery duty cycles is a plant-unique activity because the magnitude (total amperes) and duration of each segment of the duty cycle is the sum of the individual operating loads (amperes) over the time period required for the specific plant equipment under consideration.

In addition, the overall duration (total battery discharge time) of the duty cycle cannot be less than the estimated time interval necessary to restore ac power (either from an on-site engine-generator source or an off-site power source) to the battery chargers and other auxiliaries. This estimated time interval is determined by engineering judgment, which is greatly influenced by operating experience, and by the quantity, reliability, and flexibility of the specific off-site power sources (generation and transmission system network equipment) and on-site power sources (engine-generators and distribution systems).

For example, a minimum scenario may require the batteries to supply power to the system for approximately 1 min (the time between loss of ac power and the loading of the diesel) if, after such time, the charger output and dc loads return to normal. More often, the overall duration of the battery duty cycle is estimated at 1/2, 1, 2, 4, or 8 hours. The time/load current profile should consider the requirements in all operating modes. Operating requirements, such as operation while a battery charger is out for repair or while switches are operated to bring a spare charger on line, should also be considered. Battery duty cycles that require manual shedding of battery loads also require that sufficient capacity be provided to allow adequate time for such manual actions. Thus, several battery duty cycles will usually be required to address such postulated events.

After the magnitude and time period of each component load and the overall duration have been determined, each battery duty cycle should be constructed, and the battery sized, in accordance with IEEE Std 485-1983.

Consideration may be given to providing additional design margin (i.e., extra capacity) such that the battery will be able to fulfill the service requirements if it ever should become necessary to electrically remove one or more cells. This can be accomplished by using the higher end-of-discharge cell voltage (corresponding to the reduced number of cells) in the battery sizing calculation.

5.3 Installation design

The design of each battery installation should be in accordance with IEEE Std 484-1987, and should include provisions for installation, inspection, and testing.

For Class 1E nuclear applications, the provisions for installation, inspection, and testing shall comply with IEEE Std 336-1985.

5.4 Maintenance, testing, and replacement

Batteries should be maintained, tested, and replaced in accordance with IEEE Std 450-1987.

5.5 Qualification

Batteries shall be qualified (including seismic, if appropriate) for the environment in which they are installed.

For Class 1E nuclear applications, batteries shall be qualified (environmentally and seismically) in accordance with IEEE Std 535-1986.

6. Battery chargers

6.1 General description

The station battery chargers are used to convert ac to dc to charge the station batteries and to supply power to dc loads during normal operation.

6.2 Determination of rated output

The station battery chargers should be sized in accordance with the following formulas:

$$I_1 = L_c + \frac{1.1 \cdot Ah}{T} \quad (6-1)$$

$$I_2 = L_c + L_n \quad (6-2)$$

where

- I_1 is the minimum required charger rated output (in amperes)
- I_2 is the recommended charger rated output (in amperes); i.e., the larger of I_1 or I_2 ⁵
- L_c is the continuous dc load (in amperes), including future load growth
- L_n is the largest combination of noncontinuous loads (as defined in IEEE Std 485-1983, 4.2.2) that would likely be connected to the bus simultaneously during normal plant operation
- 1.1 is the constant that compensates for the battery losses
- Ah is the ampere-hours discharged from the battery. It is recommended that the 8 h ampere-hour rating of the battery be used in this formula for any duty cycle with an overall duration of 8 h or less. For longer duty cycles, use the battery rating corresponding to the overall duration.
- T is the time to recharge the battery to approximately 95% of capacity (in hours). To minimize dc system downtime, a reasonable recharge time should be selected; 8-12 h is recommended. It is recommended that the battery manufacturer be consulted for values of T less than 8 h.

⁵If it can be demonstrated that the reduction in battery capacity that results during and following the application of L_n does not compromise the ability of the battery to satisfy its intended function, the user may select equation 1 as the basis of sizing the battery charges(s).