

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 lead 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_3 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).

The battery charger specification should include (or account for) any abnormal service conditions. For example, ambient temperature, altitude, etc., may affect the charger capacity as noted in NEMA PE5-1983.

6.3 Sample calculations

Sample calculations of battery charger rating appear in annex A.1.

6.4 Qualification

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

For Class 1E nuclear applications, the chargers shall be qualified in accordance with IEEE Std 650-1990.

6.5 Output characteristics

All station battery chargers should meet the requirements of NEMA PE 5-1983, and the performance characteristics descriptions that follow.

6.5.1 Output ripple

A typical charger (without additional filtering) will produce approximately 2% rms (2.6 V on a 130 V basis) ripple when connected to a fully charged battery with an ampere-hour rating (at the 8 h rate) of at least four times the output current rating of the charger. In some cases, dc loads (for example, solid-state instruments) may require improved filtering. The maximum ripple can usually be limited to 30 mV rms by adding filters to the chargers.

6.5.2 Operation without a connected battery

For some designs, it may be appropriate to disconnect the battery from the system for maintenance of the battery. Under this condition, the charger/battery eliminator should be capable of supplying the load without a battery connected and should be so specified for these applications. However, an increase in the voltage regulation and output ripple should be expected. If the increase in voltage regulation or ripple cannot be tolerated, the maximum allowable values should be specified.

6.5.3 Load sharing between paralleled chargers

When operating considerations dictate that two chargers be connected in parallel to the dc bus, the specification should require that load-sharing circuitry be provided.

7. Distribution system and equipment

7.1 Description and rating

A circuit breaker, fuses, or a manual disconnecting device should be provided between the battery terminals and the main distribution bus. The buses in the main distribution panel should be insulated for personnel protection and to minimize the probability of bus faults. However, these buses must be insulated in designs incorporating a manual disconnecting device. In any arrangement, the positive and negative main lead cables should be run in separate conduits so as to ensure that any fault on these cables will first be polarity-to-ground before a polarity-to-polarity fault can develop. The use of nonmagnetic conduit should be considered so as to reduce the inductance of this circuit. A circuit with lower inductance will reduce the magnitude of voltage “spikes” generated, and reflected into the dc system, when high-current load circuits (e.g., motors, inverters, faults, etc.), are interrupted. In addition, a highly

inductive circuit may adversely affect the performance of current-limiting fuses, if utilized. A barrier should also be provided between the positive and negative line leads at the main distribution panel. The continuous current rating of the protective/disconnecting device should be selected to accommodate the maximum sustained current in the battery duty cycle. Where provided, the protective device should have a trip rating: a) sufficiently high to prevent damage to the fuse element or opening of the breaker at the 1 min current rating of the battery, and b) sufficiently low to protect the main lead cables.

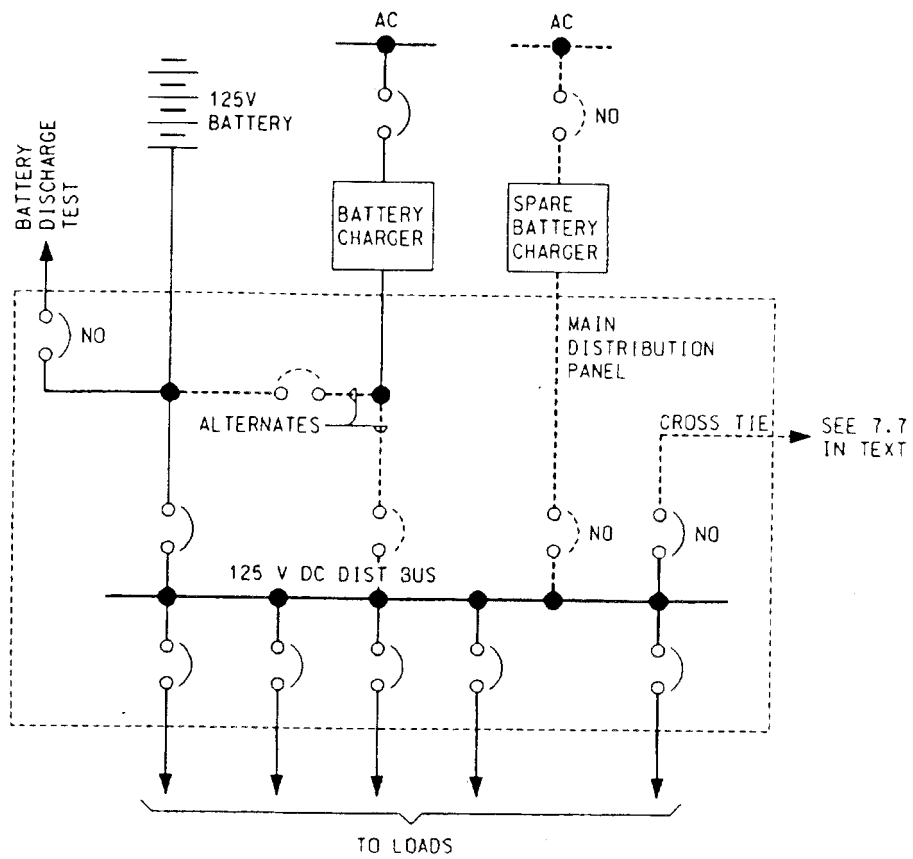
NOTES:

- 1 — In cases where a battery has been sized to meet the demand of a fractional minute load, the protective device should have a trip rating sufficiently high to prevent damage to the fuse element or opening of the breaker at the fractional minute current rating of the battery. Consult the battery manufacturer for ratings for discharge duration less than 1 minute.
- 2 — The (minimum) melt current of the fuse element at 1 minute should be above the 1 minute current rating of the battery if the maximum current is assumed to be the load for the 1 minute period.

The main protective device should coordinate with all downstream protective devices. All distribution bus protective devices should have a voltage rating consistent with the maximum system-operating voltage, and should have an interrupting capacity that exceeds the maximum short-circuit current available at that voltage. The distribution bus and any manual disconnecting device should have a short-circuit current withstand capability that exceeds the maximum short-circuit current available. All time-current coordination curves and ratings should be based on dc (not ac).

7.2 Typical diagram

The optimum dc supply and distribution system diagram for any given plant will depend on conditions and design criteria established for that plant. Figure 1 is the key diagram for one acceptable 125 V dc system.

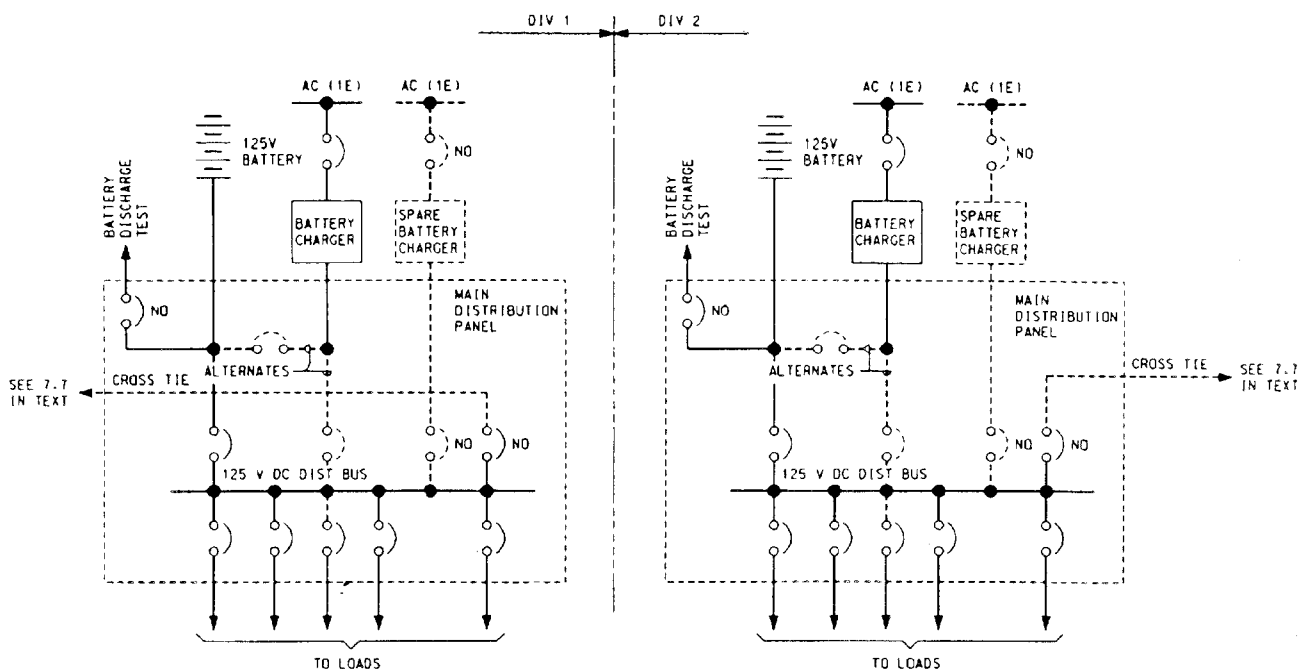


NOTES:

- 1—All breakers normally closed except those marked "NO."
- 2— "-----" indicates optional or alternate features.
- 3—Fuses may be substituted for breakers.

Figure 1—125 V dc system key diagram

For Class 1E nuclear applications, figure 2 is the key diagram for one acceptable 125 V Class 1E dc system.



NOTES:

- 1—All breakers normally closed except those identified "NO."
- 2—"-----" indicates optional or alternate features.
- 3—Fuses may be substituted for breakers.

Figure 2—125 V Class 1E dc system key diagram

7.3 Voltage ratings for dc powered components

Equipment specifications for components powered by dc systems should require the equipment to operate, as designed and without damage, over the input terminal voltage range corresponding to the variation in system voltage. For designs in which the battery is equalized while connected to the load, this range should cover the variation from equalize to the final end-of-discharge voltage (e.g., from 140 V to 105 V dc for a 60-cell nominal 125 V dc system, or from 280 V to 210 V dc for a 120 cell nominal 250 V dc system). Because of this variation, the rated (nameplate) maximum and minimum voltage of the component governs the allowable maximum and minimum voltage at the battery terminals. Table 1 provides the recommended voltage range of some (typical) dc powered components for those designs in which the battery is equalized while connected to the load.

Table 1—Recommended voltage range of 125 V and 250 V dc (nominal) rated components (for designs in which the battery is equalized while connected to the load)

Component	Voltage Range	
	125 V dc (nominal)	250 V dc (nominal)
Circuit-breaker close coil	90–140	180–280
Circuit-breaker trip coil	70–140	140–280
Motor-starter coil	90–140	180–280
Solenoid valve	90–140	180–280
Valve-operator motor	90–140	180–280
Auxiliary motor	100–140	200–280
Electro-mechanical relay coil	100–140	200–280
Solid-state relay	100–140	200–280
Instrumentation	100–140	200–280
Indicating lamp	100–140	200–280
Solid-state power supply (Inverter and converter)	100–140	200–280
NOTE — The voltage ranges listed above may not agree with those recommended in other industry standards for the equipment, but are recommended for proper component operation with main distribution-panel bus voltage which varies from 105 V–140 V (210 V–280 V).		

In addition to ampacity considerations, supply cables for dc-powered components should be sized to provide adequate voltage for proper operation during the individual component's worst-case operating condition. The worst-case condition for a constant power load such as an inverter may occur at a reduced battery-terminal voltage in which case there will be an increase in load current. A dc valve-operator motor may have a locked-rotor (starting) current of 400–1000% of rated full-load current; therefore, voltage drop during the starting of the valve operator motor is typically the worst-case condition. In addition, the voltage drop in four (rather than two) feeder conductors (from starter to motor) must be included in the total voltage drop, due to the necessity of switching the series field when reversing the valve motor. For small horsepower motors, the voltage drop across the thermal-overload relay element may be significant and should be considered. The cables should be sized accordingly.

7.4 Instrumentation, controls, and alarms

7.4.1 General

Figure 3 is a one-line diagram showing the recommended instrumentation and alarms for the 125 V dc system shown in figures 1 and 2.

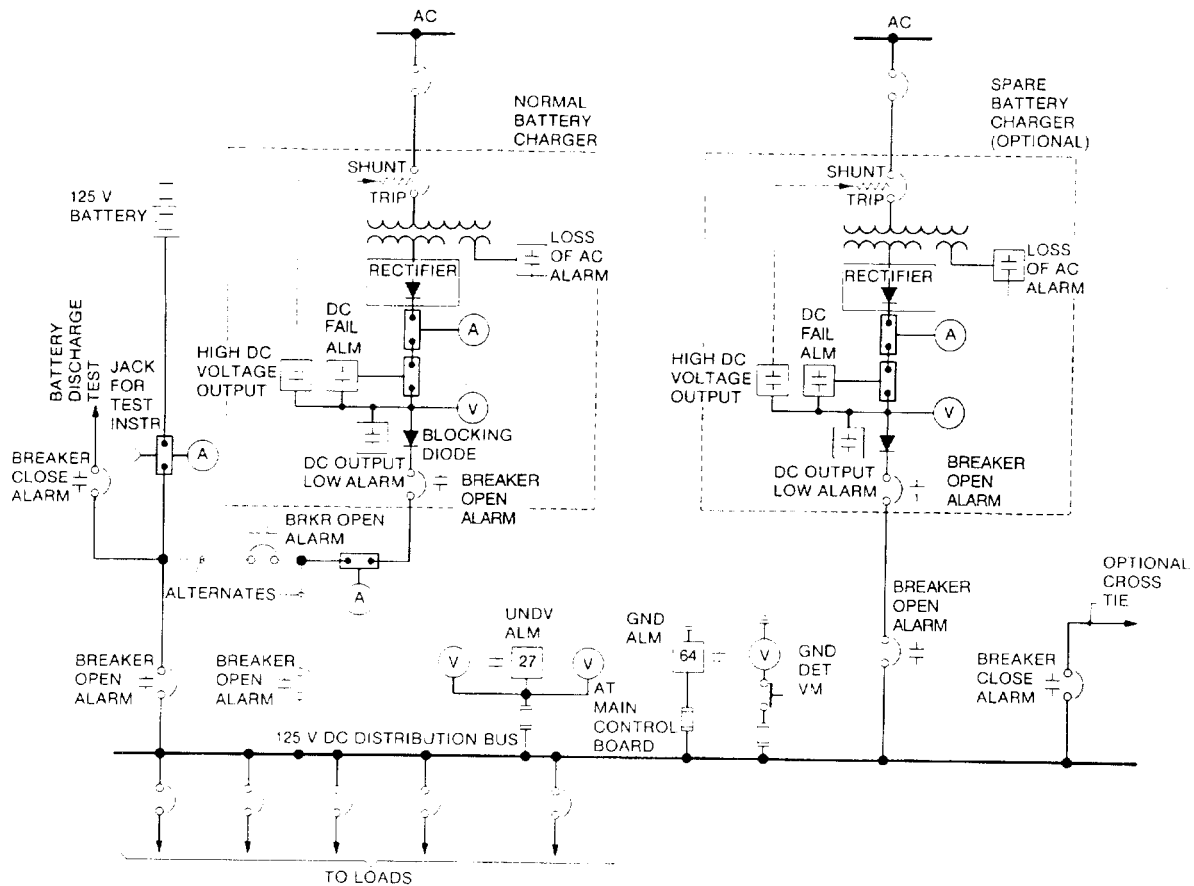


Figure 3—125 V dc system instrumentation and alarms (Class 1E and Non-Class 1E)

The recommended instruments, controls, alarms, and their locations are described in table 2.

Table 2—Instruments, controls, alarms, and their locations

Instrument/alarm/control Main control room (MCR)	Location	
	Main control room (MCR) Local	Local
a) Battery current (ammeter, charge/discharge)		X*
b) Battery charger output current (ammeter)		X
c) DC bus voltage (voltmeter)	X	X
d) Battery charger output voltage (voltmeter)		X
e) Ground-detector (voltmeter)		X
f) DC bus undervoltage alarm	X	
g) DC system ground alarm	X†	
h) Battery breaker/switch open alarm	X	
i) Battery-charger output-breaker open alarm	X†	
j) Battery charger dc output failure alarm	X†	
k) Cross-tie breaker closed alarm	X†	
l) Battery charger ac power failure alarm	X†	
m) Charger low dc voltage alarm	X†	
n) Charger high dc voltage shutdown relay (opens main ac supply breaker to the charger)		X
o) Battery test breaker closed alarm	X†	

*A Hall-effect instrument, or a jack (connected to the battery ammeter shunt) for use with a portable test instrument (microvoltmeter) may be provided to read battery charging current, and thus determine the state of charge as described in IEEE Std 450-1987, Appendix B.2.

†May be grouped with others to form one (or more) common alarms provided the actuating parameter can be readily identified.

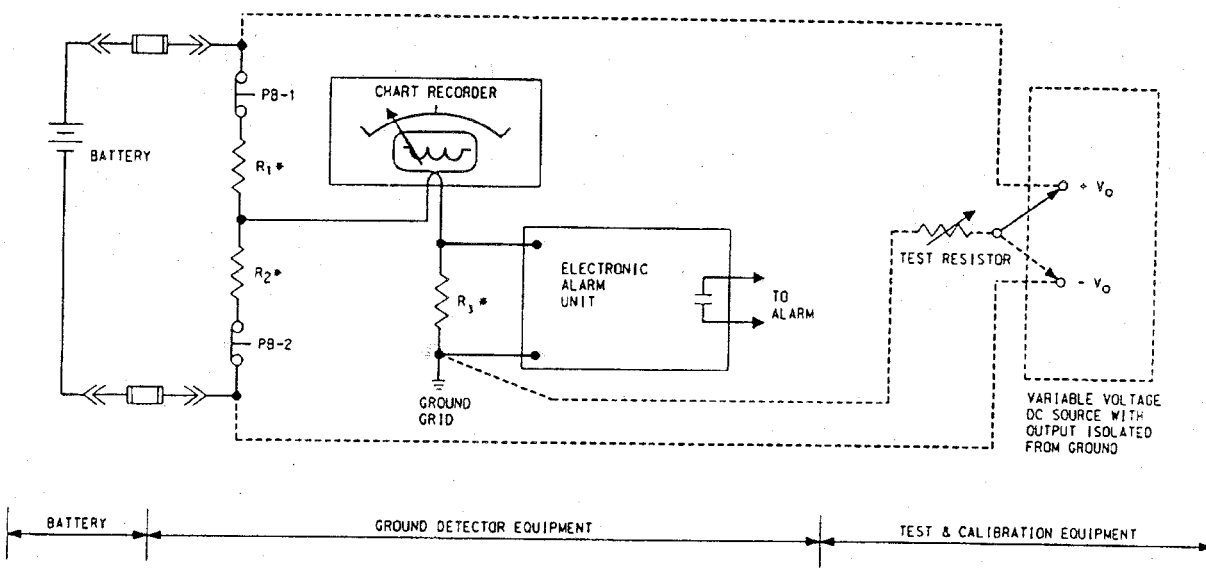
The controls for the battery and its related battery charger should be principally located in the battery area. All switching associated with the battery system should be performed at the local equipment. No remote controls should be provided.

7.4.2 DC system grounds and ground detection

Typically, a dc auxiliary power system is designed as an ungrounded system, instead of a grounded system, so that a low-resistance ground fault on one of its two polarities will not affect the operation of the system, thus increasing system reliability and continuity of service. A grounded system design may be used if there is a desire to isolate low-resistance ground faults by means of protective devices.

Ground detection should be provided for an ungrounded dc auxiliary power system. It is recommended that ground fault resistance magnitude also be monitored so as to lessen the likelihood of a low-resistance (polarity-to-polarity) fault (caused by multiple grounds) occurring and affecting the operation of the dc load(s). Figure 4 shows one ground detection design for an ungrounded system. A galvanometer or milliammeter provides indication and recording capability. The ground detector should provide a high polarity-to-ground resistance so that a single ground occurring on the system will not affect the operation of that system. Consideration must be given to the individual load (device) characteristics in order to determine the magnitude of ground resistance that could initiate operation of normally de-energized loads or inhibit drop-out of normally energized loads. A conservative approach to determine the ground

detector alarm setpoint for a dc system is to measure the normal ground leakage current of the system and set the ground detector to alarm at that value plus a margin to be determined by engineering judgment. This approach will result in a very sensitive ground detection system that will alarm on a high resistance ground. A suitable, less sensitive, ground detector alarm setpoint may be determined by the method provided in annex C. Annex C provides guidance for the determination of: a) the threshold value of ground fault resistance that may affect equipment operation if a second ground occurs in an ungrounded dc auxiliary power system and b) a suitable, less sensitive, ground detector alarm setpoint.



NOTES:


- 1—PB = Pushbutton
- 2——Fuse holder with fuse
- 3—“-----” Test equipment
- 4—* Resistance will vary with different applications

Figure 4—Ground detection for an ungrounded dc system

7.4.3 DC bus undervoltage alarm

The function of the dc bus undervoltage alarm is to alert the operator that the battery is being discharged. The dc bus undervoltage relay should be adjustable and set to alarm at a voltage slightly less than the open circuit voltage of the battery (e.g., approximately 119 V for a 58-cell, 125 V battery) rather than at the minimum allowable system voltage (typically 105 V for a 125 V system). This higher setting will alert the operator whenever the battery is supplying energy to the dc bus lead (e.g., more lead than the charger can handle), sufficiently early to take appropriate corrective action.

7.5 Special dc loads

The following equipment characteristics and system design features should be given consideration when sizing and selecting equipment.

7.5.1 Load transfers

If the dc system design is such that a lead group can be transferred to another dc source during equalizing, testing, etc., that source (battery, charger, and distribution equipment) should be sized to supply both (original plus transferred) lead groups. This would be typical of a system with a cross-tie feature.

For designs in which the battery is equalized while connected to the lead, and include an inverter with a normal ac power supply (transformer/rectifier unit), the ac supply should be designed so that it supplies the inverter while the charger is at equalize voltage. If the ac supply is so designed, and the battery equalize voltage becomes higher than the output voltage of the transformer/rectifier unit, the inverter lead will transfer from the transformer/rectifier unit to the dc system, imposing additional lead on the battery charger. In this instance, the total inverter lead must be included as a lead when the charger is sized.

7.5.2 Constant power dc loads

A dc load such as an inverter, which requires constant power, demands more current as the dc supply voltage decreases (e.g., a discharging battery). This increase in load current results in a more rapid discharge of the battery. Although this effect may be partially (or completely) offset by other loads (resistance type) that demand less current as the dc supply voltage decreases, it should be considered when sizing the battery.

7.5.3 Switching surges

Highly inductive loads may generate surges when de-energized that, if not suppressed, may impress voltage spikes on the dc system. For such loads, surge-suppression networks are recommended.

7.5.4 Electrical noise

Filtering of electrical noise should be considered in order to minimize feedback into the dc system. Sources of such noise include switching power supplies in dc to dc converters and dc to ac inverters.

7.6 Design features to assist in battery testing

The design features of each dc system should provide an effective and safe means to periodically perform a capacity discharge test on each battery. Figure I provides one configuration that allows the battery to be isolated from the dc system for testing via a dedicated *test* circuit breaker in the associated distribution panel. This test breaker should be maintained in the *open* position during all modes of system operation, except during the battery test, with an alarm in the main control room when this breaker is closed. Cables from *this* test circuit breaker should be routed to a convenient location and terminated so that connection to a discharge load bank is convenient. This method (or similar means) for a safe connection of temporary discharge test cables should be provided.

7.7 Cross-tie between buses

Cross-ties between dc distribution buses may be utilized to supply critical loads when a battery or charger is taken out of service for maintenance or testing. Cross-ties can also provide beneficial switching flexibility during such situations and can aid in accomplishing orderly plant shutdowns. A cross-tie to any independent battery system is acceptable provided the independent battery system meets the sizing requirements of 7.5.1, i.e., including the loads of both systems. One acceptable design provides a manually operated circuit breaker at each end of the cross-tie. The *cross-tie* circuit breakers should be normally *open* and should activate an alarm in the main control room if either is closed. Operating procedures should clearly define the operation of the cross-tie breakers. If cross-tie operation results in paralleling two batteries, the duration of parallel operation should be limited to the time required for switching so as to reduce the impact that circulating currents may have on battery capacity. If a longer duration of parallel operation is required, the increased available short-circuit current, resulting from the parallel sources, should also be considered.

For Class 1E nuclear applications, a cross-tie to any independent dc system, other than the dc system in the redundant safety division, is acceptable only during cold shutdown or refueling modes, and only if it can be shown that the cross-tie will not impair the ability of the Class 1E dc system to perform its safety function. In multi-unit nuclear stations, Class 1E dc systems shall not be shared between units unless it can be shown that such sharing will not impair their ability to perform their safety functions.

7.8 Qualification

Distribution equipment shall be qualified for the application.

For Class 1E nuclear applications, distribution equipment shall be qualified in accordance with IEEE Std 649-1991 (as applicable). Cable, field splices, and connections shall be qualified in accordance with IEEE 383-1974.

7.9 Available short-circuit current

For the purpose of determining the maximum available short-circuit current (e.g., the required interrupting capacity for feeder breakers/fuses and withstand capability of the distribution buses and disconnecting devices), the total short-circuit current is the sum of that delivered by the battery, charger, and motors (as applicable). When a more accurate value of maximum available short-circuit current is required, the analysis should account for interconnecting cable resistance.

7.9.1 Batteries

The current that a battery will deliver on short circuit depends on the total resistance of the short-circuit path. A conservative approach in determining the short-circuit current that the battery will deliver at 25°C is to assume that the maximum available short-circuit current is 10 times the 1 min ampere rating (to 1.75 V per cell at 25°C is the short-circuit current for the specific application should be calculated (see annex B.2) or actual test data should be obtained from the battery manufacturer. The battery nominal voltage should be used when calculating the maximum short-circuit current. Tests have shown that an increase in electrolyte temperature (above 25°C) or elevated battery terminal voltage (above nominal voltage) will have no appreciable effect on the magnitude of short-circuit current delivered by a battery (see [B2] and [B3]).

7.9.2 Chargers

The maximum current that a charger will deliver into a short circuit, coincident with the maximum battery short-circuit current, is determined by the charger current-limit circuit, see annex D.2.1. The current-limit setting is adjustable in most chargers and may vary from manufacturer to manufacturer. Thus, the maximum current that a charger will deliver on short circuit will not typically exceed 150% of the charger ampere rating.

7.9.3 Motors

DC motors, if operating, will contribute to the total fault current. The maximum current that a dc motor will deliver to a short circuit at its terminals is limited by the effective transient armature resistance (r_d)' of the motor. For dc motors of the type, speed, voltage, and size typically used in generating stations, r_d is in the range of 0.1 to 0.15 per unit (see [B1]). Thus, the maximum fault current for a short at the motor terminals will typically range from 7 to 10 times the motor's rated armature current. Therefore, it is conservative to estimate the maximum current that a motor will contribute to a fault as 10 times the motor's rated full load current. When a more accurate value is required, the short-circuit contribution should be calculated, using specific r_d data for the specific motor, or actual test data should be obtained from the motor manufacturer. For additional accuracy, the calculation should account for the resistance of the cables between the motor and the fault.

8. Spare equipment

The need for spare equipment/components depends on system design features as well as operating requirements and restrictions, e.g., restrictions imposed on a nuclear unit/station by the technical specifications. Other factors, such as operating experience, the availability of replacement equipment/parts, manufacturing lead time, the capabilities of performing in-house repairs, and component failure rates should be given consideration in determining the specific components that should be maintained as spare parts. For example, if the system design provides a readily available back-up battery charger, the need for maintaining spare battery-charger components could be reduced and possibly eliminated.

Other considerations, such as shelf life, may make it undesirable to obtain spares at an early stage in plant life. For example, spare battery cells can typically be maintained for only one year in the dry state (or three to six months when wet), and thereafter must be charged and maintained the same as a battery in service. With adequate design margin, the battery may be able to fulfill the service requirements with one or more cells electrically removed. The quantity of batteries provided and the capability to utilize back-up battery capacity through the use of cross-tie circuits may also be factors in determining the need and urgency for obtaining spare cells.

In any case, an evaluation should be performed to determine the need for spare equipment based on the combination of system design features, operating requirements, etc.

9. Bibliography

[B1] AIEE Committee Report, "Maximum Short-Circuit Current of DC Motors and Generators," *AIEE Transactions*, vol. 69, pt. 1, pp. 146-149, 1950.

[B2] *Stationary Battery Short-Circuit Test Report*, AEI Test No. 0591-1, May 1991, Alber Engineering, Inc.

[B3] *Stationary, Battery Short-Circuit Test Report*, ATI Test No. 0792-1, July 1992, Alber Technologies, Inc

(These annexes are not a part of IEEE Std 946-1992 , IEEE Recommended Practice for the Design of DC Auxiliary Power Systems for Generating Stations, but are included for information only.)

Annex A Battery charger rating sample calculations (Informative)

A.1 Introduction

This annex outlines the method, including sample calculations, for determining the required rating of battery chargers, as recommended in 6.2 and 6.3.

A.2 Formulas

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

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

$$I_2 = L_c + L_n \quad (\text{A-2})$$

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 ⁶
- 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 Ah 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 down time, 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.

The battery charger specification should include (or account for) any abnormal service conditions. For example, ambient temperature, altitude, etc. may affect the charger capacity as noted in NEMA PE 5-1983.

A.3 Sample calculations

Example 1. Determine the rating of the charger required for a battery where the continuous dc load, including future load growth, is 100 A; the largest combination of noncontinuous loads is 80 A; ampere-hours discharged from the battery is 400 Ah (rating of the battery at 8 h rate); with 12 h to recharge the battery (no abnormal service conditions).

$$I_1 = 100 + \frac{(1.1)400}{12}$$

$$I_1 = 100 + 36.7 = 136.7\text{A}$$

⁶If 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).

To account for the largest combination of noncontinuous loads, the following applies:

$$I_2 = 100 + 80 = 180\text{A}$$

$$I_3 = 180\text{ A recommended charger rated output}^7$$

Example 2. Determine the rating of the charger required for a battery where the continuous dc load, including future load growth, is 300 A; the largest combination of noncontinuous loads is 100 A; the ampere-hours discharged from the battery is 1200 Ah (rating of the battery at 8 h rate); with 10 h to recharge the battery (no abnormal service conditions).

$$I_1 = 300 + \frac{(1.1)1200}{10}$$

$$I_1 = 300 + 132 = 432\text{A}$$

To account for the largest combination of noncontinuous loads, the following applies:

$$I_2 = 300 + 100 = 400\text{A}$$

$$I_3 = 432\text{ A recommended charger rated output}$$

⁷If it can be demonstrated that the reduction in battery capacity that results from the application of 80 A (non-continuous) load does not compromise the ability of the battery to satisfy its intended function, a charger with a 136.7 A (or above) rated output would meet the minimum requirements.

Annex B Batteries, available short-circuit current—sample calculations (Informative)

(informative)

B.1 Introduction

The current that a battery will deliver on short circuit depends on the total resistance of the short-circuit path. A conservative approach in determining the short-circuit current that the battery will deliver at 25°C is to assume that the maximum available short-circuit current is 10 times the 1 minute ampere rating (to 1.75 V per cell at 25°C and specific gravity of 1.210-1.215) of the battery. As recommended in 7.9.1, a more accurate value for the short-circuit current for the specific application may be calculated or actual test data may be obtained from the battery manufacturer. Tests have shown that an increase in electrolyte temperature (above 25°C) or elevated battery terminal voltage (above nominal voltage) will have no appreciable effect on the magnitude of short-circuit current delivered by a battery (see [B2] and [B3]).

Although an increase in temperature will result in an increase in the chemical activity of the battery, it will also increase the resistance of the metallic components of the battery, thereby offsetting any appreciable change in the magnitude of short-circuit current the battery can deliver. However, the elevated temperature will result in the battery's capability to deliver the short-circuit current for a longer duration.

Elevated battery terminal voltage (above nominal voltage) during float and equalize charge does not increase the chemical energy available from the battery during short circuit. The effective voltage driving the short-circuit current is dependent on the acid concentration in direct contact with the active material in the plates of the cell. Therefore, the battery nominal voltage (2.00 V per cell) should be used when calculating the maximum short-circuit current.

B.2 Discussion

The total resistance is made up of two major parts as follows:

- a) The apparent internal resistance of the battery
- b) The external circuit resistance

The total internal resistance of the battery is equal to the sum of the internal resistance of the cells plus the resistances of the intercell connections. The value of internal cell resistance is a variable quantity that is significantly influenced by many factors; e.g., the temperature, the age, and the state of charge of the cell. The total external circuit resistance is the sum of the resistances of the various components; e.g., the connecting cables and the fault resistance.

The following sample calculations illustrate one method of calculating the internal resistance of any cell (utilizing manufacturers' published discharge characteristic curves for that cell) and then calculating the current that cell will deliver:

- a) Through a bolted short-circuit at the cell terminals (i.e., zero external resistance)
- b) Through a short circuit at the main distribution bus with a specific (0.01 Ω) external resistance and with no charger or motor contribution

B.3 Sample calculations

- a) Internal resistance of a cell can be calculated from the slope of the initial volts line. See figure B3, which shows a discharge characteristic curve for a typical 7 through 15 plate (total) cell.

$$R_t = \frac{R_p}{N_p} \quad (\text{B-1})$$

where

R_t is the total internal resistance of cell (ohms)
 R_p is the resistance per positive plate (ohms)
 N_p is the quantity of positive plates

$$R_p = \frac{V_1 - V_2}{I_2 - I_1} \text{ ohms per positive plate for any two voltage and current points along the line}$$

If we pick 1.90 V as V_1 , and 1.50 V as V_2 , I_1 is found to be 60 A/positive plate and I_2 is 370 A/positive plate. Calculation:

$$R_p = \frac{1.90 - 1.50}{370 - 60} = \frac{0.40}{310} = (0.00129\Omega)/\text{positive plate}$$

Assume that the cell being investigated has 15 (total) plates. Since the cell has 7 positive plates (connected in parallel), the total internal resistance is:

$$R_t = \frac{0.00129}{7}$$

$$= 0.00018 \Omega$$

- b) The short-circuit current available at the cell terminals is found from Ohm's Law as follows:

$$I_c = \frac{E_c}{R_t} \quad (\text{B-2})$$

where

I_c is the available short circuit current (in amperes)
 E_c is the nominal cell voltage (2.00 V)
 R_t is the total internal resistance of cell (ohms)

$$I_c = \frac{2.00}{0.00018} = 11111\text{A}$$

- c) The short-circuit current available at the main distribution bus (i.e., at the load terminals of the main/battery acb) from a battery made up of 58 cells (with an average internal resistance of 0.00018 Ω as calculated in B.3-a above), with 0.010 Ω total external resistance, and with no charger or motor contribution, is found from Ohm's Law as follows:

$$I_B = \frac{E_B}{R_T} = \frac{E_B}{R_B + R_X} \quad (\text{B-2})$$

where

- I_B is the available short-circuit current (amperes) at load terminals of main/battery acb
 E_B is the nominal battery voltage = (58 cells)(2.00 volts/cell) = 116 V
 R_B is the total internal resistance of battery
 = ($R_t \Omega/\text{cell}$) (number of cells)
 = (0.00018 Ω/cell)(58 cells) = 0.01044 Ω
 R_X is the total external circuit resistance [including resistance of main lead cables; intercell (if not included in R_B), inter-tier, and inter-rack connections; main acb or fuse; and the fault]
 = 0.0100 Ω
 R_T is the total circuit resistance = $R_B + R_X$
 = 0.01044 + 0.0100 = 0.02044 Ω

$$I_B = \frac{116\text{V}}{0.02044\Omega} = 5675\text{A}$$

The short-circuit currents calculated above may, when combined with the charger and motor contribution, be used (as described in 7.9), to determine required interrupting capacity of the circuit breakers or fuses.

NOTE — For comparison, 10 times the 1 minute ampere rating (to 1.75 V per cell at 77 °F) of the battery is 10 (1139) = 11 390A.

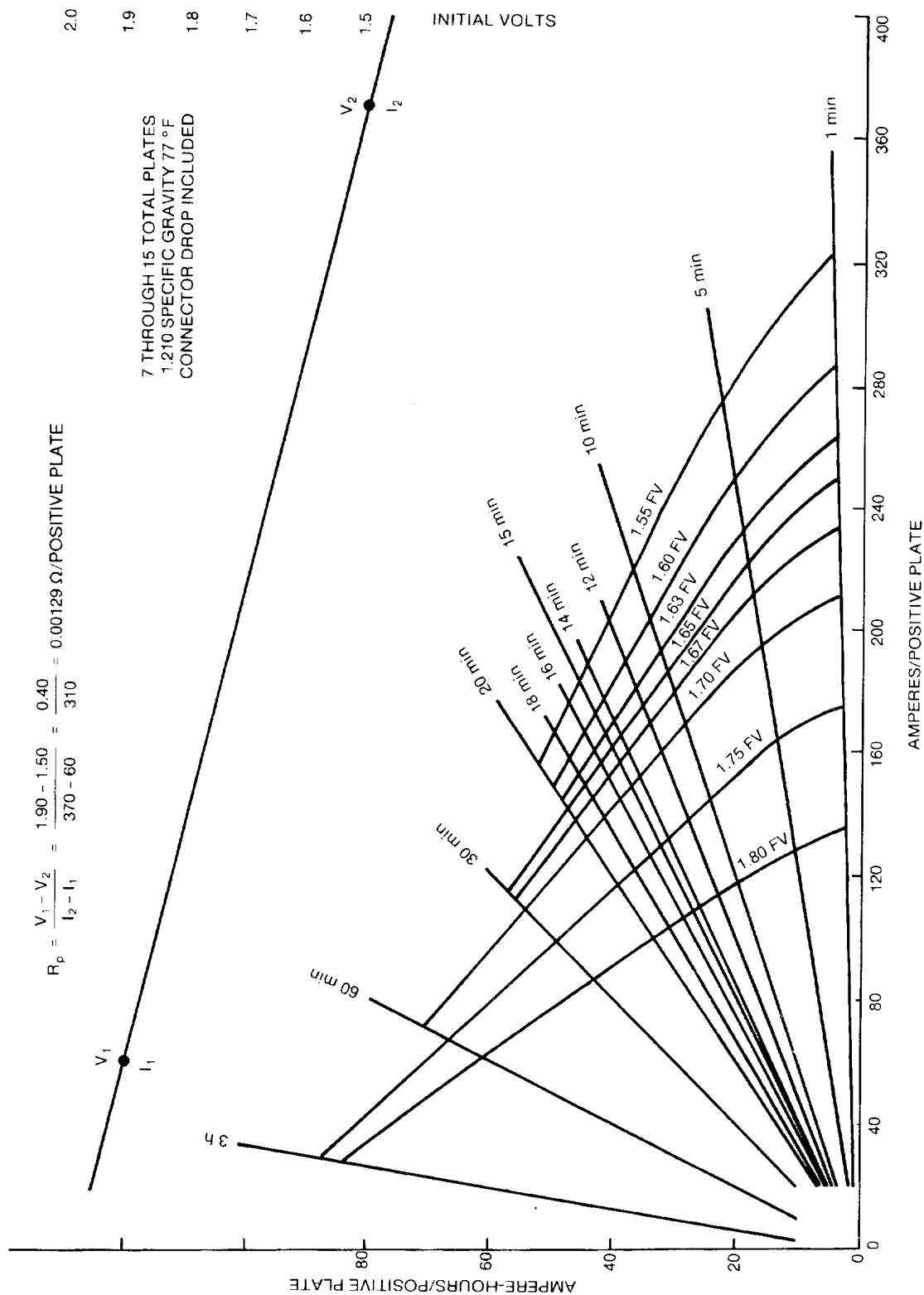


Figure B-1—Typical characteristic curve amperes/positive plate versus ampere-hours/positive plate

Annex C Effect of grounds on the operation of dc auxiliary power systems (Informative)

(informative)

C.1 Introduction

This annex provides guidance in determining: a) the threshold value of ground-fault resistance that may affect equipment operation if a second ground occurs in an ungrounded dc auxiliary power system and b) a suitable, less sensitive, ground-detector alarm setpoint.

C.2 Discussion

A single low-resistance ground on one of the two polarities of an ungrounded dc auxiliary power system will not affect the operation of the system. However, a ground of sufficiently low resistance on one polarity followed by a second ground can produce ground currents of sufficient magnitude to initiate operation of de-energized dc loads (devices) or inhibit dropout of energized dc loads (devices). The grounding configuration shown in figure C-1(A) illustrates how multiple grounds could initiate operation of a de-energized load. This condition could result in false operation of a normally de-energized load (device). The grounding configuration shown in figure C-1(B) could exist in a normally energized logic circuit, such as an Engineered Safety Feature or a Reactor Protection System, and could inhibit the drop-out of energized loads (devices). Figure C-2 shows three ground combinations which could short-out an actuating coil and/or the dc source. For low-resistance grounds, a fuse or circuit breaker would trip a circuit designed with overload and fault protection, clearing the faulted circuit and dropping out all energized loads [figure C-2(B)] or preventing operation of de-energized equipment [figure C-2(A) and C2(C)] on that circuit. A fault configured as in figure C-2(A) or figure C-2(C) could inhibit the trip of a breaker for switchgear, generator, or a large motor. The ground configuration shown in figures C-3(A) or C3(B) could cause the relay contacts associated with one piece of equipment in one circuit to affect the operation of a similarly grounded device in another circuit.

In order to determine the threshold resistance of a ground fault that, if followed by a solid ground, could initiate operation of a normally de-energized load or could inhibit dropout of a normally energized load; the most sensitive dc loads (devices) must be identified and their minimum pickup current and maximum drop-out current must be evaluated.

C.3 Sample evaluations

Example 1 (Low-resistance device): The control devices for a Type XYZ switchgear breaker trip device are rated at 125 V dc. The closing coil and trip coil are as given below.

Mechanism	Min. Pickup voltage	Resistance of coil	Current at rated voltage (125 V dc)	Minimum pickup current
Close coil	90 V	20.83 Ω	6A	*4.32A
Trip coil	70 V	20.83 Ω	6A	*3.36A

*Minimum pickup current = minimum pickup voltage ÷ resistance of coil

Assuming a dc system operating (float) voltage of 130 V, the current through the closing coil or trip coil with a 20 kΩ ground in parallel with the control contacts [figure C-1(A)] would be $130 \text{ V} \div (20 \text{ k}\Omega + 20.83 \text{ }\Omega) = 6.5 \text{ mA}$. Since the minimum pickup current for the coils is 4.32 A (closing) and 3.36 A (trip), these values are well above the value of

current (6.5 mA) that would be experienced with a 20 k Ω total ground-fault resistance. Therefore, a 20 k Ω ground, followed by a solid ground, would not cause spurious operation of the switchgear breaker. The threshold value of ground-fault resistance is $(130 \text{ V} \div 3.36 \text{ A}) - 20.83 \text{ } \Omega = 17.86 \text{ } \Omega$, neglecting the effect of the ground detector resistance.

Assuming that this circuit breaker trip coil has been identified as the most sensitive (lowest pickup or drop-out current) device connected to the dc auxiliary power system, the ground detector alarm can be set at any value above 17.86 Ω ; the appropriate margin (above the threshold value) being based on engineering judgment. A setpoint of 20 Ω will alarm at a ground fault current (3.18 A) that is 5.4% below the minimum pickup current (3.36 A). This example is for illustrative purposes only since most ground detection systems will detect grounds several orders of magnitude greater than 20 Ω .

Example 2 (High-resistance device): The operating characteristics of a normally energized Type XYZ 125 V dc relay are as given below.

Relay type	Min. dropout voltage	Coil resistance	Current at rated voltage (125 V dc)	Max. dropout current
XYZ	12.5 V	2000 Ω	62.5 mA	6.25 mA

Assuming a dc system operating (float) voltage of 130 V, the current through the relay coil with a 20 k Ω ground in parallel with the control contacts [figure C-1(B)], after they open, would be $130 \text{ V} \div (20 \text{ k} + 2 \text{ k})\Omega = 5.91 \text{ mA}$. Since the maximum dropout current for the relay is 6.25 mA, a 20 k Ω ground followed by a solid ground would be of high enough total resistance to produce a low enough ground current that would not prevent the relay from dropping out when the control contacts open. The threshold value of ground-fault resistance is $(130 \text{ V} \div 0.00625 \text{ A}) - 2000 \text{ } \Omega = 18\,800 \text{ } \Omega$, neglecting the effect of the ground detector resistance. Assuming that this relay has been identified as the most sensitive (lowest pickup or dropout current) device connected to the dc auxiliary power system, the ground detector alarm can be set at any value above 18 800 Ω ; the appropriate margin (above the threshold value) being based on engineering judgment. A set-point of 20 k Ω will alarm at a ground fault current (5.91 mA) that is 5.4% below the maximum dropout current (6.25 mA).



Figure C-1—Ground faults may energize a normally de-energized device or prevent de-energizing a normally energized device

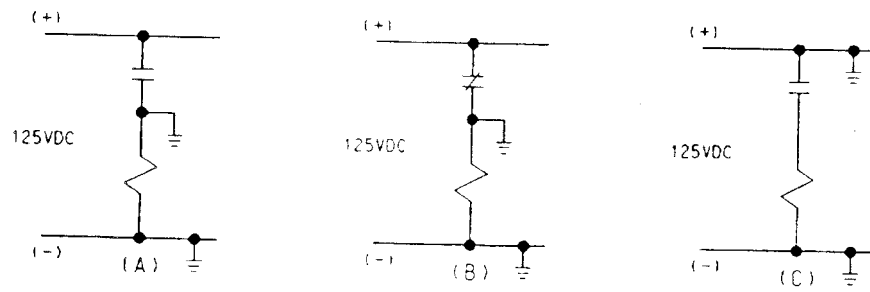


Figure C-2—Ground faults may short-out operating coil or power supply

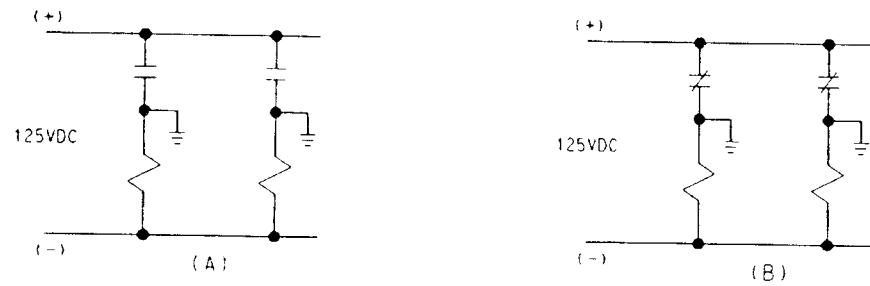


Figure C-3—Ground faults may cause contacts in one circuit to actuate devices in a different circuit

Annex D Battery charger, short-circuit current contribution (Informative)

D.1 Abstract

This annex provides a rationale for the selection of the maximum value of battery charger short-circuit current that will occur coincident with the maximum battery short-circuit current. The reason for determining the maximum combined short-circuit current is to specify equipment that is suitable for the expected fault current. It is necessary to include the contributions from connected motors, battery chargers, and batteries when calculating the total short circuit current for a fault in a dc system. For a typical station battery and a current-limited charger, it can be shown that the peak short-circuit currents occur at different times such that the charger current-limited value added to the battery peak value provides a conservative total fault-current value. The fault current contribution from a typical battery charger is current-limited to a value not greater than 150% of the charger current rating.

D.2 Discussion

D.2.1 Charger contribution

Tests on some current-limited SCR type battery chargers have shown that the initial short-circuit current can exceed the current-limited value. A large transient current spike may occur due to the stored energy in filter circuits (capacitors). This instantaneous peak short-circuit current may approach a value 200 times the charger rated current. However, the time duration of the initial transient current is so short (in the order of 5 μ s) that it need not be considered in determining the required interrupting capacity of external protective devices or the required withstand rating of buses. After the stored energy in the filter circuits is dissipated, the magnitude of the transient short-circuit current is dependent on the X/R ratio of the ac supply as well as the inductance and resistance of the transformer-rectifier-fault circuit, typically peaking at about 12 times the charger current rating.

In current-limited chargers, the current-limiting circuits will typically act to reduce the current after the first zero crossing (i.e., one-half cycle, 8 ms, or less) if internal protective devices (e.g., rectifier fuses) have not already acted to clear the fault. It is therefore conservative to assume that the maximum sustained fault current after 8 ms is the current-limiting value, a current not greater than 150% of the charger current rating.

D.2.2 Battery contribution

The fault current from a large lead storage battery resulting from a bolted short at the battery terminals will typically exhibit a rate-of-rise that delivers the peak current within 17 ms (see [B2] and [B3]). The fault current for a short at the dc distribution switchgear or panelboard will peak later (typically within 34 to 50 ms) due to the inductance of the dc system in series with the fault. The magnitude of the fault current for a short at the distribution bus will also be lower than the value at the battery due to the resistance of the cables between the battery terminals and the bus.

D.2.3 Combined effect of currents from battery and charger

For a typical dc system, the short-circuit current from the charger has already peaked and decayed before the short-circuit current from the battery reaches its peak. Due to this battery time constant, the maximum coincident short-circuit current can be conservatively calculated as the sum of the peak short-circuit current from the battery and the current-limit value from the charger (figure D-1).

Each installation should be evaluated by the design engineer to determine the magnitude of the short-circuit currents from the battery, charger, motors, etc. Any non-typical installation should be evaluated by the design engineer to verify that the peak values of the battery and charger short-circuit currents are not coincident.

D.3 Sample evaluation

The following example illustrates one method for determining the relative fault-current contributions of a battery and a current-limited charger to a fault at the distribution panel bus:

Charger and feeder cables:

Charger current rating: $I = 300 \text{ A}$
 Charger current limit: $I_c = (1.5)(300) = 450 \text{ A}$
 Cable and breaker resistance: $R_c = 0.0228 \ \Omega$

Battery and feeder cables:

Battery: 60 cells, rated 1950 Ah at 8 h rate.

Battery resistance under fault:

$$\begin{aligned} R_b &= (0.0001131) (60 \text{ cells}) \\ &= 0.006786 \ \Omega \end{aligned}$$

Time to peak short-circuit current @ five-time constants = 11 ms

Battery cables: 2-1/C 350 MCM cables/leg, each 40.5 ft

Total calculated loop resistance: $R_2 = 0.0017 \ \Omega$

Total calculated inductance: $L = 36.2 \text{ micro-Henries}$

The battery time constant and apparent inductance under short-circuit conditions are calculated as follows:

Battery time constant: $T = (11 \text{ ms})/5 = 2.2 \text{ ms}$

Battery inductance: $L = (T)(R_b) = (2.2\text{E-}3) (0.006786) = 14.9 \text{ micro-Henries}$

The time constant for the combination of the battery and cables is calculated as follows:

$$T_1 = (L_b + L) / (R_b + R_2) = (14.9\text{E-}6 + 36.2\text{E-}6) / (0.006786 + 0.0017) = 6 \text{ ms}$$

For a fault at the distribution panel bus:

Battery fault current: $I_b = (2.00 \text{ V per cell}) (60) / (R_b + R_2)$
 $= 120 \text{ V} / (0.006786 + 0.0017)$
 $= 14141 \text{ A}$

Battery fault current peaks at $(5) (T_1) = (5) (6 \text{ ms}) = 30 \text{ ms}$

The charger short-circuit contribution: $I_c = 450 \text{ A}$

Conclusion:

As illustrated in figure D-1, the maximum total combined short-circuit current is $14\,141 + 450 = 14\,591$ A and is a maximum when the battery current peaks at 30 ms after the fault.

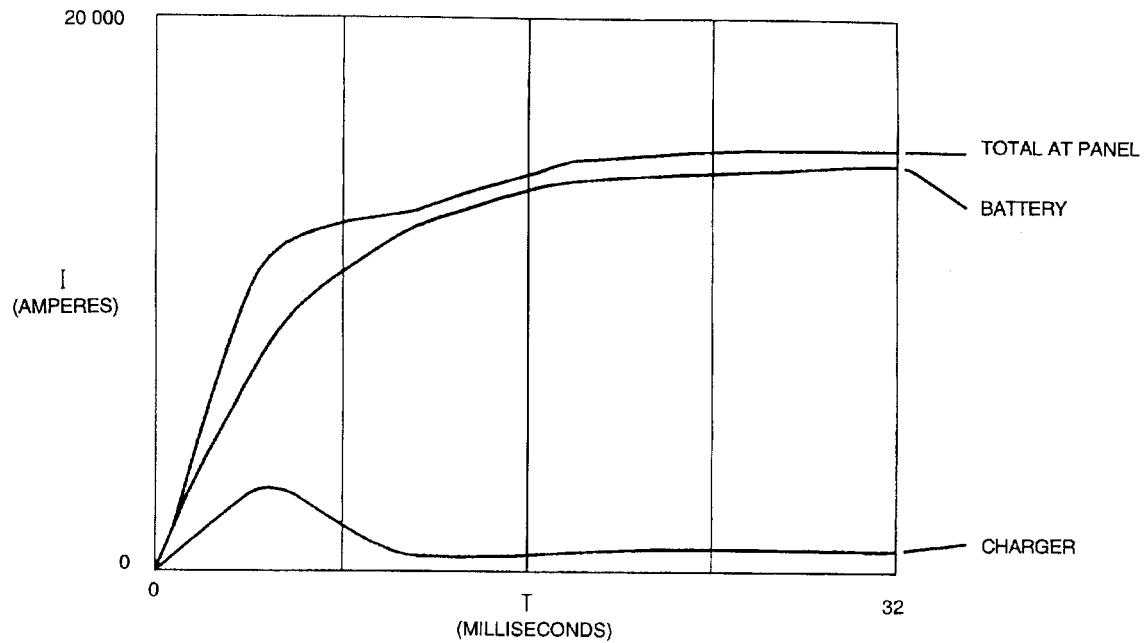


Figure D-1—Typical fault-current contributions at the dc bus with current-limited charger