



IEEE Recommended Practice for the Design of DC Power Systems for Stationary Applications

STANDARDS

IEEE Power and Energy Society

Developed by the
Energy Storage and Stationary Battery Committee

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IEEE Recommended Practice for the Design of DC Power Systems for Stationary Applications

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of the
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Abstract: Recommended practices for the design of dc power systems for stationary applications are provided in this document. The components of the dc power system addressed by this document include lead-acid and nickel-cadmium storage batteries, static battery chargers, and distribution equipment. Guidance in selecting the quantity and types of equipment, the equipment ratings, interconnections, instrumentation and protection is also provided. This recommendation is applicable for power generation, substation, and telecommunication applications.

Keywords: auxiliary, backup, battery, battery charger, charger sizing, control, cross-tie, dc, direct current, distribution, duty cycle, generating station, ground detection, IEEE 946™, instrumentation, nuclear, panels, protection coordination, rectifiers, reserve, selective protection, short-circuit, substation, telecommunication

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Introduction

This introduction is not part of IEEE Std 946-2020, IEEE Recommended Practice for the Design of DC Power Systems for Stationary Applications.

DC power systems continue to play a vital role in generating station, substation, and telecom controls and providing backup for emergencies. This recommended practice fulfils a need within the industry to provide common or standard practices for the design of dc power systems. The design features are applicable to all installations and systems capacities.

The original issue of IEEE Std 946 was published in 1985 with the title IEEE Recommended Practice for the Design of Safety-Related DC Power Systems for Nuclear Power Generating Stations. The 1992 revision changed the title to apply to all generating stations, while including specific guidance and a detailed bibliography of nuclear design reference standards. This revision makes a general update to reflect the most recent industry practices as well as substantial additions to annexes. In addition to power generation applications, this recommended practice covers dc power system design in substations and telecommunication applications. Some discussions and illustrative figures have been retained as they offer a constructive comparison to designs without having to resort to additional standards.

This recommended practice was prepared by a Working Group that is part of the Energy Storage and Stationary Battery Committee and was sponsored by the Energy Development and Power Generation Committee of the IEEE Power and Energy Society.

Note that IEEE Std 1818™ and IEEE Std 946 are complementary documents, developed by independent working groups.¹

¹Information on references can be found in [Clause 2](#).

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

1. Overview

1.1 Scope

This recommended practice provides guidance for the design of ~~the stationary~~ dc ~~auxiliary~~ power systems ~~for nuclear and non-nuclear power generating stations.~~ The components of the stationary dc ~~auxiliary~~ power system addressed by this recommended practice include ~~lead-acid~~ the following:

- Storage batteries,
- Static battery chargers, ~~and~~ /rectifiers (including sizing)
- Distribution equipment,
- Protection equipment
- Control equipment
- Interconnections
- Instrumentation

Guidance for selecting the quantity ~~and~~ types, and ratings of equipment, ~~the equipment ratings, interconnections, instrumentation, control, and protection~~ is also provided.

The considerations of each of these different components and the issue of load voltage and other load specifics are discussed in terms of their effect on the design of the whole system. Guidance on short-circuit calculation and contribution of different dc power system components is also offered to improve reliability, performance, and safety of the installation.

1.2 Purpose

The purpose of this document is to provide the user with information and recommendations concerning sizing and designing dc power systems in stationary applications.

While the recommended practices in this document apply to dc power systems in substations, additional guidance for substations is provided in IEEE Std 1818.²

1.3 Exclusions

Electrically self-contained ac-ac equipment and the following components of the dc power system, with the exception of how ~~The ac power supply to the battery chargers; the loads served by the dc systems, except as~~ they influence the dc power system design; ~~and dedicated engine starting (cranking) battery systems,~~ are ~~beyond~~ specifically excluded from the scope of this recommended practice:

- The ac power supply to the battery chargers/rectifiers
- Photovoltaic, wind, and other alternative dc power source system designs
- Loads served by dedicated engine starting battery systems
- Applications requiring dc voltage supply above 1000 V nominal
- Motor generator sets
- Battery technologies other than lead-acid (L-A) and nickel-cadmium (Ni-Cd)

Separate systems are usually recommended for the following special service applications, and are not within the scope of this document:

- Engine (cranking) starting
- Emergency lighting

²[Information on references can be found in Clause 2.](#)

— [Fire detection and annunciation](#)

— [Fire protection actuation](#)

2. Normative references

The following referenced documents are indispensable for the application of this document: [\(i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained\)](#). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

[IEEE Std 308™, IEEE Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations.](#)^{3,4}

[IEEE Std 344™, IEEE Standard for Seismic Qualification of Equipment for Nuclear Power Generating Stations.](#)

[IEEE Std 450™, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications.](#)

IEEE Std 484™, IEEE Recommended Practice for Installation Design and Installation of Vented Lead-Acid Storage Batteries for Stationary Applications.^{1,2}

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IEEE Std 485™, IEEE Recommended Practice for Sizing ~~Large-Lead-Storage-Acid~~ Batteries for ~~Generating Stations and Substations~~ [Stationary Applications](#).

IEEE Std 649™, IEEE Standard for Qualifying Class 1E Motor Control Centers for Nuclear Power Generating [Stations](#).

[IEEE Std 650™, IEEE Qualification of Class 1E Static Battery Chargers, Inverters, and Uninterruptible Power Supply Systems for Nuclear Power Generating Stations.](#)

IEEE Std 666™, IEEE Design Guide for Electric Power Service Systems for Generating Stations.

[IEEE Std 693-2005™, IEEE Recommended Practice for Seismic Design of Substations.](#)

[IEEE Std 979™, IEEE Guide for Substation Fire Protection.](#)

[IEEE Std 1106™, IEEE Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications.](#)

IEEE Std 1115™, IEEE Recommended Practice for Sizing Nickel-Cadmium Batteries for Stationary Applications.

~~IEEE Std 1184™, IEEE Guide for the Selection and Sizing of Batteries for Uninterruptible Power Systems.~~

IEEE Std 1187™, IEEE Recommended Practice for Installation Design and Installation of Valve-Regulated Lead-Acid ~~Storage~~ Batteries for Stationary Applications.

[IEEE Std 1188™, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve Regulated Lead-Acid \(VRLA\) Batteries for Stationary Applications.](#)

IEEE Std 1189™, IEEE Guide for Selection of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications.

IEEE Std 1375™, IEEE Guide for the Protection of Stationary Battery Systems.

[IEEE Std 1491™, IEEE Guide for Selection and Use of Battery Monitoring Equipment in Stationary Applications.](#)

[IEEE Std 1578™, IEEE Recommended Practice for Stationary Battery Electrolyte Spill Containment and Management.](#)

[IEEE Std 1635™, IEEE/ASHRAE Guide for the Ventilation and Thermal Management of Batteries for Stationary Applications.](#)

[IEEE Std 1818™, IEEE Guide for the Design of Low Voltage Auxiliary Systems for Electric Power Substations.](#)

[NEMA PE 5, Utility Type Battery Chargers.](#)⁵

[NFPA 70®, National Electrical Code® \(NEC®\).](#)⁶

[NFPA 70E®, Standard for Electrical Safety in the Workplace.](#)

3. Definitions

For the purposes of this ~~recommended practice~~ [document](#), the following terms and definitions [shall](#) apply. ~~The Authoritative Dictionary of IEEE Standards [B2]³, should be referenced~~ For terms not defined in this clause, [IEEE Std 1881 \[B20\], IEEE Standard Glossary of Stationary Battery Terminology \[B20\], and the IEEE Standards Dictionary Online shall be consulted.](#)⁷

³~~The numbers in brackets correspond to those of the bibliography in Annex A.~~

⁵NEMA publications are available from the National Electrical Manufacturers Association (<https://www.nema.org/>).

⁶NFPA publications are published by the National Fire Protection Association (<https://www.nfpa.org/>).

⁷IEEE Standards Dictionary Online is available at: <http://dictionary.ieee.org>. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

~~3.1 battery capacity: The amp-hours available in an installed battery as measured by test. This is measured, normally after an equalize charge, by a performance or modified performance test. The battery capacity may be larger or smaller than the rated capacity and is expressed as a per cent of rated capacity for a given duration. For lead-acid batteries, this is due to degradation of the grid, connections, welds, pellet interface to the grid, crystal surface contact interface of the lead oxides, wet surface interface between the lead oxide and the electrolyte, electrolyte specific gravity, and transport resistance of the hydrogen and oxygen between the positive and negative plates. Since the factors which affect battery performance are varied, the measured battery capacity at a long duration may differ from the measured capacity at a short duration.~~

~~3.2 battery rated capacity: The rated amp-hours available in a battery at 100% charge. This is established via "S" or fan curves by a manufacturer's test of a limited sample of cells using the interconnecting hardware supplied with the standard installation. The rated amp-hours may differ as a function of the discharge duration, long duration discharges typically utilizes the available material more effectively.~~

~~NOTE—See IEEE Std 485 for an example of the manufacturer's sizing curves.⁴~~

battery capacity: The quantity of electrical energy, measured in ampere-hours (Ah) or watt-hours (Wh), produced by a battery during discharge.

battery charger: A device to restore and maintain the charge of a secondary battery. For easier reading, "charger" is used throughout this recommended practice to refer to battery charger or a rectifier connected to a battery.

battery state of charge: The stored or remaining capacity in a battery expressed as a percentage of its fully charged capacity.

duty cycle: The sequence of loads a battery is expected to supply for specified time periods.

~~⁴Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement this standard.~~

nominal battery voltage: The value assigned to a battery of a given voltage class for the purpose of convenient designation. The operating voltage of the system may vary above or below this value.

N+X: Parallel redundancy to ensure that the system is always available. N is the minimum required number of modules/systems. X is the variable referring to extra units needed for reliable operation.

~~battery state of charge~~: A factor between 0 and 100. It establishes the available amp-hours by multiplying the state of charge times the battery capacity times the battery rated capacity for a specified discharge duration. The battery state of charge reflects the conversion or restoration of lead sulfate to lead oxide after a discharge.

4. General

4.1 Description and operation

~~All power generating stations require dc auxiliary power systems to operate those dc components that 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.~~

4. Organization of this recommended practice

Stationary dc power systems appear in many applications and industries. All have certain commonalities, while some have some unique requirements. It should be noted that these commonalities or unique requirements are derived from variance in environmental conditions, reliability expectations, and importance of application. That translates to specific feature requirements or technology differences (thyristor versus high-frequency switched mode chargers, or lead-acid versus Ni-Cd batteries) that can provide an engineering approach to the selection/design of dc power systems. For example, a substation charger can be used in a telecom application and vice versa as long as it can meet the requirements.

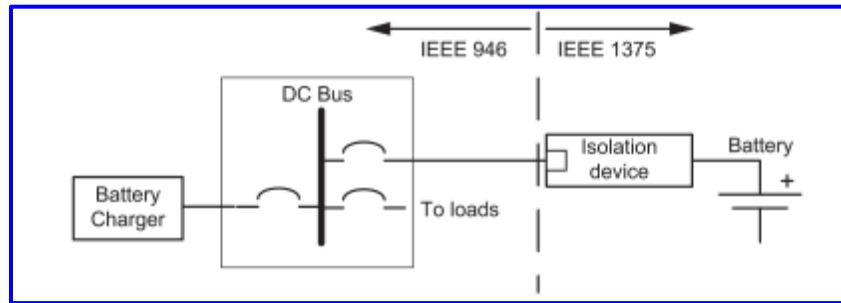
Describing every application is beyond the scope of this document, therefore the three dominant applications are generation, substations, and telecommunications. Large telecommunication carriers may have their own internal dc power system standards that examine dc power systems and their requirements in detail. This is also beyond the scope of this document, but is worthy of a mention. In this recommended practice, each section includes subparagraphs reserved for these three applications when there are unique requirements. For other industrial applications, one can use the recommendations—in part or as a whole—of one of the three dominant applications. For example, substation application recommendations may be used, where applicable, for the design of an industrial process control dc power system. It is not the intent of this recommended practice to exclude other industrial applications. Lead-acid and nickel-cadmium batteries are the types of batteries primarily used in these applications. Some other battery technologies may be used but are not fully addressed in this document.

5. Description and operation

DC power systems provide reliable power to critical loads. Examples of critical loads include auxiliary motors, circuit breakers and switchgear, relays, solenoids, SCADA, telecommunications equipment, inverters, emergency lighting equipment, fire suppression equipment, etc.

5.1 General

A dc system normally consists of one or more battery strings, one or more battery chargers/rectifiers and one or more distribution panels. If a battery isolation/protective device is used, refer to the battery protection guidelines of IEEE Std 1375. Refer to simplified typical connection in Figure 1 for the line of demarcation that limits the application of IEEE 946 versus IEEE 1375.



(New)

Figure 1—IEEE 946 versus IEEE 1375 line of demarcation

In normal operation, the battery and ~~charger(s)~~ battery charging system are both connected to the loads through a common bus or via a dc distribution bus and, therefore, panel. Therefore, they operate as parallel sources. The battery charging system applies voltage and supplies current to supply the connected loads battery in order to maintain a full state of charge in the battery. The charger, ~~in addition to charging the battery, carries~~ also generally supplies the ~~normal~~-continuous load. ~~Chargers are typically provided with a current limiting circuit for overload protection and/or~~ other loads as specified.

If ~~overloaded,~~ the ~~charger~~ load exceeds the maximum current rating of the battery charging system, the battery charging system output voltage will drop, causing all ~~loads~~current in excess of the ~~charger~~ battery charging system 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 battery charger failure~~ (or in case the removal charging system consists of the only one charger), a battery charger failure, or the battery charger being removed from service, the battery ~~must~~ should supply all ~~of~~ the power required by the load(s) for some ~~designed period~~specified periods of time. This is commonly referred to as the “duty cycle.”

5.1.1 Power generation

Specific design guidance for dc power systems for nuclear generating ~~stations~~ plants are discussed fully in numerous design standards ~~found~~ listed in Annex A.

5.1.2 Substation

For additional guidance refer to IEEE Std 1818.

5.1.3 Telecommunications

Telecommunication installations require dc power for almost all equipment, as only a small percentage of telecommunications equipment is ac-powered. Therefore, dc power systems are required for normal and backup powering of most telecommunications installations. Refer to Annex F for the specific considerations in telecommunication applications.

Telecommunication loads in substations commonly used for telemetry and telecontrol generally operate at lower voltage (e.g., -48 V dc) than the main substation dc power system voltage (e.g., 125 V dc). A dedicated dc power system might be needed to feed such loads. In cases when the power consumption is relatively low, they can be fed by the substation dc power system through dc-dc converters (e.g., 125 V dc to 48 V dc converters).

5.2 System design considerations

In addition to the load's requirements, the design should accommodate any regulatory agency requirements, safety, or other requirements. The design should also address factors such as reliability, design philosophy, maintenance, testing, ventilation, floor and wall loading, and space limitations, etc.

The equipment to be connected to the battery and battery charger will govern the minimum and maximum voltage operating voltage range of the dc power system.

The designer should consider a single system or multiple systems based on the voltage, current, and redundancy requirements of the components. For example, if a communication system requires 48 V dc input and the dc bus is 125 V dc, then consider whether the communication equipment would be either supplied by its own battery and charger or by a dc-dc converter fed from the main 125 V dc system.

A recommended practice is to create a diagram at the start of the design process showing the battery or batteries, charger(s), dc panel(s), and all connected loads. Consideration should also be given for future growth. Redundant dc power systems may also be considered. Redundancy may provide flexibility for maintenance, testing, or replacement in the event of equipment failure or the need to upgrade in the future. The ability to connect other dc power systems may also aid in maintenance activities.

Although not recommended, center-tapped battery designs have been utilized in special applications. In most cases, a center-tapped battery design should be considered as the least advantageous design, as it may result in issues such as a more complicated ground fault detection, battery state of charge imbalance, cell voltage imbalance, load imbalance, improper autonomy, etc. Designing separate systems for different voltages is recommended in lieu of center tapped battery. See informative Annex H for more details on center tapped battery.

When special loads such as inverters and dc-dc converters are connected to a dc power system, considerations should be made to understand their potential effect on the dc bus in terms of charger regulation, current and voltage ripple, transient behavior, or other disruptive interactions.

5.2.1 Power generation

The most common nominal system voltages utilized in a power generation dc power system are 24 V dc, 48 V dc, 125 V dc, and 250 V dc. The following dc voltage values are commonly seen on equipment within a plant and are provided for illustrative reference only:

— 250 V dc

— Motors for emergency pumps

- Large valve operators
- Large inverters
- 125 V dc
- Motors and valve actuators
- Control power for relay logic circuits
- Opening and closing of switchgear circuit breakers
- Smaller inverters
- Field flashing
- 48 V dc, 24 V dc, 12 V dc
- Communication systems
- Specialized instrumentation and controls

Some battery technologies (e.g., lead-acid) may exhibit a momentary voltage dip phenomenon known as the “coup de fouet” when supplying high initial inrush currents. The coup de fouet effect value is provided by the manufacturer and should be considered when sizing battery capacity in order to reduce load disturbances or shutdowns. The coup de fouet becomes greater as a battery ages.

Once the voltage limits and design parameters are established, the size of the battery (number of cells and capacity) can be established as outlined in applicable best practices or standards, e.g., IEEE Std 485 and IEEE Std 1115. It may be useful to size the battery such that the design duty cycle can be met with a reduced number of cells (N-1, N-2).

When determining system voltage in facilities with long cable runs, voltage drop should be considered. In order to evaluate the voltage drop across a cable, Ohm’s law shall be applied using the maximum current times the cable resistance provided by the manufacturer.

Legacy equipment or available equipment may constrain the choice of dc voltages.

Considerations should be taken for special operation conditions. For example, the capabilities of a black start or system restoration plan may require more than one attempt to restore the station ac service. This can be the case when the main electrical grid power is unavailable, and electrical power is provided by a backup generator.

5.2.2 Substation

Telecommunication loads in substations commonly used for telemetry and telecontrol generally operate at lower voltages (e.g., 24 V dc or –48 V dc) than the main substation dc system voltage (e.g., 125 V dc). A dedicated dc system might be needed to feed such loads. In cases where the power consumption is relatively low, it can be fed by the main substation's dc system through dc-dc converters (e.g., 125 V dc to 24 V dc or –48 V converters). In such cases, considerations for additional needs, such as required incremental power, voltage regulation, and high-frequency noise should be made when designing the main substation's dc system. For additional guidance refer to IEEE Std 1818.

5.2.3 Telecommunication

Nominal system voltages for telecommunications dc power plants are most commonly 48 V dc, 24 V dc, and 12 V dc. Minimum and maximum telecommunication equipment operating voltage levels are defined in ANSI/ATIS-0600315.2013 [B2] and ANSI/ATIS 0600315.01.2015 [B3]. It is recommended that chargers be equipped with filtered outputs to the appropriate level as charted in NEMA PE 7 [B28].

6. Batteries

Stationary batteries are used to supply dc power to specified dc loads when the source of ac power to the battery charger has been disrupted or is insufficient to support the loads. Refer to appropriate IEEE standards or the battery manufacturer's guidance for the proper selection of battery type to be used in the application. Correct battery selection is essential for reliability, useful life, cost, and maintenance planning. Factors such as operating temperature, duty cycle, battery life, and deep cycling should also be considered.

6.1 Number of battery strings

The number of battery strings in an independent dc power system should be considered at the design stage. More than one battery string for capacity or redundancy should be considered to help ensure compliance or reliability requirements.

6.1.1 Power generation

Some examples of how to improve the reliability and protection of critical loads include the following:

4.2 Number of batteries

- When loads ~~As a minimum, one battery should be provided for each unit. If the auxiliary 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~~ its own dc power system.
- When maximum dc power requirements exceed the capacity of one battery, ~~then the development~~ string, the system designer should consider either of the following:
- The use of parallel battery strings.

- The use of two independent ~~systems should be considered. Cross ties from other batteries may be provided, where appropriate (see 7.7).~~ dc power systems, each with its own battery. In this case, selectivity and coordination of dc buses and protective devices should be implemented.
- When modifications to the facility cause the dc power demand to exceed the existing dc power system's capacity, the installation of a new independent system should be considered. Other alternatives include the following:
- Replacing the existing dc power system (battery, battery charger, and possibly an addition to the main distribution bus/board) with a larger capacity system. (Note that replacing the existing battery with a larger battery may require the replacement of the main distribution.)
- Installation of a parallel battery. (Note that this may also require additional considerations such as matching existing battery capacity, recharging duration, replacement of the main distribution, etc.)
- When dc power system independence is required and multiple systems are installed, each system should be powered from separate and/or independent sections of the ac power system if an alternate ac source is available (refer to 8.1.1.1).
- When maintenance and/or emergency reasons require isolating one battery string from another, individual disconnects or a circuit breaker should be recommended in the design.
- When maintenance and/or emergency reasons require isolating one battery string from another, the loading should be reviewed to ensure that the remaining one battery string has adequate capacity to operate the worst case loading scenario.

Additional power generation applications cases include specific guidance for center tapped battery design considerations used in a power generating station (see Annex H) and for the number of batteries to be used in a nuclear generating station (see Annex I).

6.1.2 Substation

For additional guidance refer to IEEE Std 1818.

6.1.3 Telecommunications

Parallel strings are very common in telecommunications in order to meet the required backup times as needed for both the application and redundancy.

~~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. 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 guide.~~

~~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 and battery size considerations

The nominal system voltages of 250 V, 125 V, 48 V, and 24 V 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. 250 V systems are typically used to power motors for emergency pumps, large valve operators, and large inverters. 125 V systems are typically used for small inverters, dc power supplies, control power for most relay logic circuits and the closing and tripping of switchgear circuit breakers. 48 V or 24 V systems are typically used for specialized instrumentation or communications systems.

For a given dc auxiliary power system, the connected equipment governs the maximum and minimum voltage operating limits. Standards such as IEEE C37.16TM-1997 [B17], IEEE Std C37.90TM-1989 (R1994) [B18], and NEMA MG 1-1998 [B19] establish voltage limits for various equipment and relays (see 7.3). Operating outside the voltage limits may affect the expected life of the equipment, the speed at which it operates, the available torque, or the device's capability to operate. 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 485TM⁵ and IEEE Std 450TM-2002 [B7], respectively.

4.5 Physical layout

Consideration should be given to locating the equipment (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.

~~When dc power is used for control and instrumentation purposes, consideration should be given in routing the entire power system in raceways which do not contain distribution system cables subject to surges. Surges may be present in ac systems, high voltage dc systems and grounding cables as a result of switching, lightning, and faults.~~

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.~~

6.2 Determination of battery duty cycle 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,~~ To size a battery correctly, it is important to know the following:

- The number of loads (if more than one load)
- The load size and duration
- The loads sequence in case of multiple loads
- The desired design minimum voltage for any dc load when the battery reaches its end of discharge point
- The lowest anticipated temperature the battery electrolyte should encounter

Refer to IEEE Std 485 for lead-acid and IEEE Std 1115 for nickel-cadmium.

⁵~~Information on references can be found in Clause 2.~~

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)~~ the charger output to the battery ~~chargers and other auxiliaries~~ connected dc loads. 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)~~. The duty cycle may also be influenced by the accessibility of the site.

~~For example~~ In theory, a minimum sizing scenario ~~may~~ would only require the ~~batteries~~ battery to supply dc power to the ~~system load~~ for approximately 1 min (the time needed between the loss of ac power and the loading of ~~the diesel~~ if, an operational standby power source), assuming that after such time, the charger output and dc loads would return to normal. ~~More often~~ In practice, however, the ~~overall~~ duration of the battery duty cycle is generally estimated at ½ h, 1 h, 2 h, 4 h, or 8 h. ~~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~~ be anywhere from 5 min to 72 h. The selected time depends upon the overall design requirements. It may consider what to do if the standby power source fails to automatically restore power.

~~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. The resulting largest battery size from each of the different duty cycle scenarios considered becomes the worst case design basis for the battery system.~~

~~Consideration may be given to providing additional design margin such that the battery will be able to fulfill the service requirements under the following conditions:~~

- a) ~~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.~~
- b) ~~For quick turnaround of the battery to service after a discharge. Standard float or equalize charging of the battery, following a discharge, results in an exponential return of charge. Full charge may not be completed for days. Depending on the voltage setting, the battery chemistry, and the room temperature, 95% to 98% of the charge may be returned within the time period used for T, the time to recharge the battery, in 6.2. By allowing 2% to 5% margin for less than full charge when computing the battery size, the final charging period is less critical and the battery may be available for 100% return to service earlier. For nuclear applications this additional margin is not required if the postulated design basis scenario does not require multiple losses of offsite power.~~

6.2.1 Power generation

The types of dc loads encountered in a generating station can include, but are not limited to, any or all of the following:

- Annunciator system
- Inverter
- Emergency lighting
- Emergency lube oil and seal oil pumps
- Engine starting and control
- Generator field flashing
- Fire detection and actuation
- Main generator output breaker control

- [Offsite power recovery](#)
- [Relays and solenoids](#)
- [Standby or black-start power source starting and control](#)
- [Switchgear breaker operation, including spring charging motors](#)
- [Communication systems](#)
- [Squib valves](#)
- [Motorized valves](#)

6.2.2 Substation

[Most substations have a duty cycle of 8 h or more. Substations located in areas that are remote and/or difficult to access by field service personnel may require more time to respond and therefore may require a longer duty cycle. Develop a load profile in accordance with appropriate IEEE sizing standards \(i.e., IEEE Std 485 or IEEE Std 1115\) to help ensure correct battery sizing for the application.](#)

[A typical substation duty cycle needs to account for the following types of load:](#)

- [Continuous loads, e.g., relays, communications, security, and monitoring](#)
- [Non-continuous loads, e.g., emergency lights](#)
- [Larger momentary loads, e.g., breaker coils and motor-operated switches](#)

[For additional guidance refer to IEEE Std 1818.](#)

6.2.3 Telecommunication

For traditional telecommunications sites, a minimum of 3 h to 4 h of battery backup is typically provided for sites with permanent on-site, auto-start, and auto-transfer standby engine-alternators. A minimum of 8 h is typically provided for sites not served by a standby engine-alternator. In order to maintain the battery backup for the most critical loads, non-critical loads are sometimes shed.

The battery is generally sized based on a constant load current during a predefined period of time. However, if the load is constant power type in which the current rises as the battery voltage drops, then this increased current has to be considered in the battery sizing. Typical nominal dc bus voltages are +12 V, +24 V, -48 V, 380 V, and 575 V.

In general, there may be regulatory rules or guidelines that determine the amount of backup time for traditional voice service. The most common of these rules requires a minimum of 8 h of battery backup for sites not backed up by an on-site permanent auto-start, auto-transfer engine-alternator. For sites with a permanent on-site auto-start, auto-transfer engine alternator, the rule is typically 3 h of battery backup plus travel time to the site, or simply a straight minimum of 4 h of battery backup. Non-voice loads (such as broadband data and video) may be shed in some sites after a certain period of time, or after a certain voltage is reached in the discharge in order to extend the operation of more essential loads. Typically, this time could range from 5 min to several hours and is company specific. When this is done, it is typically done off of a timer activated by a commercial ac failure or “battery on discharge” alarm, or the timer starts when a certain discharge voltage is reached.

Most telecommunication dc power systems (commonly known in the telecom industry as a “dc plant”) designed for three or more hours of battery reserve use a battery designed for long-duration discharge. If the site is powered by renewable energy or has poor grid quality, a battery designed for cycling duty should be considered.

6.3 Installation design

The design of each battery installation, [signage, battery room design, and access \(when applicable\)](#) should be in accordance with [the appropriate IEEE standards and local codes. IEEE standards typically include but are not limited to the following:](#)

- ~~— IEEE Std 484, and should include provisions for installation, inspection, and testing.~~
- [Installation of vented lead-acid \(VLA\) batteries](#)

~~Many battery chemistries such as those of lead-acid batteries are sensitive to temperature variations above and below their manufacturer's rated temperature (e.g., 25 °C for U.S. manufacturers, 20 °C for European manufacturers). Although the performance impacts of these temperature variations can be accounted for in the design of the battery systems by following the recommendations of IEEE Std 485, consideration should be given to a location which is not subject to temperature variations greater than 5 °C.~~

- [IEEE Std 1187 – Installation of valve regulated lead-acid \(VRLA\) batteries](#)
- [IEEE Std 1106 – Installation, maintenance and testing of nickel-cadmium batteries](#)
- [IEEE Std 1491 – Battery monitoring](#)
- [IEEE Std 1578 – Spill containment](#)
- [IEEE Std 1635 – Ventilation and thermal management](#)
- [IEEE Std 979 – Substation fire protection](#)

[Codes commonly enforced in the US include the following:](#)

- [National Electrical Safety Code® \(NESC®\) \(Accredited Standards Committee C2\) \[B4\]](#)
- [National Electrical Code® \(NEC®\) \(NFPA 70®\)](#)
- [NFPA 70E®, Standard for Electrical Safety in the Workplace](#)

A controlled environment is recommended for all battery installations. Operating outside the manufacturer's recommended temperature range will impact the performance and lifespan of the battery.

Factors to consider in designing the optimum environment for a battery system may include the following:

- Airborne contaminants, such as corrosive coastal environments (e.g., salt, humidity)
- Particulates
- Seismic requirements (refer to IEEE Std 693-2005)
- Natural disaster exposure (e.g., floods, tsunamis, wildfires)
- Adequate hydrogen ventilation
- Spill containment
- Access, egress, and safety of personnel
- Occupancy
- Security requirements
- Fire detection and suppression
- Heat ventilation
- Space layout
- Clearance requirements (NESC [B4], NEC) and additional space needs for large cell lifting devices

Different battery types can vary substantially not only in physical dimensions, but also in the weight of the filled containers. Design should consider rack size and type (tiered, stepped, or step-tier) and limitations on number of tiers to limit the height. With very large batteries, lifting devices may be required to place containers on tiered racks. The design needs space to accommodate both installation and maintenance requirements of the battery. If racks with more than two tiers are selected, there may be a temperature gradient between top-tier and bottom-tier cells, which can affect loading of the cells and impact battery life.

Applicable national/local codes and standards should be researched and analyzed to improve compliance as required. Spill containment systems may be required in certain jurisdictions. Check with the authority having jurisdiction (AHJ) responsible for the particular jurisdiction where the site is being designed for installation if in doubt.

6.3.1 Substation

For additional guidance refer to IEEE Std 1818.

6.4 Maintenance, testing, and replacement

Batteries should be maintained, tested, and replaced in accordance with IEEE Std 450-~~2002~~ (VLA), IEEE Std 1188 (VRLA), IEEE Std 1106 (Ni-Cd), and/or IEEE Std 1184 [B18] for UPS battery replacement determination and local regulations.

The dc supply may be equipped with switching devices to facilitate the removal of a battery string from service for the purposes of offline maintenance and testing. Taking a battery offline may require prior connection of a temporary battery in order to provide continuous backup power supply to the station. Refer to Clause 8 for more guidance on additional safety isolation devices needed for this operation.

6.4.1 Substation

For additional guidance refer to IEEE Std 1818.

6.5 Qualification, relevant codes, and standards

~~DC system components should be qualified for the environment in which they are installed. This includes seismic requirements. Although “qualification” is generally construed to be a term related to the nuclear industry, the concept of understanding the capabilities and design ratings of the equipment and ensuring that the installed use of the equipment is within the design parameters is overall good engineering practice.~~

Qualification of batteries may be required depending on the application specifics.

Seismic and/or environmental qualification of battery installations is based on the appropriate local codes where the battery will be installed or on good engineering judgment based on the application and criticality of the installation.

For seismically active areas, the battery cabinets or racks, and the batteries should be seismically qualified in accordance with the seismic requirements of the International Building Code (IBC).

6.5.1 Power generation

Nuclear power plants have additional requirements based on their licensing commitments. Refer to IEEE Std 535 [B12].

6.5.2 Substation

Transmission entities might have additional requirements based on North American Electric Reliability Corporation (NERC). Other regions may have similar regulations.

6.5.3 Telecommunication

Equipment used in telecommunications applications by many large North American telecommunication companies is required to be Network Equipment-Building System (NEBS) compliant. See Annex F for further details.

7. Battery chargers

6.1 General description

The ~~station~~-battery chargers are used to ~~convert ac to dc to charge the station~~ restore electrical energy in the stationary batteries and to supply power to dc loads during normal operation.

7.1 Number of chargers

At a minimum, one battery charger should be provided for each battery. Additional battery chargers should be considered if increased operation flexibility, redundancy, or capacity is desired and/or required. For example, instead of using one very large charger, one can consider using two identical smaller size chargers in parallel. As long as the constant loads are fully supported by one charger, utilizing two chargers provides flexibility for routine maintenance and in case of a failure of one of the chargers. The continuous load would be maintained without affecting the battery, but the recharge time would be increased. Constant load would be maintained without affecting the battery. The use of modular chargers in an N+x configuration (i.e., one or more additional chargers than are necessary to support the critical load) may provide greater reliability than a single charger, but less than two fully redundant chargers.

7.1.1 Substation

For additional guidance refer to IEEE Std 1818.

7.1.2 Telecommunication

Typically, N+1 or greater rectifier redundancy is used in telecommunication stations.

7.2 Load sharing between paralleled chargers

When more than one charger is connected in parallel, load sharing between chargers should be considered. It is not recommended that chargers of different designs and/or technologies be operated in parallel. Refer to Annex G for more details about load sharing of chargers.

7.2.1 Telecommunication

Parallel operation is the normal mode of operation for telecommunication chargers. For modern rectifiers, a microprocessor controller gives them all an exact voltage to synchronize, and because of the precision of their output regulation, they may all share the load equally. If the controller fails, the rectifiers should be equipped with circuitry that will put them at a “fallback” default output voltage (typically very near, if not the same as the float voltage at 25 °C). In most systems, this “fallback” voltage is set through the controller, which the miniature microprocessor in each rectifier remembers in case of controller failure. So, even when the controller fails, a modern telecommunication rectifier system may still share the load equally among the rectifiers because all rectifiers are programmed with the exact same “fallback” voltage.

7.3 Determination of rated output

7.3.1 General

The battery charger output current should be sized to feed the connected load while recharging a fully discharged battery to reach a level greater than 90% of its capacity within a predetermined recharging time.

This estimated time is a combination of engineering, judgment, and/or regulatory requirements, and can be influenced by operating experience as well as the quantity, reliability, and flexibility of other power sources, e.g., on-site or off-site generators, auxiliary network power sources, or redundant dc power systems (batteries and battery chargers).

Equation (1) should be used to calculate the size of the charger as follows:

$$I_c = K((C \times e)/t + I_L) \quad (1)$$

where

C is the ampere-hour removed from the battery as calculated from the battery sizing calculation based on the actual duty cycle. For other considerations (7.3.3) or if this value is not known, then use the published ampere-hour rating of the battery based on the expected discharge time duration

e is the recharging efficiency factor. Suggested values, which may be overridden by the battery manufacturer, are given in Table 1

t is the recharge time in hours, usually between 6 h and 24 h. Recharge time may be impacted based on the minimum or maximum charging current. Consult the battery manufacturer

I_L refers to all constant loads and the duty cycle of non-continuous (not transient loads) currents expected to be supported by the battery charger while recharging or floating the battery (in amperes). If the load is a mixture of constant current and constant power type and the average voltage is not known, then it is recommended using the minimum voltage to determine the equivalent constant current load of the constant power load part

K refers to any factors such as but not exclusive to factors related to future load growth, temperature, altitude, etc., desired by the specified charger. If no other factor is needed, then $k = 1$

I_c is the minimum charger output current in amperes

Constant current chargers deliver the charge at a constant rate, allowing the voltage to increase. Station battery chargers are sized as though the charge were delivered by a constant current charger. Since the final voltage may exceed the maximum voltage of devices attached to the dc system, constant voltage chargers are not used in generating stations. Constant voltage charging is represented by a time period at the charger current limit, until the battery is approximately 60% to 85% charged and a subsequent exponential decay of charging current until the battery is 100% charged. Placing the constant voltage charger in equalize extends the time the charger is in current limit, increases the charging current during the exponential decay and shortens the charge time. The constant current charging formula will approximate the constant voltage charging time to 95% state of charge when a constant voltage charger is set to the equalize mode.

The station battery chargers should be sized in accordance with Equation (1) and Equation (2):

$$I_1 = I_{LC} + (1.1 \times Q) / T \quad (1)$$

$$I_2 = I_{LC} + I_{LN} \quad (2)$$

where

I_1 is the minimum required charger rated output (in amperes). Battery manufacturers often recommend that the charging rate be limited; typical values are 10% to 20% of the 8 h capacity. I_1 should be evaluated for the maximum and minimum values of I_{LC} :

I_2 is the minimum charger output (in amperes) that will supply the maximum operational load.

I_3 is the recommended charger rated output (in amperes); i.e., the larger of I_1 or I_2 . If it can be demonstrated that the reduction in battery capacity that results during and following the application of I_H 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 charger(s). Battery manufacturers often recommend that the charging rate be limited; typical values are 10% to 20% of the 8 h capacity. I_3 should be evaluated for the maximum values of I_{LC} :

I_{LC} is the continuous dc load (in amperes), including future load growth.

Table 1—Typical battery recharge factors

Battery type	Suggested -e- value
VLA	1.1
VRLA	1.15
Vented Ni-Cd	1.3
Partially recombinant Ni-Cd	1.14

(New)

Special considerations include the following:

- For some battery technologies, such as VRLA, excessive charging current might affect their expected life. Therefore, if the sum of all the loads is used to size the charger and those loads do not operate concurrently, then the charger will have too much current available for charging the battery. If that current is higher than the manufacturer recommendations, additional controls, such as charger current limiting, may be required to protect the battery.
- Recharge time factor “t” in constant voltage charging: Due to the load voltage range limitation, chargers may operate in constant voltage charging rather than in constant current charging. In this case, the battery is recharging at a lower rate and will take much more time to reach its full capacity. Hence, it is recommended that “t” is fixed to a value (between 6 h and 24 h, e.g., 8 h) depending on the site criticality and conditions.

Sample calculations of battery charger rating are given in Annex B.

7.3.2 Power generation

In addition to the information in 7.3.1, in power generation applications, the charger shall have a minimum output current (I_2) to be capable of simultaneously supplying the constant load (I_L) and the non-continuous load (I_{LN}). The following equations apply:

$$I_2 = I_L + I_{LN} \quad (2)$$

$$I_3 = \text{Max. } [I_C, I_2] \quad (3)$$