

IEEE Standard Criteria for the Protection of Class 1E Power Systems and Equipment in Nuclear Power Generating Stations

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Abstract: Criteria that establish protection requirements for Class 1E power systems and equipment are prescribed. The purpose of and the means for obtaining protection from electrical and mechanical damage or failures that can occur within a time period that is shorter than that required for operator action are described. Testing and surveillance requirements are included. Plant physical design requirements to protect against certain events are not included.

Keywords: Criteria for the protection of class 1E power systems and equipment, design requirements, nuclear power generating stations, surveillance, valve actuator motor

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Introduction

(This introduction is not part of IEEE Std 741-1997, IEEE Standard Criteria for the Protection of Class 1E Power Systems and Equipment in Nuclear Power Generating Stations.)

The IEEE has developed this standard to provide the principal design criteria, design features, and testing requirements for the protection of Class 1E power systems and equipment supplied from those systems. It is of particular use in identifying the need for special protection features where the requirements of nuclear power generating stations necessitate supplementing accepted industry practices.

Wherever possible, the standard identifies other standards or documents that provide more explicit guidance for specific protection requirements. By definition, the protection shall be adequate to sense and to determine the presence of an unacceptable condition, and to execute the operations required in order to limit degradation effects. In this role, the standard pays special attention to the requirements for design verification documentation to support the protection performance.

This standard addresses the electrical penetration assemblies installed as part of the containment structure that may require special considerations for protection. Also included are the criteria used to establish the necessity for special considerations and the resulting protection requirements.

This revision of the standard provides additional information in the following areas:

- a) Degraded voltage protection;
- b) Overload protection for valve actuator motor circuits;
- c) Protection concerns associated with auxiliary system automatic bus transfer;
- d) The use of high-speed magnetic circuit breakers for special applications.

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George Attarian
William J. Boyer
John Chiloyan

Harvey C. Leake
Gerald L. Nicely
Harold Sharma

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The following persons were on the balloting committee:

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Vincent P. Bacanskas
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Also included are the following nonvoting IEEE Standards Board liaisons:

Satish K. Aggarwal
Alan H. Cookson

Lisa S. Young
IEEE Standards Project Editor

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IEEE Standard Criteria for the Protection of Class 1E Power Systems and Equipment in Nuclear Power Generating Stations

1. Scope

This standard prescribes criteria that establish protection requirements for Class 1E power systems and equipment. It describes the purpose of and the means for obtaining protection from electrical and mechanical damage, or failures that can occur within a time period that is shorter than that required for operator action. It includes testing and surveillance requirements. It does not include plant physical design requirements to protect against events such as pipe whip, fire, dropped load, etc.

2. References

This standard shall be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.

ANSI/ISA S67.04 Part 1-1994, Setpoints for Nuclear Safety-Related Instrumentation.¹

IEEE Std 141-1993, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (ANSI).²

IEEE Std 142-1991, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (ANSI).

IEEE Std 242-1986 (Reaff 1991), IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (ANSI).

¹ANSI/ISA 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, 445 Hoes Lane, Piscataway, NJ 08855-1331, USA.

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

IEEE Std 317-1983 (Reaff 1996), IEEE Standard for Electric Penetration Assemblies in Containment Structures for Nuclear Power Generating Stations (ANSI).

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 338-1987 (Reaff 1993), IEEE Standard Criteria for the Periodic Surveillance Testing of Nuclear Power Generating Station Safety Systems (ANSI).

IEEE Std 384-1992, IEEE Standard Criteria for Independence of Class 1E Equipment and Circuits (ANSI).

IEEE Std 415-1986 (Reaff 1992), IEEE Guide for Planning of Preoperational Testing Programs for Class 1E Power Systems for Nuclear Power Generating Stations (ANSI).

IEEE Std 446-1995, IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (ANSI).

IEEE Std 487-1992, IEEE Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Power Stations (ANSI).

IEEE Std 518-1982 (Reaff 1996), IEEE Guide for the Installation of Electrical Equipment to Minimize Electrical Noise Inputs to Controllers from External Sources (ANSI).

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

IEEE Std 666-1991 (Reaff 1996), IEEE Design Guide for Electric Power Service Systems for Generating Stations (ANSI).

IEEE Std 765-1995, IEEE Standard for Preferred Power Supply (PPS) for Nuclear Power Generating Stations (ANSI).

IEEE Std 944-1986 (Reaff 1996), IEEE Recommended Practice for the Application and Testing of Uninterruptible Power Supplies for Power Generating Stations (ANSI).

IEEE Std 946-1992, IEEE Recommended Practice for the Design of DC Auxiliary Power Systems for Generating Stations (ANSI).

IEEE Std C37.91-1985 (Reaff 1990), IEEE Guide for Protective Relay Applications to Power Transformers (ANSI).

IEEE Std C37.96-1988, IEEE Guide for AC Motor Protection.³

IEEE Std C62.2-1989 (Reaff 1994), IEEE Guide for Application of Gapped Silicon-Carbide Surge Arresters for Alternating Current Systems (ANSI).

IEEE Std C62.41-1991 (Reaff 1995), IEEE Recommended Practice for Surge Voltages in Low-Voltage AC Power Circuits (ANSI).

IEEE Std C62.45-1992, IEEE Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits (ANSI).

³IEEE Std C37.96-1988 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181.

IEEE Std C62.92.3-1993, IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems, Part III—Generator Auxiliary Systems (ANSI).

NEMA ICS 2-1993, Industrial Control and Systems: Controllers, Contactors, and Overload Relays, Rated Not More than 2000 Volts AC or 750 Volts DC.⁴

3. Definitions

3.1 degraded voltage condition: A voltage deviation, above or below normal, to a level that, if sustained, could result in unacceptable performance of, or damage to, the connected loads and/or their control circuitry.

3.2 loss of voltage condition: A voltage reduction to a level that results in the immediate loss of equipment capability to perform an intended function.

3.3 pump runoff: A pump flow condition in which the pump is operating beyond its design point due to a reduction in the system head. As a result, the pump motor's brake-horsepower and full load current demand may be increased.

3.4 service factor (general-purpose alternating-current motor): A multiplier that, when applied to the rated power, indicates a permissible power loading that may be carried under the conditions specified for the service factor.

4. General design criteria

As used in this standard, protection refers to the sense, command, and execute features with their associated interconnections (see IEEE Std 603-1991)⁵ that are provided to minimize equipment damage and any interruption of electrical service resulting from mechanical or electrical failures or other unacceptable conditions. Protection includes equipment required to support the Class 1E power system in the performance of its safety function, and components whose function is to increase the availability and reliability of the safety-related equipment. The protection shall be capable of the following:

- a) Preventing failures in safety systems and equipment from disabling safety functions to below an acceptable level. The protective actions of each load group shall be independent of the protective actions provided by redundant load groups (see IEEE Std 308-1991).
- b) Operating the required devices upon detection of unacceptable conditions to reduce the severity and extent of electrical system disturbances, equipment damage, and potential personnel and property hazards.
- c) Monitoring the connected preferred power supply and, where an alternate preferred power supply is provided by the design, of automatically initiating a transfer or alerting the operator to manually transfer to the preferred alternate power supply.
- d) Providing indication and identification of the protective operations.
- e) Periodic testing to verify logic schemes and protective functions.
- f) Being designed in such a way that the availability of protection control power is monitored.
- g) Periodic testing to verify setpoints. This requirement is not applicable to fuses.

⁴NEMA publications are available from the National Electrical Manufacturers Association, 1300 N. 17th St., Ste. 1847, Rosslyn, VA 22209, USA.

⁵For information on references, see Clause 2.

Those parts of the protection that have a safety function shall meet the requirements of IEEE Std 603-1991 and IEEE Std 308-1991. Documentation requirements for the protection of Class 1E power systems and equipment are found in IEEE Std 308-1991. Those parts of the protection whose function is nonsafety related shall be designed such that their failure does not degrade the Class 1E power system below an acceptable level.

5. Principal design criteria and requirements

5.1 AC power distribution systems

5.1.1 Switchgear and bus protection

For recommended practices in application of overcurrent relays, directional relays, differential relays for bus protection, and ground fault relaying, refer to IEEE Std 141-1993, IEEE Std 242-1986, and IEEE Std 666-1991. The protection systems for the ac distribution system should be coordinated in accordance with IEEE Std 242-1986. For supplementary information on ground protection practices, refer to IEEE Std 142-1991.

If the power distribution system design cannot accommodate paralleling of bus supplies, or if paralleling can be allowed only under certain conditions, interlocks or procedural restrictions shall be provided to restrict such paralleling. Consideration shall be given to the higher fault current that may exist during parallel operation when selecting protective devices.

If the power distribution design allows for automatic bus transfers, consideration should be given to the impact of the bus transfer on the coordination of protection devices (see Annex C).

5.1.2 Bus voltage monitoring schemes

Bus voltage monitoring schemes that are used for disconnecting the preferred power source, load shedding, and starting the standby power sources are part of the protection and shall meet the criteria that follow. Voltage monitoring schemes that are used only for alarms do not have to meet these criteria.

- a) Bus voltage shall be detected directly from the Class 1E bus to which the standby power source is connected.
- b) Upon sensing preferred power supply degradation, the condition shall be alarmed in the main control room. On sensing preferred power supply degradation to an unacceptable low voltage condition, the affected preferred power supply shall be automatically disconnected from the Class 1E buses.
- c) Each division shall have an independent scheme of detection of degraded voltage and loss of voltage conditions. Within each division, common equipment may be used for the detection of both conditions (see Annex A).
- d) Each scheme shall monitor all three phases. The protection system design shall be such that a blown fuse in the voltage transformer circuit or other single phasing condition will not cause incorrect operation, nor prevent correct operation, of the scheme. Means shall be provided to detect and identify these failures.
- e) The design shall minimize unwanted operation of the standby power sources and disconnection of the preferred power supply. The use of coincident logic and time delay to override transient conditions is a way to accomplish this.
- f) Capability for test and calibration during power operation shall be provided.

- g) The selection of undervoltage and time delay setpoints shall be determined from an analysis of the voltage requirements of the Class 1E loads at all on-site distribution levels (see Annex A).
- h) Indication shall be provided in the control room for any bypass incorporated in the design.

5.1.3 Feeder circuits

For recommended practice on motor protection, refer to IEEE Std C37.96-1988, IEEE Std 242-1986, and IEEE Std 666-1991. See 5.5 for additional requirements associated with valve actuator motors. The feeder circuit protection should consider any expected operating conditions of the motor that may require electrical system demands above the motor's nameplate rating such as the following:

- a) Motor service factor;
- b) Pump runout conditions;
- c) Operation at other than rated voltage.

For recommended practice on power transformer protection, refer to IEEE Std C37.91-1985 and IEEE Std 666-1991. For recommended practice on feeder circuit to power distribution panel protection, refer to IEEE Std 141-1993 and IEEE Std 242-1986. For criteria for isolation and separation of non-Class 1E circuits from Class 1E circuits, refer to IEEE Std 384-1992.

For use of high-speed magnetic circuit breakers in special applications, refer to Annex D.

5.1.4 Standby power supply protection

For diesel generator protection recommended practice, refer to IEEE Std 242-1986.

In the manual control mode, synchronizing interlocks should be provided to prevent incorrect synchronization whenever a standby power source is required to operate in parallel with the preferred power supply.

When a standby power supply is being operated in parallel with the preferred power supply, protection shall be provided to separate the two supplies if either becomes degraded to an unacceptable level. This protection shall not lockout or prevent the availability of the power supply that is not degraded.

5.1.5 Load shedding and sequential loading

An automatic load shedding and sequential loading scheme may be included to ensure that the preferred or standby power sources can be loaded while maintaining voltage and frequency within acceptable limits.

The Class 1E bus load shedding scheme should automatically prevent shedding during sequencing of the emergency loads to the bus when connected to the standby power source.

If the preferred or standby power source breaker is tripped during or subsequent to loading, the load shedding and sequential loading scheme shall be arranged to be automatically reset to perform its function in the event that the loads are to be reapplied.

5.1.6 Surge protection

For surge protection of equipment and systems, refer to IEEE Std 141-1993 and IEEE Std 242-1986. For surge protection of induction motors, refer to IEEE Std C37.96-1988. For guidance on protection of wire line facilities used for protective relaying and data transfer circuits, refer to IEEE Std 487-1992.

For recommendations in design and installation of low-energy, low-voltage signal circuits associated with solid-state electronic equipment, refer to IEEE Std 518-1982.

Surge protection shall be provided to protect the shunt field of dc valve actuator motors. This surge protection may take the form of a resistor in the motor control center-wired in parallel with the shunt field to provide a discharge path for the shunt field's inductive voltage surges.

For guidance in the application of surge arresters to all types of power circuits and equipment, refer to IEEE Std C62.2-1987. Refer to IEEE Std C62.41-1991 for guidance in determining the surge voltage for low-voltage equipment, and to IEEE Std C62.45-1992 to provide guidance for tests that should be used to determine the surge withstand capability of the equipment used on low-voltage circuits.

5.2 DC power system

For recommended practice on protection for batteries, refer to IEEE Std 946-1992.

The dc power distribution system should be provided with coordinated protection. Coordination for dc power system circuits should include the main bus protective devices and the protective devices used in branch circuits, in switchgear control circuits, and in relay and process control panels. Care shall be taken to use appropriate correction factors or dc trip characteristic curves for protection devices.

For criteria for isolation and separation of non-Class 1E circuits from Class 1E circuits, refer to IEEE Std 384-1992.

Ground detection monitoring shall be provided for ungrounded systems.

Battery chargers shall be provided with current limiting features or overload protection, reverse current protection, output undervoltage, and overvoltage alarms and/or trips. For additional guidance on the protection of battery chargers, refer to IEEE Std 446-1987.

5.3 Instrumentation and control power system

For guidance on protection for inverters, refer to IEEE Std 446-1987. For information on ground protection practices, refer to IEEE Std 142-1991 and IEEE Std C62.92.3-1993. For criteria for isolation and separation of non-Class 1E circuits from Class 1E circuits, refer to IEEE Std 384-1992.

Where a rectifier-type power supply is used as a source for an inverter, it shall be provided with reverse current protection, current-limiting features or overload protection, and output undervoltage and overvoltage protection.

The instrumentation and control power distribution system should be provided with coordinated protection. Since inverters and motor generator sets are sources of limited short-circuit current, special attention must be given to integrating protective device sensitivity and system available fault current. Coordination should include the protective devices in the alternate supply, inverters, static switches, distribution panels, instrumentation panels and racks, and other equipment powered from the system.

Where an instrumentation and control power bus is supplied by an inverter with current limiting characteristics and an automatic transfer has been provided to an alternate source with higher available current, this alternate source may be used in order to achieve the coordinated protection described above.

Ground detection monitoring shall be provided for ungrounded systems.

The instrumentation and control power system should be provided with undervoltage, overvoltage, and underfrequency protection. Where its power is supplied from a static inverter, overfrequency protection should also be provided. For recommended practice on alarms and indication, refer to IEEE Std 944-1986.

5.4 Primary containment electrical penetration assemblies

An electrical penetration assembly shall be considered as part of the cable system between the load and the primary interrupting device. For guidance in the application of electrical circuit protection, refer to IEEE Std 242-1986, which includes information also applicable to electrical penetrations. Short-circuit, overload, and continuous current ratings and capabilities of the electrical penetration are defined in IEEE Std 317-1983.

The electrical penetration assemblies installed as part of the containment structure may require special consideration in the selection of their protection. This special consideration arises where the potential exists for a fault inside containment to result in a penetration seal failure, such that a breach of containment may occur. Where a penetration assembly can indefinitely withstand the maximum current available due to a fault inside containment, no special consideration is required.

Electrical penetrations requiring special consideration (i.e., where protection is required to ensure containment integrity) shall be provided with dual primary protection operating separate interrupting devices, or primary and backup protection operating separate interrupting devices.

The time-current curves of the dual primary protection or the primary and backup protection shall coordinate with the time-current capability curve of the electrical penetration to be protected.

Protection for non-Class 1E circuits using containment penetration assemblies do not need to be treated as Class 1E. The protection for these non-Class 1E circuits is acceptably provided by the requirements specified in the paragraphs above.⁶ For protection circuits requiring special consideration, the surveillance requirements of 6.3 shall apply.

5.5 Valve actuator motors (direct gear driven)

The selection of a protective device for the direct geared valve actuator motor shall ensure that the time current characteristic of the protective device is coordinated with the time current characteristic of the motor, as derived from motor time temperature data. In addition, the coordination shall ensure the allowable duty cycle of the valve (see Annex B) is completed without compromising the motor thermal withstand capability, while allowing margin for variations in current drawn by the motor, or in the thermal characteristics of the protective device, or both. Refer to Annex B for guidelines for selection of the protective devices. The criteria for setting mechanical devices within the valve actuator, such as torque and limit switches, are not within the scope of this standard.

The protective device(s) shall be selected to prevent the following:

- a) Motor overheating due to locked-rotor conditions;
- b) Motor overheating due to anticipated overloads;
- c) Nuisance trips during acceleration;
- d) Nuisance trips due to anticipated overloads;
- e) Nuisance trips during operation within the duty cycle of the valve.

⁶Designs that use dual protection for penetration circuits provide adequate assurance that the protection will function acceptably under all plant conditions. Since the plant design basis is that a seismic event will not cause a loss-of-coolant accident (LOCA) or high energy line break (HELB) inside containment, seismic qualification of protective devices for non-Class 1E circuits that penetrate the containment is not required.

To protect the motor during locked-rotor conditions, the protective device maximum trip time shall not exceed the allowable safe locked-rotor time, and the minimum trip time shall not be less than the acceleration time (typically less than 1 s).

Protective devices shall be coordinated with the motor allowable operating time corresponding to nominal torque and anticipated overloads. Typical anticipated valve overloads fall in the range of 150–300% of the valve actuator motor nominal torque, depending on the actuator type and application.

Short-circuit protection shall be provided for the valve actuator motor. If the device for short-circuit protection contains an overload element, this element shall be coordinated with the valve actuator motor thermal overload device.

The following shall also be considered in the derivation and coordination of the protective device setpoints:

- a) Tolerance (accuracy) of the protective device;
- b) The effect of ambient temperature;
- c) The effect of motor terminal operating voltage extremes.

Valve actuator motor current values shall be obtained from the valve actuator manufacturer at nominal torque, selected overload torque (150–300% of nominal torque), and locked-rotor torque. The current values shall be measured at nominal voltage and either measured or calculated for anticipated voltages at the terminals of the motor. These current values shall be considered in the final selection of the overload protection device.

6. Testing and surveillance

6.1 Device testing

All testing of voltage transformers, current transformers, relays, fuses, trip elements, and other devices shall be in accordance with accepted industry practice for the device being tested. For acceptable testing practices, refer to IEEE Std 141-1993. Refer to IEEE Std 336-1985 (Reaff 1991) and IEEE Std 338-1987 (Reaff 1993) for construction and periodic test requirements.

Where overload heater elements are used, they shall be tested in accordance with NEMA ICS 2-1993.

6.2 Preoperational tests

A program shall be established to assure that preoperational testing will demonstrate the satisfactory performance of the protection. For planning of a preoperational testing program, refer to IEEE Std 415-1986.

Requirements for initial preoperational testing will also apply after major modification or repair to the protection. The program shall include checks, verification, tests, and reports to demonstrate that the following are true:

- a) There is proper operation according to system design;
- b) The protection will meet requirements relating to voltage, frequency, current, power, and other limits;
- c) That where redundant power or control systems are installed, the failure or loss of one system will not prevent correct operation of the redundant system;
- d) The failure of a non-Class 1E power or control system will not adversely affect the correct functioning of the protection for Class 1E equipment;
- e) The specified requirements for the operating environment are not violated. These requirements may include cleanliness, temperature, humidity, and vibration.

6.3 Surveillance

For surveillance methods to demonstrate equipment operational status, refer to IEEE Std 308-1991. For periodic test requirements pertaining to those parts of the protection that perform a safety function, refer to IEEE Std 338-1987.

The protection shall be designed to permit periodic testing to provide assurance that the protection can perform its function. This standard does not address the periodic testing of actuated electrical equipment.

Periodic tests should duplicate as closely as practicable the performance requirements of the actuation devices. Acceptable methods for periodic testing include the following:

- a) Testing of each protection circuit from sensor through actuated equipment.
- b) Testing part of each protection circuit and actuation device individually or in previously selected groups. In this instance, overlap requirements should establish an acceptable basis for combining individual or group test results.
- c) Testing each electrical actuation circuit individually if the actuated equipment has more than one actuation device.

During periodic protection device testing, where the ability of the safety system to respond to an accident signal has been made inoperative, the following shall apply:

- a) The inoperative condition shall be indicated in the main control room;
- b) Means shall be provided to prevent any expansion of the inoperative condition to redundant systems.