IEEE Std 387-1995
(Revision of IEEE Std 387-1984)

IEEE Standard Criteria for Diesel-Generator Units Applied as Standby Power Supplies for Nuclear Power Generating Stations

Sponsor

Nuclear Power Engineering Committee
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Abstract: The criteria for the application and testing of diesel-generator units as Class 1E standby power supplies in nuclear power generating stations is described.
Keywords: aging classification, auxiliary equipment, capability, controls, design criteria, design features, diesel-generator units, documentation requirements, engine, generator, load profile, modifications, operation, periodic testing, pre-operational testing, production testing, protection, qualification requirements, rating, records, reliability program, scope, seismic qualification, site testing, standby power supply, testing requirements, test parameters, type testing

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Introduction

(This introduction is not part of IEEE Std 387-1995, IEEE Standard Criteria for Diesel-Generator Units Applied as Standby Power Supplies for Nuclear Power Generating Stations.)

This standard supplements IEEE Std 308-1991, IEEE Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations, in that it amplifies subclause 6.2.4 of that standard (Standby power supplies) concerning requirements for diesel-generator units.

The IEEE has developed this standard to provide the principal design criteria, design features, qualification considerations, and testing requirements for individual diesel-generator units, including auxiliary equipment and controls within the scope of this standard used in the standby power supply of a nuclear facility, which comply with the Nuclear Regulatory Commission's Code of Federal Regulations (10 CFR 50).

This standard presents specific procedures and criteria applicable to qualifying the diesel-generator unit and supplements the criteria described in IEEE Std 323-1983, IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations, and IEEE Std 627-1980, IEEE Standard for Design Qualification of Safety System Equipment Used in Nuclear Power Generating Stations.

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

a) Defining specific qualification requirements

b) Clarifying scope and scope diagram

c) Providing requirements for no-load and light-load operation, since extended operation under these conditions may be detrimental to unit performance

d) Expanding factory production testing and site testing criteria

e) Updating specific surveillance requirements

f) Providing guidance for test parameters (annex C)

g) Providing guidance for reliability program elements (annex D)

This revision of the standard incorporates periodic testing requirements described in IEEE Std 749-1983, IEEE Standard for Periodic Testing of Diesel-Generator Units Applied as Standby Power Supplies in Nuclear Power Generating Stations, which has been withdrawn.

Industry practice is focusing toward monitoring and trending to facilitate aging and reliability determinations. This standard provides guidance for recommended test parameters and reliability program elements as described in annexes C and D. These guidelines reflect industry practices and are in agreement with guidelines developed by the Nuclear Management and Resources Council (NUMARC), now known as the Nuclear Energy Institute (NEI).

The qualification requirements delineated in this standard consider aging considerations as potential common mode failure mechanisms. Operating experience is generally available on diesel-generator units similar to those covered by this standard, and is useful in establishing the effect of aging mechanisms for those components where the technical state-of-the-art does not allow for techniques such as accelerated aging. The basis for allowing operating experience is supplemented by noting that the application of these diesel-generator units for nuclear service is such that the actual operating time under loaded conditions is expected to be less than one year continuous service in the 40-year life expectancy of the plant. For areas where the state-of-the-art is not as limited, accelerated aging techniques should be used.

Components or assemblies that have been used for testing should not be placed into in-service use unless they have been analyzed to demonstrate their adequacy for in-service use.

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Other industry standards exist or are being developed to cover topics related to this standard, including the American Nuclear Society series standards[a] describing design requirements for diesel-generator unit auxiliary systems.

Adherence to these criteria may not suffice for ensuring public health and safety because it is the integrated performance of the structures, the fluid systems, the instrumentation systems, and the electrical systems of the station that establishes the consequences of accidents. Each applicant has the responsibility to ensure that this integrated performance is adequate.

This standard was prepared by Working Group 4.2 of the Auxiliary Power Subcommittee (SC-4) of the Nuclear Power Engineering Committee of the IEEE Power Engineering Society. At the time this standard was approved, the working group had the following membership:

E. I. Fabri, *Chair*
P. R. Johnson, *Secretary*

L. F. Bednar	D. D. Galeazzi	J. Horne
T. N. Chan	L. G. Hajos	F. Kauffmann
O. P. Chopra	K. R. Hoopingarner	D. Sandiforth
L. Fusegni		N. A. Traeger

The following persons were involved in the preparation of the standard, but were not working group members at the time of approval.

J. J. Burns	W. Farmer

The Auxiliary Power Subcommittee (SC-4) of the Nuclear Power Engineering Committee had the following membership at the time this revision was approved:

R. Weronick, *Chair* **P. B. Stevens,** *Vice Chair*
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D. T. Goodney	C. A. Petrizzo	R. L. Swallows
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The following persons (members of the Nuclear Power Engineering Committee) were on the balloting committee:

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Russell E. Allen
Vincent Bacanskas
John T. Bauer
Farouk D. Baxter
Wes W. Bowers
Dan F. Brosnan
Nissen M. Burstein
Aris S. Candris
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IEEE Standard Criteria for Diesel-Generator Units Applied as Standby Power Supplies for Nuclear Power Generating Stations

1. Overview

1.1 Scope

This standard describes the criteria for the application and testing of diesel-generator units as Class 1E standby power supplies in nuclear power generating stations.

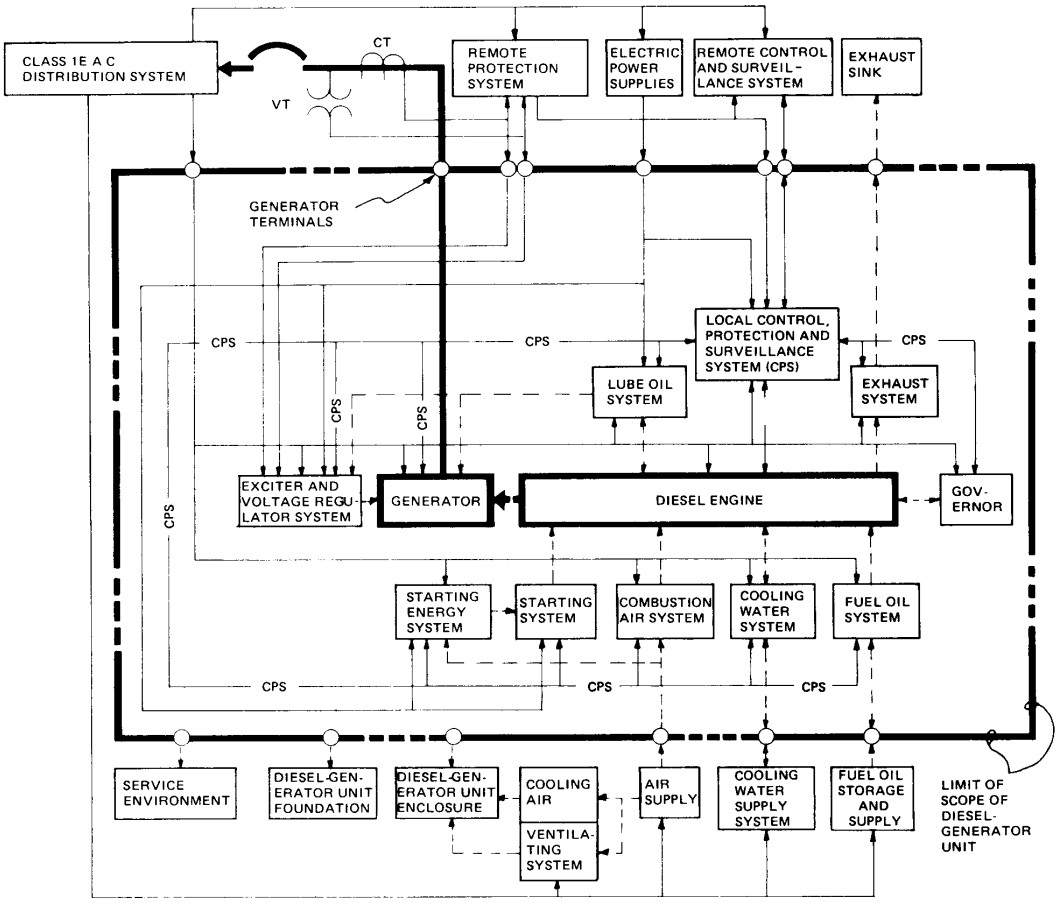
Figure 1 shows the boundaries of systems and equipment included in the scope of this standard. Site testing is covered in clause 7, and the boundaries for site testing are given in 1.1.2.

1.1.1 Inclusions

The following items are within the scope of this standard:

a) The diesel engine, including
   1) The flywheel and coupling (if applicable)
   2) The combustion air system, starting at the engine air intake connection, including the effects of any remote air intake filter or silencer, or both
   3) The starting system
   4) The starting energy system
   5) The fuel oil system, including the day tank and the filters and strainers between the day tank and the engine
   6) The lubricating oil system
   7) The cooling system, starting at the point where the cooling medium is introduced to the diesel-generator unit
   8) The exhaust system, including the exhaust silencer, but excluding piping from the engine exhaust connection to the inlet of the silencer and silencer tail pipe
   9) The governor system

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; ELECTRIC CIRCUITS (CONTROL, AUXILIARY POWER, ETC; MAIN POWER)

; NON_ELECTRICAL CHANNELS (OIL, AIR, EXHAUST, ETC; DRIVE)

LIMIT OF SCOPE OF DIESEL-GENERATOR UNIT WITH INTERFACE ( )

CPS CONTROL PROTECTION AND SURVEILLANCE SYSTEMS

Figure 1—Scope diagram

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b) The generator, including

1) The main leads terminating at the generator terminals
2) The excitation and voltage regulation systems

c) The local control, protection, and surveillance systems associated with the diesel engine, the generator, and their auxiliary equipment and systems cited above

d) The ac and dc distribution systems associated with the diesel engine, the generator, and their auxiliary equipment and systems cited above, exclusive of the auxiliary power system beyond the generator terminals

e) Those elements that are essential to the safety function of diesel-generator units within the scope of this standard (see figure 1)

f) Evaluation of the characteristics of the service environment relative to performance and qualification

1.1.2 Inclusions for site testing

The following items are included for site testing purposes only, as described in clause 7.

a) The ac and dc power distribution system, which includes

1) Circuits for conveying ac power from the diesel-generator terminals up to and including the main disconnect device

2) Circuits for conveying ac or dc power to the diesel-generator units and associated controls

3) DC power supplies, if dedicated to the diesel-generator unit

b) The remote and local control, protection, and surveillance systems, which include

1) Devices for automatic and manual starting
2) Devices for load shedding and sequencing
3) Remote devices for the protection of the diesel-generator unit and its auxiliary equipment
4) Synchronizing equipment
5) Field flashing devices

1.1.3 Exclusions

The following items are outside of the scope of this standard:

a) Diesel-generator unit enclosure and foundations

b) External service equipment and systems that are a part of, or that are housed in, the diesel-generator unit enclosure, other than those tabulated in 1.1.1, such as equipment for providing and conveying combustion air, ventilating air, etc., to the vicinity of the diesel-generator unit

c) Fuel oil storage system (day tank, storage tank, transfer pumps and filters, and strainers between the storage tank and the day tank)

d) The control, protection, and surveillance systems for

1) Protecting the loads energized by the diesel-generator unit

2) Prevention of common-mode failure between the preferred power supply and the standby power supply

e) Determination of the characteristics of the service environment

f) Fire protection system

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1.2 Purpose

The purpose of this standard is to provide the principal design criteria, the design features, testing, and qualification requirements for the individual diesel-generator units that enable them to meet their functional requirements as a part of the standby power supply under the conditions produced by the design basis events cataloged in the Plant Safety Analysis.

2. References

This standard shall be used in conjunction with the following standards.

ANS 59.51-1989, Fuel Oil Systems for Emergency Diesel Generators.[1]

ANSI C50.10-1977, American National Standard General Requirements for Synchronous Machines.[2]

ANSI/ASME 1995 Boiler and Pressure Vessel Code.[3]

ANSI/NFPA 37-1994, Stationary Combustion Engines and Gas Turbines.

IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).[4]

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

IEEE Std 323-1983 (Reaff 1990), IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations (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 344-1987 (Reaff 1993), IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations (ANSI).

IEEE Std 384-1992, IEEE Standard Criteria for Independence of Class 1E Equipment and Circuits (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 Equipment Used in Nuclear Power Generating Stations (ANSI).

IEEE Std 741-1990, IEEE Standard Criteria for the Protection of Class 1E Power Systems and Equipment in Nuclear Power Generating Stations (ANSI).

NEMA MG 1-1993, Motors and Generators.[5]

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

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3. Definitions

3.1 acceptable: Demonstrated to be adequate by the safety analysis of the plant.

3.2 continuous rating (of diesel-generator unit): The electric power output capability that the diesel-generator unit can maintain in the service environment for 8760 h of operation per year with only scheduled outages for maintenance.

3.3 design basis events: Postulated events used in the design to establish the performance requirements of the structures and systems.

3.4 design load: That combination of electric loads (kW and kvar), having the most severe power demand characteristic, which is provided with electric energy from a diesel-generator unit for the operation of engineered safety features and other systems required during and following shutdown of the reactor.

3.5 diesel-generator unit: An independent source of standby electrical power that consists of a diesel-fueled internal combustion engine (or engines) coupled directly to an electrical generator (or generators); the associated mechanical and electrical auxiliary systems; and the control, protection, and surveillance systems.

3.6 engine equilibrium temperature: The condition at which the jacket water and lube oil temperatures are both within ± 5.5 °C (10 °F) of their normal operating temperatures established by the engine manufacturer.

3.7 load profile: The magnitude and duration of loads (kW and kvar) applied in a prescribed time sequence, including the transient and steady-state characteristics of the individual loads.

3.8 qualified diesel-generator unit: A diesel-generator unit that meets the qualification requirements of this standard.

3.9 redundant equipment or system: An equipment or system that duplicates the essential function of another equipment or system to the extent that either may perform the required function regardless of the state of operation or failure of the other.

3.10 service environment: The aggregate of conditions surrounding the diesel-generator unit in its enclosure, while serving the design load during normal, accident, and post-accident operation.

3.11 short-time rating (of diesel-generator unit): The electric power output capability that the diesel-generator unit can maintain in the service environment for 2 h in any 24 h period, without exceeding the manufacturer's design limits and without reducing the maintenance interval established for the continuous rating.

NOTE—Operation at this higher rating does not limit the use of the diesel-generator unit at its continuous rating.

3.12 standby power supply: The power supply that is selected to furnish electric energy when the preferred power supply is not available.

3.13 start-diesel signal: That input signal to the diesel-generator unit start logic that initiates a diesel-generator unit start sequence.

3.14 surveillance: The determination of the state or condition of a system or subsystem.

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4. Principal design criteria

4.1 Capability

4.1.1 General

When in service, each diesel-generator unit shall have the capability of performing as a redundant unit of a standby power supply, in accordance with the requirements stated in IEEE Std 308-1991.[6]

4.1.2 Mechanical and electrical capabilities

The diesel-generator unit shall also have each of the following specific capabilities to meet the design, application, and qualification requirements of this standard:

a) *Design conditions.* The unit shall be capable of operating during and after any design basis event without support from the preferred power supply. The following design conditions, including appropriate margins as required by subclause 6.3.1.5 of IEEE Std 323-1983, shall be specified by those individuals responsible for the system application and, as a minimum, shall include

   1) Operational cycles (4000 starts[7] over a period of 40 years, unless otherwise specified)
   2) Operating hours (6000 h[8] over a period of 40 years, unless otherwise specified)
   3) Temperature at equipment locations (minimum and maximum with durations and average annual ambient)
   4) Seismic response spectra
   5) Radiation (1×10^4 rd of gamma integrated dose over a period of 40 years, unless otherwise specified)
   6) Humidity (minimum and maximum with durations)
   7) Load profile, including allowable voltage and frequency variations (see 3.7 and annex A)
   8) Absolute barometric pressure (altitude and tornado depressurization, duration, and magnitude)
   9) Combustion air contaminants (salt, sand, etc.)
   10) Fuel type and quality
   11) Auxiliary electrical power supply requirements
   12) Effect of fire protection actuation
   13) Service water quality

b) *Starting and loading.* The unit shall be capable of starting, accelerating, and being loaded with the design load within the time required by the equipment specification

   1) From the normal standby condition.
   2) With cooling not available, for a time equivalent to that required to bring the cooling equipment into service with energy from the diesel-generator unit.
   3) On a restart with an initial engine temperature equal to the continuous rating full-load engine temperature.

[6]Information on references can be found in clause 2.

[7]These figures already include margins.

[8]See footnote 7.

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c) *Light-load or no-load operation.* The unit shall be capable of accepting design load following operation at light load or no load for the time required by the equipment specification.

d) *Design load.* The unit shall be capable of carrying the design load for the time required by the equipment specification.

e) *Quality of power.* The unit shall be capable of maintaining voltage and frequency at the generator terminals within limits that will not degrade the performance of any of the loads comprising the design load below their minimum requirements, including the duration of transients caused by load application or load removal.

4.2 Ratings

4.2.1 Application

The diesel-generator unit shall have continuous and short-time ratings that reflect the output capabilities of the diesel-generator unit in accordance with the requirements of 4.1 and the following:

a) Inspections and scheduled maintenance shall be performed periodically using the manufacturer's recommendations and procedures.

b) Unscheduled maintenance shall be performed in accordance with the need as indicated by the periodic inspections and operating experience.

4.2.2 Operation

The diesel-generator units may be utilized to the limit of their power capabilities, as defined by the continuous and short-time ratings. Unless time and load parameters for light-load and no-load operation are established by tests and documentation, the following precautions shall be taken:

a) When 4 h operation at 30% or less of the continuous rating have been accumulated (without at least 0.5 h operation above 50% of the continuous rating), the unit shall be operated at a load of at least 50% of the continuous rating for a minimum of 0.5 h.

b) Operating at 30% or greater of the continuous rating shall be restricted to the manufacturer's recommendations.

4.3 Interactions

Independence between units shall not be compromised. Mechanical and electric system interactions between a particular diesel-generator unit and other units of the standby power supply, the nuclear plant, the conventional plant, and the Class 1E electric system shall be coordinated in such a way that the diesel-generator unit's design function, and capability requirements of 4.1, may be realized for any design basis event, except failure of that diesel-generator unit.

4.4 Design and application considerations

Design and application considerations shall include, but not necessarily be limited to, the considerations listed in table 1.

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Table 1—Design and application considerations

Item	Consideration
1	Avoidance of common failure mode between units of the standby power supply
2	Single failure criterion as applied to the standby power supply
3	Matching of the diesel engine, generator, excitation system, voltage regulator, and governor
4	Energy for operation of the control, protection, and surveillance systems
5	Control, protection, and surveillance systems
6	Lubrication system and equipment
7	Selection of air, water, or other means of cooling
8	Supply of cooling medium and ambient air temperature
9	Cooling system and equipment
10	Selection of electric, pneumatic, or other means of starting
11	Supply of starting energy
12	Starting system and equipment
13	Supply, temperature, and quality of combustion air
14	Combustion air system and equipment
15	Supply of fuel
16	Fuel supply system and equipment
17	Removal of products of combustion
18	Equipment design life
19	Service environment
20	Seismic design
21	Design load
22	Time available between receipt of start-diesel signal and initiation of load sequence
23	Description of loading sequence with time durations of application of individual loads
24	Maximum time available between receipt of start-diesel signal and acceptance of design load
25	Accommodation of loading sequence and time duration for application of individual loads
26	Load performance characteristics (transient and steady-state)
27	Continuous rating
28	Short-time rating
29	Light-load or no-load operation
30	Diesel-generator unit performance characteristics, including transient characteristics (cold/hot engine kW and generator step-change kVA) and any applicable engine derating due to service environment (see item 19)

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Table 1—Design and application considerations *(Continued)*

Item	Consideration
31	Electric fault conditions
32	Electric transients, including surge voltages
33	Insulation and temperature rating of electric equipment insulation systems for operating and quiescent conditions
34	Creepage and clearance distances for electric equipment contacts
35	Electrically induced thermal effects
36	Mechanically induced thermal effects
37	Thermal shock
38	Mechanical shock
39	Operating cycles that may cause thermally induced stresses
40	Physical configuration and mechanical support of attached auxiliaries, accessories, hardware, piping, wire and cable, and raceways
41	Handling during manufacture, shipping, storage, and installation
42	Fire protection system: separation between units, and possible damaging effects by actual or inadvertent operation
43	Tornado depressurization
44	Separation criteria for Class 1E and non-Class 1E wiring
45	Operational vibration
46	Monitoring diesel-generator units during accident and post-accident conditions
47	Design considerations for testability and synchronizing capability
48	Annunciation of protective devices that initiate diesel trip
49	Communication means between the diesel-generator room and control room
50	Fire protection interlocks and alarms with regard to personnel safety
51	Data acquisition system

4.5 Design features

4.5.1 Mechanical and electrical design features

4.5.1.1 Vibration

Vibration amplitudes shall be limited to be within the design capabilities of the diesel-generator unit and auxiliary components. Solenoids, relays, and other devices shall be mounted in such a way to minimize vibration effects.

4.5.1.2 Torsional vibration

Harmful torsional vibration stresses shall not occur within a range from 10% above to 10% below rated idle speed and from 5% above to 5% below rated synchronous speed.

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4.5.1.3 Overspeed

Moving parts shall be designed to withstand that level of overspeed that results from a short-time rating load rejection. Margin shall be provided to allow the overspeed device to be set sufficiently high to guarantee that the unit will not trip on short-time rating load rejection. As a minimum, the generator rotor, exciter rotor (if used), and flywheel shall be designed to withstand an overspeed of 25% without damage.

4.5.1.4 Governor operation

If the diesel engine is equipped to operate in both the isochronous and the droop mode, provisions shall be included to automatically place the engine governor in the proper mode of operation when the diesel-generator unit is required to operate automatically (see 4.5.2.2).

4.5.1.5 Voltage regulator operation

If the voltage regulator is equipped to operate in the paralleled and nonparalleled mode, provisions shall be included to automatically place the voltage regulator in the proper mode of operation when the diesel-generator unit is required to operate automatically (see 4.5.2.2).

4.5.2 Control

4.5.2.1 Control modes

The diesel-generator unit shall be provided with control systems, permitting automatic and manual control.

4.5.2.2 Automatic control

Upon receipt of an emergency start-diesel signal, the automatic control system shall provide automatic start-up and automatic adjustment of speed and voltage to a ready-to-load condition.

a) A start-diesel signal shall override all other operating modes and return control of the diesel-generator unit to the automatic control system.

b) An emergency start-diesel signal shall not override any manual non-operating modes such as those for repair and maintenance.

4.5.2.3 Control points

Provisions shall be made for control both from the control room and external to the control room.

4.5.3 Surveillance

4.5.3.1 Surveillance systems

The diesel-generator unit shall be provided with surveillance systems permitting remote and local alarms and indicating the occurrence of abnormal, pre-trip, or trip conditions.

4.5.3.2 Modes surveyed

As a minimum, the following conditions shall be surveyed:

a) Unit not running
b) Unit running, not loaded

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c) Unit running, loaded
d) Unit out of service

4.5.3.3 Surveillance instrumentation

The following systems shall have sufficient mechanical and electric instrumentation to survey the variables required for successful operation and to generate the abnormal, pre-trip, and trip signals required for alarm of such conditions:

a) Starting system
b) Lubricating system
c) Fuel system
d) Primary cooling system
e) Secondary cooling system
f) Combustion air system
g) Exhaust system
h) Generator
i) Excitation system
j) Voltage regulation system
k) Governor system

4.5.4 Protection

The diesel-generator unit shall be automatically tripped on an engine overspeed or generator differential overcurrent, or both. Protective features, other than engine overspeed and generator differential current, shall be

a) Blocked from automatically tripping the diesel-generator unit during an accident condition and shall be annunciated in the plant control room, or

b) If protective features other than engine overspeed and generator differential current are retained during accident conditions, two or more independent measurements of each of these parameters with coincident trip logic shall be provided. The design of the coincident trip logic circuitry shall provide alarm for each individual sensor initiation. All protective devices shall remain effective during the diesel-generator unit testing, and during operation in non-accident conditions.

5. Factory production testing

5.1 General

5.1.1 Implementation

Testing shall be performed in accordance with a written test plan.

5.1.2 Documentation

Test documentation shall include the following:

a) Equipment performance specifications

b) Identification of the specific feature or features to be demonstrated by the test

c) Test plan

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d) Report of test results. The report shall include the following:

1) Objective
2) Equipment tested
3) Description of test facility (test setup), instrumentation used including calibration records reference, and test environment
4) Test procedures, including acceptance/rejection criteria
5) Test data and accuracy (results)
6) Test abnormalities and failures, including their disposition and effect on test results
7) Summary, conclusions, and recommendations
8) Supporting data
9) Approval signature and date

5.1.3 Analyses

Although testing is preferred, analyses may supplement test or be substituted for test, where testing is not practical, to demonstrate conformance to the criteria stated in clause 4. Analysis shall include the basis of assumptions used.

5.1.4 Substitutions

When tests are performed at the manufacturer's or assembler's facilities, and not at the site, the exhaust muffler, intake air filter-silencer, and radiator (if applicable) normally used for shop tests may be substituted in place of the equipment to be provided for a specific site, since it is not practical to utilize the equipment and piping that will exist at the site or future sites for which the diesel-generator unit is being qualified. Results of tests shall be corrected to the condition of the service environment and design characteristics, including site exhaust muffler and intake air filter-silencer systems.

5.2 Factory production tests

The following tests are minimum requirements for factory production tests.

5.2.1 Engine tests

Each engine shall be tested, utilizing either a water brake dynamometer or a generator to provide accurate means to control power absorption. The following tests shall be performed:

a) Break-in test. Each manufacturer shall develop their own break-in schedule to best suit the engine.

b) Performance test.

1) *Test runs.* After the engine has satisfactorily completed the break-in test, the following minimum tests shall be run to establish the operating characteristics. These tests may be conducted in any order desired.

Load in% of continuous rating	Hours
50	1
75	1
100	2
110	2

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2) *Data logging.* Test logs of all of the above tests shall become a part of the records for a particular engine. The test logs shall include at least the following data:

   i) Speed (r/min)
   ii) Brake (hp or kW)
   iii) Brake specific fuel consumption
   iv) Intake manifold pressure
   v) Intake manifold temperature
   vi) Individual cylinder exhaust temperature
   vii) Turbocharger exhaust temperature
   viii) Jacket water temperature (engine inlet and outlet)
   ix) Jacket water pressure (engine inlet)
   x) Lube oil temperature (engine inlet and outlet)
   xi) Lube oil header pressure (engine inlet)
   xii) Type of fuel and fuel heat content
   xiii) Barometric pressure
   xiv) Intake air temperature

3) *Controls-alarm and shutdown.* All engine-mounted alarms and shutdowns, where applicable, shall be set and checked. The points of activation shall be on the test logs.

4) *Inspection.* At any point after the break-in test or upon completion of the above test, a post-trial inspection shall be conducted. The manufacturer's standard procedure shall be used. The results of the inspection shall be documented in the test report.

5.2.2 Generator tests

Generator testing shall be in accordance with NEMA MG 1-1993.

5.2.3 Excitation, control, and other accessories/auxiliaries

All such devices and assemblies shall be tested in accordance with the manufacturer's standard practices.

6. Qualification requirements

6.1 General

The diesel-generator units applied as part of the standby power supply shall be qualified in accordance with the requirements of this clause.[9] This qualification will provide verification that the unit will meet the requirements of clause 4 under all expected environmental conditions. Qualification shall be accomplished by performance of type tests on unaged equipment or by analysis, or by a combination of both as required in 6.2 and by functional testing as required in 6.4 following any aging or seismic testing. All qualification shall be performed in accordance with a written plan that defines analysis and tests to be performed, parameters to be monitored during tests, test instrumentation, and acceptance criteria for equipment.

6.2 Initial type tests

Diesel-generators not previously type tested as standby power sources for nuclear power generating stations shall be subject to a type testing program consisting of load capability, start and load acceptance, and margin tests. It is preferred that these tests be performed at the engine manufacturer's or assembler's factory;

[9]The requirements for qualification in this clause are based on IEEE Std 323-1983 and IEEE Std 627-1980 as applicable to diesel-generator units to ensure that the equipment can perform within its specification requirements.

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however, they may be conducted at the site if certified calibration instrumentation is provided to measure and record the same functions and characteristics normally measured under factory testing conditions.

Type tests may be performed on one or more units, and qualification of one unit will qualify like units of that type for equal or less severe service. If start and load acceptance tests (see 6.2.2) are performed using more than one identical unit, then each of these units must be tested for load capability (see 6.2.1) and margin (see 6.2.3).

Type tests shall be performed following successful completion of the factory production tests. Following the successful completion of these type tests, the equipment shall be inspected in accordance with the manufacturer's standard procedure, and inspection results shall be documented.

6.2.1 Load capability tests

These tests demonstrate the capability of the diesel-generator unit to carry the following rated loads at rated power factor for the period of time indicated, and to successfully reject load in accordance with 7.2.1.4. One successful completion of the test sequence shall satisfy this particular requirement.

a) Load equal to the continuous rating shall be applied for the time required to reach engine temperature equilibrium.

b) Immediately following step a), the short-time rated load shall be applied for a period of 2 h and the continuous rated load shall be applied for a period of 22 h.

c) The short-time rating load rejection test shall be performed. The load rejection test will be acceptable if the increase in speed of the diesel engine does not exceed 75% of the difference between nominal speed and the overspeed trip set point, or 15% above nominal, whichever is lower.

d) Light-load or no-load capability as described in 4.1.2 step c) shall be demonstrated by test. Light-load or no-load operation shall be followed by a load application ≥ 50% of the continuous kilowatt rating for a minimum of 0.5 h.

6.2.2 Start and load acceptance tests

A series of tests shall be conducted to establish the capability of the diesel-generator unit to start and accept load within the period of time necessary to satisfy the plant design requirement. An acceptable start and load acceptance test is defined as follows; however, other methods with proper justification may be found equivalent for the level of reliability to be demonstrated.[10]

A total of 100 valid start and load tests shall be performed with no failures allowed. Failure of the unit to successfully complete this series of tests, as prescribed, will require a review of the system design adequacy, the cause of the failures to be corrected, and the tests continued until 100 valid tests are achieved without any failure. The start and load tests shall be conducted as follows:

a) Engine cranking shall begin upon receipt of the start-diesel signal, and the diesel-generator unit shall accelerate to specified frequency and voltage within the required time interval.

b) Immediately following step a), the diesel-generator unit shall accept a single-step load ≥ 50% of the continuous kilowatt rating. Load may be totally resistive or a combination of resistive and inductive loads.

c) At least 90 of these tests shall be performed with the diesel-generator unit initially at warm standby, based on jacket water and lube oil temperatures at or below values recommended by the engine man-

[10]While the reliability testing is not a specific requirement of IEEE Std 323-1983 or IEEE Std 627-1980, it is a required type test for this equipment.

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ufacturer. After load is applied, the diesel-generator unit shall continue to operate until jacket water and lube oil temperatures are within ± 5.5 °C (± 10 °F) of the normal engine operating temperatures for the corresponding load.

d) At least 10 tests shall be performed with the engine initially at normal operating temperature equilibrium defined as jacket water and lube oil temperatures within ± 5.5 °C (± 10 °F) of normal operating temperatures, as established by the engine manufacturer for the corresponding load.

e) If the cause for failure to start or accept load in accordance with the preceding sequence falls under any of the categories listed below, that particular test shall be disregarded, and the test sequence shall be resumed without penalty following identification and correction of the cause for the unsuccessful attempt.

   1) Unsuccessful start attempts that can definitely be attributed to operator error, including setting of alignment control switches, rheostats, or potentiometers, or other adjustments that may have been changed inadvertently prior to that particular start test.

   2) Tests performed for verification of a scheduled maintenance procedure required during this series of tests. This maintenance procedure shall be defined prior to conducting the start and load acceptance tests and will then become a part of the normal maintenance schedule after installation.

   3) Tests performed in the process of troubleshooting. Each start attempt performed in the trouble-shooting process shall be defined as such before a start attempt is made.

   4) Successful start attempts that were terminated intentionally without loading.

   5) Failure of any of the temporary service systems such as dc power source, output circuit breaker, load, interconnecting piping and wiring, and any other temporary setup that will not be a part of the permanent installation.

6.2.3 Margin tests

Tests shall be conducted to demonstrate the diesel-generator unit capability to start and carry loads that are greater than the magnitude of the most severe step load within the plant design load profile, including step changes above base load. The limiting case step change over base load as defined by the design load profile shall be demonstrated. This is not necessarily the largest step change, but may be a smaller step change as the full-load capability of the diesel-generator unit is approached. These tests may be combined with the load capability or start and load acceptance tests. At least two margin tests shall be performed using either the same or different load arrangement. A margin test load at least 10% greater than the magnitude of the most severe single-step load within the load profile is considered sufficient for the margin test. The frequency and voltage excursions recorded may exceed those values specified for the plant design load. The criteria for margin tests are as follows:

a) Demonstrate the ability of the generator and excitation system to accept the margin test load (usually the low power factor, high inrush, and high starting current of a pump motor) without experiencing instability resulting in generator voltage collapse, or significant evidence of the inability of the voltage to recover.

b) Demonstrate that there is sufficient engine torque available to prevent engine stall, and to permit the engine speed to recover, when experiencing the margin test load.

6.3 Aging

Aging methods are described in this clause for the applicable conditions listed in 4.1.2 step a), which are determined to be significant.

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6.3.1 Safety classification

Components and assemblies within the scope of this standard (see figure 1) shall be classified into one of the two following categories:

a) Components and assemblies required to enable the diesel-generator unit to meet its capabilities in 4.1 (hereinafter called the safety-related function). These components and assemblies require consideration of aging as a potential cause for common mode failures. Examples may include the governor, generator, cable, excitation system, engine, starting air solenoid valves, and those gaskets and seals that are applied to prevent leakage that degrades unit performance.

b) Components and assemblies not required to perform a safety-related function. Each of these nonsafety-related components or assemblies requires verification that it will not degrade the safety-related function. This may be accomplished by testing or analysis. Examples may include generator resistance temperature detectors (RTDs), neutral grounding equipment, space heaters, starting air compressors and drives, keep-warm heaters and pumps, and those gaskets and seals whose failure will not degrade unit performance.

6.3.2 Aging classification

Further classification of the safety-related components identified in 6.3.1 step a) is required to address the potential for age-related failures. The categories in table 2 illustrate this classification.

Table 2—Format for component aging classification (see annex B)

Component	Items with age-related failure mechanisms	Method of aging qualification	Items without age-related failure mechanisms
List specific component, e.g., Generator Motor Engine Pump Control panels Tanks Governors Solenoid valves Valves	List all items or materials within that component that have age-related failure mechanisms, e.g., Gaskets Insulation Bearings	List the method used, e.g., Accelerated aging Periodic replacement Analysis	List all items or materials within that component that do not have age-related failure mechanisms, e.g., Metal component

Components without significant age-related failure mechanisms may be excluded. For example, it is recognized that cast iron used in the basic engine block will not represent a potential age-related failure mechanism over normal nuclear service life.

Following classification, those components with potential age-related failures shall be qualified by testing (the preferred method), analysis, or a combination of test and analysis. Components with a resultant identified qualified life less than the overall qualified life objective shall have a maintenance/replacement interval defined. If aging by test is used, it shall be followed by seismic qualification to meet IEEE Std 344-1987. In all cases, the documentation requirements in clause 6 of IEEE Std 323-1983 shall be satisfied. An example of this process is given in annex B.

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6.4 Seismic qualification requirements

Seismic qualification in accordance with IEEE Std 344-1987 is required for all safety-related components. Nonsafety-related components require analysis or test to show that they will not degrade the safety-related function of the unit during a seismic event. Seismic testing shall be followed by functional testing to verify the applicable capabilities in clause 4.

6.5 Ongoing surveillance

Ongoing surveillance, including the periodic tests described in 7.4, may be used as a basis for the identification of equipment degradation and validation of the results of the aging and aged equipment testing described in 6.3.

6.5.1 Preventive maintenance, inspection, and testing

A separate preventive maintenance, inspection, and testing program (see also 6.5.2) shall be established for the diesel-generator unit and all supporting systems based on the manufacturer's recommendations, including time intervals for parts replacement of those components with a qualified life less than the unit qualified life objective. These recommendations may be based on operating hours or fixed time intervals, or both. Procedures shall include, as a minimum, specific programs for each portion of the unit as follows:

a) The engine, including the governor, overspeed trip device, internal components to the maximum extent practical, turbocharger, lube oil components, fuel oil components, jacket water components, starting components, cleaning, adequate lubrication, and water chemistry

b) The generator and rotating exciter (if used), including insulation condition, bearings, cooling system, lubricating system, and space heaters (if applicable)

c) Electrical auxiliary equipment, including local engine and generator control, exciter and voltage regulator, and protection and surveillance components

d) Subsystems, including

   1) Starting energy, typically consisting of air receiver tanks, compressors, piping, valves, and associated instrument and control devices

   2) Fuel oil, typically consisting of pumps, filters, strainers, piping, valves, and associated instrument and control devices

   3) Lube oil, typically consisting of pumps, filters, strainers, keep-warm heaters and pumps, coolers, sump tanks, piping, valves, and associated instrument and control devices

   4) Cooling water, typically consisting of expansion tanks, heat exchangers, pumps, keep-warm heaters and pumps, piping, valves, and associated instrument and control devices

   5) Intake air, typically consisting of filters, silencers, expansion joints, and piping

   6) Exhaust, typically consisting of silencers, expansion joints, and piping

   7) Crankcase ventilation components, if applicable

6.5.2 Records and analysis

Records shall be maintained for each diesel-generator unit to provide a basis for an analysis of the unit's overall performance. These records also provide a basis for verifying any assumptions made concerning age-related failure mechanisms. The documentation may also be used to shorten or extend the replacement intervals.

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6.6 Modifications

Modifications to a previously qualified diesel-generator unit, such as governor, generator, overall system fly-wheel effect, excitation system characteristics, cooling media, or other accessories/auxiliaries that may change the capability or performance of a previously qualified diesel-generator unit, shall be analyzed to determine if the degree of change is major or minor.

a) Major changes to a qualified engine, such as changes in stroke or bore, brake mean effective pressure, speed, or diesel-generator arrangement in unique or different configuration shall be requalified in accordance with this clause.

b) Minor changes to a previously qualified diesel-generator unit, such as component parts substitution, shall be qualified by analysis or testing, or both.

6.7 Documentation

Qualification documentation shall be in accordance with IEEE Std 323-1983, and shall include the following:

a) Service and environment [see 4.1.2 item a)]
b) Classification table of all components as safety-related or nonsafety-related
c) Analysis/justification for nonsafety-related components
d) Classification table of safety-related components with or without age-related failure mechanisms
e) Justification of aging methods for various components
f) Test data for control panels, exciter/regulator (including seismic)
g) Test data for insulation systems testing
h) Test data for seismic testing of smaller mechanical components
i) Analytical data for seismic analysis of generator, engine, and major mechanical components
j) Historical data/justification for items requiring periodic replacement
k) Correlation of qualification program to instruction book information for periodic replacement, etc.

7. Site testing

7.1 Testing

Site testing shall consist of site acceptance testing, pre-operational testing, and periodic testing. Individual tests shall be as shown in table 3.

7.2 Site acceptance testing

After final assembly and preliminary start-up testing, each diesel-generator unit shall be tested at the site to demonstrate the capability of the unit to perform its intended function.

7.2.1 Tests

The tests to be given to the diesel-generator unit are shown in table 3 and shall be as follows.

7.2.1.1 Starting test

Starting tests shall demonstrate the capability to attain and stabilize frequency and voltage within the limits and time defined in the equipment specification.

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Table 3—Site testing

Reference	Tests	Site acceptance tests (7.2)	Pre-operational tests (7.3)	Availability tests (7.4.2.1)		System operation tests—shutdown/refueling (7.4.2.2)	Independence tests 10 years (7.4.2.3)
				Monthly	6 Monthly		
7.2.1.1	Starting	X					
7.2.1.2	Load acceptance	X					
7.2.1.3	Rated load	X					
7.2.1.4	Load rejection	X					
7.2.1.5	Electrical	X					
7.2.1.6	Subsystem	X					
7.3.3	Reliability		X				
7.5.1	Start			X			
7.5.2	Load run			X	X		
7.5.3	Fast start				X		
7.5.4	LOOP		X				
7.5.5	SIAS		X				
7.5.6	Combined SIAS and LOOP		X			X	
7.5.7	Largest load rejection		X			X	
7.5.8	Design load rejection		X			X	
7.5.9	Endurance and load		X[a]			X	
7.5.10	Hot restart		X			X	
7.5.11	Synchronizing		X			X	
7.5.12	Protective trip bypass		X			X	
7.5.13	Test mode override		X			X	
7.5.14	Independence		X				X

[a]Instead of 2 h and 6 h, use 2 h and 22 h.

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7.2.1.2 Load acceptance test

Load acceptance tests shall demonstrate the capability to accept the individual loads that make up the design load, as described in 3.4, in the desired sequence and time duration and to maintain the voltage and frequency within the acceptable limits.

NOTE—If the diesel-generator unit has a light-load or no-load operation capability, the load acceptance test sequence shall include consideration of the potential effects on load acceptance following such operation (see also 4.2.2).

7.2.1.3 Rated load test

Rated load tests shall demonstrate the capability of carrying the following loads for the indicated times without exceeding the manufacturer's design limits:

a) A load equal to the continuous rating for the time required to reach engine temperature equilibrium plus 1 h

b) Immediately following the load in item a), the rated short-time load shall be applied for a period of 2 h

7.2.1.4 Load rejection test

Load rejection tests shall demonstrate the capability of rejecting short-time rated load without exceeding speeds or voltages that will cause tripping or component damage.

7.2.1.5 Electrical test

Electrical tests shall demonstrate that the electrical properties of the generator, excitation system, voltage regulation system, engine governor system, and the control and surveillance systems are acceptable for the intended application.

7.2.1.6 Subsystem test

Tests shall demonstrate the capability of the control, protection, and surveillance systems to function in accordance with the requirements of the intended application.

7.2.2 Test loads

Loads to be applied, carried, and rejected during site testing shall be the design load auxiliaries located at the station. Equivalent loads may be used if these auxiliaries cannot be operated for testing.

7.3 Pre-operational testing

Following completion of the site acceptance testing, pre-operational tests shall be performed to demonstrate starting and operational adequacy of the diesel-generators and the system.

The individual pre-operational tests shall be as indicated in table 3 and as described in 7.5.

Reliability tests shall demonstrate that an acceptable level of reliability has been achieved to place the new diesel-generators into operation. This shall be achieved by a minimum of 25 valid start and load tests without failure on each installed diesel-generator.

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7.4 Periodic testing

7.4.1 General

After being placed in service, the diesel-generator unit shall be tested periodically to demonstrate that the continued capability and availability of the unit to perform its intended function is acceptable. Records and analysis described in 7.6 shall be maintained for all periodic tests. It is recognized that some of these tests may be combined and not necessarily performed individually. It is not necessary to begin these tests from standby conditions unless otherwise specified.

a) Test equipment shall not cause a loss of independence between redundant diesel-generator units or between diesel-generator load groups.

b) Periodic testing of a diesel-generator unit shall not impair the capability of the unit to supply emergency power in the required time in response to start-diesel signals.

c) All diesel-generator unit protective trips and alarms should be operative during applicable periodic testing.

d) Written procedures for testing shall be prepared and utilized. The procedures shall include the manufacturer's applicable test recommendations and shall identify all special arrangements or changes in the normal system configuration required to perform the test. The procedures shall ensure that the system is restored to its normal configuration after completion of the tests. All tests shall be in general accordance with the manufacturer's recommendations for reducing engine wear, including cool-down operation at reduced power followed by post-operation lubrication.

   Test procedures that involve starting and stopping the diesel-generator unit shall include the following steps that are pertinent to each specific test:

   1) Observe and record all pre-start data listed in table 4.
   2) Initiate the start-diesel signal and measure and record the elapsed time from the start-diesel signal to rated speed.
   3) Confirm that the generator voltage and frequency are maintained within the prescribed limits for the particular circumstances of each test.
   4) Record all parameters listed in table 4 at the beginning of any load-carrying test and at the end of any load-carrying test and at 1 h intervals during the test, if applicable. The data should be recorded under similar conditions for use in trending analyses.
   5) Observe and record all post-test data listed in table 4 after completion of the test.

e) Communication shall be established between the diesel-generator unit testing location and the main control room so that operators are cognizant of the status of the diesel-generator unit undergoing the test.

f) During system operational tests, problems may arise with individual components that do not detract from the overall test purpose. These components shall be repaired and their interface with the system shall be retested; however, the total test need not be repeated unless necessary due to the critical function of the component involved.

   Abnormal conditions discovered during any test shall be evaluated to determine if

   1) The condition would prevent the diesel-generator unit from performing its intended function.
   2) The test is a valid test.

7.4.2 Periodic tests

Periodic tests shall consist of availability, system operation, and independence verification tests.

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Table 4—Test parameters

Parameter[a]	Pre-start	During test	Post-test
Pressures			
Lube oil: engine - inlet	X	X	
Lube oil: turbo - inlet	X	X	
Lube oil: engine - filter differential		X	
Lube oil: turbo - filter differential		X	
Lube oil: engine header		X	
Lube oil: filter differential		X	
Crankcase		X	
Starting air	X		X
Temperatures			
Lube oil: engine - inlet and outlet	X	X	
Jacket water: engine - inlet and outlet	X	X	
Exhaust: each power cylinder		X	
Exhaust: turbo outlet		X	
Exhaust: exhaust manifold (if applicable)		X	
Electrical			
Frequency		X	
Power		X	
Reactive		X	
Current: generator - all phases		X	
Voltage: generator - all phases		X	
Current: field		X	
Level			
Lube oil: engine generator crankcase	X		X
Lube oil: generator bearing	X		X
Jacket water: standpipe or expansion tank		X	X

[a]These parameters are considered the minimum requirements for this standard. Additional parameters may be added for performance measurements.

7.4.2.1 Availability tests

These tests demonstrate the continued capability of the diesel-generators to start and accept load.

Each diesel-generator unit shall be started and loaded at least once in 31 days (slow-start and load-run test). In lieu of the above test, once every six months a fast-start and load-run test shall be performed.

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7.4.2.2 System operation tests

This series of tests demonstrates the ability of the diesel-generator unit to perform its intended function under simulated accident conditions. These tests shall be performed at shutdown/refueling outages once every two years.

7.4.2.3 Independence verification test

Subsequent to any modifications where diesel-generator unit independence may have been affected, or every 10 years during a plant shutdown or refueling outage, whichever is the shorter, an independent verification test shall be conducted.

7.5 Test descriptions

The following descriptions apply to the tests listed in table 3. These tests should be preceded by a pre-lube period and should be in general accordance with the manufacturer's recommendations for reducing engine wear, including cool-down operation at reduced power followed by post-operation lubrication. Unless otherwise noted, these tests should be performed at a power factor as close as practical to the design load power factor as plant voltage conditions permit.

7.5.1 Slow-start test

Demonstrate proper start-up from standby conditions and verify that the required design voltage and frequency are attained. The unit should reach rated speed on a prescribed schedule selected to minimize stress and wear on the diesel-generator unit.

7.5.2 Load-run test

Demonstrate load-carrying capability, with load equivalent to 90–100% of the continuous rating of the diesel-generator unit, for an interval of not less than 1 h and until temperature equilibrium has been attained. This test may be accomplished by synchronizing the generator with offsite power. Testing may be performed at unity power factor or at a lagging power factor within the diesel-generator unit capability. The loading and unloading of a diesel-generator unit during this test should be gradual and based on a prescribed schedule selected to minimize stress and wear on the diesel-generator unit.

7.5.3 Fast-start test

Demonstrate that each diesel-generator unit starts from standby conditions (if a plant has normally operating pre-warm systems, this would constitute its standby conditions) and verify that the diesel-generator unit reaches required voltage and frequency within acceptable limits and time, as defined in the plant technical specifications.

7.5.4 Loss-of-offsite power (LOOP) test

Demonstrate by simulating a loss of offsite power that

a) The emergency buses are de-energized and the loads are shed from the emergency buses.

b) The diesel-generator unit starts on the auto-start signal from its standby conditions, attains the required voltage and frequency within acceptable limits and time, energizes the auto-connected shut-down loads through the load sequencer, and operates for a minimum of 5 min.

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7.5.5 Safety injection actuation signal (SIAS) test

Demonstrate that on a SIAS, the diesel-generator unit starts on the auto-start signal from its standby conditions, attains the required voltage and frequency within acceptable limits and time, and operates on standby for a minimum of 5 min.

7.5.6 Combined SIAS and LOOP test

Demonstrate by simulating a loss of offsite power in conjunction with SIAS that

a) The emergency buses are de-energized and the loads are shed from the emergency buses.

b) The diesel-generator unit starts on the auto-start signal from its standby conditions, attains the required voltage and frequency within acceptable limits and time, energizes the auto-connected shut-down loads through the load sequencer, and operates for a minimum of 5 min.

7.5.7 Largest-load rejection test

Demonstrate the emergency diesel-generator unit's capability to reject a loss of the largest single load, and verify that the voltage and frequency requirements are met and that the unit will not trip on overspeed.

7.5.8 Design-load rejection test

Demonstrate the diesel-generator unit's capability to reject a load equal to 90–100% of the design loads, and verify that the unit will not trip on overspeed.

7.5.9 Endurance and load test

Demonstrate load-carrying capability for an interval of not less than 8 h, of which 2 h should be at a load equivalent to the short-time rating of the diesel-generator unit and 6 h at a load equivalent to 90–100% of the continuous rating. (For the pre-operational test, use 2 h and 22 h.) Verify that voltage and frequency requirements are maintained.

7.5.10 Hot restart test

Demonstrate hot restart functional capability at full-load temperature conditions by verifying that the diesel-generator unit starts on a manual or auto-start signal, attains the required voltage and frequency within acceptable limits and time, and operates for a minimum of 5 min.

7.5.11 Synchronizing test

Demonstrate the ability to

a) Synchronize the diesel-generator unit with offsite power while the unit is connected to the emergency load.

b) Transfer this load to the offsite power.

c) Isolate the diesel-generator unit.

d) Restore the diesel-generator unit to standby status.

7.5.12 Protective-trip bypass test

Demonstrate that specified automatic diesel-generator unit trips are automatically bypassed as designed. Typically, engine overspeed and generator differential current trip are not bypassed.

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7.5.13 Test mode override test

Demonstrate that with the diesel-generator unit operating in the automatic test mode while connected to its bus, a simulated safety injection signal overrides the test mode by

a) Returning the diesel-generator unit to standby operations.
b) Automatically energizing the emergency loads from offsite power.

7.5.14 Independence test

Demonstrate that, by starting and running (unloaded) redundant units simultaneously, potential common failure modes that may be undetected in single diesel-generator unit tests do not occur.

7.6 Records

Records shall be maintained for each diesel-generator unit to provide a basis for an analysis of the unit's overall performance. The records shall be retrievable and shall provide a basis for verifying any assumptions made. The documentation may also be used to shorten or extend the replacement intervals or to extend equipment or station life. The records shall include, as a minimum, the following features:

a) All start attempts, including those from bona fide signals; maintenance, repair, and out-of-service time histories, as well as cumulative maintenance and operating data; cumulative statistical analysis of diesel-generator unit test results, together with results of operation of the diesel-generator unit when required by actual demand

b) Critical failure mechanisms, human errors, and common mode failures, including cause and corrective action

c) Test parameter data indicated in table 4 that may have application for reliability and data trending

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Annex A

(informative)

Method for establishing a load profile for a diesel-generator unit

The load profile shows the magnitude and duration of loads applied in a prescribed time sequence, including the transient and steady-state characteristics of the individual loads for the most severe conditions, including both the automatically and manually sequenced loads. The diesel-generator unit is typically specified in the design stage, before the actual characteristics of these loads are known. Most of these loads are applied to the diesel-generator unit in a combination of block loads, sequenced to best suit the design objectives of the power plant. The majority of these loads are induction motors. Knowledge of the characteristics of each load within the block load is essential to establish the rating of the diesel-generator unit, a critical application for accelerating large loads in rapid succession. To avoid confusion, the following data should be established to properly size the unit:

a) Available time to attain rated conditions preceding initial load acceptance

b) Identification of each load block and its application with respect to time sequence

c) Type of loads in each load block, e.g., transformer, induction motor or resistive load, pump, fan, etc.

d) Load characteristics:

   1) Transformer loads:

      i) Rated kilovoltamperes, percent impedance (minimum specified), or inrush kilovoltamperes at rated voltage

      ii) Connected load (power factor and characteristics)

      iii) Efficiency

   2) Resistive loads: kilowatts at rated voltage

   3) Motor loads:

      i) Rated nameplate voltage, frequency, and speed

      ii) Rated nameplate horsepower and horsepower at maximum operating conditions; for these conditions include current, power factor, and efficiency

      iii) Locked rotor characteristics at rated voltage, including starting power factor and locked rotor current (as percent of full load rating)

      iv) Acceleration conditions at rated and minimum required starting voltage, e.g., 75%, including starting profile as shown in figure A.1

NOTE—Depressed voltage below rated value at the motor terminals, resulting from transformer and distribution losses, will affect motor characteristics and should be identified.

Typical large motor characteristic values are:

— Horsepower, voltage, and frequency (nameplate)
— Locked rotor current (inrush) = 6.0–6.5 times rated (approximately 5.5–6.0 kVA/hp)
— Locked rotor power factor = 20%
— Breakdown kilowatts = 2.2 hp (typical)
— Running efficiency = 92%
— Running power factor = 85%
— Accelerating time = 2.5–4.0 s (loaded), 1.5 s (unloaded)

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4) Load profiles:

i) A typical load kW/kVA profile for starting the indicated block loads is shown in figure A.2.

ii) Most load profiles include a transformer or group of transformers to be energized. The inrush kilovolt-amperes of the transformer may result in an instantaneous voltage dip in excess of the specification. The effect of the voltage drop should be considered to the extent that it shall not degrade the performance of the design load.

NOTES
1—Various computer programs are available for analyzing performance of the diesel-generator unit under simulated operating and load conditions.
2—Provisions for manually added loads and future load growth shall be considered in developing the load profile.

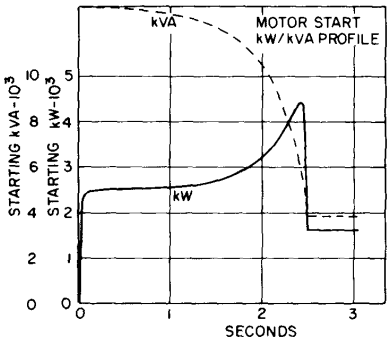


Figure A.1—Typical motor starting profile, kVA and kW versus time (shown at rated voltage)

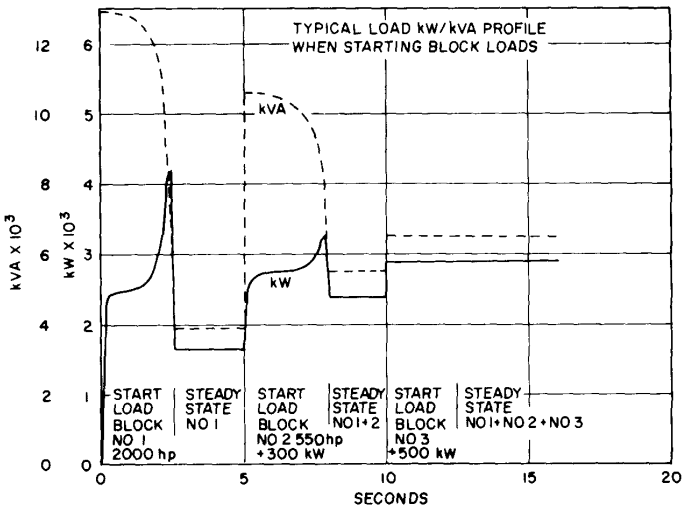


Figure A.2—Typical load profile, kVA and kW versus time for the various load blocks

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Annex B

(informative)

Example of aging and aged equipment testing[11]

B.1 Method of qualification

The process for addressing the effects of aging on a standby diesel-generator unit is described in this example. This example is an illustration only and is not necessarily meant to be universally applicable. For a typical application, consider a diesel-generator unit with the following basic equipment and conditions:

a) Generator: 7000 kW (8750 kVA), 4.16 kV, 60 Hz with static exciter

b) Engine: 7258 kW (9734 brake hp), 16 cylinders, 1551 kPa (225 lbf/in^2) break mean effective pressure, 450 r/min

c) Starting air: two independent systems, receiver, after-cooler, dryer, filter-direct injection at 1729 kPa (250 lbf/in^2)

d) Fuel oil: engine drive pump, strainer, filter, waste tank, waste ejector pump, day tank, booster pump

e) Cooling: water-to-water heat exchanger, standpipe, engine-driven pump, keep-warm pump and heater

f) Lube oil: strainer, filters, sump tank, engine-driven pump, keep-warm heater and pump, lube oil heat exchanger engine panel, generator

g) Miscellaneous: panel, neutral grounding equipment, intake filter, intake silencer, exhaust silencer

h) Service conditions:

   1) 6000 starts over a 40-year period

   2) 4000 operating hours over a 40-year period

   3) Temperature range 15–49 °C (60–120 °F) with a 24 °C (75 °F) average annual ambient

   4) Seismic response spectra supplied

   5) 1×10^4 rd of gamma radiation integrated dose over a 40-year period

   6) 0–95% relative humidity

   7) Load profile provided with 25% allowable voltage drop and 5% allowable frequency drop

   8) Elevation 188.5 m (620 ft) above sea level

   9) No unusual combustion air contaminants

   10) No. 2 diesel fuel

   11) AC power: 480 V ± 10%, dc power: 105–140 V

   12) CO_2 fire protection system

   13) Service water: 4.5–32 °C (40–90 °F) maximum, 6895 kPa (1000 lbf/in^2) pressure drop in cooling system at rated maximum flow, 3785 L/min (1000 gal/min) minimum

[11] See also 6.3.

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Following definition of the equipment and its conditions, the components are analyzed and categorized as safety related or nonsafety related. Justification is documented for those items categorized as nonsafety, typically as shown in table B.1.

Table B.1—Examples of nonsafety related components

Examples of nonsafety related components	Discussion
Starting air compressor/dryer	These components and any other items upstream of the safety-related isolation check valve are nonsafety related.
Neutral grounding transformer/resistor	Analysis of electrical system shows that possible failure modes (short, ground, open circuit) will not affect safety-related function, thus no electrical isolation is required.
Lube oil keep-warm pump and heater	The lube oil system is safety related, but these components are not. Pumping and heating of lube oil improves starting time and overall performance (only slightly), but is not required for a 10 s start and loading. Analysis or test is required to verify that, with the keep-warm systems inoperable, the 10 s criteria is still met.

For each of the items in table B.1, seismic analysis or testing is documented to ensure there will be no interference with the safety-related function of other components.

The next step in the process is to categorize all safety-related components as components with or without age-related failure mechanisms. Components with age-related failure mechanisms are required to be tested or analyzed to determine their respective qualified life. Components that are in the non-aging category require justification to show why they would not age under the circumstances. As described in 6.3.2 of this standard, this may be presented in tabular form.

Table B.2 illustrates some specific examples of the classification method.

Following identification and classification, the qualification shall be accomplished. Testing of the various components is preferred. For the control panels, the individual applicable components are aged, assembled in the unit or on a fixture (simulated mounting), and seismically tested. Documentation of post-test operational parameters is required. Burn-in of a unit with electronic components may be a part of the qualification process. For the generator, aging testing of winding materials is performed followed by seismic simulation. The generator assembly, overall, is seismically analyzed according to IEEE Std 344-1987.[12] For mechanical components, seismic analysis is accomplished where testing is impractical (e.g., air receivers, engines, and smaller mechanical off-engine components such as pumps, filters, strainers, etc.).

Complete documentation of all seismic test and analysis is required.

Radiation testing is not required for this example; a brief material analysis is sufficient.

[12]Standards referenced in this annex can be found in B.2.

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Table B.2—Aging classifications of safety-related components

Component	Items with age-related failure mechanisms	Method of aging qualification	Items without age-related failure mechanisms
Generator	Insulation materials	Accelerated aging per IEEE Std 275-1992	Rotor and stator steel } aging insignificant over 40 year objective
	Bearings	Abnormal wear identified through periodic testing and possible replacement	Uninsulated copper wire } aging insignificant over 40 year objective
	Brushes	Expected life based on operating experience and replacement interval identified (normal maintenance)	Copper busbar } aging insignificant over 40 year objective
Class 1E ac motors	Insulation materials	Accelerated aging per IEEE Std 117-1974 and IEEE Std 275-1992 or IEEE Std 334-1994	Rotor and stator steel
	Bearings	Abnormal wear identified through periodic testing and possible replacement	
Control panels	Circuit breakers and switches	Mechanical fatigue is predominant failure mode. Cycle 4000 times and accelerate age coils (as applicable) prior to seismic testing of panel.	Panel steel } aging insignificant over 40 year objective Copper busbar } aging insignificant over 40 year objective
	Electromechanical relays	Analyze operating modes and cycle accordingly. Accelerate age coil system per IEEE Std 117-1974 and IEEE Std 275-1992.	Wireways } material analysis and justification required Circuit board materials } material analysis and justification required
	Wire and cable including connectors and terminals	Accelerated age per IEEE Std 383-1974	
Governor/ tachometer and control	Gaskets and o-rings	Expected life based on operating experience and replacement interval identified (normal maintenance)	Metal chassis Certain electronic components: silicon semiconductors, resistors, ceramic capacitors, dry paper and film capacitors (reference discussion in IEEE Std 650-1990 and analyze application accordingly)

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Table B.2—Aging classifications of safety-related components *(Continued)*

Component	Items with age-related failure mechanisms	Method of aging qualification	Items without age-related failure mechanisms
Static exciter/ voltage regulator	Transformers and other magnetic components' insulation systems	Accelerated aging per IEEE Std 117-1974 and IEEE Std 275-1992. Transformers per IEEE Std 259-1994.	Metal chassis Certain electronic components: silicon semiconductors, resistors, ceramic capacitors, dry paper and film capacitors (reference discussion in IEEE Std 650-1990 and analyze application accordingly)
	Electrolytic capacitors	Expected life data from manufacturer used as guide to determine required periodic replacement interval	
	Circuit breakers, relays, switches	Mechanical fatigue is predominant failure mode. Cycle 4000 times and accelerate age coils (as applicable) prior to seismic testing of panel.	
	Wire and cable	Accelerated age per IEEE Std 383-1974	
Brushless exciter	Winding insulation	Accelerated aging per IEEE Std 117-1974 and IEEE Std 275-1992	Rotor and stator steel
Starting air solenoid valves	Coil insulation; gasket, o-rings, discs, wire and cable	Accelerated aging per IEEE Std 117-1974 and IEEE Std 275-1992. Periodic replacement interval as required. Accelerated aging per IEEE Std 383-1974. (NOTE—The above is all inclusive; however, an overall program similar to IEEE Std 382-1985 is acceptable.)	Metal enclosure
Engine and mechanical auxiliaries	Gaskets, o-rings, seals, etc.	Expected life based on operating experience and replacement interval identified (normal maintenance)	Metallic components not subject to wear
	Metallic components subject to wear (valves, pistons, bearings, etc.)	Abnormal wear identified through periodic testing and inspection, followed by possible replacement	

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B.2 Bibliography

[B1] IEEE Std 117-1974 (Reaff 1991), IEEE Standard Test Procedure for Evaluation of Systems of Insulating Materials for Random-Wound AC Electric Machinery (ANSI).

[B2] IEEE Std 259-1994, IEEE Standard Test Procedure for Evaluation of Systems of Insulation for Specialty Transformers (ANSI).

[B3] IEEE Std 275-1992, IEEE Recommended Practice for Thermal Evaluation of Insulation Systems for Alternating-Current Electric Machinery Employing Form-Wound Preinsulated Stator Coils for Machines Rated 6900 V and Below (ANSI).

[B4] IEEE Std 334-1994, IEEE Standard for Qualifying Continuous Duty Class 1E Motors for Nuclear Power Generating Stations (ANSI).

[B5] IEEE Std 344-1987 (Reaff 1993), IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations (ANSI).

[B6] IEEE Std 382-1985, IEEE Standard for Qualification of Actuators for Power Operated Valve Assemblies With Safety-Related Functions for Nuclear Power Plants (ANSI).

[B7] 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).

[B8] IEEE Std 650-1990, IEEE Standard for Qualification of Class 1E Static Battery Chargers and Inverters for Nuclear Power Generating Stations (ANSI).

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Annex C

(informative)

Recommended diesel-generator unit monitoring and trending parameters

C.1 General

The industry and regulatory philosophy is shifting away from reliance on statistical testing and toward monitoring and trending to facilitate aging/reliability determinations. This annex lists parameters and gives information generally useful for this purpose. The required data may be obtained by monthly testing. The test duration should be adequate to obtain several sets of data to confirm engine and generator operability.

C.2 Purpose

The purpose of the monthly tests is to perform a “health check” of the engine and generator system. If most of the recommended parameters are checked each month, immediate engine condition is determined. By trending certain parameters, the long-term degradation mechanisms can also be determined. These parameters may be recorded each month for unit management purposes.

C.3 Recommended parameters

Table C.1 lists monitoring and trending parameters generally useful for determining the status of important engine and generator parameters. Many installations have the necessary sensors and gages already in place to obtain this data. Some installations have fewer sensors and gages installed. Where additional sensors and gages are needed, commercial grade components may be installed since the data is advisory in nature. These commercial grade components would not jeopardize the unit safety function if they fail to operate.

The regular review and use of these recommended parameters should increase the unit reliability and reduce aging concerns by detecting substandard performance early before failures occur. Monitoring and trending use in diesel-generator unit management is now generally considered more practical for reliability assurance than depending upon start and run statistical information.

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Table C.1—Monitoring and trending parameters

Parameter and general data required	Primary use of data
Generator data	
Winding temperature	• Evaluate condition of windings • Detect loss of cooling capacity
Bearing temperature (one or two bearings) Oil temperature	• Detect scuffed bearings
Engine cooling water	
Water pressure to engine	• Ensure engine operability (mission safety) • Detect plugged jacket water system
Water temperature to and from engine	• Monitor control valve operation • Monitor heat exchanger performance • High engine load will increase temperature difference
Water temperature to and from engine water cooler (could be radiator)	• Monitor heat exchanger fouling • Detect incorrect control valve operation
Water temperature to and from raw water cooler	• Monitor cooler fouling • Water pump operation
Water temperature to and from turbocharger	• Fouling of turbocharger • Monitor turbocharger loading
Water temperature to and from turbocharger after cooler	• Monitor cooler fouling
Water pressure and temperature to and from lube oil cooler	• Monitor cooler fouling
Lubricating oil	
Oil pressure to engine	• Ensure engine operability • Detect filter plugging • Troubleshooting for regulating valve and engine wear • Detect incorrect oil viscosity (too low or too high)
Oil temperature to and from engine (oil sump temperature)	• Detect fouling of heat exchanger • Monitor control valve operation
Oil pressure to and from lube oil filter	• Detect filter element plugging • Detect damaged elements (low delta p)
Oil temperature to and from lube oil cooler	• Detect cooler fouling • Monitor control valve operation
Oil pressure to and from lube oil cooler	• Detect cooler fouling
Oil pressure to turbocharger	• Detect incorrect pressure regulating valve setting
Oil temperature to and from turbocharger	• Monitor turbocharger bearings • Detect incorrect oil

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Table C.1—Monitoring and trending parameters *(Continued)*

Parameter and general data required	Primary use of data
Air to engine	
Ambient air temperature, barometric pressure, and relative humidity	• Needed for monitoring standard air conditions and efficiency calculations
Air pressure and temperature to turbocharger	• Turbocharger efficiency calculations
Air pressure to and from after-cooler	• Turbocharger efficiency calculations • Detect air side cooler fouling
Exhaust	
Exhaust temperature out of each cylinder (cylinder no. 1, no. 2, etc.)	• Monitor fuel injector performance • Detect broken rocker-arms, worn rings, or valve problems • Acceptable balance between cylinders
Exhaust temperature to turbocharger turbine (pre-turbine temperature); more than one thermocouple may be required	• Turbocharger efficiency • Safety to ensure temperature limit to turbocharger is not exceeded
Exhaust temperature from turbine	• Monitor turbocharger performance
Fuel oil	
Fuel oil pressure to and from engine filter	• Detect filter plugging or damage
Fuel oil pressure to and from fuel oil pump	• Monitor regulating valve adjustment • Monitor pump wear
Fuel pump rack setting	
All cylinders	• Compare to exhaust temperatures for performance (both should be reasonably even) • Monitor cam timing • Detect uneven cylinder compression pressure
Miscellaneous data	
Turbocharger r/min	• Monitor turbine efficiency • Detect fouling of compressor discharge • Detect poor engine combustion
Crankcase vacuum or pressure	• Monitor excessive ring blow-by • Detect faulty ejector
Amount of oil added	• Monitor engine operation and ring wear
Lubricating oil analysis (recommended quarterly)	• Detect wear particles • Monitor fuel oil dilution
Engine cooling water analysis (recommended quarterly)	• Detect corrosion products • Ensure correct water chemistry

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Annex D

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Diesel-generator unit reliability program elements

D.1 General

Nuclear power generating stations are developing formal reliability programs for the installed diesel-generator units. Guidelines for an effective program have been developed and published by the Nuclear Management and Resources Council (NUMARC), now known as the Nuclear Energy Institute (NEI). This description is intended to highlight the technical points and major diesel-generator unit reliability program elements that should be universally applicable. Station specific administrative details and supporting formal procedures should be developed to amplify these major reliability elements.

D.2 Major reliability program elements

The principal elements of an effective diesel-generator unit reliability program are the following:

a) Overall diesel-generator unit reliability program plan
b) Defined management and technical responsibilities for each program element
c) Plant-specific surveillance and monitoring plan
d) Plant record and data management system designed for easy data retrieval
e) Defined maintenance program with a reliability focus
f) Procedures for failure identification, root cause analysis, and future failure prevention
g) Procedures and criteria for problem closeout and follow-up

D.3 Element discussion

The principal element of a reliability program is an overall plan. The plan should specifically address all other plan elements by addressing their appropriate importance in an integrated manner. Plan procedures, surveillance, training, monitoring and trending, and failure resolution documentation should all be a part of the reliability plan.The management and technical responsibilities for each program element should be established in written procedures. The plan should address training of qualified personnel in detailed engine and governor maintenance procedures similar to that offered by manufacturers of this equipment. An overall responsibility for diesel-generator unit related matters and coordination may give the best results.

The periodic testing and monitoring element should address reliability by use of monthly system operation intended to determine the condition of important engine/generator parameters. These typically should consist of oil, water, and gas temperatures and pressures in the various engine subsystems during operation and while generating power equal to the plant emergency power requirements. Daily, weekly, monthly, and quarterly surveillance should also be specified. Engine and generator operating parameters and surveillances associated with degraded performance and aging should be trended, where such trending could detect incipient failures and permit corrective maintenance before the actual failure occurs.

A record and data management system, designed for easy data retrieval, should be available for use by plant personnel. Diesel-generator unit records are important and should support the other program elements. Measures should be taken to safely store these records and prevent their loss. A computer-managed system is recommended to reduce costs and improve access to the data.

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The maintenance program should have a reliability improvement intent. In some cases, past practices of certain preventive maintenance procedures and routine disassembly for inspection purposes have been shown to have negative results on reliability. A good maintenance program should, over time, eliminate those procedures. Systems with higher failure rates, such as the instrument and control system, should receive additional maintenance effort for improved reliability. Diesel-generator unit system modifications may be included in the plan under the maintenance responsibilities. Reliability considerations should be a part of the modification review process.

Failure identification, analysis for failure root cause, and correction should be defined in procedures. Each analysis should have the intent to reduce failures by identifying a corrective action to prevent future failures. For some failures of an intermittent nature, it may be impossible to assign an exact root cause.

Problem closeout should include follow-up to ensure that the problem has been corrected and that related problems are not recurring. Failures with a recurring root cause show that corrective actions taken in the past were not correct and a new analysis should be performed with a more appropriate corrective action as the expected result. The plant records should be reviewed for each analysis and problem closeout to ensure that recurring failures are eliminated.

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