11. QUALIFICATION, SITE ACCEPTANCE AND SURVEILLANCE TESTING

Learning Objectives

The primary objectives for this lesson are to present the tests that EDGs are subjected to: (1) during their initial "type qualification" for nuclear service, (2) by the EDG supplier, upon installation at the site, to demonstrate compliance with the purchase contract, (3) as part of the licensee's pre-operational tests to verify performance and develop baseline data, and (4) during regular surveillance runs by the licensee. A typical surveillance run will be outlined, including the control of KW and KVAR load with the EDG connected to the grid. To reinforce this material, the lesson will then conclude with some comments about EDG selection, plus operational examples that help explain the relevance of these tests to actual operations.

Upon completing this lesson, students will have a better understanding of:

1. How EDGs are type-qualified for nuclear power plant service.
2. Installation, break-in run, inspection, and full load run by the EDG supplier.
3. The licensee's pre-operational test program to verify EDG performance and establish critical baseline data.
4. The licensee's ongoing surveillance testing of their diesel generators.
5. A typical EDG surveillance run by the licensee, including control of KW and KVAR loading when on the grid.
6. Comments on the relevance of this material to EDG selection/operation.

NOTE: Principle design and application criteria for EDG units in nuclear power plants are listed in Clause 4 and Table 1 of IEEE 387-1995. Chapter 1 of this Manual introduced the fundamental goal of 4000 EDG starts and 6000 operating hours over a service life of 40 years. Other important design criteria include the maximum and minimum temperatures and humidity to which equipment will be exposed, seismic response spectra, radiation, barometric pressure (altitude), potential contamination of combustion air or support systems by salt spray / sand / dust, the service water quality and temperature, and also the effect of potential events such as severe weather and possible actuation of the fire protection system. The focus of this Chapter is on EDG testing but some of the above design criteria are factors in the case histories discussed in other parts of this Manual.

11.1 EDG Type Qualification Tests for Nuclear Service

In order for a diesel generator to be used as an on-site emergency standby power source at a nuclear power plant, it must first be "type qualified" for that service by successfully passing rigorous performance tests and analyses to prove it can perform its intended function. Regulatory Guide 1.9 (now Revision 4, March 2007) contains the basic requirement for that and IEEE 387 (1995 edition) provides detailed guidance. Prior qualification of an EDG of similar design is permitted to be used to reduce the testing and analysis required. Analysis is most often used when testing is seen as impractical or unneeded.

The initial "type qualification tests" for EDGs are listed and discussed in Clause 6 of IEEE 387-1995, "Standard Criteria for Diesel-Generator Units Applied as Standby Power Supplies for Nuclear Power Generating Stations." Diesel generator qualification tests may be performed by the manufacturer or by an independent third party supplier. *The latter arrangement is most likely due to the manufacturer of the engine-generator set not maintaining an approved 1O CFR 50 Appendix B quality assurance program.* Usually, qualification is completed by the manufacturer, prior to delivery of the EDG units to the plant site. In a few early 1970's vintage plants, part or all of the EDG type qualification testing was conducted on-site. This was because the IEEE 387 type qualification tests were not formally endorsed by Regulatory Guide 1.9 until after manufacture and delivery of the EDGs to those early nuclear plant sites. Modified qualification testing was agreed to by the licensees and performed on-site.

11.1.1 Three Basic "Type Qualification" Tests for Nuclear Service EDGs

The tests outlined in Clause 6 of IEEE 387-1995 will be covered in more detail later in this Chapter. The present discussion will serve to introduce the three basic tests that are used to verify the ability of an EDG to perform its design basis mission. They are:

Load Capability Tests:

This is to demonstrate the EDG's ability to carry the following loads at rated power factor, for the periods of time indicated, to successfully reject a heavy load, and also to operate at light load (or no load) as specified by the manufacturer.

1. Carry load equal to continuous rated load for time required to achieve engine temperature equilibrium, followed by:

2. Carry the short-time rated load for 2 hours and the continuous rated load for 22 hours. These different loads are permitted to be applied in either order.

3. Complete a load rejection test at the short-time load rating. Speed increase shall be less than 75% of the difference between nominal speed and the over-speed trip set-point, or 15% over the nominal (60Hz) RPM, whichever is less.

4. Complete light/no-load test equal to the design light load, for allowed duration. (Follow with ≥50% load for ≥0.5 hour.)

Start and Load Acceptance Tests:

This is a very intense and grueling portion of the qualification tests. It requires starting and loading an EDG, or group of EDGs of the type being qualified, to verity the capability to start and accept load within the time permitted by the plant design basis. A total of 100 starts are performed, with zero failures permitted. (Previous editions of this Standard required 300 starts, with no more than 3 failures.) If multiple engines are used, to speed up the testing, each engine must be tested for Load Capability, and Margin (the latter test is discussed on the next page). Additional test criteria can be found in Clause 6.2.2 of IEEE 387-1995.

This effort can also be challenging to the test facility, as it is very labor intensive and takes weeks (or even months) to complete, depending on any problems or failures. An overview of these tests follows:

1. Start and achieve specified voltage and frequency within the required time.

2. Immediately accept a single step load equal to or greater than 50% of the continuous kilowatt (KW) rating.

3. At least 90 of these tests shall be with the EDG initially at warm-standby, with lube oil and water jacket temperatures being kept at or below the values recommended by the mfr. After load is applied, run until temperatures are stabilized at normal levels for the load.

4. At least 10 of these tests shall be with the engine at its normal operating temperatures for the load ("hot start").

5. Any failure requires a design review, corrective action, and continuation of the tests until reaching 100 consecutive starts without failure.

NOTE: Allowance is made to disregard any test start categorized below, and resume the test sequence without penalty:

A. Unsuccessful attempts that are clearly the result of operator error.

B. Tests performed to verify a scheduled normal maintenance procedure.

C. Tests performed for troubleshooting purposes, defined as such in advance.

D. Successful start attempts which were terminated intentionally, without loading.

E. Failure of any temporary service system or any temporary hookup that will not be part of the permanent EDG installation.

Margin Tests (transient conditions):

This is a series of extra high stress tests intended to demonstrate that the EDG has a performance safety margin for that plant's design. It requires two or more loaded run tests applying loads greater than the most severe step load in the plant design profile, including step changes above a base load (any steady point on the loading profile). The limiting case (worst case) step change over base load, as defined by the design load profile, shall be demonstrated.

"Worst case" is not necessarily the largest single step load, as the most severe step may be a smaller load applied as the EDG's full-load capability is approached. However, a margin step load at least 10% greater than the magnitude of the most severe single-step load within the load profile is deemed sufficient for the margin test. The criteria for margin tests are:

1. Demonstrate the ability of the generator, exciter, and automatic voltage regulator to accept the margin test load (usually a low power factor, high inrush starting current to a pump motor), without generator instability resulting in voltage collapse or inability of the voltage to recover.

2. Demonstrate the ability of the engine and its speed-regulating governor to accept that load without stalling, and to recover to normal operating speed.

NOTE: Frequency and voltage excursions recorded during this test may exceed those values specified for the plant design load, as this test load should never be reached in the course of normal emergency service.

11.1.2 Additional EDG Evaluation by Test or Analyses

Aging of Components and Assemblies:

Clause 6 of IEEE 387-1995 introduced comprehensive evaluation of ageing over the design life of the EDG plant. Those components and assemblies required to enable the unit to meet its design capabilities were deemed "safety-related." Examples include starting air solenoid valves, the governor, functionally required gaskets/seals for which failure (leakage) would degrade performance, and electrical cable (discussed in a subsequent chapter).

Other, nonsafety-related components and assemblies still require verification that they will not degrade a safety-related function. This may be done by testing, analyses, or a combination of test and analysis.

For those components and assemblies that were classified as safety-related, their age-related failure mechanism potential must be evaluated. Those with significant potential for age-related failures must be qualified by testing (preferred), analysis, or both. The components with a qualified lifetime less than the EDG system life objective shall have a maintenance/replacement interval defined. If aging by test is used, it must be followed by seismic qualification to meet IEEE 344-1987.

Seismic Qualification Requirements

Seismic qualification per IEEE 344-1987 is required for all safety-related components. Nonsafety-related components require analysis/test to show they will not degrade the EDG's safety-related function during a seismic event. Seismic testing shall be followed by functional testing to verify the relevant principle design criteria covered in Clause 4 of IEEE 387-1995.

11.1.3 Analysis/Test of Design Change to EDG Previously Qualified

Any design change or modification to a previously qualified EDG must be tested and/or analyzed "as needed" to assess the impact on performance. IEEE 387 requires that changes be analyzed to determine if the degree of change is major or minor:

Major changes to a qualified EDG, such as a difference in the number of cylinders, stroke, bore, BMEP, running speed, or how the engine-generator is configured shall require requalification (as if a new design).

Minor changes to a qualified EDG, such as component parts substitution, shall be qualified by analysis, or testing, or both.

The category assigned to a (proposed) design change or modification is influenced by the use of that part or design feature in other EDGs (especially of the same series) and by experienced engineering judgment.

11.2 "Factory" Production Testing

Clause 5 of IEEE 387-1995 requires that EDGs have "factory" production tests as described below. However, these may be done by the manufacturer or the supplier, at the factory, at the assembler's facility, or on-site after delivery to the NPP. Typically the manufacturer will have run the engine briefly at the factory, followed by a lower end check for potential problems, but the following tests are most often done on-site:

1. Initial "break-in" run as recommended by the manufacturer.

2. Load the engine as follows, using either a dynamometer or generator: (These tests may be run in any order). One hour at 50% of the continuous rating, one hour at 75%, two hours each at 100% and 110%. *Log data per 5.2.1 of IEEE 387-1995*. Set and check engine-mounted alarms and shutdowns. Perform and document post-test inspections per mfr's spec.

3. Generator shall be tested per NEMA MG 1-1993.

11.3 Initial On-Site Set-up of EDG

Factory/supplier field service and utility personnel conduct on-site inspections, adjustment, and testing to assure the EDG will perform satisfactorily on location. If the "factory" tests discussed in 11.2 are done on-site, they would follow this initial set-up. The tasks listed below illustrate how much is involved in a typical EDG set-up on-site:

1. Remove shipping restraints and covers.

2. EDG base anchor setting followed by an acceptance alignment of the generator and engine, verified by crankshaft web deflection checks.

3. Engine internal checks and inspections, including:

   - Internal cleaning and flushing to remove protective coatings.
   - Bearing clearance (including thrust)
   - Cylinder bore and clearance/gap.
   - Valve train set-up and clearance.
   - Fuel injection component checks.

4. Engine speed-regulating Governor set-up and calibration.

5. Engine over-speed Governor set-up and calibration.

6. Engine trip and alarm relay calibrations.

7. Generator internal checks, including:

   - Rotor to stator gap and concentricity
   - Insulation resistance (megger test)
   - Slip ring and brush alignment, condition, and brush tension check.

8. Automatic voltage regulator set-up and calibration.

9. Generator output breaker installation and alignment in the cubical, trip and auxiliary relay calibration, and auxiliary contact operation checks.

10. Generator-Emergency (Class 1E) Bus automatic load sequencer or load sequence relay checks, calibration.

11. Engine Air start system, including:

    - Pressure integrity tests.
    - Relief valve tests.
    - Air Compressor setting, alignment, and motor phase rotation checks.
    - Air Compressor capacity; confirm time to fill the air receiver.
    - Air pressure switch setpoint calibrations, including verification of compressor starting (low) and stopping (high) pressure settings.

12. Fuel Storage and transfer system, including the following:
    - Pressure integrity tests (no leaks).
    - Pressure relief valve tests.
    - Fuel oil storage tank capacity and fill level monitor calibration checks.
    - Fuel filter and strainer checks.
    - Off-skid fuel oil transfer pump setting, motor-pump alignment, and motor phase rotation checks.
    - Transfer pump capacity checks, where the time to fill the fuel oil day tank is confirmed.
    - Fuel Oil Day Tank Transfer Pump level control switch calibration, including verifying starting (low) and stopping (high) level settings.
    - Verify fuel oil is per manufacturer's specs for site ambient conditions.
    - Fuel Oil Day Tank Transfer Pump overfill ("high-high") level setpoint calibration (trip and alarm).

13. Lube oil system checks, including:
    - Pressure integrity test.
    - Relief valve setpoint test.
    - Off-skid lube oil pump setting and alignment, plus (if applicable) motor phase rotation check.
    - Lube oil pump capacity test.
    - Oil filter and strainer checks.
    - Lube oil system pressure switch setpoint calibration.
    - Lube oil system temperature switch setpoint calibration.
    - Lube oil sump level verified.
    - Lube oil quality samples taken for analysis to verify spec compliance.

14. Cooling system checks, including:
    - Pressure integrity tests.
    - Relief valve tests.
    - Off-skid coolant pump setting and alignment; motor phase rotation verified (if applicable).
    - Coolant pump capacity verified.
    - Coolant pump pressure switch setpoint calibrations.
    - Coolant system temperature switch setpoint calibration.
    - Coolant expansion tank level.
    - Coolant quality samples taken for analysis.

15. Ventilation system checks, including:
    - Fan alignment and motor phase rotation verified.
    - Fan balancing.
    - Fan flow and distribution verified.
    - Ventilation system temperature switch high and low calibration.

All the above pre-operational inspections, checks, and tests are to verify that the EDG is properly assembled, anchored, and set up, the support systems and their controls are properly configured and functioning, and also that coolant, lube oil, and fuel oil compliant with the specs are present in the proper quantities. At this point the EDG is ready for initial site acceptance tests and subsequent transfer to utility ownership.

11.4 Site Acceptance Testing

Upon completion of system, subsystem, and component level checks and tests associated with EDG initial set-up, the following on-site acceptance tests are conducted. These are full scope tests to demonstrate the capability of the unit to perform its intended function, as installed. They are described in IEEE 387-1995 Clause 7 and listed in Table 3.

Starting Test: Demonstrates the capability to attain and stabilize rated frequency and voltage within the limits and time specified.

Load Acceptance Test: Demonstrates the capability to accept the individual loads that make up the design load at that NPP, in the desired sequence and time duration, while maintaining voltage and frequency within acceptable limits.

Rated Load Test: Demonstrates ability to carry the following loads without exceeding the manufacturer's design limits: (1) A load equal to the continuous rating, maintained until engine temperatures reach equilibrium plus one hour, followed by (2) The rated short-time load, applied for two hours.

NOTE: The short-time load is typically 110% of the continuous rating and by definition can be applied 2 of each 24 hours (with the other 22 hours at continuous load) without exceeding design limits or requiring less time between maintenance intervals.

Electrical Tests: Verify characteristics of the generator, excitation system, voltage regulation system, engine governor, and the control and surveillance systems.

Subsystem Tests: Demonstrate control, protection, and surveillance systems are in accordance with requirements.

11.5 Pre-Operational EDG Testing

Following completion of site acceptance testing, pre-operational tests are performed to demonstrate starting and operational adequacy of the system. These are as listed in Table 3 (reproduced herein) and described in Clause 7.5 of IEEE 387-1995.

Whereas the Site Acceptance tests formed the basis for the utility to consider the EDG acceptable for its initial use, and to make final payment to the manufacturer, the Pre-Operational tests are the first regulatory-based site tests in which the licensee must legally demonstrate and document EDG performance. As "Pre-Operational" implies, they are a prerequisite to declaring the site emergency power system operational.

During the course of the pre-operational test program, the EDG is started using all of the following methods:

- Manual Start pushbuttons, both from the Control Room and at the EDG local control panel.
- Simulated Loss-of-Offsite Power event (LOOP), from the ESF bus "27" relays.
- Simulated Safety Injection Actuation Signal (SIAS) from the Reactor Protection System (RPS).
- Combined LOOP and SAIS signals

Unlike Qualification, "Factory" and Site Acceptance testing, the Pre-Operational tests confirm proper functioning of all logic circuits and controls programming. Generic Letter 96-01 addresses that requirement.

NOTE: For all on-site testing, including Pre-Operational and Availability tests, follow the manufacturer's recommendations for reducing engine wear. These include engine pre-lube, use of keep-warm system (if provided), and a cool-down at reduced power following the test run. This issue will be discussed in a later chapter, as some licensees continue to subject their EDGs to unnecessary stress and wear by running rapid cold start tests with immediate heavy step load.

Before discussing Pre-Operational tests it may be helpful to describe the sequence of events that occur when offsite power is lost: Voltage sensing relays in the ESF bus trip the related offsite power supply breaker and shed non-permanent bus electrical loads. The EDG receives a start signal and loading is initiated when sensors report it has reached pre-determined speed and voltage. The EDG output breaker will then close, picking up ESF bus permanent loads immediately. Auxiliary contacts in the outbreak breakers also close, energizing logic sequencers that control sequential loading of the ESF bus by larger loads.

Reliability Test: This is to demonstrate that an acceptable level of reliability has been achieved to place the new EDGs into operation. It requires a minimum of 25 valid start and load tests without failure, on each installed EDG.

Slow-Start Test: This is only to verify design frequency and voltage are attained. As the name implies, the unit is slowly brought up to speed, on a prescribed schedule that minimizes stress and wear.

Load-Run Test: This demonstrates basic load-carrying capability, equivalent to 90-100%, for not less than 1 hour. It may be run by synchronizing the unit with the grid in order to achieve the required load and PF. Again, loading and unloading are gradual, to minimize stress and wear.

Fast-Start Test: Each EDG unit will be started from standby conditions to verify that it reaches the required voltage and frequency within acceptable limits and time. There is no loading with this test.

NOTE: From this point forward, the Pre-Operational tests become more demanding in order to more closely simulate various emergency demand start scenarios and verify control systems are properly set up.

Loss-of-Offsite Power (LOOP) Test: A LOOP event is simulated as follows.

- Emergency buses are de-energized and the loads are shed
- EDG must start, attain required voltage-frequency within acceptable limits and time, energize the auto-connected shut-down loads through load sequencer, and operate a minimum of 5 minutes.

Safety Injection Actuation Signal (SIAS) Test: This demonstrates that on SIAS the EDG starts from its standby condition upon receipt of the auto-start signal, attains the required voltage and frequency within limits, and operates 5 minutes at no load.

NOTE: During a plant emergency in which Safety Injection cooling is required the plant Main Turbine Generator will be off-line, due to loss of steam supply. The risk of grid destabilization and loss of the preferred (offsite) power supply is increased. The intent of this test is to confirm that upon an SIAS signal the EDG will start to a running standby mode, ready to accept ESF bus loads in the event a LOOP event occurs. That places the EDG in the best possible status to immediately accept loads upon breaker closure and thereby minimize the disruption of SI reactor cooling.

Combined SIAS and LOOP Test: This combines the two tests immediately above, and applies the same pass/fail criteria.

Largest-Load Rejection Test: When the largest single load is shed the EDG must stay within acceptable voltage-frequency limits and also not trip out on over-speed.

Design Load Rejection Test: The EDG must not trip out on over-speed when it sheds a load equal to 90-100% of design loads. (There are no limits on voltage/frequency excursions, as this scenario presumes that all loads have been shed.)

NOTE: Preventing over-speed trip of the EDG is critical when all loads have been lost. This minimizes EDG recovery time for restoration of service to the related ESF bus electrical loads. Once the cause for full load rejection is isolated and corrected, the EDG output breaker can quickly be re-closed to restore electrical service to the ESF bus.

Although over-speed is an unacceptable outcome of the load rejection test, it may occur in which case manual reset of the over-speed trip latch is required. Several events have occurred as a consequence of failure to reset the over-speed trip latch. Immediate trips have occurred on startup. Delayed trips have occurred when the latch was not fully reset and vibrated loose during a run. (See IN 93-96 for details.)

Endurance and Load Test: Demonstrates capability to carry heavy loads for at least 24 hours, of which 2 hours should be the short-time rating, and 22 hours is 90-100% of the continuous load rating. Voltage and frequency criteria must be met throughout. Presumably the loads may be applied in either order, as is explicitly permitted for basically the same EDG qualification test, Load Capability, part (2). See 11.1.1.

Hot Restart Test: Demonstrates capability to restart immediately after a run at full load has stabilized engine temperatures at their full load values. (This can reveal one potential failure mode: Badly leaking fuel injectors in a hot engine can create a vapor lock that is sufficient to prevent a restart.)

NOTE: As with previously described Slow Start and Fast Start tests, the Hot Restart test does not involve applying load to the EDG. These tests just confirm that it can achieve the running standby mode, ready to accept loads. In the running standby mode, control is as follows:

- EDG is at rated speed and frequency, with frequency control on the governor.
- Generator is at rated voltage, controlled by the Automatic Voltage Regulator.

Synchronizing Test: This demonstrates ability to transfer emergency loads from the EDG to normal (offsite) power. It involves synchronizing the EDG with the grid, then transferring its load back to offsite power, isolating the diesel-generator unit from the grid, and restoring it to standby status.

Protective Trip Bypass Test: This is to verify that protective trips are bypassed in emergency operation as designed. In most facilities, engine over-speed and generator differential current trip are not bypassed.

Test Mode Override Test: Demonstrates that with the EDG operating in automatic test mode while connected to its bus, a simulated SIAS overrides test mode by:

- Returning EDG to standby operation
- Automatically energizing emergency loads from offsite power

Independence Test: This demonstrates that simultaneously starting and running redundant EDG units does not result in any potential common failure modes that may be undetectable in single-unit tests.

11.6 Periodic Testing (Surveillance)

Periodic tests demonstrate the continued capability of the EDGs to start and accept loads. They consist of availability, system operation, and independence verification tests. See Table 3 from IEEE 387-1995, reproduced in this Chapter as Figure 11-1.

11.6.1 Availability Test: Each EDG unit shall be started and loaded at least once in 31 days (slow start and load-run test, to minimize engine stress and wear). Every 6th month, a combined Fast-Start, Load-Run test shall be done, simultaneously satisfying the Availability Test and that one semi-annual test requirement.

NOTE: IEEE 387-1995, Clause 7.4.2.1, can be interpreted differently. However, RG 1.9 (2.3.2.2) makes the intent clear, as above.

11.6.2 System Operation Tests: This is a series of tests to verify the ability of the EDG to perform its intended function under simulated accident conditions. These tests shall be performed at shutdown/refueling outages (typically once every two years).

The System Operation Tests listed in Table 3 have all been described previously in this Chapter. They include the following:

- Slow-Start
- Load-Run
- Fast-Start
- Loss-of-Offsite Power (LOOP)
- Safety Injection Actuation (SIAS)
- Combined SIAS and LOOP
- Largest-Load Rejection
- Design-Load Rejection
- Endurance and Load
- Hot Restart
- Synchronizing
- Protective-Trip Bypass
- Test Mode Override
- Independence (Verification)

Independence Verification Test: Following any modifications where the independence of EDG units may have been affected, or at least every 10 years during plant shutdown or refueling outage, an independence verification test shall be performed. (This subject will be included in the case history discussions of Chapter 13.)

11.7 Records for Each EDG Unit

Extensive records shall be maintained and retrievable for each EDG unit to provide a basis for analysis of its performance, to verify assumptions made, and to extend or shorten equipment maintenance intervals and replacement schedules. The records must include the following, as a minimum:

a) All start attempt, maintenance, repair, and out-of-service histories, cumulative operating and maintenance data, statistical analysis of EDG test results as well as actual demand runs.

b) Critical failure mechanisms, human errors, and common mode failures, with causes and corrective actions included.

c) Test parameter data in accordance with IEEE 387-1995, Table 4, which lists minimum engine operating data that must be maintained. (See Figure 11-2, herein.)

NOTE: All nuclear plants are required to have a program or measures in place to address corrective actions, in accordance with 10 CFR 50, Appendix B, Criterion XVI. An effective corrective action provides the means for analyzing problems, finding root causes, developing corrective actions, and implementing solutions.

11.8 Concerns about the Adequacy of Licensee Periodic (Surveillance) Testing

The NRC issued Temporary Instruction (TI) 2515/176 in May, 2008, to address their concerns regarding the adequacy of EDG surveillance testing. The catalyst for this action was a finding that endurance tests at Dresden NPS did not adequately verify EDG operability because test loading did not envelop the predicted design-basis event (DBE) loading. The inconsistency was subsequently identified at other sites. Further, the NRR staff also identified issues related to test loading requirements, peak design-basis loading values and durations, and EDG ratings when reviewing license amendment requests to correct endurance and margin testing acceptance criteria. Therefore, NRR staff issued the above TI to assess the extent of these issues and to evaluate the adequacy of EDG testing as prescribed in plant-specific TS and design bases.

EDG loading is generally designed for a concurrent loss-of-offsite power and a loss of cooling accident (LOOP+LOCA). The loading profile for a concurrent LOOP and large-break (LB) LOCA is typically high. However, at some sites the calculated load values were greater for a LOOP coincident with a small-break (SB) LOCA or a main steamline break (MSLB) than they were for the presumptive LOOP-LBLOCA. The timing of these events can also have an impact on the resulting load, depending on which one occurs first and the time interval between them. Furthermore, the definition of "short-time rating" is subject to some interpretation, as engine manufacturers typically have several ratings higher than "continuous" (e.g., for running intervals of 2000, 4, 2, and 0.5 hours).

TI 2515/176 requested the collection of extensive data for every EDG used as an onsite standby power supply, as the first step in addressing this general concern. This will be a current topic for years, until completion of analyses, follow-up, and needed corrective action by licensees.

11.9 NRC Position on the Use of EDGs for Peaking

Branch Technical Position ICSB-8 (PSB), "Use of Diesel Generator Sets for Peaking."

The Instrument and Controls Systems Branch issued this technical position in 1981 concluding that "... the potential for common mode failure modes should preclude interconnection of the onsite and offsite power sources except for short periods for the purpose of load testing."

Clearly, the use of EDGs for peaking is strongly discouraged, if not prohibited. Both EDG systems should never be run in parallel with the grid at the same time, as a power line drop, a plant substation fault, or transient could take out both standby power systems at the same time, leaving the station very vulnerable to a subsequent LOOP event or other emergency.

11.10 Observations on EDG Control When in Parallel with Grid

Monthly EDG Load-Run tests are usually accomplished by synchronizing with the grid in order to facilitate achieving the required load. Achieving the proper load (90-100% of continuous), while avoiding potential problems related to running in parallel with the grid can sometimes pose a challenge to the EDG operator.

11.10.1 Frequency–Load Control Issues When Connected to the Grid

There can be several causes for EDG frequency-load changes or swings while connected with the grid. The EDG cannot have significant impact on the grid but can certainly be affected by grid changes.

Slight grid frequency changes show up as KW load swings on the EDG. Therefore, one of the causes for EDG load swings while connected to the grid are slight variations in grid frequency. Obviously, since the plant EDG operator has no direct ability to control grid frequency, slight adjustments in EDG speed governor reference frequency are often required over the duration of the loaded run test.

- If grid frequency drops in relation to EDG reference frequency, the EDG picks up more grid KW load. It could trip from overload when conducting rated load and overload testing.

- If grid frequency increases in relation to EDG reference frequency, the grid takes KW load off the EDG. It could trip from reverse power if synchronized and operating at low loads.

Slight changes in the EDG governor circuit can result in EDG speed reference signal anomalies. These are typically due to things causing changes in governor speed reference circuit resistance, such as circuit relay contacts and motor operating potentiometers (MOPs).

- If the EDG speed reference signal drops in relation to grid frequency, the grid takes KW load off the EDG.

- If the EDG speed reference signal increases in relation to grid frequency, the EDG picks up more KW load from the grid. Overload trip may occur.

11.10.2 Voltage-KVAR Control Issues When Connected to the Grid

There can be several causes for EDG voltage–KVAR changes or swings while connected with the grid. The primary causes for EDG KVAR swings are:

Slight grid voltage changes show up as KVA (and therefore KVAR) load changes on the EDG. Since the plant EDG operator has no direct ability to control grid voltage, slight adjustments in EDG AVR reference voltage are often required over the duration of the loaded run test, in order to maintain the required KVAR and the directly-related power factor (pf).

- If grid voltage drops in relation to EDG reference voltage, the generator will take on more KVAR load from the grid. This will result in a decrease in the EDG power factor and an increase in generator output current. The generator overload trip relay is sensitive to current whether from KW or KVAR.

- If the grid voltage increases in relation to EDG reference voltage, the grid relieves some of the KVAR load from the EDG. This will result in an increase or improvement in the EDG power factor. When operating near unity power factor, this may cause a generator loss of field trip (LOFT).

Slight changes in the EDG AVR circuit resulting in EDG voltage reference signal anomalies. These anomalies are typical due to changes in the AVR voltage reference circuit resistance such as circuit relay contacts and potentiometers (PDPs).

- If the EDG voltage reference signal drops in relation to grid voltage, the grid takes KVA (and, therefore, KVAR) load off the EDG. This will result in an increase or improvement in the EDG power factor, which may cause LOFT.

- If the EDG voltage reference signal increases in relation to grid voltage, the EDG picks up more KVAR load from the grid. This will result in an increase in generator output current and could cause generator overload trips.

The operational impact of the above can be summarized by these three statements:

1. The engine "feels" KW load and is not affected by KVAR load except to the extent that power factor impacts the generator's efficiency. The KW load is increased by the governor attempting to increase RPM (generator frequency) by adding more fuel. Of course it can't, as the engine-driven generator is locked in sync with the grid as long as connected to it, so the result is the EDG picks up more KW load. The opposite is also true, such that steadily reducing engine power, as if attempting to slow down, takes off KW load, eventually to where power flow reverses and the generator becomes a motor driven by the grid.

2. The generator "feels" KVA and, as a result, KVAR load. The KVAR load is increased by the voltage regulator attempting to increase the generator output voltage (via the field). Of course, it can't raise grid voltage so that simply results in the generator picking up more KVAR load. The reverse is also true, such that if the voltage regulator tries to lower generator output voltage below line voltage it will eventually get the field so low a loss-of-field trip occurs.

3. To prevent problems, the EDG operator will always connect to the grid with the generator synchronized (but rotating at a slightly higher frequency than the grid) and with the generator output voltage slightly higher than grid voltage. The subsequent disconnect will be made before getting too close to zero load. Of course the EDG must be in "droop" mode whenever connected to the grid, to prevent inadvertent overload.

NOTE: Clause 4.5.2.2 of IEEE 387-1995 requires that upon receipt of an emergency start-diesel signal, the EDG's automatic control system shall provide automatic start-up and adjustment of the speed (frequency) and voltage to a ready-to-load condition in the isochronous mode. This is to prevent reduced EDG performance in an emergency from being left in "droop" mode at the conclusion of licensee's monthly surveillance testing.

11.11 Typical EDG Surveillance Run

Following completion of pre-operational testing and licensing, EDG surveillance testing is required by Plant Technical Specifications to ensure acceptable continued performance and reliability.

EDG Starting:

The EDG is started, briefly warmed up, and gradually raised to rated speed.

EDG Loaded Run:

NOTE: To protect the EDG while paralleled to the grid, the governor control is placed in the droop mode. In droop mode, with the governor at a given speed reference point, an increase in load application to the EDG tends to allow a decrease in EDG speed, thereby limiting new load acceptance. Therefore, with the governor in the droop mode, a deliberate change in the governor speed reference point is required to increase or decrease EDG load.

The EDG is synchronized and paralleled with its associated ESF emergency bus, which is already powered from the preferred offsite power supply (i.e. grid). To do this, diesel speed is increased to the point where frequency is just slightly higher than the grid (synchroscope rotating "slowly in the fast direction"). Typically, the generator output breaker is closed while the synchroscope is between 10 to 12 o'clock in one of its revolutions (unit paralleled). At this point the diesel will be carrying some minimal load (part of it from the interconnecting 4KV bus, plus some from the grid).

KW load is then gradually increased to 90-100% of continuous for a period of not less than one (1) hour. The increase in load on the EDG is accomplished by adjusting the governor speed reference potentiometer (MOP) that will attempt to increase engine speed. However, since EDG speed is limited and locked by grid frequency while operating in parallel, the increase in fuel demand to the cylinders simply results in the EDG accepting more load from the grid. Therefore, as the governor speed reference MOP is adjusted:

- The governor repositions fuel racks to uniformly increase fuel to all the cylinders.
- However, EDG speed cannot increase as it is synchronized with the grid.
- Therefore, instead of an EDG speed increase, load is uniformly increased on all EDG cylinders. In this manner, load is gradually increased, often in steps, until reaching nominal rated EDG load.
- Engine temperatures are monitored and the test continued for 1 hour min., or until temperatures stabilize at full load.
- The EDG is loaded and unloaded in steps to minimize the stress and wear on the unit.
- Engine, generator, and support system parameters are closely monitored as the test progresses.
- The generator load is monitored and adjusted as necessary throughout the loaded run, while engine and generator operating parameters continue to be recorded as required by IEEE 387-1995 Clause 7.6 ("Records") and Table 4 ("Test Parameters"), reproduced here as Figure 11-2. All such data are required to be "retrievable" for review.

EDG Unloading:

Once EDG temperatures have stabilized, and the EDG has been at rated load at least 1 hour, the generator can be unloaded. The EDG is unloaded by adjusting the same governor potentiometer in a manner that will tend to decrease the engine reference speed. Generator load is thereby reduced gradually to the minimum allowed in the following manner:

Load is then gradually reduced from 90 to 100 percent to no less than10 percent of its rated load. (This compensates for meter and meter reading errors and minor fluctuations in frequency in order to avoid reverse power trips.) The decrease in load on the EDG is accomplished by adjustment of the governor speed reference potentiometer (MOP) such that it will attempt to decrease engine speed. However, since EDG speed is limited and locked by grid frequency while continuing to operate in parallel the decrease in fuel demand to the cylinders allows the EDG to reject most of its load back to the grid. Therefore, as the governor speed reference MOP is adjusted:

- The governor repositions fuel racks to uniformly decrease fuel to all the cylinders;
- However, the EDG speed cannot decrease, as the grid will keep the generator in lock step with it, whether generating or being driven as a motor.
- Therefore, EDG RPM cannot decrease, and load is uniformly decreased on all cylinders, often in steps, until the EDG has been unloaded to the desired KW value for disconnection from the grid.

Securing EDG Operation:

- The engine is allowed to operate for a "cool down" interval, then shut down.
- The EDG engine, generator, and support systems are verified properly aligned for emergency standby operation.

11.12 Observations Pertaining to EDG Selection and Operation

The general EDG criteria applied include:

"…continuous load rating (the 8760 hour rating, per IEEE-387) equal to the sum of the conservatively estimated loads (nameplate) needed to be powered by that unit at any one time plus a 10 to 15 percent margin."

"…at no time during the loading sequence should the frequency decrease to less than 95% of the nominal nor voltage decrease to less than 75% of nominal…."

"…frequency should be restored to within 2% of the nominal (60 Hz) in less than 60% of each load-sequence interval for stepload increase and less than 80% of each load-sequence interval for disconnection of single largest load. Voltage should be restored to within 10% of nominal within 60% of each load-sequence (reduction) time interval."

"…during recovery from transients caused by the disconnection of the largest single load, the speed of the diesel generator unit should not exceed the nominal speed plus 75% of the difference between nominal speed and the over-speed trip setpoint, or 115% of nominal, whichever is lower.

Further, the transient following the complete loss of load should not cause the speed of the unit to attain the speed of the overspeed trip setpoint."

Following are several simplified examples that may help demonstrate the relationship between load application and the EDG voltage and frequency.

Continuous Load Example: If a plant identifies in the design stage that the required loads on the emergency onsite alternating current (AC) power supply will be 4500 KW, the minimum specified diesel generator continuous load rating should be 5000 KW (or 4950 KW, rounded up for conservatism). This will accommodate for slight design calculation errors without exceeding diesel generator continuous rated capacity. The NPP's approaching or perhaps even exceeding their initial EDG electrical load ratings are typically earlier design and construction plants that were adversely impacted by TMI backfits that increased the required loads.

Load Sequencing Example: Safety system motor loads at nuclear power plants are primarily large induction motors. This type of motor, with full voltage applied, draws a starting current five to eight times its rated operating current. The generator and diesel engine selected must have sufficient capacity to support the startup of such equipment without adversely affecting the performance of other equipment already operating. The following scenario may demonstrate what could happen during such conditions at a plant utilizing a pressurized water reactor.

An EDG is started in response to a Safety Injection (SI) with Loss of Offsite Power (LOOP) signal and the output breaker closes within 10 seconds. The EDG accepts primary motor loads in the following sequence:

- Charging Pump rated @ 450 KW.
- High Head Safety Injection Pump rated @ 300 KW.
- Low Head Safety Injection (RHR) Pump rated @ 300 KW.
- Component Cooling Water Pump rated @ 400 KW.
- Essential Cooling Water Pump rated @ 350 KW.
- Motor Driven Auxiliary Feedwater Pump rated @ 450 KW.
- Containment Spray Pump rated @ **450** KW.

At the point when it becomes necessary to bring the Containment Spray (CS) Pump on line, a substantial portion of the EDGs rated load is already applied. This is also a significant load in itself. If the diesel generator is undersized, this can cause an undesirable transient response as the pump motor breaker (motor contactor) is closed, connecting the pump motor to the bus being supplied by the EDG. A nominal load sequence interval (point of load application to point of meeting acceptance criteria) is about 3 seconds. The following is a basic overview of what physically occurs in response to this transient.

Discussion of Voltage Transient, for the described load application: As the motor contactors close, the 4KV Bus voltage decreases (dips). This primarily occurs due to the sudden motor starting inrush current (as much as 5 to 8 times higher than nominal running current) required to accelerate the 450KW CS Pump motor, which is likely already under system load (system demand). As a result, diesel generator output voltage also drops. The EDG voltage regulator senses the voltage drop and the voltage regulator acts to restore the desired generator output voltage (most often 4160 volts) in respond to the transient. This transient response characteristic of the generator and regulator is critical in the selection process. As noted earlier, Regulatory Guide 1.9 requires that:

- Voltage should not drop below 75% of nominal (3120 volts, if 4160 nominal).
- Generator output should be capable of restoring voltage to within 90% of nominal (in this case, 3744 volts) within 60% of each load sequence interval (i.e., 1.8 seconds for a nominal 3 seconds interval).

NOTE: For analysis of EDG frequency, remember that the generator frequency is a dependent variable of engine speed and, therefore, whenever engine speed changes the generator frequency is also changed in the same proportion.

Frequency Transient Overview for the described load application: At the same time that the generator is reacting to restore voltage, the engine senses the transient in the form of decreasing unit speed (RPM) caused by direct generator feedback (i.e. generator load application). From steady state analysis, generator voltage will be restored to the same nominal 4160 volts. However, there will be a new higher current and KVA output. Generators are rated in KVA, and the addition of the Containment Spray Pump load will increase the KVA output of the generator closer to its rated KVA output. This increase in generator load is directly applied to the engine. The increased load on the engine tends to cause it to slow down (decrease in RPM). The engine governor senses this transient reduction in RPM and acts to move fuel racks to increase the fuel to engine cylinders in order to restore engine RPM to what is required for 60 Hz generator output. As noted earlier, RG 1.9 requires that:

- The frequency not drop below 95% of nominal (57 Hz).
- Engine and governor response should be capable of restoring frequency to within 2% of nominal (58.8) within 60% of each stepload increase sequence interval (1.8 seconds for a 3s interval).

If the diesel generator output, based on generator or engine capabilities or both, is selected too close to system demand requirements, the resulting transient response characteristics will likely be unacceptable. This becomes increasingly evident when large loads are placed on the unit already carrying a substantial portion of its rated load.

Load Disconnection (reject or loss) Example: Both voltage and frequency will tend to increase on a loss of load. The following scenario may demonstrate what could happen during the trip of the Centrifugal Charging Pump or the Motor Driven Auxiliary Feedwater Pump at the example pressurized water reactor plant.

Voltage Transient Overview (for loss of load): As the motor contactors open, the 4KV Bus voltage tends to increase due to the sudden reduction in current required to operate the 450 KW pump motor. As a result, generator output terminal voltage also increases. The voltage regulator senses the voltage increase and acts to decrease the generator voltage to the desired value (nominally 4160 volts) in response to this transient. As noted earlier, RG 1.9 requires that: Generator output should be capable of restoring voltage to within 90% of nominal (typically 4576 volts) within 60% of each load sequence interval (1.8 seconds for a nominal 3 seconds interval).

Frequency Transient Overview (for loss of load): If a sudden loss of a large load occurs (e.g. breaker trip to one of the 450 KW motor, single largest loads, applied), this loss of load will cause EDG speed (RPM) to rapidly increase. This speed increase occurs since fuel racks are set to provide more fuel (meaning a higher heat, firing pressure, and power output) than required to maintain rated speed for the new (lower) load. In this case, the engine governor will sense the speed increase and rapidly respond to move fuel racks to decrease fuel delivery to the engine cylinders and restore engine RPM to the desired range (equivalent to 60 Hz). Since the EDG has no braking system, speed reduction is partly dependent on the remaining load and the unit's inertial (WR^2) characteristics.

As noted previously, Regulatory Guide 1.9 requires that: Frequency should not exceed 75% of the difference between nominal engine speed and the over-speed trip setpoint, or 115% of nominal, whichever is lower. (At 115% speed the generator frequency would be 115% of 60Hz, resulting in 69Hz output.) Engine and governor response should be capable of restoring frequency to within 2% of nominal (60 ± 1.2 Hz) within 80% of the single largest load disconnection sequence interval (2.4 seconds when the nominal load disconnect interval is 3 seconds).

EDG Governor, Speed and Frequency: There are two modes of governor operation applicable to most EDG applications at nuclear power plants. These are referred to as "isochronous" (constant speed) and "droop" (speed reduction as load increase).

Governor Control Under Emergency Operation: An EDG operating in response to a design basis event will be connected to an isolated 4KV Bus (i.e. isolated from the offsite grid). In this condition the desirable EDG governor speed control is referred to as isochronous (constant speed control). In isochronous speed control, the governor will attempt to maintain engine speed constant regardless of the load applied, so the generator will provide approximately 60Hz power.

Governor Control Under Normal Test Operation: Frequently, for purposes of testing and restoration of power to the grid, the EDG must be paralleled with the grid. In this condition, the desirable governor speed control characteristic is called the droop mode of operation. The generator on the system grid with the highest frequency (speed) will attempt to be the lead unit (and hence, “hog system load”).

In the case of a diesel generator having a nominal output of perhaps 5000 KW = 5 Mega Watts (MW), and synchronized to a grid with a load demand in the thousands of MW, trying to be the lead unit could be catastrophic. Therefore, whenever running in parallel with the grid, the governor must be in the droop mode so that its speed is reduced slightly as the load is increased. In droop mode the governor limits the load on the EDG and how much it can increase in response to grid transients.

As an example, most governors are set for a speed droop between 2.5% and 5% when going from no-load to full-load operation. The former results in 61.5 Hz at no load and the latter setting results in 63Hz at no load. For any droop setting the frequency at full load operation is a nominal 60 Hz. When in parallel with the grid, the governor's droop circuit is enabled and the speed regulation circuit (usually through a motor operated potentiometer or MOP) is used to change the "speed reference point" thereby enabling EDG load control.

Technical Specification Limits for Frequency and Voltage: Typical EDG Technical Specifications require the generator regulator be capable of maintaining output voltage within 10% of a nominal 4160 volts (4160 ± 420 volts) and the governor to maintain engine speed (frequency) within 2% of 60 Hz (60 ± 1.2 Hz) at steady state. These minimum EDG performance criteria are aimed at maintaining voltage and frequency within limits acceptable to most Engineered Safety Features (ESF) loads. However, note that some ESF loads can have more limiting frequency requirements, meaning they are less tolerant of frequency changes based on their design performance criteria.

For example, if an accident analysis expects an ESF pump to have a minimum design basis flow corresponding to a speed greater than the minimum EDG frequency allowed (frequency and engine speed being directly related), that pump's safety margin is eroded. Therefore, the licensee will analyze for adverse ESF load impacts associated with EDG frequency within the allowed governor speed control band. Occasionally this design basis analysis of ESF loads can result in establishing more stringent frequency (EDG governor speed control) band limits.

System Load Power Factor In Generator Selection Considerations: Generators are selected and constructed in accordance with National Electrical Manufacturers Association (NEMA) Standards, primarily:

- MG-1
- MG-2

Load power factor is one of the significant considerations given in generator selection. Unless otherwise specified, system power factor is assumed to be 0.8 ("lagging") for generator selection. Since power factor is actually a characteristic of the system load and not the generator it is important that the system load have a power factor of 0.8 lagging, or better. Simplified, power factor can be viewed as the byproduct of a "parasitic" system load (KVAR, or system reactive load), one that must be supplied by the generator but does no work.

As previously noted, generators are typically rated in KVA with this associated limiting load power factor (pf) applied to determine the theoretical "true" or "real" power available to operate loads. In many cases, since load power factor is better than 0.8 (lagging), available "true" power is higher than rated. An expected "worst case" load power factor is specified or assumed in order to establish the generator characteristic "design point" that will determine its system transient and full load response capabilities.

As discussed in an earlier chapter, power factor can be expressed several different ways and one common method of expression is true power (KW) over apparent power (KVA) or (PF = KW/KVA). Another way to define power factor is the amount by which the generator current lags the output voltage. Regardless, most emergency diesel generators are designed to accommodate a 0.8 lagging system power factor at the rated KW output. For example, a generator required to supply 5000 KW to an isolated 4KV bus operating @ a 0.8 power factor (PF = 0.8), requires a generator KVA rating of 5000/0.8, or 6250 KVA.

NOTE: Most plant 4KV systems actually have power factors of 0.85 or better.

Table 3—Site testing

Reference	Tests	Site acceptance tests (7.2)	Pre-operational tests (7.3)	Availability tests (7.4.2.1) Monthly	Availability tests (7.4.2.1) 6 Monthly	System operation tests—shutdown/ refueling (7.4.2.2)	Indepen-dence tests 10 years (7.4.2.3)
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	Synchroni-zing		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.

Table 4—Test parameters

Parameter[a]	Pre-start	During test	Post-test
<u>Pressures</u>			
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
<u>Temperatures</u>			
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	
<u>Electrical</u>			
Frequency		X	
Power		X	
Reactive		X	
Current: generator - all phases		X	
Voltage: generator - all phases		X	
Current: field		X	
<u>Level</u>			
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.

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