1. DIESEL GENERATORS AS EMERGENCY POWER SOURCES

Learning Objectives

The predominant means of supplying onsite emergency (standby) electrical power for nuclear power plants is the use of emergency diesel generators (EDG's). Therefore, diesel generator sets are the specific focus of this NRC training course. Upon completing this lesson students will understand the fundamental criteria used in selection of emergency diesel generators for onsite electric power supplies at nuclear power plants (NPP's). That will include an overview of the primary applicable federal regulations, regulatory guides, codes, and industry standards.

In addition, this lesson will conclude with a summary overview of the EDG and its associated systems and components, as well as remarks on how they interface with site facilities. For the EDG to be capable of performing its design basis function, all of its on-skid and off-skid support systems and components must also meet their own design basis functional requirements.

The primary objective of this lesson is to set the stage for later Chapters by giving students a fundamental understanding of:

1. The basic regulatory requirements establishing the need for redundant power systems (onsite and offsite) for operating nuclear power plants.
2. Three fundamental performance requirements that emergency diesel generators (EDG's) must meet.
3. Why diesel engines are used as the prime movers for emergency power generators instead of alternative engine designs.
4. An overview of the regulations, codes, guides, and standards that establish the design basis for these emergency power systems.
5. How the above documents are translated into the licensee's application and design for a nuclear power station.
6. The major components of a diesel generator system, as well as some considerations involving site facilities that support EDG operation.

NOTE: Many participants in this course will already be very familiar with the regulatory criteria applicable to EDG's. However, the NRC *requires* such documentation to be part of the course because some attendees may be relatively new on the job. Even those with considerable experience may benefit from a brief review of the underlying documentation. This Chapter provides an overview of the fundamental requirements relevant to EDG's in nuclear service. For both new and experienced staff it can serve as a convenient reference.

1.1 Regulatory Basis for Redundant, Independent Power Systems

Federal regulations applicable to nuclear power plants, and hence onsite emergency power supplies, originate in Title 10, Part 50 of the Code of Federal Regulations (10 CFR 50). This document is the successor to the Atomic Energy Commission (AEC) General Design Criteria of 10 July 1967, to which many early Nuclear Power Plants, meaning those starting construction prior to 1972, were licensed. Supporting regulatory guides, codes, and industry standards used to implement these federal regulations are briefly described in this Chapter.

One of the most important nuclear power plant safety requirements is for redundant, and independent, power systems. This is contained in 10 CFR 50 Appendix A, General Design Criterion (GDC) 17, which specifically requires both off-site and onsite power systems "to permit functioning of structures, systems, and components important to safety."

GDC 17 further states that onsite electric power supplies, including the distribution system, shall have *sufficient independence, redundancy, and testability to perform their safety functions assuming a single failure*. This requires emergency power systems to be designed such that failure of one will not adversely impact the other (more about that later). Each electric power source must be capable of providing the capacity and capability to assure that:

1. "Fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded" for any anticipated occurrences, and

2. The "core is cooled and containment integrity and other vital functions are maintained in the event of postulated accidents."

A Loss of Offsite Power (LOOP) event is one "postulated" accident but regulations require much more complex scenarios to be considered in selecting EDG systems.

Independence is the absence of shared components that could result in the simultaneous failure of both units. That includes physical and electrical separation, such that a transformer or cable tray fire, for example, would not impact operation of the other emergency diesel generator.

Redundancy is required to achieve the desired operational reliability, and also to accommodate "down time" for testing and maintenance. This means a dual EDG installation, where the required power is available with either unit out of service.

Testability is somewhat self-explanatory. EDG testing is discussed in a later Chapter.

1.2 Regulatory Guide (RG) 1.9 sets the Three Fundamental Performance Requirements for EDG's

Regulatory Guide 1.9, Rev 4 (March 2007) is "Application and Testing of Safety-Related Diesel Generators in Nuclear Power Plants" (*new title for this edition*) and evolved from AEC Safety Guide 9. A copy of RG 1.9, Rev 4 is included in this Manual as Appendix 2. It establishes the three fundamental performance requirements every EDG must meet to perform its design function. They are as follows:

1. The unit must be able to "...start and accelerate a number of large motor loads in rapid succession while maintaining voltage and frequency within acceptable limits...."

2. The unit must also be able to "...provide power promptly to engineered safety features if a loss of offsite power *and* an accident occur during the same time period...."

3. The unit must "...supply power continuously to the equipment needed to maintain the plant in a safe condition...."

A later chapter will cover the challenge of complying with the first of these three performance requirements (EDG loading). Item (2) immediately above introduces the requirement to cope with *two* events (failures / accidents) that occur either simultaneously or with one following the other. Finally, please note Item (3) has *no* endurance time. "Continuously" is open-ended and effectively means "until normal power is restored" (however long it takes).

1.3 Why DIESEL Generators?

There is no requirement that emergency diesel generators must be used for onsite electric power supplies at nuclear power plants. Hence, a natural question could be, why have diesel generators been selected as the predominant means of supplying this power? Some other potential sources that could have been selected are:

- Gas Engine Generators
- Gas Turbine Generators
- Steam Turbine generators
- Hydro Generators

The answer to “why diesel generators” can usually be found by looking at the time requirement set for the onsite emergency power source to be “ready to accept loads” following loss of offsite power. So, two fundamental questions asked in the selection of the emergency onsite power source are:

1. Based on the plant-specific accident analysis, how fast must electrical power be restored to support Emergency Core Cooling System (ECCS) operation to prevent core damage (i.e., to keep from exceeding peak fuel clad temperature)? Stated another way, how soon must the emergency electrical source be running with breaker closed, ready to accept the required step loads? By analysis, many of the reactor designs required power to be available within 15 to 30 seconds after receiving a start signal. Although this time included the inherent delay for protective circuits to sense the loss of power and initiate a start signal to the emergency power source, the bulk of it represented the start-up time necessary to spin up the generator, energize its field, and get it switched on line.

To assure an acceptable margin of safety, the accident analysis for many reactor designs assumed emergency generator power would be available within 10 seconds. NOTE: In some plants where nuclear fuel upgrades have been implemented and new core damage accident analysis calculations performed, they have frequently supported a corresponding increase in the delay time for emergency generator availability. However, it was not unusual to have the containment integrity support systems (e.g. Containment Spray System) become the new limiting consideration.

2. Once the accident analysis has set the time limitations on restoration of power to vital safety equipment, the only remaining question is what power supplies are readily available that could reliably supply the needed power within those time limitations?

With the exception of large gas engines, which have other onsite energy availability and safety concerns, none of the sources listed above could reliably match the required response time and output power as well as diesel generators could. To use a football analogy, they have the muscle to do the job and the speed to get there in time. Furthermore, diesel generators were readily available and their proven reliability had already gained them acceptance as emergency power supplies under the Naval Reactors program.

Therefore, although other factors such as site location and engine type familiarity had some influence, the answers to the two questions above ultimately decided the question of what type of generators to use for NPP applications. Fundamentally, the decision became “what diesel generators will best fill our emergency power needs?"

1.4 An Overview of EDG Regulations, Guides, Codes, and Standards

1.4.1 Early Plants Licensed under AEC General Design Criteria (i.e., those starting construction before 1972)

The primary design criteria applicable from early AEC regulatory requirements...those still being the GDC of record at many older nuclear power plants…are as follows:

Criterion 38: Reliability and Testability of Engineered Safety Features. All engineered safety features shall be designed to provide high functional reliability and ready testability. In determining the suitability of a facility for proposed site, the degree of reliance upon the acceptance of the inherent and engineered safety afforded by the system, including the engineered safety features, will be influenced by the known and the demonstrated performance capability and reliability of the systems, and by the extent to which the operability of such systems can be tested and inspected where appropriate during the life of the plant.

Criterion 39: Emergency Power for Engineered Safety Features. Alternate power systems shall be provided and designed with adequate independency (independence), redundancy, capacity, and testability to permit the functioning required of the engineered safety features. As a minimum, the onsite power system and the offsite power system shall each, independently, provide this capacity assuming a failure of a single active component in each power system.

Criterion 48: Testing of Operational Sequence of Emergency Core Cooling Systems. A capability shall be provided to test under conditions as close to design as practical the full operational sequence that would bring the emergency core cooling systems into action, including the transfer to alternate power sources.

Even the casual reader will note the close similarity between Criterions 38, 39, 48 and parts of 10 CFR 50 Appendix A, GDC 17.

The AEC had other GDC's which formed the basis for those currently appearing in 10 CFR 50 Appendix A. Likewise, AEC Safety Guides that were used to interpret and implement those early design criteria became the foundation for current NRC Regulatory Guides. Some early NPP's have voluntarily adopted portions of current requirements applicable to EDG's, such as IEEE 387 (discussed later). Therefore, no further time will be spent on early criteria.

1.4.2 Plants Licensed by NRC using the GDC of 10 CFR 50 Appendix A (construction began 1972 or later)

As explained in Section 1.1, the 10 CFR 50 Appendix A General Design Criteria are the successor documents to AEC GDC's. Those listed below provide primary design criteria for EDG's. Some others that have relevant secondary criteria such as for the physical plant design will not be described (e.g., GDC 2, 4, 5, and 50).

Criterion 17: "Electrical Power Systems" To recap the previous discussions on page 1-2, GDC 17 states the fundamental safety mission for on-site (and off-site) electrical systems, as well as the key attributes of independence, redundancy, and testability.

Criterion 18: "Inspection and Testing of Electrical Power Systems" Electric power systems important to safety shall be designed to permit appropriate periodic inspection and testing of important areas and features, such as wiring, insulation, connections, and switchboards, to assess the continuity of the systems and the condition of their components. The systems shall be designed with a capability to test periodically (1) the operability and functional performance of the components of the systems, such as onsite power sources, relays, switches, and buses, and (2) the operability of the systems as a whole and, under conditions as close to design as practical, the full operation sequence that brings the systems into operation, including operation of applicable portions of the protection system, and the transfer of power among the nuclear power unit, the offsite power system, and the onsite power system.

Criterion 33, 34, 35, 38, 41, and 44: Establish the criteria for specific safety systems to be able to perform their required functions even assuming a Loss of Offsite Power (LOOP) and a single failure of a source of onsite power (e.g. one EDG Train or Division).

1.4.3 "Top Level" NRC Regulations that Pertain to NPP Licensing, Construction, Commissioning, and Operation:

- **10 CFR 50.10** − License required.

- **10 CFR 50.23** − Construction permits. A permit for the construction of a production or utilization facility will be issued prior to the issuance of a license if the application is otherwise acceptable, and will be converted upon due completion of the facility and Commission action into a license as provided in 50.56 of this part.

- **10 CFR 50.34** – Details the contents of applications; technical information. For purposes of this course, the following excerpts from this document are of particular significance to EDG selection:

"(a) *Preliminary safety analysis report*. Each application for a construction permit shall include a preliminary safety analysis report. …(3) The preliminary design of the facility including:
(i) The principal design criteria for the facility. Appendix A, General Design Criteria for Nuclear Power Plants, establishes minimum requirements for the principal design criteria for water-cooled nuclear power plants similar in design and location to plants for which construction permits have previously been issued by the Commission and provides guidance to applicants for construction permits in establishing principal design criteria for other types of nuclear power units;
(ii) The design bases and the relation of the design bases to the principal design criteria;
(iii) Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety..."

"(b) *Final safety analysis report*. Each application for a license to operate a facility shall include a final safety analysis report. The final safety analysis report shall include information that describes the facility, presents the design bases and the limits on its operation, and presents a safety analysis of the structures, systems, and components and of the facility as a whole…"

- **10 CFR 50.36** – This document covers technical specifications intended to define safety system limiting conditions for operation that may prevent design and license safety function. More about this topic appears later in the Chapter, under Regulatory Guides 1.93, 1.156.

- **10 CFR 50.54** − Conditions of licenses.

- **10 CFR 50.55a** − Codes and standards. "Each operating license for a boiling or pressurized water-cooled nuclear power facility is subject to the conditions in paragraphs (f)* and (g)* of this section and each construction permit for a utilization facility is subject to the following conditions in addition to those specified in §50.55:

  "(a)(1) Structures, systems, and components must be designed, fabricated, erected, constructed, tested, and inspected to quality standards commensurate with the importance of the safety function to be performed…."

  * NOTE: Items (f) and (g) above refer to In-service inspection requirements.

- **10 CFR 50.56** − Conversion of construction permit to license; or amendment of license. Upon completion of the construction or alteration of a facility, in compliance with the terms and conditions of the construction permit and subject to any necessary testing of the facility for health or safety purposes, the Commission will, in the absence of good cause shown to the contrary issue a license of the class for which the construction permit was issued or an appropriate amendment of the license, as the case may be.

- **10 CFR 50.57** − Issuance of operating license.

- **10 CFR 50.63** − Loss of All Alternating Current Power (Station Blackout). This is an additional source of functional regulatory requirements involving Emergency Diesel Generators. Target EDG reliability is used to determine station blackout coping capability.

- **10 CFR 50 Appendix A, General Design Criteria**. – Previously discussed in this Chapter. See Section 1.1, etc.

1.5 Implementation of these Criteria into Site-Specific System Design

1.5.1 Overview of Primary Regulatory Guides and Referenced Standards Used to Implement Design Criteria

For early nuclear plants licensed under AEC General Design Criteria the applicable design requirements were implemented via the AEC's Safety Guides. With transition of the criteria to 10 CFR 50, Appendix A, the NRC's Regulatory Guides (RG's) became the means to implement requirements into NPP design.

Under both of these regimes, codes and standards developed by industry groups or national organizations (e.g., ANSI, IEEE, NFPA, etc.) were incorporated into the regulations. This training course provides just an overview of the more important documents relevant to EDG's.

- **Regulatory Guide 1.6 – "**Independence Between Redundant Standby (Onsite) Power Sources and Between Their Distribution Systems,**"** (Formerly Safety Guide 6). Each power supply (e.g. EDG) shall have the "...capability of performing as a redundant unit of a standby power supply." Therefore, mechanically and electrically, the Emergency Diesel Generator must be able to operate during and after any design basis event without support from a preferred power source.

- **Regulatory Guide 1.9 – "**Selection, Design, Qualification, and Testing of Emergency Diesel Generator Units Used as Class 1E Onsite Electric Power Systems at Nuclear Power Plants,**"** (formerly AEC Safety Guide 9). RG 1.9, Rev 4 (March, 2007) was introduced in 1.2 of this Chapter and gave three fundamental performance requirements for EDG's. It incorporates portions of **GDC 17** − Electric Power Systems, and **GDC 18** − Inspection and Testing of Electrical Power Systems. RG 1.9 also invokes the following IEEE documents:

- **IEEE 308** – **"**Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations.**"** In practice, Section 6.2.4, "Standby Power Supplies," of the IEEE 308 standard is implemented through IEEE 387.

- **IEEE 387 (1972, 1977, 1984, 1995) – "**IEEE Standard Criteria for Diesel-Generator Units Applied as Standby Power Supplies for Nuclear Power Generating Stations.**"** The parent standard to IEEE 387-1995 (and 1984) is IEEE Standard 308-1980. IEEE 387 expands on IEEE 308, Section 6.2.4, "Standby Power Supplies" with respect to application of diesel generator units.

This standard provides many amplifying and supplemental details, in conjunction with Regulatory Guide 1.9, regarding the design, testing, and qualification of Emergency Diesel Generators used in nuclear applications. Not all plants are committed to use IEEE 387, especially those licensed prior to 1972. IEEE 387 also endorses several other codes and standards including the Diesel Engine Manufacturers Association (DEMA) guide "Standard Practices for Low and Medium Speed Stationary Diesel and Gas Engines," last revised in 1972. DEMA is no longer an active association but its guidelines are still relevant to the design criteria applied to EDGs installed at most US nuclear power plants. Post-1977 versions of the IEEE 387 standard also outline criteria for initial EDG "first unit" qualification tests for NPP service. *These will be discussed in Chapter 11.*

NOTE: IEEE 387-1995 gives the design basis for nuclear service EDG's as 4000 starts and 6000 operating hours, over a specified service life of 40 years. Such intermittent duty is very different from typical commercial service! This course will point out the profound impact that has on EDG maintenance and testing, as well as some design implications. A copy of IEEE 387-1995 is Appendix 3.

- **IEEE 323** – **"**Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations.**"**

- **Regulatory Guide 1.32 – "**Criteria for Safety-Related Electric Power Systems for Nuclear Power Plants.**"** RG 1.32 seeks to implement compliance with portions of the following document:

- **GDC 17 –** Electric Power Systems.

- **IEEE 308 – "**Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations.**"** Invoked by RG 1.32, this Standard specifies capabilities of a Standby Power Supply (e.g. EDG) to serve as an independent / redundant unit (or Train or Division) of power.

- **Regulatory Guide 1.75 – "**Physical Independence of Electric Systems.**"** Deals more with the physical than functional independence or separation between classes and Trains or Divisions. The criteria are intended to ensure adequate independence through physical separation and barriers to assure continued function under all postulated plant events. RG 1.75 also invokes the following Standards:

- **IEEE 384 – "**Standard Criteria for Independence of Class 1E Equipment and Circuits."

- **Regulatory Guide 1.93 – "**Availability of Electric Power Sources.**"** *RG 1.93 provides guidance for the application of **10 CFR 50.36** (above), particularly section 50.36(c)(2), "Limiting Conditions for Operation," (LCO) when less than the number of power supplies required by GDC 17 are available.*

- **Regulatory Guide 1.108 – "**Periodic

Testing of Diesel Generator Units Used as Onsite Electric Power Systems at Nuclear Power Plants." (*Withdrawn. See 58 FR 41813, 5 August 1993. Superseded by Regulatory Guide 1.9, Revision 3*).

NOTE: Some of the early design plants previously committed to Regulatory Guide 1.108 only adopted portions of Regulatory Guide 1.9.

- **Regulatory Guide 1.137 – "**Fuel-Oil Systems for Standby Diesel Generators.**"** RG 1.137 also seeks to implement compliance with portions of GDC 17, Electric Power Systems (above), and it endorses the following standard for regulatory compliance.

- **ANSI N195 / ANS 59.51 – "**Fuel Oil Systems for Emergency Diesel Generators.**"**

- **Regulatory Guide 1.155 – "**Station Blackout.**"** This Guide seeks to implement compliance with all of:

- **10 CFR 50.63, "Loss of all Alternating Current Power."**…The specified station blackout duration shall be based on the following factors:

  "(i) The redundancy of the onsite emergency ac power sources;
  (ii) The reliability of the onsite emergency ac power sources;…**"**

  RG 1.155 also invokes NUMARC 8700**:** Guidlines and Technical Bases for NUMARC Initiatives Addressing Station Blackout at Light Water Reactors.

1.5.2 Licensee's Implementation of EDG System Design Criteria

It should be evident the criteria for design have evolved and what is applicable to a specific plant depends to a large extent on the time frame in which it was constructed and licensed. Licensees take whatever documents are applicable at the time their project moves forward, including the proper revision dates, and implement them into their plant-specific design and operations. The resulting EDG documents include:

- System drawings and isometrics
- System specifications
- Equipment specification
- Purchase specifications
- Installation and Test Criteria

The design criteria which were applied to the plant are typically listed or referenced in the licensee design and equipment specifications and the Final safety Analysis Report / Updated Final Safety Analysis Report (FSAR / UFSAR).

Highlights of Licensee FSAR / UFSAR:

- **FSAR / UFSAR Chapter 1, Plant (Design) Description:** Typically outlines the design criteria applicable to the plant design, construction, and operation. **NOTE:** Subsequent updates of regulatory criteria may be difficult, or impractical, for a licensee to back-fit.

  The licensee's Final Safety Analysis Report or Updated Final Safety Analysis Report (FSAR/ UFSAR) will document the regulatory requirements followed in their licensing process.

- **FSAR / UFSAR Chapter 8, Section 8.3(4), Onsite Emergency (AC) Power Systems:** The bulk of the plant-specific design criteria applied by the licensee to the EDGs is typically included here.

- **FSAR / UFSAR Chapter 9, Plant Auxiliary Systems:** Typically includes design criteria for many of the major EDG support systems such as Fuel Oil, Jacket Water, Lube oil, and Starting Air.

All licensees were required to develop plant Technical Specifications that prescribe plant **Limiting Conditions of Operation (LCO's)** for required safety systems. As outlined in 10 CFR 50.36, **"**…The technical specifications will be derived from the analyses and evaluation included in the safety analysis report, and amendments thereto, submitted pursuant to 50.34…. (c) Technical specifications will include items in the following categories:

(1) ***Safety limits, limiting safety system settings, and limiting control settings***. (i)(A) Safety limits for nuclear reactors are limits upon important process variables that are found to be necessary to reasonably protect the integrity of certain of the physical barriers that guard against the uncontrolled release of radioactivity. **If any safety limit is exceeded, the reactor must be shut down…."**

The following are key typical Technical Specifications which apply to EDGs:

3/4.8: Electrical Power Systems
3 / 4.8.1: AC Sources - Operating
3 / 4 .8.2: AC Sources - Shutdown

Additional limiting requirements for the availability of Emergency Power supplies are contained within the Technical Specifications for the supported safety systems. These Technical Specifications typically identify the plant mode and required number of available Trains or Divisions of that safety system. Regulatory Guide 1.93 (see previous) should be referenced to assist with determining implementation and compliance with Electric Power Technical Specification LCO's, including Emergency Diesel Generators.

- **FSAR/USFAR Chapter 14, Accident (Safety) Analysis:** The following constitute a few of the generic plant design basis events or accidents where Emergency Diesel generators are required to mitigate the resulting effects:

  Loss of Coolant Accident (LOCA) with LOOP: Safety Injection Actuation (SIAS) due to large or small break Loss of Coolant Accident, with a concurrent or subsequent Loss of Offsite (preferred) Power (LOCA / LOOP or SI / LOOP).

  NOTE: Many plants were originally designed for a LOCA with a concurrent LOOP in such a manner that other scenarios may not have been adequately addressed. Be aware of associated issues contained within IN 93-17 and TI 2515/176 regarding LOCA with a subsequent LOOP, and LOOP with subsequent LOCA.

  Loss of Offsite Power (LOOP): Loss of normal and preferred electric power to station auxiliaries.

NOTE: Issues have previously been identified where actual monitoring for loss of offsite power was not being performed at the 4KV class 1E buses. This presents scenarios where the 4KV bus may become disconnected from the offsite (preferred) source (i.e. loss power), with no automatic initiation of the EDG to restore.

High Energy Line Break (HELB): Steam or feedwater system piping failure with Loss of Offsite Power (LOOP).

NOTE: Issues have been identified where at least one of the Emergency Diesel Generators could be adversely impacted by the postulated HELB and was not previously protected against.

The preferred plant power source is always the normal offsite power supply, as defined in Regulatory Guide 1.9 and associated standards, including IEEE 308-1980, "Criteria for Class 1E Power Systems for Nuclear Power Generating Stations."

1.5.3 EDG Component Selection

Each emergency diesel generator is one of the most unique and complex "support systems" found within a nuclear power plant. The EDG is itself an independent miniature power plant serving critical safety equipment within the much larger facility.

Figure 1-1 "Diesel Generator Systems" on the following page is from RG 1.9 and illustrates an EDG system, including most of its support systems. The selection of EDG's to serve as independent, redundant, power sources for nuclear power plant emergency systems involves evaluation of the following major components, support systems, and circuits:

Generator: Serving as the interconnected emergency electrical source, the generator follows (responds to) the electrical load demands placed on the ESF bus. Major components of generators are:

- Generator housing and stator
- Generator rotor and exciter
- Voltage Regulator
- EDG emergency trip controls and relays

Diesel Engine: Most of the diesel engines installed at current nuclear power plants were selected using guidance of the Diesel Engine Manufacturers Association (DEMA). Their "Standard Practices for Low and Medium Speed Diesel and Gas Engines, DEMA-1972, was the 6th edition of this standard, which has not been actively updated since.

As the prime mover, the diesel engine follows (responds to) both the steady state and transient load demands applied to the generator. Its major components and systems are:

- Governor
- Starting System (air or electric)
- Fuel Oil Delivery System
- Combustion Air Intake
- Exhaust System
- Lubrication System
- Cooling (Jacket Water) System
- Crankcase Ventilation
- EDG start logic controls and relays
- Emergency run controls and Relays

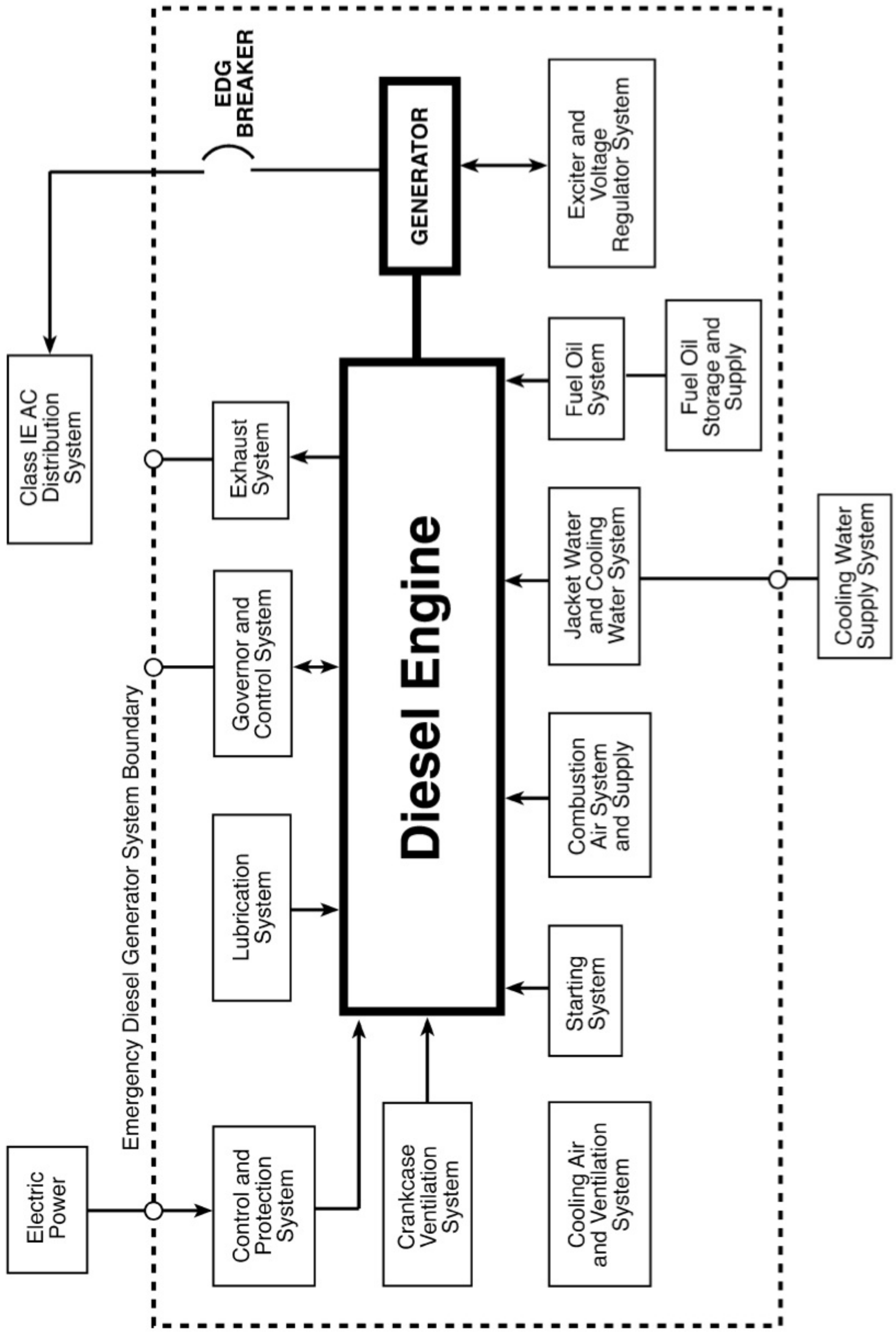

Figure 1-1 Diesel Generator Systems