A SunCam online continuing education course

Electrical Emergency Power Systems: Part 1

by

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Learning Objectives

This continuing education course is intended to provide training and education about the following topics:

1. The definition of Emergency Power Supply (EPS) and Emergency Power Supply Systems (EPSS)
2. The EPSS classifications of type, class, and level
3. Types of electrical distribution equipment used in EPSS for single and multi-generator systems
4. Criteria for the design of EPSS electrical distribution equipment

Introduction

Emergency Power Supply Systems are a critical part of many commercial, industrial, and institutional buildings and installations. These systems are intended to improve life safety and comfort when there is a loss of the normal power source. Several of the codes and standards that define when these systems should be used, and their system performance will be referenced. Some of the codes and standards have multiple applications and exceptions. The references are provided so you can investigate these topics in more detail.

Codes and standards referenced in this course include:

NFPA 70 – The National Electric Code
NFPA 99 – Health Care Facilities Code
NFPA 110 – Standard for Emergency and Standby Power Systems

Emergency Power Supply Systems

An emergency power supply (EPS) is the source of energy that provides an alternate source of power when the normal source fails. This includes the power source, any common bussing to connect more than one power source, and associated overcurrent protection devices.

NFPA 110 which is titled the "Standard for Emergency and Standby Power Systems" describes an emergency power supply system (EPSS) as:

> "A complete and functioning emergency power supply coupled to a system of conductors, disconnecting means, and overcurrent protective devices, transfer switches and all control, supervisory and support devices up to and including the load terminals of the transfer equipment needed for the system to operate as a safe and reliable source of electrical power."

This highlights the distinction between an emergency power supply and an emergency power supply system. The EPSS includes the EPS and the equipment that distributes the electricity generated by the EPS from the output of the EPS to the load terminals of the transfer switches. This is shown in the single line drawing in Figure 1.

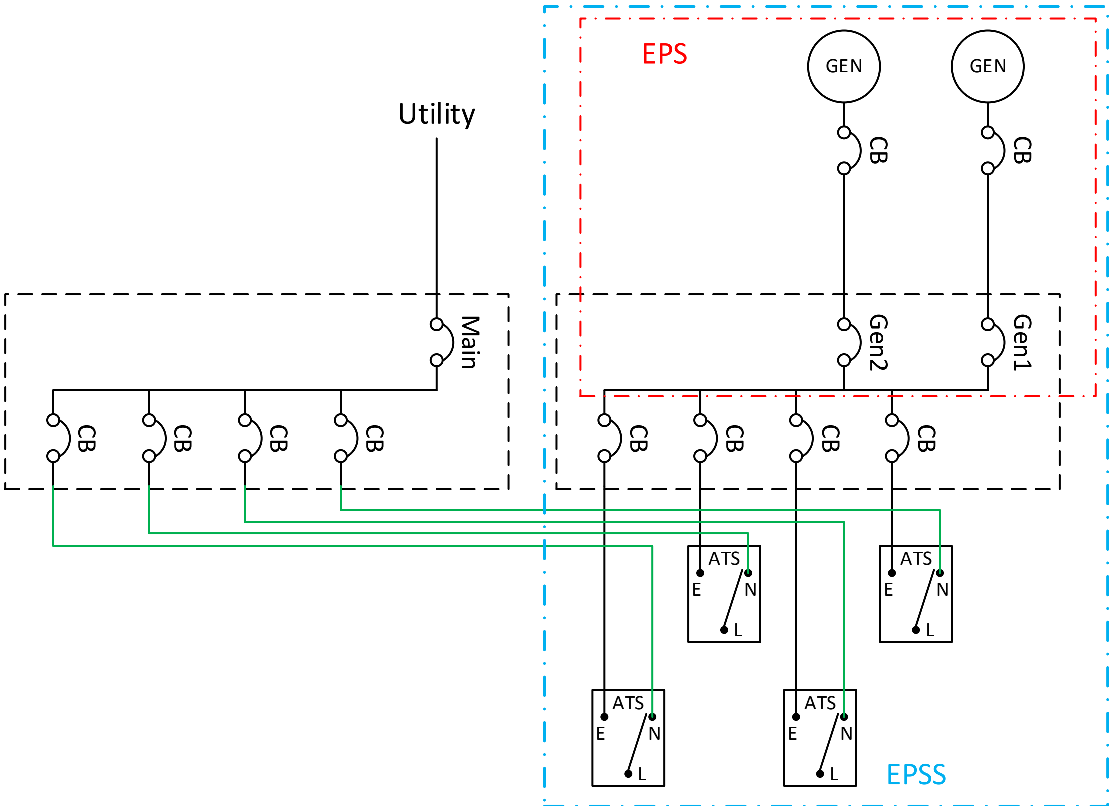

Figure 1: Single Line Drawing showing equipment of the EPS and EPSS

When designing an emergency power supply system and applying NFPA 110, engineers must determine the type, class, and level of the required system. These are described in NFPA 110, chapter 4.

The EPSS type refers to the amount of time that is allowed to occur between the loss of the normal power source and the availability of the alternate or standby source. Options for time are shown in Table 1. They are 10 seconds, 60 seconds, 120 seconds, manual, and uninterruptable (U). Uninterruptable is the type used when no amount of time with loss of power is acceptable and is used for uninterruptable power supply systems. Type U systems are not applicable to standby generator systems. There is also type M, which is a manual system with no time limit.

Table 1: Emergency Power Supply System Types

NFPA 110 Emergency Power Supply System Types	
Type	Maximum allowable time until power is restored
U	No interruption allowed, uninterruptable
10	10 seconds
60	60 seconds
120	120 seconds
M	Manual, no time limit

The EPSS class refers to the time the systems can run before the alternate or standby source needs to be refueled or recharged. The runtime classes are shown in Table 2. They are 5 minutes, 15 minutes, 2 hours, 6 hours, 48 hours, and class X. Class X is a timeframe requirement that is defined in other sections of NFPA 110, by other codes, or by the authority having jurisdiction.

Table 2: Emergency Power Supply System Classes

NFPA 110 Emergency Power Supply System Classes	
Class	Minimum acceptable runtime at full load without refueling
0.083	5 minutes (0.083 hours)
0.25	15 minutes (0.25 hours)
2	2 hours
6	6 hours
48	48 hours
X	Other runtime as dictated by codes or users

The EPSS level is related to the type of loads that will be served by the system. The difference between a level 1 and level 2 is differentiated by the risk to loss of human life if there is a failure of the EPSS. An EPSS must be classified as level 1 where failure of the equipment to perform could result in loss of human life or serious injury. This can be found in NFPA 110 section 4.4.1 and typically corresponds to legally required system requirements in NEC article 700 and life safety load requirements in NFPA 99: Health Care Facilities Code. Level 2 systems are specified when the failure of the EPSS to perform is less critical to human life and safety. This typically corresponds to legally required standby system requirements in NEC article 701 or optional standby system requirements in NEC article 702.

Electrical Distribution Equipment for EPS/EPSS

Distribution Equipment and NEC codes

When determining what equipment and systems the EPSS is required to power in the event of the normal power source failure, input should be solicited from the architect, building owner / operator, state and local building codes, and the authority having jurisdiction (AHJ) for the facility. This input will be used to determine the system classification level, type, and class.

The National Electric Code (NEC) does not define when a standby power system is needed, however it provides information about the installation, operations, and maintenance of emergency power systems. The EPS should be characterized as an emergency, legally required standby, or optional standby system. Requirements for each of these systems is found in the following NEC articles:

1. Article 700 – Emergency Systems
2. Article 701 – Legally Required Standby systems
3. Article 702 – Optional Standby Systems

Emergency systems governed by NEC article 700 are systems which are legally required by municipal, state, federal, or other codes, or the authority having jurisdiction (AHJ). They are generally installed where artificial lighting is required for safe exit and panic control in buildings which are commonly occupied by large numbers of people. These types of buildings include hotels, theaters, sports arenas, health care facilities, educational facilities, and similar institutions. In addition to lighting, emergency systems provide power to equipment functions which are essential to maintain life, fire detection and alarm systems, elevators, fire pumps, public safety communications systems, and industrial processes where interruption would produce serious life safety or hazardous conditions. Following is a list of systems which are in this category:

1. Exit signs and means of egress lighting
2. Elevator car lighting
3. Fire alarm systems
4. Automatic fire detection systems
5. Electrically powered fire pumps
6. Emergency voice and alarm communication systems
7. Power and lighting for a fire command center

For branch circuits that supply loads classified as emergency, the load should be transferred automatically to the emergency supply sources upon the failure of the normal power supply.

Legally required standby systems which are governed by NEC article 701 are installed to serve loads that when stopped or have an interruption of the normal electric supply, could create hazards or hamper rescue and firefighting operations. This equipment could include heating, refrigeration, communications, ventilation and smoke removal systems, sewage disposal, and lighting. These systems are classified by municipal, state, federal, or other codes or the agency having jurisdiction. The standby systems for legally required loads are required to automatically transfer the loads to the standby power source.

Optional standby systems which are governed by NEC article 702 are intended to supply power to systems where life safety does not depend on the performance of these systems. Typical loads served by these systems are heating and refrigeration systems, data processing, communications systems, and process equipment that when stopped during power outages may cause discomfort, serious process interruption, or damage to product or processes. They may transfer power to these loads either automatically or manually.

A distribution switchboard with connections to a standby generator, and loads classified by NEC 700, 701 and 702 are shown in Figure 2. More detail about the design requirements for emergency switchboards will be addressed in a later section.

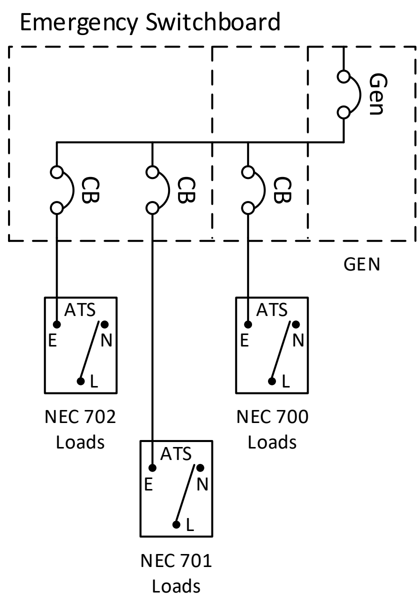

Figure 2: Emergency Switchboard with emergency source and loads

Transfer Switch Equipment

Transfer switches are used to transfer the power source feeding loads from the normal source to the emergency or standby power source when the normal source is unavailable. These are also used to transfer power back to the normal source when it becomes available. They are available in manual and automatic versions.

When the EPSS is classified as an emergency system or feeds critical loads an automatic transfer switch (ATS) should be used and should be listed under UL 1008 for emergency service. The transfer equipment should include either a mechanical interlock or other approved method to prevent connection of the normal and standby power sources. An ATS must be capable of electrical operation to transfer from normal to standby power source, and retransfer from standby to normal power source automatically.

The ATS will have a voltage sensing device that monitors the voltage of the normal power source to identify when this power source is not available. When the normal source is not available, the ATS will send a signal to start the generator and manage the process of transferring the load connection to the standby power source. When the ATS voltage sensors indicate that the normal power source has been restored to an acceptable level, there will normally be a programmed time delay before the ATS initiates the retransfer from the standby power source to the normal power source. An ATS has connections to the normal power source (N), the emergency power source (E), and the load (L) as shown in Figure 3. Some applications require an ATS with bypass isolation. The bypass contacts allow power to flow from either the normal or emergency power source around the ATS to the load. This allows the load to remain in service while the ATS is being maintained.

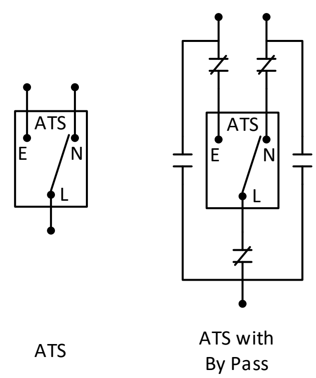

Figure 3: Symbols for Automatic Transfer Switches

When an ATS is used to provide power to essential loads, there will be a device to monitor the voltage and frequency to ensure that it is within the allowable tolerance before the ATS will operate. NFPA 110 defines the time delay for the ATS to use when providing power to essential loads. More details can be found in Section 6.2 of NFPA 110. When validating the time required to provide standby power to the essential loads after the loss of normal power you must consider the time required to detect the loss of normal voltage, time to initiate the starting of the standby generators, time for the generators to reach stable, acceptable voltage and frequency, and the time to operate the transfer switch.

Generator Paralleling Switchgear for Multiple Generators

When there are multiple generators available in the emergency power supply system there are additional design considerations in terms of the power distribution equipment and the control system. When multiple generators operate in parallel, additional equipment is required to combine the power from the generators to a common generator bus. This generator bus will have feeder circuits to send power to the loads. A control system will be required to safely connect the generators together and provide flexibility regarding which loads receive power by opening and closing the feeder circuit breakers.

Generator paralleling switchgear typically has input breakers to bring the power from each generator to a common bus. This equipment can be low voltage switchgear or switchboards or medium voltage switchgear. Specifying a generator paralleling system requires specifying the switchgear and the control system to operate this system in accordance with the project requirements.

Connecting multiple generators requires synchronizing the waveform of the voltage output. This requires that the voltage level, frequency, and phase angle be within certain tolerances before connecting their outputs together. Typical tolerances are show in Table 3. If the output of the generators is not within these tolerances and the generator outputs are connected, the magnetic fields will be mismatched and cause high mechanical and electrical shocks that have the potential to damage the generators or the electrical system.

Table 3: Tolerances for safe generator paralleling

Measurement	Tolerance
Voltage level	+/- 5%
Frequency	+/- 0.1 Hz
Phase Angle	+/- 10°

Understanding the synchronization process requires a basic understanding of generator control. The generator output is controlled by the governor and the voltage regulator. The governor controls the engine speed and the resulting power output. As more fuel is supplied to the engine, the power output will increase. The voltage regulator controls the voltage output by changing the DC field in the alternator. Each generator will have its own generator controller. The paralleling control systems will send setpoints to the generator controller which controls the governor and voltage regulator.

When starting multiple generators, one of the generators will be designated as the primary generator source. This generator will be used to establish the voltage and frequency that the other generators will need to match. When the primary generator is at the rated voltage and frequency, its breaker will close, connecting it to the generator switchgear bus. The circuit breaker for generator 2 will only close when the voltage, frequency, and phase angle of that generator are within the required tolerance of the primary generator. A sync check relay is used to prevent a generator breaker from closing when the voltage, frequency, and phase angle are not within certain programmed tolerances. When this condition is satisfied, the breaker will close, connecting generator 2 to the switchgear bus. The two generators can now be controlled to share the output load. This is shown in Figure 4.

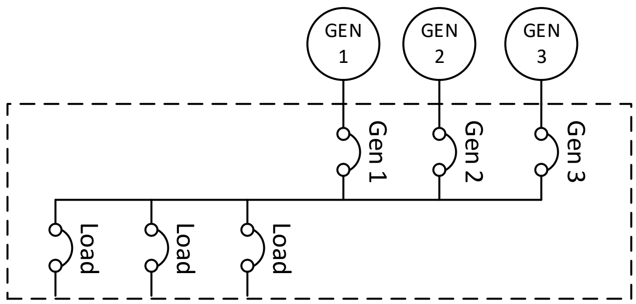

Figure 4: Single Line Drawing of multiple generator distribution switchboard

If an EPSS uses two or more generators as an alternate power source, the transfer of loads to the EPS requires a sequencing of the loads based on priority. This will set a priority for essential loads over all other loads. The system designers, along with the owners, need to identify and categorize the priority of the essential loads.

After the load priorities are categorized and a sequence of operations has been defined, a control system can be developed that controls the generator and feeder circuit breakers to control power flow to the most critical loads first. The sequence of operations should describe all scenarios within the design and expected operations along with relevant programming parameters. Typical scenarios could include:

1. Breaker conditions during normal operation
2. Loss of utility power
3. Restoration of utility power
4. Loss of one or more of the standby generator sources
5. Restored availability of a standby generator source
6. Overload condition

System parameters to be included in the sequence of operations could include:

1. Time delay to start an engine upon loss of utility
2. Time delay before transferring load to the standby power source

3. Time delay after utility power is restored before load is retransferred to that source
4. Engine cooling time

In a muti-generator standby system, when the first generator reaches acceptable voltage and frequency, the ATS for the highest priority loads can be transferred to the standby system. Loads can continue to be added to the standby power source in the order of their priority until a load limit for the first generator is reached. As additional generators reach their acceptable voltage and frequency and are connected to the generator bus, addition loads can be added based on their priority.

While running on the standby system, if a generator were to fail, the control system should begin shedding the lowest priority loads until the total load on the generator bus is lower than the available power from the operating standby generators. If additional generation becomes available, additional loads can be added based on their priority. This is referred to as a load-add / load-shed priority control system.

Generator Switchboard Design

This section explains the requirements for a generator switchboard (GSB) design with a single generator and different types of loads. One area of concern is how different types of loads must be separated to comply with the NEC articles 700, 701, and 702.

Generator Overcurrent Protection

NEC 700.10(B) states that the wiring and overcurrent protection devices from an emergency source shall be kept entirely independent of all other wiring and equipment unless permitted for certain exceptions. The intent is that a circuit breaker connecting the generator to the GSB should be in a separate section.

NEC 700.31 states that ground fault protection which automatically opens upon a ground fault condition is not required to be provided when using an automatic disconnecting means, such as a circuit breaker. However, if ground fault protection is not provided, ground-fault indication shall be provided in accordance with NEC 700.6(D).

An additional requirement for the selection of the generator overcurrent protective device is included in NEC 700.32. This states that emergency system overcurrent protective devices shall be selectively coordinated with supply-side overcurrent protective devices. Selective coordination is a design approach where overcurrent protection devices are selected so that their opening times are adjusted in order that the circuit breaker closest to fault opens first. The objective is to isolate the circuit closest to the fault, restricting the outage to the affected circuit.

Selective coordination shall be selected by a licensed professional engineer or other qualified person. The selective coordination must be documented and is typically provided as part of a power system study during the project execution.

If the generator breaker is rated or can be adjusted to 1200A or higher, NEC 240.87 applies, requiring that an arc energy reduction method be implemented. One of the following methods shall be provided:

1. Zone selective interlocking
2. Differential relaying
3. Energy-reducing maintenance switch with local status indicator
4. Energy-reducing active arc flash mitigation system
5. An instantaneous trip setting
6. An instantaneous override
7. An approved equivalent method

Load Feeder Circuit Protection

NEC 700.10(B)(5)(c) states that emergency circuits shall not originate from the same vertical section as other circuits. Therefore, feeder circuit breakers serving emergency circuits should be in a separate section.

NEC 701.10 states that wiring for legally required standby systems shall be permitted to occupy the same cabinet as other general wiring.

NEC 702.10 states that wiring for optional standby systems shall be permitted to occupy the same cabinet as other general wiring.

Since the wiring for legally required standby systems and optional standby systems are both permitted to be in the same cabinet as general wiring, it could be interpreted that these types of wiring would be allowed in the same section. Since the NEC does not explicitly state that legally required standby systems and optional standby systems wiring can be in the same section, this is subject to interpretation and should be reviewed with the owner and the authority having jurisdiction for their agreement on the interpretation.

A switchboard having one generator and loads classified as emergency, legally required standby, and optionally required standby back up power, could look like the switchboard GSB single line shown in Figure 5. This shows a switchboard constructed in three sections with a separate section for the generator circuit breaker, a separate section for the emergency circuits (NEC 700), and a section for the legally required (NEC 701) and optional circuits (NEC 702).

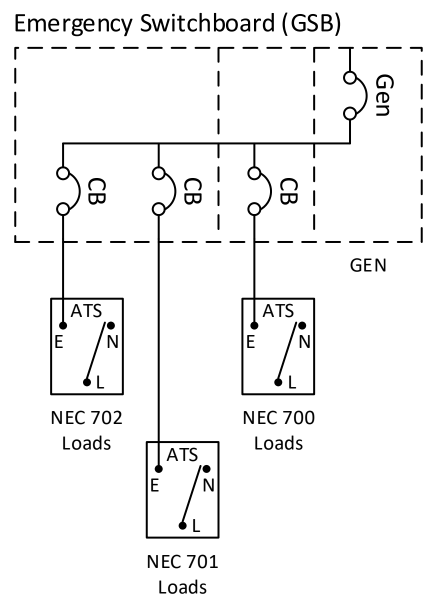

Figure 5: Emergency Switchboard single line diagram with ATS switches

For further information regarding wiring and installation of emergency systems in health care facilities, consult NEC article 517.

Installation & Environmental Considerations

An important consideration in the design and installation of an EPSS is to minimize the probability of failures. This is one of the reasons for keeping the circuit protection and wiring for emergency systems separate from other systems. Some other considerations are:

1. Install EPSS equipment in a location that is protected from natural hazards such as storms, floods, earthquakes etc. and human causes such as vandalism.
2. Segregate the feeders for the normal power source from the circuits for the standby power source, to prevent a single failure damaging both circuits.
3. Locate the EPSS to have a short distance from the generation to the loads to be served.

Installations and layout of electrical distribution equipment for the EPSS must provide proper working clearances and proper entrance and egress from the space. These are defined in NEC 110.26 for equipment rated 1000V or less. This article describes the space requirements in the front, sides, and rear of the equipment as well as the height of the working space. For equipment rated above 1000V, refer to NEC 110.32 through 110.34 for working space clearance, and equipment accessibility requirements.

For a level 1 EPS located indoors, NFPA 110 requires installation in a separate room from the rest of the building. This room shall have a two-hour fire-resistant rating. If the normal power system is rated greater than 150 volts and 1,000 amps or greater, the normal service equipment shall not be installed in the EPS room.

Bringing it All Together

This course is intended to provide a foundation for understanding emergency power supply systems. Depending on the installation application there are several codes and standards which govern their design, installation, and maintenance. A list of applicable codes and standards are listed in Appendix A.

Installation and design requirements for emergency power supply systems in health care facilities is beyond the scope of this course, however it is worth noting that they must meet the requirements of with NFPA 99: Health Care Facilities Code and NEC 700, except as amended by NEC article 517.

Appendix A – Industry Agencies and Governing Bodies

The following is a list of organizations and institutions engaged in setting standards and codes that govern the design, manufacturing, installation, and/or testing of electrical equipment. The codes and standards from these organizations are commonly referenced on electrical engineering plans and specifications.

IEEE – The Institute of Electrical and Electronic Engineers is a non-profit professional association. The IEEE produces a wide range of publications which include consensus-based standards.

ANSI – The American National Standards Institute oversees standards and conformity assessment activities in the United States. The Institute facilitates and promotes voluntary consensus standards and conformity assessment systems, and safeguards their integrity.

IEC – The International Electrotechnical Commission is an international organization which publishes standards for electrical equipment.

NEMA – The National Electrical Manufacturers Association establishes standards for the operating performance, characteristics, construction and testing of equipment to ensure standardization of electrical equipment.

NFPA – The National Fire Protection Association is a global nonprofit organization devoted to eliminating death, injury, and property or economic loss due to fire, electrical and related hazards. They deliver information and knowledge through more than 300 consensus codes and standards, research, training, education, outreach, and advocacy.

NFPA 70 – One of the codes published by the NFPA and is the benchmark for safe electrical design, installation, and inspection to protect people and property from electrical hazards. This is also known as the National Electric Code.

NFPA 70B – Details preventive maintenance for electrical, electronic, and communication systems and equipment to prevent equipment failures and worker injuries. This applies to systems and equipment used in industrial plants, institutional and commercial buildings, and large multi-family residential complexes.

NFPA 70E – One of the codes published by the NFPA that establishes requirements for safe work practices to protect personnel by reducing exposure to major electrical hazards. Originally developed at OSHA's request, NFPA 70E helps companies and employees avoid workplace injuries and fatalities due to shock, electrocution, arc flash and arc blast, and assists in complying with OSHA 1910 Subpart S and OSHA 1926 Subpart K.

NFPA 99 – Establishes criteria for levels of health care services or systems based on risk to the patients, staff, or visitors in health care facilities to minimize the hazards of fire, explosion, and electricity.

NFPA 110 – Covers performance requirements for emergency and standby power systems providing an alternate source of electrical power in buildings and facilities in the event that the normal electrical power source fails. Systems include power sources, transfer equipment, controls, supervisory equipment, and accessory equipment needed to supply electrical power to the selected circuits.

