Emergency and Standby Power Systems

Produced and Distributed by

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Table of Contents

Course Description

The purpose of this course is to familiarize engineers with emergency and standby internal combustion diesel engine-generator set power systems under 600V. This course can serve as an introduction to emergency and standby power systems and applications for engineers with little or no professional electrical design experience. The course also presents practical emergency and standby power system application information that will benefit even the most seasoned electrical design professional.

Emergency and Standby power systems – why are they worth learning about?

The nature of electrical power failures, interruptions, and their duration covers a range in time from micro seconds to days. In the face of possible failures of normal electrical utility power sources, a reliable alternate supply of electric power must be provided for facilities and systems that cannot go without power e.g. health care facilities, data processing, life safety systems, mission critical operations, etc… As an answer to this need, a wide range of electric energy sources have been developed. This course focuses on engine-generator sets (also referred to as gen sets in this course) as the source of reliable alternate electrical energy.

Disclaimer

The information presented in this course is intended to introduce emergency and standby power engine-generator set systems and their practical application. This course is not intended to be a design guideline and may not, in any way, replace the judgment and expertise of an experienced professional electrical engineer. If such services are required, you should seek the assistance of a qualified professional.

I. Introduction

Engine – generator sets (or gen sets) are an electric energy source alternative to the normal electrical utility company supply. Gen sets can serve the following functions:

- Continuously operating independent electric energy sources, particularly on sites not having convenient or affordable access to utility service.
- Demand reduction (peak shaving) at installations where the gen set has other functions or where the economics of the utility's demand charges favors the operation of the gen sets.
- Cogeneration, where the engine's rejected energy (heat) is harnessed to provide heat or hot water to the facility.
- Standby and/or emergency power where gen sets are started to pick up standby, legally required and emergency loads when the normal utility supply fails.

As suggested by its title, this course will focus exclusively on the last of these functions – standby and emergency power.

Definitions

Automatic transfer switch - Self-acting equipment for transferring one or more load conductor connections from one power source to another.

Battery - Two or more cells electrically connected for producing electric energy.

Bypass/isolation switch - A manually operated device used in conjunction with an automatic transfer switch to provide a means of directly connecting load conductors to a power source and of disconnecting the automatic transfer switch.

Control Panel – comprises the devices required for proper operation of an engine – generator set (gen set) including but not limited to voltage regulator, frequency regulator and monitoring of voltage, amperes, and frequency and such indicators as water temperature, run time, over cranking and fuel level.

Emergency Power Systems - are those systems legally required and classed as emergency by municipal, state, federal or other codes, or by any governmental agency having jurisdiction. These systems are intended to automatically supply illumination, power or both to designated areas and equipment in the event of failure of the normal supply or in the event of accident to elements of a system intended to supply, distributed, and control power and illumination <u>essential for safety to human life</u> (from NFPA 70 – National Electrical Code®).

Exhaust System – the system for proper discharge of combustion gases. It includes the exhaust manifold, pipes, and silencer (muffler) to attenuate or silence the exhaust noise.

Fuel System – All the necessary components for the proper fuel supply to the gen set consisting of fuel lines, fuel tank, transfer pump(s) and regulators.

Gen set – abbreviation for engine – generator set.

Harmonic Distortion – disturbances to voltage or current operating with a frequency equaling integral (e.g. 1, 3, 3, etc…) multiples of the power waveforms fundamental frequency (typically 60 Hz in the USA).

Legally Required Standby Systems - are intended to provide electric power <u>to aid in fire fighting, rescue operations, control of health hazards, and similar operations.</u> The requirements of legally required standby systems are much the same as emergency systems except for a few differences according to the NEC (Article 701). When normal power is lost legally required systems must be able to supply standby power in 60 seconds whereas as emergency systems have a requirement of 10 seconds or less. Wiring for legally required standby systems may occupy the same raceways, cables, boxes and cabinets as other general wiring, whereas wiring for emergency systems must be kept entirely independent from other wiring (from NFPA 70 – National Electrical Code®).

Power failure - Any variation in electric power supply that causes unacceptable performance of the user's equipment.

Power outage: - Complete absence of power at the point of use.

Prime mover - The machine used to develop mechanical horsepower to drive an emergency or standby generator to produce electrical power.

Prime power - The source of supply of electrical energy that is normally available and used continuously day and night, usually supplied by an electric utility company, but sometimes supplied by base-loaded user-owned generators.

Standby Power Systems or <u>optional</u> standby power systems - are those in which failure can cause physical discomfort, serious interruption of an industrial process, damage to process equipment, or disruption of business (from NFPA 70 – National Electrical Code®).

Starting System – comprised of batteries, automatic batteries and cables connected to engine starter.

References

1. IEEE 446-1995 Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications is the primary basis of the information presented in this course.

2. Several codes and standards require and/or guide the application of emergency and standby generators. There are three main codes that govern the "system" aspects and numerous other codes that govern individual equipment. The three codes are:

    a. NFPA 110 – "Standard for Emergency and Standby Power Systems" is a broad performance specification. It presents *"performance requirements"* for power systems providing and alternate source of electrical power to loads in buildings and facilities in the event that normal source fails…to the load terminals at the transfer equipment. (NFPA 110).

    b. NFPA 70 - "National Electrical Code ®" (NEC) Article 700, covers "the *electrical safety* of the design, installation and operation and maintenance of emergency systems…for illumination and/or power to required facilities when the normal electrical supply or system is interrupted". "Emergency systems are those systems legally required and classed as emergency by…governmental agencies having jurisdiction.” Article 701 of the NEC covers “legally required standby systems”. Article 702 of the NEC covers “optional standby systems”.

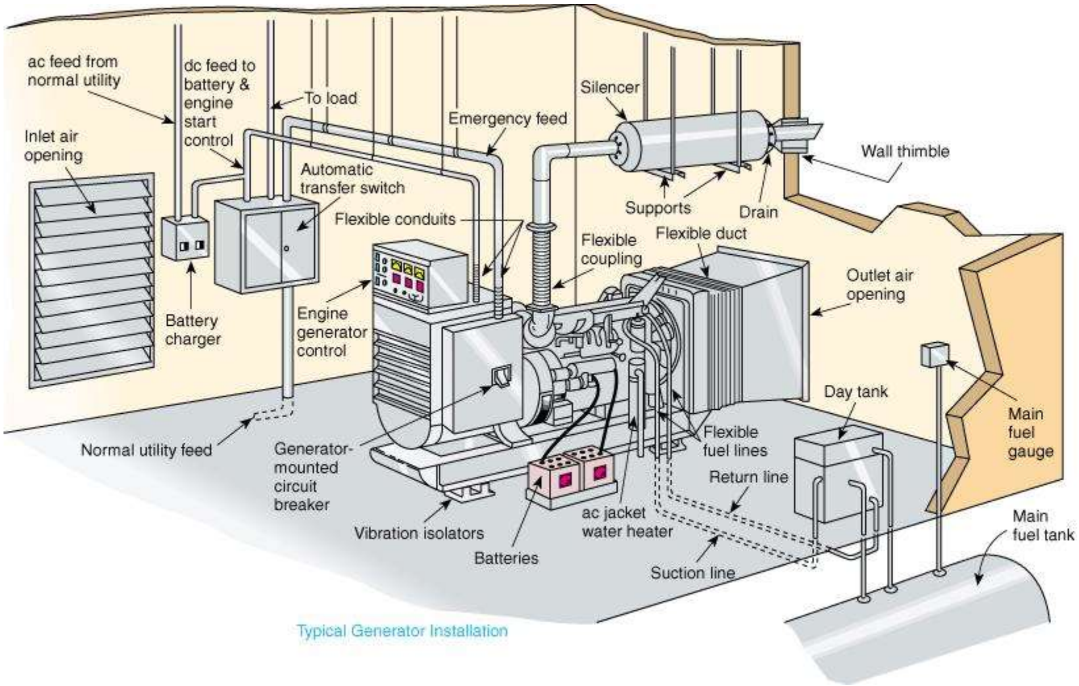
c. NFPA 99 – “Standard for Health Care Facilities” lists performance requirements for emergency/standby electrical systems for hospitals, nursing homes and residential custodial care facilities and other health care facilities”.

d. NFPA 37 - Standard for the Installation and Use of Stationary Combustion Engines and Gas Turbines. The contents of this standard will not be addressed or referenced in this course. NFPA 37 governs the fire safety requirements associated with combustion engines.

II. Typical Emergency/Standby Power System Components

Figure 1 depicts the basic components of a typical emergency or standby power system which include the following

1. Engine – generator set
2. Transfer Switch
3. Battery System
4. Engine/Generator Control
5. Fuel System/Storage
6. Exhaust and Inlet/Outlet Air



Typical Engine Generator Set Installation (Figure complements of Caterpillar)
Figure 1

Basic Components

1. Engine – generator set which consists of an engine coupled with a generator that it drives.

2. Transfer switch

The Transfer switch is the component in the emergency and standby power system that transfers power from the "normal" power source to the alternate power source when the “normal” source of power fails.

The design and installation of transfer switches must meet several standards, including but not limited to:

NFPA 70 National Electrical Code
NFPA 99 Health Care Code (for Health Care projects)
NFPA 110 – Standard for Generators
NEMA ICS10
UL 1008

Transfer switches are offered in different configurations and operating schemes that are discussed later in the course.

3. Battery System:

Purpose – The reliability is paramount in emergency and standby power applications. A common cause of engine generator sets failure to start is a battery failure.

Gen set starting – Engines are typically started by using battery powered electric motor starters. In rare cases, engines may be started by compressed air operated motors depending on the type of engine and the availability of compressed air. The starting batteries must have sufficient capacity for 60 seconds of continuous cranking. The engine manufacturers define required battery capacity in terms of cold cranking amperes.

Battery Types – Both lead acid and nickel cadmium batteries are commonly available. The most common voltage for diesel gen set battery systems is 24 Volts DC.

Charger - A properly specified battery charger offers accurate and automated battery charging that automatically adjusts to changing input voltage, load, battery and ambient temperature conditions. This can prevent battery overcharging and the consequent loss of battery electrolyte. Most charging systems require a 120V, 20A supply circuit however requirements must be confirmed with specified charger manufacturers.

4. Controls

Both engines and the generator require panels for displaying operating conditions and for mounting the controls, providing protection and displaying alarms.

Engine Panel – the engine control panel provides the following typical functionality

- Cranking control equipment, including cranking cycle, battery charger state and battery condition.
- Control switches, RUN – OFF – AUTOMATIC switch
- Shutdown and lock-out control to operate from the protection system
- Annunciator to respond to protection system
- Emergency shutdown

Engine Protection – safety indications and protection required by NFPA 110 Table 5.6.5.2 is shown in Figure 2 below.

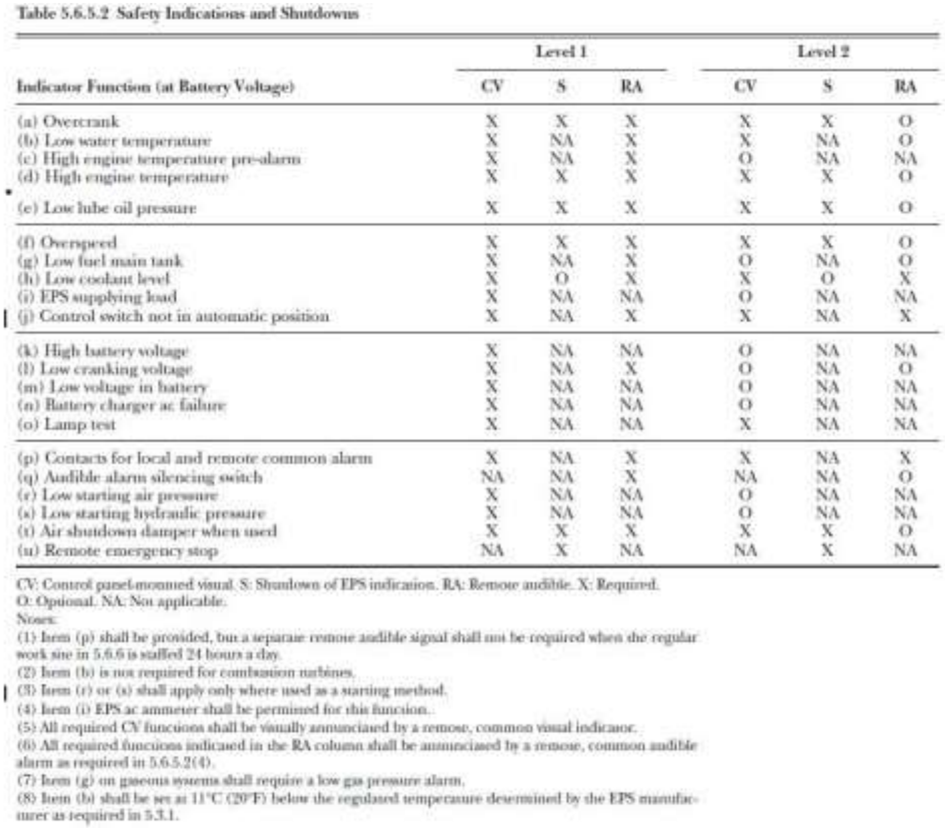


Table 5.6.5.2 Safety Indications and Shutdowns

	Level 1			Level 2		
Indicator Function (at Battery Voltage)	**CV**	**S**	**RA**	**CV**	**S**	**RA**
(a) Overcrank	X	X	X	X	X	O
(b) Low water temperature	X	NA	X	X	NA	O
(c) High engine temperature pre-alarm	X	NA	X	O	NA	NA
(d) High engine temperature	X	X	X	X	X	O
(e) Low lube oil pressure	X	X	X	X	X	O
(f) Overspeed	X	X	X	X	X	O
(g) Low fuel main tank	X	NA	X	O	NA	O
(h) Low coolant level	X	O	X	X	O	X
(i) EPS supplying load	X	NA	NA	O	NA	NA
(j) Control switch not in automatic position	X	NA	X	X	NA	X
(k) High battery voltage	X	NA	NA	O	NA	NA
(l) Low cranking voltage	X	NA	X	O	NA	O
(m) Low voltage in battery	X	NA	NA	O	NA	NA
(n) Battery charger ac failure	X	NA	NA	O	NA	NA
(o) Lamp test	X	NA	NA	X	NA	NA
(p) Contacts for local and remote common alarm	X	NA	X	X	NA	X
(q) Audible alarm silencing switch	NA	NA	X	NA	NA	O
(r) Low starting air pressure	X	NA	NA	O	NA	NA
(s) Low starting hydraulic pressure	X	NA	NA	O	NA	NA
(t) Air shutdown damper when used	X	X	X	X	X	O
(u) Remote emergency stop	NA	X	NA	NA	X	NA

CV: Control panel-mounted visual. S: Shutdown of EPS indication. RA: Remote audible. X: Required.
O: Optional. NA: Not applicable.
Notes:
(1) Item (p) shall be provided, but a separate remote audible signal shall not be required when the regular work site in 5.6.6 is staffed 24 hours a day.
(2) Item (b) is not required for combustion turbines.
(3) Item (r) or (s) shall apply only where used as a starting method.
(4) Item (i) EPS ac ammeter shall be permitted for this function.
(5) All required CV functions shall be visually annunciated by a remote, common visual indicator.
(6) All required functions indicated in the RA column shall be annunciated by a remote, common audible alarm as required in 5.6.5.2(4).
(7) Item (g) on gaseous systems shall require a low gas pressure alarm.
(8) Item (b) shall be set at 11°C (20°F) below the regulated temperature determined by the EPS manufacturer as required in 5.3.1.

Safety Indications and Shutdown from NFPA 110 Table 5.6.5.2
Figure 2

Generator Panel – the generator control panel provides the following typical functionality:

- An AC voltmeter with the ability to select the phase monitored
- An AC ammeter with the ability to select the phase monitored
- A frequency meter
- Voltage adjustment for the voltage regulator
- Protective relaying or relay settings

Generator Protection – the generator is typically protected by the following devices or functions:

- Phase overcurrent relays
- A differential relay for each stator winding
- A reverse power relay
- A ground fault relay (for certain units when required by NEC article 230)
- An output circuit breaker

5. Fuel storage and pumping system:

A typical fuel system consists of a day tank and a bulk storage tank.

Day Tank: A day tank mounted on or near the engine, provides a small supply of fuel at a relatively constant level, regardless of the level of the bulk storage tank. The day tank does not necessarily hold a “days” supply for fuel. Usually, a day tank is specified to hold at least the amount of fuel that would be consumed in one hour at rated load. When the bulk storage tank is positioned at an elevation or height sufficiently above the day tank to cause adequate gravity flow, a float operated valve or float switch and fuel shutoff solenoid can be used to fill the day tank. Otherwise a fuel transfer pump is required.

Bulk Storage Tank: The capacity of a bulk storage tank is dependent on the expected length of a power outage and any disaster that could interrupt fuel delivery in addition to the frequency with which an owner desires to have to refill the bulk storage tank during a sustained outage.

The piping between fuel tanks should be designed and specified by a qualified mechanical design professional.

6. Air Supply and Exhaust – A means of providing an unimpeded flow of fresh outside air into the generator is necessary and serves two purposes:

    a) Cooling air for the generator and to keep the generator room comfortable and,

    b) To provide clean air available to the engine for combustion.

The lowest cost way of providing this fresh air is to use a pusher-type fan on the radiator and to connect the radiator to the outside with an appropriately sized duct. The air intake opening into the room is usually sized to be 25% - 50% larger than the duct. Exhaust piping inside a building should be covered with gas tight insulation to protect personnel and reduce room temperature. The exhaust piping must be of sufficient diameter to avoid exhaust back pressure and should be specified by a qualified mechanical design professional. Consideration should be given to directing the exhaust away from any air intakes.

Noise reduction – vibration must be frequently isolated from structures to reduce noise. Noise reducing mufflers are rated according to their degree of silencing by such terms as industrial, residential or critical and are usually specified to meet noise standards. An air intake muffler is usually not installed since an engine is normally supplied with an intake air filter that serves as an intake air silencer. It is important to note that the majority of the noise emanating from an engine-generator set is radiated off of the engine block and not via the exhaust. For critical noise applications, sound attenuated enclosures are often required in addition to and are more important than a critical muffler in limiting the noise produced by an engine-generator set.

7. Foundations / concrete pads - should always be designed by a qualified professional. However, for preliminary site planning purposes, the following guidelines can be of use for laying out a possible pad on level, compacted soil (for gen sets located outdoors):

    i. Provide pad extending one foot (or as desired) beyond the limits of the generator enclosure.

    ii. The weight of the concrete should be 125% of the total weight wet (including oil and full fuel tank is sub base tank is used) of the gen set and enclosure. If the genset has vibration isolators (springs at its base) then the concrete should weigh 100% of the total gen set wet weight.

iii. Foundation / concrete pad thickness of 12” – 24” is typical but sometimes a pad as thick as 30” is warranted.

iv. Diesel fuel can be estimated to weigh approximately 7.1 lbs per gallon.

v. Typical concrete density is 12 lbs per square foot per inch of pad thickness or 144 lbs per cubic foot.

vi. Reinforce according to structural engineer or architect’s design.

Example: a 1250 kW gen set with 4300 gallon sub base tank and weatherproof enclosure has a combine gen set, enclosure, sub base tank and fuel have a total wet weight of 60,000 lbs. The gen set has no vibration isolation. The desired pad dimensions are 12’ x 36’. What is the estimated thickness of the reinforced concrete pad required to support the gen set?

Step one – determine weight of concrete: Pad should weigh 125% of gen set wet weight (since there is no vibration isolation). Pad should weigh 1.25 x 60,000 lbs or 75,000 lbs.

Step two – determine area of concrete pad – a 12’ x 36’ pad covers 432 square feet.

Step three – determine pad thickness by dividing total weight by the area of the pad and then the density of concrete used. 75,000 lbs divided by 432 square feet divided by 12 lbs per square foot per inch of pad thickness is approximately 14.7 inches of reinforced concrete pad.

III. System Component Features and Options

Engine driven generators are work horses that fulfill the need for reliable emergency and standby power. They are available from 1 kVA units up to several thousand kVA. When properly maintained and kept warm, they dependably come on line within 8-15 seconds (IEEE 446).

Engine – generator sets are just that – an engine coupled with and driving an electrical generator. There are several types of gen sets that are classified by the energy source (fuel) of their prime mover (in this case the engine):

Gasoline Engine
Diesel Engine
Gas turbine

Gasoline Engine sets are available from several hundred watts to about 100 kW. Smaller sets use two- and four-cycle high speed, lightweight engines. Larger sets use multiple cylinder engines built for automobiles and trucks.

Diesel Engine sets are available for just under 100 kW to 10,000 kW. Diesel gen sets are rugged, dependable and most suitable for continuous duty. The fire and explosion hazard is considerably lower than for gasoline engines/

Gas turbine gen sets are available up to 10,000 kW. They are compact and lightweight compared to the other prime movers making them suitable location and mounting in restricted spaces on roofs of buildings. The gas turbines are modified air craft auxiliary power and small propulsion power turbines. The sets require as much as 120 seconds to start, reach rated speed and deliver power making them not suitable for emergency power applications.

Affect of Environment: Altitude and high ambient temperature can adversely affect an engine's ability to deliver the torque required for the full generator output. Over sizing the engine is absolutely necessary for higher altitudes. A general rule for de-rating engine power loss with increases in altitude is to de-rate 4% for each 1000 feet increase in altitude above sea level. Turbo charged engines usually do not need to be de-rated below a certain minimum altitude, typically 2500 – 5000 feet above sea level.

An average de-rating factor for high ambient temperature is 1% for each 10 degrees F above 60 degrees F. Temperature de-rating is not considered as important as altitude de-rating.

Generators operating in the tropics are likely to encounter excessive moisture, high ambient temperatures, fungus, vermin, etc…and may require special tropical insulation and space heaters to keep the windings dry and the insulation from deteriorating (IEEE 446).

Fuel Choices – Diesel, gasoline and natural gas and liquid petroleum (LP) gas are the typical fuel choices. Diesel engines are by far are the most prevalent engines used for emergency and standby applications.

Natural gas and LP gas gen sets can be a reliable emergency or standby system in small kW sizes but there are generally some significant drawbacks for systems over 100 kW.

The biggest drawback of natural and LP gas units when compared to diesel is initial cost. If a unit is above 150 kW standby rating then (according to Caterpillar sales reps) natural gas units cost 2 to 2.5 times the cost of diesel per kW. One reason for this is because the BTU’s in gas are a lot less than diesel per unit volume. Therefore you need a bigger engine to produce the same power with gas than with a diesel.

The natural gas supply can be interrupted (think large tree with extensive root system – uprooting the pipes) whereas with diesel you have reliable on site fuel supply. Because of the energy density issue, on site bulk storage of natural gas with switchover from the gas utility adds complexity to the system.

Natural gas units can only block load up to 25% of rated load whereas diesel units can block load 100% of rated load.

Service intervals are the same for natural gas and diesel gen sets. Natural gas units do not have replaceable fuel filters, however ignition system maintenance costs for natural gas units far outweigh fuel filter savings.

Operating Cost – at the present time – the cost of producing electrical energy with diesel is approximately 4 cents per kWh more than with natural gas (25 cents versus 21 cents per kWh).

However, operating costs are not a significant factor in the specifying or purchasing decision of a emergency or standby power system gen set. This is because the limited run time associated with emergency or standby gen sets provides limited payback opportunity (whereas as with a prime power application operating cost would be a more significant consideration).

Governor – The governor regulates or “governs” the amount of fuel delivered to the engine at various loads to keep the speed or frequency of the generator relatively constant.

The mechanical governor using rotating flyball to sense speed and operate against a reference spring to actuate the throttle. Higher performance governors use hydraulic pressure or electric actuators to operate the engine throttle or fuel rack.

Governors are of two typical types, droop and isochronous. With a droop type governor, the engine’s speed is slightly higher at light loads than at heavy loads, while an isochronous governor maintains a steady speed at any load up to full load. An isochronous governor is recommend when a gen set provides power to power semi-conductor loads.

Transfer Switches

Transfer switches are offered in different configurations and operating schemes including:

Automatic
Non Automatic (manual)

Bypass – Isolation

Open Transition
Closed Transition
Closed Transition – Soft Load

Automatic – The automatic transfer switch transfers power between two power sources without requiring the intervention of an operator. The switch monitors the electrical conditions of both power sources (normal and alternate) i.e. voltage, frequency, phase rotation and load. When one of the systems characteristics deviates from the specified allowed range, the transfer switch transfers to the other system if has more suitable power available.

Some automatic transfer switches also include provisions for non automatic manual operation in the event of failure of the switches automatic features.

Non Automatic Switches require the manual action of an operator and cannot be used for emergency power applications.

Transfer Switches with Bypass – Isolation consist of an automatic transfer switch with one parallel and isolated (in a separate enclosure section) manual transfer switch. In the event of a failure of the automatic transfer switch the bypass switch will allow the load to be fed while allowing the automatic transfer switch to be removed for service, repair or replacement.

Open transition automatic transfer switches transfer power between sources with a momentary interruption of power (also called break before make) so that both sources of power are never connected at the same time to the load (the sources are never connected in parallel with each other). Open transition switches are the standard automatic transfer switch offering.

Closed transition automatic transfer switches parallel (connected both together at the same time) both sources of power when both are available and of suitable quality. To do this, the transfer switch either actively or passively waits for the two sources of power to be synchronized prior to removing the second power source. In the event of the failure of one of the sources the switch will operate as a standard, open transition switch. Many utilities do not allow for sustained paralleling of alternate power sources with utility power.

A variation of the closed transition transfer switch – is closed transition - soft load. This configuration allows for a momentary make before break transfer between power sources with no interruption of service to the loads served by the transfer switch. Typically a half cycle (8 millisec) overlap is allowed). This configuration, when allowed by the utility, is helpful for peak demand shaving or interruptible load utility agreement applications. Whenever closed transition switches are specified and paralleling with the utility is anticipated, even momentarily, it is vital that the utility be contacted to discuss the application and the utility's requirements early in the planning phase of the project.

Automatic Transfer Switches that do not incorporate integral overcurrent protection devices must be protected by upstream (line side) protective devices. Transfer switches that incorporate molded case circuit breakers do not required external protective devices on the protected source. Service Entrance rated transfer switches that can receive power directly from a utility transformer without secondary protection are available.

Automatic transfer switches must be manufactured and listed to comply with UL 1008 which stipulates endurance test and life expectancy requirements. The short circuit rating of a transfer switch must be specified and must match or exceed the fault current available through the power system at the switch. For closed transition switches which allow for the paralleling of two power sources, the available fault current at the switch will be the sum of the fault currents available through both sources.

Transfer switches are commonly manufactured to two configurations related to the number of switch "poles", three (3) pole and four (4) pole. Three pole automatic transfer switches switch only the hot, phase conductors and should be specified when the alternate power source is

NOT a separately derived system. That is, when the generator does not have its own neutral – ground bond but relies on the utility neutral – ground bond it is not a separately derived system because is shares the utilities neutral connection and as a result the neutral can not be switched.

Conversely, a four pole transfer switch is required when the alternate power source IS a separately derived system. In a separately derived system no system conductors are shared. Generators with their own neutral – ground bond do not share the utility neutral and must have a four pole switch (and switched neutral so that the utility and generator neutral ground bonds are not connected at any time which would allow neutral current to flow through grounding conductors between the two parallel neutral – ground bonds – a violation of the National Electrical Code.

Diesel Fuel Tanks

Types of Tanks – There are two basic ways to store in bulk the diesel fuel oil required by diesel combustion engine generator sets.

A large tank can be mounted remotely from the gen set (either above ground or below ground). Remotely mounted storage tanks usually require a smaller day tank and fuel transfer pumps if gravity flow cannot occur between the tanks. Day tanks normally provide fuel for two hours of operation.

A sub-base tank is one that is located below the base of the generator but manufactured / integrated with the generator base and often with the gen set enclosure for gen sets located outdoors. A sub-base tank is typically more economical and eliminates additional piping and transfer pipes. However, sub-base tanks present additional considerations that must be address such as – additional weight impacting foundation sizing requirements and potential adding significant height to the installed gen-set depending on the tank capacity – requiring steps/stairs for outdoor gen set enclosures or room ceiling height for indoor locations. Sub-base tanks must be double walled and meet appropriate NFPA and EPA requirements. Sub-base tanks can be factory assembled and integrated with the gen set reducing site adaption requirements and installation time.

Tank Sizing – Diesel combustion engine gensets can be conservatively estimated to have an approximate consumption rate of .1 gallons per kW per hour at 100% rated load. Most jurisdictions will specify the minimum operating hours (based on the facility occupancy) in the event of a failure of the normal power system. Based on the required or desired run time and estimated load the main tank capacity can be calculated and specified.

Other factors impacting the desired fuel storage tank capacity are – desired intervals between fuel deliveries during a power outage (e.g. after a natural disaster where reliable fuel delivery or availability might be interrupted).

One downside associated with having too large a bulk storage fuel tank is that diesel fuel oil can go bad or turn if it is stored for too long. There are fuel additives available to mitigate the risk of this happening if a gen set is run infrequently.

Generator Protection

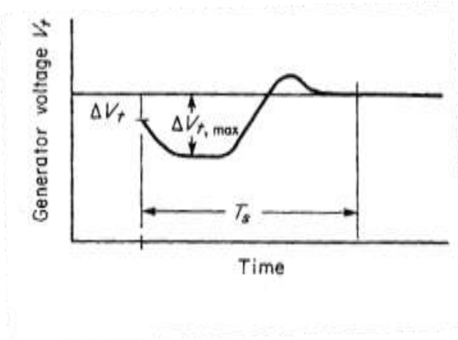
Generators require protection against internal and external electrical faults and other conditions that can damage the generator and/or its engine under two types of operation. The first type of operation is when the gen set is operating continuously or on standby independent of the utility line. In the second the generator is paralleled with the utility line and is operating in order to shave or share load. The scope of this course addressed only the first type of operation. For paralleling applications you must contact and work closely with the utility company.

IV. Generator Loading

Introduction – When sizing and selecting generators for emergency/standby systems, the behavior of both the generator output voltage and the current it provides under steady state load and transient load conditions may become critical. The generator output voltage may run out of the acceptable range for sensitive loads and current demanded of generator may exceed the range that can be delivered by the generator.

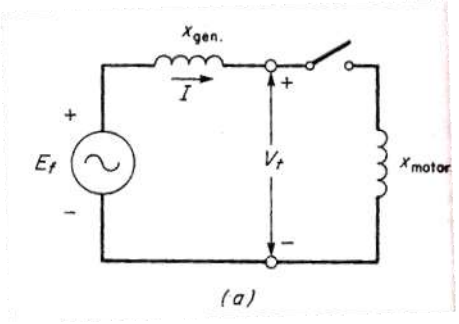
Generator Impedance – the electrical characteristics of a generator is relatively complex because its impedance varies depending on the loading conditions. The internal impedance of a generator consists of a) winding resistance, b) the winding leakage reactance and c) the magnetizing reactance. All the impedances for generator products are available from the manufacturer. Voltage drop in a generator has three components related to each of the three impedance components.

Suddenly Applied Load – The typical behavior of the generator voltage for a suddenly applied load, such as starting a large motor is shown in figure 3 below



Voltage response Gen Set starting motor - Generator voltage versus time
Figure 3

When the load is suddenly applied, the voltage drops initially by ΔV_t, the voltage drops further to $\Delta V_{t\ max}$ until the voltage regulator take control. The voltage finally recovers with an overshoot and returns to nominal value in a specific time T_s. The extend of the voltage dip and recovery time are set by the parameters and adjustment of the generator excitation and regulation systems. The initial dip ΔV_t can be calculated by representing the generator in Figure 4 by its subtransient reactance X''_d and the motor by its locked rotor impedance X_{lr}. The maximum dip $\Delta V_{t\ max}$ before the voltage regulator acts can be calculated in the same way except for representing the generator by its transient reactance X'_d.



Gen set starting motor – Equivalent Circuit
Figure 4

Power Semiconductor Load – Incompatibility issues regarding emergency and standby generator systems and downstream sensitive electronic load equipment have been gaining recognition in recent years. According to IEEE 1100 Recommended Practice for Powering and Grounding Electronic Equipment, generators should be specified to have the following features to minimize adverse interactions when supplying non-linear loads:

i. Isochronous electronic governor to regulate frequency. These governors typically maintain frequency regulation with .25% of the setting as opposed to approximately 3% for mechanical governors.

ii. Permanent magnet excitation system or filtering means to isolate the voltage regulator power circuit from the distorted generator load waveform.

iii. Generators with 2/3 pitch stator winding design to minimize third harmonic waveform distortion.

iv. Low subtransient reactance to minimize voltage waveform distortion. This is accomplished by coupling and oversized generator with a standard sized engine and must be coordinate with generator manufacturers.

V. Generator Testing and Maintenance

Required Engine Generator Set Testing – The proof that acceptable equipment has been specified and purchased is demonstrated by testing in the factory (Factory Acceptance Test or FAT) and at the site (Site Acceptance Test or SAT). The following are typical sequences of tests for engine – generator sets:

i. Factory Tests – The vendor submits a test plan to the end user. After approval of the test plan, the end user or his representative witnesses the tests or simply requests documentation that the test occurred. If the tests are satisfactory, the equipment is approved for shipment to the site. If the tests fail, the equipment must be modified and the tests are repeated.

ii. Site Test – Tests made at the factory are repeated at the site by using all of the assembled on-site equipment – gen set – transfer switch – battery charger etc. The equipment is tested with dummy load or load bank which is brought in for the test.

iii. Site Test with Actual Load – The actual load, e.g. data processing center equipment, water treatment plant pumps, building loads etc… All of the emergency and standby sequences are tested including engine-generator starting on power failure, transfer switch operation, interaction of generator and UPS's and VFD controlled motors.

Operation – Emergency and Standby Power systems are designed so that no manned operation is required. When utility power fails, the system us supposed to take over automatically and supply electrical loads in the prescribed manner. However, emergency and standby generator systems do require periodic testing, preventive maintenance and repairs. Most failures of emergency/standby systems are the result of inadequate maintenance.

Maintenance – the following questions must be resolved for each component that is part of the emergency/standby power system:

a. *Who will do the maintenance?* It can be performed by trained on-site owner's personnel, by the vendors' service organization or by and independent contractor.

b. *What spare parts are required?* They can be provided and maintained by the end user or by the maintenance organization. The vendor can also provide a back up supply of spare parts. An orderly process may be required to ensure that the supply of spare or consumable parts is monitored and up to date.

c. *What will the preventive maintenance program be?* Maintenance can be performed annually, semi-annually, or at intervals recommended by the vendor (recommended to not void warrantees). The factors that have the greatest influence on the required preventive maintenance intervals are the type of fuel, starting frequency, environment and level of reliability required.

d. Who will keep the maintenance records and update drawings and instruction manuals? All of the material should be the responsibility of one person or office and kept in a central location at the site.

Preventive Maintenance – Long life and high reliability are characteristics of internal combustion engine – generator sets, but only if properly maintained. Preventive maintenance programs greatly contribute to service life and reliability.

In establishing a preventive maintenance program the best starting point is the manufacturer’s service manual. This will provide a guide for specific points to be checked and will indicate the frequency of inspection. These recommendations can be modified to fit particular installation and operating conditions. More than any other factor, lubrication determines an engine’s useful life. Various parts of the engine may require different lubrications and different frequencies of application. It is important to follow the manufacturer’s recommendations as to type and frequency of lubrication. Cleanliness should be the foundation of a preventive maintenance program. While there may be minimum wear, there is always a possibility of contamination by corrosive dirt and grit buildup. Dirt is a MAJOR cause of equipment failure. Before performing any inspection or service, all fittings, caps, filler and level plugs and their adjoining surfaces should be carefully cleaned to prevent contamination of lubricants and coolants.

Routinely scheduled inspection items should include:

- Radiator coolant level
- Antifreeze if utilized
- Crankcase oil level
- Fuel supply
- Air cleaner
- A drain check should be made to eliminate condensed water from fuel tank and filters
- The engine should be visually inspected for loose nuts, bolts and other hardware and leaks at seals, gaskets and other connections in the fuel, cooling, lubrication and exhaust systems.

Maintenance Intervals – the following is not intended as a recommendation but is presented as a typical maintenance schedule for diesel internal combustion engines in an emergency or standby power application (extracted from IEEE Std 446 – Recommended Guideline for Emergency and Standby Power Systems for Industrial and Commercial Applications):

1. Every 25 hours of operation (or 4 months)

    a. Adjust fan and alternator belt
    b. Add oil to cup for distributor housing
    c. Change oil in oil-type air filter

2. Every 50 hours of operation (or 6 months)

    a. Drain and refill crankcase
    b. Clean crankcase ventilation air cleaner
    c. Clean dry type air cleaners
    d. Check transmission oil
    e. Check battery
    f. Clean external engine surface
    g. Perform 25 hour service (above)

3. Every 100 hours of operation (or 8 months)

    a. Replace oil filter element
    b. Check crankcase ventilator valve

   c. Clean crankcase inlet air cleaner
   d. Clean fuel filter
   e. Replace dry-type air cleaner
   f. Perform 25 and 50 hour service (above)

4. Every 200 hours of operation (or 12 months)

   a. Adjust distributor contact points
   b. Check spark plugs for fouling and proper gap
   c. Check timing
   d. Check carburetor adjustments
   e. Perform 25, 50 and 100 hour service (above)

5. Every 500 hours of operation (or 24 months)

   a. Drain and refill transmission
   b. Replace crankcase ventilator valve
   c. Replace one-piece-type fuel filter
   d. Check valve-tappet clearance
   e. Check crankcase vacuum
   f. Check engine compression
   g. Perform 25, 50, 100 and 200 hour service (above)

VI. Generator Sizing

Introduction – For some buildings, the maximum continuous generator load will be the total load when all the equipment in the building is operating. For others it may be more practical or economical to feed just selected circuits so that only the emergency or legally required loads are fed by the generator.

Motor starting considerations – if the maximum momentary voltage dip that is acceptable to the loads fed by the generator is known, it is possible to select the size of the engine-generator that will be able to start given sized motors without exceeding the allowable voltage dip. If it is possible that two or more motors can be started simultaneously, the sum of coincident horsepower ratings should be used as the basis of the motor starting requirements or controls provided to preclude simultaneous starting.

A time delay after energization relay (with a motor starting contact that would close only after a prescribed amount of time after the relay being energized) can be provided in motor starting control circuitry with an adjustable time delay to provide a staggered start of motors after receiving a start signal or after the restoration of power following an outage. Without such a relay it is possible that all motors that were on prior to a power failure would remain on line and all attempt to start once a generator came on line and attempted to assume system load.

Engines driving generators need to be sized to handle the continuous kilowatt load to be supplied to the power system it feeds plus the motor starting requirements and the generator losses.

In sizing an engine generator set for motor starting, the locked rotor or in-rush kVA (kilovolt-ampere) rating of the motors should be used. Manufacturer's data can usually be obtained giving the maximum amount of short duration kVA available for motor starting duty without exceeding a specified voltage dip. Motor starting load has a very low power factor due to the fact that the motors magnetic field has not been established and that must be considered in calculating the voltage dip. One other factor that must be considered is the effect of generator voltage dip on motor starting torque. Motor starting torque is proportional to the KVA input to a motor, but since voltage dip to as much as 70% of rated voltage (30% voltage dip) results in a 51% reduction of motor starting torque (proportional to the square of the voltage or V^2 so starting torque is .7 x .7 of or .49 of full starting torque) into a stalled motor rotor. Problems could arise in starting motors under load unless this is taken into consideration.

Generators are usually sized for the maximum continuous KVA demand. Should there be unusually high inertia loads to start without the benefit of reduced voltage starting (to limit in rush or starting kVA) or if voltage and frequency regulation other than specified cannot be tolerated during the start up period, THEN a higher rated generator may be required.

Load transient considerations – A voltage regulator with sufficient response is required to minimize sags or surges after load transients (sudden changes in load). The engine-generator set should be of sufficient capacity and design capability to minimize the effect of load transients.

Software Sizing Programs – There are many variables that go into selecting and specifying an appropriate engine generator set. For that reason it is recommended that you neither size nor specify a gen set without working with a few gen set manufacturers to select a “basis of design” gen set for your project. Manufacturer’s and their sales and engineering staffs are valuable resource to a specifying engineer.

Most major engine generator set manufacturers have developed their own generator sizing programs that allow a designer to enter project and load criteria and data into the program and retrieve a recommended engine-generator set selection. Gen set manufacturer sales staff or sales representatives are usually willing to perform sizing calculations and will provide a recommended product that will meet your project’s requirements and that they will stand behind. In addition to generating computer based gen set sizing caculations and motor starting modeling, many engine-generator set manufacturer’s will sell and possibly give their gen set sizing/modeling programs to consulting engineers who ask for them.

Depending on the size of the motor with respect to the engine generator, motor starting can represent a small or a large disturbance to the generator. In extreme cases, starting a very large motor can be almost as severe as a short-circuit condition for the generator. Under a short-circuit condition, the generator reactance jumps down from its steady-state value (X_d)to subtransient value (X''_d) and then changes to transient value (X'_d) and gradually back to its steady-state value (X_d).

Therefore, to correctly model a motor acceleration on an engine generator, the generator model should include its field and damper windings, so that both the subtransient and transient behaviors are modeled. In additon to this, the rotor model used for the motor should include the effect of speed on the rotor reactance and resistance. This means that a transient stability program, which can include the effect of generator exciter and governor systems, should be used for motor acceleration studies.

For a snapshot study where the objective is to calculate the maximum voltage dip during starting, simple models for the generator and motor can be used. For this purpose, the generator can be modeled as a constant voltage source behind its transient reactance and the starting motor is modeled as constant locked-rotor sub transient impedance.

Engines driving generators should be sized to handle the continuous kW load, plus motor starting requirements and the generator losses. It is important to note in the example calculation above that the initial starting kW exceeds the kW FL by 50%. During acceleration the kW requirement may become twice the initial requirement when the motor reaches breakdown speed, as determined by the breakdown torque rating. The generator engine must be capable of driving the starting kW requirements. In sizing the engine generators for motor starting, the locked-rotor kVA rating of the motors should be compared with the maximum motor starting kVA capability of the generator. Manufacturers’ data can usually be obtained, giving the maximum rating in kVA of the engine generator as well as its continuous rating. The maximum starting kvar rating would be the maximum amount of the short-duration kVA available for motor-starting duty without exceeding a specified voltage dip.

Generator set manufacturers are usually willing to furnish a guide for calculating motor-starting effects. A rule of thumb of 0.5 hp/kW is frequently used; however, the final decision should be based upon the manufacturer's data. When motor-starting kVA or continued kW exceed the rated values of the generator set, the effects of the resulting voltage and frequency deviation on equipment other than the motor being started should be evaluated (that is, motor starters, relays, computers, communication equipment, etc.).

Generators are usually sized for the maximum continuous kVA demand. Should there be unusually high inertia loads to start without benefit of reduced-voltage starting, or if voltage and frequency regulation other than specified cannot be tolerated during the startup period, a higher rated generator may be required.

Gen set sizing example No. 1 – Sizing selection

A standby engine generator set is needed to supply a maximum load of 1000 kVA with 10% spare capacity. Included in this load is an induction motor rated at 600 HP with across the line (full voltage) starting, a power factor of .85 and 90% full load efficiency. The gen set manufacturer selected by the owner states that their gen set cannot start an induction motor across the line if the motor rating is more than 50% of the gen set rating without causing excessive voltage dip. Select the minimum required gen set for this scenario from units rated 1000, 1250 and 1500 kVA.

Solution No. 1 –

The gen set size based on maximum load would be:

Rating for load = 1000 kVA x 1.1 (10% spare capacity) or 1100 kVA

The gen set size based on motor starting requirements would be:

$$\text{Motor rating} = \frac{600\text{ hp} \times .746\text{ kW/hp}}{.85\text{ pf} \times .90\text{ eff}} = 585\text{ kVA}$$

Rating for motor starting = 585 kVa/.5 = 1170 kVA

(Reflecting that the particular gen set can only start a motor half of its rating)

The minimum rating to satisfy both the load and motor starting requirements is 1250 kVA.

Gen set sizing example No. 2 – Motor Starting

Find the maximum horsepower rating that can be started – across the line (full voltage) from the following gen set without exceeding 15% voltage dip.

Gen set: 500 kVA, subtransient reactance $X''_d = .12$

Motor: 6 x full load starting amps, .85 pf, .92 efficiency

Solution No. 2 –

The voltage dip per each unit of motor input kVA is

V dip / KVA of load = (motor kVA/500 kVA) x 6 x .12
= motor kVA x .00144
% voltage dip = motor kVA x .144

The max motor load that can be started with only 15% dip is:

Motor kVA = 15/.144 = 104 kVA is max motor load that can be started with this gen set and 15% voltage dip.

The motor hp is found by the conversion:

$$\text{Motor hp} = \frac{104\ \text{kVa} \times .85\ \text{pf} \times .92\ \text{eff}}{.746\ \text{kW/hp}} = 109\ \text{hp}$$

So - the largest standard rating motor that can be started with 15% voltage drop (on the generator) is 100 hp.

VII. Construction Coordination Issues:

Remote annunciator – when remote annunciators are required to satisfy codes (NFPA 99 for Health Care projects) or for owner monitoring a suitable manned location in monitored location needs to be chosen. If the location is in a finished location then a recessed rather than surface mounted annunciator will be desired. In many cases, attention should be given to the appearance of both the annunciator face and color and finish of the trim plate.

Monitoring by other monitoring system SCADA or BMS – when generator status or alarms are to be monitored by a system other than the generator remote annunciator panel, a generator discrete input / output (I/O) module will be required to create auxiliary signals that can be monitored by another system. This is not a standard item and will need to be specified and coordinated with the manufacturer.

Required circuits and conduit

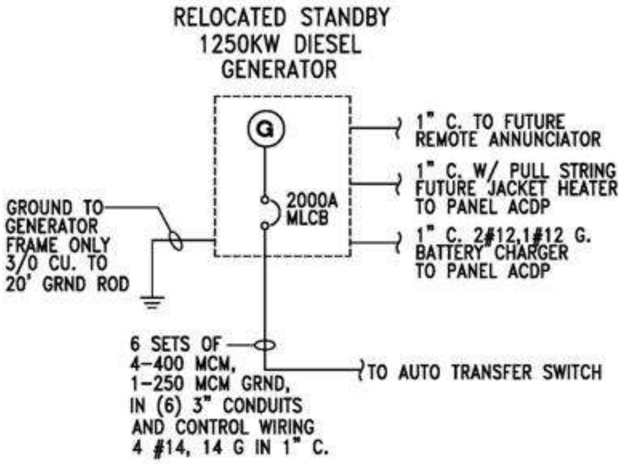
1) Battery charger – a battery charger typically requires a 20A – 120V circuit.

2) Jacket water heater – a factory installed jacket water heater system is recommended for cold starting capability. The system includes heater, isolation valves, hoses, auto disconnect and wiring. Caterpillar recommends 3000 Watt heaters for 225 – 400 kW units, 6000 Watt for 500 – 1100 kW units and 12000 Watt for 1100 – 2250 kW units. Voltage is either 240 or 480V – 2 pole circuit. Check with manufacturer’s literature.

3) Start signal – generator start signal typically comes from the automatic transfer switch and can be control wiring. Wire gage number 14 or larger and 600V insulated wire is typical allowing the wiring to be installed in the conduit with the generator feeder.

4) Remote annunciator – wiring requirements between the generator control panel and the remote annunciator should be coordinated with the gen set manufacturer.

These interface wiring requirements are sometimes not coordinated or shown on electrical plans causing problems during construction. One technique to avoid such problems is to include the interface wiring requirement on the single line diagram to make sure the requirements are coordinated. An example is shown in figure 5 below.



Example Single Line Diagram Block Showing Gen Set Interface Wiring
Figure 5

VIII. Power Generation Cost Analysis – Purchase versus generate your own power decisions

A cost /benefit analysis is a normal process of the design of any system and the selection of components. The decision to generate your own electricity versus purchasing electricity from an electrical utility is relatively simple.

Cost of generating your own electricity

First cost – the installed cost of a typical diesel engine generator set and automatic transfer switch system (including feeder conduit and wire) can be estimated at $450 / kW. Depending on the load to be served this can be a significant investment and one that typically dissuades owners from generating their own electricity for purely economic motives.

Operating cost – at the time of this course being prepared, diesel fuel cost approximately $2.50 per gallon. Diesel engine generator sets typically consume 1/10 gallon per kW-hour of energy produced for a cost of 25 cents per kWh.

Maintenance cost – Annual maintenance costs can be estimated at 1.5 cents per kWh (according to Caterpillar representatives) to cover oil changes, filters, etc).

Using conventional diesel gen set, the variable cost of an owner producing their own electricity can be estimated at 26.5 cents per kWh.

Cost of purchasing utility generated and transmitted electricity – according to local utilities, the average cost of purchasing utility generated and transmitted power can be estimated at approximately 10 cents per kWh. This average rate includes both fuel/energy costs and demand charges for the average customers.

Break even consumption – if the variable operating and maintenance costs self generated electricity were less than the cost of utility generated electricity, then it would be possible to calculate how much self generated electricity would need to be generated instead of buying utility generated power in order to pay off the first cost that would need to be invested in the genset, transfer switch and required power distribution. Clearly when the incremental production cost of self generated power ($.25 per kWh) is more than the cost of readily available utility power ($.10/kWh) there is no cost savings associated with with an investment in generating equipment and therefore there is no way to pay back the required initial investment in generator, fuel storage and transfer switch systems that is required to generate your own electricity.

IX. Application Specific Requirements

Lighting

i. For short time durations (up to 1.5 hours required by NFPA 101) – primary lighting for life safety/emergency egress purposes – battery units are a satisfactory approach. However when longer durations or increased lighting levels (NFPA only requires an average of 1 foot candle of illumination along the egress path) and therefore heavier loads are required, engine – generator power is usually recommended.

ii. High Intensity (HID) Lighting: If mercury vapor, metal halide, high or low pressure sodium or other types of High Intensity Discharge lighting are used as the normal lighting source, consideration should be given to providing other lighting sources like LED, Fluorescent or MR 16 (tungsten)

iii. Switching of lighting when using generator powered egress lighting – when a facility has an emergency generator it is natural to consider feeding the NFPA 101 egress path emergency lighting with generator backed up power. One obstacle that must be overcome in considering this emergency power application is how to control the lights – that is to turn them on and off – for energy conservation and ambient lighting control purposes – while assuring that the lights will come on during a power outage to provide the code required emergency lighting. There are several options available to solve this riddle:

1. The first and simplest option is for all emergency lights to be unswitched and remain lit at all times – essentially serving as night lights when a space is unoccupied. Of course, this wastes energy and money and hastens life expectancy of lamps and lighting ballasts.

2. A second option is to control emergency lighting circuits through a UL 924 emergency shunt relay like the one shown below. The emergency shunt relay allows for manual (switch or dimmer) control of emergency lighting by sensing normal power to the space served and then automatically shunting (closing in a

normally closed, electrical held open relay contact) on the emergency power upon failure of the normal power to space bypassing the manual or dimmer control that may call for the lighting to be "off" at the time of the power failure.

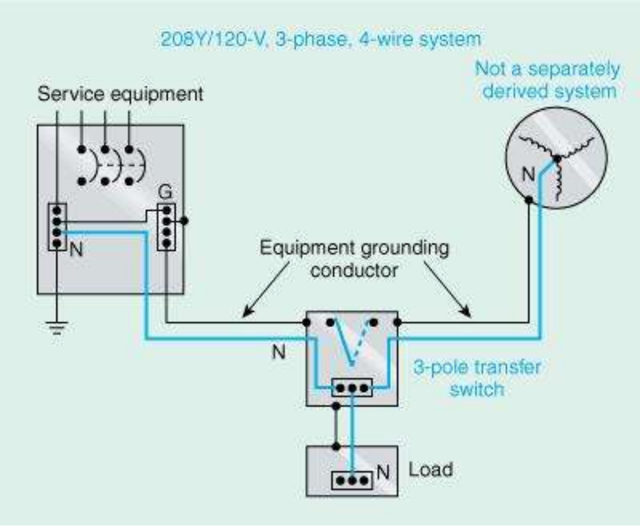
Emergency Relay
Figure 6

3. The most advanced solution for dual use fixtures (normal control but to come on emergency power during normal power outage) is to utilize branch transfer switches. This approach to generator powered emergency lighting is used in many theaters and theme park attractions where sophisticated lighting control is required of normal "house" lighting and when dimmed lighting is desired to be used as emergency lighting in lieu of a completely separate lighting system being installed. In this approach, each dimmed "normal" circuit is fed through a 20A branch transfer switch which switches the dimmed lighting fixtures over to full voltage emergency power in order to achieve 100% lighting output during a normal power outage. Note – for this application, when the normal power and generator sources are both separately derived systems (i.e. when they each have their own neutral – ground bond), the neutral conductor for each circuit also needs to be switched.

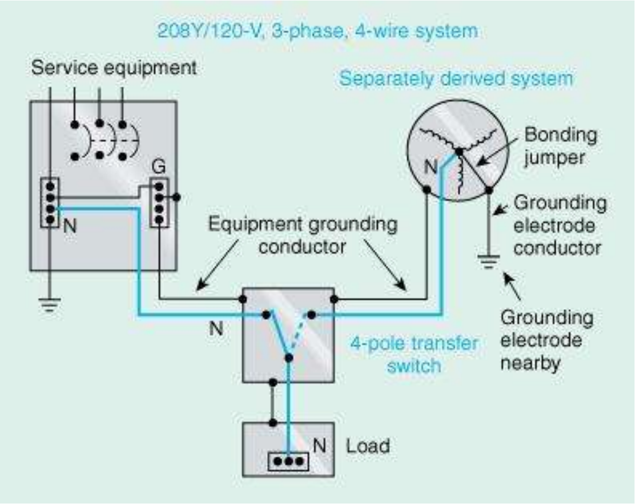
Generator located in separate facility / separate service: In other sections of this course we have discussed separately derived systems. A generator is a separately derived system according to the National Electrical Code IF it has a neutral – ground bond that is separate and distinct from the utility service entrance neutral – ground bond.

A generator fed emergency or standby power system is also considered a separately derived system when it is located in a different building and bonded to a <u>different</u> normal utility power system than the normal power system for which is being used as an alternate or standby source.

Emergency power systems that are separately derived from the normal source of power that a transfer switch must selected between, require that the neutral conductor be switched by the transfer switch. This is to prevent more than one neutral – ground bond being placed in parallel and objectionable currents from flowing through grounding conductors. The differences are illustrated below in figures 7 and 8.



Not a Separately Derived System – neutral not switched!
Figure 7



Separately Derived System – Neutral is switched! Figure 8

Emergency and Standyby Power Systems

Course Examination

After you have completed answering all of the questions, go back and check your work. Make certain that you have marked only one answer for each question. There is only one correct answer to each question. Make certain that you have answered each question. Any question that is left blank will be counted as incorrect.

A score of 70% is required to complete the course. Failing to achieve a 70% score all your answers will be erased. You will have three opportunities to achieve a passing grade. Failing to score a passing grade on the third attempt will block you from further attempts and your course fee returned to you.

Once you have successfully completed exam you will be able to print out your completion certificate. We suggest you file it electronically or print it out should you be audited by your licensure board for compliance with continuing education requirements. At that time you will also be able to compare your answers to the school answers on questions you may have missed.

Emergency and Standby Power Systems Examination

1. True or False – according to the National Electrical Code, wiring for legally required standby systems <u>may occupy</u> the same raceways, cables, boxes and cabinets as other <u>general wiring</u>. Wiring for emergency systems <u>need not</u> be kept entirely independent from other wiring.

   a) True
   b) False

2. True or false – a fuel transfer pump is always required to provide fuel between fuel storage tanks, day tanks, and the gen set?

   a) True
   b) False

3. A means of providing an unimpeded flow of fresh outside air into the generator space is necessary and serves the following purposes <u>except</u> the following:

   a) Cooling air for the generator.

   b) To provide make up air and to maintain the ambient temperature in the location the generator is housed.

   c) To allow a column of intake air to attenuate noise that would otherwise leave the space

   d) To provide clean air available to the engine for combustion.

   e) None of the above (All are true).

4. The majority of the noise emanating from an engine-generator set is radiated from:

   a) the exhaust system.
   b) the radiator fan.
   c) the engine block.
   d) the vibrating gen set foundation.
   e) none of the above.

5. A general rule for de-rating engine power loss due to increases in altitude is to de-rate what amount for each 1000 feet increase in altitude above sea level?

   a) 1.5 %
   b) 4%
   c) 10%
   d) None of the above

6. According to IEEE 446, when properly maintained and kept warm, diesel engine generator sets dependably come on line within:

   a) 8-15 seconds
   b) 10 seconds
   c) 60 seconds
   d) 5 seconds of transfer
   e) None of the above

7. An average de-rating factor for high ambient temperature what % of gen set capacity for each 10 degrees F above 60 degrees F.

   a) derating is not required for higher ambient temperatures.
   b) 1%.
   c) 5%.
   d) 10%.
   e) None of the above.

8. Which of the following are IEEE 1100 recommended techniques for powering semiconductor loads with engine – generator sets

   a) Isochronous electronic governor to regulate frequency instead of mechanical governor.
   b) Permanent magnet excitation system.
   c) Generators with 2/3 pitch stator winding design.
   d) Low subtransient reactance.
   e) All of the above

9. The factor(s) that have the greatest influence on a gen sets required preventive maintenance intervals are:

   a) the type of fuel
   b) gen set starting frequency
   c) environment
   d) level of reliability required
   e) all of the above

10. The factors that have the greatest influence on the required preventive maintenance intervals for gen sets are all of the following except:

   a) gen set starting frequency
   b) whether an owner will self perform the required maintenance
   c) environment
   d) level of reliability required
   e) none of the above (all of the above are factors)

11. Which of the following are FALSE:

   a) Preventive maintenance programs greatly contribute to service life and reliability.
   b) More than any other factor, lubrication determines an engine’s useful life.
   c) Dirt is a MAJOR cause of equipment failure.
   d) A common cause of engine generator sets failure to start is a battery failure.
   e) None of the above (meaning all are TRUE)

12. True or False: Operating costs are a significant factor in the specifying or purchasing decision of an emergency or standby power system gen set.

   a) True
   b) False

13. If an owner's fuel (operating) cost of generating electricity (in $/kW-h) with a diesel engine – generator set is more than the cost of simply purchasing electricity from a utility (also in $/kW-h), then:

    a) There is <u>no way</u> to pay back the required initial investment in generator, fuel storage and transfer switch systems that is required to generate your own electricity.
    b) There can be sufficient energy cost savings realized to warrant the initial investment in equipment to generate power.
    c) There are no energy cost savings to be realized.
    d) Both a and c.
    e) None of the above.

14. True or False: In order to satisfy the National Electrical Code, Emergency power systems that are separately derived from the normal source of power that a transfer switch must select between, must have the neutral conductor switched by the transfer switch. This is to prevent more than one neutral – ground bond being placed in parallel and objectionable currents from flowing through grounding conductors.

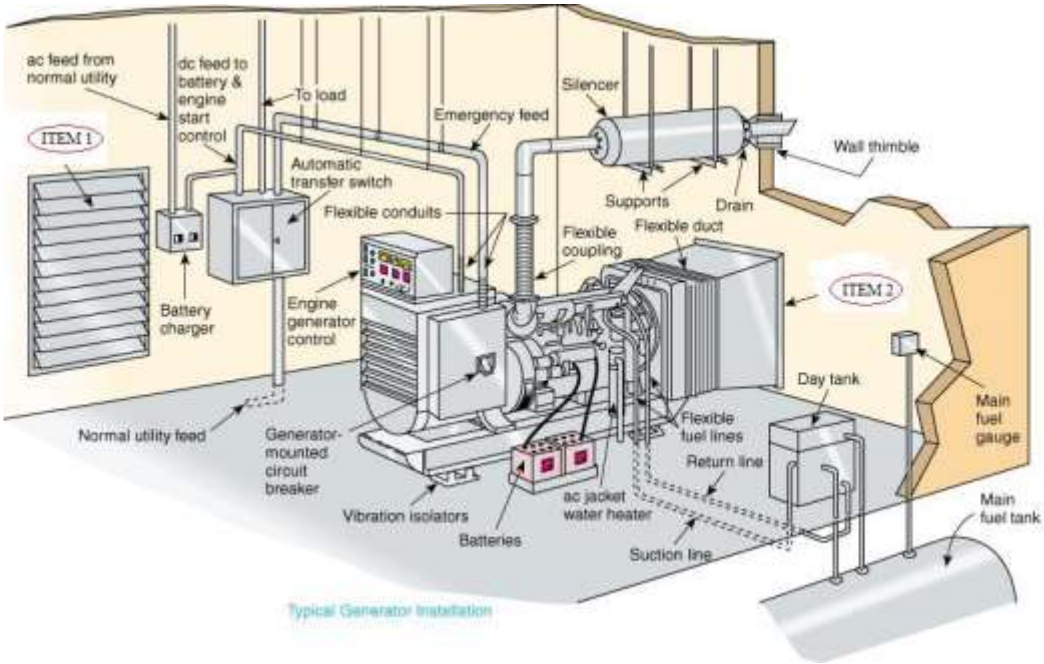
    a) True
    b) False

15. Which of the following are <u>TRUE</u>:

    a) One option to address how to control emergency lights ensuring that they will be on during a normal power failure is for the lights to be unswitched and remain lit at all times.
    b) Emergency lighting circuits may be controlled using a UL 924 listed emergency shunt relay.
    c) None of the above
    d) All of the above

16. In the following illustration which of the following are correct?

    a) Item 1 is outlet air opening and item 2 is inlet air opening.
    b) Item 1 is inlet air opening and item 2 is outlet air opening.
    c) None of the above



Typical Generator Installation

17. Which of the following are components of an emergency or standby power engine – generator set installation?

    a) Transfer Switch
    b) Batteries
    c) Fuel System
    d) Engine/Generator Control
    e) All of the above

18. While emergency systems have a requirement to supply standby power in 10 seconds or less when normal power is lost, what is the requirement for legally required standby systems to have power restored?

    a) 5 seconds.
    b) 20 seconds.
    c) 60 seconds.
    d) 5 seconds after the gen set starts.
    e) None of the above

19. A 500 kW gen set with 1000 gallon sub base tank and weatherproof enclosure has a combined gen set, enclosure, sub base tank and fuel have a total wet weight of 25,000 lbs. The gen set has vibration isolators. The desired pad dimensions are 12’ x 15’. For site planning purposes only, what is the approximate estimated thickness of the concrete pad required to support the gen set?

    a) 11.6 inches
    b) 5.9 inches
    c) 18 inches
    d) 13.9 inches
    e) None of the above

20. Which of the following are reasons one might choose to specify a diesel fuel fired combustion engine driven gen set instead of one that is natural gas fired?

    a) Natural gas gen sets can only block load 25% of their capacity
    b) Natural gas gen sets cost more than their diesel counterparts
    c) Diesel fuel costs less per kWh generated than does natural gas generated electrical energy.
    d) All of the above
    e) a and b only

END OF TEST