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# Design & Application Information

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## YOUR KOHLER DISTRIBUTOR

Kohler generator sets, automatic transfer switches, switchgear, and accessories are sold throughout the United States and internationally by a network of factory-trained and field-experienced distributors. They provide single source availability of the entire product line and the protection of one overall warranty covering all components.

The knowledge a distributor can bring to the installation of a dependable standby or prime power

system establishes him as an important adjunct to the architect-engineer-contractor team. His knowledge and experience benefit the specifier concerned with providing a source of reliable electricity. He has studied system performance through regular servicing of many different types of generator installations and is an expert in this area. The Kohler distributor's reputation as a professional is backed by long experience and regular participation in factory service schools.

**KOHLER**® POWER SYSTEMS

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## 1. Introduction

The Kohler® Engineer's Guidebook provides the reader with the information necessary to plan, size, design, and specify a complete power system. The sample specifications are a guide in the selection of quality equipment installed in a manner that will provide a well-engineered, reliable power source.

The first five sections deal exclusively with engine generator sets. They begin with general information to help the reader determine whether a generator set is required, its size, and approximate configuration. These are followed by more specific information on generator design, accessories, and installation.

Electrical controls, including manual and automatic transfer switches, accessories, and switchgear are covered in a separate section. Basic equipment required to operate generator sets in parallel is described as well as special adaptations for peak shaving and cogeneration.

Sample specifications are provided on an enclosed diskette for generator sets, transfer switches, and

switchgear. They are not proprietary, but rather performance specifications intended to assure procurement of all the equipment and accessories required to provide an integrated system of reliable components utilizing current technology. The information in the first sections of the Guidebook will enable the user to select the system components best suited for a variety of different applications.

A sample service agreement is provided as a basis for development of a contract fitting the particular requirements of each project. Including such an agreement in the procurement documents helps establish an effective relationship between the user and the servicing agent. It also helps insure that the equipment supplied is backed by competent, local service.

Finally, the appendices and glossary provide a variety of charts, definitions, tables, graphs, formulas, and conversion factors which should be particularly useful to anyone working in the specialized area of electrical power generation systems.

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## 2. Preliminary Planning

### 2.1 Requirements (Codes)

Standby power systems may be either legally required or provided at the option of the owner to protect business or property where human life or safety does not depend on the performance of the system.

National codes which refer to standby power systems include the following:

- National Electrical Code®, NFPA 70–1990
- Standard for Health Care Facilities NFPA 99–1987
- Life Safety Code, NFPA 101–1988
- Emergency and Standby Power Systems, NFPA 110–1988
- Model Building Codes

(See 10.4 Appendix, for addresses of code writing organizations.)

In addition, many state and local codes require standby power systems in various types of buildings.

A number of commercial/industrial facilities are not legally required to have standby power systems, but frequently include them. Examples:

- Data processing facilities

- Retail stores with point-of-sale computers
- Greenhouses
- Research facilities
- Refrigerated storage facilities
- Communication centers
- Chemical process plants
- Foundries, heat treating, plastic and other manufacturing operations where power interruptions cause expensive scrapping.

Also not a matter of code, some facilities have standby power systems as a result of federal or state financing requirements:

- Correctional institutions
- Law enforcement centers
- Airports
- Water and sewage treatment plants

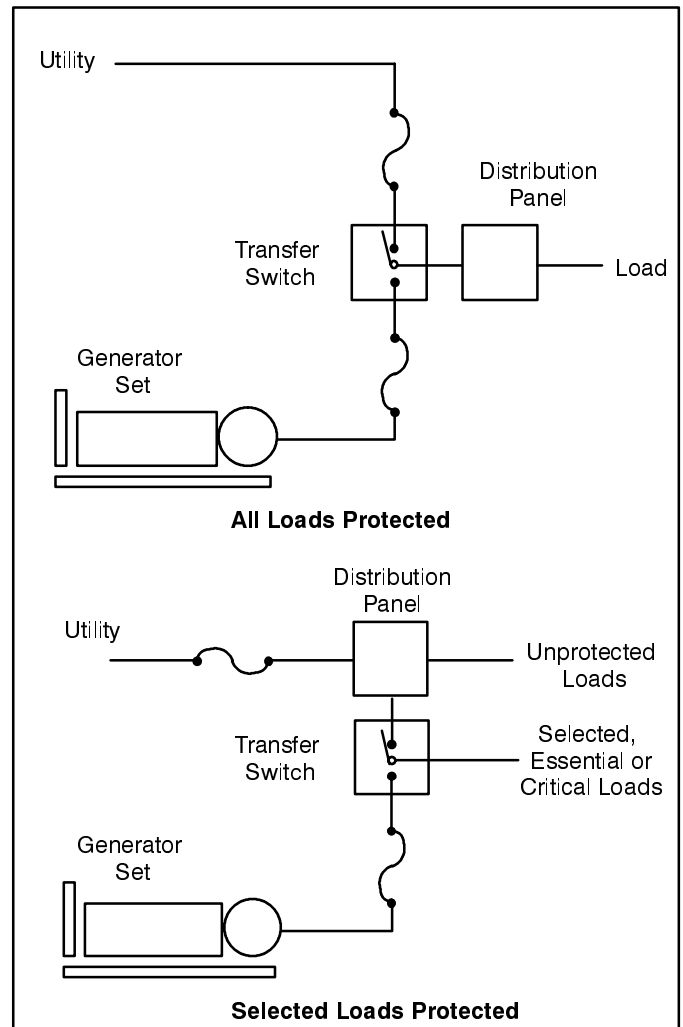
The following codes are not complete and do not represent the official position of the appropriate governing bodies on the referenced subject. This would be represented only by the standard in its entirety.

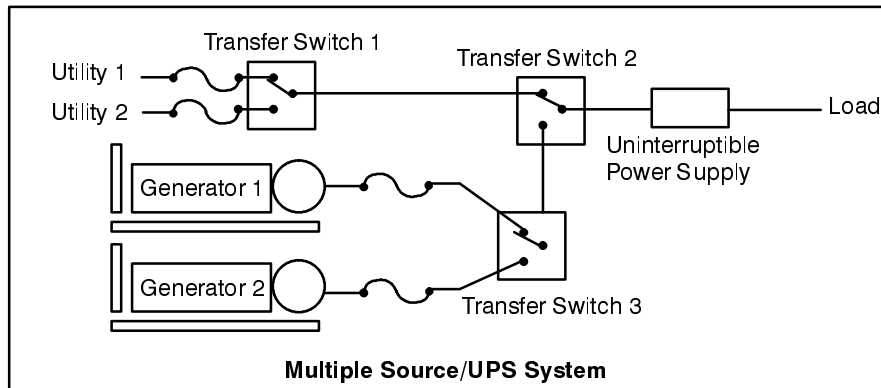
### 2.1.1 National Electrical Code®, NFPA 70-1990

The NEC® is the law in almost all localities in the United States and therefore must be carefully observed. The local authority having jurisdiction, usually the local electrical inspector, knows this code forward and backward and he will enforce its requirements according to his interpretation.

Important articles of the NEC® are: Article 445-Generators, Article 700-Emergency Systems, Article 701-Legally Required Standby Systems, Article 702-Optional Standby Systems, Article 705-Interconnected Power Systems and portions of Article 230-Services, Article 250-Grounding, and Article 517-Health Care Facilities.

The scope of the NEC® is installation of electrical conductors and equipment. Over the years, many items of performance have been placed in the code. However, performance is generally the assignment of other code bodies. In fact, it is difficult to draw the line between installation and performance and much disagreement has come about between code bodies as to what constitutes performance.





In interpreting the code, it is important to know that the inspector thinks in terms of protection. He will always look at an installation as one in which a conductor has no possibility of being overheated and in which no shock hazard exists.

Article 445 contains requirements for safety, such as generator type suitable for location, nameplate markings, protection of live parts, guards, and bushings.

**Article 445-4 (a)-Overcurrent Protection Constant Voltage Generators** explains that the generator must somehow be protected from overloads. A wide latitude of types of protection methods are permitted, including inherent design, circuit breakers, fuses, or other acceptable or overcurrent protection means.

**Article 445-5-Ampacity of Conductors** recognizes that a circuit breaker or fuses cannot always be installed at the generator. The requirement is that the ampacity of the phase conductors from generator terminals to the first overcurrent device shall not be less than 115% of the nameplate current rating of the generator. Many inspectors do not like this particular paragraph, but the installation is safe because of the requirements of Article 445-5 (a).

By far the most important section of the code for the generator set industry is **Article 700-Emergency**

**Systems.** Wherever emergency systems are legally required, they must be installed in accordance with this article.

Under **Article 700-12 Sources-of-Power Requirements**, six sources of power are permissible under various circumstances. Generator sets are under (b). Requirements are:

- Automatic start, automatic transfer and a minimal 15-min. time delay when returning from emergency to normal.
- Two hours on-site fuel supply for liquid fuels.
- Prime mover shall not be solely dependent on the public utility gas system for its fuel supply or a municipal water supply for its cooling systems. Means shall be provided for automatically transferring from one fuel supply to another, where dual fuel supplies are used. An exception permits use of other than on-site fuel where there is a low probability of simultaneous failure of the off-site fuel delivery system and the power from an electrical utility company.

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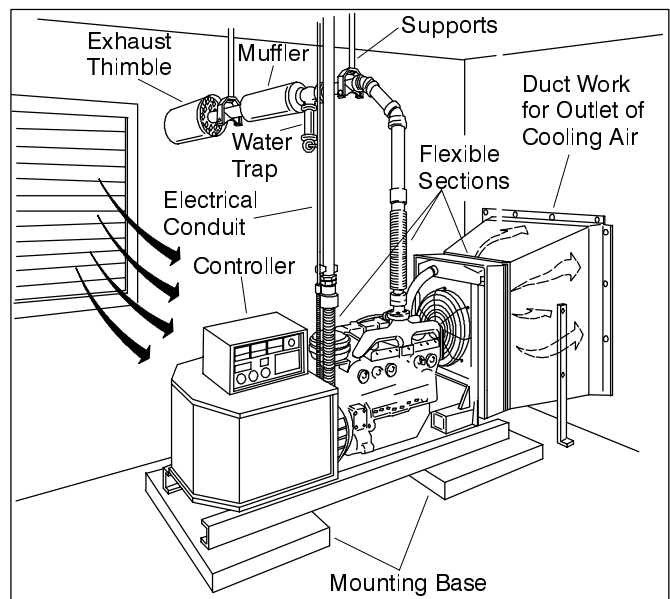
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However, the system must be acceptable to the authority having jurisdiction. The exception would not be acceptable in an earthquake or flood area, for example.

- An automatic battery charger for the cranking battery is required.
- Generator sets that require more than 10 seconds to develop power must have an auxiliary power supply which will energize the emergency system until generator can pick up the load. This requirement would apply to gas turbine generator sets which generally cannot start within 10 seconds.

Note that in addition to a generator, 700-12 also permits five other sources of power for emergency circuits; battery, dual utility service, connection ahead of the service, UPS, and unit equipment.

**Article 700-7-Signals** also is important. Both audible and visual devices are required where practical to indicate: 1) that the emergency source is deranged, 2) that the alternate source is carrying the load, 3) malfunction of the battery charger, 4) that the starting equipment of the prime mover is not functioning, and 5) ground fault where ground fault protection (circuit to 1,000 amp or more) is required on the normal source.



Typical Stationary Duty Installation

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**Article 700–4–Tests and Maintenance** gives the testing requirement for an emergency system. An initial witnessed test at maximum anticipated load is required as well as continuing scheduled periodic tests and maintenance with a written record. Since the maximum anticipated load is probably not available at the time of start–up, an extra load bank is usually required for start–up test.

**Article 700–5 (a)–Capacity and Rating** allows for load factors when calculating the maximum anticipated load referred to in 700–4.

**Article 701–Legally Required Standby Systems** is similar to Article 700. However, it applies more to operation of equipment such as heating, refrigeration, communication, ventilation or industrial processes, than it does to life–safety equipment such as emergency lighting, operating rooms, and signaling systems. An automatic transfer switch is required. The start–up time is 60 seconds instead of 10 seconds. Wiring need not be kept in separate raceways as is required with emergency systems.

**Article 702–Optional Standby Systems** applies to standby equipment that is voluntarily installed. A transfer switch is required, not necessarily automatic. The owner is permitted to select the loads to be operated by the standby equipment, putting

responsibility upon him to see that the set is not overloaded.

**Article 705–Interconnected Power Systems** covers basic safety requirements for interconnecting power systems.

Items to note are that a disconnecting means, lockable in the open position and in an accessible location is required to disconnect the on–site source from the utility. For sources 100 kW and smaller, the only permitted connection point between the two systems is at the service disconnect. Connecting a wind generator, for example, at some other point in the system, is not acceptable.


Another extremely important item is that means must be provided for disconnecting from the utility in the event of a utility failure. Systems that are self excited (synchronous generators, for example), and are capable of carrying the remaining system load, may require a signal from the utility. However, this may be difficult and expensive to obtain.

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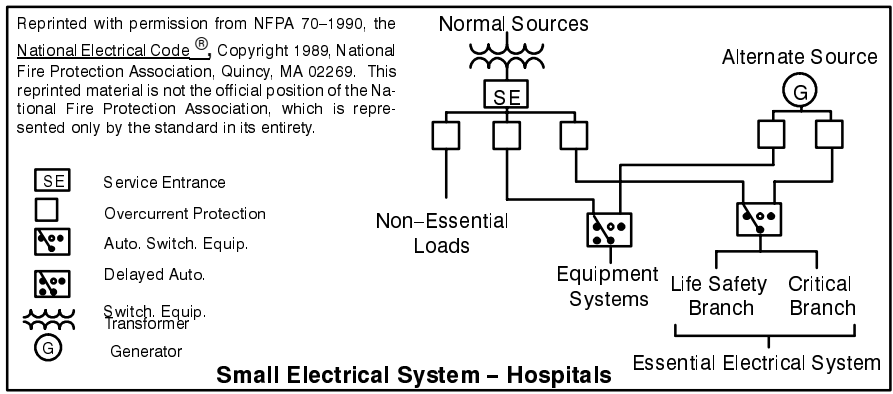


With the current interest in cogeneration, applications of this article are expected to multiply rapidly.

**Article 250–Grounding** is one of the most important subject in the NEC®. Article 445, which covers generators, does not mention grounding. Therefore, Article 250 must be utilized to determine what systems must be grounded.

**Article 250–5–Alternating–Current Circuits and Systems to Be Grounded** states that the system must be grounded when the maximum voltage to ground on the ungrounded conductors does not exceed 150 volts. In addition, this applies on 277/480 volt Wye systems in which the neutral is used as a circuit conductor. The only common systems that do not have to be grounded are the 240– and 480– volt, 3–wire, 3–phase systems.

**Article 250–5 (d)–Separately Derived Systems** says that a generator meeting the aforementioned requirements must be grounded if it has no connection with another system. If, however, it has a grounded neutral connection common with the utility, it does not have to be separately grounded.



**Article 250-6-Portable and Vehicle-Mounted Generators** covers the grounding rules for these units. Essentially, if the system meets the requirement of being self-contained, the frame of the generator (in the case of portable generators) may be used for the ground instead of an earth ground which might be impractical.

**Article 517-Health Care Facilities**, section 517-35b states that the alternate source of power for a hospital must be a generator. Section 517-44b has the same requirement for nursing homes and residential care facilities. The emergency system of a hospital is required to have two branches, a life-safety branch and a critical branch.

The life-safety branch takes care of all exit lights, the signaling system, the alarm system and the communication system. The critical branch covers task illumination in critical areas. A hospital also has an equipment section that may be restored after a time delay or may be manually restored by a manual transfer switch.

Except for very small facilities, a minimum of two transfer switches are required. The NEC® has established a small facility as one having 150 kVA (120 kW) or less emergency load. Article 517 is the only place in the code that contains wiring diagrams. Diagrams for nursing homes are shown in section

517-41 (1), (2) and (3). Diagrams for hospitals are shown in section 517-30 (1), (2) and (3).

**Article 230-Services** includes requirements that may be applied to generator sets. Section 230-70 requires a disconnect in the building for the service entrance conductors. Many inspectors will apply this requirement to an emergency generator set although, in the opinion of some, such a generator set does not meet the general definition of a service.

**Article 230-83 Transfer Equipment** contains the definition for transfer switches and also, in its exceptions (1) and (2), has the only reference to parallel operation. Essentially this paragraph says you must disconnect all ungrounded conductors at one source of supply before any ungrounded conductors of the second source are connected. The exception is where parallel operation is anticipated and suitable equipment to ensure satisfactory operation in parallel is provided.

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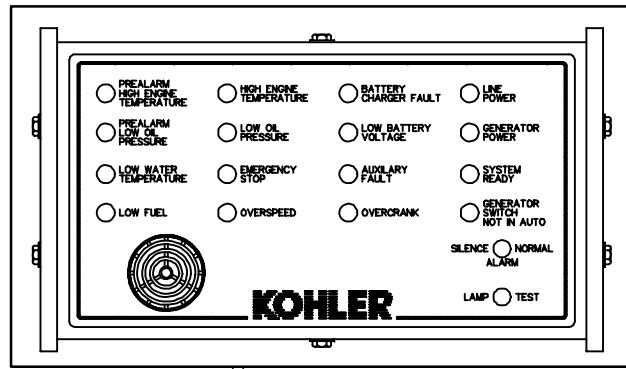
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**Article 230-95-Ground-Fault Protection of Equipment** states that ground fault protection is required for services rated 1,000 amp or more. This automatically makes emergency systems of this rating require ground fault indication in article 700, section 700-7 (d) as indicated before.

These are the most obvious requirements in the National Electrical Code® for the electrical generating systems industry. However, those responsible for electrical generator installations would be wise to learn as much about the code as possible. Article 240 on overcurrent protection is very important.

The requirement for ground-fault circuit interruption for protection of personnel for receptacles at construction sites is in Article 305, section 305-6 (a). Generators involved in this section are ungrounded, rated up to 5 kW and may be used without ground-fault protection.

Section 384-3f shows requirements for 3-phase center-tap Delta systems.



Kohler® Remote Annunciator

### 2.1.2 Standard for Health Care Facilities, NFPA 99–1987

This standard deals with safety sensors on the generator set and a remote annunciator that indicates alarm conditions at the nurses call station or some named location. The required sensor devices are listed in paragraph 3–3.2.1.14. They include low water temperature, pre–alarm high temperature, pre–alarm low oil pressure, overcrank, overspeed, low lubricating oil pressure, and high engine temperature.

The requirements for the annunciator are given in paragraph 3–3.2.1.15. They are: an indication that the emergency power source is operating to supply power to the load, battery charger malfunction, low lubricating oil pressure, low water temperature, excessive water temperature, low fuel, overcrank, and overspeed.

Paragraph 3–5.1.2.3 (b) requires that the set be tested under load conditions for at least 30 minutes at intervals of not more than 30 days. This has been a problem in health care facilities because hospital people do not want to disrupt their functions to run a test of the emergency system.

### 2.1.3 Life Safety Code, NFPA 101–1988

Performance requirements for emergency lighting in public buildings call for a minimum illumination of one footcandle for a period of one and one–half hours. The emergency lighting system is to be so arranged as to provide the required illumination automatically in the event of any interruption of normal power. In the case where an electric generator set is the alternate source of power, a delay of not more than 10 seconds is permitted.

The reference concerning what occupancies require emergency lighting is listed under each type of occupancy in Chapter 8 through 30. Generally, public occupancies require emergency lighting. Generator sets are required as the emergency power source for health care facilities having life support systems and for buildings higher than six stories to power smoke control or automatic extinguishing equipment.

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## 2.1.4 Emergency and Standby Power Systems, NFPA 110–1988

This standard covers installation, maintenance, operation, testing, and performance requirements of power systems, and a full understanding can only be gained by reading it in its entirety. The following is a summary of its requirements for generator sets and accessories.

### Chapter 1 – General

NFPA 110 does not specify where emergency power systems are required. It covers how systems should be installed, tested, and perform where required by other codes and standards. It covers new installations and does not require that existing installations be modified to meet it.

### Chapter 2 – Definition and Classification

A significant feature of NFPA 110 is that it classifies emergency power systems according to type, class, category, and level. Type defines the maximum time the power system allows the load terminals of the automatic transfer switch to be without power. The types are:

- Type U – UPS Systems
- Type 10 – 10 seconds
- Type 60 – 60 seconds
- Type 120 – 120 seconds
- Type M – Manual system – No time limit

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Class defines the minimum hours the emergency power system can be operated at rated load without refueling. The classes are:

- Class .083 – 5 minutes
- Class .25 – 15 minutes
- Class 2 – 2 hours
- Class 6 – 6 hours
- Class 48 – 48 hours
- Class X – Other time as required

Power systems are divided into two categories. Category A is stored energy devices which get energy solely from the normal power source. Category B is all devices not covered by "A." The requirements for stored energy devices, such as batteries for UPS are in a new standard NFPA 110A-1989.

Power systems are also classified by level. Level 1 covers permanently installed systems where failure of the equipment could result in loss of human life or serious injury. Level 2 covers permanently installed systems where equipment failure is less critical to human life and safety. Level 3 covers all systems not covered by Level 1 or 2. The standard has no requirements for Level 3 systems.

### Chapter 3 – Power Supply

Both liquid and gaseous petroleum products are acceptable fuels for Category B emergency power systems. Where the probability that off site fuel

supplies (natural gas) will be interrupted is high, an alternate fuel must be stored on site and the prime mover equipped with an automatic/changeover fuel system if the installation is Level 1.

"Energy converters" (generator sets) for Level 1 applications must be factory tested with all accessories which might affect power output. The tests are normally to be performed on prototype units and designed to demonstrate that normal and abnormal conditions (including motor starting loads, SCR loads, overspeed, overtemperature, and overloads) are not likely to render the system inoperative.

Generator sets for Level 1 applications must be installed in equipment rooms maintained at 70° F (21° C) or equipped with heaters to maintain 90° F (32° C) engine temperature. Enclosures for generator sets installed outdoors must be maintained at 32° F (0° C) minimum or equipped with heaters to maintain starting battery temperature between 50° F (10° C) and 90° F (32° C). Ether-type engine starting aids are not permitted.

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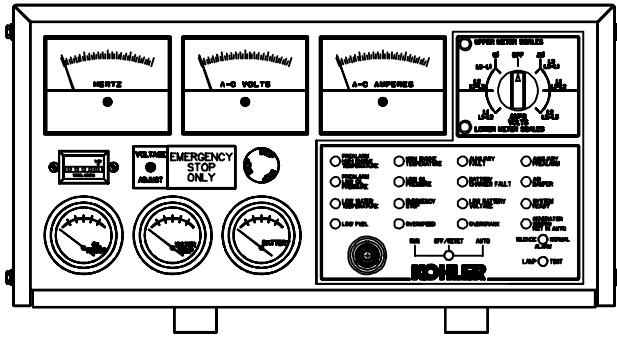
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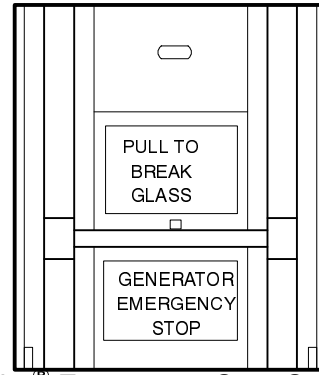
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Liquid-fueled engines must have a low fuel alarm to indicate the available fuel is less than the minimum required for the installation class. The fuel tank must have a minimum capacity of 133% of the amount required by the installation class. For example, a 30 kW Class 48 generator set that uses 2.5 gallons of fuel per hour is required to have a fuel tank capacity of  $48 \times 2.5 \times 1.33$  or 160 gallons.

Fuel and water solenoid valves must be provided with means for manual operation. Liquid-cooled engines with pressure lubrication must be equipped with gauges for oil pressure, coolant temperature, running time, and battery charging. Engines on generator sets above 15kW are required to have cranking cycles for a total of 75 seconds (15 seconds crank, 15 seconds rest, etc.) For Level 1 installations below 15kW and for all Level 2 installations, 45 seconds of continuous cranking is acceptable. Batteries must be capable of two complete cranking cycles. Fully automatic float battery chargers with voltmeters, ammeters, low voltage alarm contacts, and capable of recharging a fully discharged battery within 24 or 36 hours for Level 1 and 2 installations respectively, are required.



Kohler® Dec-3 Controller



Kohler® Emergency Stop Switch

Engine controls must include low oil pressure, high engine temperature, overspeed, and overcranking protection plus provision for remote emergency shutdown. Level 1 installations must have a remote emergency stop station of the "break glass" or similar type located outside the generator room. Level 1 installations are required to have unit-mounted visual and remote audible alarm signals for the four shutdown functions listed above, plus low water temperature, anticipatory high engine temperature, and low oil pressure, low fuel, and control switch not in automatic position. Visual indicators only are required for generator supplying load (AC ammeter), battery charger malfunction, and low battery voltage. Level 2 installations must have visual alarm indications for high and low engine temperature, low oil pressure, overspeed, and overcrank. No remote audible alarm is required.

Power for remote radiator fans and pumps must be supplied from a tap at the generator load terminals or ahead of the first load circuit overcurrent protective device.

Generators must be drip-proof, equipped with amortisseur windings, and a voltage adjusting rheostat with an adjustment range of  $\pm 5\%$ .

#### Chapter 4 – Electrical Switching and Protection


Automatic transfer switches must be mechanically held and equipped with undervoltage sensors on all ungrounded lines of the normal power source. They must also have both voltage and frequency sensors on one ungrounded line of the emergency source, be mechanically interlocked, and include provision for manual operation. Switches must include time delays on engine starting and retransfer to normal. The time delay on retransfer must be adjustable and equipped with a bypass circuit to automatically retransfer to normal if the emergency source fails and normal is available. An adjustable time delay on transfer to emergency is required on Level 1 systems if loads must be sequenced. A minimum five-minute cool-off delay on engine shutdown after retransfer to normal is required, either in the transfer switch or the generator control panel.

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Transfer switches must include a timer to exercise the generator set under load with provision to automatically retransfer to normal if the emergency source fails during the exercise period. They must also include a test switch, pilot lights to indicate switch position, and provision to reduce currents associated with motor load transfer if those currents may damage the emergency power system or cause nuisance tripping of breakers.

When multiple generator sets operating in parallel are used as the emergency power source, loads should be added to the system in sequence, highest priority first. If one or more generators fail, the system shall automatically shed load, lowest priority first.

Overcurrent protective devices in the emergency system must be coordinated to ensure selective tripping under short-circuit conditions.

### **Chapter 5 – Installation**

Generator sets must be installed indoors in a separate room or outdoors in an enclosure that will prevent the entry of snow or rain. Generator sets and transfer switches installed indoors must be in areas provided with battery-powered emergency lighting of 30-foot candle intensity. Generator sets are required to be equipped with vibration isolators and installed on raised foundations at least six inches high.

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Flexible connections are required between the engine and fuel lines, exhaust piping and cooling air ducts or louvers. Exhaust and fuel systems must comply with NFPA 37 requirements.

A site test of the complete emergency power system is required to verify that the generator set will start from cold, assume and carry the building load for one hour, and retransfer the load as required for the type installation without overheating or other malfunction. After this test, the generator set must be allowed to cool for five minutes and then given a two-hour full load test using a load bank, building load or both. The load may be at unity power factor if the generator set has been factory tested at rated load and rated power factor. The generator set must demonstrate the ability to pick up 100% of nameplate kW rating, less any applicable site derating factors, in one step immediately after being started and reaching rated rpm. Tests must also be performed to demonstrate the operation of the cranking cycle and all engine safety devices. At the time of the acceptance test, the generator set supplier must provide evidence that a similar generator set has been prototype tested, certification that the engine generator set has no harmful torsional vibrations, certification that the equipment as installed meets this standard, and a copy of the factory test report.

### **Chapter 6 – Maintenance and Testing**

Two sets of instruction manuals for generator sets and transfer switches are required. Generator sets and transfer switches for Level 1 systems must be exercised under at least 30% of rated load at least every 30 days for 30 minutes or more. Transfer switch time delay must be set for one second minimum on engine start, 5 minutes minimum on retransfer to normal and five minutes for engine cooloff.

Low voltage circuit breakers must be exercised annually on Level 1 systems. A log of all testing and maintenance on the system must be kept.

### **Chapter 7 – Referenced Publications**

The National Electrical Code®, NFPA 70, and the Standard for the Installation and Use of Stationary Combustion Engines and Gas Turbines, NFPA 37, are incorporated in NFPA 110 by reference.

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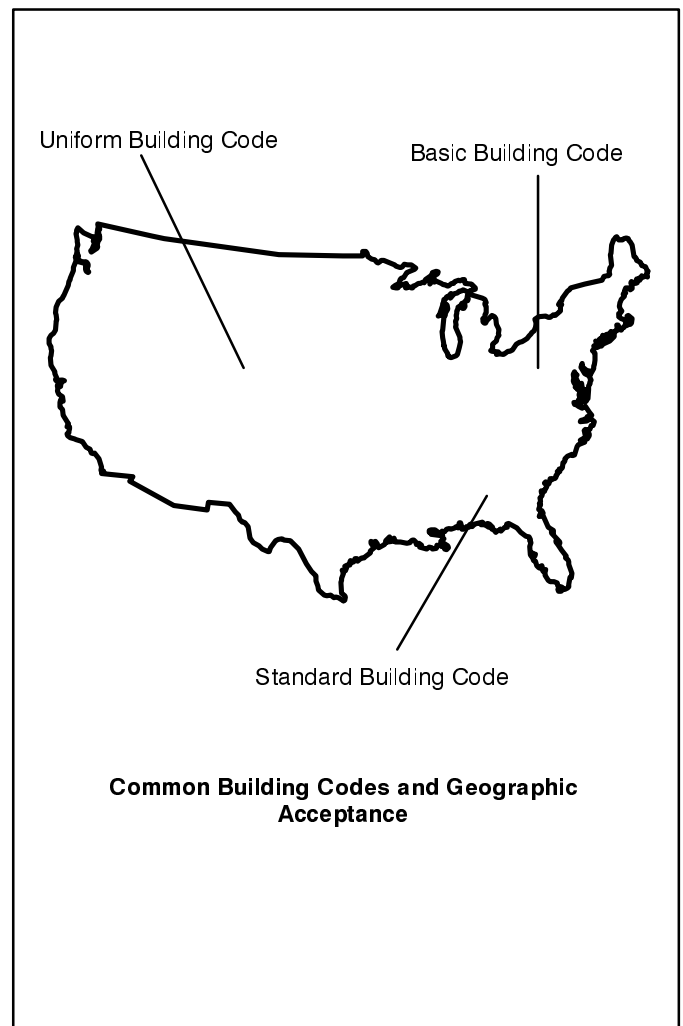
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### 2.1.5 Model Building Codes

Emergency or standby power also may be legally required if the municipality involved has adopted one of the model building codes as an ordinance. The three commonly used building codes are written by separate organizations. Each has its own region where it is popular.

The Basic Building Code is generally used in the northeastern United States, the Uniform Building Code is used west of the Mississippi, and the Standard Building Code is used in the southeastern states. The requirements for emergency power are similar to the life-safety code. Requirements vary somewhat between the three building codes. However, each has emergency requirements for removing smoke and supplying fresh air, egress lighting and elevator operation.

A fourth building code – the National Building Code sponsored by the American Insurance Association – is frequently used by insurance inspectors in approving buildings. This is also an important code as compliance or non-compliance affects insurance rates.



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### 2.1.6 Other Codes

Other codes that have pertinence to specifying engineers when specifying electrical generating systems are listed below.

**NFPA 20 – Centrifugal Fire Pumps** which has special requirements concerning transfer switches, system arrangement and motor starting for fire pumps.

**NFPA 37 – Stationary Combustion Engines and Gas Turbines** has installation requirements for prime movers.

**NFPA 30 – Flammable Liquids, NFPA 54 – National Fuel Gas Code, and NFPA 58 – Liquid Petroleum Gas Storage** all deal with fuel installations.

### 2.2 Location

Once it has been determined that a project will include a standby power system, thought should be given to where the engine-generator set can be located to best advantage. Regardless of the type of prime mover selected for the generator, it will produce noise and odors from fuel and exhaust. In addition, exhaust fumes are poisonous and must be discharged to an area where they will not be inhaled by humans or animals. Exhaust noise can be substantially muffled quite easily. Mechanical noise is inherent with engines and will vary roughly with size from 90–110 dBA measured at a distance of six feet from the engine.

Engines, generators, and controls all require periodic maintenance and should be located in an accessible area. At least three feet of working space should be allowed on all sides of a generator set. Consideration should be given to how the generator set will be moved into place initially, as well as the possibility that it may be necessary to remove it for repair or replacement. While generator sets are often installed outdoors in sheet metal enclosures, this is the least desirable location from a service and reliability standpoint.

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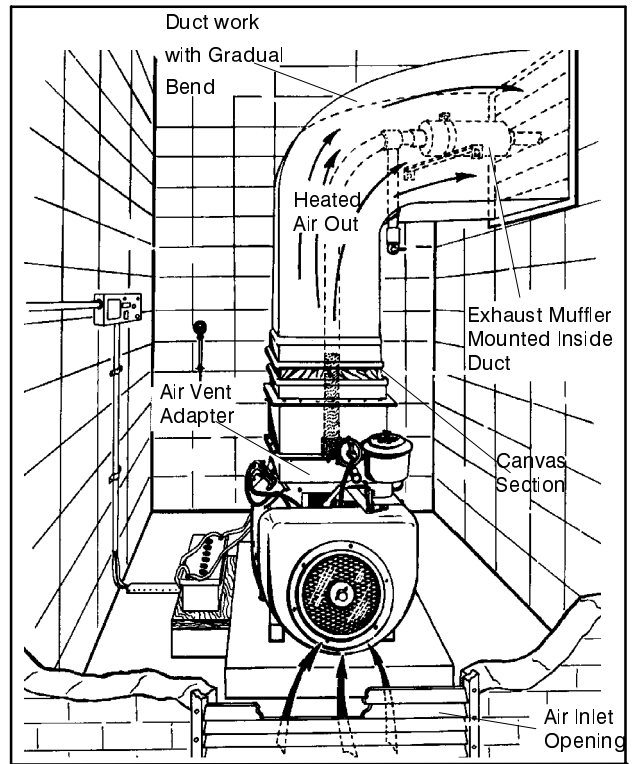


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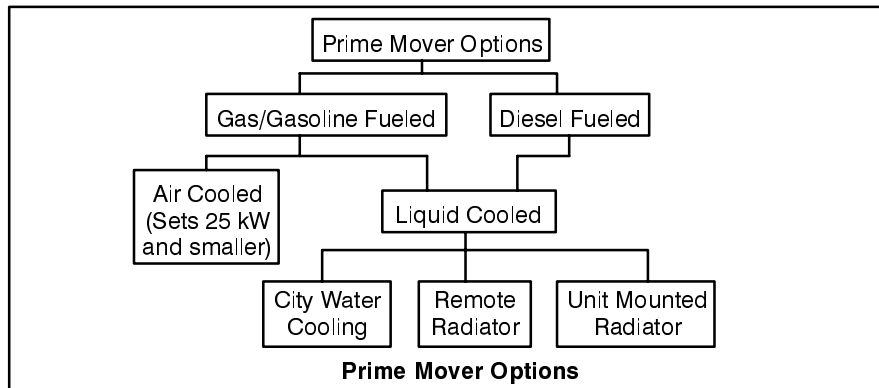
Heat  
Air O

All types of prime movers require substantial air for cooling and combustion. Air is also required to cool the generator. Various engine cooling system options allow heat to be carried away from the generator set as hot water, but substantial minimum air requirements must still be brought to and taken away from the set. Approximate total air requirements can range from 50 to over 200 cfm per kW of generator set capacity. This should be considered before locating a generator set in a sub-basement or other location not easily ventilated.

Transfer switch location is usually near the generator set but system performance is not affected by separating them. Any location accessible for service will be satisfactory. As with generator sets, indoor locations are preferred, although weatherproof enclosures are available. The cost of the necessary conduit runs from the switch to the generator set, normal supply, and load may be a determining factor in switch location.



Air Vent System on Air Cooled Set



## 2.3 Prime Mover Options

There are several choices when selecting the prime mover for a generator set. In sizes below 1500 kW, the most cost-effective choices are reduced to air, or liquid-cooled spark ignition (gas) or compression ignition (diesel) internal-combustion piston engines.

Air cooling is the most simple and economical cooling system, but is readily available only on generator sets smaller than 25 kW. Liquid cooling systems include city water cooling, remote radiator and unit-mounted radiator systems. Liquid cooling systems have the advantage of being readily adaptable to engine jacket water heaters which effectively ensure quick engine starts over a wide ambient temperature range. The choices among liquid cooling systems mainly offer ways to reduce the amount of air which must be provided directly to the generator set. City water and remote radiator systems required approximately one half the total cooling air of comparable unit-mounted radiator systems.

The National Electrical Code® requirement that a prime mover not be dependent on the municipal water system eliminates the choice of a city water cooling system for most installations.

Compression ignition (diesel) engines have the advantage of using an on-site fuel supply not subject

to rapid deterioration. Below 100 kw diesels are generally more expensive than spark ignition (gas) engine; above 100 kw through 1500 kw they are usually lower cost.

Spark ignition engines are available with fuel systems suitable for a variety of liquid and gaseous fuels, or combinations of them. Gasoline as a primary fuel is least desirable since it deteriorates when stored more than a few months, and is hazardous. Natural gas and LP gas (butane, propane or a mixture of both) burn clean, do not deteriorate, and give longer engine life with less maintenance than gasoline in the same engine.

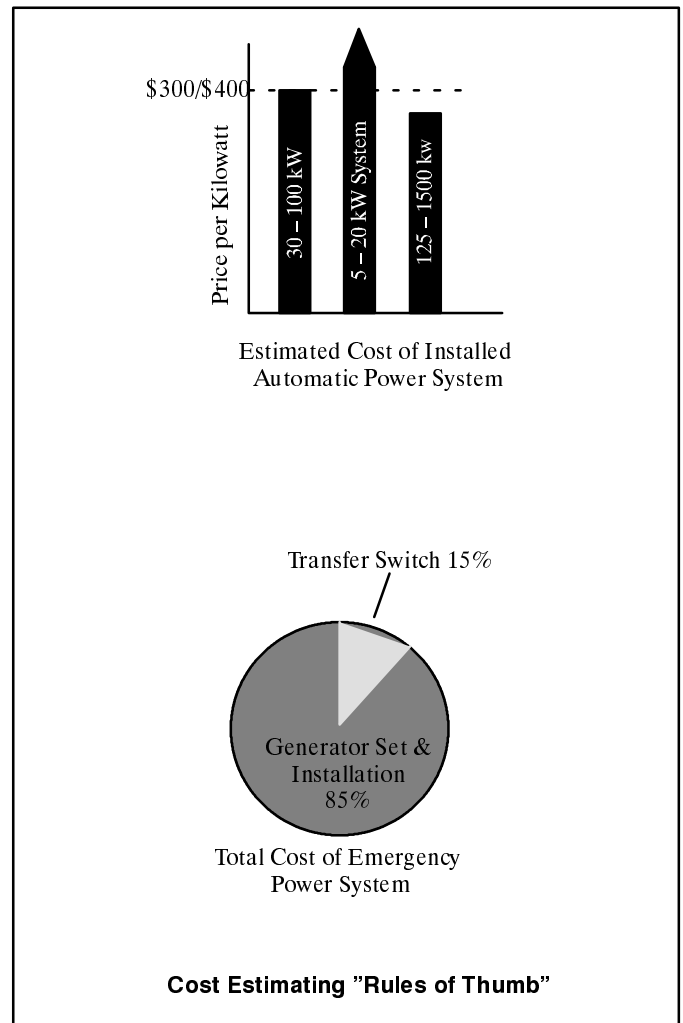
## 2.4 Cost Estimating

Suggestions for making preliminary cost estimates are necessarily general and imprecise. Cost vary significantly from one geographic area to another. The cost of adding an emergency power system to an existing facility may be much higher than providing a comparable system in new construction.

The following "Rules of Thumb" should be used with discretion.

- At this writing, the installed cost of an automatic standby power system can be estimated at \$300–\$400 per kW. Cost tend to be higher if the system is less than 30 kW and may be lower above 100 kW. The estimate assumes gas fuel below 100 kW, diesel above. (See last paragraph in this section.)
- The automatic transfer switch(es) usually represent(s) less than 15% of the total cost of an automatic system. Manual switches are available for approximately half the cost of automatic switches.
- Below 100 kW, diesel generator sets are usually at least \$1,000 more expensive than natural, LP gas or gasoline models. Above 100 kW, gas-powered generator sets may be 50–100% more expensive than comparable diesels.

Regardless of fuel, generator sets larger than approximately 1500 kW are likely to significantly more expensive because 1800 RPM engines are not available in larger sizes.



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## 3. Equipment Sizing

### 3.1 Sizing (Summary)

The first step in sizing the generator set is to determine what loads will be connected to it. The choices are:

- All loads in the project.
- Only loads required to be protected by code.
- Selected loads considered essential but not required to be protected by code.
- Exit, stairway, and corridor lighting.
- Alarm systems.
- Fire pumps.
- Communications systems.
- Heating systems.
- Well and sump pumps.
- Elevators.
- Automatically operated doors.

One justification for connecting all loads to a generator set is often that it is more economical. Rather than pay for labor and materials to isolate emergency circuits to operate with a small generator set, it may be cheaper to connect all circuits – emergency and non-emergency – to a larger generator set. This is particularly likely in the case of an addition to existing construction.

Loads which require protection are listed in the following U.S. codes:

- National Electrical Code®, NFPA 70.
- Standard for Health Care Facilities, NFPA 99.
- Life Safety Code, NFPA 101.

Examples of essential loads are:

### 3.2 Load Calculation

Having decided what loads will be connected to the standby power system, the next step is to find the total connected load in kiloWatts. See 3.7 Generator Sizing. The total can be determined working either with Watts (Watts/1,000 = kilowatts) or amperes. For single-phase systems, use only two columns for "phase A" and "phase B." For three-phase systems, use all columns. Total the amperes and/or Watts and determine the maximum running load according to the instructions for the worksheet. The minimum size generator set required is one that will handle this running load.

### 3.3 Motor Loads

Motor loads require special consideration because they can draw six-to-ten times their full load running current during starting. As the proportion of the total emergency system running load consisting of one or more motors approaches 50%, it becomes likely that the generator set will need to be somewhat oversized to accommodate the high inrush current. To determine whether this is the case, you must first calculate the maximum inrush current (kVA load) on the generator.

Refer to 3.7.3 Motor Starting Data Tables, Table 3-1 and determine the starting kVA requirements of each individual motor, assuming the horsepower and code are known. If the code is not known, a frequent practice is to use Code G for 15 hp and up; Code H, 7.5-10 hp; Code K, 3-5 hp; and Code M for 2 hp and smaller.

Add the starting kVA of all motors to be started simultaneously, together with any other loads that will be connected to the generator at the same time. Refer to 3.7.3 Motor Starting Data Tables, Table 3-2 to find a generator that will handle the starting kVA load with an acceptable voltage dip. If motors start unloaded, such as fans, centrifugal pumps and motor-generators, an instantaneous voltage dip in the range of 30% should be acceptable. If voltage

Starting kVA

hp	Code E	Code F	Cod
1	4.7	5.3	
2	9.5	10.6	
3	14.2	15.9	
7.5	23.7	26.5	
10	47.5	53	
15	71.2	79.5	
20	95	106	
25	118.7	132	
30	142	159	
40	190	212	
50	237	265	
60	285	318	
75	356	398	
100	475	530	
125	594	667	
150	712	775	
200	950	1060	
250	1187	1350	
300	1425	1650	
400	1900	2200	
500	2375	2750	

See Table 3-1 for Complete Motor Starting Data

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dip exceeds 35%, motor starting contactors and control relays may not remain closed long enough to allow the motor to start. If motors start loaded, or if some control circuits known to be unusually sensitive to voltage dip are included in the system, it may be necessary to limit voltage dip to 20 or 25%. Rarely, if ever, will it be necessary to size a generator set for less than 20% instantaneous voltage dip. Keep in mind that the maximum voltage dip will have a typical duration of only 3–5 Hz (.05–.08 seconds). After that, the voltage will rapidly recover to 85–90% of rated voltage even though the load may be as much as twice the generator’s rated kVA. The combination of voltage dip and low power factor prevent overloading the prime mover.

### 3.4 Special Considerations for Single-Phase

When multiple single-phase motors are started on a 3-phase generator, so that they present an approximately balanced load on all three phases, the sizing procedure is the same as for 3-phase motor loads. (See 3.3 Motor Loads.)

When all the load is single-phase and a single-phase connected generator is used, only 2/3 of the generator windings are effectively used, and only 2/3 of the

maximum kVA figures in Table 3–2 will be available from any given generator.

Likewise, if a large single-phase load is applied to one (phase to neutral) or two phases of a 3-phase connected generator, as little as one-sixth of the generator windings on Delta connections or one-third on Wye connections may be effective.

In selecting the proper size generator set, two additional points should be understood:

- The motor starting characteristics of different size generators from one manufacturer, as well as the same sizes from different manufacturers, may differ greatly. Specifications should be written so that the generator supplier assumes responsibility for delivering specified kVA at no more than specified voltage dip.
- The principal factor in generator life is thermal aging of the winding insulation. It stands to reason that if there is less load applied there will be less heat developed and therefore, the longer the expected life will be. This is not the case with

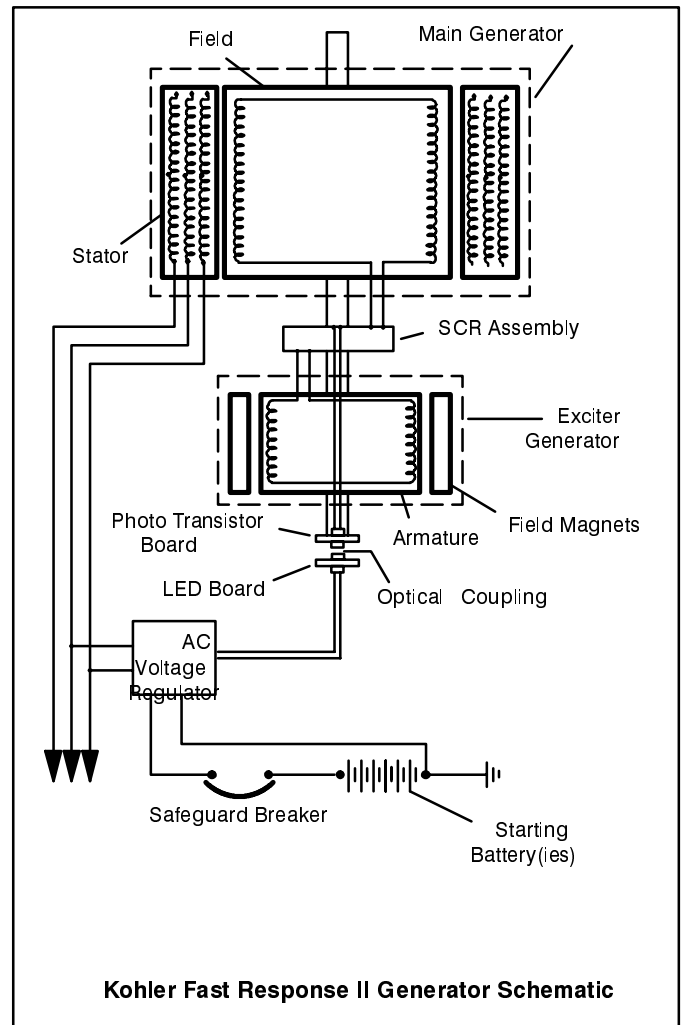
the prime mover. Engine life is reduced by operation at either maximum or minimum loads, and optimum life will generally be obtained with loads in the 50%–90% range. Therefore, it is important that the generator set be neither undersized nor oversized.

### 3.5 Special Applications

#### 3.5.1 SCR Loads

Various types of loads consisting of Silicon Controlled Rectifiers (thyristors) present special problems for generator sets. The problems are generator stator heating and interference with the generator voltage regulation system.

The most commonly encountered SCR loads are battery chargers, rectifiers in Uninterruptible Power Supplies (UPS systems), solid state reduced voltage motor starters, and variable frequency drive motor speed controls. In general, generators with permanent magnet exciters or pilot exciters provide the best performance on this type of load. Other excitation systems typically require voltage regulator filtering, generator derating, or both, when used with this type of load. Even if the generator is able to maintain stable voltage and frequency, the



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extreme harmonic distortion of its output resulting from the SCR switching in the load may cause problems with the load control circuits. Particularly with UPS systems, it may require a generator set sized for two or three times the nominal power requirements of the load in order to assure satisfactory, stable operation. Specifications for generator sets to be used with an SCR load should include detailed information on the equipment to be operated so the generator and equipment suppliers can consult and provide the options required to ensure satisfactory performance.

### 3.5.2 Elevators

Many special applications may be encountered, one of these is elevators. Two general types of elevators are frequently encountered – hydraulic and motor-generator. The motor-generator types usually have locked rotor amperes as well as running amperes given. This makes it easy to calculate motor starting kVA ( $\text{Volts} \times \text{amperes} \times 1.73 / 1000 = \text{kVA}$  for 3 phase power). These motors are usually fairly easy to start, however, they may have sensitive controls which limit the acceptable voltage dip. Another factor which is a real concern with this type of elevator is regenerative or "pump back" power when the elevator is running

fully loaded or stopping. The generator cannot absorb more than about 20% of rating without overspeeding.

Any regenerative power over 20% of the generator set rating must be balanced by other loads on the set at all times or a dummy load on the set when regeneration occurs.

Hydraulic elevator applications must be carefully analyzed. Because of the intermittent nature of the application, motors are often used at higher than their rated power. For this reason, it is important that maximum starting and running amperes be known. Some hydraulic elevators have unloading valves which permit the motor to come up to speed before picking up the load. Others have to start under full load torque condition. The latter type must be conservatively applied to generator sets. Many hydraulic elevators use wye-delta reduced voltage starters. Such starters can present major problems unless the controls are so arranged that the motor comes up to nearly full speed before switching to delta. A commitment needs to be obtained from the manufacturer on the ampere requirement at the switching point.

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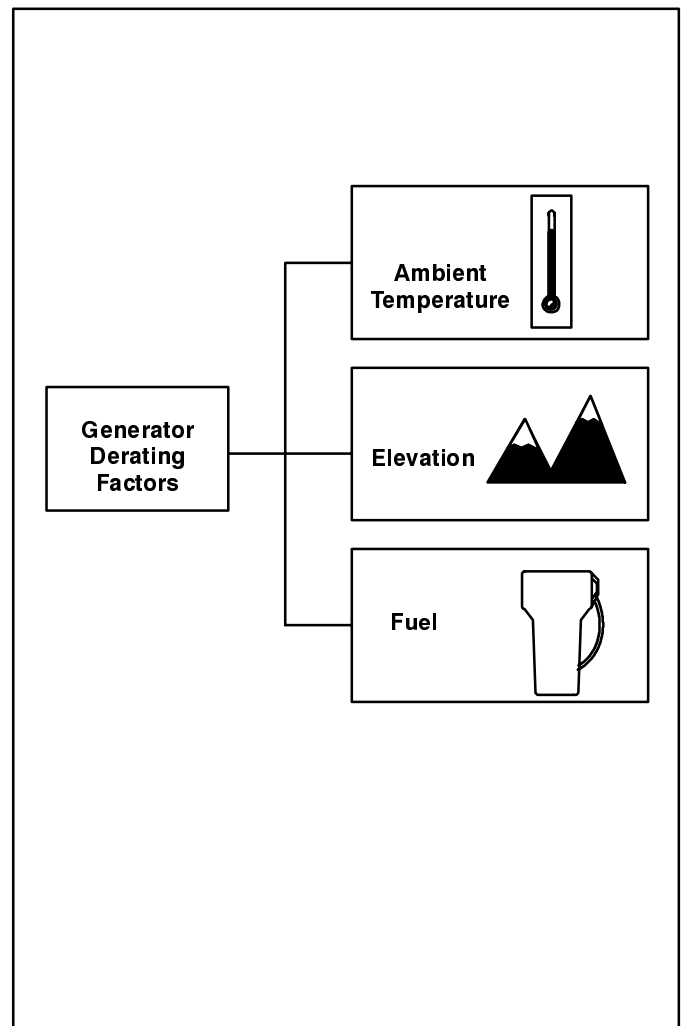
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### 3.6 Derating

All generator sets are subject to derating for altitude and temperature. In addition, gasoline engines are subject to derating when operated on fuels other than gasoline: natural or LP gas.

Generator set deratings result from the effects of reduced air density in both the generator cooling and engine combustion processes whenever ambient temperature increases or atmospheric pressure decreases. It is common for manufacturers to use the same engine or generator on more than one generator set with different ratings. As a consequence, reserve engine and/or generator capacity will vary the point at which generator set derating begins. After that point, ratings, typically, are reduced 3-1/2% per 1,000 feet elevation and 1% per 10°F (5.5°C) increase in ambient temperature.

Gasoline engine power is typically reduced 5% on LP gas or 10% on natural gas, all other factors being equal. Some manufacturers offer high compression engines which reduce the power loss with gaseous fuels.



### 3.7 Generator Sizing

#### 3.7.1 Generator Sizing Worksheet (Blank)

1. Load Description	2. Phase A (L1) kW Amperes	3. Phase B (L2) kW Amperes	4. Phase C (L3) kW Amperes	5. Total kW	6. Starting kVA	7. Load Step
<b>Total</b>						

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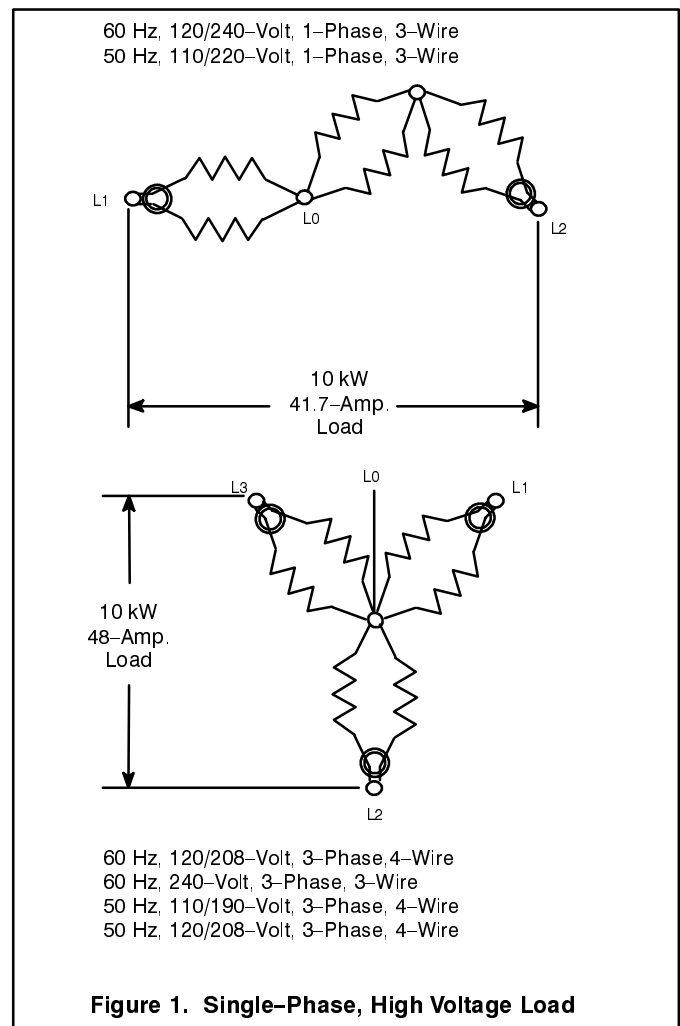


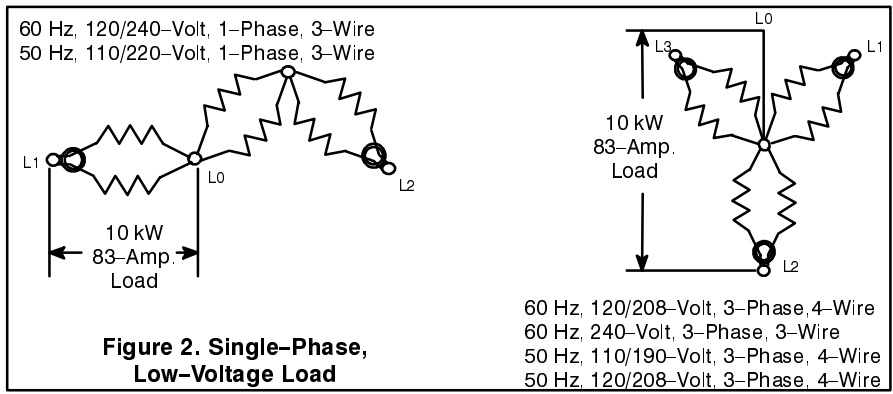
### 3.7.2 Instructions

1. List individual load components in Column 1. Include motor horsepower and code letter if known. If only horsepower is known, use average codes shown under 3.3 Motor Loads.
2. Fill in Columns 2, 3, and 4 (3-phase systems only) with amperes.
  - a. Balance single-phase loads across all phases of 3-phase generators as evenly as possible.

Single-phase loads given in amperes or kW, and requiring the higher voltage of a dual voltage generator will load the two lines of a single-phase generator, or two phases of a three-phase generator. See Figure 1.

Single-phase loads given in amperes or kW, and requiring the lower voltage of a dual-voltage generator, load one line and neutral of a single-phase generator, or one phase and neutral of a three-phase generator. See Figure 2. Balance 120-Volt single-phase loads between phases A and B on single-phase generators.





**Figure 2. Single-Phase, Low-Voltage Load**

b. Three-phase load given in amperes will automatically divide with the total load amperes appearing on each phase.

$$\text{Single-Phase Amperes} = \frac{\text{kW} \times 1000}{\text{Volts}}$$

$$\text{Three-Phase Amperes} = \frac{\text{kW} \times 1000}{\text{Volts} \times \sqrt{3}}$$

c. For motor loads, see 3.7.3 Motor Starting Data Tables, Table 3-3 to convert motor hp to amperes.

3. Enter running kW in Column 5 for each component of load as follows:

a. See 3.7.3 Motor Starting Data Tables, Table 3-3 for motor loads.

b. Single-phase

$$\text{kW} = \frac{\text{Volts} \times \text{Amperes}}{1,000}$$

(Be sure to use correct voltage depending on load connection, see Figures 1 and 2).

c. Three-phase

$$\text{kW} = \frac{\text{Volts} \times \text{Amperes} \times \sqrt{3}}{1,000}$$

(Do not add the amperes in each phase.)

4. Total the kW figures in Column 5 at the bottom of the column. This is the total maximum running load. The generator set required must have at least this standby kW rating after derating for fuel, altitude and temperature conditions. A reserve of 10-to-15%, for possible changes or future load additions, is suggested.

5.

a. Fill in the starting kVA loads for each motor in Column 6. These can be taken directly from Table 3-1 (of 3.7.3 Motor Starting Data Tables) or calculated from locked rotor Amperes.

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Single-phase

$$\text{kVA} = \frac{\text{Volts} \times \text{Amperes}}{1,000}$$

Three-phase

$$\text{kVA} = \frac{\text{Volts} \times \text{Amperes} \times \sqrt{3}}{1,000}$$

- b. For non-motor loads, use the kW figures in Column 5 for starting kVA in Column 6.
- c. Total the figures in Column 6 and enter at the bottom of the column. Consult Table 3-2 (of 3.7.3 Motor Starting Data Tables) for the size of generator capable of providing the required kVA at an acceptable voltage dip.

**Motor Starting kVA for Kohler Generators**

60 Hz. Standby Rating Range	Generator Model	Maximum Starting 3-Phase, Wye-Co Voltage		
		15%	20%	25%
10-17.5	4K7	17	23	28
20	4L4	45	60	76
30-33	4P5	56	74	9
40	4P7	88	117	
45-55	4P8	105	140	
60	4P10	111	148	
70-80	4S7	118	15	
100	4S9	171	2'	
125-150	4S13	257	?	
180	4U7	206		
200-230	4U9	300		
250	4U10	355		
275-300	4U13	47		
350	4MM24	3		
400	4MM28	'		
450	4MM32			
500	4MM37			
600	4MM45			
750	4MM5'			
800	4MM5'			
900	4MM			

**See Table 3-2 for Complete Motor Starting kVA Information**

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The voltage dips shown in Table 3–2 (of 3.7.3 Motor Starting Data Tables) are instantaneous, with a typical duration of .05–.5 Sec. depending on the size and design of the generator. Most standard magnetically held motor starting contactors will hold in during an instantaneous voltage dip of up to 35%. Lower voltage dips are occasionally required for some types of control circuits, or specialized equipment such as X-ray and other medical diagnostic machines.

6. If the starting kVA load requires a generator set more than 25% larger than the running kW requirement, consider applying the load in steps. This can be accomplished in several ways:

- a. Use multiple transfer switches with different settings of the time delay Normal to Emergency.
  - b. Add a load sequencing control to the transfer switch (See 7.1.4 Paralleling Switchgear).
  - c. Put individual time delays in the controls of loads to be started sequentially.
7. If it is not practical to divide the load, consider the use of reduced voltage motor starters on large motors, or consult with the generator supplier on the possibility of providing an oversize generator, with the engine required for the running kW load.

### 3.7.3 Motor Starting Data Tables

Table 3-1.

Motor Starting kVA and Full-Load Running kW per hp

hp	Starting kVA						Running kW
	Code E	Code F	Code G	Code H	Code J	Code K	
1	4.7	5.3	5.9	6.7	7.5	8.5	1
2	9.5	10.6	11.9	13.4	15.1	17	1.9
3	14.2	15.9	17.9	20.1	22.6	25.5	2.8
7.5	23.7	26.5	29.8	33.5	37.8	42.5	4.6
10	47.5	53	59.5	67	75.5	85	8.8
15	71.2	79.5	89.2	100			13
20	95	106	119	134			17.2
25	118.7	132	149	168			21.6
30	142	159	179	201			25.5
40	190	212	238	268			35.2
50	237	265	298	336			43.5
60	285	318	357				51.5
75	356	398	446				63
100	475	530	595				84
125	594	662	744				106
150	712	795	893				125
200	950	1060	1190				164
250	1187	1325	1490				200
300	1425	1590	1785				246
400	1900	2120	2380				328
500	2375	2650	2975				404

Table 3–2.

Motor Starting kVA for Kohler Generators

60 Hz. Standby Rating Range	Generator Model	Maximum Starting kVA, 3-Phase, Wye-Connected Voltage Dip			
		15%	20%	25%	30%
9	4J5	20	30	35	40
10/15	4K7	20	25	30	35
12/18	4J7	30	40	45	55
20	4P4	60	75	90	105
30/33	4P5	70	90	105	120
40	4P7	95	120	140	160
45/55	4P8	105	130	160	185
60	4P10	125	155	190	225
70–80	4S7	125	155	190	225
100	4S9	135	180	225	275
125/150	4S13	250	310	380	450
180	4U7	200	270	340	410
200/230	4U9	290	380	480	575
250/275	4U10	300	425	550	670
300	4U13	400	525	680	825
350	4MM24	240	330	450	580
400	4MM28	260	360	500	640
450	4MM32	360	520	700	900
500	4MM37	360	520	700	920
600	4MM45	575	800	1075	1350
750	4MM52	750	1050	1350	1700
800	4MM56	850	1150	1500	1900
900	4MM60	650	900	1200	1550
1000	4MM64	680	1040	1480	1900
1200	4MM72	850	1200	1650	2250
1500	4MM84	1200	1700	2350	3100

**Table 3-3.**

**Motor Full-Load Currents (Amperes)**

**Single-Phase**

**Three-Phase**

hp	115-Volt	230-Volt
1/6	4.4	2.2
1/4	5.8	2.9
1/3	7.2	3.6
1/2	9.8	4.9
3/4	13.8	6.9
1	16	8
1-1/2	20	10
2	24	12
3	34	17
5	56	28
7-1/2	80	50
10	100	50
15		
20		
25		
30		
40		
50		
60		
75		
100		
125		
150		
200		

208-Volt	230-Volt	460-Volt
2.2	2	1
3.1	2.8	1.4
4	3.6	1.8
5.7	5.2	2.6
7.5	6.8	3.4
10.6	9.6	4.8
16.7	15.2	7.6
31	22	11
31	28	14
46	42	21
59	54	27
75	68	34
88	80	40
114	104	52
143	130	65
169	154	77
211	192	96
273	248	124
343	312	156
396	360	180
528	480	240

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### 3.7.4 Generator Sizing – Example

This procedural example will size a generator set for the following load:

- 25 hp, 208-Volt, 3-phase Code G elevator motor
- 50 hp, 208-Volt, 3-phase Code G fire pump motor
- 208-Volt, 3-phase 7.5 kW heater
- 120-Volt, 100-Amp lighting panel
- 208-Volt, 1-phase, 30-Amp dryer
- 20-Amp, 208-Volt, 3-phase miscellaneous load

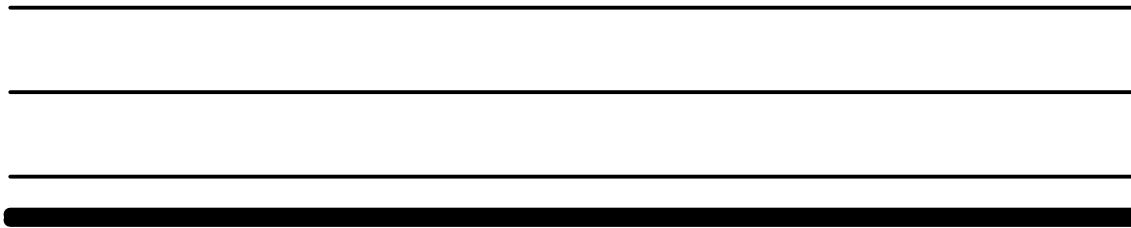
1. List individual load components in column 1 of 3.7.5 Generator Sizing Worksheet – Example.
2. Fill in columns 2, 3, and 4.
  - a. Balance single-phase loads on phases of three-phase generator as evenly as possible. Balance the 100-Amp lighting by entering 50 Amps each, under columns 1 (Phase A) and 2 (Phase B). Connect the 30-Amp dryer across phases B and C by entering 30 Amps in columns 3 and 4.

- b. Three-phase load amperes balance with rated Amps on each phase 7.5 kW (heater) Amps would be:

$$\frac{7.5 \times 1000}{208 \times \sqrt{3}} = 20.8 \text{ Amps.}$$

Enter 20.8 in columns 2, 3, and 4. For the miscellaneous load, enter 20 (Amps) in columns 2, 3, and 4.

- c. For motor loads, refer to Table 3-3 (of 3.7.3 Motor Starting Data Tables). Full-load current of a 208-Volt, 25 hp motor is 75 amps. Enter 75 Amps in columns 2, 3, and 4. Full-load current of a 208-Volt, 50 hp motor is 143 Amps. Enter 143 Amps in columns 2, 3, and 4.
3. Fill in column 5 for each load component as follows:
    - a. For motor loads, see Table 3-1 (of 3.7.3 Motor Starting Data Tables). The 25 hp motor requires 21.6 kW at full load; the 50 hp motor, 43.5 kW.



b. For single-phase loads

$$\text{kW} = \frac{\text{Volts} \times \text{Amps}}{1,000}$$

Thus, for the lighting load,

$$\frac{120 \times 100}{1000} = 12 \text{ kW}$$

For the dryer load,

$$\frac{208 \times 30}{1000} = 6.2 \text{ kW}$$

c. For three-phase load,

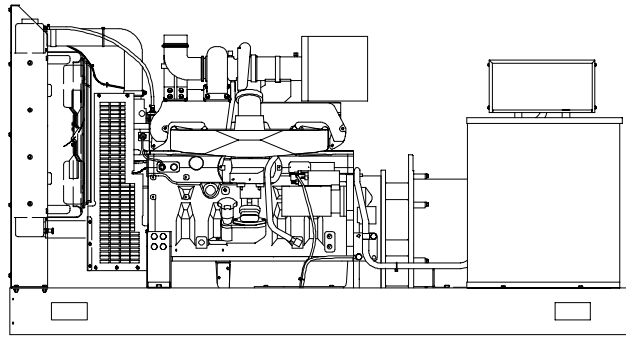
$$\text{kW} = \frac{\text{Volts} \times \text{Amperes} \times \sqrt{3}}{1,000}$$

Thus, for the miscellaneous load,

$$\frac{208 \times 20 \times \sqrt{3}}{1000} = 7.2 \text{ kW}$$

**NOTE**

Power factor has been ignored in these calculations, since it will not significantly affect the results in most cases.



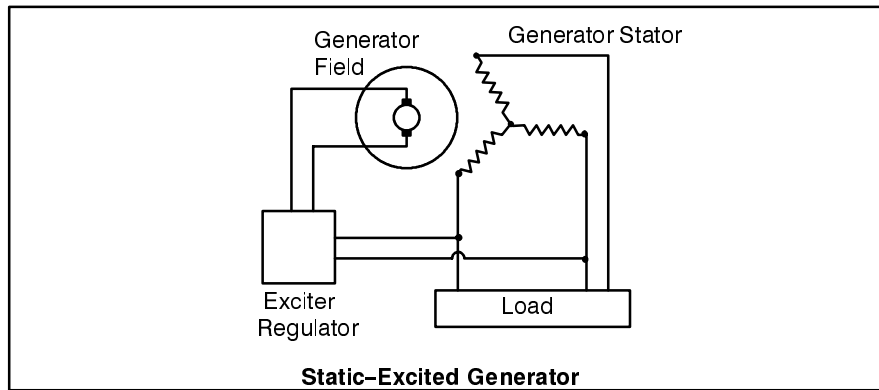
Kohler® 135ROZJ Generator Set

4. Total the figures entered in column 5 – the example totaling 98 kW. The generator set must have a standby rating of 98 kW, after derating for altitude, temperature and fuel.
5. Fill in column 6 (starting kVA) for each load component as follows:
  - a. See Table 3–1 (of 3.7.3 Motor Starting Data Tables) for starting kVA required by particular motors. Starting kVA for the 25 hp Code G motor is 149; for the 50 hp, Code G motor, 298 kVA.
  - b. For non–motor loads, enter the kW figures from column 5 in column 6.
  - c. Total the figures entered in column 6 – the example totaling 479.9 kVA. Referring to Table 3–2 (of 3.7.3 Motor Starting Data Tables), a 150 kW generator set would be required to start all loads in a single step. Voltage dip upon application of the full load would be less than 30%.
6. Since the generator set selected in step 5 is approximately 50% larger than the running load from step 4 (98 kW), consider applying the load in steps. If the 50 hp motor were started separately, with the other loads being applied either before or after, the maximum single–step load would be 298 kVA. The other step would be 181.9 kVA (149 + 7.5 + 12 + 6.2 + 7.2). Referring to Table 3–2 (of 3.7.3 Motor Starting Data Tables), shows that either a 100 or 125 kW generator set would handle the total kVA load in two steps. A 125 kW generator set would be recommended to provide reserve for increase of individual loads and/or future load additions.
7. Total the Ampere figures in columns 2, 3, and 4. The rated Amperes of the generator selected must be at least equal to the highest of the three column totals.

**KOHLER® POWER SYSTEMS**

### 3.7.5 Generator Sizing Worksheet – Example

1.  Load Description	2. Phase A (L1) kW Amperes	3. Phase B (L2) kW Amperes	4. Phase C (L3) kW Amperes	5. Total kW	6. Starting kVA	7. Load Step
25 hp, Code G	75-A	75-A	75-A	21.6	149	181.9
50 hp, Code G	143-A	143-A	143-A	43.5	298	298
7.5 kW Heater	20.8-A	20.8-A	20.8-A	7.5	7.5	
Lighting	50-A	50-A		12	12	
Dryer		30-A	30-A	6.2	6.2	
Miscellaneous	20-A	20-A	20-A	7.2	7.2	
<b>Total</b>	<b>308.8-A</b>	<b>338.8-A</b>	<b>288.8-A</b>	<b>98</b>	<b>479.9</b>	



## 4. Generator Design and Application

Generators furnished for the standby/prime market are now almost universally salient pole, rotating field types. Very little variation exists in the AC power-producing part of the machine. When we come to excitation systems, however, a great number of variations have been used. We will discuss four basic types, which are commonly seen in the industry today.

### 4.1 Static Excited (Exciter Regulators)

This system rectifies AC power from the output of the generator and sends a controlled DC current to the rotating field through brushes/collector rings. This exciter can be of a magnetic amplifier type; however, it is usually an SCR bridge controlled by a solid state voltage regulator circuit. This system is quite fast operating and can be designed to have excellent load response and voltage regulation.

Kohler's patented PowerBoost™ features automatic voltage control and integral transient voltage protection. It employs an separate auxiliary winding (independent of the main output) to power the field during fluctuations caused by load-on/load-off

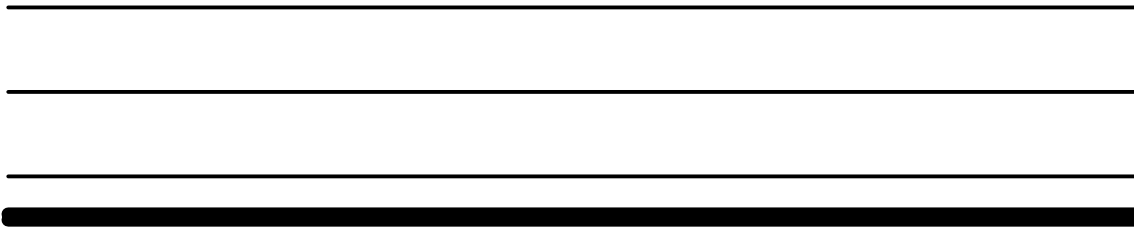
situations. This system provides excellent motor starting ability and maintains virtually constant voltage.

Disadvantages of static excited designs are found in the rotor collector rings and brushes. These components are subject to routine maintenance.

### 4.2 Wound-Field Brushless Excited

The most common type of generator found today, uses a salient pole exciter with field coils wound on each pole. This system uses a voltage regulator which supplies a regulated DC current to the exciter field by means of rectifying a small amount of the AC output from the generator. The system uses a solid state voltage regulator and is immune from the large power spikes inherent in the static excited-type machine. It is also completely brushless. It is self-protecting on short circuit or extreme overload, as the generator voltage collapses,

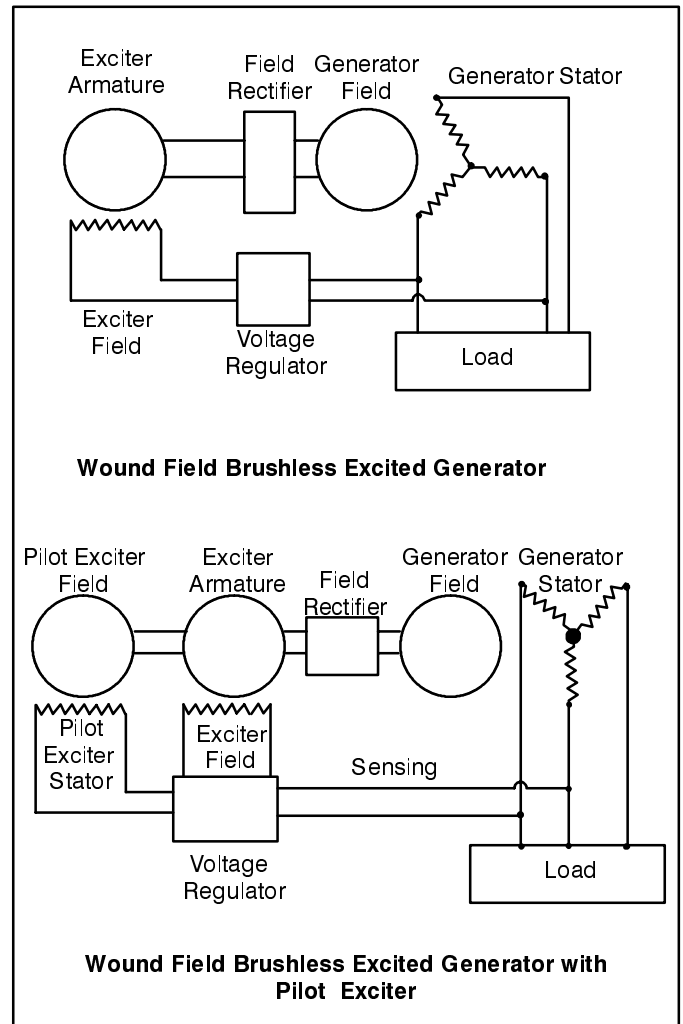
**KOHLER® POWER SYSTEMS**

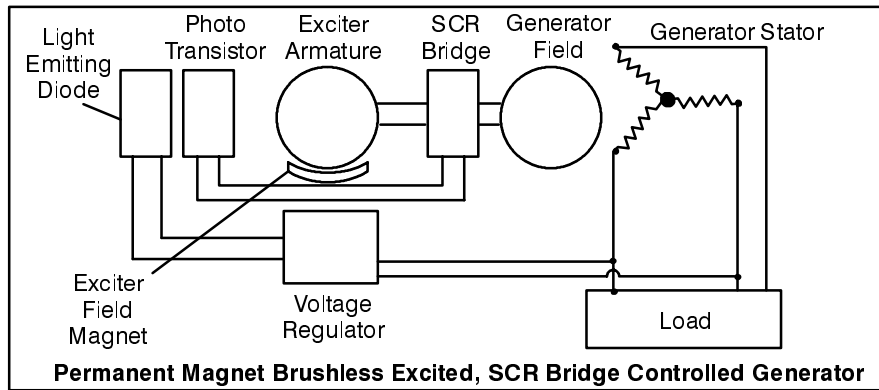


but leaves connected loads without power. The chief disadvantage of this type system is that it has the inherent time constant of the exciter field, which makes it considerably slower in recovery time, compared to the static excited-type.

While this type machine is self-protecting, it will not selectively trip branch circuit breakers because of its collapsing voltage characteristic.

A variation of the conventional brushless design described above uses a pilot permanent magnet exciter to supply the field in place of the generator output. This allows the generator to support short circuit currents and has the added advantage of making the voltage regulator relatively immune to the effects of SCR load induced harmonics, since the regulator is connected to the load only for sensing. This design is used on Kohler generator sets 350–1500 kW.





### 4.3 Permanent Magnet Excited, SCR Bridge Controlled

The fourth type excitation system uses a permanent magnet exciter with a rotating SCR (thyristor)-type bridge, which controls the amount of the DC current fed to the generator field. This type of system uses a voltage regulator, which signals the rotating SCR bridge through an optical coupling. The voltage regulator senses the output voltage of the generator and turns a stationary LED (light emitting diode) on or off, depending upon the level of the output voltage. The LED is mounted on the end of the generator shaft opposite a photo transistor, which rotates on the shaft. The photo transistor picks up the signal from the LED and tells the SCR rotating bridge to turn on or off, depending upon the need, as dictated by the voltage regulator. This type generator has a voltage recovery time several times faster than the conventional wound field brushless generator, because it does not have the inductance of the exciter field to contend with. It combines the fast response characteristics of the static exciter generator with the short circuit current sustaining capability and relative immunity to load induced harmonics of the pilot exciter design. Kohler Co. holds the patent on the SCR bridge controlled-type generator, and has been furnishing it

since 1975. Kohler generators 20 kW through 300 kW use this principle.

### 4.4 Broad-Range Generators

Most of the generators furnished in the industry today are of the broad range, 12-lead type. The winding is basically a three-phase winding, with each phase wound in two sections. The generator is able to function properly over the range of 110 to 139-volts per section. For such a winding, a generator can be connected for service in 120/208-volt, 277/480-volt, three-phase Wye, 120/240-volt, three-phase Delta, and 120/240 volt, single-phase, 60 Hz systems. It can also be used for 380 or 416-volt, 50 Hz systems. This flexibility enables the generator to be used with the great majority of systems in the world. The only sizable exception is the 600-volt system used in Canada. Separate 600-volt windings are used for the latter application.

By the use of dual-scale meters and three current transformers, the voltages and currents on any of the systems can also be measured without changing current transformer connections or ratios. The arrangement of these connections for one series of generators is shown in Figure 3. Some variation in the connections does occur between series of generators; therefore, the connection guide furnished with the generator should always be used.

### 4.5 Generator Ratings

The basic standard for generator ratings is NEMA MG-1, Parts 16 and 22. Almost all generators furnished today use Class F or Class H insulation. In an ambient of 104°F (40°C), Class F insulation allows a temperature rise of 266°F (130°C) for standby and 221°F (105°C) continuous.

Class H insulation allows a temperature rise of 125°C continuous of 150°C standby. Kohler generators use Class H insulation but are rated according to the temperature rise limits of Class F insulation. The temperature rise of the windings is measured by the resistance method, in which the resistance of the winding at the cold temperature is compared to the resistance when the generator has reached stabilized temperature. If the generator

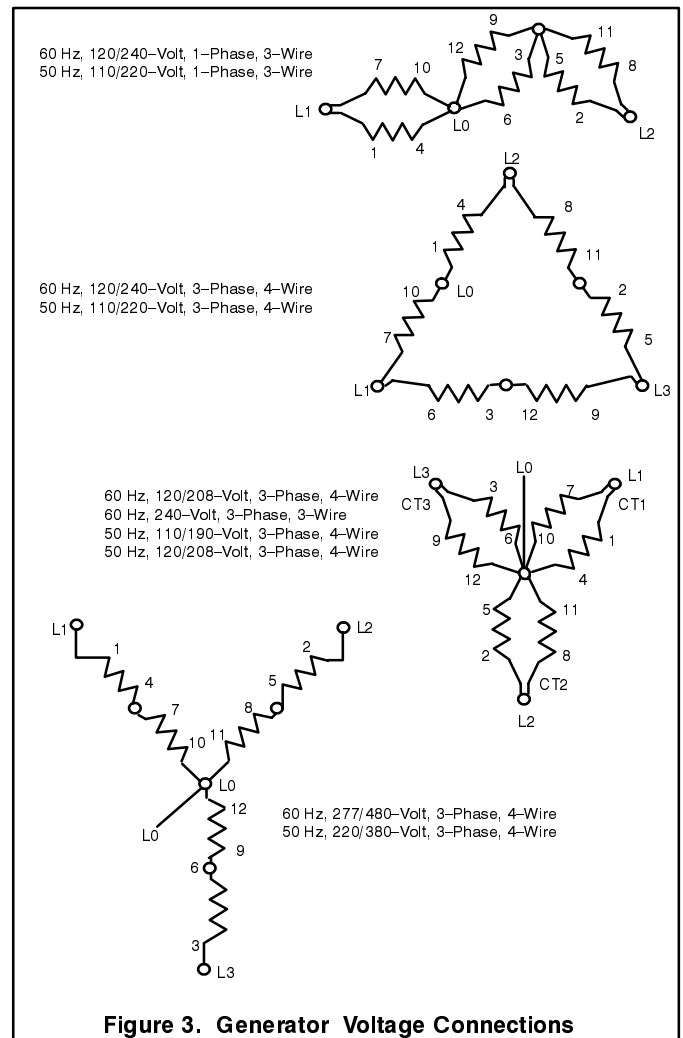


Figure 3. Generator Voltage Connections

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were operated at maximum ambient temperature and at rated load continuously, the projected life for the continuous rating is 20,000 hours. Such load conditions are virtually non-existent. Therefore, it is obvious that generator winding standards are very conservative. In fact, generators almost never fail from being operated at rated load. Generator winding failures result from environmental conditions, a weakness in the winding, continuous overload, or load unbalance.

#### **4.6 Load Application in Unbalanced Three-Phase Delta Systems**

Generators which are used in a system having a combination of single-phase and three-phase loads are susceptible to load unbalance. Three-phase loads are self-balancing; however, single-phase loads must be carefully planned and distributed between the phases to obtain balanced voltages and prevent overloading one or two phases. This is a fairly simple thing to do for Wye connected generators; however, when the three-phase 120/240 volt Delta system is used, a compromise must be made. In general, loads should be arranged such that the current rating of the generator is not exceeded on any phase.

When calculating three-phase systems, it is often assumed that the loads to be carried will be evenly balanced.

The problem is, experience proves the opposite. Most of the systems encountered have unbalanced loads. The most glaring example of this is the 120/240 volt three-phase Delta system used for combinations of 120 volt and 240 volt, single-phase loads and 240 volt, three-phase loads. Unbalance is fundamental in this type of system, such as a supermarket with lighting and cash registers on single-phase and refrigeration and freezer motors on three-phase.

If generator manufacturers had their preference, that type of system would not be used. However, we often find ourselves confronted with supplying power to an existing load of this type.

It is relatively simple for the system designer connecting his load to a utility to select three single-phase transformers, one of which is made large enough to handle the single-phase load. But the supplier of standby power for such a system has

a problem. The three-phase windings of a generator are all equal in size, and he has very little control over the load. He would prefer a small single-phase load and a larger three-phase load, but that situation is rarely encountered.

There are actually two problems. One, how to avoid damage to the generator from the unbalanced load, and two, how to avoid damaging three-phase motors connected to systems with unbalanced loads?

Figure 4 shows a six-winding Delta connected generator with three-phase terminals L1, L2, and L3, and a grounded neutral at L0. Single-phase 240-volt loads are connected to L1 and L3 shown at A and single-phase 120-volt loads are connected as shown at B and C. Without going into the mathematics of the generator, some things are obvious from looking at the diagram. Load A is supplied not only from the windings between L1 and L0 and L0 and L3 but also those between L1 and L2 and L2 and L3. Current is higher in the L1 and L3 leg, but the system is not unlike the Double Delta system which is frequently used for single-phase generator connection.

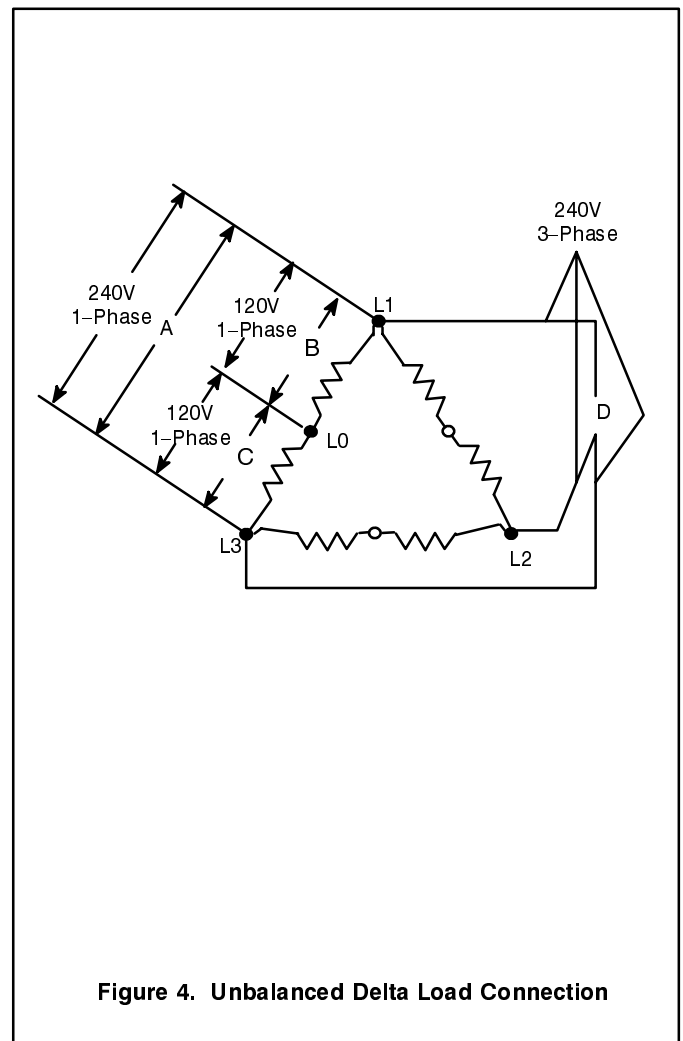


Figure 4. Unbalanced Delta Load Connection

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A bigger problem comes when loads are supplied, as at B or C. If load is applied at B only with nothing at C, it is obvious that the load must be supplied by one of the six coils of the generator, and this means that it would be very easy to overload that part of the generator.

If a balancing load is connected at C, the problem is less severe. Equal loads at B and C act the same as load A. Thus, the first precaution is to make certain that loads at B and C are as nearly equal as practicable. Careful attention to these 120-volt circuit load balances will avoid generator damage. In any event, the total single-phase plus three-phase current on terminal L1 or L3 should not exceed the current rating of the generator.

Up to this point, we have encountered no problems with furnishing satisfactory power to the loads. When we come to the three-phase loads, however, as at D, we do have a problem which we can do very little about. NEMA MG1, Section 20.55, recommends that motor voltage unbalance should not exceed 1%. With single-phase loads equal to half the rating of the generator often encountered in these systems, the voltage unbalance in the three-phase lines is likely to be several times 1%. NEMA prescribes a derating system whereby the motor must be derated if unbalanced voltages exist, so it doesn't overheat. At

5% unbalance, the derate is 25%. The current unbalance at normal operating speed is stated to be six to ten times the voltage unbalance.

As we become more conscious of motor efficiencies, this situation may become more critical as designers will tend to operate motors at near to their full load rating. The only thing that the generator supplier can do to alleviate this problem is to supply an oversized generator. Even three-phase sensing on the voltage regulation does not help balance the voltages. If single-phase loads are very heavy and if the three-phase motors involved are loaded up to their rating, the alternative of an oversized generator is recommended.

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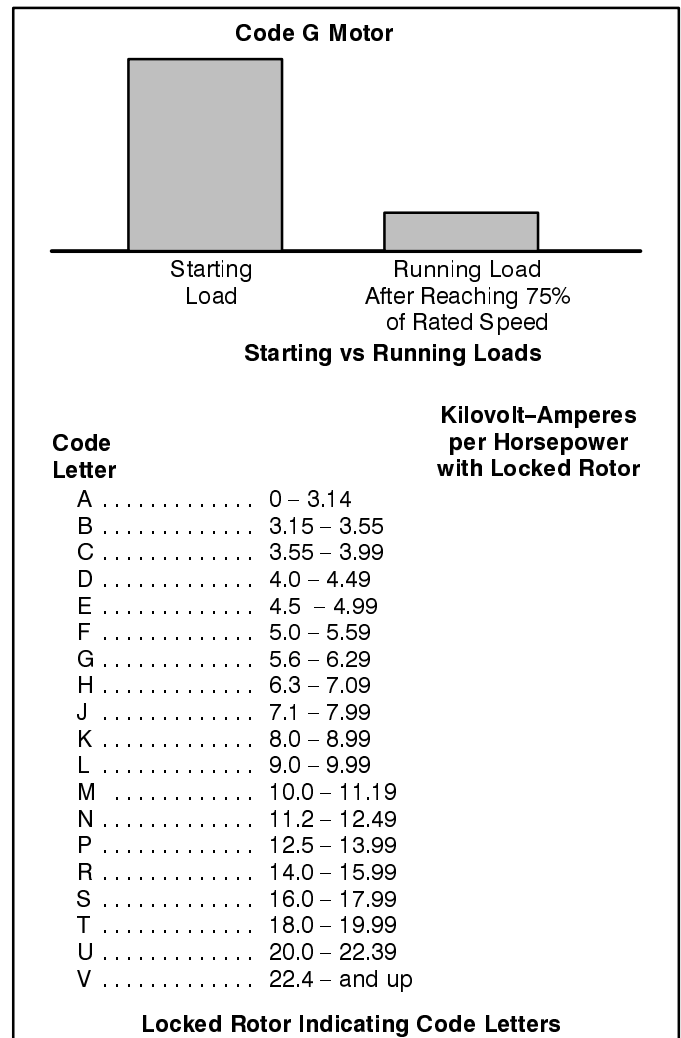
In a nutshell, the basic points to remember are these:

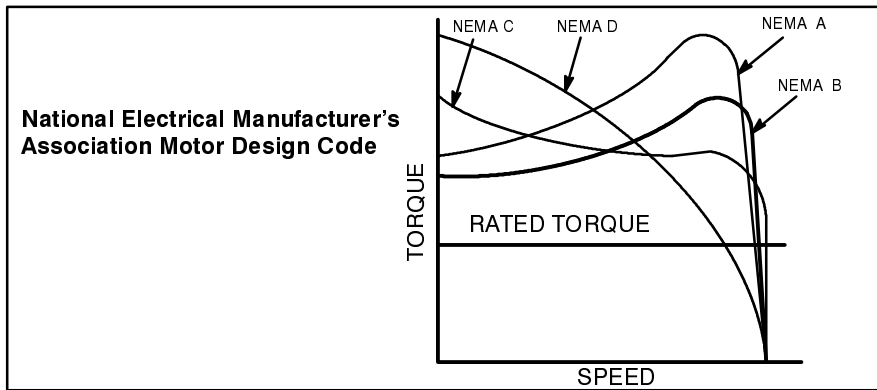
- Balance the loads between B and C
- Try to keep the single-phase loads to less than 50% of the rating of the generator
- Keep the line current at any of the three terminals, particularly terminals L1 and L3, within the current rating of the generator, and
- Do not load connected motors beyond 80% of their full load rating.

### 4.7 Applying Generator Sets to Motor Loads

Motor starting is one of the major applications of both prime power and standby generator sets.

The basic characteristic of motor loads that causes difficulty is that motors draw starting currents when started at full voltage. A typical motor, if there is such a thing, draws approximately six times its rated full load current when starting, and continues to do so with only a slight reduction until it reaches about 75% of rated speed.





The kVA required by a motor starting at full voltage is quite close to the “locked rotor kVA” requirement of the motor, which is usually fairly easily determined either from the actual motor’s nameplate or from the manufacturer. The National Electrical Manufacturer’s Association (NEMA) sets design standards for motors, and has established a NEMA Code letter designation to classify motors by the ratio of locked rotor kVA per horsepower. These code letters range from A to V, covering motors with a locked rotor kVA per horsepower or more.

Small motors commonly have a higher NEMA Code letter and corresponding higher locked rotor kVA per horsepower requirement than large motors. Typical motor sizes and codes are:

Size	Code	Locked Rotor kVA/HP
1–2 HP	L or M	9–11
3 HP	K	8–9
5 HP	J	7–8
7.5–10 HP	H	6–7
15 HP and up	G	5.6–6.3

Fractional horsepower motors usually have even higher locked rotor kVA requirements.

In trying to identify motors, the NEMA Code letter should not be confused with the NEMA Design letter which refers to the motor’s torque curve.

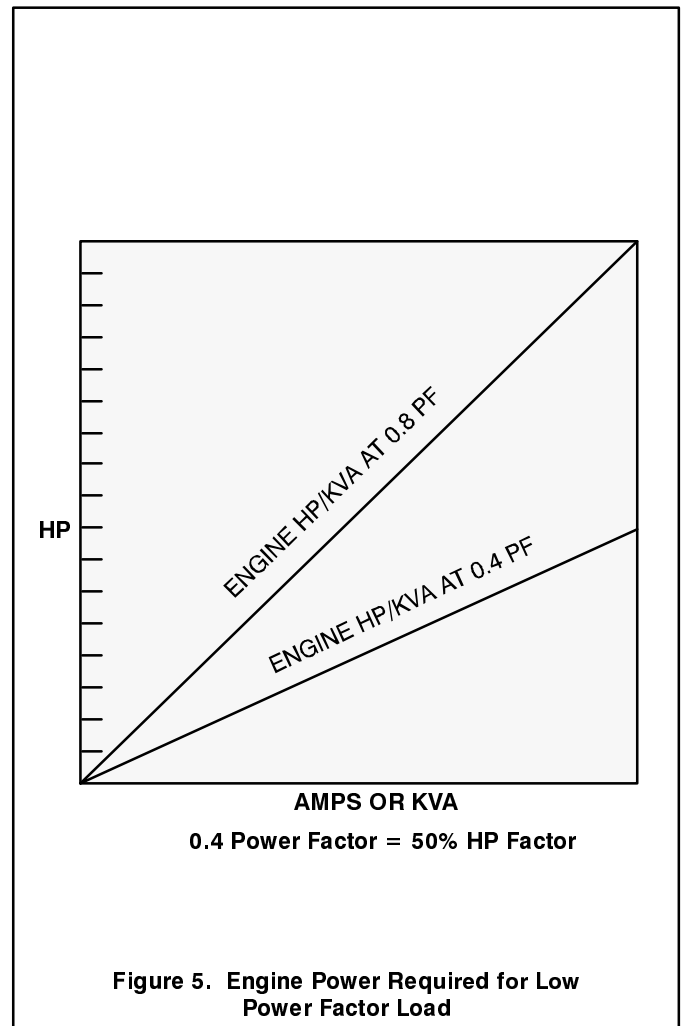
Since the kVA requirements of a motor running at full load and rated speed are normally somewhat less than one kVA per horsepower except for small motors, it would be very inefficient to size a generator set by matching its rated continuous or standby kVA to the motor’s locked rotor or starting kVA rating. Several factors combine to make this conservative approach unnecessary.

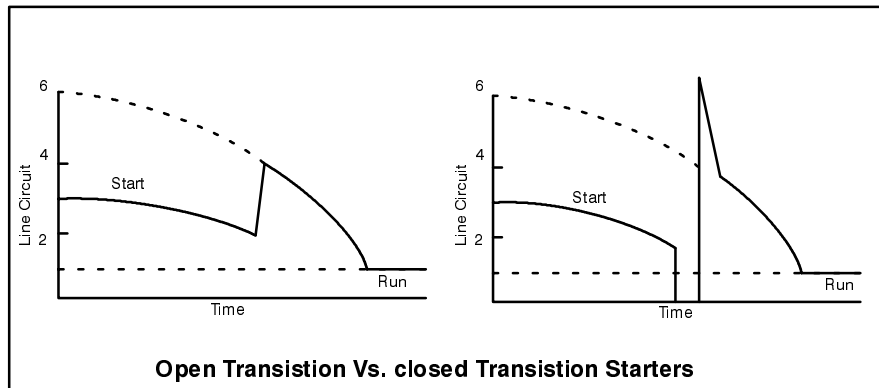
One of these is **power factor**. Three phase generator sets are usually rated in kVA at 0.8 power factor. The actual power factor of a given motor load during starting is difficult, if not impossible to measure since it is changing constantly. Various sources put it in the range of 0.3 to 0.5. A typical generator set will produce somewhere near twice its continuous rated kVA at 0.4 power factor for the time required to accelerate a motor to the speed at which its kVA requirement drops sharply. The engine does not stall even though the generator set is delivering more than rated kVA, because only slightly more horsepower is required for reduced generator efficiency on low power factor loads, see [Figure 5](#).

This generator characteristic enables satisfactory motor starting results with generators half the size, which would theoretically be required using the most conservative approach of matching the generator 0.8 power factor kVA rating to the motor locked rotor kVA rating.

The other factor which can substantially reduce the size generator set needed for a particular motor load is **voltage dip**. Values for motor locked rotor current or kVA are based on full voltage starting. In practice, there is always some voltage dip even when starting on utility power. When voltage drops, current also is reduced proportionately so that starting kVA is reduced as the square of the voltage dip. A 30% voltage dip reduces kVA by about 50% (0.7 volts x 0.7 amps. = 0.49 kVA).

The voltage dip for a given motor load on a particular generator set does not change without modification to one or the other. At least for the first few cycles, it is determined by the size of the load (locked rotor kVA draw) and the amount of copper and iron in the generator. The problem of selecting a generator for a particular load can be considered as a problem of determining what voltage dip will be acceptable, considering its effect on all components in the system.





Voltage dip has important effects on motor loads themselves, aside from any possible effects on other equipment in an emergency system. One is that excessive voltage dip will cause control relays or magnetically held motor starting contactors to drop out. If this happens, the contactor or relay opening immediately removes the load from the generator, causing voltage to rise, and the cycle repeats rapidly. This can damage contactors if allowed to continue. Typically, most control relays and motor starting contactors will stand a 40% voltage dip. There are exceptions however, where relays or contactors will chatter if subjected to more than a 20% dip. To assure satisfactory operation the voltage limitations of control components should be obtained from their manufacturers or suppliers.

The second effect of voltage dip which may determine whether a generator will successfully start a motor is that it reduces the torque available from the motor. A common NEMA Design B motor will develop 150% of rated full load torque during starting. Torque is proportional to the kVA delivered to the motor, so the same 30% voltage dip that reduces kVA to 49% of the rated locked rotor value reduces torque to 49% of its rating at any given speed and 100% voltage. If the motor starts unloaded as most fans, centrifugal pumps and motor-generators used with elevators do, this produces no problem other than a somewhat longer

acceleration time. Other types of loads such as positive displacement pumps may require more torque than the motor can develop at reduced voltage, and the motor will not come up to speed. To be sure of a successful start on these applications, it is necessary to compare the torque curves of the pump and the motor, correcting the latter for the effect of the expected voltage dip.

#### 4.7.1 Reduced Voltage Motor Starters

The high inrush current and high starting torque associated with across-the-line starting of motors may create problems with the equipment driven by the motor or objections from the power company. Reduced voltage starters are used to solve these problems.

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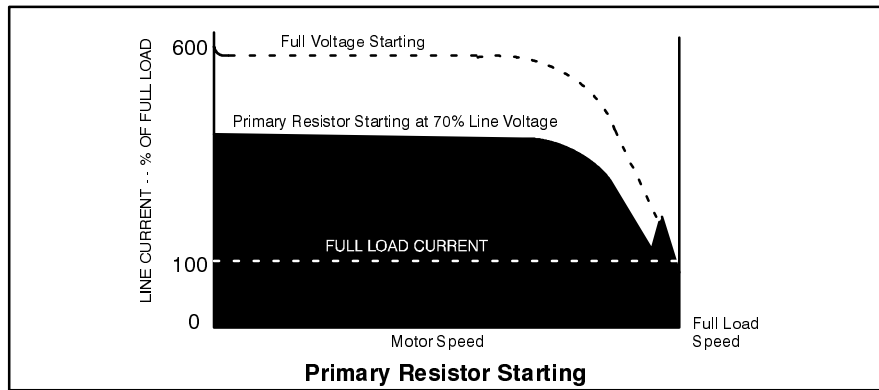
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There are various types of reduced voltage starters, and their use sometimes allows successful starting of a given motor on a smaller generator set than would otherwise be the case. Most such starters involve applying the load to the power source in two or more steps. The starters are "open" or "closed" transition type depending on whether the load is momentarily disconnected from the power source between steps. Open transition starters are of no value in reducing voltage dip when the power source is a generator set. The maximum dip at the transition can be higher than the maximum starting the same motor across-the-line.

This is because the motor acts as a generator, for a few cycles after power is removed, until the residual voltage decays. When the motor is reconnected to the power source the effect is the same as connecting two generators out-of-phase – high inrush current. Closed transition starters do reduce the maximum voltage dip, but the amount of reduction depends on the speed of the motor at the time of transition. To keep the voltage dip to a minimum, it is important to allow as much time for the motor to accelerate as possible before making the transition. The starters usually have an adjustable time delay for this purpose.



## 4.7.2 Types of Reduced Voltage Starters

### Primary Resistor Starting

In this type of starter, resistors are connected in the motor lines to produce a voltage drop due to the motor starting current. A timing relay is connected to short out the resistors after motor acceleration. The motor starts at reduced voltage and operates at full voltage. These starters provide very smooth starting due to increasing voltage across the motor terminals as the motor accelerates. Since motor current decreases as speed increases, the voltage drop across the resistor is less as the motor approaches rated speed. When the resistor is shorted out when the motor is nearly at rated speed, there is little increase in current or torque. Standard primary resistor starters provide one step of resistance with about 70% of line voltage at the motor terminals at the time the starting contacts close. Line current is also reduced to about 70% of rated locked rotor current and about 49% of rated locked rotor torque is available.

Maximum inrush kVA is also limited to about 50% of the motor's rated locked rotor kVA. Because this type of starter increases the power factor of the motor starting load, we find that it frequently overloads the engine on the generator set. Use of resistance starters on generator sets is typically not recommended.

### Primary Reactor Starting

This type of starter uses reactors connected in the motor lines to reduce starting power requirements. These starters provide a low power factor load, but must be designed to match the characteristics of the particular motor being started.

Primary reactor starters reduce the starting kVA load by 35–50% and reduce the starting torque available from the motor by 60–75%. When properly applied, these starters work well with generator sets.

### Wye–Delta Starting

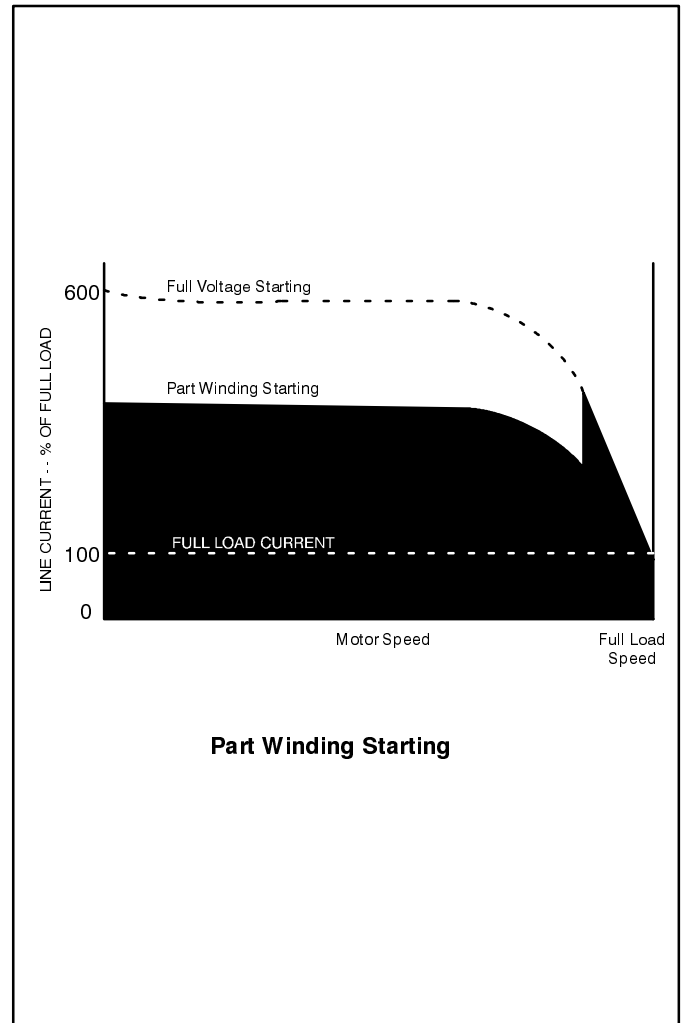
Some motors have 6 leads which allow them to be connected in either wye or delta. When wye connected, the motor has a voltage rating 173% of its delta voltage rating. By connecting the motor winding in the wye configuration and using a voltage source corresponding to the delta rating, starting current and torque are reduced. The starter is not

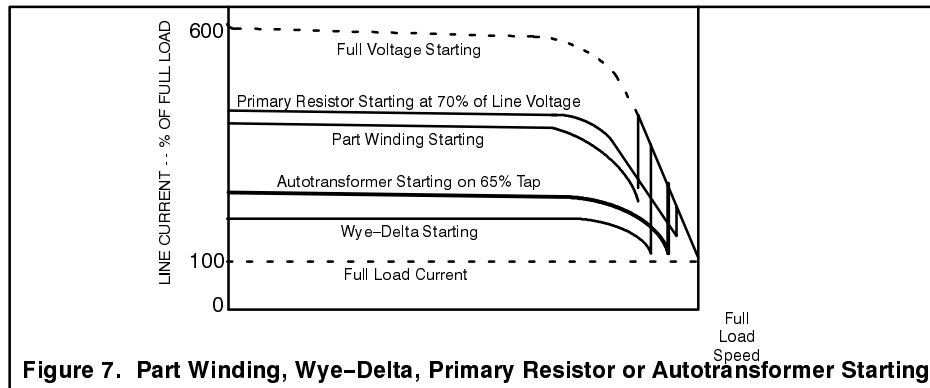
truly a reduced voltage type, but the effect is the same. Wye-delta starters are usually open transition type. On the initial start, two contactors close; one to connect the windings in wye and one to energize them. After a time delay the wye contactor opens and third contactor closes to reconnect the motor in delta. With the motor connected in wye, both starting torque and current are 33% of the delta connection values.

Because of the high current inherent with the open transition, the maximum voltage dip on a generator set is not improved over normal full voltage starting. Special closed transition starters are available which will reduce the maximum inrush current and kVA to approximately 60% of the maximum starting the same motor across-the-line, delta connected. Because of the very low starting torque, the time to the transition point must be relatively long to avoid high currents at that point.

### Part Winding Starting

Part Winding starters are used with motors having two identical windings intended to be connected in parallel. These windings can be energized in sequence to provide reduced starting current and torque. When one winding is energized, the torque is about 50% of "both winding" rating, and line current is 60-70%, depending on motor design.





Part winding starters are not truly reduced voltage starters, but the effect is similar. Since they are inherently closed transition, the maximum inrush current occurs at the moment the first winding is energized and the maximum inrush kVA load on a generator set will be 60–70% of the normal across-the-line rating of the same motor.

#### Auto-Transformer Starting

This type of starter generally gives the best results with generator sets. The starter provides reduced voltage at the motor terminals from a tapped 3-phase auto-transformer. Taps on the transformer provide selection of 80, 65, or 50 percent of line voltage to the motor terminals initially. Starting torque is reduced to 64%, 42%, or 25% of the full voltage value but because of transformer action line current and kVA are reduced in the same amounts, depending on the transformer tap selected.

#### Summary

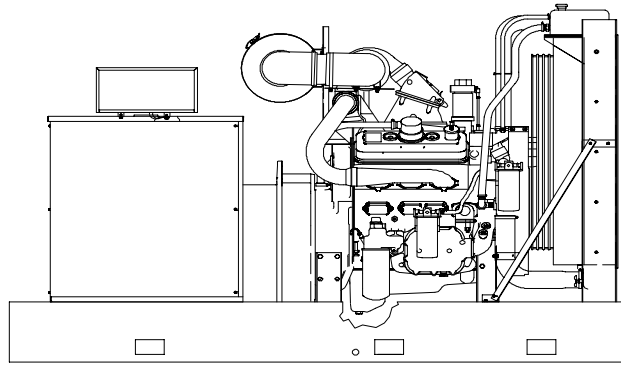
Figure 6 shows the various types of reduced voltage starters and summarizes their relative advantages and disadvantages. Figure 7 shows the inrush current characteristics of the various types of starters on a single graph for comparison.

Because there will still be some voltage dip when the motor is started on a generator set, and that dip

further reduces available torque, it usually is not practical to use the 50% tap with a generator set. Closed transition type autotransformer reduced voltage starters can be helpful when starting large motors on generator sets.

**Figure 6. Reduced Voltage Starters Application Data**

Type of Starter	Percent of Full Voltage Values			Advantages	Disadvantages
	Voltage at Motor	Line Current	Starting Torque		
Autotransformer		Taps		<ol style="list-style-type: none"> <li>1. Provides highest torque per ampere of line current.</li> <li>2. Taps on autotransformer permit adjustments of starting voltage.</li> <li>3. Suitable for long starting periods.</li> <li>4. Closed transition starting.</li> <li>5. While starting, motor current is greater than line current.</li> <li>6. Low power factor.</li> </ol>	<ol style="list-style-type: none"> <li>1. In lower HP ratings, is most expensive design.</li> </ol>
	80	64	64		
	65	42	42		
	50	25	25		
Primary Resistor	70	70	49	<ol style="list-style-type: none"> <li>1. Smooth acceleration – motor voltage increases with speed.</li> <li>2. Closed transition starting.</li> <li>3. Less expensive than autotransformer starter in lower HP ratings.</li> <li>4. Available with as many as 7 accelerating points.</li> </ol>	<ol style="list-style-type: none"> <li>1. Low torque efficiency.</li> <li>2. Resistor gives off heat.</li> <li>3. Starting time in excess of 5 seconds requires expensive resistor.</li> <li>4. Starting voltage difficult to adjust to meet varying conditions.</li> <li>5. High power factor during start.</li> </ol>
Part Winding	100	65	48	<ol style="list-style-type: none"> <li>1. Least expensive reduced voltage starter</li> <li>2. Closed transition starting.</li> <li>3. Most dual voltage motors can be started part winding on lower of two voltages.</li> <li>4. Small size.</li> </ol>	<ol style="list-style-type: none"> <li>1. Unsited for high inertia, long starting periods.</li> <li>2. Requires special motor design for voltages higher than 230 V.</li> </ol>
Wye-Delta	100	33- -1/2	33- -1/2	<ol style="list-style-type: none"> <li>1. Moderate cost – less than primary resistor or autotransformer.</li> <li>2. Suitable for high inertia, long acceleration loads.</li> <li>3. High torque efficiency.</li> </ol>	<ol style="list-style-type: none"> <li>1. Requires special motor design.</li> <li>2. Starting torque is low.</li> <li>3. Inherently open transition – closed transition available at added cost.</li> </ol>



**Kohler® 275ROZD Generator Set**

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## 5. Selecting Generator Set Model and Accessories

### 5.1 Fuel Systems

The choice of fuel system for a generator set will be influenced by the size as determined in the previous sections. Up to 100 kW, spark ignition engines (gasoline, natural, or LP gas fueled) are substantially less expensive than compression ignition (diesel) engines. Above 100 kW, and through 1500 kW, the situation reverses and the few spark ignition engines available are as much as twice the cost of comparable diesels. Comparative advantages and disadvantages of the available fuel systems are described in the following paragraphs. Fuel cost considerations were intentionally omitted due to market price fluctuations in geographic areas. However, fuel usage and cost per Btu calculations should be used as influential factors.

#### 5.1.1 Diesel

Diesel power dominates the standby generator set market above 75 kW.

Diesel advantages:

- Fuel is readily available in most parts of the world.
- Existence of an on-site fuel supply makes the emergency power system independent of any disturbance to the natural gas supply or distribution system.
- Most diesel engines will operate on #2 fuel oil which is often available on-site for the heating system and eliminates the requirement for separate storage tanks.
- Diesel fuel is relatively stable and can be stored for long periods without deterioration.
- Diesel engines have no ignition or carburetion systems to require periodic maintenance.

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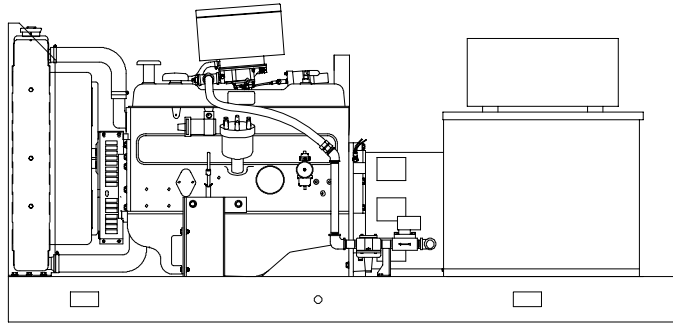
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Diesel disadvantages:

- Engines are more expensive in sizes below 100 kW.
- The mechanical noise of the engine is greater than a comparative spark ignition engine.
- The odor of diesel fuel or exhaust may be objectionable.
- If the engine requires service, mechanics with diesel experience may be harder to find in some localities.
- Regulations covering fuel tanks, especially underground tanks, add significant costs.

While four-cycle diesels seem to be more common in the marketplace, it is not necessarily true that there are inherent advantages. Two-cycle and four-cycle engines are different, but quality designed and built engines of both types provide excellent, reliable power for generator sets in all applications.



**Kohler® 35RZ Generator Set**

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### 5.1.2 Gasoline

Gasoline advantages:

- Fuel is readily available.
- On site fuel supply makes the standby system independent.
- Engines are less expensive than diesel engines in models below 100 kW.
- Service personnel with basic knowledge of spark ignition engines are easily located.

Gasoline disadvantages:

- The fuel cannot be stored for more than six months without some deterioration.
- The fuel system is subject to malfunction due to build-up of gum and deposits, aggravated by light use.
- Fuel is explosive and requires special storage precautions. Codes often prohibit gasoline storage within the building in which the generator is installed.

- New regulations for storage tanks, especially underground tanks, add significant costs.

### 5.1.3 Natural Gas

Natural gas engines share the cost and service advantages of gasoline engines, plus:

- There are no fuel storage problems
- Engines operated on clean-burning natural gas approach the reliability and life of diesel engines.

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The principal disadvantages of natural gas fuel is that it is not an independent fuel source and is subject to interruption, possibly at the same time as commercial power. Many codes, including the National Electrical Code®, require a minimum on-site fuel supply (see NFPA 70-1989 for exceptions). LP gas is a frequent and dependable on-site backup which does meet the full intent of the code.

Combination natural gas/gasoline fuel systems meet the letter of code requirements for on-site fuel, but where gasoline is the standby fuel, it is doubtful they meet the spirit. The principal disadvantage of gasoline fuel is that it does not store well, and that in a matter of months gum will form to make carburetors inoperative. When gasoline is used as a standby fuel for a standby generator, it is almost a certainty that the gasoline fuel system will not function when and if needed. Combination natural gas/LP gas systems are available and have none of the disadvantages of combination gasoline systems. In addition, the combination natural gas/LP system can easily be supplied to automatically switch between fuels under load with minimum disturbance to the electrical load. One other disadvantage of natural gas fuel is that the power available for the engine will be approximately 10% less than from the same engine using gasoline, unless a special high-compression-ratio engine is used.

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In areas where natural gas has a heat value of less than 1000 Btu per cubic foot, engine power may be further reduced.

#### 5.1.4 LP Gas

Liquified Petroleum (LP), usually propane, or butane, or a mixture of both, is nearly ideal for standby generators. It combines the advantages of both gasoline and natural gas to provide both on-site fuel supply and a clean burning fuel which can be stored indefinitely. The disadvantages of LP fuel are the cost of the pressurized fuel storage tank required, and the need for an oversize tank or separate vaporizer to ensure availability of gaseous fuel in low ambient temperatures.

#### 5.1.5 Fuel System Accessories

- All fuel systems require flexible fuel connections to absorb vibration and relative motion between the vibro-mounted generator set and stationary fuel piping.
- Most diesel installations will require a day or transfer tank, plus a main storage tank.

- Natural gas or LP gas systems require a fuel solenoid valve interlocked with the engine starting controls.

Fuel consumption is not usually a consideration in standby power systems. The engine is normally operated less than 200 hours a year and fuel cost is not a significant part of total operating cost. The exception to this would be a generator set used for both standby power and peak shaving. In such an installation, both fuel economy and engine life are important.

### 5.2 Cooling Systems

The choice of a cooling system for a generator set is influenced by the size of the set. In general, only liquid cooling systems are available above 25 kW, and only air cooling below 10 kW. The following briefly describes the available systems for their relative advantages.

#### 5.2.1 Air Cooling


This is the simplest of systems and theoretically the most reliable.

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Because the cooling air is heated to a higher temperature, less air volume is required per kW of generator set capacity than with a comparably sized liquid-cooled engine with a unit-mounted radiator. Therefore, smaller intake and exhaust vents can be installed in the generator room.

One disadvantage is that mechanical noise from an air-cooled engine is slightly more noticeable than it is with a liquid-cooled engine, which benefits from the insulating effect of a water jacket.

Another problem affecting air-cooled engines is that of applying heat to ensure reliable starting in low ambient temperatures. The usual practice is to install a thermostatically controlled oil sump heater. However, the result is likely to be condensation in the engine crankcase, reducing the life of the lubricant and of the engine. Unless a heating element with a very low wattage for each square inch of surface area is used, engine oil near the heater will be partially decomposed and "coking" problems will occur.

Cooling air discharge ducts are usually necessary with indoor installations of air-cooled generator sets. Flexible connections are required between the engine air discharge and the building duct work.

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## 5.2.2 Liquid Cooling

There are three common systems used with standby generator sets:

- Unit mounted. A radiator system mounted on the generator set is the most popular solution to the problem of engine/generator cooling and has few disadvantages. In its favor is that it is entirely self-contained. Nevertheless, it requires relatively large volumes of cooling air to be moved to and away from the unit with minimum restriction.
- Remote radiator. Remote radiator systems are similar to unit-mounted systems except that the radiator and electric motor-driven fan are packaged as a separate module to be located outdoors where the supply of cooling air is unlimited. Some heat will still be rejected from the generator and the hot surfaces of the engine, so air must be provided to the unit for cooling and combustion. Usually about 50% of the air required for a unit-mounted radiator system is needed for a remote radiator, but that is only a rough guide. A credible percentage figure should be available from the generator set manufacturer, derived from the testing of its prototype models.
- City water cooled. City water cooling systems are similar to remote radiator systems. That is, they allow heat to be carried out of the generator room as hot water rather than as hot air. The systems are usually designed for a maximum raw water temperature of less than 90°F (32°C). Water is piped from the building domestic water supply and, after being heated in the engine, is expelled into the sewer. This type of system, however, is dependent on an external water supply and forbidden by Article 700-12(b)3 of the National Electrical Code®. A system using a cooling tower or an on-site well, on the other hand, would meet that code requirement.

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### 5.3 Options – Water Cooling Systems

After a choice has been made from the three available types of water cooling systems, special installation considerations and option selections must be determined.

Normally all radiator-cooled generator sets use "pusher" type fans, which draw air across the generator and engine, and discharges it through the radiator to the outdoors. A radiator duct flange provides a convenient connection to duct work for the exhaust air. A short canvas or other flexible section should be installed between the radiator duct flange and the exhaust duct. Flexible water connections are required for city water-cooled or remote radiator-cooled units.

Water-cooled exhaust manifolds have little value on unit-mounted radiator systems. They can reduce the ventilating air requirement from 5% to 10% for remote radiator or city water systems, but reduce the efficiency of turbochargers and add substantial cost. Insulated exhaust manifolds are available for most engines above 75 kW and provide similar reduction in ventilating air requirements at lower cost and no effect on engine power.

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If selected, city water cooling systems should include heat exchangers to prevent the build-up of scale in the engine water jacket. They should also include thermostatic valves – to conserve water – and electric solenoid water shut-off valves interlocked with the engine starting control.

Engine block heaters are recommended to ensure reliable starting in ambient temperatures below 60° F (16°C). Crankcase oil heaters theoretically perform the same function, but as described in the air-cooled section above, they may cause more problems than they prevent.

## 5.4 Exhaust System Accessories

Exhaust silencers are generally available in three degrees of silencing: industrial, residential, and critical. Although each installation will necessarily be different, the approximate sound levels at a distance of 10 feet from the discharge will be over 96 dBA, under 95 dBA, and under 85 dBA respectively. Silencers should be selected to provide an acceptable level of back pressure on the engine including allowance for piping. Do not assume that a silencer of the same size as the engine exhaust outlet will meet

any given engine's back pressure limits. (See Table 10-1 for detailed exhaust system sizing information.)

All stationary installations require a flexible connection between the engine exhaust outlet and the rest of the exhaust system. Seamless stainless steel connectors are strongly recommended, since exhaust fumes are poisonous and an exhaust leak is a potential health and fire hazard.

## 5.5 Governors

Standard governors supplied with most generator set engines provide no-load-to-full-load speed regulation within 5% (3Hz), or better. They also typically provide steady state regulation within +/-0.5%. Very few items on an emergency system are frequency sensitive. Even computer equipment will often stand +/-1 Hz frequency variations. The greatest problem with the imprecise frequency regulation on a generator set is likely to be electric clocks gaining or losing time during routine exercise periods.

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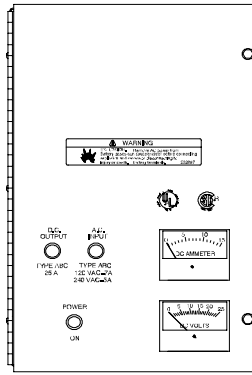
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Optional isochronous governors, either hydraulic or electric, are available for most 20 kW or larger generator sets. They provide steady state speed regulation in the range of  $\pm 0.25\%$  and constant speed regulation during no load to full load transitions. Such close regulation is not possible under transient conditions and no governor is able to prevent temporary speed changes in the range of  $\pm 2$  Hz with load changes of 50% or more. Critical equipment that cannot stand momentary speed changes of that magnitude should have its own isolated power supply.

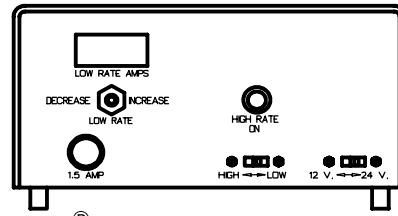
## **5.6 Engine Electrical System Accessories**

The basic electrical system accessories are battery, battery rack, battery cables, and battery charger.

Batteries are usually lead acid type, and specified to provide some minimum cranking time (at least one minute) in the lowest anticipated ambient temperature. Other types of batteries, such as lead calcium and nickel cadmium may provide longer life but at far greater cost. The combination of high initial cost and lack of readily available replacements limit applications for other than lead acid batteries.



Kohler® “Float/Equalize” Battery Charger



Kohler® “Trickle” Battery Charger

Chargers may be of either the adjustable trickle type or automatic float type. The most common cause for failure of a standby generator set is a dead battery(ies). The most common reason is overcharging, which boils out the electrolyte. There is no substitute for regular maintenance and exercising of a standby system, but a good automatic float charger can prevent some problems. A maximum charge rate of two to ten amperes is adequate for most installations since the engine-driven battery-charging alternator will normally restore the charge lost during engine cranking.

Battery racks and cables require little description. Racks should be wood or metal with an acid-resisting finish. Cables should be as recommended by the engine or generator set manufacturer. Occasionally, batteries are remotely located so they can be in a heated area while the engine is exposed to low ambient temperatures. The disadvantage of losses in the extended cable runs generally offsets the advantage of higher power available from a warm battery. A better solution is a battery box heater with batteries located as near the engine as possible.

## 5.7 Weather Housings

If a generator set must be installed outdoors, it should be enclosed in either a basic metal or fiberglass enclosure, or a waterproof enclosure. The former is fully ventilated and serves only to keep rain or snow from falling directly on the unit. Although commonly used in all climates, it is more suitable for emergency generator sets only in moderate climates (temperatures generally above 30° F [-1° C]). In areas of extreme dust, blowing sand, or snow, a weatherproof shelter, preferably walk-in type, is recommended. These are sealed against dirt, rain, and snow, are often insulated and heated, and equipped with electrically operated louvers to provide ventilation only when the engine operates.

## 5.8 Generator Accessories


The most common generator accessory is a circuit breaker. The common types are line, field, and a hybrid line-sensing field breaker. All generators require overload protection and the National

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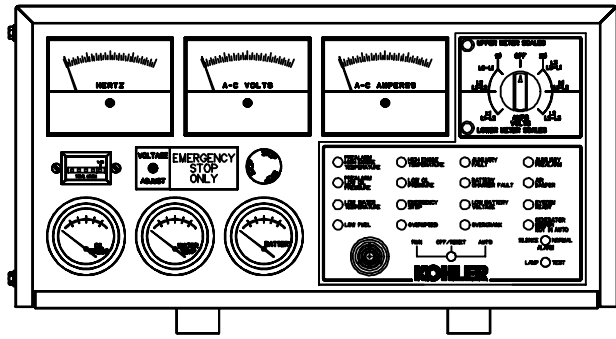


Electrical Code® recognizes this. The code also recognizes that the type of protection which is appropriate depends on the generator design.

Line circuit breakers, unless specially calibrated, generally provide little overload protection for the generator. Field circuit breakers sense and interrupt field current. They can provide only limited protection against high power factor or unbalanced overloads. A device which senses current in each phase and interrupts the field or voltage regulator power supply is often the most effective generator set overload protection device.

Other generator accessories include:

- Drip Cover – If basic generator design is not drip proof, a generator drip cover can be used to keep water from dripping into the generator.
- Generator Heater – In damp locations, a generator heater can be used to prevent dampness or moisture accumulation in the generator windings.
- Reactive Droop Compensation – Used only where generators operate in parallel, allowing them to share reactive load.



Kohler® Dec-3 Controller

## 5.9 Controller Accessories

A basic generator set controller for standby power applications provides some essential functions. Most can be equipped with a great variety of options. The two principal functions are engine start/stop control and generator protection, regulation and/or monitoring.

Engine control functions require provision in the controller for remote two-wire engine stop/start control, and overcranking protection for the battery and starter in the event the engine does not start. The controller often contains or acts on signals from engine protective devices including low oil pressure, high engine temperature, and overspeed. It may also include generator field flashing circuitry to ensure voltage build-up, and voltage regulator or stabilizer

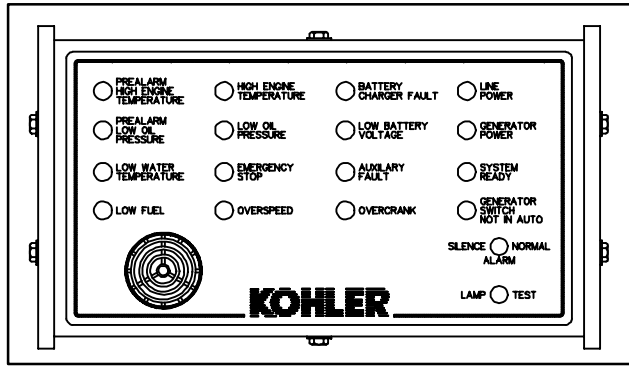
Generators below 20kW usually provide at least 5% voltage regulation and larger generators provide 2%. ANSI Standard C84.1, 1977 calls for +6% to -13% voltage regulation on 60 Hz electric power systems, and therefore, standard voltage regulation systems are suitable for most equipment. All figures above are steady state, and transient voltage dips or overshoots of 30% can be expected with generator sets (and commercial power systems). Delicate equipment which cannot stand either the steady state or transient

voltage variations listed above should be provided with their own isolated precision regulated power supplies.

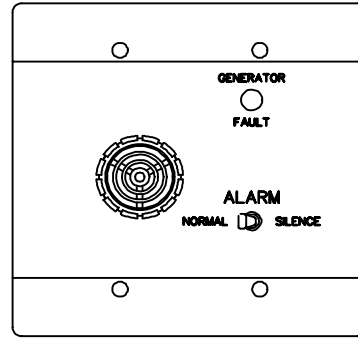
Other common controller features which may be desirable include:

- Voltage adjusting rheostat—generally available only on 20kW and larger generators with automatic voltage regulators. Provides manual adjustment of regulated voltage within approximately 10% range.
- Engine meter kit—may include various engine related gauges including oil pressure gauge, water temperature gauge, battery charging ammeter or voltmeter, and engine running time meter.
- AC meter kit—may include various AC generator output monitors including AC voltmeter, AC ammeter, phase selector switch to enable one each voltmeter and ammeter to show current in each phase and voltages both phase-to-phase and phase-to neutral.





Kohler® Remote Annunciator



Kohler® AV Alarm

- Alarm lights:

- *Common alarm light* –

indicates unit has been shut down by one of the protective devices, without indicating the cause.

- *Basic individual alarm light group* –

provides individual lights to indicate whether unit has shut down from low oil pressure, high temperature, overspeed, or overcrank.

- *NFPA 99 Alarm Package* –

NFPA 99, the standard for health care facilities, requires individual alarm lights for 7 conditions:

- Low engine temperature (engine heater not functioning).
- High temperature prealarm—engine temperature approaching shut-down.
- Low oil pressure prealarm—engine oil pressure approaching shut-down.
- Unit shut down due to low oil pressure.
- Unit shut down due to high temperature.
- Unit shut down due to overcrank.
- Unit shut down due to overspeed.

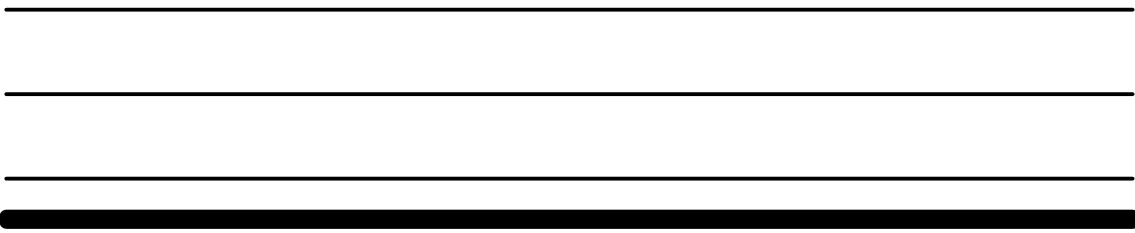
NFPA 99 also requires a remote annunciator with the above visible indications plus:

- Emergency power source supplying load.
- Battery charger malfunction.
- Low fuel—main tank contains less than a 3-hour supply.

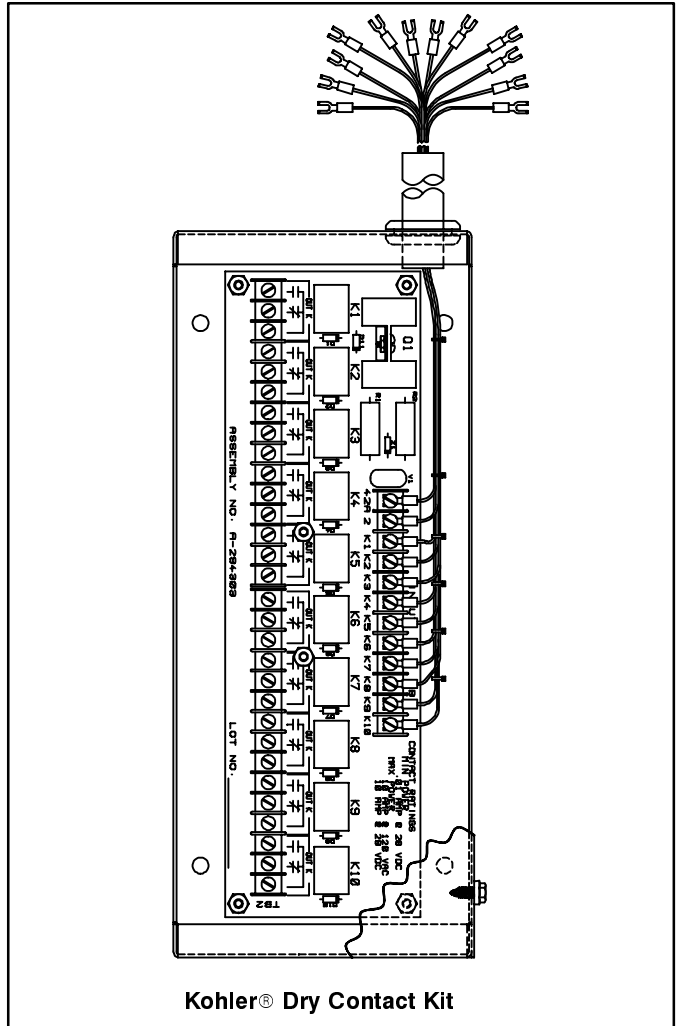
- *Other* –

a variety of other code requirements for visible alarm indications, either at the unit, or a remote location may be encountered. Some of the more common are:

- Alarm horn silencing switch off.
- Emergency stop—unit has been stopped by local or remote emergency stop switch.
- Start switch off (unit unable to start automatically).
- Normal power source supplying load.
- Low battery voltage.
- System ready—no alarm conditions present, all controls in "automatic."



- Dry contacts—provides a single pole, double throw relay contact for connection to building derangement panel, remote telemetering equipment or other requirement. Relay operates on any specified alarm, shutdown or combination of conditions.
- Cyclic cranking—provides for alternating crank and rest periods within fixed cranking cycle. Reduces drain on starting battery and guards against overheating the starter motor compared to one continuous cranking cycle.
- Overvoltage shut-down—shuts down generator set in event of failure of automatic voltage regulation system, resulting in sustained overvoltage condition.
- Local or remote emergency stop switch shuts down generator set by manual intervention, usually the fire chief.
- Run relay—contacts close on engine start signal, open on stop signal, used to control electrically operated louvers.
- Remote audible/visual alarm panel—alarm panel with one common failure light and alarm horn as required by NFPA 110, standard for emergency and standby power systems.



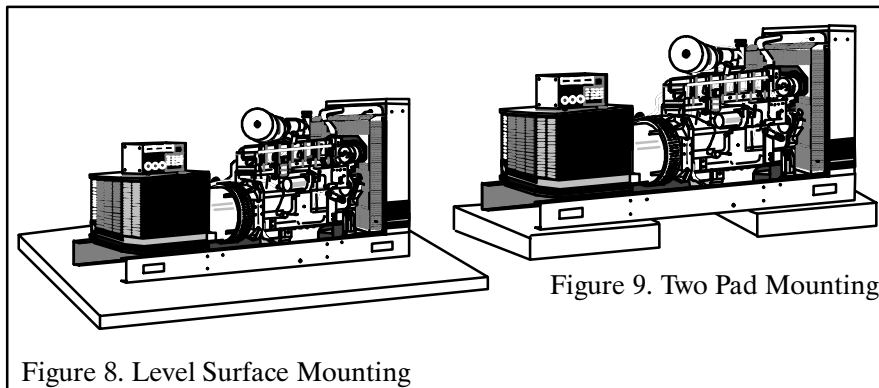


Figure 8. Level Surface Mounting

Figure 9. Two Pad Mounting

## 6. Installation

### 6.1 Location and Support

Basic considerations in the choice of location are given in the preliminary planning section. Once the location is chosen, the mounting details can be determined.

The recommended mounting surface is a concrete mounting pad. This can be a level surface as shown in [Figure 8](#), or raised pads as shown in [Figures 9 and 10](#). The advantage of the arrangement shown in [Figure 9](#) is that the engine oil can be drained more conveniently. The oil drain is usually piped to the side of the mounting base by the manufacturer. If there is not sufficient clearance below the oil outlet for a pan large enough to hold the full engine oil capacity, it will be necessary to use a pump whenever oil is changed.

The double pedestal arrangement shown in [Figure 10](#) has the advantage of providing more working room under the engine without raising the engine or generator set off its mountings. With either arrangement, the mounting pad should extend six inches (15 cm) beyond the mounting base dimensions. When using the double pedestal arrangement, the pedestals should extend at least six inches (16 cm)

back from the location of the front engine mount and six inches (153 mm) toward the engine from the generator mounting point.

The composition of the mounting pad should follow standard practice for the required loading. Common specifications call for 2500–3000 psi (176–211 kg/cm<sup>2</sup>) concrete reinforced with eight-gauge wire fabric or Number 6 reinforcing bars on 12-inch centers. The total weight of the mounting pad should be at least equal to the weight of the generator set (a density of 150 lbs. per cubic foot (68.4 kg per 0.03 m<sup>3</sup>) for concrete can be used for this calculation). Suggested concrete mixture by volume is 1:2:3 parts of cement, sand, and aggregate. A layer of 8–10 inches (21–26 cm) of sand or gravel should surround the pad for proper support and isolation of a pad located at or below grade.

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Mounting bases for generator sets 30 kW and larger are typically made from "I" or "C" section channel iron with a width of 2–3 inches per channel. Length varies with the size of the unit, resulting in a static load on the mounting surface of 10–25 psi (0.703–1.758 kg/cm<sup>2</sup>) if the total bottom surface of the channel is in contact with the mounting pad. All generator sets should have vibration isolation between the engine–generator and the mounting surface. This may consist of neoprene or combination spring and neoprene isolators between the engine–generator and the base, or spring–type mounts between the base and mounting pad. An advantage of factory installed mounts between the engine–generator and the base is that engine–generator alignment is not affected by stress induced in handling, shipment, or mounting on an uneven surface. In addition, a less rigid base can be used reducing weight, cost, and installation time.

Generator sets, 350 kW and larger, are usually direct mounted to a structural iron base. For these units, the manufacturer's recommended vibration isolators should be installed between the base and mounting pad. Because of the reduced mounting surface area of these individual mounts, the static load on the mounting surface will increase to the range of 50–100 psi (3.515–7.03 kg/cm<sup>2</sup>).

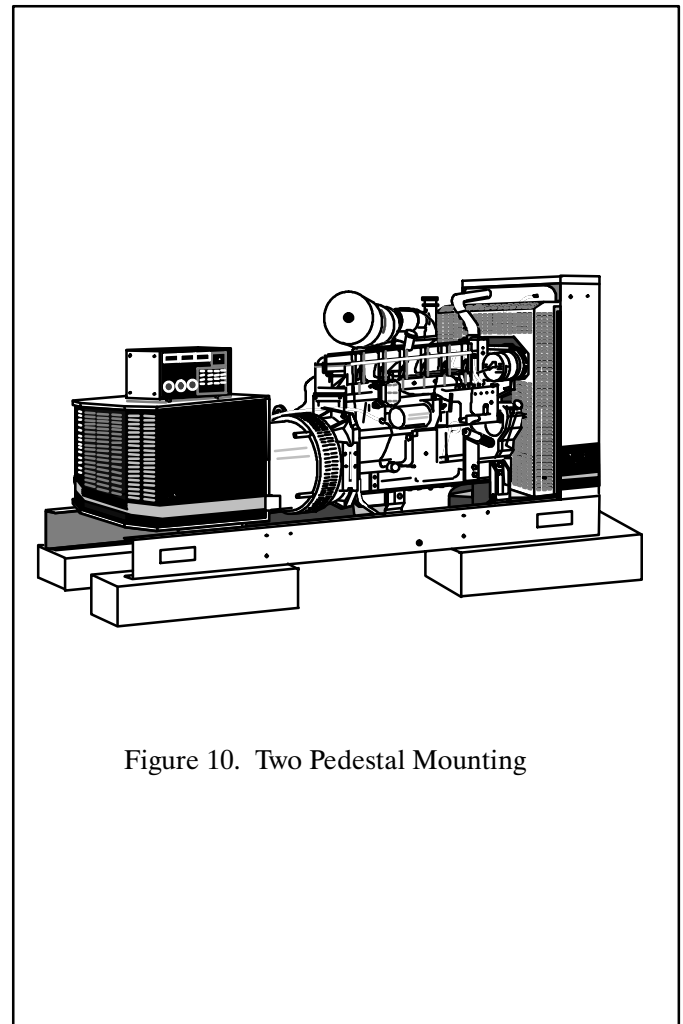


Figure 10. Two Pedestal Mounting

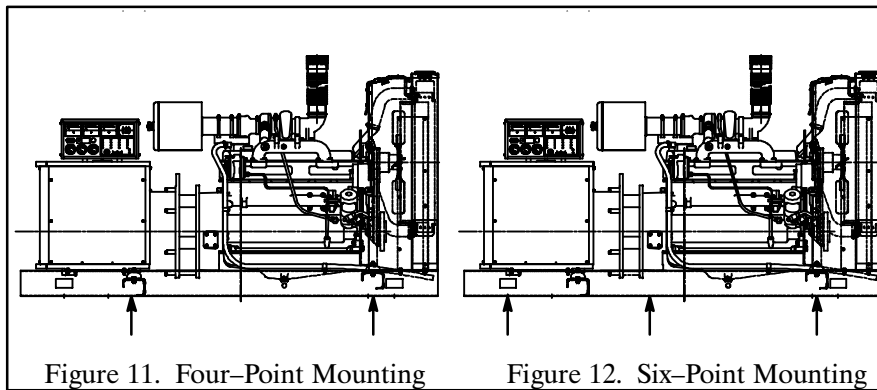


Figure 11. Four-Point Mounting

Figure 12. Six-Point Mounting

The vibration isolation efficiency of neoprene pad type mounts is approximately 90%. When installed at or below grade, this degree of isolation will prevent transmission of objectionable vibration to the surrounding structure. Spring-type isolators can be expected to provide isolation efficiency of 98%. This type of mount is recommended for above grade installations. The generator set manufacturer's recommendations should be followed for the type, number, and location of mounts used.

In some critical applications where the generator set is installed above grade or where earthquake-proof mounts are specified; it may be necessary to install spring-type vibration isolators under the generator set mounting base. Accessory vibro mounts should not be installed at the locations of the standard predrilled mounting holes. The mounting base is designed to be supported evenly along the total length of the side rails. If it is to be supported at only two or three points on each side, these points should be directly under the factory-installed mounts between the engine/generator and the base.

If a four-point mounting system is used, one mount should be located under each frame rail in line with the engine mounts. The other two mounts should be placed one under each frame rail in line with the generator mounts. See Figure 11.

If a six-point mounting system is used, common practice recommends placing two mounts under the engine as described above. The remaining four mounts should be installed, two under each frame rail, equidistant on either side of the factory-supplied generator-to-base mounts. See Figure 12.

## 6.2 Diesel Fuel Systems

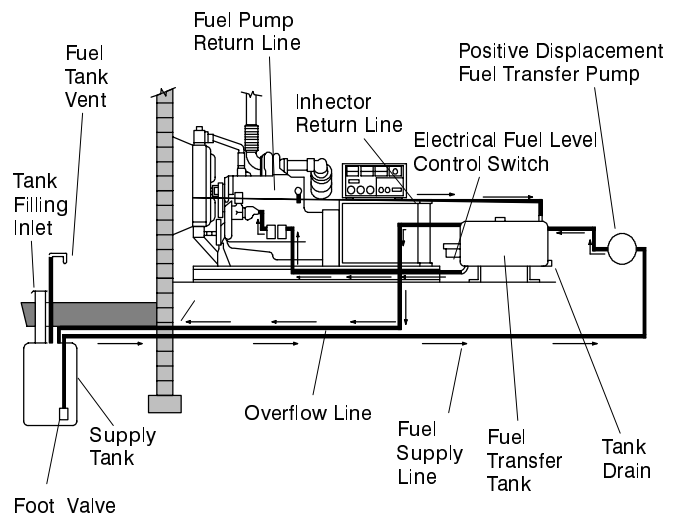
The main components of a diesel fuel system are a main fuel storage tank, fuel line, transfer tank, and auxiliary fuel pump. See Figure 13.

### 6.2.1 Main Fuel Tank

Fuel storage tanks may be located above ground indoors or outdoors, or buried underground. National codes covering tank location and construction include NFPA 30, Flammable and Combustible Liquids Code, and NFPA 37, Stationary Combustion Engines and Gas Turbines.

Most diesel engines will operate satisfactorily on #2 domestic burner oil as furnished in most parts of the United States. The engine can be supplied from the same tank used for heating oil if both use the same fuel. This is desirable both because of the cost saving and the further advantage that fuel will be used and replaced regularly, ensuring a fresh fuel supply for the engine. Where more than one engine or an engine and other appliance(s) are fueled from the same main tank, each engine should have its own supply line.

Codes requiring standby power often specify minimum on-site fuel supply. Such requirements are included in NFPA 70, National Electrical Code®; and NFPA 99, Standard for Health Care Facilities. Diesel fuel will deteriorate if stored for more than a year, so the tank should not be oversized to the point that its contents cannot be used in one year of regular exercising. If there are no applicable code requirements, a tank sized for eight hours operation at rated load is suggested.



Diesel Fuel System

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## 6.2.2 Fuel Lines

Fuel lines should be constructed of Schedule 40 black iron pipe or copper tubing. Galvanized pipe, fittings or tanks should never be used with diesel fuel systems. The fuel will react chemically with the galvanized coating, causing it to peel and clog fuel filters and damage fuel injection system components.

Fuel line sizes should be the minimum required to deliver the volume necessary to the equipment within an acceptable pressure drop – 1 psi average (0.07 kg/cm<sup>2</sup>). The use of excessively large piping increases the chance that air will be introduced into the system, and that fuel pumps will be damaged by operating dry when priming the systems.

Flexible connections should be used wherever there may be relative motion between piping and supplied equipment. Always use flexible lines at the engine connections. These should be a minimum of six inches (15.3 cm) long, or as recommended by the engine supplier.

Diesel engines require at least two fuel lines: one supply and at least one return from the fuel injectors. More fuel is delivered to the injectors than the engine will use and the excess must be returned to a transfer tank or the main storage tank. Fuel return lines should

be at least the size of the supply lines. They should be unrestricted, as short as possible, and allow gravity return of fuel to the storage tanks.

In some installations it may be difficult or inconvenient to route return lines so that fuel will flow by gravity. Before designing a system which will have any head of fuel on the return lines, the details should be approved by the engine supplier. Serious problems with engine hydraulic lock or uncontrollable overspeeding will result from any return fuel line restriction on some diesel fuel systems.

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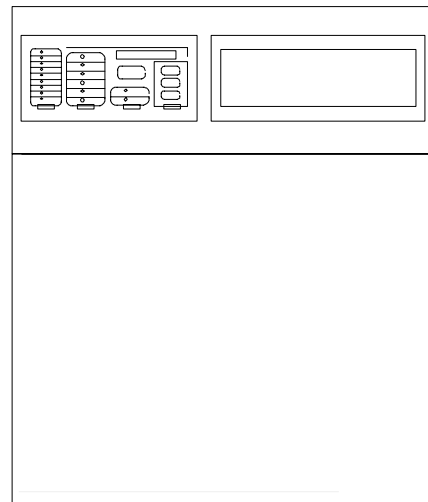
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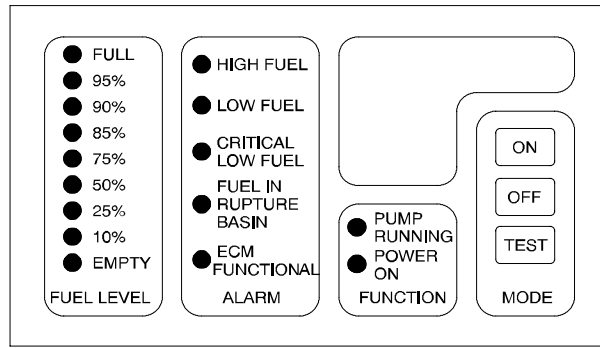
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### 6.2.3 Transfer Tanks

The terms "transfer tank" and "day tank" are often used interchangeably. Both are used to ensure engine starting in the minimum possible time after a power failure by means of a quantity of fuel stored in a tank adjacent to the engine. This allows the engine fuel transfer pump to easily draw fuel when starting and provides a convenient location to connect injector return lines. Standard tanks are available in sizes from 5–275 gallons (19–1040 L) with or without integral electric fuel transfer pumps. They can also be provided with fuel level gauges, manual priming pumps, float switches for pump control, float valves, and low level alarms. A float switch controlled solenoid anti-siphon valve or a float valve should be used whenever there is a possibility of siphoning fuel from the main storage tank, or when the fuel level in the main tank may be above the level of the transfer tank inlet. Some engines are subject to derating for fuel temperature above 100°F, and are subject to damage if operated with fuel temperature above 140°F. A day tank sized for two hours fuel consumption should prevent excessive fuel heating by fuel returned from the engine. If smaller day tanks are used, the engine supplier may recommend routing engine fuel return lines to the main storage, or installation of a fuel cooler.



**Standard Day Tank**



Day Tank Control Panel

## 6.2.4 Auxiliary Fuel Pumps

Engine driven fuel transfer pumps usually are diaphragm-type pumps which develop a maximum of 7 psi (0.49 kg/cm<sup>2</sup>) pressure and have a lift capacity of 4–6 feet (1.22–1.83 m). Even if the engine pump can draw fuel a greater distance, a more reliable system results if a transfer tank and/or auxiliary pump are used when the vertical lift exceeds three feet or fuel must be drawn horizontally more than 20 feet (6.1 m). On engines using less than ten gallons (38 L) of fuel per hour (approximately 100 kW or less), an electric fuel transfer pump powered by the engine starting battery can be installed in series with the engine driven transfer pump. Best results are obtained when the electric pump is located near the fuel tank rather than near the engine.

Where fuel must be lifted six feet (1.83 m) or more, or long horizontal runs are involved, an electric motor driven positive displacement pump should be used with a transfer tank and float switch. The power supply for the pump should always be from the load side of the transfer switch for maximum reliability. Such pumps typically are capable of lifting fuel 18 feet (5.5 m) or drawing it horizontally up to 200 feet (61 m). Where vertical or horizontal runs exceed these limits, the pump should be remote mounted adjacent to the

fuel storage tank. When so located, these pumps can push fuel over 1,000 feet (305 m) horizontally or more than 100 feet (30.5 m) vertically and deliver adequate fuel for generator sets up to 1500 kW. Positive displacement pumps should never be connected directly to an engine; a transfer tank and float switch should always be used so the engine fuel system is not subjected to excessive fuel pressure.

See Tables E-1, E-2, E-3, and E-4 to estimate frictional loss in pipe and fittings, for altitude deviations, and pump discharge pressure. If the site design requires more than 17 feet vertically between the main and day tank, one recommendation is a remote pumping station be placed at the main tank. This will allow utilization of the head (pushing) capabilities of the pump. The pump's head is the theoretical vertical distance it will push fuel. Use the following examples and complete the work sheet to determine pump lift and head.

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To determine the total available lift the following factors need to be considered:

1. Vertical distance from tank to pump.
2. Total length of pipe and size.
3. Fittings in line.
4. Elevation above sea level.

**Example – Determining Required Lift**

Given: Vertical distance  
12 feet  
Total length of pipe  
100 feet  
Pipe size 1 in. diameter  
Pump size 2 GPM  
Fitting 3 elbows  
Elevation above sea level  
3,000 feet

Solution: Referring to Table E-2, an elbow equals 2.6 feet of pipe (2.6 x 3 elbows = 7.8 feet). The corrected length of pipe is now 107.8 feet. Refer to Table E-1, a 1 in. diameter pipe is equal to 0.5 feet of frictional head loss for 100 feet of pipe ( $107.8 \times 0.5 / 100 = .54$  feet). The actual head loss is .54 feet. Therefore, the total lift needed for this system is the vertical distance plus 0.54 feet or 12.54 feet.

Since the pump is safely capable of lifting 15 feet at 3,000 foot elevation (see Table E-3) the previous example will perform satisfactorily.

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To determine the total available head three factors need to be considered:

1. Vertical distance from pump to day tank.
2. Total length of pipe and size.
3. Fittings in line.

**Example – Determining Required Head**

Given: Vertical distance

150 feet

Total length of pipe

175 feet

Pipe size 3/8 in. diameter

Fittings 2 elbows

1 check valve

1 solenoid valve

Pump 2 GPM

pipe is:  $175 + 2.8 + 3.6 + 1.39 = 183$  feet. Referring to Table E-1, 183 feet of 3/8 in. pipe with a 2 GPM pump interpolated to 27.8 feet of head loss ( $1.83 \times 15.2$ ). Therefore, total equivalent height is  $(150 + 27.8) = 177.8$  feet. (Note: Since the resulting pressure at the day tank is [231 feet subtract 177.8 feet] divided by  $2.31 = 23$  psi). The pump system will work and push fuel to a height of 231 feet.

**NOTE**

Elevation does not need to be considered in head calculations.

Solution: Referring to Table E-2, a 3/8 elbow equals 1.4 feet of pipe ( $1.4 \times 2 = 2.8$ ). The check valve equals 3.6 feet of pipe. Also the solenoid valve has a 0.6 psi drop (consult manufacturer), which calculates to 1.39 feet of pipe ( $0.6 \times 2.31$ ). The total adjusted length of

GPM	PIPE SIZE						
	3/8	1/2	3/4	1	1-1/4	1-1/2	2
2	15.2	5.5	1.1	0.5	0.2		
4	55.5	20.3	5.1	1.4	0.5	0.2	
7		61.0	15.3	4.6	1.2	0.5	
10			26.3	8.5	2.5	0.9	0.2
19				28.5	7.5	3.5	1.2

**Table E-1. Frictional Head Loss (in feet) for 100 feet of standard weight pipe at 60° F at sea level – diesel fuel**

Pipe Size (in.)	Ball Valve	45 Deg. Elbow	Std. Elbow	Std. Tee	Check Valve	Angle Valve	Globe Valve	Diaphragm Valve
3/8	.28	.70	1.4	2.6	3.6	8.6	16.5	
1/2	.35	.78	1.7	3.3	4.3	9.3	18.6	40
3/4	.44	.97	2.1	4.2	5.3	11.5	23.1	
1	.56	1.23	2.6	5.3	6.8	14.7	29.4	
1-1/4	.74	1.6	3.5	7.0	8.9	19.3	38.6	
1-1/2	.86	1.9	4.1	8.1	10.4	22.6	45.2	
2	1.1	2.4	5.2	10.4	13.4	29.0	58.0	

**Table E-2. Frictional Loss in Pipe Fittings in terms of equivalent feet of straight pipe**

	Elevation						
	Sea Level	1000 Feet	2000 Feet	3000 Feet	4000 Feet	5000 Feet	6000 Feet
<b>Atmospheric Pressure (in psi)</b>	14.7	14.2	13.6	13.1	12.6	12.1	11.7
<b>Available Lift (in feet)</b>	17	16	15.5	15	14.5	14	13.5

**Table E-3. Lifting Capacities at Various Elevations**

Nominal Pump Size (GPM) at 1725 RPM	Motor Horsepower						
	1/3	1/2	3/4	1	1-1/2	2	3
2	100						
4	60	100					
7	2	20	40	100			
10		2	20	40	80	125	150
19				20	40	60	125
23				2	20	60	125

**NOTE**

Pump discharge volumes (GPM) can decrease by as much as 25% when higher pressures are required. Consult pump manufacturer for borderline consumption rates.

**Table E-4. Pump Discharge Pressure (psi)**

## 6.2.5 Pump Lift/Head Worksheet

### Lift Required for Day Tank Above Main Tank and Head Required for Day Tank Below Main Tank

**Directions:** Use lines 1–10 for both applications, use lines 11–14 for day tank above main tank and lines 15–18 for day tank below main tank.

1. Total vertical length of pipe (pump inlet to main tank bottom) ..... \_\_\_\_\_ ft.
2. Total length of pipe (vertical and horizontal) (each pipe size inline must be calculated separately) ..... \_\_\_\_\_ ft.
3. Added length due to fitting in line (see Table E–2) ..... \_\_\_\_\_ ft.
4. Add lines 2 and 3 ..... \_\_\_\_\_ ft.
5. Divide line 4 by 100 ..... \_\_\_\_\_ C ft.
6. Pipe size ..... \_\_\_\_\_ inches
7. Pump capacity ..... \_\_\_\_\_ GPM
8. Friction head loss for 100 feet (see Table E–1) ..... \_\_\_\_\_ ft.
9. Additional head loss – multiply line 5 by line 8 ..... \_\_\_\_\_ ft.
10. Repeat lines 2 thru 9 for each pipe size used inline ..... \_\_\_\_\_ ft.

**Use lines 11 thru 14 for calculating pump lift.**

11. Total lifting capacity needed (add lines 1, 9, and 10) ..... \_\_\_\_\_ ft.
12. Elevation above sea level ..... \_\_\_\_\_ ft.
13. Available pump lift (see Table E–3) ..... \_\_\_\_\_ ft.
14. Subtract line 11 from line 13 ..... \_\_\_\_\_ ft.

**Use lines 15 thru 18 for calculating pump head.**

15. Total head capacity needed (add lines 1, 9, and 10) ..... \_\_\_\_\_ ft.
16. Pump discharge pressure (see Table E–4) ..... \_\_\_\_\_ psi
17. Available pump head (multiply line 16 by 2.31) ..... \_\_\_\_\_ ft.
18. Subtract line 15 from line 17 ..... \_\_\_\_\_ ft.

**Pump Lift Results**

If line 14 is a positive number the system is properly sized. If line 14 is a negative number the system is beyond its safe lifting capacity. If line 1 is less than line 13, increase pipe size. If line 1 is larger than line 13 a remote pumping unit is required.

**Pump Head Results**

If line 18 is a positive number the system is properly sized. If line 18 is a negative number the system is beyond its safe pushing capacity.

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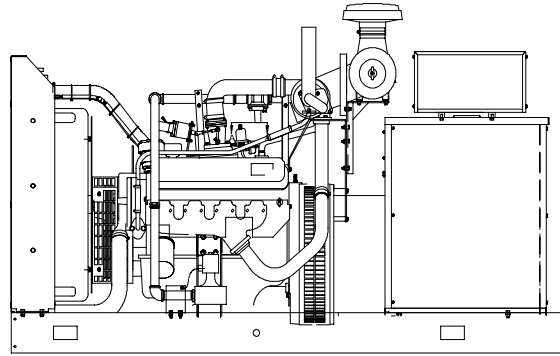
## 6.3 Gasoline Fuel Systems

Due to code restrictions which do not allow storage of more than one gallon (3.8 L) of gasoline inside a building, gasoline fuel systems are usually limited to housed generator sets installed outdoors or portable trailer-mounted units.

Gasoline will deteriorate if stored for more than six months, so storage tank size should be kept to the minimum required by code. Engine fuel pumps usually will lift fuel up to four feet or draw it horizontally up to 20 feet (6.01 m). Auxiliary electric pumps powered by the engine starting battery can be connected in series with the engine pump. Auxiliary pump pressure should be limited to approximately 5 psi (0.35 kg/cm<sup>2</sup>). If the auxiliary pump is located at the fuel tank, horizontal and vertical distance limits approximately twice those of the engine pump alone are practical.

Fuel supply lines should be Schedule 40 black iron pipe or copper tubing. Galvanized pipe and fittings are not recommended. Line size should be kept to the minimum necessary for the required fuel flow.

Flexible connections at least six inches (15.3 cm) in length should be used between stationary piping and the engine fuel inlet connection.



Kohler® 80RZ Generator Set

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FUEL TRANSFER TANKS AND POSITIVE DISPLACEMENT FUEL PUMPS DESIGNED FOR DIESEL FUEL SYSTEMS SHOULD NEVER BE USED WITH GASOLINE.

Combination natural gas–gasoline fuel systems are sometimes used with gasoline as a standby fuel to meet code requirements for on–site fuel supply. Such systems are not recommended unless the engine will be operated on gasoline often enough to ensure that fuel does not deteriorate and the carburetor will not be disabled by accumulated gum and fuel deposits.

If a fuel storage tank is located above the engine, an anti–siphon fuel solenoid valve or air bleed hole in the fuel tank dip tube (near top of tube inside tank) should be used to prevent siphoning of gasoline.

## 6.4 Natural or LP Gas Fuel Systems

Natural and LP (Liquified Petroleum) gas fuel systems should be designed and installed in accordance with the requirements of NFPA 54, National Fuel Gas Code, and all applicable local codes.

Gas piping should be Schedule 40 black iron pipe. Copper tubing may be used if the fuel does not contain hydrogen sulfide or other ingredients which will react

chemically with copper. Fuel piping should never be used to ground electrical equipment. Piping should be sized according to the requirements of the equipment to be operated, following the procedure in 10.2.2 Pipe Size Requirements for Gaseous Fuel Systems.

Various types of gas fuel systems are available as follows:

- LP–Natural gas vapor
- Combination LP or Natural Gas–Gasoline
- Combination Natural Gas–LP Gas
- LP Gas–Liquid Withdrawal

Components of each of these systems are shown in [Figures 14 to 15](#). The engine mounted components of all these systems are similar and usually include a carburetor, secondary gas regulator, electric gas fuel solenoid shut–off valve, and flexible fuel connector.

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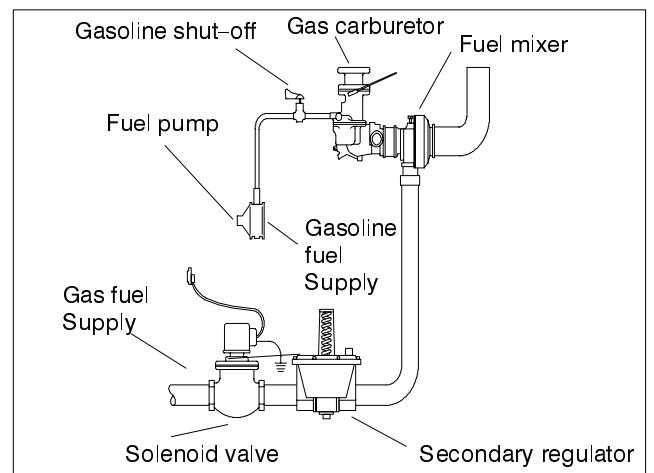
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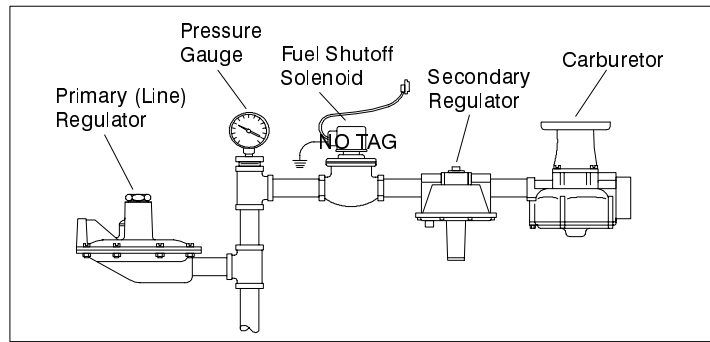
An approved flexible connector should always be used between stationary gas piping and the engine mounted fuel system components. It should be at least six inches (15.3 cm) long, or as recommended by the engine supplier.

Although the regulators are designed to close and shut off fuel when the engine stops, a solenoid valve should be located ahead of the regulator and the flexible fuel connector to ensure against the accumulation of an explosive mixture of gas and air, should either the flexible connection or regulator develop a leak. The solenoid valve is normally closed and wired by the generator set supplier to the engine starting controls so it will open (with battery power) when the engine cranks or runs.

Engine mounted regulators are designed for a maximum inlet pressure of six ounces per square inch (168 g/6.5 cm<sup>2</sup>), or 11 inches (27.94 cm) of water column. The engine will operate satisfactorily at four ounces (112 g), or 7 inches (17.78 cm) of water column, or less, but lower pressures may result in poor response to load changes where the primary regulator is not near the engine. (The primary regulator reduces the natural gas transmission line pressure of LP gas tank pressure of 20–200 psi (1.4–14.06 kg/cm<sup>2</sup>) to the four to six ounce normally used inside a building.)



Combination Natural Gas–Gasoline Fuel System



LP-Natural Gas Fuel System

LP gas is usually stored in a large on-site tank provided by the gas supplier. The tank contains up to 90% LP liquid with the space above the liquid occupied by gas under pressure. The vapor pressure depends on the fuel – butane, propane, or a mixture of the two – and on the temperature. The pressure range is shown in 10.2.3, LP Vapor Pressure Curve. As vapor is withdrawn from the top of the tank, heat is absorbed through the tank walls by the liquid vaporizing. The larger the surface area of the tank wetted by liquid and the higher the ambient temperature, the more fuel can be vaporized in any given unit of time.

It can be seen from the vapor pressure curve that it is important to use propane rather than butane, or a mixture of the two, to ensure maximum vaporization in cold climates. A rule of thumb for tank sizing is that one gallon of tank capacity will produce 1000 Btu of propane vapor, or 0.4 cubic feet (0.012 m<sup>3</sup>) perhour in ambient temperature down to 0°F

(-18°C). A local fuel supplier is likely to be the best source of information on what size tank will be necessary to provide adequate fuel vapor.

If it is not practical to provide a tank large enough to supply all LP fueled equipment in the lowest expected temperature, there are several ways of adding heat to vaporize additional fuel. Electric heating tape can be

wrapped around the outside of the tank, or fuel can be withdrawn in liquid form and vaporized in an electrically, engine water jacket, or LP gas heated vaporizer.

Liquid withdrawal fuel systems can be supplied for generator sets, **but are not recommended for automatic standby service.** With these systems, LP is piped to the engine in liquid form. A combination vaporizer and primary regulator changes the liquid to vapor using heat from the engine cooling system and supplies vapor at six to eight ounces (168–244 g) pressure to the secondary regulator. This requires fuel under high pressure to be delivered to the engine, but in many areas codes prohibit gas fuel at a pressure greater than 5 psi (0.35 kg/cm<sup>2</sup>) inside a building. Even where it is permissible to bring liquid fuel to the engine, there may be problems vaporizing enough fuel to keep the engine running under the connected load until engine jacket water is warmed to the degree necessary to vaporize enough fuel for full load operation.

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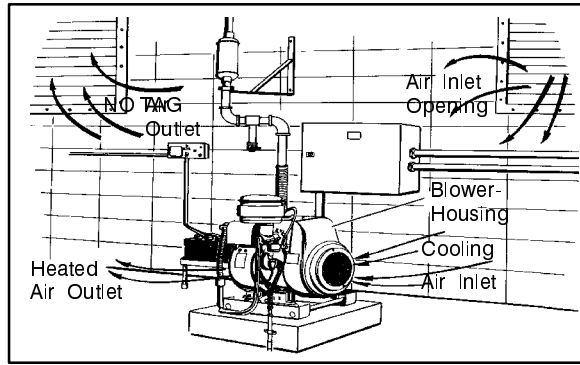
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## 6.5 Cooling Systems

All engines and generators radiate heat to the surrounding air. To prevent overheating of the equipment and excessively high temperatures around it, substantial volumes of cooling air must be circulated through the room in which a generator set is installed. A general idea of the amount of heat involved is given by the following:

- Only 20–30% of the heat value of the fuel consumed is converted into usable engine power.
- About 90% of the power delivered to the generator is converted to usable electrical energy. The remainder is lost as heat.
- About 40% of the engine heat loss is rejected to the coolant. The remaining 60% is divided between exhaust heat loss and heat radiated to ambient air. Approximately 15% of the waste heat is radiated to ambient air, but this will vary with engine configuration and whether the exhaust manifolds are dry, insulated, or water cooled.



Cooling Air, Room Circulation

### 6.5.1 Air Cooling

Generator sets below 25 kW are available with either air-cooled gas, gasoline, or diesel engines. These engines typically have a flywheel driven fan which draws air across cooling fins on the engine cylinders and exhausts heated air either into the surrounding atmosphere or an exhaust air duct. Total air requirements for cooling and combustion range between 50 and 100 cfm per kW of generator set capacity.

Figure 16 shows the typical cooling air flow across an air cooled generator set. Figure 17 shows a typical arrangement of air inlet and outlet ducts from a generator room. With this arrangement, an auxiliary ventilating fan must be used either to force fresh air into the room or to pull heated air out. The fan capacity should be at least equal to the minimum air requirement of the generator set after allowing for duct and louver losses.

Minimum suggested air inlet and outlet sizes are one (1) square foot (0.09 m<sup>2</sup>) for generators up to 4 kW and .25 square foot (0.023 m<sup>2</sup>) per kW of capacity for larger models. This is based on unrestricted openings. Usually fixed or movable louvers, screening, furnace filters, or a combination of these are used.

Since these reduce the free air openings, inlet and outlet area should be increased approximately 50% where louvers are used, 80% with window screen, and 120% with furnace filters.

Figure 18 shows an installation in which the engine driven fan force ventilates the room with the heated air ducted away from the engine and outside the room.

Duct work should be designed to limit the total static pressure on the engine fan to 1/2 inch (1.27 cm) water column.

Air inlet and outlet locations should be chosen to prevent air recirculation either inside or outside the room.

Consideration should also be given to prevailing winds, facing inlets into expected winds, and outlets on the down wind side. Inlets and outlets should be located where they are not likely to be blocked by accumulated snow, foliage, or any other obstruction, and where noise will not be objectionable.

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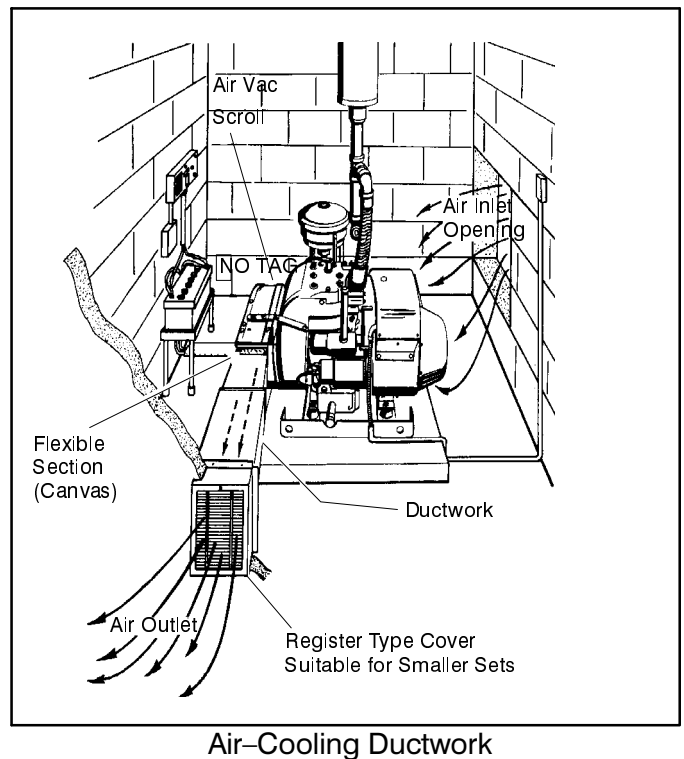
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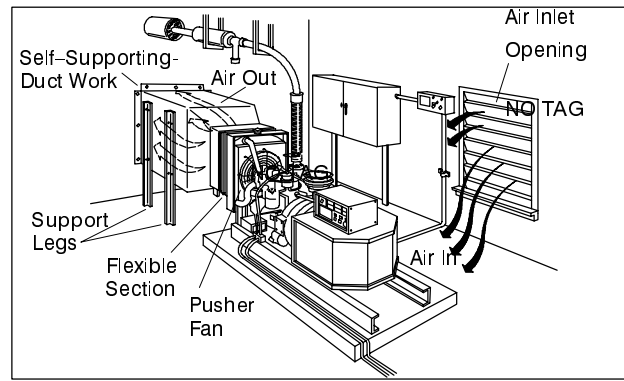
## 6.5.2 Liquid Cooling Systems

The three most common liquid cooling systems used for generator sets are unit mounted radiator cooling, city water cooling, and remote radiator cooling. Since each involves somewhat different installation considerations, they will be discussed separately.

### 6.5.3 Unit Mounted–Radiator Cooling

This is the most common cooling system used for engine driven generator sets 30 kW and larger. The major system components are an engine driven fan and circulating water pump, radiator, and thermostat. The pump circulates water through the engine until it reaches operating temperature. Then the engine thermostat opens and allows circulation through the radiator, restricting the flow as necessary to prevent overcooling. The fan blows air from the engine side of the radiator across the cooling surface as shown in [Figure 19](#).





Radiator Cooling Air Flow

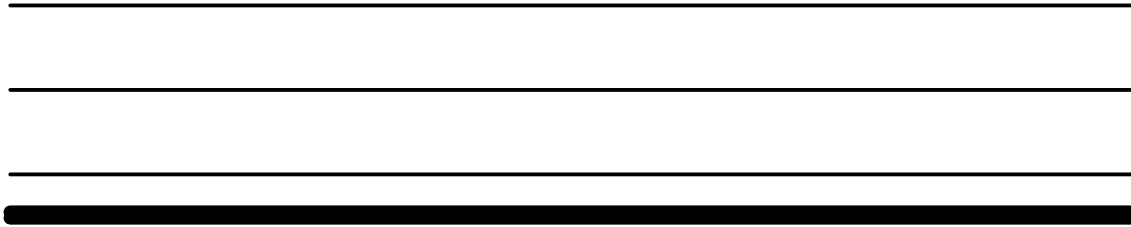
Cooling air flow can be reversed by using a suction fan, but this is generally not recommended because it may interfere with generator cooling air flow, which flows in the same direction as that of the engine's standard pusher fan. Also, a suction fan would result in higher temperature combustion air being drawn into the air cleaner, reducing the maximum engine power available.

Whenever a generator set is installed inside a building or enclosure, the radiator air should be ducted outside the room or enclosure. A typical arrangement is shown in [Figure 20](#). Ductwork should be as short, straight, and unobstructed as possible. Static pressure of more than 1/2 inch (1.27 cm) water column on the fan from inlet or exhaust restrictions will reduce air flow to the point of limiting maximum power and/or ambient temperature at which overheating will occur.

The connection from the radiator duct flange to the ductwork should be heavy canvas or similar flexible material to prevent noise and vibration transmission. In general, the outlet duct should have an unrestricted area 150% greater than that enclosed by the radiator duct flange. The inlet opening should be at least as large and preferable 50% larger than the outlet. If screens, louvers, or filters are used in the inlet or outlet openings, they should be increased in size to compensate for the restriction. In general, when

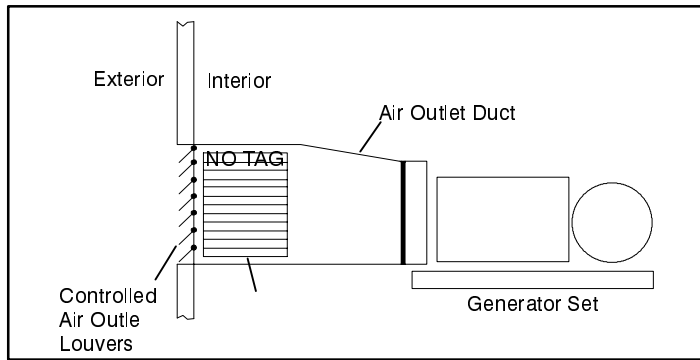
louvers are used, increase the opening area 50%; when window screening is used, increase the opening area 80%; when furnace filters are used, increase the opening area 120%.

Air inlet and outlet locations should be chosen to prevent air recirculation inside or outside the enclosure. Consideration should also be given to prevailing winds, facing inlets into the expected winds, and outlets on the down wind side where possible. Inlets and outlets should be located where they will not be blocked by accumulated snow or any other obstruction. Keep in mind that the exhaust air of larger units is both high-volume and high-velocity. It may be accompanied by a high sound level and should be directed away from areas that may be occupied by people or animals.



Be sure to design any temperature controlling louvers so that inlet air is not restricted to the point that pressure inside the building is reduced. Low pressure can cause pilot lights on gas fired appliances to be extinguished, fuel gas flow to be restricted or reversed, or other problems with the building ventilation system.

Bringing large quantities of winter air into a building can waste building heat and even result in frozen water pipes in normally heated spaces. An arrangement as shown in [Figure 21](#) using thermostatic controls, can eliminate such problems and allow recovery of engine heat to supplement the building heating system. For cold outdoor ambients, louvers to the exterior would close, with those to the interior open. Controls would be set to reverse the condition for warm outdoor temperatures.



Air Control Louvers

### 6.5.4 Remote Radiator Cooling

If the generator set is located in an area in which it is difficult to bring in the volume of air required to cool the radiator, such as a basement, a remote radiator can be mounted outside the building (Figure 22). An electric motor-driven fan is mounted on the radiator to circulate air across its cooling fins. The fan is wired to the generator output so it operates whenever the generator does. There is no need for thermostatic control of the fan motor because the engine thermostat will prevent overcooling as it does on unit mounted radiator systems.

The radiators themselves are available for either horizontal or vertical air discharge.

The engine water pump can be used to circulate water through the remote radiator provided:

- The vertical distance from the engine water pump to the top of the radiator does not exceed the engine manufacturer's recommendations. The allowable static head may range from 17–50 feet. This is important because greater height will result in excessive head pressure on engine components and leaking water pump seals are likely.
- The piping between the engine and remote radiator must be sized for a maximum of 2 psi

(0.141 kg/cm<sup>2</sup>) pressure drop at the rated flow of the engine water pump.

Where either the horizontal or vertical distances exceed the above limitations, a hot well tank or heat exchanger and auxiliary circulating pump as shown in Figure 23 should be used.

A hot well tank is divided into two compartments by a partial baffle. The engine pump delivers heated water to the "hot" side, and the auxiliary pump delivers it to the remote radiator. Cooled water returns from the radiator to the "cold" side of the hot well tank, from which the engine pump circulates it through the engine. Head pressures are confined to the hot well tank and the engine is subject only to normal pressure. The tank should be sized for the capacity of the remote radiator and all piping between tank and radiator, plus at least 10% for expansion. When the engine is not operating, all coolant drains back into the tank. The pump must be sized to lift water the vertical distance between the pump and the radiator, and to circulate the coolant at the rated capacity of the engine pump.

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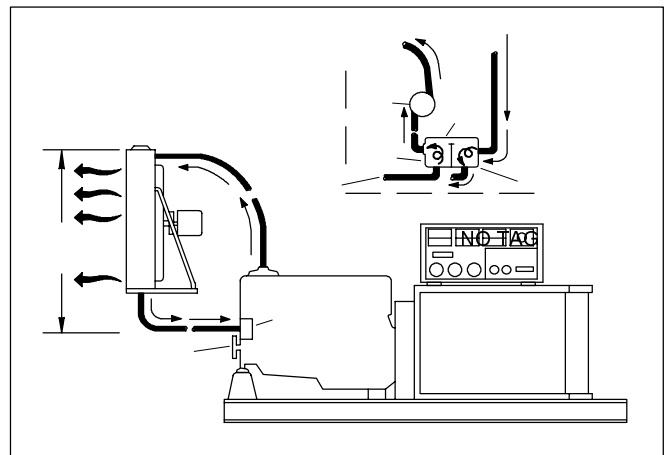
The heat exchanger system is similar with the engine pump circulating coolant through the block and one side of the heat exchanger, and the auxiliary pump circulating coolant through the other side of the heat exchanger and the remote radiator. Head pressures are confined to the radiator side of the heat exchanger.

The heat exchanger should be sized and supplied by the remote radiator manufacturer who will also specify auxiliary pump capacity to ensure proper system operation. A surge tank should be provided at the highest point in the engine side of the system (Figure 24).

Whenever an auxiliary circulating pump is specified, it should be wired in parallel with the remote radiator fan to operate whenever the generator set operates. For maximum reliability, both should be connected directly to the generator output.

Connection of an auxiliary pump in series with the engine circulating pump should be avoided. Unless the pumps are very closely matched, there is a possibility of one or both cavitating, introducing air into the system. Air trapped in the engine block can cause serious engine damage.

In any remote radiator system, the top of the radiator must be the highest point in the system for proper operation.



Remote Radiator System

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### 6.5.5 City Water Cooling

These systems use city water for cooling and are similar to remote radiator systems in that they require less cooling air than unit mounted radiator systems. Unless the cooling water is obtained from an on-site well, they are forbidden by the National Electrical Code® articles 700–12b (3) and 701–11b (3) for legally required emergency and standby systems. Those articles required that cooling systems not be solely dependent upon municipal water supplies.

City water cooling systems may be of two types, either direct or heat exchanger. The direct systems circulate water directly through the engine block before dumping it in a drain. To avoid damage to the engine from thermal shock resulting when cold water contacts a hot engine, a tempering tank is built into the engine cooling system. A similar variation is standpipe cooling, where a separate standpipe serves as a tempering tank. Direct systems have the disadvantage of subjecting the engine to a buildup of lime and other mineral deposits which may clog cooling passages and subject cooling systems to corrosion. This can be prevented in a closed system by chemical inhibitors.

The heat exchanger cooling system confines the effects of city water to one side of a heat exchanger

which is relatively easy to clean or replace, while engine coolant circulates in a closed system similar to a radiator system. It is the preferred system since it allows better control of engine temperature, permits the use of antifreeze and coolant conditioners, and is better suited to the use of an engine block heater as a starting aid.

The common components of all city water cooling systems are a thermostatically controlled flow control valve to conserve cooling water, and an electric solenoid water shut-off valve, usually powered by the engine battery and connected to the engine starting controls, to open whenever the engine runs.

Installation considerations include the necessity for flexible connections between the engine and supply and drain piping, and provision for adequate air ventilation. Be sure that the solenoid valve is located upstream of the supply flexible connection. A typical installation is shown in [Figure 25](#).

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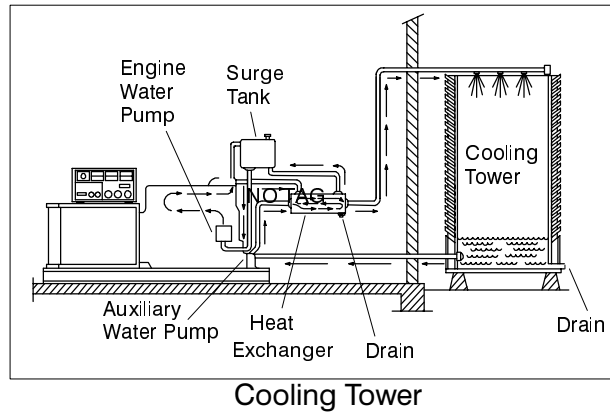
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### 6.5.6 Cooling Tower

In warm, dry climates, a cooling tower may be a suitable source of generator set cooling water. A typical system is shown in [Figure 26](#). This is a variation of city water cooling with heat exchanger. The engine water pump circulates coolant in a closed system through one side of a heat exchanger, a surge tank, and the engine block. A separate pump circulates water through the other side of the heat exchanger and to the top of the cooling tower where it is sprayed down to cool by evaporation. Since some water is constantly being lost by evaporation, the system must include provision for makeup water.

Flexible connections should be used between rigid piping and the engine. Standard heat exchangers used in city water cooling systems are usually sized for 90° F (32°C) maximum raw water. If water temperature from the cooling tower is higher, a special heat exchanger sized for the specific application will be necessary.



## 6.6 Exhaust Systems

Proper design of the exhaust system is essential to obtain satisfactory performance from a generator set. The most important factor is that the installed system must not exceed the engine manufacturer's maximum exhaust-back pressure limit. Any exhaust-back pressure will limit the maximum power available from the engine. Excessive back pressure may cause serious engine damage.

Excessive back pressure usually results from one or a combination of the following:

- Exhaust pipe diameter too small.
- Exhaust pipe too long.
- Too many sharp bends in the exhaust system.
- Too small an exhaust silencer or incorrect silencer design.

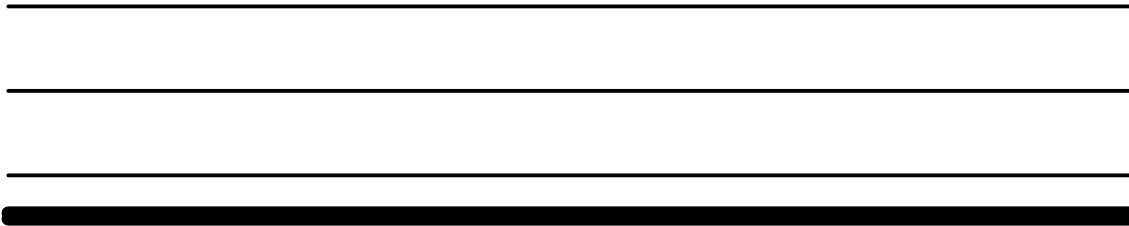
Figure 27 shows the general arrangement of a recommended exhaust system.

Exhaust lines should be as short and straight as possible. Schedule 40 black iron pipe is the recommended material. Use 10.2.6 Exhaust System Back Pressure to determine exhaust line dimensions.

Where possible, sweep elbows with a radius at least three times the pipe diameter should be used.

A section of flexible exhaust line should be installed within two feet (60.1 cm) of the engine exhaust outlet to limit the stress on the engine exhaust manifold or turbocharger, resulting from engine motion on its vibration mounts and temperature induced changes in pipe dimensions. The flexible section should be at least 12 inches (30.5 cm) long. Where threaded flexible exhaust connectors are used, a 6–8 inch (15.3–20.4 cm) length of pipe should separate them from the exhaust manifold. This will serve to reduce the temperature of the flexible connection and extend its life. It also makes it easier to remove the flexible section, if necessary, without putting excessive strain on the engine manifold. Since typical exhaust temperatures range from 800°F (427°C) to over 1200°F (649°C) for some gas engines, seamless stainless steel should be used for the flexible section.

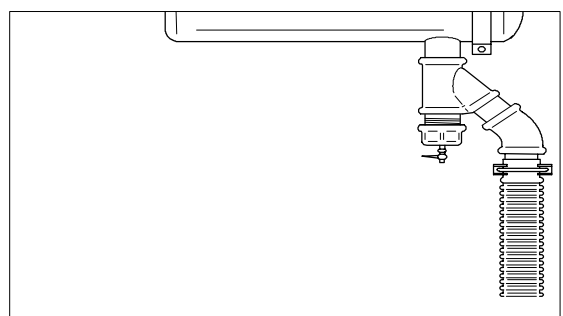
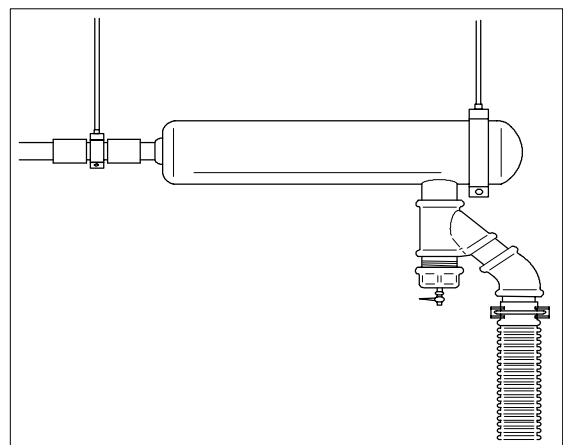
A wye or tee type condensation trap with drain plug or petcock should be installed between the engine and exhaust silencer as shown in Figure 28. This will prevent condensed moisture in the engine exhaust from draining back into the engine when it is shut down.

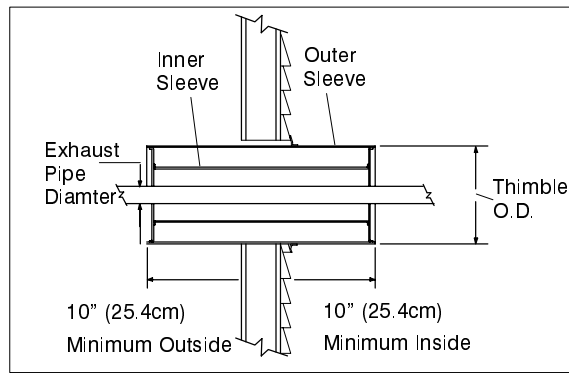


Exhaust silencers may be of the industrial, residential, or critical type. The differences are in the degree of silencing. Industrial silencers provide a moderate degree of silencing for areas where exhaust noise is of little concern. Residential silencers typically limit exhaust noise to 95 dBA measured at ten feet in a free field environment. Critical silencers typically limit exhaust noise to 85 dBA measured under the same conditions.

Exhaust silencer back pressure must be added to the pressure calculated for system piping to estimate total back pressure on the engine. The back pressure of various types of silencers with different exhaust flow rates can be calculated using the procedure in 10.2.6 Exhaust System Back Pressure.

Exhaust piping should conform to NFPA 37 and any applicable local codes. In general, exhaust temperatures will be less than 1000°F (538°C) measured at the engine exhaust outlet, except for infrequent brief periods, and standards for low heat appliances will apply. Construction details of typical double-sleeve thimbles to be used where exhaust piping passes through a combustible wall or roof are shown in [Figure 29](#). The heat rejected from exhaust piping, and consequently the amount of ventilating air required, can be substantially reduced by insulating exhaust piping with suitable high temperature insulation.





Through-Wall Thimble

Care should be taken with the location of exhaust outlets so that people will not come in contact with hot surfaces. Exhaust gases are poisonous and should be directed away from any area occupied by people or animals. **Be certain that exhaust gases cannot be drawn into any air intake vents, windows, doors, or other openings to enclosed spaces where gases could accumulate.**

The outlet of the exhaust system should be covered with a rain cap or screen to prevent the entry of birds or rodents. Either a rain cap or long-radius elbow can be used to prevent the entry of rain and snow.

## 6.7 Batteries And Chargers

Electric starting systems are generally used on standby generator sets below 1500 kW, although hydraulic and air starting systems can also be adapted to engines in this size range. Main components of the electric starting system are the starter motor, batteries, engine-driven battery charging alternator, and AC powered battery charger.

Starting motors are either 12- or 24-Volt, with 12-Volt being generally used below 100 kW, 24-Volt above 200 kW, and dual 24-Volt starters above 500 kW.

Starting batteries are usually lead-acid type sized according to the engine manufacturer's recommendation for the particular ambient temperature conditions and required cranking time. Starting motors will be damaged by overheating if operated continuously for more than one minute. Recommended cranking periods are specified in NFPA 110. It allows a single 45-second cranking cycle for generator sets below 20 kW. For larger models, three, 15-second crank cycles separated by 15-second rests are required. The battery industry rating standard most commonly used to specify batteries is the cold-cranking ampere rating.

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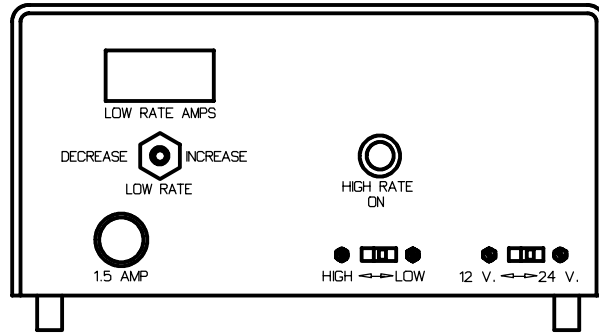
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The rating is defined as the load in amperes which a fully charged battery at 0°F (-18°C) can deliver for 30 seconds and maintain a voltage of 1.2-Volts per cell or higher. Other common battery ratings are reserve capacity and ampere-hours. Reserve capacity is the number of minutes a fully charged battery at 80°F (27°C) can be discharged at 25 amperes and maintain a voltage of 1.75-Volts per cell or higher. The ampere-hour rating, now obsolete, required that the battery be discharged at 80°F (27°C) at the maximum rate which could be sustained for 20 hours and maintain a voltage of 1.75-Volts per cell or higher. This ampere rate was then multiplied by 20 to give an ampere-hour rating.

Nickel cadmium batteries are sometimes used for standby generator sets because of their long life (20 years). This is offset by their high initial cost, larger space requirements, and special charging requirements. Conventional lead-acid batteries have proven satisfactory for the majority of generator set applications.



Kohler® “Trickle” Battery Charger

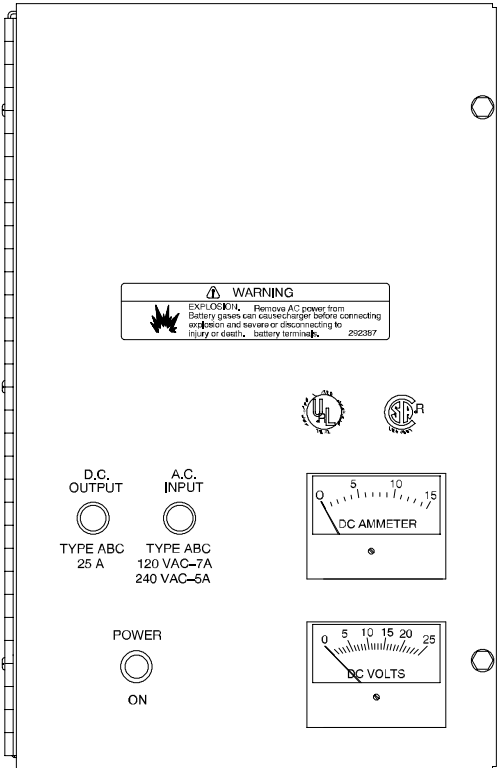
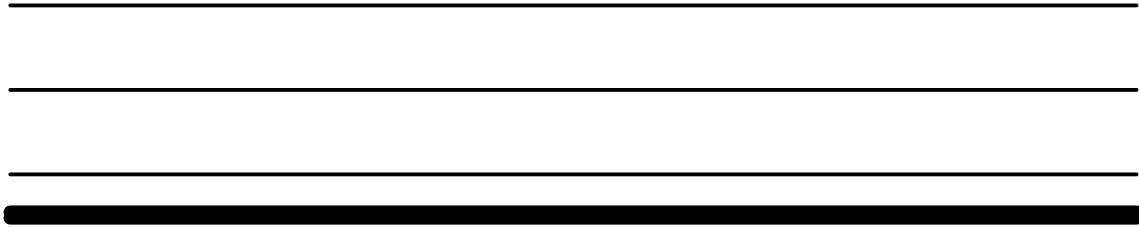
Batteries should be as close to the engine starter as possible, either on a unit mounted or free standing rack. Occasionally, batteries are remote mounted in a heated building when the generator set is to be located outdoors, subject to low ambient temperatures. The cranking performance gained by keeping the battery warm is offset by the losses in extending battery cables, and a more practical solution is to use a heated battery rack or battery warmer to maintain cranking performance in low temperatures.

Batteries are charged by engine-driven, battery charging alternators whenever the generator set operates. These systems are normally capable of charge rates of 30-amperes or more and can restore the charge used in a normal cranking cycle within a short period of operation. When the engine is not operating, a very low charge rate from an AC powered battery charger is sufficient to maintain the batteries fully charged. These chargers may be manual or automatic with a high charge rate of two-amperes and a trickle charge rate up to 300-milliamperes. They can be separate, self-contained units or compartments built into the automatic transfer switch. Due to the low maximum charge rate, they are not well suited to restoring fully discharged batteries. Automatic float chargers with high charge rates of ten-amperes or more are available if full recovery

capability independent of the engine-driven charging system is required.

The most common reason for the failure of an emergency generator set to start when needed is starting battery failure. Two common causes of battery failure are either a manual charge rate set too low to maintain the battery, or set too high which results in loss of battery electrolyte. For this reason, automatic float chargers, which vary the charge rate in response to battery condition, are strongly recommended over manual types.

For large engines using two starters, either one bank of batteries and charger for both starters, or separate battery systems may be used. The latter system is preferable since it reduces the chance of one component's failure making the entire system inoperative.



Kohler® “Float/Equalize” Battery Chargers

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## 7. Electrical Controls

### 7.1 Requirements

After the sizing requirements for the generator set(s) are resolved, it becomes necessary to tie it into the distribution system that it will feed. In addition to pure emergency standby use, the system may be designed to reduce cost by peak shaving, and/or allowance for utility-planned service interruptions made possible by special rate agreements. Any one of several methods may be selected to meet your client's requirements.

#### 7.1.1 Automatic Transfer Switch

The Automatic Transfer Switch is connected to the normal source and the generator set. This combination functions on a failure of the normal system, and after the generator set starts (normally ten seconds), the load will then be reenergized by the generator set until the normal source returns.

#### 7.1.2 Automatic Transfer/Bypass-Isolation Switch

The bypass portion of the automatic transfer switch serves as a manual transfer switch, providing the ability, by throwing one of two handles, to conduct power around the transfer switch, thus energizing the load from either the normal or emergency source. Through the means of the second handle, it provides a means of isolating the transfer switch. These two handles are suitably interlocked to prevent improper operation. Isolating the transfer switch is done in three modes:

- Connected, where the transfer switch is connected to the normal, emergency, and load.
- Test, where the transfer switch is disconnected from the load, but with its control circuit energized, allowing maintenance or tests to be performed on the switch, and check out proper operation ensuring that maintenance has been done correctly.
- Withdrawn, whereby the transfer switch is totally disconnected from any source of power, and can be physically removed from the switchgear assembly for either maintenance or replacement.

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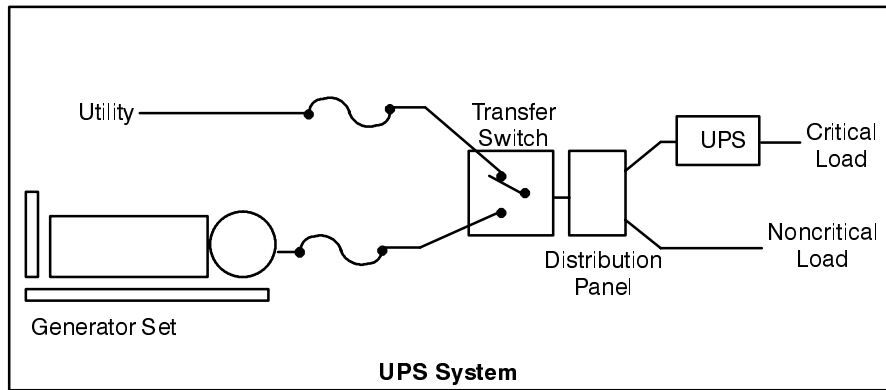
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### 7.1.3 Uninterruptible Power Systems

Uninterruptible Power Systems normally use generator sets to provide long-time backup to their usual battery capacity. The UPS accomplishes two purposes in that it furnishes "clean power" (free of unacceptable transients), and in the event of a power failure, provides uninterrupted power to critical sensitive loads such as computers and instrumentation. Normally the battery capacity is adequate for anywhere from 5 to 15 minutes. If longer times are required, additional batteries not only become quite expensive, but require additional physical room for installation. In many cases, it is more feasible to provide a generator set for additional uninterrupted power, since the generator set availability is limited only by the system's fuel capacity.

### 7.1.4 Paralleling Switchgear

Paralleling switchgear can be used to connect generator sets to utilities, either through the use of automatic transfer switches, or directly. When they are used directly, their function in reality is energy



management. They can be programmed through the use of paralleling switchgear to either provide peak shaving, reducing peak demands (and your client's utility bills), or cogenerating to feed power back to the utility while collecting a fee for so doing.

Paralleling switchgear or distribution switchgear may be designed to house all of the above, plus a distribution section to feed and segregate individual loads to accomplish load shedding. In most cases it is not necessary to energize all loads during a power outage. This type of system selects which loads will be shed and accomplishes the shedding itself.

The transfer switch may also be used in a system to select load priorities. For example, with five separate loads, one of which must be maintained, the second only if the first is maintained, etc., you can either use individual ATS's or switchgear containing ATS's such that when multiple generator sets are used, the first generator set on-line will provide power to critical load number 1, set number two to critical load two, etc. Thus, regardless of which generator set comes on-line first, it will immediately go to priority load number one.

## 7.2 Utility Analysis And Switchgear Sizing

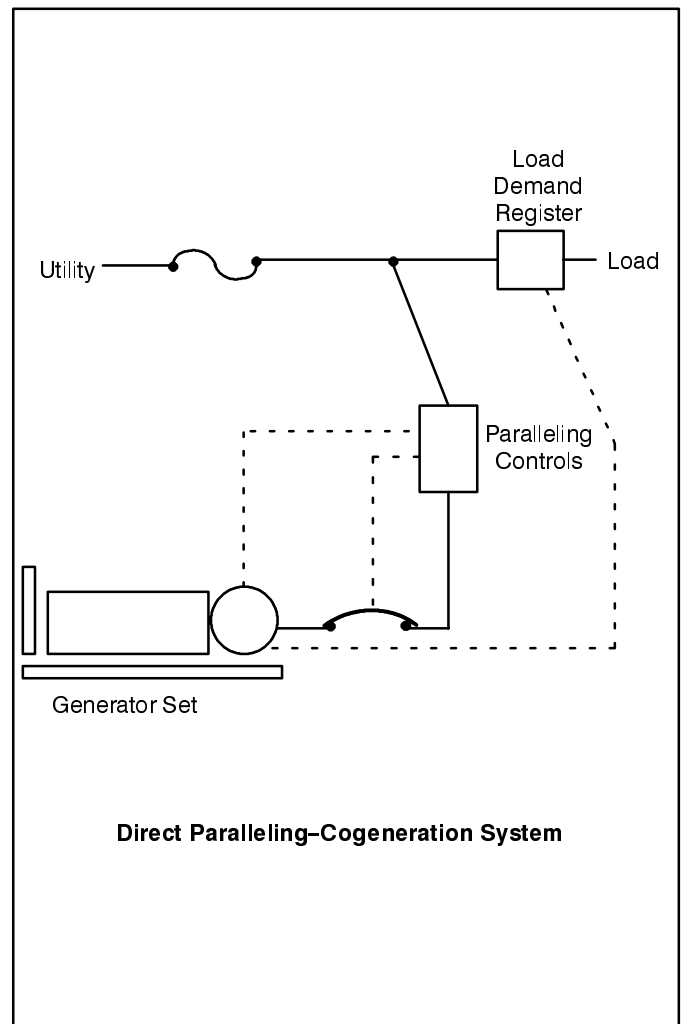
After the load analysis has been made, if an ATS, bypass isolation switch, UPS, or paralleling switchgear are to be incorporated, it is necessary to analyze the normal (utility) source of power to determine its ampacity capabilities at the point of installation of these devices.

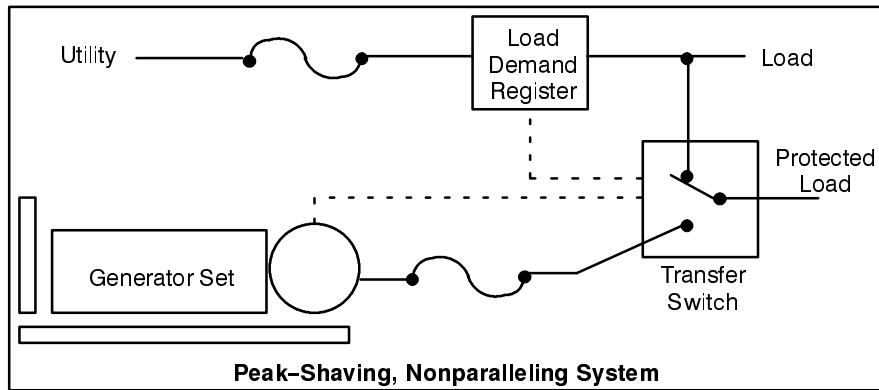
Be sure to determine:

- the supply voltage
- the supply frequency
- the maximum continuous load current plus additional future capacity that will be required
- the peak overload currents and their duration
- maximum available short-circuit current, including the reactance-to-resistance ratio of the supply to a fault on the line side of each circuit element.
- the type of circuit disconnect being used, (for example, bolted pressure switch with Class L fuses, low voltage circuit breaker, or molded case circuit breaker, etc.)
- maximum ambient temperature, and other environmental conditions.

In general, these devices are available with the following ratings:

- Nominal and Maximum Voltages—All voltages to 5 kV. Over 600–Volts may not be available from all manufacturers.
- Frequency—Nominally 50 or 60 Hz. DC is available from some manufacturers, as is higher frequency, i.e., 415 Hz.
- Continuous Current—Generally speaking, the standard currents for this type of equipment are: 30, 50, 60, 70, 100, 150, 225, 250, 260, 280, 400, 600, 800, 1000, 1200, 1600, 2000, 2500, 3000, 4000 amperes.
- With Stand Rating or Short Time Current —Some manufacturers publish ratings, but most tabulate the upstream protection devices that can be used with each switch. The general approach is to rate the ATS along with a fuse or circuit breaker.
- Maximum Ambient Temperature.
- Interrupting current. At least 6–times is required by UL, however, a 12 or 15–times minimum is necessary for an ATS if the ATS could possibly open during an overload, short circuit, or ground fault application.





## 7.3 Selection of Automatic Transfer Switches and Accessories

### 7.3.1 Automatic Transfer Switches

The automatic transfer switch, along with its related controls, is located in the electrical system where it can switch power from either the normal or emergency source, to the electrical loads.

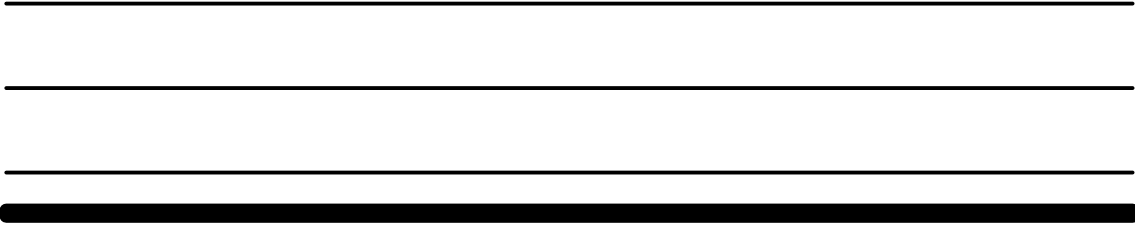
For maximum protection, a transfer switch has always been located as close as possible to the electric loads that operate through it, and should be powered by the source to which loads are being transferred.

The controls have the intelligence to monitor the normal source. If there is a supply outage, or any other cause of diminished power supply, the controls signal the generator set to start. When the generator reaches proper voltage and frequency, the controls cause the switch to transfer the connected loads to the generator.

When the normal source is restored, the loads are retransferred back to the normal source. After transfer, the engine is shut down, usually after a cool-down period. The entire sequence handled automatically by the automatic transfer switch.

Combining the information contained in selection of electrical controls, five steps to proper selection are usually all that is required:

1. Determine the required phase-to-phase voltage, frequency, and number of poles.
2. Determine the current rating by totaling all lighting, motor, and other loads. In some cases, consideration must be given to whether the lights are tungsten, fluorescent, or others such as sodium vapor; and in these cases, derating may be necessary in order to accommodate the high in-rush currents associated with such loads. Motor loads are evaluated on the basis of full-load running current only.
3. Based on the above, and considering the system voltage, select the appropriate switch and add the desired optional accessories. It must be remembered that the emergency and normal sources are fed through the transfer switch, and, therefore, the switch must be sized to the larger source. In many cases, a transfer switch is improperly selected because it is sized only to the



generator set, which may be selected to supply only critical loads that are necessary during the nonavailability of the utility source. In such cases the normal source determines the ampacity of the automatic transfer switch.

- 4. Determine the operating environment of the switch—whether it is indoors, outdoors, in dusty conditions, or in an explosive atmosphere—and specify the appropriate cabinetry.
- 5. Check for conformance to the available with-stand, closing, and interrupting ratings that the switch must handle during a possible short circuit on the system and other specifications where applicable.

Transfer switches are available with many accessories. In most cases, as standard, the basic switch is provided with full-phase sensing on the normal source and single-phase sensing on the emergency source. The normal source is usually monitored with voltage-sensing relays that are factory set somewhere between 70% and 80% for dropout and 90% to 95% for pickup. In most cases the emergency source sensing is a conventional relay that will pick up at approximately 50% to 60% voltage and 40% to 60% of frequency. In general, accessories are

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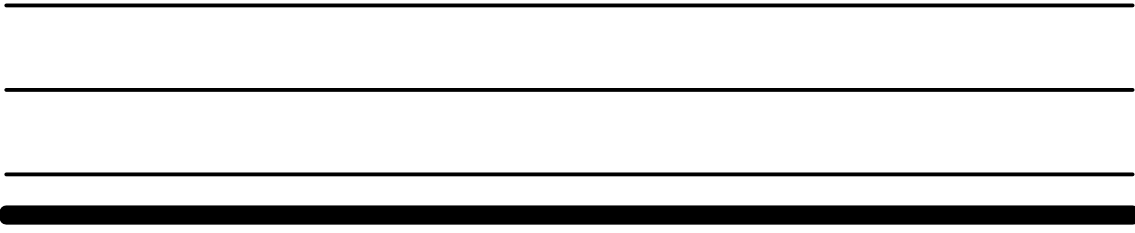
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selected based on the needs of the emergency source. However, for some applications, accessories are used on the normal source, to provide more stringent sensing than the average switch provides. In all cases, UL requires that an automatic transfer switch be provided with a test switch mounted on the external portion of the cabinet, usually on the door. This switch will simulate a normal power failure and initiate action of the transfer switch. It will initiate engine start, and transfer the load to the generator set as long as the switch is in the test position. Either of two types of switches are provided, momentary contact or maintained contact. Since this switch is exposed and available to the passer-by, it is suggested that momentary-contact test switches be utilized. If maintained contact switches are utilized, it is possible, because of human error, that the switch will be left in the test position and the load will continue to be fed by the generator set until the switch is restored to the automatic position. It is also possible under such operation that the fuel tanks can run dry, causing the normally associated problems.

Generally speaking, transfer switches should be supplied with a minimum accessory package. In general, it is suggested that the following accessories be included as standard for the accompanying reasons.

- Time delay on engine starting is suggested. This can be a fixed-time delay of two- to four-seconds or an adjustable-time period depending upon the need. This time delay is suggested because, in the event of an upstream reclosure functioning, the normal source will be interrupted, and then, within one to four seconds, reappear. The reclosure action may have cleared the fault, and in this case, it is considered undesirable to start the generator set for an outage of one to four seconds, because the generator set takes longer to start.
- Time delay on transfer from emergency to normal is suggested. Normally this is a timer having an adjustable-time delay range from 0 to 30 minutes; nominally it is set at a time period of 25 to 30 minutes. Its special function is a minimum generator run time (this is especially

### 7.3.2 Accessories



important with a diesel-powered generator set). In the event the generator set is started and the power returns within 5 to 10 minutes, it is desirable to insure the engine has a minimum running time and is allowed to reach its operating temperature and run for a short time under load. In addition, this time delay insures that the normal source has stabilized before retransfer. It does so because of the duration of the time delay.

- A voltage/frequency-module sensing device on the emergency source is suggested to insure that the generator set has reached proper operating voltage and frequency before load is transferred to it.
- You also may wish to consider the use of a time delay from normal to emergency. This time delay comes into effect after voltage/frequency module has established that the generator has reached proper voltage and frequency. This device normally is an adjustable time delay from zero to one minute. It permits the engine to run for whatever time-delay setting is dialed into the timer before load is applied to it, in order to allow the engine to stabilize and also allows loads to be sequenced.

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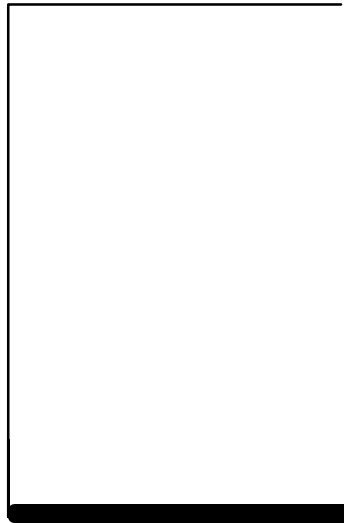
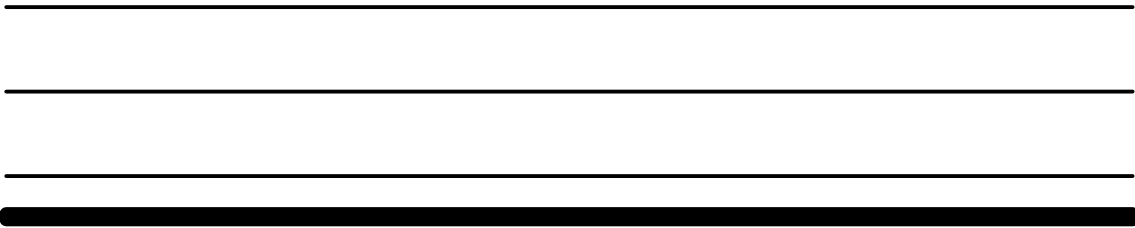
The before mentioned accessories are suggested for use on every transfer switch that is used with a generator set. When a transfer switch is used with two utility sources, only time–delay–normal–to–emergency and time–delay–emergency–to–normal should be considered. They should be considered because it is not desirable to transfer rapidly from one source to the other and back again, with the resulting load transient caused by such transfers.

Manufacturers provide a multitude of other accessories that should be considered depending upon the degree of sophistication and convenience that is required in the installation. These accessories are as follows:

- Time delay on engine cool–off. Normally this is an adjustable timer from 1 to 30 minutes and provides unloaded running time for the engine, to insure that the engine cools down and that the exhaust system is properly heated so that excess moisture is evaporated. In many cases this timer is included in the engine controller, which is why it is placed here in the other accessories grouping. This timer begins to time when the switch transfers back to the normal source.
- Underfrequency adjustable modules to monitor the emergency source provide precise adjustment of the point at which transfer will be permitted. In

addition, overfrequency modules can be supplied.

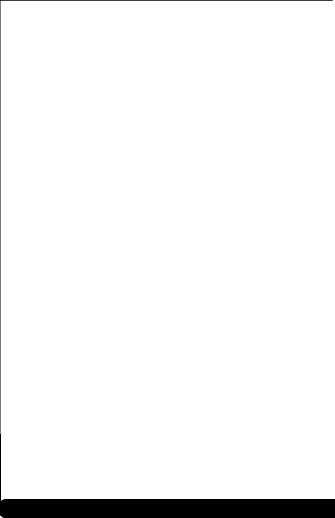
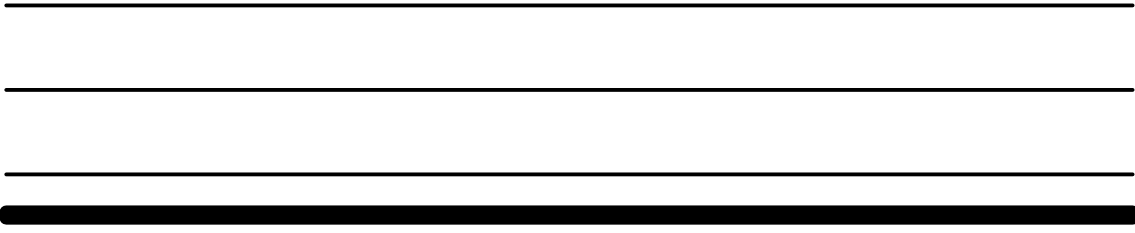
- As with frequency, under and overvoltage modules can be furnished. Nominally these are adjustable with the range of 70% to 100% for pickup and 71% to 100% for dropout and from 100% to 115% for overvoltage. Normally these modules are single–phase; however, three–phase modules are also available.
- Four–position selector switches permit four modes of ATS operation: test, auto, off, and engine start. The off position de–energizes control circuitry and opens the engine–start circuit. The transfer switch will not operate nor will the engine start on power failure. The test position simulates a normal power failure in exactly the same manner as the test switch. The auto position returns the transfer switch to automatic operation. The engine–start position closes the engine–start circuit. The switch will not transfer unless the normal source fails.



Normally with this accessory, a lamp is provided that lights in all positions except the auto position. This provides a visual indication that the switch is not in the auto position.

- Push-button, time-delay overrides for either the normal-to-emergency or emergency-to-normal time delays can also be furnished. These switches have some use during test mode operation of the transfer switch in start-up. The time delays can be set to the values that will be used in actual practice; however, the switch provides the means to override them so that, in the case of the time-delay, emergency-to-normal set at 30 minutes, the 30-minute time period does not have to be observed.
- In some cases a two-position selector switch is desired, usually when there are two utility sources or there are two generator sets. This switch permits selection of either source one or source two as the preferred power source. The preferred source is the one to which the switch will always transfer if that source is available.
- Pilot lights, either to indicate that the switch is connected to the normal source, or that the switch is connected to the emergency source, are often furnished. These lights, as is the case with many other accessories, can be mounted on the transfer switch or can be mounted remotely.

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- In addition to indicating switch position, pilot lights can also be furnished to indicate source condition. These lights merely indicate that either the normal and/or the emergency source are present and available.
  - Relay auxiliary contacts can be provided on either the normal or emergency source to perform additional control functions external to the transfer switch. The normal relay auxiliary contact(s) is energized whenever the normal power source is available. If the normal power source fails, these contacts will retransfer. The emergency relay contacts, however, indicate whenever the emergency source is energized, regardless of whether the switch is connected to it or not. They are generally used in operating cooling air control louvers.
  - Auxiliary contacts, either on normal source or the emergency source, are provided to indicate the transfer switch position (normal or emergency). These switches are dry contacts, and truly indicate the switch position, as opposed to relay auxiliary contacts. They are used in the control-circuitry-external-transfer switch, such as elevator controls. They are often called main shaft auxiliary contacts.
  - Voltmeters, ammeters, the associated selector switches and running-time meters, frequency meters, etc., can be provided with the transfer switch, either mounted on the enclosure, or for external remote use.
  - Plant exercisers can be provided for automatic periodic exercising of the emergency generator set. These timers are adjustable over either a 168-hour (7 day) or 336-hour (14 day) period and are adjustable in increments of either 15 or 30 minutes respectively. These exercisers (timers) can be connected to exercise only the generator set, or exercise the complete system including load transfer. A selector switch can also be furnished that will provide selection between either of the previously mentioned two modes of operation. Plant exercisers should be connected and energized from the load terminals. This minimizes the amount of time the clock is stopped while the power is truly out. If the clock is connected to the normal source, it will be inoperative when the normal source is out, thereby causing the setting of the clock to be in much greater error than it would be if it were



connected to the load terminals. In addition, whenever provision is made for the exerciser to exercise the generator set under load (provide the automatic transfer switch to transfer), care should be given to insure that an override circuit is included in the exerciser's circuitry. This override circuit will insure that, in the event that generator set power is interrupted, the transfer switch will recognize this and cause retransfer to the available normal source. Should this override circuit not be provided, the transfer switch will remain in the emergency position and provide no power to the load until the emergency source is restored or the switch manually retransferred to normal. The override circuit is required by NFPA 99-1987.

- Adjustable battery chargers can be furnished that provide either float charging or whatever charging requirements may be necessary for the application. In general, this is a two-ampere charger with an adjustable float level. In most cases, it is convenient to mount the battery charger in the transfer switch because a source of power to energize it is readily available. It is quite easy to run two DC leads to the batteries to keep them on-float. Generally speaking, a float charger of this type is all that is required.

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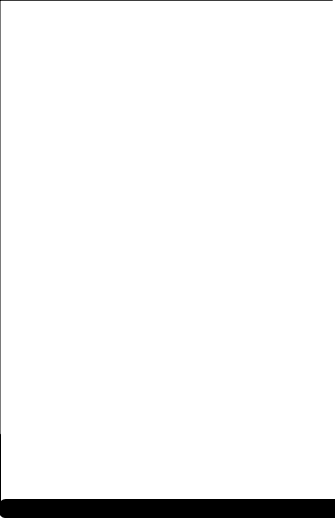
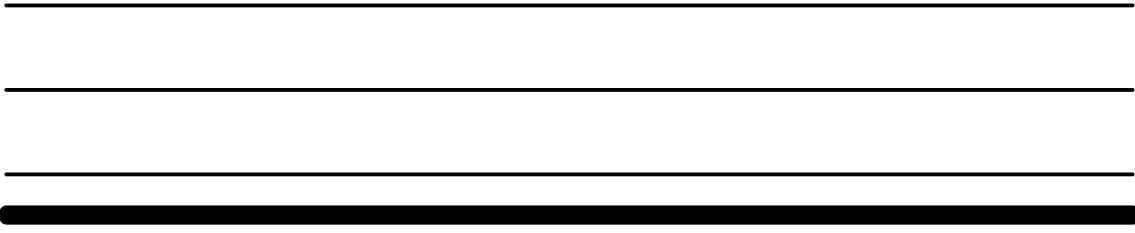
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Normally the generator set has an internal charger on it, so that when running, it will rapidly recharge the batteries after starting. Thus, this charger merely maintains the batteries and keeps them charged.

- Area protection with override circuit is also available. These are used with an external area protection panel. It transfers the load to emergency upon receiving an open contact signal from the area protection panel. In the event that the emergency source fails and the normal source is present, the override circuit will bypass the area-panel signal and retransfer the switch to the normal source.
- Underfrequency, overfrequency, and overvoltage protection can also be furnished for the normal source in addition to the usually furnished undervoltage protection.
- Fuses for the intelligence circuit should be considered for those applications where you desire to fuse nonessential functions such as indicating lights, etc.
- Push-button operation is available either from the normal-to-emergency position, or from the

emergency-to-normal position or a combination of both. These pushbuttons should be considered when it is desirable to run the generator until the condition that caused the power outage has been extensively analyzed and corrective action taken. Use of these accessories will accomplish this. They are also available with selector switches.

- Audible alarms are available with transfer switches and can signify many different things. Normally, audible alarm is hooked to the switch and will sound whenever the switch is in the emergency position. Silencing switches are normally furnished with alarms.
- In-phase monitors monitor the normal and emergency sources and prevent transfer in either direction until the phase voltages and frequencies are within necessary tolerance to enable a transfer to be made. These devices normally lock themselves out if for some reason only one source is available or if both sources are below 70%. This accessory, in addition to the



following accessory, are usually used when there are motors connected to the transfer switch that are 50 hp or larger. Their use facilitates transfer at a point where excess in-rush currents due to out-of-phase voltages between the motor, regenerated voltage during transfer, and the source to which it is going to be transferred are experienced.

- Load-shedding contacts which provide anticipatory contact transfers, either before and/or after transfer, will also accomplish the same function as an in-phase monitor. They are the recommended accessory to use when large motors are involved. Their major advantage over an in-phase monitor is that they permit restoration of the rest of the load just as rapidly as the transfer switch is able to accomplish it, and provide a necessary de-energized time for the motor load(s) that require it. In most cases, this is the most cost-effective solution to problems involving high-speed transfer of motor loads. It is also useful in controlling elevators under emergency conditions.

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- Space heaters should be considered for enclosed switches where the switch is going to be installed in an excessively humid location or where wide variations in temperature occur. These are available as a fixed heater or are available with a thermostatic control.
  - Automatic transfer switches are provided in configurations of two-pole and four-pole (in some cases this is called three poles with an overlapping neutral). The overlapping neutral is a fourth pole that operates in a make-before-break mode and thus connects both neutrals together for a short period of time during transfer. By definition, it cannot be called a pole, since it does not have an interrupting rating, and is not required to interrupt any load. The overlapping neutral does have the same with-stand and closing ratings as the other poles.
  - With many transfer switches a time-delay neutral or open- (programmed) transition accessory is furnished when the transfer switch is of the low speed variety (with transfer time in excess 1/6 of a second). This particular accessory is normally used with motors rated 50 hp or greater. Its function is to disconnect the load from the source to which it is transferring for an adjustable time period, in order

to allow the motor regeneration voltage to decay. Thus the purpose is the same as for load-shed contacts and in-phase monitors. This time-delay does, however, cause total power outage during the delay.

### 7.3.3 Bypass-Isolation Switches

Bypass isolation switches can be provided either as a discrete item or in combination with automatic transfer switches. Automatic transfer/bypass-isolation switches should be considered whenever maximum continuity of load power is required.


Good electrical practice requires periodic testing, inspection, and maintenance of all components of the standby emergency power system. An automatic transfer/bypass-isolation switch not only performs all the functions of an automatic transfer switch but, in addition, provides a means of bypassing source power around the transfer switch to the load. It also electrically isolates the automatic transfer switch, allowing preventive maintenance to be performed on the switch without loss of load power.

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The load is bypassed by using one of the two operating handles provided. Operation of the second handle isolates the ATS for maintenance or testing. If the automatic transfer switch is connected to the source carrying load, the bypass operation is made without the load's circuit power interruption. The bypass switch has the capability to bypass either the normal or emergency source to the load facilitating periodic testing, maintenance, and inspection.

The isolation handle provides three positions: closed, test, and open. The test position permits functional testing on the ATS without disturbing the load. The open position completely isolates the transfer switch from both lines and load without actual removal of the line or load conductors and allows its removal for inspection adjustment and maintenance. Also, while in the test or open positions, the bypass switch functions as a manual transfer switch. This allows load transfer to either source of power regardless of the position or condition of the transfer switch, including the condition when the automatic transfer switch is removed and without reconnecting the load terminals of the ATS.

The isolation handle cannot be actuated unless the bypass handle is in one of the bypass positions, nor can the bypass handle be returned unless the isolation handle is in the automatic position.

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## 8. Sample Specifications

The examples found on the Kohler Sample Specifications diskette (part no. G22-37) are intended to represent actual specifications as presented by the specification writer or consulting engineer. While the components vary with equipment, the basic principles remain the same. The following is a description of the main elements and their purpose in the specification.

**General Requirements** – a brief, but detailed description of what is required. Usually main components are listed (e.g. diesel-powered generator set, automatic transfer switch, etc.)

**Submittal** – this includes what is expected by the writer for initial review. It is a representation that the manufacturer is making a bona fide attempt to comply with the specification. Engineering drawings are usually requested to assist in development.

**Testing** – the testing requirements during manufacture and at time of installation are listed here. Required industry standards should be quoted where applicable.

**Warranty** – the warranty period is listed here. Industry practice suggests 1, 2, or 5 years. A copy of the warranty statement may be requested. The

complete service agreement is usually spelled out in a separate form. See 9. Service Agreement for further explanation.

**Equipment** – define specified ratings of requested equipment (e.g. volts, phase, kW, etc.). Include particulars if request does not follow standard industry parameters.

**Engine (Generator Sets only)** – define specifications of engine and include fuel, governor type, cooling system, etc.

**Generator (Generator Sets only)** – indicate generator requirements including frequency and voltage regulation. This section contains further details not shown in "General Requirements" section.

**Controller (Generator Sets only)** – designate required operating controls, protection equipment, and failure alert devices.

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**Instrument Panel** – define needs for operation and for monitoring of proper function. Includes lights, meters, gauges, etc.

**Accessories** – this is a two-part section where *installed* and *shipped loose* accessories are identified. This is where unique or specialty devices would be listed.

**Certification (Transfer Switch and Switchgear only)** – certifies compliance with specification. Actual test results of output and other data may be requested.

**Operation (Transfer Switch and Switchgear only)** – specific needs can be called out such as provisions for service and manual operation considerations.

**Ratings (Transfer Switch and Switchgear only)** – indicate here which industry standards are to be met such as Underwriters’ Laboratories, Inc. Standard for Safety UL–1008.

**Construction (Transfer Switch and Switchgear only)** – industry preference is usually for one manufacturer of both automatic transfer switch and bypass–isolation switch. NEMA and UL standards are usually requested to be followed.

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**Operation Sequence (Transfer Switch and Switchgear only)** – listed in steps to describe required sequence of operation. Details operations to be performed for proper function and usage.

**Engine-Generator Cubicle (Transfer Switch and Switchgear only)** – similar to "Instrument Panel." Lists equipment necessary for a complete and operable system locally.

**Master Control Cubicle (Transfer Switch and Switchgear only)** – lists equipment necessary for a complete and operable system in a remote "centralized" location.

**Components (Transfer Switch and Switchgear only)** – lists component standards to be met. Indicates responsibility of wiring requirements. Industry preference to be of one manufacturer of switchgear and transfer switches.

**Main Interface Cubicle (Transfer Switch and Switchgear only)** – lists equipment necessary for a complete and operable system in the interface cubicle.

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## 9. Service Agreement

### 9.1 Service Requirements

In addition to proper system design and specification, the client's needs and security must be considered during the operating life of the system. The warranty coverage and after-market service capability of the system supplier should be given attention, with respect to the client's interests.

Standby system and generator set service agreements are often used to establish effective service relationships between the client/customer and servicing agent. Typical agreements variously cover descriptions of system components to be serviced, a list of operations to be performed, frequency of service, prices, limits on liability, etc.

The following sample agreement may be reproduced and used as desired, to the mutual benefit of you and your client.

## 9.2 Service Agreement – Emergency/Standby Electrical Generating System

Upon acceptance of this agreement, the Servicing Agent will perform the specified services on described equipment, at intervals specified.

Customer:

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Servicing Agent:

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Equipment Description

Location: \_\_\_\_\_

Date Placed In Service: \_\_\_\_\_

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**Generator Set(s)**

Mfr. \_\_\_\_\_ Model \_\_\_\_\_ kW \_\_\_\_\_, kVA \_\_\_\_\_, Phase \_\_\_\_\_

Volts \_\_\_\_\_ / \_\_\_\_\_, Amps \_\_\_\_\_

Serial No. \_\_\_\_\_ Spec No. \_\_\_\_\_

Engine, Make \_\_\_\_\_, Model \_\_\_\_\_, Fuel \_\_\_\_\_

Cooling System \_\_\_\_\_

( ) Indoor                      ( ) Outdoor

**Transfer Switch**

Mfr. \_\_\_\_\_, Part No. \_\_\_\_\_, Serial No. \_\_\_\_\_

Volts \_\_\_\_\_, Amps \_\_\_\_\_, Poles \_\_\_\_\_, Wires \_\_\_\_\_

Logic \_\_\_\_\_ Location \_\_\_\_\_

Accessories (List): \_\_\_\_\_

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**Paralleling Equipment**

Mfr. \_\_\_\_\_, Part No. \_\_\_\_\_

Description \_\_\_\_\_

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**Battery Charger**

Mfr. \_\_\_\_\_, Part No. \_\_\_\_\_, Volts \_\_\_\_\_, Amps \_\_\_\_\_, Type \_\_\_\_\_

**Battery(ies)**

Qty. \_\_\_\_\_, Type \_\_\_\_\_, Amps Per Battery \_\_\_\_\_

**Service**

**Preventive Maintenance List** — Services are to be performed per equipment manufacturer’s applicable instruction manuals.

- ( ) Lube oil, and filter change.( ) Emergency system operation
- ( ) Fuel filter change. without load transfer.
- ( ) Engine tune-up with parts.( ) Frequency check/gov. adj.
- ( ) Service/replace air cleaner.( ) Check transfer switch and
- ( ) Check coolant level. accessory operation.
- ( ) Test anti-freeze and adj.( ) Check engine alternator
- ( ) Inspect cooling system hoses. charge rate.
- ( ) Service/replace belts as required.( ) Check engine and generator,
- ( ) Check engine heater operation. gauge, and indicator operation.
- ( ) Check generator set for fuel, oil,( ) Check generator set controller  
coolant leaks. operation including shutdown
- ( ) Check air intakes and outlets. functions and emergency stop.
- ( ) Check transfer tank operation.( ) Check generator output voltage
- ( ) Drain exhaust line. and adjust as necessary.
- ( ) Inspect silencer. ( ) Load bank test.
- ( ) Check battery charger operation( ) Check paralleling equipment  
and charge rate. operation.
- ( ) Check battery electrolyte levels( ) \_\_\_\_\_  
and specific gravity.( ) \_\_\_\_\_
- ( ) Emergency system operation with( ) \_\_\_\_\_  
load transfer. ( ) \_\_\_\_\_  
( ) \_\_\_\_\_  
( ) \_\_\_\_\_

**Preventative Maintenance Schedule** — Listed services are to be performed at intervals stated in equipment manufacturer’s applicable instruction manuals.

Months:

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )

Day Of Month(s) Checked: \_\_\_\_\_

Time-Of-Day: \_\_\_\_\_

**Service Charges**

No services or materials are under this contract unless specifically referred to herein. Replacement parts will be billed at prices prevailing at time of use. It is agreed that the Servicing Agent will supply Labor, and Test Equipment, as necessary to perform the above indicated Preventative Maintenance, per the above indicated Schedule, for the price of:

\_\_\_\_\_ Dollars (\$ . ) Per Year. Rate subject to review and change on an annual basis.

Terms: \_\_\_\_\_

**Taxes**

Prices do not include federal, state, or local sales, use, property, or excise taxes. If any such taxes are imposed, the Servicing Agent will bill them to the customer as a separate item. In lieu of such taxes, the customer shall provide with each order, a tax exemption certificate, acceptable to the proper taxing authorities.

**Emergency Service**

Emergency service between scheduled service dates will be provided at rates in effect at time of service for labor, parts, and travel. Travel rates shall only apply for travel to locations accessible by public roads. Lodging and miscellaneous expenses shall be billed at cost. Additional agreements regarding Emergency Service are as follows:

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**Customer Responsibility**

The customer or customer’s authorized agent shall maintain a regular recommended service procedure as outlined in the attached Appendix A. These procedures should be followed to minimize possible emergency service needs and assure minimum maintenance costs. A record of these maintenance procedures should be maintained for reference.

**Servicing Agent Responsibility**

Insofar as practical, the Servicing Agent shall maintain a complete service history and necessary drawings and service procedure data for reference in service of the equipment. It is agreed that the agreement covers only those items as above outlined and that it does not include any expense to repair damage caused by abuse, accident, theft, acts of a third person, forces of nature, alteration of equipment, or improper operation.

The Servicing Agent agrees to maintain a representative stock of replacement parts and a competent factory-trained service organization. The Servicing Agent shall not be responsible for: failure to render the service due to causes beyond its control including strikes, labor disputes, acts of God, etc., or any consequential damages.

After each inspection, the customer will be furnished a written report detailing any conditions found and advising further service required, if any, to assure operating dependability of the equipment under contract.

While periodic service and maintenance should result in maximum availability of generating equipment, the Servicing Agent makes no warranties or guarantees as to availability of plant or loss of the use of equipment covered under this contract.

This agreement is not subject to alteration except as mutually agreed in writing. It may be terminated at any time by either party upon thirty days’ written notice, or other notice as required by law addressed to the last known address of the other party, and no claim for damages on account of such termination shall arise against either party.

ACCEPTED

ACCEPTED

Customer \_\_\_\_\_  
By \_\_\_\_\_  
Date \_\_\_\_\_

Servicing Agent \_\_\_\_\_  
By \_\_\_\_\_  
Date \_\_\_\_\_

This proposal may be withdrawn by the Servicing Agent if not accepted within 30 days.

**APPENDIX A**

Perform routine maintenance checks in accordance with the equipment manufacturer’s applicable instruction manuals.

# 10. Appendices

## 10.1 Appendix – Generator and Electrical

### 10.1.1 Generator Ratings Three-Phase Amperes – 0.8 Power Factor

kW	kVA	208– Volt	220– Volt	240– Volt	380– Volt	400– Volt	480– Volt	600– Volt
5	6.3	17.5	16.5	15.2	9.6	9.1	7.6	6.1
7.5	9.4	26.1	24.7	22.6	14.3	13.6	11.3	9.1
10	12.5	34.7	33	30.1	19.2	18.2	15.1	12
15	18.7	52	49.5	45	28.8	27.3	22.5	18
20	25	69.5	66	60.2	38.4	36.4	30.1	24
25	31.3	87	82.5	75.5	48	45.5	37.8	30
30	37.5	104	99	90.3	57.6	54.6	45.2	36
40	50	139	132	120	77	73	60	48
50	62.5	173	165	152	96	91	76	61
60	75	208	198	181	115	109	91	72
75	93.8	261	247	226	143	136	113	90
80	100	278	264	240	154	146	120	96
100	125	347	330	301	192	182	150	120
125	156	433	413	375	240	228	188	150
150	187	520	495	450	288	273	225	180
175	219	608	577	527	335	318	264	211
200	250	694	660	601	384	364	301	241
250	312	866	825	751	480	455	376	300
300	375	1040	990	903	576	546	451	361
350	438	1220	1155	1053	672	637	527	422
400	500	1390	1320	1203	770	730	602	481
500	625	1735	1650	1504	960	910	752	602
600	750	2080	1980	1803	1150	1090	902	721
700	875	2430	2310	2104	1344	1274	1052	842
800	1000	2780	2640	2405	1540	1460	1203	962
900	1125	3120	2970	2709	1730	1640	1354	1082
1000	1250	3470	3300	3009	1920	1820	1504	1202
1100	1375	3817	3608	3308	2089	1985	1654	1323
1200	1500	4164	3936	3608	2279	2165	1804	1443
1300	1625	4511	4265	3909	2469	2345	1955	1564
1400	1750	4858	4593	4210	2659	2526	2105	1684
1500	1875	5204	4921	4511	2849	2706	2255	1804
1600	2000	5551	5249	4811	3039	2887	2406	1925

### 10.1.2 Maximum Three-Phase Locked Rotor Amperes

hp	Voltage					
	200	220/230	440/460	550/575	2300	4160
1/2	23	20	10	8		
3/4	29	25	12.5	10		
1	34.5	30	15	12		
1-1/2	46	40	20	16		
2	57.5	50	25	20		
3	73.5	64	32	25		
5	106	92	46	37		
7-1/2	146	127	63	51		
10	186	162	81	65		
15	267	232	116	93		
20	334	290	145	116		
25	420	365	182	146	35	19
30	500	435	217	174	41	23
40	667	580	290	232	55	30
50	834	725	362	290	69	38
60	1000	870	435	348	83	46
75	1250	1085	592	435	104	57
100	1670	1450	725	580	139	76
125	2085	1815	907	726	173	96
150	2500	2170	1085	870	208	115
200	3340	2900	1450	1160	278	153
250	4200	3650	1825	1460	349	193
300	5050	4400	2200	1760	420	232
350	5860	5100	2550	2040	488	270
400	6670	5800	2900	2320	555	306
450	7470	6500	3250	2600	620	344
500	8340	7250	3625	2900	693	383

### 10.1.3 Motor Starting kVA per hp

$$\text{Starting kVA per hp} = \frac{\text{Volts} \times \text{Locked-Rotor Amperes}}{1000 \times \text{hp}} \times \begin{cases} 1, & \text{for single-phase or} \\ \sqrt{3}, & \text{for three-phase} \end{cases}$$

### 10.1.4 NEMA Code Letters Usually Applied to Ratings of Motors Normally Started on Full Voltage

NEMA Code Letters	Horsepower	
	3-phase	1-phase
F	15 up	–
G	10 – 7-1/2	5
H	5	3
J	3	2 – 1-1/2
K	2 – 1-1/2	1-3/4
L	1	1/2

NEMA Code Letters	Kilovolt–Amperes per Horsepower with Locked Rotor
A	0 – 3.14
B	3.15 – 3.55
C	3.55 – 3.99
D	4.0 – 4.49
E	4.5 – 4.99
F	5.0 – 5.59
G	5.6 – 6.29
H	6.3 – 7.09
J	7.1 – 7.99
K	8.0 – 8.99
L	9.0 – 9.99
M	10.0 – 11.19
N	11.2 – 12.49
P	12.5 – 13.99
R	14.0 – 15.99
S	16.0 – 17.99
T	18.0 – 19.99
U	20.0 – 22.39
V	22.4 – and up

### 10.1.5 NEMA Size Starters for Maximum Horsepower – Full-Voltage Starting

NEMA Size	Single-Phase Motors	
	115-Volt	230-Volt
00	1/3	1
0	1	2
1	2	3
1-1/2	3	5
2	–	7-1/2
3	–	15

NEMA Size	Three-Phase Motors		
	200-Volt	230-Volt	230-Volt
00	1-1/2	1-1/2	2
0	3	3	5
1	7-1/2	7-1/2	10
2	10	15	25
3	25	30	50
4	40	50	100
5	75	100	200
6	150	200	400
7		300	600
8		450	900

### 10.1.6 Motor – Full Load Currents

Three-Phase A.C. Induction Type – Squirrel Cage and Wound Rotor							
hp	115- Volt	200- Volt	230- Volt	460- Volt	575- Volt	2300- Volt	4160- Volt
1/2	4	2.3	2	1	.8		
3/4	5.6	3.2	2.8	1.4	1.1		
1	7.2	4.15	3.6	1.8	1.4		
1-1/2	10.4	6	5.2	2.6	2.1		
2	13.6	7.8	6.8	3.4	2.7		
3		11	9.6	4.8	3.9		
5		17.5	15.2	7.6	6.1		
7-1/2		25	22	11	9		
10		32	28	14	11		
15		48	42	21	17		
20		62	54	27	22		
25		78	68	34	27		
30		92	80	40	32		
40		120	104	52	41		
50		150	130	65	52		
60		177	154	77	62	16	8.9
75		221	192	96	77	20	11
100		285	248	124	99	26	14.4
125		358	312	156	125	31	17
150		415	360	180	144	37	20.5
200		550	480	240	192	49	27
Over 200 Approx. Amp./hp		2.75	2.40	1.20	.96	.24	.133

Three-Phase Synchronous Motors Unity Power Factor									
hp	440- Volt	550- Volt	2300- Volt	4160- Volt	hp	440- Volt	550- Volt	2300- Volt	4160- Volt
100	106	85	20	11.2	400	420	336	80.5	44.4
125	132	106	25	14.0	500	525	420	100	55.5
150	158	127	30	16.7	600	630	505	120	66.5
200	210	168	40	22.2	700	736	588	141	77.7
250	262	210	50	27.7	800	840	671	161	88.8
300	315	252	60	33.3	900	945	755	181	100
350	368	295	70.5	38.9	1000	1050	840	192	110

### 10.1.6 Motor – Full Load Currents (cont'd.)

Single-Phase		
hp	115-Volt	230-Volt
1/6	4.4	2.2
1/4	5.8	2.9
1/3	7.2	3.6
1/2	9.8	4.9
3/4	13.8	6.9
1	16	8
1-1/2	20	10
2	24	12
3	34	17
5	56	28
7-1/2	80	40
10	100	50

### 10.1.7 Maximum Rating or Setting of Motor Branch-Circuit Protective Devices

Type of Motor	Percent of Full-Load Current			
	Nontime-Delay Fuse	Dual-Element (Time-Delay) Fuse	Instant. Trip Type Breaker	Time-Limit Breaker
All A.C. single-phase and polyphase squirrel-cage and synchronous motors with full-voltage resistance or reactor starting:				
No code letter	300	175	700	250
Code letter F to V	300	175	700	250
Code letter B to E	250	175	700	200
Code letter A	150	150	700	150
All A.C. squirrel-cage and synchronous motors with auto-transformer starting:				
Code letter F to V	250	175	700	200
Code letter B to E	200	175	700	200
Code letter A	150	150	700	150
Wound Rotor	150	150	700	150

## 10.1.8 Conductor Properties

Size AWG/ MCM	Area Cir. Mils	DC Resistance at 75°C, 176°F				Copper		Aluminum
		Stranding		Overall		Uncoated ohm/MFT	Coated ohm/MFT	ohm/MFT
		Qty.	Diam. in.	Diam in.	Area in. <sup>2</sup>			
18	1620	1	–	0.040	0.001	7.77	8.08	12.8
18	1620	7	0.015	0.046	0.002	7.95	8.45	13.1
16	2580	1	–	0.051	0.002	4.89	5.08	8.05
16	2580	7	0.019	0.058	0.003	4.99	5.29	8.21
14	4110	1	–	0.064	0.003	3.07	3.19	5.06
14	4110	7	0.024	0.073	0.004	3.14	3.26	5.17
12	6530	1	–	0.081	0.005	1.93	2.01	3.18
12	6530	7	0.030	0.092	0.006	1.98	2.05	3.25
10	10380	1	–	0.102	0.008	1.21	1.26	2.00
10	10380	7	0.038	0.116	0.011	1.24	1.29	2.04
8	16510	1	–	0.128	0.013	0.764	0.786	1.26
8	16510	7	0.049	0.146	0.017	0.778	0.809	1.28
6	26240	7	0.061	0.184	0.027	0.491	0.510	0.808
4	41740	7	0.077	0.232	0.042	0.308	0.321	0.508
3	52620	7	0.087	0.260	0.053	0.245	0.254	0.403
2	66360	7	0.097	0.292	0.067	0.194	0.201	0.319
1	83690	19	0.066	0.332	0.087	0.154	0.160	0.253
1/0	105600	19	0.074	0.373	0.109	0.122	0.127	0.201
2/0	133100	19	0.084	0.419	0.138	0.967	0.101	0.159
3/0	167800	19	0.094	0.470	0.173	0.0766	0.0797	0.126
4/0	211600	19	0.106	0.528	0.219	0.0608	0.0626	0.100
250	–	37	0.082	0.575	0.260	0.0515	0.0535	0.0847
300	–	37	0.090	0.630	0.312	0.0429	0.0446	0.0707
400	–	37	0.104	0.728	0.416	0.0321	0.0331	0.0529
450	–	37	0.097	0.681	0.364	0.0367	0.0382	0.0605
500	–	37	0.116	0.813	0.519	0.0258	0.0265	0.0424
600	–	61	0.992	0.893	0.626	0.0214	0.0223	0.0353
700	–	61	0.107	0.964	0.730	0.0184	0.0189	0.0303
750	–	61	0.111	0.998	0.782	0.0171	0.0176	0.0282
800	–	61	0.114	1.03	0.834	0.0161	0.0166	0.0265
900	–	61	0.122	1.09	0.940	0.0143	0.0147	0.0235
1000	–	61	0.128	1.15	1.04	0.0129	0.0132	0.0212
1250	–	91	0.117	1.29	1.30	0.0103	0.0106	0.0169
1500	–	91	0.128	1.41	1.57	0.00858	0.00883	0.0141
1750	–	127	0.117	1.52	1.83	0.00735	0.00756	0.0121
2000	–	127	0.126	1.63	2.09	0.00643	0.00662	0.0106

These resistance values are valid ONLY for the parameters as given. Using conductors having coated strands, different stranding type, and especially, other temperatures, change the resistance.

Formula for temperature change:  $R_2 = R_1 [1 + \alpha (T_2 - 20)]$  where:  $\alpha_{Cu} = 0.00393$ ,  $\alpha_{AL} = 0.00403$ .

Class B stranding is listed as well as solid for some sizes. Its overall diameter and area is that of its circumscribing circle. The construction information is per NEMA WC8–1976 (Rev 5–1980). The resistance is calculated per National Bureau of Standards Handbook 100, dated 1966, and Handbook 109, dated 1972.

Conductors with compact and compressed stranding have about 9 percent and 3 percent, respectively, smaller bare conductor diameters than those shown.

The IACS conductivities used: bare copper = 100%, aluminum = 61%.

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**10.1.9 AC Resistance and Reactance  
600 V cables, 3 phase, 60 Hz., 75°C – Three Single Conductors in Conduit**

Size AWG/ MCM	Ohms to Neutral per M Ft.							
	Uncoated Copper				Aluminum			
	Nonmagnetic		Magnetic		Nonmagnetic		Magnetic	
	Rac	X <sub>L</sub>	Rac	X <sub>L</sub>	Rac	X <sub>L</sub>	Rac	X <sub>L</sub>
14	3.1	0.054	3.1	0.068				
12	2.0	0.051	1.9	0.064	3.2	0.051	3.2	0.064
10	1.2	0.048	1.2	0.059	2.0	0.048	2.4	0.059
8	0.78	0.048	0.78	0.060	1.3	0.048	1.3	0.060
6	0.49	0.046	0.49	0.057	0.81	0.046	0.81	0.057
4	0.31	0.043	0.31	0.054	0.51	0.043	0.51	0.054
3	0.24	0.042	0.24	0.053	0.40	0.042	0.40	0.053
2	0.19	0.041	0.19	0.052	0.32	0.041	0.32	0.052
1	0.15	0.041	0.15	0.052	0.25	0.041	0.25	0.052
1/0	0.12	0.040	0.12	0.050	0.20	0.040	0.20	0.050
2/0	0.097	0.039	0.098	0.049	0.16	0.039	0.16	0.049
3/0	0.077	0.038	0.078	0.048	0.13	0.038	0.13	0.048
4/0	0.061	0.038	0.062	0.047	0.10	0.038	0.10	0.047
250	0.052	0.038	0.053	0.048	0.085	0.038	0.086	0.048
300	0.044	0.037	0.045	0.046	0.071	0.037	0.072	0.046
350	0.038	0.037	0.039	0.046	0.061	0.037	0.062	0.046
400	0.034	0.036	0.035	0.045	0.053	0.036	0.054	0.045
500	0.027	0.036	0.029	0.044	0.043	0.036	0.044	0.044
600	0.023	0.036	0.026	0.045	0.036	0.036	0.037	0.045
750	0.019	0.035	0.022	0.044	0.029	0.035	0.030	0.044
1000	0.016	0.034	0.019	0.043	0.022	0.034	0.024	0.043

Class B stranding was used; the computations are based upon 100 percent IACS copper, 61 percent IACS aluminum.

The values are valid ONLY for the parameters as given. Different operating temperatures and/or different installation configurations or environment will change the values.

At the stated parameters, capacitive reactance is negligible, so only inductive reactance is given.

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### 10.1.10 Ampacities of Insulated Conductors Rated 0–2000 Volts, 60°C to 90°C

Not More Than Three Conductors in Raceway or Cable or Earth (Directly Buried), Based on Ambient Temperature of 30°C, 86°F

Size		Temperature Rating of Conductor								Size
AWG MCM	60°C, 140°F	75°C, 167°F	85°C, 185°F	90°C, 194°F	60°C, 140°F	75°C, 167°F	85°C, 185°F	90°C, 194°F	AWG MCM	
	Types †RUW, †T, †TW, †UF	Types †FEPW, †RH, †RHW, †RUH, †THW, †THWN, †XHHW, †USE, †ZW	Types V, MI	Types TA, TBS, SA, AVB, SIS, †FEP, †FEPB, †RHH, †THHN, †XHHW*	Types †RUW, †T, †TW, †UF	Types †RH, †RHW, †RUH, †THW, †THWN, †XHHW, †USE	Types V, MI	Types TA, TBS, SA, AVB, SIS, †RHH, †THHN, †XHHW*		
	COPPER				ALUMINUM OR COPPER-CLAD ALUMINUM					
18	–	–	–	14	–	–	–	–	–	
16	–	–	18	18	–	–	–	–	–	
14	20†	20†	25	25†	–	–	–	–	–	
12	25†	25†	30	30†	20†	20†	25	25†	12	
10	30	35†	40	40†	25	30†	30	35†	10	
8	40	50	55	55	30	40	40	45	8	
6	55	65	70	75	40	50	55	60	6	
4	70	85	95	95	55	65	75	75	4	
3	85	100	110	110	65	75	85	85	3	
2	95	115	125	130	75	90	100	100	2	
1	110	130	145	150	85	100	110	115	1	
0	125	150	165	170	100	120	130	135	0	
00	145	175	190	195	115	135	145	150	00	
000	165	200	215	225	130	155	170	175	000	
0000	195	230	250	260	150	180	195	205	0000	
250	215	255	275	290	170	205	220	230	250	
300	240	285	310	320	190	230	250	255	300	
350	260	310	340	350	210	250	270	280	350	
400	280	335	365	380	225	270	295	305	400	
500	320	380	415	430	260	310	335	350	500	
600	355	420	460	475	285	340	370	385	600	
700	385	460	500	520	310	375	405	420	700	
750	400	475	515	535	320	385	420	435	750	
800	410	490	535	555	330	395	430	450	800	
900	435	520	565	585	355	425	465	480	900	
1000	455	545	590	615	375	445	485	500	1000	
1250	495	590	640	665	405	485	525	545	1250	
1500	520	625	680	705	435	520	565	585	1500	
1750	545	650	705	735	455	545	595	615	1750	
2000	560	665	725	750	470	560	610	630	2000	

### 10.1.10 Ampacities of Insulated Conductors Rated 0–2000 Volts, 60°C to 90°C (continued)

Not More Than Three Conductors in Raceway or Cable or Earth  
(Directly Buried), Based on Ambient Temperature of 30°C, 86°F

Ampacity Correction Factors									
Ambient Temp. °C	For ambient temperatures other than 30°C, 86°F, multiply the ampacities shown in the preceding chart by the appropriate factor shown below.								Ambient Temp. °F
31–40	.82	.88	.90	.91	.82	.88	.90	.91	87–104
41–45	.71	.82	.85	.87	.71	.82	.85	.87	105–113
46–50	.58	.75	.80	.82	.58	.75	.80	.82	114–122
51–60	–	.58	.67	.71	–	.58	.67	.71	123–141
61–70	–	.35	.52	.58	–	.35	.52	.58	142–158
71–80	–	–	.30	.41	–	–	.30	.41	159–176

†The overcurrent protection for conductor types marked with an obelisk (†) shall not exceed 15 amperes for 14 AWG, 20 amperes for 12 AWG, and 30 amperes for 10 AWG copper, or 15 amperes for 12 AWG and 25 amperes for 10 AWG aluminum and copper-clad aluminum after any correction factors for ambient temperature and number of conductors have been applied.

\*For dry locations only. See 75°C, 167°F column for wet locations.

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### 10.1.11 Miscellaneous Electrical Formulae

#### Power – A.C. Circuits:

$$\text{Power Factor} = \frac{\text{Watts}}{\text{Volts} \times \text{Amperes}}$$

$$\text{Three-Phase Kilowatts} = \frac{\text{Volts} \times \text{Amperes} \times \text{Power Factor} \times \sqrt{3}}{1000}$$

$$\text{Three-Phase Amperes} = \frac{\text{Volts} \times \text{Amperes} \times \sqrt{3}}{\text{Volts}}$$

$$\text{Three-Phase Amperes} = \frac{746 \times \text{Horsepower}}{\sqrt{3} \times \text{Volts} \times \text{Efficiency} \times \text{Power Factor}}$$

$$\text{Single-Phase Kilowatts} = \frac{\text{Volts} \times \text{Amperes} \times \text{Power Factor}}{1000}$$

$$\text{Single-Phase Amperes} = \frac{746 \times \text{Horsepower}}{\text{Volts} \times \text{Efficiency} \times \text{Power Factor}}$$

#### Motor Application Formulae:

$$\text{Torque (lb.-ft.)} = \frac{\text{Horsepower} \times 5250}{\text{rpm}}$$

For Pumps:

$$\text{Horsepower} = \frac{\text{gpm} \times \text{Head in Feet} \times \text{Specific Gravity}}{3960 \times \text{Efficiency of pump}}$$

For Fans and Blowers:

$$\text{Horsepower} = \frac{\text{cfm} \times \text{Pressure (pounds/sq./ft.)}}{33000 \times \text{Efficiency}}$$

#### Speed:

$$\text{Synchronous rpm} = \frac{\text{Hz} \times 120}{\text{Poles}}$$

$$\text{Percent Slip} = \frac{\text{Synchronous rpm} - \text{Full Load rpm}}{\text{Synchronous rpm}}$$

### 10.2 Appendix – Engine

### 10.2.1 Engine Fuels – Physical Properties

<b>Physical Property @ 60°F (15°C)</b>	<b>Butane</b>	<b>Propane</b>	<b>Natural Gas</b>
Normal Atmospheric State	Gas	Gas	Gas
Boiling Point Initial End	+32°F (0°C) +32°F (0°C)	-44°F (-42°C) -44°F (-42°C)	-259°F (-162°C) -259°F (-162°C)
Heating Value, Btu's per: Gallon (Net – LVH) Gallon (Gross) Cubic Foot (Gas)	94,670 102,032 3264	83,340 91,547 2516	63,310  1000
Density Cubic feet of Gas per Gallon (Liquid)	31.26	36.39	57.75
Weight (lbs.) per Gallon Liquid	4.81	4.24	2.65
Octane Number: Research Motor	94 90	110+ 97	110+
<b>Physical Property @ 60°F (15°C)</b>	<b>Mfgd. or Sewage Gas</b>	<b>Gasoline</b>	<b>Diesel Fuel</b>
Normal Atmospheric State	Gas	Liquid	Liquid
Boiling Point Initial End		+97°F (36°C) +420°F (216°C)	+350°F (177°C) +675°F (357°C)
Heating Value, Btu's per: Gallon (Net – LVH) Gallon (Gross) Cubic Foot (Gas)	600–700	116,400 124,600 6390	130,300 139,000
Density Cubic feet of Gas per Gallon (Liquid)		19.50	
Weight (lbs.) per Gallon Liquid		6.16	7.08
Octane Number: Research Motor		82–100 75–90	

## 10.2.2 Pipe Size Requirements for Gaseous Fuel Systems

The type of fuel, the distance it must travel from gas meter/tank to fuel shutoff solenoid, and the amount consumed by the engine must all be considered when determining fuel line pipe size. To find the correction necessary for the different specific gravity of the particular fuel used refer to "Correction Factors" following. The Gas Flow – Pipe Size Chart is based on a pressure drop of 1/2 in. water column with a normal amount of restriction from fittings, etc. To figure the correct pipe size for a specific installation, refer to the chart and follow the procedure outlined below.

1. Determine length of pipe between gas meter/tank and fuel shutoff solenoid at generator set. *EXAMPLE:* 114 ft. (34.7 m).
2. Find figure closest to pipe length in "Length of Pipe" column on chart. *EXAMPLE:* 125 ft. (38.1 m).
3. Refer to fuel consumption of model specification sheet. Note type of fuel used, and cubic feet per hour (m<sup>3</sup>/hr.) consumption at 100% load. *EXAMPLE:* 70kW, Natural Gas – 1200 ft<sup>3</sup>/hr. (34 m<sup>3</sup>/hr.).
4. Refer to Correction Factors below. Locate factor for specific gravity of fuel used. *EXAMPLE:* Natural Gas specific gravity – .65, correction factor – .962. Gas systems supplied with a gas of specific gravity of 0.7 or less can be sized directly from the table.

### Correction Factors

Fuel	Specific Gravity	Factor
Sewage Gas	0.55	1.040
Natural Gas	0.65	0.962
Air	1.00	0.775
Propane	1.50	0.633
Butane	2.10	0.535

5. Divide consumption figure (from No. 3) by correction factor. *EXAMPLE:* 1200 ft<sup>3</sup>/hr. (34 m<sup>3</sup>/hr.) divided by .962 = 1247 ft<sup>3</sup>/hr. (33 m<sup>3</sup>/hr.).
6. Move vertically across page from determined point in "Length of Pipe" column (125 ft. [38.1 m] in example). Stop at first figure equal to or greater than corrected consumption figure. *EXAMPLE:* 1650 ft.<sup>3</sup>/hr. (47 m<sup>3</sup>/hr.).
7. Move to left column from that figure to determine correct pipe size. *EXAMPLE:* At 1650 ft<sup>3</sup>/hr. (47 m<sup>3</sup>/hr.), Pipe Size – 2-1/2"IPS.

## 10.2.2 Pipe Size Requirements for Gaseous Fuel Systems (cont'd.)

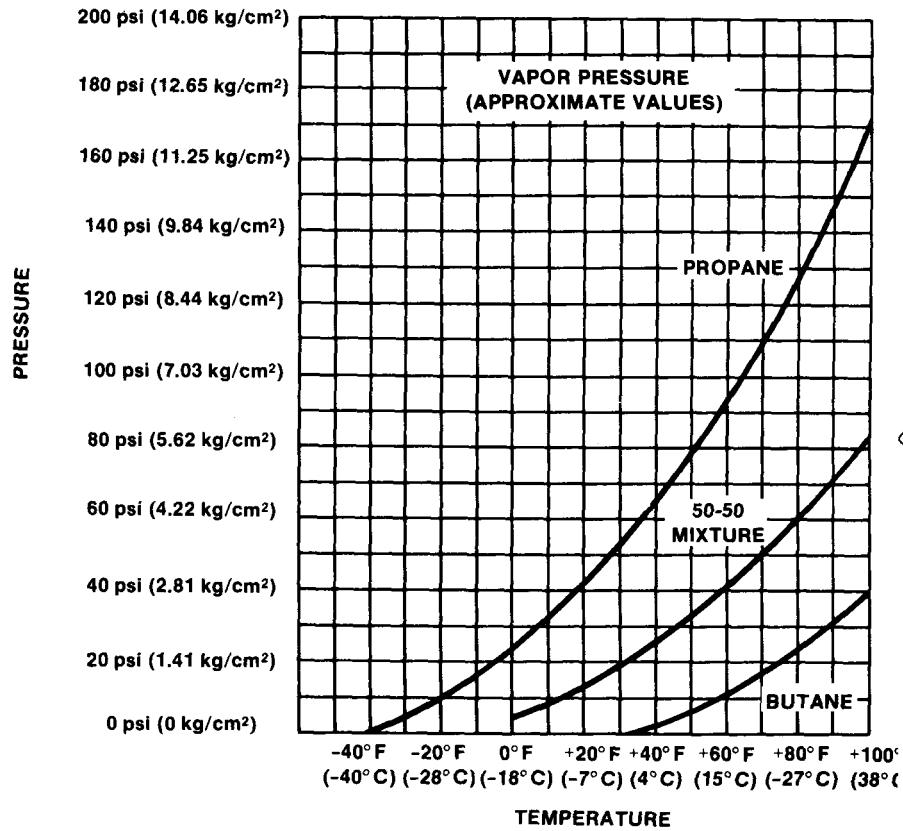
### Maximum Capacity of Pipe in Cubic Feet of Gas per Hour for Gas Pressures of 0.5 Psig or Less and a Pressure Drop of 0.5 Inch Water Column

(Based on a 0.60 Specific Gravity Gas)

Nominal Iron Pipe Size, Inches	Internal Diameter, Inches	Length of Pipe, Feet						
		10	20	30	40	50	60	70
1/4	.364	43	29	24	20	18	16	15
3/8	.493	95	65	52	45	40	36	33
1/2	.622	175	120	97	82	73	66	61
3/4	.824	360	250	200	170	151	138	125
1	1.049	680	465	375	320	285	260	240
1-1/4	1.380	1,400	950	770	660	580	490	460
1-1/2	1.610	2,100	1,460	1,180	990	900	810	750
2	2.067	3,950	2,750	2,200	1,900	1,680	1,520	1,400
2-1/2	2.469	6,300	4,350	3,520	3,000	2,650	2,400	2,250
3	3.068	11,000	7,700	6,250	5,300	4,750	4,300	3,900
4	4.026	23,000	15,800	12,800	10,900	9,700	8,800	8,100

Nominal Iron Pipe Size, Inches	Internal Diameter, Inches	Length of Pipe, Feet						
		80	90	100	125	150	175	200
1/4	.364	14	13	12	11	10	9	8
3/8	.493	31	29	27	24	22	20	19
1/2	.622	57	53	50	44	40	37	35
3/4	.824	118	110	103	93	84	77	72
1	1.049	220	205	195	175	160	145	135
1-1/4	1.380	460	430	400	360	325	300	280
1-1/2	1.610	690	650	620	550	500	460	430
2	2.067	1,300	1,220	1,150	1,020	950	850	800
2-1/2	2.469	2,050	1,950	1,850	1,650	1,500	1,370	1,280
3	3.068	3,700	3,450	3,250	2,950	2,650	2,450	2,280
4	4.026	7,500	7,200	6,700	6,000	5,500	5,000	4,600

### 10.2.3 LP Vapor Pressure Curve



### 10.2.4 Heat Rejection to Ambient Air

#### Dry Exhaust Manifold:

$$\text{Btu/min.} = \frac{(\text{GPH} \times \text{heat value} \times 0.1)}{60} + \text{kW} \times (1 - \text{generator efficiency}) \times 57$$

#### Wet Exhaust Manifold:

$$\text{Btu/min.} = \frac{(\text{GPH} \times \text{heat value} \times 0.06)}{60} + \text{kW} \times (1 - \text{generator efficiency}) \times 57$$

### 10.2.5 Air Flow Required to Dissipate Heat Rejected to Ambient Air

$$\text{cfm} = \frac{\text{Btu/min.}}{0.018 \times \text{°F allowable heat rise}}$$

## 10.2.6 Exhaust System Back Pressure

The total back pressure produced by the complete exhaust system must be determined by calculating the effects of the individual system components and adding them.

The procedure is as follows:

1. Refer to Table 10–1 and determine the part number of the exhaust silencer to be used.
2. Determine the exhaust gas velocity through the silencer. Refer to Table 10–2 for the inlet diameter of the silencer selected in Step 1. Use Table 10–3 to find the corresponding inlet area in square feet. Divide the engine exhaust gas flow (cfm) by the silencer inlet area to get flow velocity in feet-per-minute (engine exhaust gas flow is shown in Table 10–1 and on individual generator set specification sheets).
3. Refer to Table 10–2 for the back pressure reference curve which applies to the silencer selected. Read silencer back pressure from Figure 10–1 for the velocity determined in Step 2.
4. Total the number of elbows and flexible sections to be used in the system between the engine and the exhaust system outlet. Determine the equivalent feet of straight pipe for the elbows and flexible sections from the following:

$$45^\circ \text{ elbows} = \frac{9 \times \text{Diameter (inches)}}{12}$$

$$90^\circ \text{ elbows} = \frac{16 \times \text{Diameter (inches)}}{12}$$

$$\text{Flexible Sections} = \frac{2 \times \text{Diameter (inches)}}{12}$$

(Use the diameter of the silencer inlet from Step 2 for the initial calculation.)

5. Determine total length of straight pipe to be used in exhaust system. Add this to equivalent feet for elbows and flexible sections obtained in Step 4.
6. Refer to Chart 10–1 if pipe size is 4 inches or less, Chart 10–2 if pipe size is 5 inches or larger. Place a straight edge across the chart with the edge in line with the pipe size to be used on the right column and the engine exhaust flow (from Step 2) on the left column. Read back pressure per foot from the center column. Calculate total piping system back pressure by multiplying total equivalent feet of pipe from Step 5, times pressure per foot determined in this step.
7. Add the back pressure of piping determined in Step 6 to back pressure of silencer determined in Step 3. Total should not exceed engine manufacturer's maximum allowable system back pressure given in Table 10–1, or on individual generator set specification sheet. If this total is exceeded, it will be necessary to use either a larger pipe size or silencer, or both. The back pressure calculation should then be repeated to verify that system back pressure will not exceed the limit using the larger component(s).

**Table 10-1. Recommended Silencers**

kW	Fuel	Engine Manufacturer and Model	Engine Outlet Size	Industrial Silencer	Residential Silencer	Critical Silencer	Max. Back Pressure in. of Hg	Exhaust Flow CFM
5	Gas	Kohler 301	1 in.	150201	285732	289714	1.4	77
5	Diesel	MWM D302-1	1-1/4 in	150201	285732	289714	3.0	50
7	Gas	Kohler K582	1-1/2 in.	150201	285732	289714	1.4	70
10	Gas	Ford VSG-411	1-1/2 in.	150201	285732	289714	2.0	65
10	Diesel	MWM D302-2	2 in.	280157	290482	290494	3.0	106
15	Gas	Wisconsin VG4D	1-1/2 in.	150201	285720	289715	1.5	120
15	Diesel	MWM D327-2	2 in.	280157	290482	290494	3.0	125
17	Gas	Ford LSG-423	1-3/4 in.	255332#	-	255333#	1.5	180
20	Gas	Ford LSG-423	1-3/4 in.	255332#	-	255333#	2.5	180
20/30	Diesel	John Deere 4239D	2-1/2 in.	273669	-	290496	2.2	300
				273718#	-	253236#		
30	Gas	Ford LSG-423T	1-3/4 in.	255332#	-	255333#	1.5	240
33/45	Gas	Ford CSG-649	2 in.	253237#	-	253236#	2.5	400
40	Diesel	John Deere 4239D	2-1/2 in.	273669	-	290496	2.2	300
				273718#	-	253236#		
50	Gas	Ford LSG-875	3 in.	253237#	-	253236#	1.5	660
50/60	Diesel	John Deere 4239T	4 in.	273669	-	290496	2.2	438
				273718#	-	253236#		
60/70	Gas	Ford LSG-875	3 in.	253237#	-	253236#	1.5	685
80	Gas	Ford LSG-875	3 in.	253614#	-	253613#	1.5	700
80	Diesel	John Deere 6359T	4 in.	273670	-	290490	2.2	675
				273719#	-	273720#		
100	Gas	Ford LSG-875	3 in.	253614#	-	253613#	1.5	854
100	Diesel	John Deere 6059T	4 in.	273670	-	290490	2.2	708
				273719#	-	273720#		
125	Diesel	John Deere 6076T	4 in.	273670	-	290490	2.2	1110
				273719#	-	273720#		
150	Diesel	John Deere 6076A	4 in.	-	290488	290493	2.2	1440
				-	273843#	273844#		
180	Diesel	John Deere 6076A	4 in.	-	290488	290493	2.2	1640
				-	273843#	273844#		
200	Diesel	Detroit Diesel 6-71T	6 in.	-	290488	291533	2.0	2430
				-	273843#	274294#		
230	Diesel	Detroit Diesel 6V-92T	6 in.	-	290488	290493	2.0	2670
				-	273843#	274294#		
250	Diesel	Detroit Diesel 6V-92TA	6 in.	-	290488	291533	2.0	2470
				-	274293#	274294#		
275/300	Diesel	Detroit Diesel 6V-92TA	6 in.	-	291532	291533	2.0	3040
				-	274293#	274294#		
350	Diesel	Detroit Diesel 8V-92TA	6 in.	-	291532	291533	2.0	4180
				-	274293#	274294#		
400	Diesel	Detroit Diesel 8V-92TTA	8 in.	-	291532	291533	2.0	4180
				-	274293#	274296#		
450	Diesel	Detroit Diesel 12V-92T	8 in.	-	291532	291533	2.0	5440
				-	274293#	274294#		

NOTE: All silencers are end inlet/end outlet unless identified by (#) which are side inlet/end outlet.

**Table 10–1. Recommended Silencers (cont'd.)**

kW	Fuel	Engine Manufacturer and Model	Engine Outlet Size	Industrial Silencer	Residential Silencer	Critical Silencer	Max. Back Pressure in. of Hg	Exhaust Flow CFM
500/600	Diesel	Detroit Diesel 12V–92TA	8 in.	–	291532 274293#	291533 274294#	2.0	6080
750/800	Diesel	Detroit Diesel 16V–92TA	8 in.	–	291532 274295#	293701 274296#	2.0	8490
900	Diesel	Detroit Diesel 12V–149T1	8 in.	–	293700 274295#	293701 274298#	2.5	9000
1000	Diesel	Detroit Diesel 12V–149T1	8 in.	–	293700 274295#	293701 274298#	2.5	9500
1200	Diesel	Detroit Diesel 12V–149T1B	8 in.	–	293700 274295#	293701 274298#	2.5	11100
1500	Diesel	Detroit Diesel 16V–149T1B	10 in.	–	274291 274297#	274292 274298#	2.5	14980

NOTE: All silencers are end inlet/end outlet unless identified by (#) which are side inlet/end outlet.

**Table 10–2. Silencer Dimensions**

Part Number	Back Pressure Ref. Curve	Overall Length (in.)	Diameter (in.)	Inlet (in. NPT)	Outlet (in. NPT)	Part Number	Back Pressure Ref. Curve	Overall Length (in.)	Diameter (in.)	Inlet (in. NPT)	Outlet (in. NPT)
150201	C	16–1/2	4–5/8	1–1/2	1–1/2	274295	B	88	22–1/8	10	10
253236	A	38	8–7/8	3	3	274296	A	83	26–1/8	10	10
253237	C	29–1/2	8–1/2	3*	3*	274297	B	83	26–1/8	12	12
253613	A	60–7/8	12–1/8	4*	4*	274298	A	108	30–1/8	12	12
253614	C	32–1/4	10–1/8	4*	4*	280157	C	25–1/8	6–5/8	2	2
255332	C	24–1/8	6–1/8	1–7/8*	1–7/8*	285720	B	34–1/4	7	2	2
255333	A	32–5/8	8–1/8	1–7/8*	1–7/8*	285732	B	28	6	1–1/2	1–1/2
273669	C	36–5/8	8–1/2	3	3	289714	B	26	7	1–1/2	1–1/2
273670	C	38	10–1/8	4	4	289715	B	25	10–1/4	2	2
273718	C	33–5/8	8–1/2	3	3	290482	B	35–5/8	8–1/8	2	2
273719	C	34–3/4	9	4	4	290488	B	68–1/2	14–1/8	6	6
273720	A	60–7/8	12–1/8	4	4	290490	A	66–5/8	12–1/8	4	4
273843	B	61–3/8	14–1/8	6	6	290493	A	84	16–1/8	6	6
273844	A	76–3/4	16–1/8	6	6	290494	A	44	9	2	2
274291	B	87	26–1/8	12	12	290496	A	55–5/8	11–1/8	3	3
274292	A	112	30–1/8	12	12	291532	B	67–1/4	22–1/8	8	8
274293	B	60	22–1/8	8	8	291533	A	89–1/4	22–1/8	8	8
274294	A	82	22–1/8	8	8	293700	B	92	22–1/8	10	10
* Inside Diameter – Slip Fit						293701	A	87	26–1/8	10	10

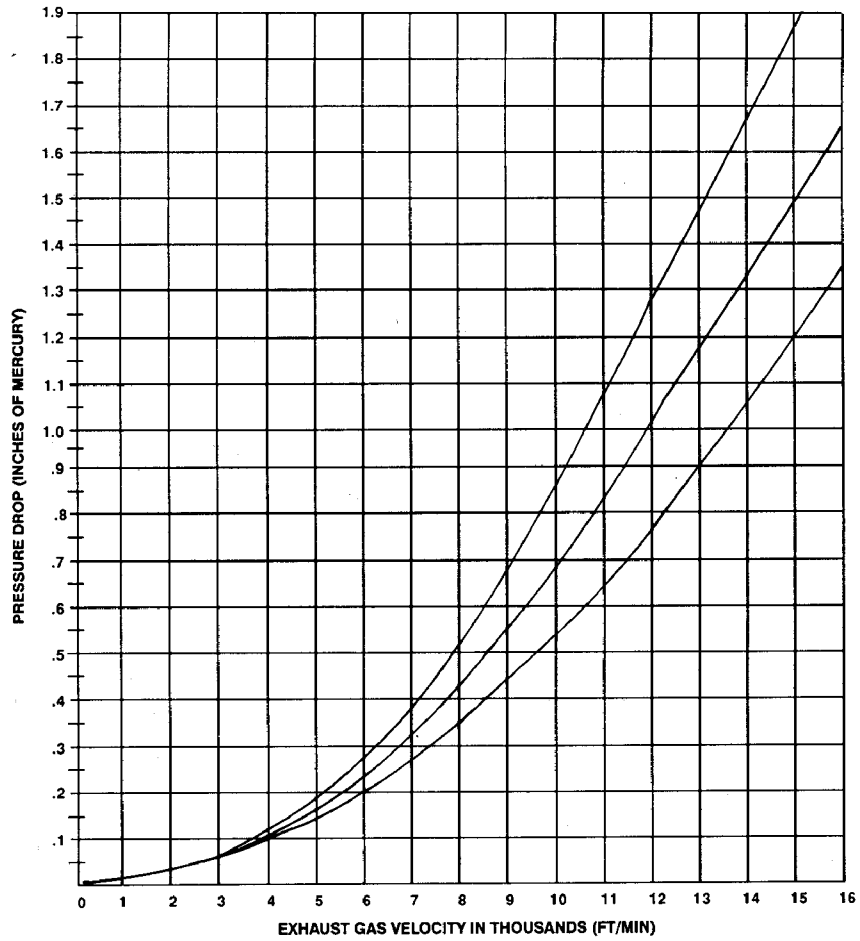
**Table 10–3. Cross Sectional Area for Standard Silencer Sizes**

Pipe Size – NPT	1 in.	1–1/4 in.	1–1/2 in.	2 in.	2–1/2 in.	3 in.
Inlet Area – ft <sup>2</sup>	.006	.0104	.0141	.0233	.0332	.0513

Pipe Size – NPT	4 in.	5 in.	6 in.	8 in.	10 in.	12 in.
Inlet Area – ft <sup>2</sup>	.0884	.139	.201	.347	.548	.777

**Figure 10–1. Silencer Pressure Drop**

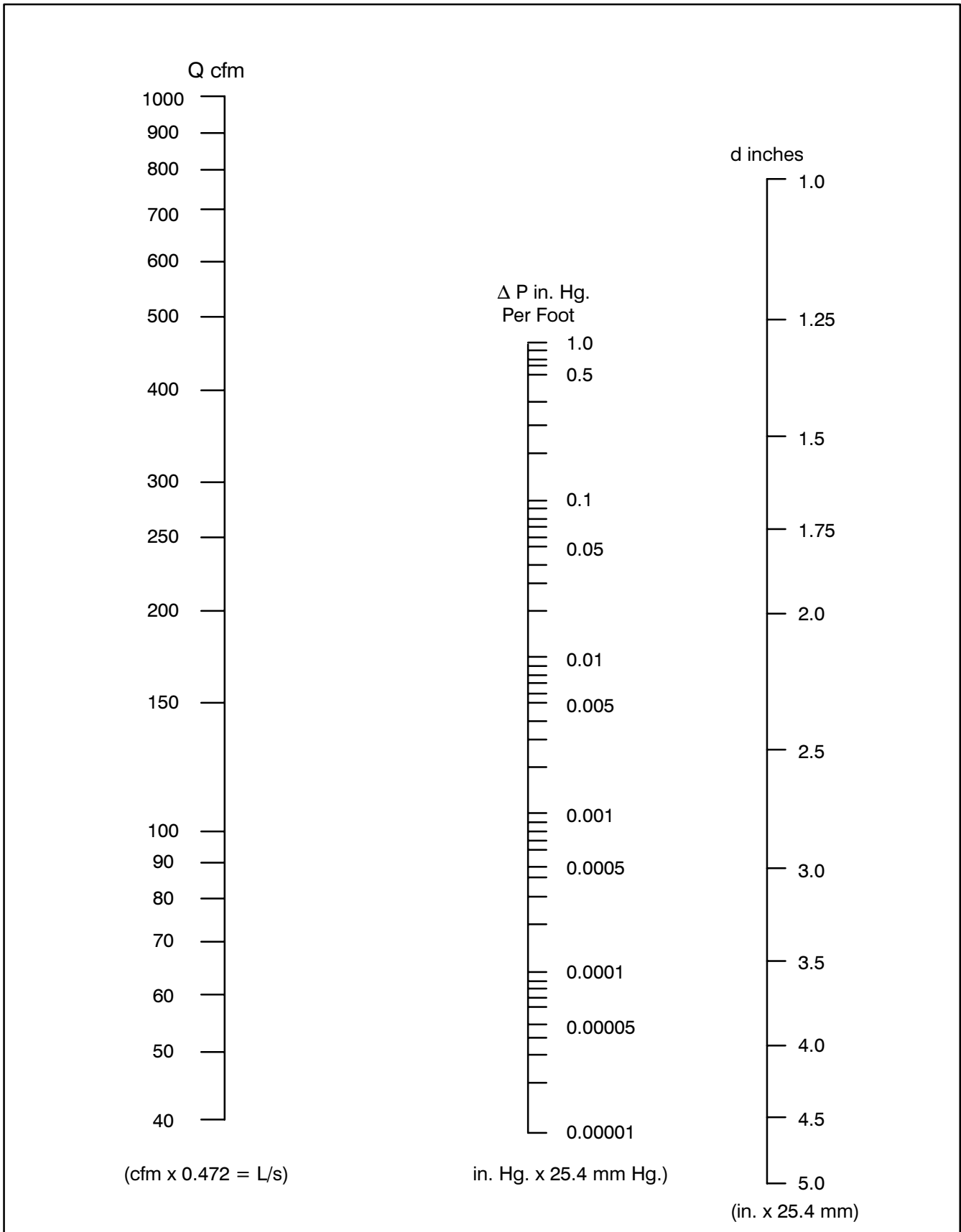
Figure 10-1. Silencer Pressure Drop



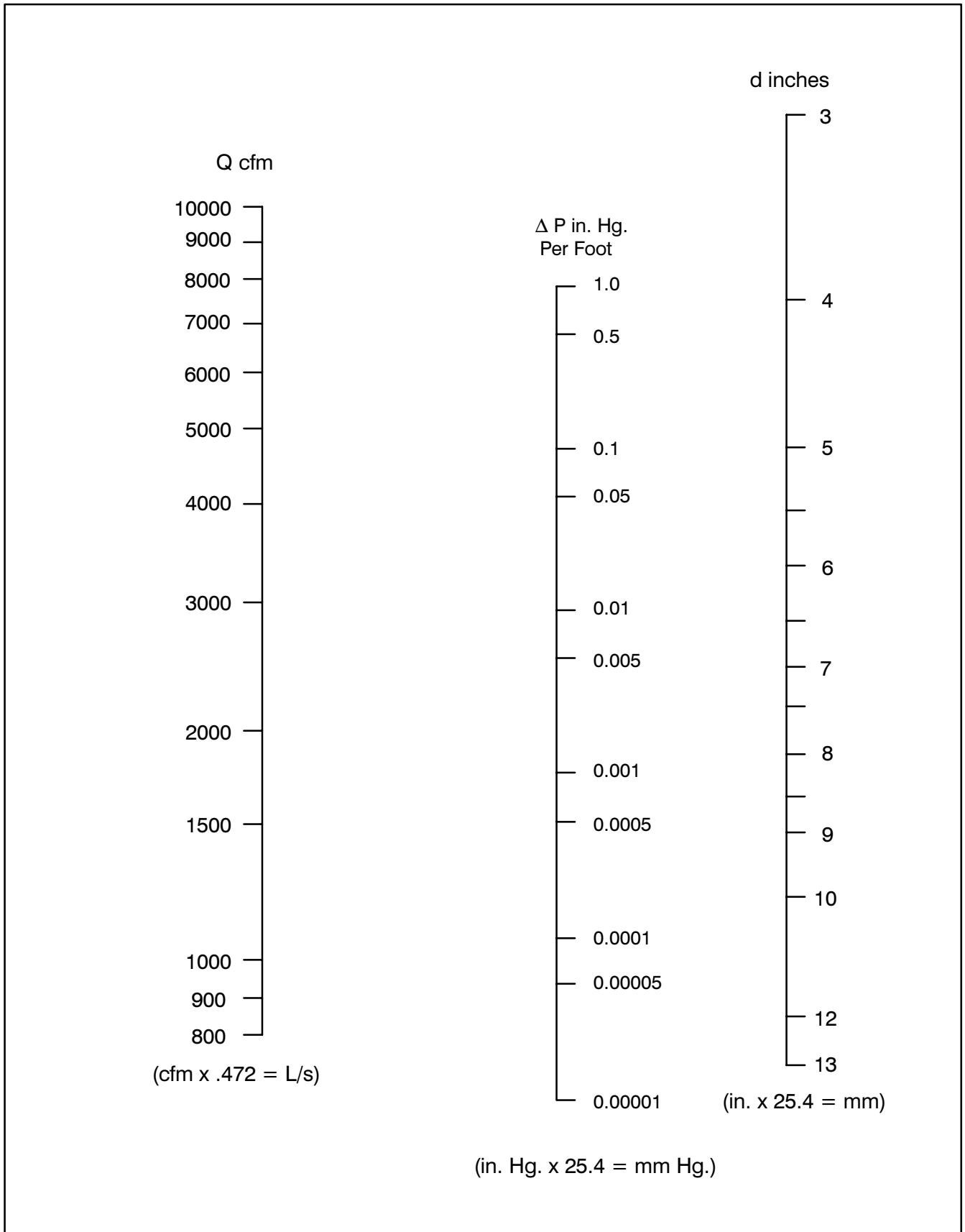
NOTE

When figuring silencer pressure drop for side inlet, add 3 in. of water (0.22 in. mercury) to back pressure shown on Figure 10-1.

**Chart 10-1. Back Pressure Per Foot**



**Chart 10-2. Back Pressure Per Foot**



## 10.3 Appendix – Conversion Factors

### 10.3.1 Area

1 sq. foot = 144 sq. inches  
1 sq. yard = .836 sq. meters  
1 sq. meter = 1.196 sq. yards

1 sq. ft. = 0.0929 sq. meters  
1 sq. inch = 6.452 sq. cm  
1 sq. cm = .155 sq. inch

### 10.3.2 Angle

1 quadrant = 90 degrees  
1 quadrant = 1.57 radians  
1 radian = 57.3 degrees

1 degree = .0175 radian  
1 minute = .01667 degree  
1 minute =  $2.9 \times 10^4$  radian

### 10.3.3 Length

1 yard = .9144 meters  
1 meter = 3.28 feet  
1 meter = 39.37 inches

1 foot = .3048 meters  
1 inch = 2.54 centimeters  
1 centimeter = .394 inch

### 10.3.4 Weight

1 short ton = 2000 pounds  
1 short ton = 907.2 kilograms  
1 kilogram = 2.205 pounds

1 pound = 453.6 grams  
1 ounce = 28.35 grams  
1 gram = .0353 ounces

### 10.3.5 Dry Volume

1 cu. meter = 1.308 cu. yards  
1 cu. yard = .7646 cu. meters

1 cu. meter = 35.31 cu. feet  
1 cu. foot = .0283 cu. meters

### 10.3.6 Liquid Volume

1 U.S. gallon = 3.785 liters  
1 liter = .2642 U.S. gallons

1 quart = .9463 liters  
1 liter = 1.057 U.S. quarts

### 10.3.7 Power

1 horsepower = .746 kW  
1 horsepower = 33000 ft. lb./min.  
1 horsepower = 550 ft. lb./sec.  
1 ft. lb. = 0.138 kgm

1 Btu/hour = .293 watts  
1 Btu = 252 gram-calories  
1 Btu = 778.17 ft. lbs.  
1 Btu = 1.05506 kJ

### 10.3.8 Pressure

$$1 \text{ psi} = 0.070 \text{ kg/cm}^2$$

$$1 \text{ psi} = 6.895 \text{ kPa}$$

$$1 \text{ in. H}_2\text{O} = 0.0732 \text{ in. Hg}$$

$$1 \text{ in. Hg} = 13.66 \text{ in. H}_2\text{O}$$

### 10.3.9 Temperature Conversion

$$^{\circ}\text{C} = \frac{(^{\circ}\text{F} - 32)}{1.8}$$

$$^{\circ}\text{F} = (^{\circ}\text{C} \times 1.8) + 32$$

$$^{\circ}\text{K} = ^{\circ}\text{C} + 273.15$$

$$^{\circ}\text{K} = \frac{(^{\circ}\text{F} + 459.67)}{1.8}$$

Locate known temperature in  $^{\circ}\text{C}/^{\circ}\text{F}$  column. Read converted temperature in  $^{\circ}\text{C}$  or  $^{\circ}\text{F}$  column.

$^{\circ}\text{C}$	$^{\circ}\text{C}/^{\circ}\text{F}$	$^{\circ}\text{F}$
-45.4	-50	-58
-42.7	-45	-49
-40	-40	-40
-37.2	-35	-31
-34.4	-30	-22
-32.2	-25	-13
-29.4	-20	-4
-26.6	-15	5
-23.8	-10	14
-20.5	-5	14
-17.8	0	32
-15	5	41
-12.2	10	50
-9.4	15	59
-6.7	20	68
-3.9	25	77
-1.1	30	86
1.7	35	95
4.4	40	104
7.2	45	113
10	50	122
12.8	55	131

$^{\circ}\text{C}$	$^{\circ}\text{C}/^{\circ}\text{F}$	$^{\circ}\text{F}$
15.5	60	140
18.3	65	149
21.1	70	158
23.9	75	167
26.6	80	176
29.4	85	185
32.2	90	194
36	95	203
37.8	100	212
40.5	105	221
43.4	110	230
46.1	115	239
48.9	120	248
51.6	125	257
54.4	130	266
57.1	135	275
60	140	284
62.7	145	293
65.5	150	302
68.3	155	311
71	160	320
73.8	165	329

$^{\circ}\text{C}$	$^{\circ}\text{C}/^{\circ}\text{F}$	$^{\circ}\text{F}$
76.5	170	338
79.3	175	347
82.1	180	366
85	185	365
87.6	190	374
90.4	195	383
93.2	200	392
96	205	401
96.8	210	410
101.6	215	419
104.4	220	428
107.2	225	437
110	230	446
112.8	235	455
115.6	240	464
118.2	245	473
120.9	250	482
123.7	255	491
126.5	260	500
129.3	265	509
132.2	270	518
135	275	527

## 10.4 Appendix – Standard And Code–Making Organizations

American National Standards Institute, Inc. (ANSI)  
1430 Broadway  
New York, NY 10018 USA

British Standards Institution (BSI)  
2 Park Street  
London W1A 2BS, England

Canadian Standards Association/Association Canadienne de Normalisation (CSA)  
178 Rexdale Boulevard  
Rexdale, Ontario, Canada M9W 1R3

Deutsches Institut für Normung e.V. (DIN)  
Burggrafenstrasse 4–10, D–1000 Berlin 30 Germany

Electrical Generating Systems Assn. (EGSA)  
Box 9257  
Coral Springs, FL 33065 USA

Institute of Electrical and Electronics Engineers, Inc. (IEEE)  
345 East 47th Street  
New York, NY 10017 USA

National Electrical Manufacturers Assn. (NEMA)  
2101 L Street N.W.  
Washington, DC 20037 USA

National Fire Protection Assn. (NFPA)  
60 Batterymarch Park  
Quincy, MA 02269 USA

Society of Automotive Engineers, Inc. (SAE)  
400 Commonwealth Drive  
Warrendale, PA 15096 USA

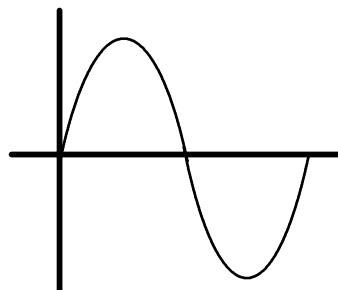
Underwriters Laboratories, Inc. (UL)  
333 Pfingsten Road  
Northbrook, IL 60062 USA

## 11. Glossary

**11.1. Alternating Current – (Symbol AC):** A current which periodically reverses in direction and changes its magnitude as it flows through a conductor or electrical circuit.

The magnitude of an alternating current rises from zero to maximum value in one direction, returns to zero, and then follows the same variation in the opposite direction. One complete alternation is one cycle or 360 electrical degrees. In the case of 60-cycle alternating current the cycle is completed 60 times per second.

Alternating current is far more widely used than direct current because it can be easily transformed from one voltage to another for transmission and use, and electricity is always generated in revolving machines as alternating current. A DC generator is basically an AC generator with the addition of a device called a commutator which changes AC to DC.



AC Wave

**11.2. Alternator:** A term frequently used for AC generator. "AC generator" is preferred.

**11.3. Ambient Temperature:** The temperature of the surrounding air in which the equipment operates. This may be expressed in degrees Celsius or Fahrenheit. Normally, ambient temperature is expressed in degrees Celsius when referring to electrical equipment. Degrees Fahrenheit is more frequently used for engines and mechanical equipment.

**11.4. Ammeter:** This device measures current. Current measuring instruments must be connected in series with a circuit and never in parallel with it. AC ammeters are often used with current transformers to reduce meter current. Typical transformer ratios are 100:5 and 500:5.

**11.5. Amortisseur Winding:** The revolving field structures of synchronous machines are provided with poles with faces slotted parallel to the shaft. Conducting bars are built into these slots, and the ends of the bars are short circuited to form a structure similar to the squirrel-cage winding of an induction motor. These windings dampen out the tendency of the generator to "hunt" with load changes. They are required for all revolving field generators which are driven by internal combustion engines and which may be required to operate in parallel and/or single-phase.

**11.6. Ampere – (Symbol I, A, i, a):** A unit of measurement of the rate of flow of electricity. One ampere of current flows when a pressure of one volt is applied across an impedance of one ohm.

**11.7. Apparent Power – (Symbol kVA, VA):** When the current and voltage are not in phase, i.e., voltage and current do not reach corresponding values at the same instant, the resultant product of voltage and current is apparent power instead of actual power. Apparent power is measured in volt-amperes or kilo-volt-amperes. Actual power (kW) is the product of kVA and the power factor.

**11.8. Armature Reaction:** We know that if current flows through a coil surrounding an iron core, a magnet is formed. This is true of the stator as well as of the rotor. Current flowing through the stator coils will result in magnetic poles, in general, opposite in position and direction to the poles of the rotor. This characteristic of the stator, tending to oppose and to force down flux developed by the rotor, is known as armature reaction.

**11.9. Automatic Synchronizer:** This device, in its simplest form, is a magnetic-type control relay which will automatically close the generator switch when the conditions for paralleling are satisfied.

**11.10. Automatic Transfer Switch:** This switch is a double-throw, electrically operated switch which will, on a given signal, open one set of contacts and throw over to the second set of contacts. As normally used in hospitals, television and radio stations, and other applications where automatic emergency power is used, the switch automatically transfers a load from a normal source of electrical power to an emergency source on failure of the normal. The load is automatically returned to the normal source when that source is restored to proper operating condition. Relays for delayed operation, engine starting, manual reset, and similar features are available. As normally used, the switch is electrically operated, mechanically held, and has a positive interlock to prevent the two sets of contacts being engaged at the same time.

**11.11. American Wire Gauge – (Symbol AWG):** Wires are manufactured in sizes numbered according to a table, known as the American Wire Gauge. (This gauge was formerly known as Brown & Sharp, abbreviated B&S). As the wire diameters become smaller, the gauge numbers become larger. The ratio of the diameter corresponding to a given gauge number to the diameter corresponding to the next higher gauge number is a constant 1.123. The cross sectional area varies as the square of the diameter. The cross sectional area is approximately halved or doubled every three gauge numbers. The cross sectional area is increased or decreased 10 times for every 10 gauge numbers. Using No. 10 wire as a base (approximate diameter 100 mils, approximate cross sectional area 10,400 circular mils and 1 ohm per 1000 feet), it is possible to quickly estimate cross sectional area and wire size without referring directly to a wire table.

**11.12. Brake Mean Effective Pressure (BMEP):** Is the theoretical average pressure on the piston of an engine during the power stroke when the engine is producing a given number of horsepower. It is usually expressed in pounds per square inch. \*For two-cycle engines, divide result by 2.

$$*BMEP = \frac{792,000}{\text{Displacement (cu. in.)}} \times \frac{\text{Horsepower}}{\text{RPM}}$$

The value is strictly a calculation and cannot be measured, since the actual cylinder pressure is constantly changing. The mean or average pressure is used to compare engines on the assumption that the lower the BMEP, the greater the expected engine life and reliability. In practice, it is not a reliable indicator of engine performance for several reasons.

The formula favors older design engines with relatively low power output per cubic inch of displacement in comparison to more modern designs. Modern engines do operate with higher average cylinder pressures, but bearings and other engine parts are designed to withstand these pressures, but bearings and other engine parts are designed to withstand these pressures and still provide equal or greater life and reliability than their predecessors. The formula also implies greater reliability when the same engine produces the same power at a higher speed. Other things being equal, it is doubtful that a 60 Hz. generator set operating at 1800 is more reliable than a comparable 50 Hz generator set operating at 1500 rpm. Likewise, it is highly unlikely that any generator set operating at 3600 rpm will be more reliable than one operating at 1800 rpm even if the latter engine has a significantly higher BMEP. The BMEP for any given generator set will vary with the rating which changes depending on fuel, attitude, and temperature. The BMEP is also affected by generator efficiency which varies with voltage and load.

**11.13. Broad Range:** Generators having a range within which the output voltage can be adjusted are said to be "broad range" machines. For example a generator rated 416–480 volt can be adjusted to put out anywhere between 416–volts and 480–volts.

**11.14. Capacitance (Symbol C):** If voltage is applied to two conductors separated by an insulator, the insulator will take an electrical charge. If an alternating voltage is applied, an alternating current will flow into and out of the

insulator (in this case called a dielectric) as it charges and discharges with reversal of applied voltage. On alternating current circuits the charge is a maximum, but the current becomes zero, as the voltage reaches a maximum. The current change thus precedes the voltage change, or the current leads the voltage; this being opposite to inductance. The characteristics of being able to take an electrical charge is known as capacity (C) and is measured in Farads.

**11.15. Capacitive Reactance – (Symbol  $X_c$ ):** When considered in an AC circuit with a definite frequency, capacitance results in a capacitive reactance which is measured in ohms. Capacitive reactance causes the current to lead the voltage by 90 electrical degrees. The value in ohms is determined by the formula:

$$X_C = 1/2 \pi f c$$

Where:

f = Frequency

c = Capacitance (Farads)

$\pi = 3.1416$

**11.16. Charge:** There are two types of charge, positive (+, proton) and negative (–, electron). An atom with electrons missing is unbalanced—it has more protons than electrons and is, therefore, positively charged. The same analysis applies to an atom having more electrons than it should—it is negatively charged. Like charges repel each other. Unlike charges attract each other.

**11.17. Circuit Breaker:** A special switch used to protect electrical circuits is called a circuit breaker. It is generally designed to open or break the circuit when some abnormal condition, such as an overload occurs. The circuit breaker usually has a higher initial cost than a fused knife switch, but has the advantages of opening the circuit faster and can be reset easier after the cause of the overload has been removed. Circuit breakers are difficult to size as necessary to protect an engine-driven generator. A circuit breaker rating of 125% generator rating is usually used, however, engine power usually limits generator load to less than 125%.

**11.18. Compound:** A **chemical** combination of elements that cannot be separated by simple physical means such as by dissolving one out and leaving the others or by filtering or distillation, etc. There must be a chemical reaction to separate a compound.

**11.19. Continuous Standby:** The rating at which a generator set may be operated for the duration of a power outage. No overload capacity is guaranteed.

**11.20. Cross Current Compensation:** Cross current compensation is used to divide reactive kVA equally between generators operating in parallel, and is accomplished by a current transformer. Division of reactive kVA between AC generators operating in parallel is a function of generator excitation. When operating AC generators in parallel, it is necessary that the reactive kVA outputs of the individual generators be equalized. This is to prevent one generator from being overloaded by carrying all of the reactive kVA because its individual excitation is higher than that of the other machines. It is accomplished by the current transformer limiting or controlling the voltage sensitive element of each voltage regulator with reactive current. This reactive current divides the kVAR among the generators according to their rating and enables the generators to all operate at the same power factor. Frequently, reactive droop compensation is used without the cross-current connection.

**11.21. Current:** Current is a flow of electricity. DC flows from negative to positive. AC alternates in direction. The standard symbol for current is "I" and it is measured in Amperes (Amps). The current flow theory is used conventionally in power and the current direction is positive to negative—opposite the flow of electrons.

**11.22. Cyclic Irregularity:** Cyclic irregularity is the ratio of magnitude of fluctuation of speed over the average speed. This is a calculated value based upon firing diagrams and the mass of the system. Torsional characteristics are not involved and the system is assumed rigid.

$$\text{Cyclic Irregularity Ratio} = \frac{\text{Max. Instantaneous Speed} - \text{Min. Instantaneous Speed}}{\text{Average Speed}}$$

Its application to specific problems is critical in very large, low speed engines driving generators having many poles (18 or 36), or small 4 or 6 pole sets having less than one firing stroke per 2 cycles, where the instantaneous speed of the flywheel may drop considerably between firing impulses.

**11.23. Delta Connection:** The delta connection is so named because it resembles the Greek letter. To make a delta connection, the finish end of the first winding is connected to the start of the second winding, the finish of the second winding is connected to the start of the third winding and the finished of the third winding is connected to he start of the first winding.

Modern generators are normally connected in a wye or star pattern rather than delta for several reasons. The delta-connected generator has no advantages over the wye-connected machine, and the wye machine has the advantage of being able to bring out the neutral wire. Also, in the delta-connected machine it is difficult to design the generator to keep the circulating currents low in magnitude. Normally the wye-connected machine will give better wave form characteristics than the delta-connected generator. In the wye machine the harmonics tend to cancel each other out when line-to-line voltage is checked between two legs or phases. In the delta-connected machine the line-to-line voltage is across one coil or set of coils and there is no cancellation of harmonic effects, except that the third harmonic and its multiples are shorted out, and do not appear in the output. Delta-connected generators are used to supply 120/240-volt, three-phase/single-phase, 4-wire systems.

**11.24. Dielectric Test:** National Electrical Manufacturers Association (NEMA) standards provide that each generator of 250 watts output or more be given the following high potential factory test to check generator insulation.

Stator Windings—Apply two times the normal voltage plus 1000-volts.

Field Windings—Apply ten times the exciter voltage, but in no case less than 1500-volts.

**11.25. Direct Current – (Symbol DC):** A current that flows in one direction only for a given voltage and electrical resistance. A direct current is usually constant in magnitude for a given load. Electricity is generated as alternating current in revolving machines. In DC generators the AC current is changed to direct current by commutation. While DC voltage is substantially constant in a DC generator, a slight ripple is due to commutation.

**11.26. Distribution Panel:** Multicircuit switchgear panel used to feed power to individual loads.

**11.27. Drip-Proof:** Per NEMA MG1-1.20, a drip-proof generator is an open machine in which the ventilating openings are so constructed that drops of liquid or solid particles falling on the machine at any angle not greater than 15 degrees from the vertical cannot enter the machine either directly or by striking and running along a horizontal or inwardly inclined surface.

**11.28. Dual Range Generator:** Any 10-wire or 12-wire generator can be connected such that the stator windings in each phase are in series or parallel. When in series, the output voltage will be high. When in parallel, the output voltage will be one-half of the high voltage, but the current capacity will be doubled. A typical rating would be 240/480-volt. If the machine is also broad range, a typical rating would be 208-240/ 416-480-volt.

**11.29. Efficiency:** Input times efficiency equals output divided by the output plus losses. Efficiencies of generators are commonly given at 4/4, 3/4, and 1/2 load. Unless otherwise stated, the efficiency of the generator is always based on the kVA and power factor at which it is rated.

**11.30. Element:** A substance which cannot be broken down into a simpler substance which will retain the original characteristics. For example, copper, hydrogen, and oxygen are all elements; they cannot be reduced to anything simpler without destroying their properties.

**11.31. EMF:** Electromotive Force. See Volt.

**11.32. Exciter:** Synchronous AC generators require DC field excitation current. Most such generators today are furnished with exciters which are AC generators having rectified output.

**11.33. Flywheel Effect:** Internal combustion engine-driven generator sets must be provided with flywheel effect to meet the following conditions:

1. Harmful torsional vibrations must be avoided;
2. Speed variation, when operating alone, must be reduced to a point where objectionable variations in voltage or frequency are avoided;
3. Operation in parallel with a large system must be possible.
4. The neutral frequency must differ from forcing frequencies, of generator sets with which it is operating in parallel, by at least 20%.

In accordance with present practice, it is the responsibility of the engine manufacturer or set assembler to determine that the proper flywheel effect is provided to meet the conditions outlined above. The generator manufacturer will provide information on shaft stiffness and other details which are required in these calculations.

**11.34. Frequency – (Symbol Hz):** The number of cycles per second the current alternates is called the frequency. Most common frequency in the United States is 60 Hz. 50 Hz current is used in most other countries. Generators are also made in special high frequencies for certain applications. The unit for measurement of frequency is the Hertz equivalent to one cycle per second.

**11.35. Harmonics:** Any irregularity in a wave form can be resolved into a fundamental sine wave of the system frequency and one or more sine waves of higher frequencies which modify the fundamental. In AC circuits only odd harmonics occur. The possible harmonics for various stator connections follow:

Connection	Grounded	Possible Harmonics
Wye	Yes	1, 3, 5, 7, 9, 11, etc.
Wye	No	1, 5, 7, 11, etc.
Delta		3, 9, 15, 21, etc (circulating) and 1, 5, 7, 9, etc. (line)

**11.36. Impedance – (Symbol Z):** The total opposition to the flow of alternating current in a circuit that contains resistance and reactance is called impedance. Strictly speaking the reactance component takes into account both the capacitive and inductive components, but for all practical purposes in power circuits, we can neglect the capacitive reactance ( $X_C$ ).

$$\text{Total Impedance} = Z = \sqrt{R^2 + (X_L - X_C)^2}$$

R = pure resistance

$X_L$  = inductive reactance

$X_C$  = capacitive reactance

If we neglect  $X_C$  the formula reduces to:

$$\sqrt{R^2 + X_L^2}$$

**11.37. Inductance (L):** Any device with iron in the magnetic structure has what amounts to magnetic inertia. This inertia opposes any change in current. It is quite apparent on alternating current since the voltage is continually in instantaneous value and this inertia has the effect of continually causing change in current to a lag behind changes in voltage. The characteristic of a circuit which causes this magnetic inertia is known as self inductance; it is measured in Henries and the symbol is "L."

**Inductive Reactance (XL):** When considered in an AC circuit with a definite frequency, inductance results in an inductive reactance (XL), which is measured in ohms and is determined as follows:

$$X_L \text{ (ohms)} = 2 \pi f L$$

**11.38. Inertia:** Inertia means the resistance of a mass to a change in velocity. A mass in motion will tend to travel in a straight line and at the same speed unless acted upon by an external force. Inertia is the force that pushes you forward when an automobile is decelerating or comes to a sudden stop.

**11.39. Interruptible Service:** A plan whereby an electric utility, elects to interrupt service to a specific customer at any time. Special rates are often available to customers under such agreements.

**11.40. Insulation:** Insulating materials are used in all electrical machinery to isolate and maintain the flow of current through the conductors. Temperature influences the life of insulation. The failure of insulating materials is generally mechanical, resulting from extended exposure to moisture, foreign materials, and higher temperatures than the limiting temperature of the materials used. Most insulation used in today's generators is Class F, with a permissible temperature rise of 189°F (105°C) continuous, and 234°F (130°C) standby over a 104°F (40°C) ambient.

**11.41. Isochronous Governor:** A governor that maintains constant engine speed from no-load to full-load. It is a zero-droop governor. Typical accuracy is +/- .25% of rated speed.

**11.42. Kilowatt – (Symbol kW):** Power is the rate of doing work. Electric power is expressed in Watts or kiloWatts (1000 Watts). One horsepower equals 0.746 kW or approximately 3/4 kW. Inversely one kW equals 1.34 horsepower. Actual power (kW) equals apparent power (kVA) times power factor (expressed as a decimal).

$$\text{Horsepower} = \frac{\text{kW}}{.746 \times \text{Generator Efficiency}}$$

To calculate the kW input of an electric motor:

$$\text{Kilowatts} = \frac{\text{Motor Horsepower} \times .746}{\text{Motor Efficiency}}$$

A rule of thumb based on 90% generator efficiency:

$$\text{Engine hp} = \text{Generator kW} \times 1.5$$

For single-phase generator:

$$\text{kW} = \frac{\text{Volts} \times \text{Amperes} \times \text{Power Factor}}{1000}$$

For three-phase generator:

$$\text{kW} = \frac{\text{Volts} \times \text{Amperes} \times \text{Power Factor} \times \sqrt{3}}{1000}$$

**11.43. Kilowatt Hour – (Symbol kWh):** The measure of electrical energy is the kilowatt hour. One kilowatt of electrical power consumed for one hour equals one kilowatt-hour (kWh) of electric energy. This energy can be measured by a kilowatt-hour meter which is a small, sensitive electric motor, the rotor speed of which is proportional to the kilowatts flowing in the circuit to which the meter is connected. Revolutions of the motor are transmitted through a gear train to pointers on a register dial calibrated in kWh. Kilowatt hour meters can be used to give approximate instantaneous kW load readings by measuring the rate of disc rotation.

**11.44. Kilovolt-Ampere – (Symbol kVA):** In AC circuits, kVA is the measure of the apparent power flowing in the circuit. To find the true or actual power (kW), the kVA must be multiplied by the power factor (expressed as a decimal).

**11.45. Magnetism:** A phenomenon of certain materials (iron, nickel, cobalt), such that, when the atoms are aligned within the materials, a field of force is set up which can effect other magnetic materials that are within that field. One end of a magnet is called the north pole and the other end is the south pole.

**11.46. Magnetic Field:** The lines of force due to the proper alignment of the atoms are called magnetic flux lines and make up the magnetic field. By convention, the lines begin at the north pole and end at the south pole.

**11.47. Magnetizing Current:** Transformers, motors and other electro-magnetic devices containing iron in the magnetic circuit must be magnetized in order to operate. It is customary to speak of the lagging inductive current as a magnetizing current.

**11.48. Molecule:** The smallest particle of a compound that retains the properties of that compound. A molecule is made up of two or more atoms depending on the compound. One molecule of water (H<sub>2</sub>O) is made up of two hydrogen atoms and one oxygen atom.

**11.49. National Electrical Code® – (NEC®):** The National Electrical Code® is a volume of standard electrical rules prepared by the National Fire Protection Association. The code contains basic minimum provisions considered necessary for safety. These minimum rules are modified, expanded and interpreted by local electrical safety governing bodies. Local electrical and building inspectors in a particular community should be consulted for answers to specific questions and interpretation of the local codes covering a particular installation.

**11.50. National Electrical Manufacturers Association – (NEMA):** This is an organization of electrical manufacturers set up to provide limited information pertaining to certain types of electrical equipment. A main function of the organization is to establish uniform nomenclature throughout the industry and to promote manufacturing economics. NEMA Standards do not cover traction generators, arc welding generators or the self-regulated type generator because these are specialized types of equipment from manufacturers setting acceptable standards.

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**11.51. NEMA Design B:** Normal-Torque, general purpose induction motors. These motors comprise about 90% of all induction motors.

**11.52. NEMA Design C:** High-Starting-Torque, low-starting-current motors—often used for starting and running loaded compressors, pumps, etc., where a high starting torque is required.

**11.53. NEMA Design D:** High-Starting-Torque, high-slip motors—are usually found in loads having a flywheel effect, such as elevators, hoists, punch presses, etc.

**11.54. Ohm:** The unit which represents the amount of electrical resistance or impedance to the flow of electric current.

**11.55. Ohm's Law:** This is the fundamental law of electricity. The current in any electrical circuit is inversely proportional to the resistance of the circuit and directly proportional to the electromotive force in the circuit. This law may be expressed in three ways:

**For DC:**

$$I = \frac{E}{R}$$

$$R = \frac{E}{I}$$

$$E = IR$$

**I = current is amperes**

**E = potential difference in volts**

**R = resistance in ohms**

**For AC:**

$$I = \frac{E}{Z}$$

$$Z = \frac{E}{I}$$

$$E = IZ$$

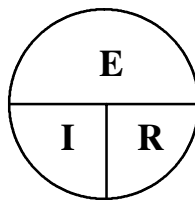
**I = current is amperes**

**E = potential difference in volts**

**Z = electrical impedance in ohms. For direct current Z is numerically equal to the resistance R. In AC circuits Z is made up of resistance R and reactance X.**

**(See impedance)**

One volt is required to cause one ampere of electric current to flow through an impedance of one ohm.



With this diagram you cover the value desired with your finger and the proper mathematical relationship remains showing. For example, if you want to determine the resistance (R), you find

$$\frac{E}{I} \text{ Therefore, } R = \frac{E}{I}$$

**11.56. Overload:** NEMA Standard MG1-16.41—Overload Capability – States: General purpose, prime power synchronous generators shall be capable of carrying 10% overload for two hours out of any 24. It is recognized that the temperature rise will differ from rated values when generators are subjected to overload condition.

**11.57. Overspeed:** NEMA Standards for Synchronous Generators MG1-16.46 – Overspeeds states: General purpose synchronous generators shall be so constructed that, in an emergency, not to exceed 1 minute, generators rated for 1800 rpm or less, will withstand an overspeed of 25% without mechanical injury.

**11.58. Parallel Operation:** Units to be paralleled must have the same frequency, the same number of phases, the same voltage, the same phase rotation. The latter merely means that the voltages across the terminals must reach their maximum and minimum values in the same order. Otherwise, the magnetic forces would try to turn the rotors in opposite directions.

**11.59. Power:** DC power is always the product of Volts times Amps and is expressed in Watts.

$$\text{Watts} = \text{Volts} \times \text{Amps} \quad (P = E \times I)$$

AC output of a generator is the apparent power and is equal to the Volts times Amps, as measured at the generator.

$$\text{11.60. Apparent Power (kVA)} = \frac{EI}{1000}$$

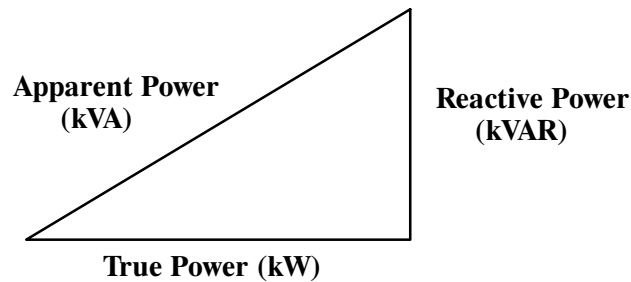
The apparent power (kVA) developed by the generator is used in two places:

1. Useable power for the load (kW).
2. Lost power due to reactance (kVAR) of the load.

The power used in the load is called the useable or real power and is expressed in Watts or kiloWatts (kW). Whenever the words Watts or kW is used, it means useable power.

The power lost because of the reactance is called reactive power or kilo Volt–Amps–reactive (kVAR). This lost power does no work.

The following triangle is a graphic representation of the relationships between apparent, real, and reactive power.



**11.61. Power Conditioner:** A device which removes undesirable transients and distortion from a power source.

**11.62. Power Factor—(Symbol PF):** Power factor is the ratio for expressing what part of the apparent power (kVA) flowing in an AC circuit is true power (kW).

$$\text{Power Factor} = \frac{\text{kW}}{\text{kVA}}$$

At unity power factor the kW and kVA are equal. At any power other than unity (leading or lagging power factor), the kVA are greater than the kW. When this is true there is a reactive component of the total kVA flowing in the circuit.

Mathematically, power factor is equal to the cosine of the angle by which the current leads or lags the voltage.

With a low power factor load, the reactive component is larger and thus more kVA capacity is required of the generator supplying the power. For a given kW load the increase in kVA caused by a low power factor means increased Amperes through the coils. The capacity (kVA) of generators, transformers, etc., is normally limited by the current capacity and heating limits of the coils.

**11.63. Prime Power:** The rating at which a generator may be operated continuously as a sole source of power, with intermittent overloads up to the standby rating.

**11.64. Reactive Droop Compensation:** A system similar to cross current compensation (see definition) in which an artificial voltage droop is introduced on reactive power, only as necessary to force generators to divide reactive load when operating in parallel. No cross-current connection between generators is required. This system is usually preferred to cross-current compensation.

**11.65. Reactive Kilovolt-Amperes – (Symbol RkVA or kVAR):** Reactive kVA is the measure of the reactive or magnetizing component of the total kVA flowing in a circuit. The out-of-phase or reactive component serves the important function of magnetizing the magnetic equipment, i.e., induction motors, transformers, etc., during a portion of each cycle. The magnitude of this component is determined by the proportion of magnetic equipment to the pure resistance loads which determines the amount of the current lags the voltage. Mathematically the tangent of the angle of lag is equal to the reactive kVA divided by the kW. In a three-phase circuit:

$$\text{kVAR} = \frac{\sqrt{3} \times \text{volts} \times \text{reactive amperes}}{1000}$$

**11.66. Rectifier:** If only alternating current is available, it may be converted into direct current by using devices which offer a high resistance to the flow of current in one direction and a low resistance to the flow in the opposite direction. These devices are called rectifiers. A common rectifier is the diode.

**11.67. Regulation:** Voltage regulation is defined as the rise in voltage (field current and speed remaining constant), when full load is thrown off the generator.

$$\% \text{ Voltage Regulation} = \frac{(\text{voltage at no load} - \text{voltage at full load}) \times 100}{\text{voltage at full load}}$$

Speed regulation is similar.

$$\% \text{ speed regulation} = \frac{(\text{no load rpm} - \text{full load rpm}) \times 100}{\text{full load rpm}}$$

**11.68. Resistance:** Electrical resistance is that quality of an electric circuit that opposes the flow of current through it. In the electric circuit, the larger the diameter of the wires the lower will be their electrical resistance to the flow of current through them. Temperature also affects the resistance of electrical conductors to some extent. In most conductors (copper, aluminum, etc.) the resistance increases with temperature.

**11.69. Resistor:** A device used to limit current flow.

**11.70. Rheostat:** An adjustable resistance used for the purpose of controlling, limiting or adjusting the amount of current flow in a circuit is called a rheostat or potentiometer. Rheostats are often so constructed that the resistance in the circuit may be varied by turning a knob or moving a lever.

**11.71. Right-Hand Rule:** When using the "current flow theory" the current flows from positive to negative. If the thumb of the right hand is pointed along the conductor in the direction of current flow then the fingers, when wrapped around the conductor, will indicate the direction of the magnetic lines of force.

**11.72. Short-Circuit Ratio:** The ratio of the exciter field current for rated open circuit armature voltage at rated frequency to the field current for rated armature current on sustained symmetrical short circuit at rated frequency is called the short-circuit ratio of the generator.

**11.73. Single-Phase:** A single-phase AC circuit is generally served by 2 or 3 wires. Single-phase is most commonly used for lighting and fractional-horsepower loads. Single-phase may be obtained from a single-phase generator, from a three-phase generator between any phase and neutral, or between any two phases.

**11.74. Star Connection:** See Wye Connection.

**11.75. Starting kVA:** Induction motors demand more kVA to start than is required for steady state operation. "Starting kVA" is used to define the condition of this extra demand, which normally lasts for a brief period of seconds or less. It is a transient effect, but of great importance. Standard motors have a code letter indicating starting kVA per hp.

**11.76. Synchronous Speed:** The number of poles in an AC generator is directly related to the synchronous or operating speed. Any speed can be obtained that corresponds to any even number or pair of poles and the desired frequency.

$$N = \frac{120f}{P}$$

**f = frequency in cycles per second**  
**N = synchronous speed in RPM**  
**P = Number of poles**

60 Hz.		50 Hz.	
rpm	Number of Poles	rpm	Number of Poles
1800	4	1500	4
1200	6	1000	6
900	8		

To maintain rated frequency, the speed of the generator must be maintained as shown above.

**11.77. Synchroscope:** A synchroscope is an instrument for indicating when generators are in proper phase relation for connecting in parallel and at the same time showing whether the incoming generator is running fast or slow. The instrument has two independent circuits, one being connected to the incoming generator and the other to the bus. The magnetic fields set up by these two circuits cause the hand to rotate. When the hand comes to a standstill at the mark on the dial indicating synchronism, the switch connecting the generator to the bus line may be closed.

**11.78. Telephone Influence Factor – (Symbol TIF):** This is the measure of the inductive effect of a power system on nearby telephone circuits as represented by the noise level in the telephone receiver. Technically, the TIF of a three-phase synchronous machine is the ratio of the square root of the sum of the squares of the weighted RMS values of the fundamental and non-triple series harmonics to the TMS value of the normal no-load voltage wave. Telephone receivers are normally designed at a resonant frequency of approximately 1100 Hz. The human ear is very sensitive to the frequency of 1100 Hz. A high TIF indicates presence of harmonics which show as a high pitched hum in a nearby telephone circuit. A 60-cycle pure sine wave has a TIF of unity. A commercially acceptable normal balanced TIF for generators with kVA ratings from 6.25 to 62.5 is 250. From 62.5 to 500 kVA, acceptable TIF is 150.

**11.79. Temperature Rating:** A generator with a temperature rise rating of 189°F (105°C), is one in which the manufacturer guarantees that the temperature of the generator will not rise more than 189°F (105°C) above an ambient (surrounding air) temperature of 104°F (40°C), when carrying full rated load continuously, at an altitude not exceeding 3300 ft. (1006m) above sea-level. The term "rated load" implies that the voltage and power factor are as called for by the nameplate of the generator. The same generator is permitted (by NEMA MG1-1640) to have a 234°F (130°C) temperature rise at a standby rating.

The temperature rise of 189°F (105°C) over ambient temperature given above, is based on measurement of rotor and stator temperature by resistance.

**11.80. Three-Phase:** A three-phase AC circuit is a combination of three electrical circuits with a voltage phase difference of 120 electrical degrees (1/3 cycle). A three-phase system may either be 3-wire, or 4-wire (3-wires and a neutral).

**11.81. Time Constant:** Any device with iron in the magnetic circuit has what amounts to magnetic inertia. This inertia opposes any change of current even though the voltage is changing. If a generator is short circuited, the time required for the short-circuit current to drop to 36.8% of the original maximum short-circuit current is called the generator time constant. This constant is important in determining the voltage change and voltage recovery of a generator when a sudden load change occurs.

**11.82. Torsional Vibration:** Torsional vibration may be found in the shafting of any rotating machinery in which there is cyclic torque variation. A torsional vibration is a periodic oscillation about a central axis. Should this vibration reach dangerous proportions at a so-called critical speed, serious damage could be inflicted on the associated machinery. The torsional stress of engine generator sets must be calculated and/or tested to assure satisfactory performance.

**11.83. Uninterruptible Power Supply (UPS):** A system designed to provide power without delay or transients during any period that the normal power supply is incapable of performing acceptably.

**11.84. Volt – (Symbol V or E):** The unit for measuring electric pressure or electromotive force required to force an electric current to flow. Voltage actually shows the difference in electromotive force between two points in a circuit. One volt is required to force one ampere through one ohm of resistance. In an AC circuit having a true sine wave the RMS (root mean square) or effective volts is equal to 0.707 times the maximum volts. The usual AC voltmeter generally measures effective volts, and unless otherwise specified, voltage values are always given as effective volts.

**11.85. Voltages – Standard:** The electrical manufacturing industry has standardized to a certain extent on voltages. Standard generator voltages are higher than motor or nominal voltages to allow for some voltage drop in the distribution lines. As a general rule, AC electric motors are designed to operate successfully on plus or minus 10% of nameplate or nominal voltage. Most externally regulated generators will operate within plus or minus 2% of nameplate voltage.

### Alternating Current Standard Voltage

Generator	Motor or Nominal	
120 (1,4)	115	(1) 3-phase, 3-wire
120/240 (2,3)	115/230	
208/120 (2)	200	(2) 3-phase, 4-wire
240 (1,4)	230	
480/277 (2)	460	(3) Single-phase, 3-wire
480 (1)	460	
600 (1)	575	(4) Single-phase, 2-wire
2400 (1)	2300	
4160/2400 (2)	4000	

**11.86. Voltage Dip:** "Voltage Dip" is the momentary drop of generator output voltage that occurs whenever a load is added to the system. There is a momentary increase in output voltage whenever a load is removed from the system. This is called "Voltage Rise." "Voltage Rise" is seldom of concern with an adequate voltage regulator.

**11.87. Voltmeter:** This instrument when connected across the line will indicate the potential difference in volts. Actually, these instruments usually operate on the same principle as an ammeter except that a high resistance is placed in series with the coil so that the current flow is limited when the meter is connected across the line. The current in the coil is therefore proportional to the line voltage. The scale is not uniformly divided, as on DC voltmeters, for the deflections are very nearly proportional to the square of the voltage. The divisions at the lower part of the scale are crowded so that poor precision is obtained. The divisions at the middle and upper portions of the scale, however, are usually such that they may be read with precision.

**11.88. Watt:** See kilowatt.

**11.89. Wattmeter:** Electric power is measured by means of a wattmeter. Because electric power is a function of current and voltage, a wattmeter must have two elements, one for current and the other for voltage. The power indicated by a wattmeter is a result of the voltage across the load, the current through the load, and the power factor on the load. In effect, the wattmeter multiplies the voltage, current and power factor to indicate the true power. When using a wattmeter, take all precautions mentioned for ammeters and voltmeters. In addition, make sure that neither the current nor voltage exceeds the wattmeter capacity. Test the circuit with a voltmeter and ammeter before connecting a wattmeter. The wattmeter scale deflection does not indicate whether the meter is overloaded or not. The voltage may be low and the current high and still indicate a true power within the meter scale limit, but the current element may be overloaded.

**11.90. Wave Form:** The shape of the voltage wave which a generator produces is largely under the control of the designer, although most machines are designed to produce waves that closely approximate the true sine wave. Such factors as hysteresis, rotor and stator slotting, and armature reactance prevent a perfect sine from being generated.

**11.91. Wye Connection:** In a wye or star-connected generator the three start ends of each single-phase winding are connected together to a common neutral point, and the opposite or finish ends are connected to the line terminals. When both low-voltage, single-phase loads and higher-voltage, three-phase loads are encountered, a line to the neutral or common point will serve as a common return circuit for all three phases, i.e., 120/208-volt, 3-phase, 4-wire machine. In a wye-connected machine the voltage from line to line is equal to the product of 1.73 and the line to neutral voltage. For example, in a 208-volt machine the line to neutral voltage is  $\frac{208}{\sqrt{3}}$  or 120 volts.

With a 4-wire, 120/208-volt generator, motors can be operated on the 3-phase, 208-volt leads, and 120-volt lighting loads can be connected anywhere in the circuit between the various lines and the neutral. If this is done it is important to balance the 120-volt, single-phase load as much as possible so that all of the added lighting load is not connected to one single-phase leg or coil.

**11.92. Wound-Rotor Motor:** The wound-rotor or slip-ring induction motor is used when it is necessary to vary the rotor resistance in order to limit the starting current or to vary the motor speed. The high resistance is used for starting and when the motor comes up to speed the resistance is cut out. The running characteristics are about the same as a standard squirrel-cage motor. The wound-rotor motor gives high starting torque with comparatively low starting current. On the other hand, its initial and maintenance costs are high and the external resistance is bulky.

Normally a wound-rotor motor will have an instantaneous starting current of 150–160% of rated full-load current and the current during acceleration is approximately 125% of full-load current. With the high resistance in the starting circuit the power factor is high on start, so the usual limiting factor in the selection of a generator set is kW capacity of the engine-generator set.

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