Application Manual
Liquid Cooled Generator Sets

T–030f

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CHAPTER 1 CONTENTS

1 – INTRODUCTION

Overview

The world is becoming more and more electricity–dependent. Electric power supplies are critical to almost any facility, and a reliable electric supply is vital to an increasing number of facilities. Facilities such as large office buildings and factories, as well as telecommunications installations, data centers, and Internet service providers are dependent on electric power that is available 24 hours a day, seven days a week with essentially no interruptions. This need is also fueled by the continuing proliferation of electronic computers in data processing, process control, life support systems, and global communications — all of which require a continuous, uninterrupted flow of electrical energy. Beyond reliability concerns, there are growing economic incentives favoring the installation of on–site engine–generator sets. As a result, engine–generator sets are routinely being specified for new building construction as well as for retrofits. They provide emergency power in the event of utility power failure and can be used to reduce the cost of electricity where the local utility rate structure and policy make that a viable option. Because of their important role, generator sets must be specified and applied in such a way as to provide reliable electrical power of the quality and capacity required.

Prime power electrical supplies, to both remote communities that are not served by a commercial electric power grid, and to those sites where the commercial power grid is for some reason not available for extended periods of time, are also becoming a requirement, rather than a luxury, to many users.

Whatever the use of the on–site power is intended to be, reliability of service from the on–site equipment, performance, and cost–effectiveness are primary concerns of users. The purpose of this manual is to provide guidance to system and facility designers in the selection of appropriate equipment for a specific facility, and the design of the facility, so that these common system needs are fulfilled.

About this Manual

This manual describes the specification and application of stationary, liquid–cooled, diesel and spark ignited engine–generator sets – referred to as “generator sets” in this manual. This manual consists of seven major sections: Preliminary Design, Electrical Load Impact on Generator Sizing, Equipment Selection, Electrical Design, Mechanical Design and Appendix.

Preliminary Design describes preliminary considerations for a generator set project. Equipment and installation requirements vary depending on the reasons for having the generator set and its intended use. When designing a generator set installation, Reviewing and understanding these reasons is useful as a starting point for the system design and equipment choices.

Electrical Load Impact on Generator Sizing explains various load types, their characteristics and their impact on the generator set size, operation and equipment choices. Also covered is the topic of sequence of load connection.

Equipment Selection explains the fundamental parts of a generator set and related equipment, their functions and interrelationships, and criteria for choices. Functional characteristics, criteria for choices and optional equipment needed are discussed.

Electrical Design covers installation design of the generator and related electrical systems, their interface with the facility along with load and generator protection topics. The electrical design and planning of the on–site generation system is critical for proper system operation and reliability.

Mechanical Design covers installation design for the generator set and related mechanical systems along with their interface with the facility. The mechanical design and planning of the on–site generation system is critical for proper system operation and reliability. Topics include foundation and mounting, exhaust systems, cooling systems, ventilation, fuel systems, noise reduction, fire protection and equipment room.

The Appendix contains numerous useful topics including an overview of GenSize sizing software and the Power Suite contents. Also included are a discussion of reduced voltage motor starting and useful references to world voltages, maintenance concerns, formulas, Code and Standards references and a glossary of terms.

This manual describes the application of stationary gensets. This manual does not cover the application of stationary–designed commercial gensets into mobile applications, which are generally considered to be an unintended application. Cummins Power Generation (CPG) does not approve any mobile application of its commercial gensets except for those applications specifically designed and tested by CPG. If CPG's distributors or customers desire to apply stationary–designed commercial gensets into other mobile applications, then they should do so only after extensive analysis, testing, and clear communication with the end–use customer regarding possible limitations on the use or design life of the genset. CPG cannot ensure that the attributes of the product are the proper and sufficient ones for customers' mobile applications, therefore each customer must satisfy itself on that point. Each customer is responsible for the design and function of its own applications and installation.

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Related Application Manuals

Every generator set installation will require power transfer equipment, either transfer switch(es) or paralleling switchgear. The proper system for the job and its proper application are crucial to reliable and safe operation. The following Cummins Power Generation application manuals address related aspects of standby and emergency power systems. Because these manuals cover aspects requiring decisions that must be taken early in the design process, they should be reviewed along with this manual.

Application Manual T–011–Automatic Power Transfer Systems. Many applications utilize multiple power sources to enhance electric power system reliability. These often include both utility (mains) service and generator set service to critical loads. T–011 covers the various types of power transfer systems available, and considerations for their use and application. Careful consideration of power switching system at the start of a project will enable a designer to offer the most economically viable and most reliable service to the facility user.

Application Manual T–016–Paralleling and Paralleling Switch Gear. Paralleling equipment makes two or more generator sets perform as one large set. This can be economically advantageous, especially when the total load is greater than 1000 kW. The decision whether to parallel sets must be made in the early stages of design, especially if space and the need for future expansion are critical factors.

Safety

Safety should be a primary concern of the facility design engineer. Safety involves two aspects: safe operation of the generator set itself (and its accessories) and reliable operation of the system. Reliable operation of the system is related to safety because equipment affecting life and health is often dependent on the generator set – such as hospital life–support systems, emergency egress lighting, building ventilators, elevators, fire pumps, security and communications.

Refer to the Technical Reference section for information on applicable electrical and fire codes for North America, Central America and Europe. Standards, and the codes that reference them, are periodically updated, requiring continual review. Compliance with all applicable codes is the responsibility of the facility design engineer. For example, some areas may require a certificate–of–need, zoning permit, building permit or other site–specific certificate. Be sure to check with all local governmental authorities early in the planning process.

NOTE: While the information in this and related manuals is intended to be accurate and useful, there is no substitute for the judgment of a skilled, experienced facility design professional. Each end user must determine whether the selected generator set and emergency/standby system is proper for the application.

CHAPTER 2 CONTENTS

2 – PRELIMINARY DESIGN

Overview

Designing a generator set installation requires consideration of equipment and installation requirements. These vary depending on the reasons for having the generator set and its intended use. Reviewing and understanding these reasons is an appropriate starting point for the system design and equipment choices.

Power Requirements

General Requirements

The need for on–site generation of emergency and standby electricity is usually driven by mandatory installations to meet building code requirements, and/or risk of economic loss due to loss of electric power.

Mandatory installations for emergency and standby power follow, from building code requirements referenced by the regulations of federal, state, local, or any other governmental authority. These installations are justified on the basis of safety to human life, where loss of the normal power supply would introduce life safety or health hazards. Voluntary installations of standby power for economic reasons are typically justified by a mitigation of the risk of loss of services, data, or other valuable assets. Mandatory and voluntary installations of on–site generation may be justified on the basis of favorable load curtailment rates offered by the electric utility. The same on–site generation system may be used for both of these general needs, provided that life safety needs have priority, e.g. generator capacity and load transfer arrangements.

Specific Requirements

A wide range of specific requirements will result in the need for on–site electric generation systems. Some common needs are outlined below.

Lighting: Egress lighting for evacuation, illuminated exit signs, security lighting, warning lights, operating room lighting, elevator car lighting, generator room lighting, etc.

Control Power: Control power for boilers, air compressors, and other equipment with critical functions.

Transportation: Elevators for fire department use.

Mechanical Systems: Smoke control and pressurization fans, waste water treatment, etc.

Heating: Critical process heat.

Refrigeration: Blood banks, food storage, etc.

Production: Critical process power for laboratories, pharmaceutical production processes, etc.

Space Conditioning: Cooling for computer equipment rooms, cooling and heating for vulnerable people, ventilation of hazardous atmospheres, ventilation of pollutants or biological contamination, etc.

Fire Protection: Fire pumps, jockey pumps, alarm and annunciation.

Data Processing: UPS systems and cooling to prevent data loss, memory loss, program corruption.

Life Support: Hospitals, nursing homes, and other health care facilities.

Communications Systems: 911 service, police and fire stations, hi–rise building public address systems, etc.

Signal Systems: Railroad, ship, and air traffic control.

System Types and Ratings

On–site power generation systems can be classified by type and generating equipment rating. The generating equipment is rated using standby, prime, and continuous ratings. The ratings definitions are important to understand when applying the equipment. Please refer to the ratings guidelines that follow. The type of on–site generation system and the appropriate rating to use is based on the application. See **Table 2–1** and descriptions of the following.

Emergency Systems

Emergency systems are generally installed as required for public safety and mandated by law. They are typically intended to provide power and lighting for short periods of time for three purposes: to permit safe evacuation of buildings, for life support and critical equipment for vulnerable people, or for critical communications systems and facilities used for public safety. Code requirements typically specify the minimum load equipment to be served.

Legally–Required Standby

Legally–required standby systems are generally installed as mandated by legal requirements for public safety. These systems are typically intended to provide power and lighting for short periods of time where necessary to prevent hazards or to facilitate fire–fighting operations. Code requirements typically specify the minimum load equipment to be served.

Optional Standby

Optional Standby systems are generally installed where safety is not at stake, but loss of power could cause an economic loss of business or revenue, interrupt a critical process, or cause an inconvenience or discomfort. These systems are typically installed in data centers, farms, commercial and industrial buildings, and residences. The owner of the system is permitted to select the loads connected to the system.

In addition to providing a standby source of power in case of loss of a normal power supply, on–site generation systems are also used for the following purposes.

Prime Power

Prime power installations use on–site generation in lieu of a utility electricity supply, typically where utility power is not available. A simple prime power system uses at least two generator sets and a transfer switch to transfer supply to the loads between them. One or the other of the generator sets runs continuously with a variable load, and the second generator set serves as backup in case of a failure, and to allow downtime for required maintenance. A changeover clock within the transfer switch alternates the lead generator set on a predetermined interval.

Peak Shaving

Peak shaving installations use on–site generation to reduce or flatten peak electricity use for the purpose of saving money on energy demand charges. Peak shaving systems require a controller that starts and runs the on–site generator at the appropriate times to flatten the user’s peak demands. Generation installed for standby purposes may also be used for peak shaving.

Rate Curtailment

Rate curtailment installations use on–site generation in accordance with electric energy rate agreements with the serving electric utility. In exchange for favorable energy rates the user agrees to run the generators and assume a specified amount of load (kW) at times determined by the utility, typically not to exceed a specified number of hours per year. Generation installed for standby purposes may also be used for rate curtailment.

Continuous Base Load

Continuous base load installations use on–site generation to supply a constant power (kW) typically through interconnection equipment into a utility grid. These installations are usually owned by electric utilities or under their control.

Co–Generation

Often, continuous base load generation is used in Co–Gen application. Simply put, Co–Gen is utilizing both the direct electricity generation and waste exhaust heat to substitute for utility supplied energy. The waste heat is captured and either used directly or converted to electricity.

	Generator Set Rating		
	Standby	**Prime**	**Continuous**
System Type	Emergency	Prime Power	Base Load
	Legally–required Standby	Peak Shaving	Co–Gen
	Optional Standby	Rate Curtailment	

Table 2–1. Rating and System Types

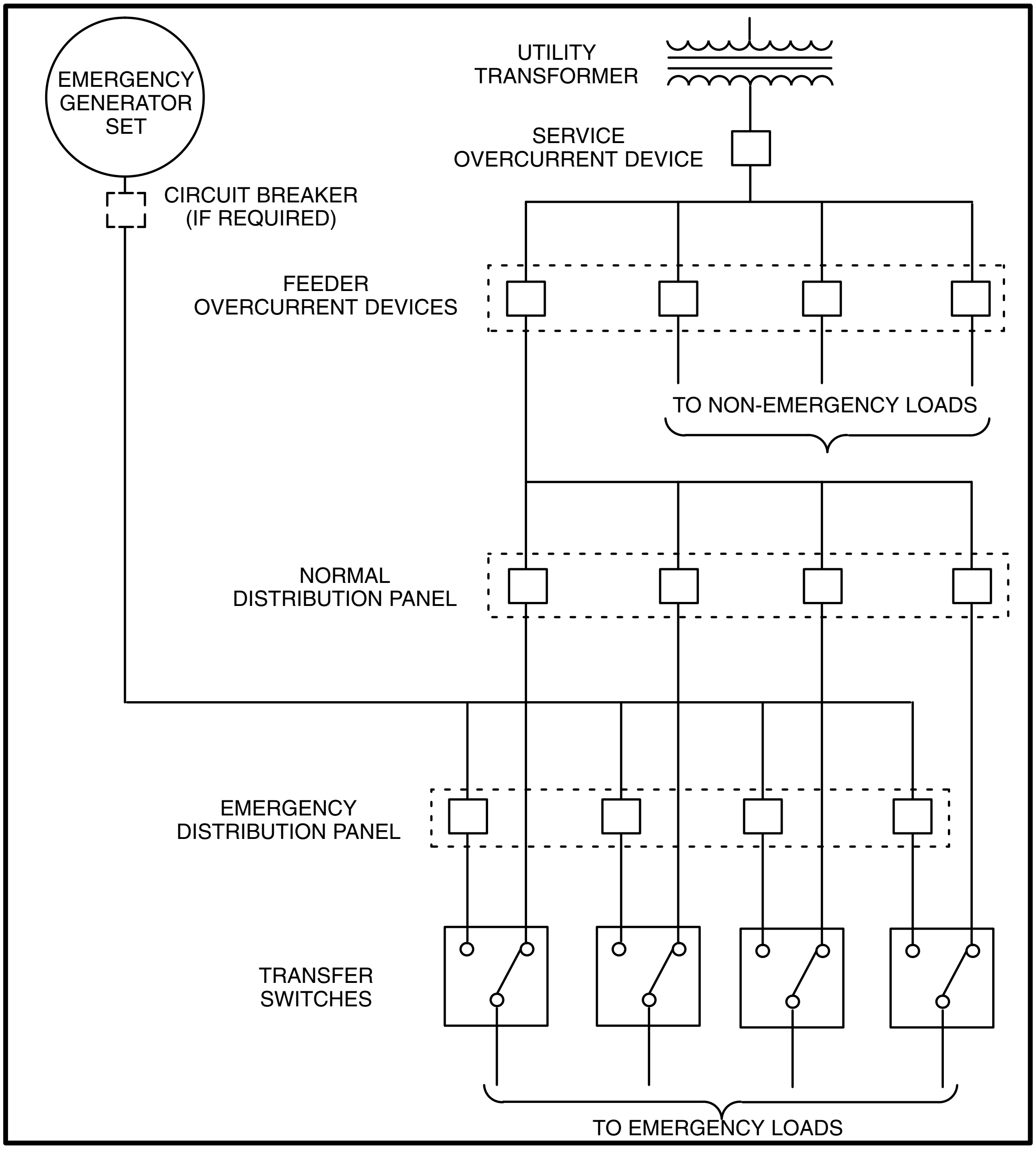


Figure 2–1. Typical One-Line Diagram of an Electrical Distribution System

The One–Line Diagram

A one–line electrical system diagram is an important element for understanding the system and connection arrangement. It can be especially critical for communicating that information during planning, installation, startup and/or servicing the system. These diagrams depict the major components such as generator(s), power transfer equipment, protective relaying, overcurrent protection and the overall connection scheme. A one–line diagram should be developed as early as possible during the project planning to aid the system design. **Figure 2–1** is a typical one–line diagram of a basic generation system.

Guidelines for Generator Set Power Ratings

Power ratings for generator sets are published by the manufacturers[1]. These ratings describe maximum allowable loading conditions on a generator set. The generator set will provide acceptable performance and life (time between overhauls) when applied according to the published ratings. It is also important to operate generator sets at a sufficient minimum load to achieve normal temperatures and properly burn fuel. Cummins Power Generation recommends that a generator set be operated at a minimum of 30% of its nameplate rating.

The following explanations describe the ratings types used by Cummins Power Generation. The associated **Figures, 2–2 thru 2–5,** depict the load levels (P_1, P_2, P_3, etc.) and time at that load level (T_1, T_2, T_3, etc.) allowed under the various ratings.

Standby Power Rating

The standby power rating is applicable to emergency power applications where power is supplied for the duration of normal power interruption. No sustained overload capability is available for this rating (Equivalent to Fuel Stop Power in accordance with ISO3046, AS2789, DIN6271 and BS5514). This rating is applicable to installations served by a reliable normal utility source. This rating is only applicable to variable loads with an average load factor of 80 percent of the standby rating for a maximum of 200 hours of operation per year and a maximum of 25 hours per year at 100% of its standby rating. In installations where operation will likely exceed 200 hours per year at variable load or 25 hours per year at 100% of rating, the prime power rating should be applied. The standby rating is only applicable to emergency and standby applications where the generator set serves as the back up to the normal utility source. No sustained utility parallel operation is permitted with this rating. For applications requiring sustained utility parallel operation, the prime power or base load rating must be utilized.

Prime Power Rating

The prime power rating is applicable when supplying electric power in lieu of commercially purchased power. The number of allowable operating hours per year is unlimited for variable load applications but is limited for constant load applications as described below. (Equivalent to Prime Power in accordance with ISO8528 and Over Load Power in accordance with ISO3046, AS2789, DIN6271 and BS5514.)

Unlimited Running Time Prime Power

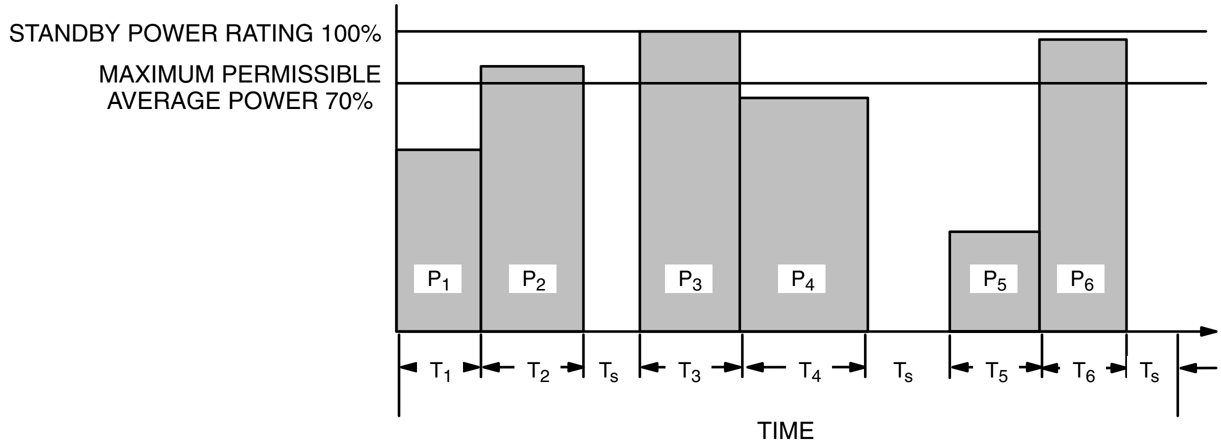
Prime power is available for an unlimited number of annual operating hours in variable load applications. Applications requiring any utility parallel operation at constant load are subject to running time limitations. In variable load applications, the average load factor should not exceed 70 percent of the Prime Power Rating. A 10 percent overload capability is available for a period of 1 hour within a 12–hour period of operation, but not to exceed 25 hours per year. The total operating time at the Prime Power Rating must not exceed 500 hours per year.

Limited Running Time Prime Power

Prime power is available for a limited number of annual operating hours in constant load applications such as interruptible, load curtailment, peak shaving and other applications that normally involve utility parallel operation. Generator sets may operate in parallel with the utility source up to 750 hours per year at power levels not to exceed the Prime Power Rating. It should be noted that engine life will be reduced by constant high load operation. Any application requiring more than 750 hours of operation per year at the Prime Power Rating should use the Base Load Power Rating.

1 Ratings for generator sets from Cummins Power Generation are published in the Power Suite software package.

$$\text{AVERAGE POWER} = \frac{(P_1 \times T_1) + (P_2 \times T_2) + (P_3 \times T_3) + (P_4 \times T_4) + (P_5 \times T_5) + (P_6 \times T_6) + \ldots + (P_n \times T_n)}{T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + \ldots + T_n}$$



NOTES:

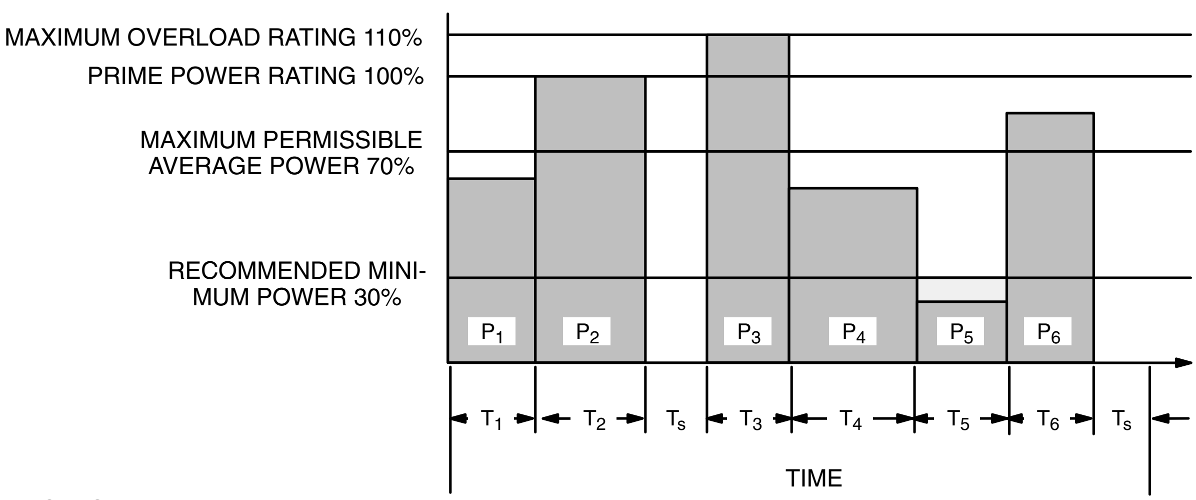
I Total running time ($T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + \ldots + T_n$) must not exceed 200 hours.

II Do not count periods of shutdown (T_s).

III There is no overload capability.

Figure 2–2. Standby Power Rating.

$$\text{AVERAGE POWER} = \frac{(P_1 \times T_1) + (P_2 \times T_2) + (P_3 \times T_3) + (P_4 \times T_4) + (P_5 \times T_5) + (P_6 \times T_6) + \ldots + (P_n \times T_n)}{T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + \ldots + T_n}$$



NOTES:

I Count loadings of less than 30 percent as 30 percent (P_5).

II Do not count periods of shutdown (T_s).

III The total number of hours per year at or above the Prime Power Rating (P_2 and P_3) must not exceed 500 hours.

Figure 2–3. Unlimited Running Time Prime Power

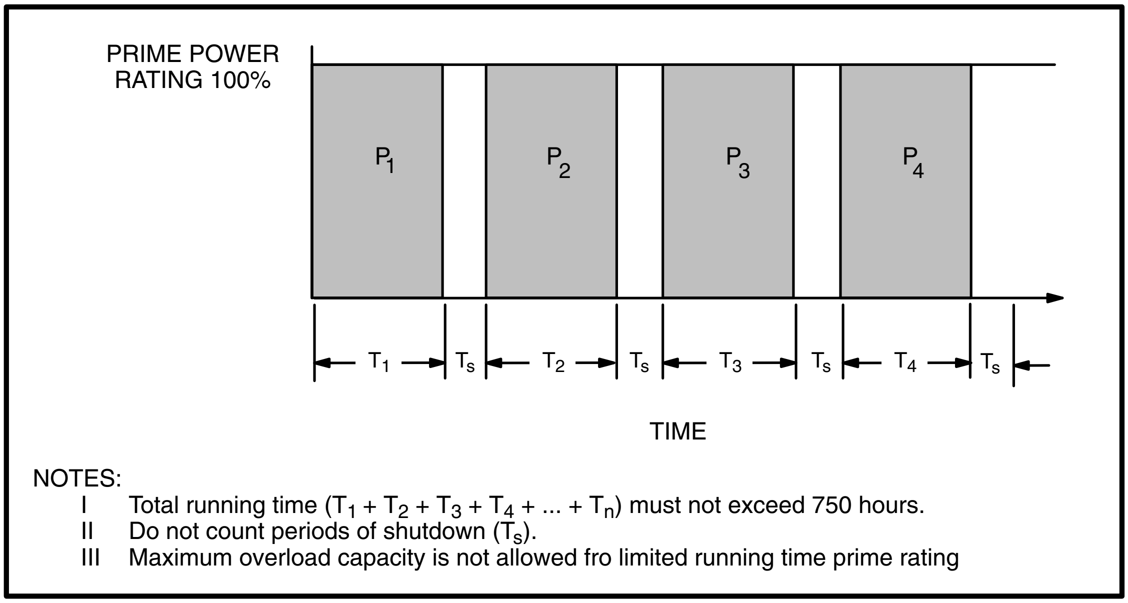


Figure 2–4. Limited Running Time Prime Power

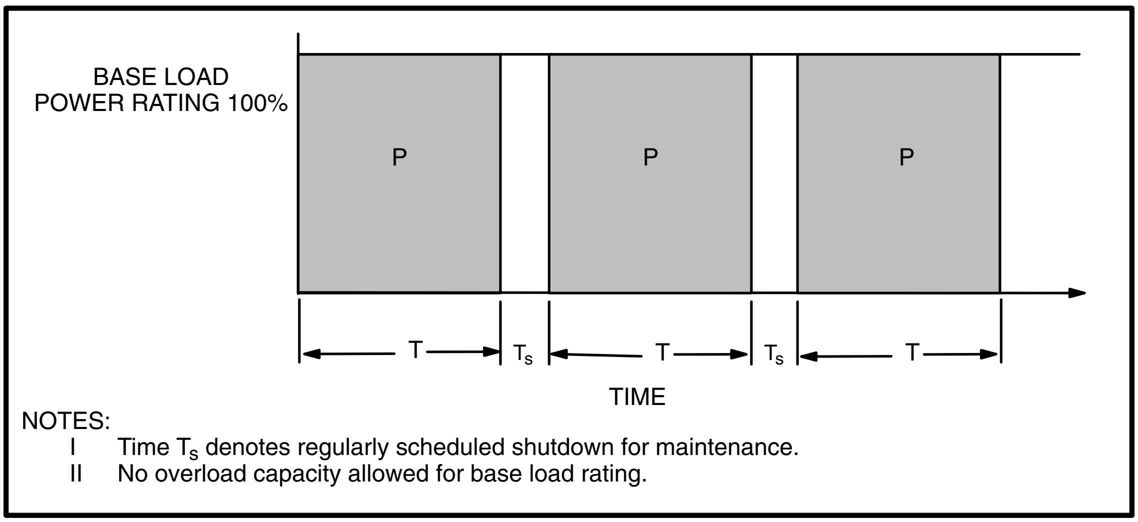


Figure 2–5. Base Load Power

Base Load Power Rating (Continuous Power Rating)

The base load power rating is applicable for supplying power continuously to a load up to 100 percent of the base rating for unlimited hours. No sustained overload capability is available at this rating (Equivalent to Continuous Power in accordance with ISO8528, ISO3046, AS2789, DIN6271 and BS5514). This rating is applicable for utility base load operation. In these applications, generator sets are operated in parallel with a utility source and run under constant loads for extended periods of time.

Sizing

It is important to assemble a reasonably accurate load schedule as soon as possible for budgeting project costs. If all the load equipment information is not available early in the project, estimates and assumptions will have to be made for the first sizing calculations These calculations should be iterated as more accurate information becomes available. Large motor loads, uninterruptible power supplies (UPS), variable frequency drives (VFD), fire pumps, and medical diagnostic imaging equipment have considerable effect on generator set sizing and should be looked at closely. Tight specifications on transient performance, voltage and frequency dip and recovery times, during motor starting and block load acceptance also have considerable effect on sizing. See section 3*, Electrical Load Impact on Generator Sizing* in this manual regarding sizing calculation and the kinds of information needed for different types of load equipment.

For preliminary estimation purposes some conservative rules of thumb may be used:

- Motors – HP per kW.
- UPS – 40% oversize for 1∅ and 6 pulse, or 15% oversize for 6 pulse with input filters and 12 pulse UPS.
- VFD – 100% oversize unless pulse–width–modulated, then 40% oversize.

When loading the generator set, division of the loads into discrete steps or blocks of load may have a favorable effect on the size of generator set required. Use of multiple transfer switches or some other means (time delay relays, PLC, etc.) would be necessary to allow the generator set voltage and frequency to stabilize between steps.

Depending on the total load (generally above 500 kW), it may be advantageous to parallel generator sets. Although technically feasible, it is usually not economically feasible to parallel generator sets when the total load is 300 kW or less.

Location Considerations

One of the first design decisions will be to determine whether the location of the generator set will be inside a building or outside in a shelter or housing. The overall cost and ease of installation of the power system depend upon the layout and physical location of all elements of the system — generator set, fuel tanks, ventilation ducts and louvers, accessories, etc. For both indoor and outdoor locations, consider these issues:

- Generator set mounting
- Location of distribution switchboard and transfer switches
- Branch circuits for coolant heaters, battery charger, etc.
- Security from flooding, fire, icing, and vandalism
- Containment of accidentally spilled or leaked fuel and coolant
- Possible simultaneous damage to normal and emergency services
- Service access for general maintenance and inspections.
- Access and working space for major work such as overhauls or component removal/ replacement.
- Access for load bank testing when required for maintenance, proper excersize, or code.

Outdoor Location Considerations

- Airborne noise and treatment. Sound barriers may be required. In addition, increased distance between the generator set and the noise sensitive area will decrease the perceived noise. Acoustic housings are often available and may be required to meet customer expectations or local noise ordinances.
- Weather protective housing may be required, as their name suggests, for protection from weather but also may provide a certain level of security as well as aesthetic containment of the generator set.

- Starting and accepting load, and doing so within specific time constraints, in cold ambient temperatures may be an issue. Emergency systems as defined by codes require the ambient temperature around the genset to be maintained at minimum levels. Examples are NFPA110 which requires the minimum ambient temperature around the generator set to be 40° F (4° C), and CSA 282 which requires this minimum temperature to be 10° C (50° F). Maintaining these minimum tempeature requirements in a "skin–tight" or other similar housing may be difficult or impossible. An insulated and perhaps heated housing may be required. A housing that is designed strictly for acoustic treatment will contain insulation material but may not provide sufficient heat containment. Single unit "drop over" housings or walk in enclosures are usually available with insulation, motorized or gravity louvers, and heaters if necessary.
- Several auxiliary heating devices may be required for starting or improved load acceptance, even if the application is not an emergency system. Heaters for coolant, batteries, even oil may be necessary. Refer to the section in this manual titled Standby Heating Devices for Generator Sets under section 4, *Equipment Selection* for more detailed information.
- Fuel conditioning and heating. At cold ambient temperatures diesel fuel will become cloudy, clog filters and pumps, or not flow sufficiently. Blended fuels are often used to address this issue however, fuel heating may be required for reliable operation.
- The salt air in coastal regions may cause corrosion issues on outdoor–installed steel genset enclosures, skid bases, and fuel tanks. The use of an optional aluminum genset enclosure and skirt, whenever offered by CPG, is considered to be proper installation practice due to the additionial corrosion resistance and is thus required for outdoor applications in coastal regions, defined as locations 60 miles and closer to bodies of saltwater.
- Service access for major repairs, component replacement (such as radiator or alternator), or overhaul, should be considered in the design of housings and placement of generator sets near other equipment or structures. If major work is required due to high hours of operation or major component damage/failure, access allowances will be critical. These allowances include access covers, removable housing walls, adequate spaces to nearby structures, and access of required support equipment.
- Security fences and sight barriers
- Property line distances
- Engine exhaust must be directed away from vents and building openings.
- Grounding – Electrodes or grounding rings may be required for separately–derived system and/or equipment grounding.
- Lightning protection

Indoor Location Considerations

- Dedicated generator room – For emergency power systems, certain codes may require that the generator room be dedicated for that purpose only. Also consider the effect that large ventilating airflow would have on other equipment in the same room, such as building heating equipment.
- Fire rating of room construction – Codes typically specify a 1 or 2–hour minimum fire resistance rating. Consult local authorities for applicable requirements.

- Working space – Working space around electrical equipment is usually specified by code. In practice, there should be at least three feet (1 M) of clearance around each generator set. The alternator should be replaceable without removing the entire set or any accessories. Also, access for major work (such as overhaul or component replacement such as a radiator) should be allowed for in the installation design.
- Type of cooling system – A factory–mounted radiator is recommended, however, the radiator fan can create a significant negative pressure in the room. Access doors should therefore swing into the room – or be louvered — so that they can be opened when the set is running. See Generator Cooling in the *Mechanical Design* section for additional cooling options.
- Ventilation involves large volumes of air. An optimum room design draws intake air directly from outdoors and discharges the air directly outdoors through the opposite wall. Room ventilation fans will be required for optional generator set cooling configurations that involve heat exchanger or remote radiators.
- Engine exhaust – The engine exhaust outlet should be as high as practical on the prevailing down–wind side of the building and directed away from building intake vents and openings.
- Fuel storage and piping – Local codes may specify fuel storage methods inside buildings and restrict fuel storage amounts. Early consultation with the local Cummins Power Generation dealer or the local fire marshal is recommended. Access will be required for refilling storage tanks. See Fuel Selection below.
- It is recommended that provisions be included in the electrical distribution system for connection of a temporary genset load bank.
- Location within a building must allow for access both for initial product delivery and installation, and later for servicing and maintenance. The logical preferred location for a generator set in a building based on this is on the ground floor, near a parking lot or access driveway, or in an open parking ramp. Understanding that this is the premium building space, if forced to an alternative location, keep in mind that heavy equipment may be needed for placement or major service of the unit. Also, deliveries of fuel, coolant, oil, etc. are needed at various intervals. A fuel system will most likely be designed with supply tanks, pumps, lines, day tanks, etc. but lubricating oil and coolant changes can be difficult if the materials have to be hand carried in barrels or buckets.
- Rooftop installations, while common, require further planning and structural design consideration. Vibration and fuel storage/delivery may be problematic with rooftop installations.
- Indoor locations generally require a dedicated room with fire resistive construction. Providing the required airflow to an interior room may be difficult. Fire dampers in ductwork to interior rooms are generally not permitted. Ideally the room will have two exterior walls opposite each other so that intake air flows over the generator set and is discharged out the opposite wall on the radiator end of the unit.

Generator installations tend to see a wide range of climatic conditions. While the product may be designed to function effectively in majority of these conditions, there would be some additional considerations required for adverse climatic conditions. As an example:

Costal environment:

- Salinity of the air and condensation due to the higher humidity may require additional attention.

- Alternator heaters are a must in humid environments to keep the moisture at bay. It should be noted that the purpose of an alternator heater to keep moisture out and not a 'cold weather only' item.
- It is important to keep water from accumulating accumulating around the generator. A special lourve design or baffles may be used to ensure the life and performance of the genset.
- Please refer to 'environmental conditioning' after section 4–3 in this manual.

Arid/ Dusty climates:

- The genset room must be kept free from dirt and debris. Dust and sand particles also pose threats for maintenance and operation of a generator. Protective features such as screening filters for the ventilation air at the installation site are recommended. This could prevent the 'sand blasting' effect caused by the high velocity of the sand particles as they flow over the generator and through the radiator. It should be noted that such filters would add restriction to the air flow and would thus require larger openings for the air to enter and leave the installation site. The total restriction, including filters, must remain below the total allowed restriction listed in the genset technical information. (See Airflow Restriction, page 6–76.).
- If ventilation system filters are installed, a system for detecting plugged filters shall be in place. If filters are used, there should be provisions in place to monitor their condition and detect clogged filters. Pressure drop indicators can be installed on the room ventilation system. Other solutions may also be acceptable.
- Fin spacing on the radiator core and number of blades also become a criterion in dusty climates. A high number of fins per inch are unacceptable for dirty (dusty, sandy, etc.) environments. Debris can easily be trapped in radiator cores with tight fin spacing, negatively impacting radiator performance. Wider fin spacing will allow sand, small dirt particles, etc. to pass through the core without becoming trapped.
- System should be designed for 115% cooling capability to account for system degradation. When cleaned according to manufacturer's recommended methods and frequency, a capacity of 100% should always be available. This is particularly important for gensets installed in dusty / dirty environments.
- Care should also be taken to keep any contaminants out of the diesel fuel.

Altitude:

- High altitudes result in lower air densities. These lower densities de–rate the performance of engines, alternators, cooling systems to name a few. Please refer to model specific literature for accurate de–rate information.
- Alternators with medium and high voltages may be restricted to certain altitudes to avoid corona discharge.

Please contact your local Cummins distributor for a full list of options which may be recommended at your job site.

Fuel Selection Considerations

The selection of natural gas, diesel, or LPG fuel will affect generator set availability and sizing. Consider the following:

Diesel Fuel

- Diesel fuel is recommended for emergency and standby applications. ASTM D975 No. 2–D Grade diesel fuel is recommended for good starting performance and maximum engine life. Consult the engine manufacturer distributor regarding the use of alternative grades of diesel fuel for various engines.
- On–site fuel storage must be provided, however the tank should not be too large. Diesel fuel lasts up to two years in storage, so the supply tank should be sized to allow for fuel turnover based on scheduled exercise and testing in that time period. A microbicide may need to be added if fuel turnover is low, or if high–moisture conditions promote the growth of fuel microbes. Microbes in the fuel can clog fuel filters and disable or damage the engine.
- Cold climates — Premium No. 1–D Grade fuel should be used when ambient temperatures are below freezing. Fuel heating may be required to prevent fuel filters from clogging when temperatures fall below the cloud point of the fuel — approximately 20° F (–6° C) for No. 2–D and –15° F (–26° C) for No. 1–D.
- Emissions requirements may be applicable. See Environmental Considerations.

Biodiesel Fuel

- Biodiesel fuels are derived from a broad variety of renewable sources such as vegetable oils, animal fats, and cooking oils. Collectively, these fuels are known as Fatty Acid Methyl Esters (FAME). When used in diesel engines, typically smoke, power, and fuel economy are all reduced. While smoke is reduced, the effect on other emissions varies, with some pollutants being reduced while others are increased. Biodiesel fuel is a substitute fuel, meaning the performance and emissions of the engine cannot be warranted when operated on this fuel[2].
- A blend of up to 5% volume concentration biodiesel fuel with quality diesel fuel should not cause serious problems. Above 5% concentration serious operational problems should be expected. Cummins neither approves nor disapproves of the use of biodiesel blends. Consult Cummins for additional information.

Natural Gas

- No on–site fuel storage is required for most sites.
- Natural gas may be an economical fuel choice where available, at required flow rates and pressure.
- An on–site backup LPG fuel supply may be required for emergency power supply systems.
- Field natural gas can be used with certain generator sets. However, fuel analysis and consultation with the engine manufacturer are required to determine potential power derating and whether fuel composition will lead to engine damage due to poor combustion, detonation, or corrosion.
- Detonation and engine damage may result when some utilities occasionally add butane to maintain line pressure. Natural gas engines require clean, dry, pipeline–quality gas to generate rated power and ensure optimal engine life.
- Frequency stability of spark–ignited engine generator sets may not be as good as diesel engine generator sets. Good frequency stability is important when supplying UPS loads.
- Cold climates — In ambient temperatures below 20° F (–7° C) spark–ignited engines generally start easier and accept load sooner than diesel engines.

2 Cummins Power Generation assumes no warranty responsibility for repairs or increased costs of operation with biodiesel fuel.

NOTE: Cummins Power Generation does not recommend piping high–pressure natural gas (5 psig [34 kPa] or more) into buildings.

LPG (Liquefied Petroleum Gas)

- The local availability of LPG should be investigated and confirmed prior to selecting an LPG–powered generator set.
- On–site fuel storage must be provided. LPG can be stored indefinitely.
- Frequency stability of spark–ignited engine generator sets may not be as good as diesel engine generator sets. This is an important consideration when supplying UPS loads.
- Cold climates — Either the LPG storage tank must be sized to provide the required rate of vaporization at the lowest ambient temperature expected, or liquid withdrawal with a vaporizing heater must be provided.

NOTE: Cummins Power Generation does not recommend piping high–pressure LPG (20 psig [138 kPa] or more), liquid or vapor, into buildings.

Gasoline

Gasoline is not a suitable fuel for stationary standby generator sets due to volatility and shelf life of gasoline fuel.

Substitute Fuels

In general, diesel engines may be run on substitute **fuels with acceptable lubricity** during periods when the supply of No. 2–D diesel fuel is temporarily limited. Use of substitute fuels may affect warranty coverage, engine performance, and emissions. The following substitute fuels are generally within prescribed limits:

- 1–D and 3–D diesel fuel
- Grade No. 2 fuel oil (heating fuel)
- Grade Jet A and Jet A–1 aviation turbine fuel (commercial jet fuel)
- Grade No. 1 GT and No. 2 GT non–aviation gas turbine fuel
- Grade No. 1–K and No. 2–K kerosene

Environmental Considerations

The following is a brief approach to evaluating environmental issues related to noise, exhaust emissions, and fuel storage. Refer to the *Mechanical Design* chapter for more complete information.

Noise and Noise Treatment

Noise treatment, if required, needs to be considered early in the preliminary design. Generally, noise treatment methods will add a considerable cost and increase the physical area required for the installation. A generator set is a complex noise source that includes the cooling fan noise, the engine noise, and the exhaust noise. Effective noise treatment has to address all of these sources of noise. For the most part, the recommended noise treatment methods modify or redirect the path for the noise from the generator set source to people hearing it. Simply using a critical grade muffler may or may not do anything to reduce the noise level at a specific location. Because noise is directional, careful consideration needs to be given to the location, orientation, and distance of the generator set with respect to property lines or places where the noise may be objectionable.

NOISE ZONES	PEAK DAYTIME dB(A)	PEAK NIGHTTIME dB(A)	CONTINUOUS DAYTIME dB(A)	CONTINUOUS NIGHTTIME dB(A)
Urban—Residential	62	52	57	47
Suburban—Residential	57	47	52	42
Very Quiet Suburban or Rural Residential	52	42	47	37
Urban—Nearby Industry	67	57	62	52
Heavy Industry	72	62	67	57

Table 2–2. Representative Outside Noise Levels

Noise Levels and Regulations

In North America, state and local codes establish maximum noise levels for given areas. Most community noise regulations specify the maximum allowable noise level at the property line. **Table 2–2** shows some representative outdoor noise level regulations. Compliance with noise regulations requires an understanding of the ambient noise level and the resultant noise level with the generator set running at full load in that ambient.

Noise regulations also exist to protect worker's hearing. Persons working in generator rooms should always wear ear protection while a generator set is running.

Engine Exhaust Emissions Regulations

Generator sets, regardless of application, may be subject to engine exhaust emissions regulations on a local or national level or both. Compliance with emissions regulations usually requires special permits. Certain localities may have specific designations requiring gaseous–fueled engines and/or exhaust after–treatment strategies for diesels. Check with the local air quality agency early in the design phase of any project for permitting requirements.

Table 2–3 shows the EPA exhaust emission regulations for non road applications. Please note that these emission numbers are the maximum limits based on a weighted 5 cycle test and are not representative of emissions at any particular load levels. For emission values at 100%, 75%, 50% and 25% loads, please contact your distributor. Also note that emission numbers vary greatly depending on site conditions such as temperature, relative humidity, fuel quality, etc. Suitable correction factors may be needed to predict emissions at installation site from the data collected in test cells.

Fuel Storage Regulations

Fuel supply tank design and installation in many areas is controlled by regulations that are generally written for two separate purposes: environmental protection and fire protection. Because the regulations, their enforcement and exemptions from regulation vary by location, it is necessary to research and understand local requirements.

In North America, environmental protection regulations generally exist at both federal and state levels. Different sets of regulations apply to underground vs. aboveground fuel storage tanks. These regulations cover design and construction standards, registration, tank testing, and leak detection. They also cover closure requirements, preparation of spill prevention plans, provisions for financial responsibility, and trust fund coverage. As a general statement subject to local verification, exemptions from regulation are granted for underground and above–ground diesel storage tanks serving on–site emergency generator sets where 1) the capacity of the facility storage tanks is 1,320 gallons (500 L) or less, 2) no single tank has a capacity in excess of 660 gallons (250 L), and 3) the fuel is consumed at the facility (not dispensed).

Requirements in **black** are same as nonroad; requirements in red are unique for stationary.

NOx / NMHC / CO / PM (g/kW-hr)
(NOx+NMHC) / CO / PM (g/kW-hr) [Conversion: (g/kW-hr) x 0.7457 = g/bhp-hr]

<table>
<tr><th>kW</th><th>(HP)</th><th>2007</th><th>2008</th><th>2009</th><th>2010</th><th>2011</th><th>2012</th><th>2013</th><th>2014</th><th>2015</th><th>2016</th><th>2017</th></tr>
<tr><td>0 - 7</td><td>(0 - 10)</td><td></td><td colspan="10" rowspan="2">(7.5) / 6.6 / 0.40</td></tr>
<tr><td>8 - 18</td><td>(11 - 24)</td><td></td></tr>
<tr><td>19 - 36</td><td>(25 - 48)</td><td></td><td colspan="5">(7.5) / 5.5 / 0.30</td><td colspan="5" rowspan="2">(4.7) / 5.0 / 0.03
Emergency: Stay at previous tier</td></tr>
<tr><td>37 - 55</td><td>(49 - 74)</td><td rowspan="2"></td><td colspan="4">Opt T4i 0.30 PM: 37-55 kW</td><td>Note 6</td></tr>
<tr><td>56 - 74</td><td>(75 - 99)</td><td colspan="4">(4.7) / 5.0 / 0.40: 37-74 kW</td><td colspan="3" rowspan="2">3.4 / 0.19 / 5.0 / 0.02
Emergency: Tier 3</td><td colspan="3" rowspan="2">0.40 / 0.19 / 5.0 / 0.02
Emergency: Tier 3</td></tr>
<tr><td>75 - 129</td><td>(100 - 173)</td><td colspan="5">(4.0) / 5.0 / 0.30</td></tr>
<tr><td>130 - 224</td><td>(174 - 301)</td><td colspan="4">(4.0) / 3.5 / 0.20</td><td colspan="3" rowspan="3">2.0 / 0.19 / 3.5 / 0.02
Emergency: Tier 3</td><td colspan="4" rowspan="3">0.40 / 0.19 / 3.5 / 0.02
Emergency: Tier 3</td></tr>
<tr><td>225 - 449</td><td>(302 - 602)</td><td colspan="4">(4.0) / 3.5 / 0.20</td></tr>
<tr><td>450 - 560</td><td>(603 - 751)</td><td colspan="4">(4.0) / 3.5 / 0.20</td></tr>
<tr><td>>560</td><td>(>751)</td><td colspan="4">(6.4) / 3.5 / 0.20
Stationary >3000 hp: Tier 1</td><td colspan="4">3.5 / 0.40 / 3.5 / 0.10
0.67 / 0.40 / 3.5 / 0.10 [a]
Emergency: Tier 2</td><td colspan="3">3.5 / 0.19 / 3.5 / 0.04
0.67/ 0.19/ 3.5/ 0.03 [b]
Emergency: Tier 2</td></tr>
<tr><td></td><td></td><td>T2</td><td colspan="3">Tier 3</td><td colspan="3">Tier 4 Interim</td><td colspan="4">Tier 4 Final</td></tr>
</table>

a. Applies to non-emergency power gen engines >900kW (>1207hp).
b. Applies to non-emergency power gen engines >560kW (>751hp).

(1) Compliance with optional 'Option 1' 0.30 g/kW-hr PM limit in 2008 allows 1-year delay of T4 until 2013.
Option 1 engines in 2008 are T4i engines, not T3 engines.
(2) Fire pump requirements for 2007+ generally delayed three years.
(3) Engines $\geq$ 10 L/cyl must meet T2 marine requirements of 40 CFR 94.8.
(4) There is NO TPEM program for engines in stationary applications.

Rev 14 April 2009

Table 2–3. EPA CI NSPS for Stationary Engines Standards (60.4201, 60.4202, 60.4204 & 60.4205)

Even when an installation is exempt from regulation it must be recognized that cleanup expenses may be very high for even small amounts of fuel spill resulting from leaks, overfilling, etc. The trend in diesel fuel storage for on–site generator sets both indoors and outdoors, has been towards third party certified above ground dual–wall sub–base tanks with leak detection and overfill protection. See Section 6, *Mechanical Design*, for more information on fuel system design.

Fire Protection

In North America, fire protection regulations typically adopt or reference one or more of the National Fire Protection Association (NFPA) standards. These standards cover such requirements for indoor fuel storage capacity, fuel piping systems, the design and construction of fuel tanks, fuel tank locations, diking, and/or safe drainage provisions. Refer to NFPA Standard No. 37, Installation of Stationary Engines. Local fire authorities may have more restrictive requirements or interpretations of requirements than those in the national standards.

PRELIMINARY DESIGN CHECKLIST

System Type

- [ ] Emergency
- [ ] Legally–Required Standby
- [ ] Optional Standby
- [ ] Optional Standby
- [ ] Prime Power
- [ ] Peak Shaving
- [ ] Load Curtailment
- [ ] Base Load

Generator Set Rating

- [ ] Standby Rating
- [ ] Prime Rating
- [ ] Continuous Rating

Generator Set Size

- [ ] Single Unit ___ kW ___ kVA ___ PF
- [ ] Parallel Units ___# ___ kW ___kVA ___PF

Generator Set Voltage and Frequency

___ Voltage ___ HZ

- [ ] Single–phase
- [ ] Three–phase

Location

- [ ] Indoor
- [ ] Ground Level
- [ ] Upper Level
- [ ] Below Ground
- [ ] Outdoor
- [ ] Ground Level
- [ ] Rooftop

Direct Access for Instal/Service
Yes ___ No ___

Fuel

- [ ] Diesel
- [ ] Natural Gas
- [ ] LPG

Fuel Supply – Diesel

- [ ] Day Tank
- [ ] Sub–Base Tank
- [ ] Outdoor Tank

Fuel Supply – LP

- [ ] Vapor Withdrawal
- [ ] Liquid Withdrawal

Housing

- [ ] Weather Protective
- [ ] Acoustic
- [ ] Walk-In Enclosure
- [ ] Drop Over
- [ ] Coastal Region

Accessories

- [ ] Paralleling Switchgear
- [ ] Automatic Transfer Switch
- [ ] Battery Chargers
- [ ] Network Interface
- [ ] Remote Alarms/Monitoring
- [ ] Circuit Breakers(s)
- [ ] Paralleling Control Modules
- [ ] Muffler
- [ ] Vibration Isolators

Special Alternator Requirements

- [ ] Reduced Temperature Rating, 105C 80C
- [ ] RTDs or Thermistors

Cooling System

- [ ] Unit Mounted Radiator
- [ ] Remote Radiator

CHAPTER 3 CONTENTS

3 – ELECTRICAL LOAD IMPACT ON GENERATOR SIZING

Overview

This section focuses on the impact of loads on generator set sizing. It is important to assemble a reasonably accurate load schedule early in the design phase of power generation projects because the load is the single most important factor in generator sizing. If all the load equipment information needed for sizing is not available early in the project, the first sizing calculations will have to be based on estimates and assumptions. This should be followed by recalculations when actual, more accurate information becomes available. Different load types – motors, uninterruptible power supplies (UPS), variable frequency drives (VFD), medical diagnostic imaging equipment and fire pumps, have considerable and different influences on generator set sizing.

Applications and Duty Ratings

Generator Set Duty Ratings

Determining the loads required to be supported by a generator set is a function of the type of application and required duty. Generally, there are three duty classifications for generator set applications, Standby, Prime or Continuous. These classifications are defined in Section NO TAG, *Preliminary Design*. Available ratings for generator sets vary according to these classifications. A generator set used in Standby applications is used as a backup to the primary (utility) power source and is expected to be used infrequently, so the Standby rating is the highest available for the set. Prime rated sets are expected to operate unlimited hours and the generator set is considered the primary source of power for varying loads, so the Prime rating is typically about 90% of the Standby rating. In Continuous duty applications, the set is expected to produce rated output for unlimited hours at constant load (applications where the set may be operated in parallel with a utility source and base loaded), so the Continuous rating is typically about 70% of the Standby rating. Load carrying capability of the generator set is a function of the expected life or interval between overhauls.

Mandated and Optional Applications

Fundamentally, generator set applications can be lumped into two basic categories, those that are mandated by codes (legally required) and those that are desired for economics (generally associated with power availability or reliability). These categories will drive a completely different set of choices when decisions must be made regarding what loads to put on the generator set.

Code Mandated

These applications are typically those judged by authorities as emergency or legally required standby, where life safety and life support are paramount. These types of applications may be stipulated in building codes or codes specific to life safety, and typically involve facilities such as health care (hospitals, nursing care, clinics), high rise construction, and places of assembly (theaters, assembly halls, sporting facilities, hotels). Typically, the generator set will provide backup power to loads such as egress lighting, ventilation, fire detection and alarm systems, elevators, fire pumps, public safety communication systems, and even industrial process where power loss creates a life safety or health hazard. Other legally required systems are mandated when it is determined that loss of the normal utility power constitutes a hazard or will hamper rescue or fire fighting operations. To determine the minimum loads that must be supplied by the generator, confer with the local code authority and related standards. Additional optional loads may be applied to the generator in most applications if approved by the local code authority.

Optional Standby

This type of system installation has become more frequent as power availability has become more critical. These systems power facilities like industrial and commercial buildings and serve loads such as heating, refrigeration, data processing communications, and critical industrial processes. Generators are often justifiable where loss of utility power could cause discomfort or interruption of critical process threatening products or process equipment.

Prime and Continuous

Applications for generator sets that supply prime or continuous duty power are becoming increasingly prevalent in developing countries and for many distributed power generation applications. Many opportunities exist with utilities on the generation side and utility customers on the consumption side. Deregulation and more strict environmental regulations have electric utilities seeking alternative power production and distribution alternatives to new central generating plant construction like peak shaving and interruptible rate structures to satisfy increasing demand. Utility customers are using on–site generation to reduce utility peak demand and continue to pursue cogeneration opportunities where simultaneous demand for both electric power and heat exist.

In any case, one must be aware that generator sets generally are a small power source compared to the normal utility source and the load operating characteristics can have a profound effect on power quality if the generator is not sized properly. Given that a generator is a limited power source, whenever loads are connected to or disconnected from a generator, voltage and frequency disturbances must be expected. These disturbances must be maintained within limits acceptable to all connected loads. In addition, voltage distortion of the generator output voltage will result when non–linear loads producing harmonic currents are connected. This distortion can be considerably greater when operating on generator than when the load is supplied from the utility/mains and will cause additional heating in both the generator and the load equipment if not kept in check. Consequently, generators larger than required to supply adequate load running power are needed to limit voltage and frequency disturbance during transient loading and limit harmonic distortion where serving non–linear loads like computers, UPSs and VFDs.

Generator sizing software programs now allow precise generator set selection and provide a higher level of confidence for purchasing a system large enough for your needs – and no larger. While most generator set sizing exercises are best done with sizing programs such as GenSize from Cummins Power Generation (See Appendix A) – or with the help of a manufacturer’s representative – it is still instructive to know what goes into selecting the right generator set for your application.

Besides connected load, numerous other factors affect the generator set sizing; starting requirements of loads such as motors and their mechanical loads, single–phase load imbalance, non–linear loads such as UPS equipment, voltage dip restrictions, cyclic loads, etc.

Understanding Loads

Load Running and Starting Requirements

The power required by many load types can be considerably higher while starting the load than required for continuous steady state running (most motor driven loads that don’t employ some type of soft start equipment). Some loads also require higher peak power during operation than while running (welding and medical imaging equipment, for example). Still other loads (non–linear loads like UPS, computers, VFDs and other electronic loads) cause excessive generator distortion unless the generator is sized larger than what is required to power the load. The power source must be capable of supplying all operating power requirements of the load.

During starting or peak load operating conditions, sudden load transients can cause voltage and frequency disturbances harmful to the connected load or large enough to prevent successful starting or proper load operation if the generator is undersized. While some loads are quite tolerant of short term transient voltage and frequency disturbances, other loads are quite sensitive. In some cases, the load equipment may have protective controls that cause the load to shut down under these conditions. Although not as critical, other effects like lights dimming or momentary surging of elevators can be, at the least, disturbing.

A generator set is a limited power source both in terms of engine power (kW) and generator volt–amperes (kVA), regardless of the type of excitation system. Because of this, load changes will cause transient excursions in both voltage and frequency. The magnitude and duration of these excursions are affected by the characteristics of the load and the size of the generator relative to the load. A generator set is a relatively high impedance source when compared to the typical utility transformer. See further information in Section 4, *Equipment Selection.*

Load Step Sequencing

In many applications, it may be advisable to limit the amount of load to be connected or started by the generator set at any one time. Loads are commonly stepped onto the generator set in sequence to reduce the starting requirements and, thus, the size of generator required. This requires load control and equipment to switch the load onto the generator[1]. Multiple transfer switches are commonly used for this purpose. Individual transfer switches can be adjusted to connect loads at different times using standard time delay transfer settings to stagger loads. A few seconds time delay to allow the generator to stabilize voltage and frequency is recommended between load steps. This, of course, will mean that any emergency or legally required loads will need to be connected first to meet code requirements. Loads requiring higher starting power, like large motor loads, should be started while minimum load is connected. UPS loads can be left to last since the UPS load is being carried on battery.

With that basic background, individual load operating characteristics are discussed below.

Load Types

Lighting Loads

Calculations of lighting are fairly straightforward, a summation of the lamp or fixture wattage or required wattage for lighting circuits, plus the wattage required for ballasts. Common lighting types are Incandescent – standard bulb–type lamp assemblies that typically use a tungsten filament, fluorescent – a ballast driven ionized gas lamp – also apply for gas discharge lighting, and discharge – low–pressure sodium, high–pressure sodium, etc. Tables 3–1 and 3–2 contain some useful representative data.

TYPE OF LIGHTING	SPF	RPF
Fluorescent	0.95	0.95
Incandescent	1.00	1.00
High Intensity Discharge	0.85	0.90

Table 3–1. Lighting Power Factors (Starting and Running)

LAMP	BALLAST
48 Inch T–12, 40 W, Preheat	10 W
48 Inch T–12, 40 W, Rapid Start	14 W
High Output 40 W Fluorescent	25 W
Mercury, 100 W	18–35 W
Mercury, 400 W	25–65 W

Table 3–2. Ballast Power

1 Cummins Power Generation offers network–based cascading load–control systems.

Air Conditioning Loads

Air conditioning loads are generally specified in tons. To estimate power requirements in kilowatts, a conversion of 2 HP/ton is used as a very conservative estimate of the total load for a lower efficiency unit. If you want a more exact size and know the individual component motor loads in the A/C equipment, sum them individually and come up with a demand factor for what loads are likely to start simultaneously.

Motor Loads

There is a wide variety of motor types and types of loads connected to those motors, each of which affects the motor's starting and running characteristics. Following is a discussion of many of these differences and characteristics and their affects on generator set sizing choices.

Low– and High–Inertia

The moment of inertia of a rotating mass, such as a motor and its load, is a measure of its resistance to acceleration by motor starting torque. Starting torque requires more generator set engine power (SkW) than running load. Rather than having to perform calculations, however, it is usually sufficient to broadly characterize loads as high–inertia loads or as low–inertia loads for the purpose of determining engine power needed to start and accelerate motor loads. Therefore, low–inertia loads are those that can be accelerated when a service factor of 1.5 or less can be assumed, whereas, high–inertia loads are those where a service factor greater than 1.5 must be assumed. A higher service factor must also be assumed for mechanically unbalanced or pulsating loads. **Table 3–3** shows categorizations of common loads.

Low–inertia Loads*	High–Inertia Loads**
Fans and centrifugal blowers	Elevators
Rotary compressors	Single– and Multi–Cylinder Pumps
Rotary and centrifugal pumps	Single– and Multi–Cylinder Compressors
	Rock Crushers
	Conveyers

Table 3–3. Rotating Inertia Summary

*Exceptionally large fans or pumps that work against tall heads may not qualify as lo inertia loads. If unsure, assume High–Inertia.
**High–inertia loads include mechanically pulsating and unbalanced loads.

Over 50 HP

A large motor started across–the–line with a generator set represents a low impedance load while at locked rotor or initial stalled condition. The result is a high inrush current, typically six times the rated (running) current. The high inrush current causes generator voltage dip. This voltage dip is composed of the instantaneous transient voltage dip and the recovery voltage dip.

The instantaneous transient voltage dip occurs at the instant the motor is connected to generator output and is strictly a function of the relative impedances of the generator and the motor. Instantaneous voltage dip is the voltage dip predicted by the voltage dip curves published on the alternator data sheets[2]. These dip curves provide an idea of

2 Voltage dig curves for Cummins Power Generation equipment are available on the Power Suite Library CD.

what might be expected for the instantaneous dip, assuming frequency is constant. If the engine slows down due to a heavy starting kW requirement, the transient voltage dip may be exaggerated as the torque–matching characteristic of the voltage regulator rolls off alternator excitation to help the engine recover speed.

Following detection of the instantaneous transient voltage dip, the generator excitation system responds by increasing excitation to recover to rated voltage — at the same time as the motor is accelerating to running speed (assuming the motor develops enough torque). Motor torque, for induction motors, is directly proportional to the square of the applied voltage. Motor acceleration is a function of the difference between motor torque and the torque requirements of the load. In order to avoid excessive acceleration times, or motor stall, the generator must recover to rated voltage as quickly as possible.

The manner in which generator voltage recovers is a function of the relative sizes of the generator and motor, engine power (kW capacity) and generator excitation forcing capability. Several milliseconds after the initial transient voltage dip, the voltage regulator applies full forcing voltage to the generator exciter resulting in a buildup of the main generator field current in accordance with the exciter and main field time constants. Generator set components are designed and matched to achieve the shortest possible response time while maintaining voltage stability and avoiding engine overload. Excitation systems that respond too quickly or that are too “stiff” can actually overload the engine when starting large motors. Depending on the severity of the load, the generator should recover to rated voltage within several cycles, or at most, a few seconds.

For motor starting applications, both the initial transient voltage dip and the recovery voltage need be considered. A generator should be sized so that it will not exceed the initial transient voltage dip specified for the project, and so that it will recover to a minimum of 90 percent of rated output voltage with the full motor locked rotor kVA applied. Thus, the motor can deliver approximately 81 percent (0.9 x 0.9 = 0.81) of its rated torque during acceleration, which has proven adequate for most starting applications. In lieu of unique project specifications, a 35% starting voltage dip is considered acceptable in a generator set motor starting situation.

Various types of reduced–voltage motor starters are available to reduce the starting kVA of a motor in applications where reduced motor torque is acceptable. Reducing motor starting kVA can reduce the voltage dip, the size of the generator set and provide a softer mechanical start. As discussed next, however, caution must be used when applying these starters to generator sets.

Three–Phase Starting Methods

There are several methods available for starting three–phase motors, as summarized in **Table 3–4** and as elaborated in the Appendix C – Reduced voltage Motor Starting. The most common starting method is direct, across–the–line (full voltage) starting. Motor starting requirements can be reduced by applying some type of reduced–voltage or solid–state starter, resulting in a smaller recommended generator set. However, caution must be used when applying any of these reduce–voltage starting methods. Since motor torque is a function of the applied voltage, any method that reduces motor voltage also reduces motor torque during starting. These starting methods should only be applied to low–inertia motor loads unless it can be determined that the motor will produce adequate torque for accelerating during starting. Additionally, these starting methods can produce very high inrush currents when they transition from start to run (if the transition occurs before the motor reaches operating speed), resulting in starting requirements approaching an across–the–line start. If the motor does not reach near–rated operating speed prior to transition, excessive voltage and frequency dips can occur when employing these starters with generator sets. If unsure how the starter and load will react, assume across–the–line starting.

Variable Frequency Drives (VFDs)

Of all classes of non–linear load, variable frequency drives, which are used to control the speed of induction motors, induce the most distortion in generator output voltage. Larger alternators are required to prevent alternator overheating due to the harmonic currents induced by the variable frequency drive, and to limit system voltage distortion by lowering alternator reactance.

For example, conventional current source inverter type VFD loads on a generator must be less than approximately 50 percent of generator capacity to limit total harmonic distortion to less than 15 percent. More recently, Pulse Width Modulated type VFD's have become increasingly more cost effective and prevalent and induce substantially lower harmonics. The alternator need only be oversized by about 40% for these drives.

STARTING METHOD	% FULL VOLTAGE APPLIED (TAP)	% FULL VOLTAGE kVA	% FULL VOLTAGE TORQUE	SkVA MULTIPLY-ING FAC-TOR	SPF
Full Voltage	100	100	100	1.0	–
Reduced Voltage Auto-transformer	80 65 50	64 42 25	64 42 25	0.64 0.42 0.25	– – –
Series Reactor	80 65 50	80 65 50	64 42 25	0.80 0.65 0.50	– – –
Series Resistor	80 65 50	80 65 50	64 42 25	0.80 0.65 0.50	0.60 0.70 0.80
Star Delta	100	33	33	0.33	–
Part Winding (Typical)	100	60	48	0.6	–
Wound Rotor Motor	100	160*	100*	1.6*	–

* – These are percents or factors of running current, which depend on the value of the series resistances added to the rotor windings.

Table 3–4. Reduced Voltage Starting Methods and Characteristics

For variable speed drive applications, size the generator set for the full nameplate rating of the drive, not the nameplate rating of the driven motor. Harmonics may be higher with the drive operating at partial load and it may be possible that a larger motor, up to the full capacity of the drive, could be installed in the future.

NEMA Motor Code Letter

In North America, the NEMA standard for motors and generators (MG1) designates acceptable ranges for motor starting kVA with Code Letters "A" through "V." Motor design must limit starting (locked rotor) kVA to a value within the range specified for the Code Letter marked on the motor. To calculate motor starting kVA, multiply motor horsepower by the value in **Table 3–5** that corresponds with the Code Letter. The values in **Table 3–5** are the averages of the specified ranges of values for the Code Letters.

Code Letter	Factor	Code Letter	Factor	Code Letter	Factor
A	2	H	6.7	R	15
B	3.3	J	7.5	S	16
C	3.8	K	8.5	T	19
D	4.2	L	9.5	U	21.2
E	4.7	M	10.6	V	23
F	5.3	N	11.8		
G	5.9	P	13.2		

Table 3–5. Multiplying Factors Corresponding with Code Letters

Three–Phase Motor Design

In North America, design B, C, or D type motors are three–phase squirrel–cage induction motors classified by NEMA (National Electrical Manufacturers Association) with respect to a maximum value for locked rotor current and minimum values for locked rotor torque, pull–up torque and breakdown torque. High Efficiency type motors are premium–efficiency three–phase squirrel–cage induction motors with minimum torque values similar to design B type motors, but with higher maximum locked rotor current and higher nominal full–load efficiency. See **Table 3–6** for nominal standard values for Design B, C, D and High Efficiency motors.

Single–Phase Motor Design

See **Table 3–7** for nominal standard values for single–phase induction motors.

Uninterruptible Power Supply Loads

A static uninterruptible power supply (UPS) uses silicon controlled rectifiers (SCRs) or other static devices to convert AC voltage to DC voltage. The DC voltage is used to produce AC voltage through an inverter circuit at the output of the UPS. The DC voltage is also used to charge batteries. the energy storage medium for the UPS. The switching SCRs at the input induce harmonic currents in the generator set's alternator. The affects of these currents include additional winding heating, reduced efficiency, and AC waveform distortion. The result is a requirement for a larger alternator for a given kW output from the genset.

UPS devices can also be sensitive to voltage dip and frequency excursions. When the rectifier is ramping up, relatively broad swings in frequency and voltage can occur without disrupting operation. However, once the bypass is enabled, both frequency and voltage must be very stable or an alarm condition will occur.

Past problems of incompatibility between generator sets and static UPS devices led to many misconceptions about sizing generator sets for this type of load. In the past, UPS suppliers recommended oversizing the generator set by two to five times the UPS rating, but even then some problems persisted. Since then, most UPS manufacturers have addressed the problems of incompatibility and it is now more cost effective to require UPS devices to be compatible with the generator set than to significantly oversize the generator.

When sizing a generator use the nameplate rating of the UPS, even though the UPS itself may not be fully loaded, plus the battery charge rating. The UPS will typically have a battery charging capability of 10 to 50 percent of its UPS rating. If the batteries are discharged when the UPS is operating on the generator set, the generator set must be capable of supplying both the output load and the battery charging. Most UPSs have an adjustable current limit. If this limit is set at 110% – 150% of UPS rating, that is the peak load the generator set will need to supply immediately after a utility power outage. A second reason for using the full UPS rating is that additional loads up to nameplate rating may be added to the UPS in the future. The same applies to redundant UPS systems. Size the generator set for the combined nameplate ratings of the individual UPS devices in applications where, for example, one UPS is installed to back up another and the two are on line at all times with 50 percent load or less.

Due to being non–linear loads, UPS equipment induces harmonics in the generator output. UPS devices equipped with harmonic input filters have lower harmonic currents than those without. Harmonic filters must be reduced or switched out when the load on the UPS is small. If not, these filters can cause leading power factor on the generator set. See *Leading Power Factor Load* in the *Mechanical Design* section. The number of rectifiers (pulses) also dictates the degree of alternator over–sizing required. A 12 pulse rectifier with a harmonic filter results in the smallest recommended generator set.

Most UPS devices have a current–limiting function to control the maximum load that the system can apply to its power supply, which is expressed as a percentage of the full load rating of the UPS. The total load which the UPS applies to its power supply is controlled to that value by limiting its battery charging rate. If, therefore, the maximum load is limited to 125 percent and the UPS is operating at 75 percent of rated capacity, battery charging is limited to 50 percent of the UPS rating. Some UPS devices reduce the battery charging rate to a lower value during the time that a generator set is powering the UPS.

HP	DESIGN *B, C &D* MOTORS		HIGH EFFICIENCY MOTORS		FOR ALL MOTORS	
	NEMA CODE LETTER*	EFFICIENCY (%)	NEMA CODE LETTER*	EFFICIENCY (%)	STARTING PF (SPF)	RUNNING PF (RPF)
1	N	73	N	86	0.76	0.70
1–1/2	L	77	L	87	0.72	0.76
2	L	79	L	88	0.70	0.79
3	K	83	L	89	0.66	0.82
5	J	84	L	90	0.61	0.85
7–1/2	H	85	L	91	0.56	0.87
10	H	86	K	92	0.53	0.87
15	G	87	K	93	0.49	0.88
20	G	87	K	93	0.46	0.89
25	G	88	K	94	0.44	0.89
30	G	88	K	94	0.42	0.89
40	G	89	K	94	0.39	0.90
50	G	90	K	95	0.36	0.90
60	G	90	K	95	0.36	0.90
75	G	90	K	95	0.34	0.90
100	G	91	J	96	0.31	0.91
125	G	91	J	96	0.29	0.91
150	G	91	J	96	0.28	0.91
200	G	92	J	96	0.25	0.91
250	G	92	J	96	0.24	0.91
300	G	92	J	96	0.22	0.92
350	G	93	J	97	0.21	0.92
400	G	93	J	97	0.21	0.92
500 & UP	G	94	J	97	0.19	0.92

Table 3–6. Three–Phase Motor Defaults: NEMA Code, EFF, SPF, RPF

HP	NEMA CODE LETTER*	EFFICIENCY (%)	STARTING PF (SPF)	RUNNING PF (RPF)
SPLIT–PHASE				
1/6	U	70	0.8	0.66
1/4	T	70	0.8	0.69
1/3	S	70	0.8	0.70
1/2	R	70	0.8	0.70
PERMANENT SPLIT CAPACITOR (PSC)				
1/6	G	70	0.8	0.66
1/4	G	70	0.8	0.69
1/3	G	70	0.8	0.70
1/2	G	70	0.8	0.72
CAPACITOR START/INDUCTION RUN				
1/6	R	40	0.8	0.66
1/4	P	47	0.8	0.68
1/3	N	51	0.8	0.70
1/2	M	56	0.8	0.73
3/4	L	60	0.8	0.75
1	L	62	0.8	0.76
1–1/2	L	64	0.8	0.78
2	L	65	0.8	0.78
3 to 15	L	66	0.8	0.79
CAPACITOR START/CAPACITOR RUN				
1/6	S	40	0.8	0.66
1/4	R	47	0.8	0.68
1/3	M	51	0.8	0.70
1/2	N	56	0.8	0.73
3/4	M	60	0.8	0.75
1	M	62	0.8	0.76
1–1/2	M	64	0.8	0.78
2	M	65	0.8	0.78
3 to 15	M	66	0.8	0.79

Table 3–7. Single–Phase Motor Defaults: NEMA Code, EFF, SPF, RPF

Battery Charger Loads

Battery Chargers typically use silicon–controlled rectifiers (SCRs). A battery charger is a non–linear load, requiring an over–sized alternator to accommodate additional heating and minimize voltage distortion caused by battery charger induced harmonic currents. The number of rectifiers (pulses) dictates the degree of alternator over–sizing required. A 12 pulse rectifier results in the smallest recommended generator set.

Medical Imaging Equipment (X–ray, Cat Scan, MRI)

Imaging equipment such as X–Ray, Cat Scan and MRI produce unique starting and running characteristics that must be considered when sizing a generator set. Peak kVA load (kVP x ma) and allowable voltage dip are the essential factors for sizing a generator set for medical imaging applications. Two additional factors must be understood for all medical imaging applications.

First, when the medical imaging equipment is powered by the generator set, the image may be different than when it is powered by the commercial utility line. The reason for this is due to the difference in voltage dip characteristics. As **Figure 3–1** illustrates, the dip will tend to be constant when the utility is the power source, and be deeper and more variable when the generator set is the power source. The generator set voltage regulator's attempt to regulate the voltage will also affect the voltage dip characteristic.

Second, between the time the operator makes the adjustment for the image and takes the image, no large load changes should take place from elevators or air conditioning switching on or off.

Medical imaging equipment is usually designed to be powered by the utility source. Most equipment, however, has a line voltage compensator, adjustable either by the installer or the operator. In applications where the generator set is the only power source, the line voltage compensator can be adjusted for the voltage dip expected with the generator set. When the imaging equipment has been adjusted for utility power, the generator set will have to duplicate the voltage dip of the utility as closely a possible. From past experience, satisfactory images can be expected when the generator (alternator) kVA rating is at least 2.5 times the peak kVA of the imaging equipment. A voltage dip of 5 to 10 percent can be expected when sizing on this basis. Peak kVA and required generator set kVA for variously rated imaging equipment is listed in **Table 3–8.**

Fire Pump Applications[3]

Special consideration must be given to fire pumps due to their critical status and special code requirements. The North American National Electrical Code (NEC) contains requirements limiting voltage dip to 15 percent when starting fire pumps. This limit is imposed so that motor starters will not drop out during extended locked rotor conditions and so that fire pump motors will deliver adequate torque to accelerate pumps to rated speeds to obtain rated pump pressures and flows. The generator set does not have to be sized to provide the locked rotor kVA of the fire pump motor indefinitely. That would result in an oversized generator set, which could lead to maintenance and reliability due to an under–utilized generator set.

3 This is Cummins Power Generation's interpretation of the 1996 edition of NFPA Standard No. 20, Centrifugal Fire Pumps. Design engineers should also review the standard itself.

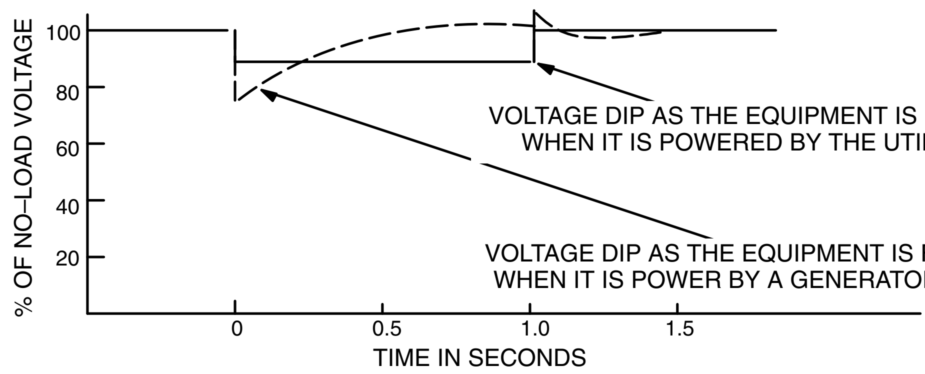


Figure 3–1. Voltage Dip in Medical Imaging Applications

IMAGING EQUIPMENT RATING		PEAK kVA*	MINIMUM GENERATOR kVA
Ma	kVP		
15	100	1.5	3.8
20	85	1.7	4.3
40	125	5.0	12.5
50	125	6.3	15.8
100	125	12.5	31.3
200	125	25.0	62.5
300	125	37.5	93.8
300	150	45.0	112.0
500	125	62.5	156.0
500	150	75.0	187.0
700	110	77.0	192.0
1200	90	108.0	270.0
* – Multiply the peak kVA by the power factor (PF) to obtain Peak kW. If PF is unknown, assume 1.0.			

Table 3–8. Generator Set Requirements for Medical Imaging Applications

Whenever a reduced voltage starter is used for a fire pump motor, regardless of the type, allow generator capacity for across–the–line starting. The fire pump controller includes either a manual–mechanical, manual–electrical, or automatic means to start the pump across–the–line in the case of a controller malfunction.

The additional generation capacity can be managed, if practical, by providing automatic load–shedding controls on low–priority connected loads so that otherwise idle generator set capacity for the fire pump may be used for those same loads. The controls should be arranged to shed loads prior to starting the fire pump.

Another option is to consider a diesel engine driven fire pump rather than an electric motor pump. The economics generally favor electric motor driven pumps, but the fire protection engineer may prefer a diesel engine drive. That way, the fire protection system and the emergency power system are kept entirely separate. Some engineers and insurers believe this improves the reliability of both systems. The cost of a transfer switch for the fire pump would be avoided. The generator set does not have to be sized to provide the locked rotor kVA of the fire pump motor indefinitely. That could result in an oversized generator set, which could experience maintenance and reliability issues from being under–utilized.

Load Characteristics

Load Voltage and Frequency Tolerances

Table 3–9 summarizes the tolerance that various loads have for changes in voltage and frequency.

Regenerative Power

The application of generator sets to loads having motor–generator (MG) drives such as elevators, cranes and hoists, require the consideration of regenerative power. In these applications, the descent of the elevator car or hoist is slowed by the motor–generator which "pumps" electrical power back to the source to be absorbed. The normal utility source easily absorbs the "regenerated" power because it is an essentially unlimited power source. The power produced by the load simply serves other loads reducing the actual load on the utility (mains). A generator set, on the other hand, is an isolated power source that has a limited capability of absorbing regenerative power. Regenerative power absorption is a function of engine friction horsepower at governed speed, fan horsepower, generator friction, windage and core losses (the power required to maintain rated generator output voltage). The regenerative power rating of the set appears on the recommended generator set Specification Sheet and is, typically, 10 to 20 percent of the generator set power rating. (The generator drives the engine, which absorbs energy through frictional losses.)

EQUIPMENT	VOLTAGE	FREQUENCY	COMMENTS
Induction Motors	+/– 10%	+/– 5%	Low voltage results in low torque and increased temperature. High voltage results in increased torque and starting amps.
Coils, Motor Starters%	+/–10	N/A	The holding force of a coil and its time constant of decay are proportional to the ampere–turns of the coil. Smaller coils may drop out within these tolerances for transient dip. A transient voltage dip of 30 to 40 percent for more than two cycles may cause coil dropout.
Incandescent Lighting	+10%, –25%	N/A	Low voltage results in 65% light. High voltage results in 50% life. Low frequency may result in light flicker.
Fluorescent Lighting	+/– 10%	N/A	High voltage results in overheating.
HID Lighting	+10%, –20%	N/A	Low voltage results in extinguishment. High voltage results in overheating.
Static UPS	+10%, –15%	+/– 5%	No battery discharge down to –20% voltage. UPS are sensitive to a frequency change rate (slew rate) greater than 0.5 Hz/sec. Oversizing of the generator may be necessary to limit harmonic voltage distortion.
Variable Frequency Drives (VFD)	+10%, –15%	+/– 5%	VFD are sensitive to a frequency change rate greater than 1 Hz/sec. Oversizing of the generator may be necessary to limit harmonic voltage distortion.
If voltage does not recover to 90 percent, undervoltage protective devices may lockout, overcurrent devices may interrupt, reduced voltage starters may lockout or step and motors may stall or not have acceptable acceleration.			

Table 3–9. Typical Voltage and Frequency Tolerances

An insufficient regenerative power rating for the application can result in excessive elevator descent speed and overspeeding of the generator set.

NOTE: Excessive regenerative loads can cause a generator set to overspeed and shut down. Applications that are most susceptible to this type of problem are small buildings where the elevator is the major load on the generator set.

Generally, the regeneration problem can be solved by making sure there are other connected loads to absorb the regenerative power. For example, in small buildings where the elevator is the major load, the lighting load should be transferred to the generator before transferring the elevator. In some cases auxiliary load banks with load bank controls may be needed to help absorb regenerative loads.

Load Power Factor (PF)

Inductances and capacitances in AC load circuits cause the point at which the sinusoidal current wave passes through zero to lag or lead the point at which the voltage wave passes through zero. Capacitive loads, overexcited synchronous motors, etc. cause leading power factor, where current leads voltage. Lagging power factor, where current lags voltage, is more typically the case and is a result of the inductance in the circuit. Power factor is the cosine of the angle by which current leads or lags voltage, where one full sinusoidal cycle is 360 degrees. Power factor is usually expressed as a decimal figure (0.8) or as a percentage (80%). Power factor is the ratio of kW to kVA. Therefore:

kW = kVA x PF

Note that three–phase generator sets are rated for 0.8 PF loads and single–phase generator sets for 1.0 PF loads. Loads which cause power factors lower than those at which generators are rated may cause GenSize to recommend a larger alternator or generator set to serve the load properly.

Reactive loads that cause leading power factor can be problematic, causing damage to alternators, loads, or tripping protective equipment. The most common sources of leading power factor are lightly loaded UPS systems using input line harmonic filters or power factor correction devices (capacitor banks) used with motors. Leading power factor load must be avoided with generator sets. The system capacitance becomes a source of generator excitation and loss of voltage control can become a problem. Always switch power factor correction capacitors on and off the system with the load. See Leading Power Factor Loads in the *Electrical Design* section.

Single–Phase Loads and Load Balance

Single phase loads should be distributed as evenly as possible between the three phases of a three–phase generator set in order to fully utilize generator capacity and limit voltage unbalance. For example, as little as a 10 percent single–phase load unbalance may require limiting the three–phase balanced load to not more than 75 percent of rated capacity. To help prevent overheating and premature insulation failure in three–phase motors, voltage unbalance should be kept below about two percent. See Allowable Single–Phase Load Unbalance Calculation in the *Electrical Design* section.

CHAPTER 4 CONTENTS

4 – EQUIPMENT SELECTION

Overview

When the decision has been made as to generator set(s) size and load sequence, the task of choosing the equipment for the job can begin.

This section deals with various generator set equipment for a complete and functional installation. Functional characteristics, criteria for choices and optional equipment needed are discussed.

Alternators

rnators

Voltage

Low Voltage

The application largely determines the generator set voltage selected. In emergency and standby applications, generator output voltage usually corresponds to the utilization voltage of the loads. Most commercially used voltages and connection configurations are available as standard options from alternator manufacturers. Some rare–use voltages may require special windings which may require considerable lead times to produce. Most alternators have voltage adjustment of at least ±5% from the nominal voltage specified to allow adjustment to specific site requirements. See the Table of World Voltages in *Appendix B*.

Medium Voltage[1]

In prime power or base load applications, or when overall application conditions are conducive, medium voltage generator sets (greater than 600 volts) are being used with more frequency. Generally, medium voltages should be considered when output would exceed 2,000 amps from a low voltage generator. Another criteria driving medium voltage use is the size/capacity of power switching equipment and amount of conductors required vs. low voltage. While medium voltage equipment will be more expensive, the conductors required (on the order of 10–20 times less ampacity) combined with reduced conduit, support structures, and installation time, can offset the higher alternator cost.

Insulation and Ratings

Generally, alternators in the range from 20 kW to 2,000 kW have NEMA Class F or Class H winding insulation. Class H insulation is designed to resist higher temperatures than Class F. Alternator ratings are referred to in terms of temperature rise limits. Alternators with Class H insulation have kW and kVA output ratings that remain within the class temperature rises of 80° C, 105° C, 125° C and 150° C above an ambient of 40° C. An alternator operated at its 80° C rating will have longer life than at its higher temperature ratings. Lower temperature rise rated alternators for a given generator set rating will result in improved motor starting, lesser voltage dips, greater non–linear or imbalanced load capability, as well as higher fault current capability. Most Cummins Power Generation generator sets have more than one size of alternator available, making it possible to match a wide range of applications.

Many alternators for a specific generator set will have multiple ratings such as 125/105/80 (S,P,C). This means that alternator choice will operate within a different temperature limit depending on the generator set rating, i.e. it will remain within 125° C temperature rise at the Standby rating, within 105° C rise at the Prime rating and within 80° C rise at the Continuous rating.

1 Medium voltage alternators are available on Cummins Power Generation products rated 750 kW and larger.

Additional Guidelines

Environmental Conditioning

With any saline environment, the possibility of sodium chloride deposits on windings, untreated metal (not necessarily just ferrous) surfaces, etc., will lead to two connected issues: – Corrosion and hygroscopic attraction of moisture leading to the insulation becoming compromised. It is important to remove as much moisture from the atmosphere in the generator enclosure as possible, both at the time of potential moisture ingress and also subsequently, when condensation may occur. Louvers should be designed with rain–trap louvers that provide a tortuous path with an intake velocity as low as possible, allowing moisture droplets to coalesce in the intake. This will leave a residual amount of moisture and most of this should be prevented from direct contact with the rear of the alternator by means of a baffle. The alternator should be allowed to draw its air from air that is passing by the machine, in the correct direction to avoid recirculation, not air that is directed at the machine. In this way, additional tortuous paths are created giving additional opportunities for coalescence and precipitation of moisture prior to entering the alternator. Creation of additional tortuous paths may give rise to additional restriction on air flow and air flow modeling prior to construction is recommended.

The enclosure should contain space heaters, sized to give at least a 5 degree Celsius temperature rise above ambient and controlled by temperature and dew point (humidity) controls. Consider air conditioning the engine enclosure for when weather is warm and moist as this can effectively reduce the humidity without unduly heating the environment within the enclosure. Again, controlling the air conditioning using a mix of temperature and dew point controls will economise electrical loading. Anti–condensation heaters within the alternators are mandatory in this application, must be wired to a suitably sized electrical supply, and must be active when the conditions are such that condensation might occur, and only when the generator is stationary.

The enclosure should be fitted with spring open – motor closing louvers and these should be closed as soon as possible after stopping of the machine, consistent with avoiding abnormal temperature built–up. All enclosure parts must either be galvanized or powder coated or painted with a salt–resisting paint to avoid corrosion and particular care must be taken with areas where moisture can be trapped.

Water within the enclosure

It is vital that water that does enter the enclosure is not allowed to ”pond” under the alternator as the air intake flow will give rise to turbulence beneath the machine and may allow water droplets, possibly contaminated with oil, fuel, coolant and salt to enter the machine. If water can lay under the alternator, consider inclusion of a baffle to prevent micro–droplets being drawn into the alternator air intake.

Winding Protection

On certain ranges of alternators CGT are able to offer a harsh environment impregnation treatment that will afford additional protection to the windings from moisture. This process is applied only to the main stator. This additional treatment will result in a derate of some 3–5% from the peak continuous (150/163 rises) ratings, although there is no intrinsic derate for this process for base continuous ratings (105/125 rises). This should not be regarded as being an ’instead of’ for the environmental treatment above, it is an ’as well as’. There is an additional cost for this treatment as it increases the impregnation time and materials.

Protection of bare metal internal parts

CGT are able to provide an additional treatment of bare metal surfaces within the machine. These include the shaft and various components mounted on the shaft and machine barrel. There is an additional cost for this treatment.

Operation

The machine should be sized and system controls programmed such that the alternator operates at sufficient load to ensure that the windings reach and maintain a temperature of at least 100 degrees C. This temperature should be attained in the coolest conditions that can be encountered on the site. This will help to maintain the windings in a moisture–free condition and will help to drive moisture from the windings.

Non–linear Load

Because of the predominance of non–linear loads on these sites, CGT recommends that if P7x machines are being used, that these are specified as PE7 (the embedded generation design of machine). PE7 alternators designs can better accommodate the higher crest factors that can exist in these applications. The machine should be sized at class F rating. Thich will result in a derate but will mean less heating effect in the laminations, coupled with a lower effective machine reactance, thereby yielding a better waveform.

Filters

CGT do not recommend filters in applications where water ingress is the issue – filters should be used to remove dry dusts only. Filters will quickly become waterlogged which will restrict the air intake and after shutdown, the water contained in the filter will tend to make the atmosphere within the alternator very humid which may encourage the growth of mold.

Maintenance Regime

A program of monthly runs where the alternator is held at normal operating temperature (windings at least 100 degrees C) for 4 hours or more will assist in maintaining the windings in a moisture–free condition and will discourage mold formation.

Windings and Connections

Alternators are available in various winding and connections configurations. Understanding some of the terminology used will help in making the choice that best suits an application.

Reconnectable

Many alternators are designed with individual lead–outs of the separate phase windings that can be reconnected into WYE or Delta configurations. These are often referred to as 6–lead alternators. Often, reconnectable alternators have six separate windings, two in each phase, that can be reconnected in series or parallel, and wye or delta configurations. These are referred to as 12–lead reconnectable. These types of alternators are primarily produced for flexibility and efficiency in manufacturing and are connected and tested at the factory to the desired configuration.

Broad Range

Some alternators are designed to produce a wide range of nominal voltage outputs such as a range from 208 to 240 or 190 to 220 volts with only an adjustment of excitation level. When combined with the reconnectable feature, this is termed ***Broad Range Reconnectable***.

Extended Range

This term refers to alternators designed to produce a wider range of voltages than broad range. Where a broad range may produce nominally 416–480 volts, an extended range may produce 380–480 volts.

Limited Range

As the name suggests, limited range alternators have a very limited nominal voltage range adjustment (for example 440–480 volts) or may be designed to produce only one specific nominal voltage and connection such as 480 volt WYE.

Increased Motor Starting

This term is used to describe a larger alternator or one with special winding characteristics to produce a higher motor starting current capability. Although as mentioned earlier, increased motor starting capability will also be achieved by choosing a lower temperature rise limit alternator.

Fundamentals and Excitation

It is desirable to have some understanding of the fundamentals of AC generators and generator excitation systems with respect to transient loading response, interaction of the voltage regulator with the load, and response of the excitation system to generator output faults.

A generator converts rotating mechanical energy into electrical energy. It consists essentially of a rotor and a stator, as shown in the cross section in **Figure 4–1.** The rotor carries the generator field (shown as four–pole), which is turned by the engine. The field is energized by a DC source called the exciter, which is connected to the "+" and "–" ends of the field windings. The generator is constructed such that the lines of force of the magnetic field cut perpendicularly across the stator windings when the engine turns the rotor, inducing voltage in the stator winding elements. The voltage in a winding element reverses each time the polarity changes (twice each revolution in a four–pole generator). Typically, a generator has four times as many "winding slots" as shown

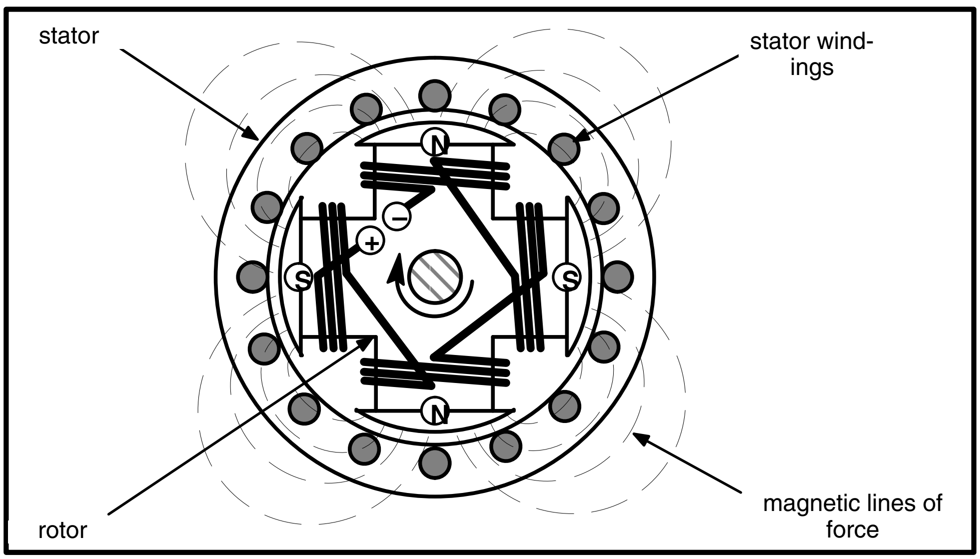


Figure 4–1. Four-Pole Generator Cross Section

and is "wound" to obtain a sinusoidal, alternating, single– or three–phase output.

The induced voltage in each winding element depends on the strength of the field (which could be represented by a higher density of the lines of force), the velocity with which the lines of force cut across the winding elements (rpm), and the "stack length". Therefore, in order to vary the output voltage of a generator of given size and operating speed, it is necessary to vary the strength of the field. This is done by the voltage regulator, which controls the output current of the exciter.

Generators are equipped with self–excited or separately–excited (PMG) excitation systems.

Self–Excited Generators

The excitation system of a self–excited generator is powered, via the automatic voltage regulator (AVR), by tapping (shunting) power from the generator power output. The voltage regulator senses generator output voltage and frequency, compares them to reference values and then supplies a regulated DC output to the exciter field windings. The exciter field induces an AC output in the exciter rotor, which is on the rotating, engine–driven generator shaft. Exciter output is rectified by the rotating diodes, also on the generator shaft, to supply DC for the main rotor (generator field). The voltage regulator increases or decreases exciter current as it senses changes in output voltage and frequency due to changes in load, thus increasing or decreasing the generator field strength. Generator output is directly proportional to field strength. Refer to **Figure 4–2**.

Typically, a self–excited generator excitation system is the least expensive system available from a manufacturer. It provides good service under all operating conditions when the generator set is sized properly for the application. The advantage of a self–excited system over a separately–excited system is that the self–excited system is inherently self protecting under symmetrical short circuit conditions because the field "collapses". Because of this, a main line circuit breaker for protecting the generator and the conductors to the first level of distribution may not be considered necessary, further reducing the installed cost of the system.

The disadvantages of a self excited system are:

- It might be necessary to select a larger generator in order to provide acceptable motor starting performance.
- Self–excited machines rely on residual magnetism to energize the field. If residual magnetism is not sufficient, it will be necessary to "flash" the field with a DC power source.
- It might not sustain fault currents long enough to trip downstream circuit breakers.

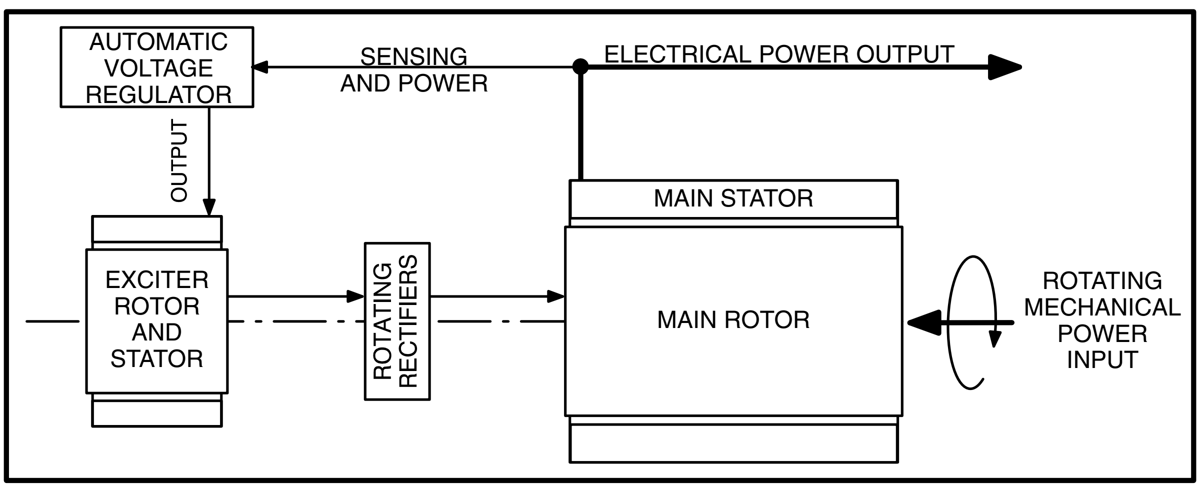


Figure 4–2. Self-Excited Generator

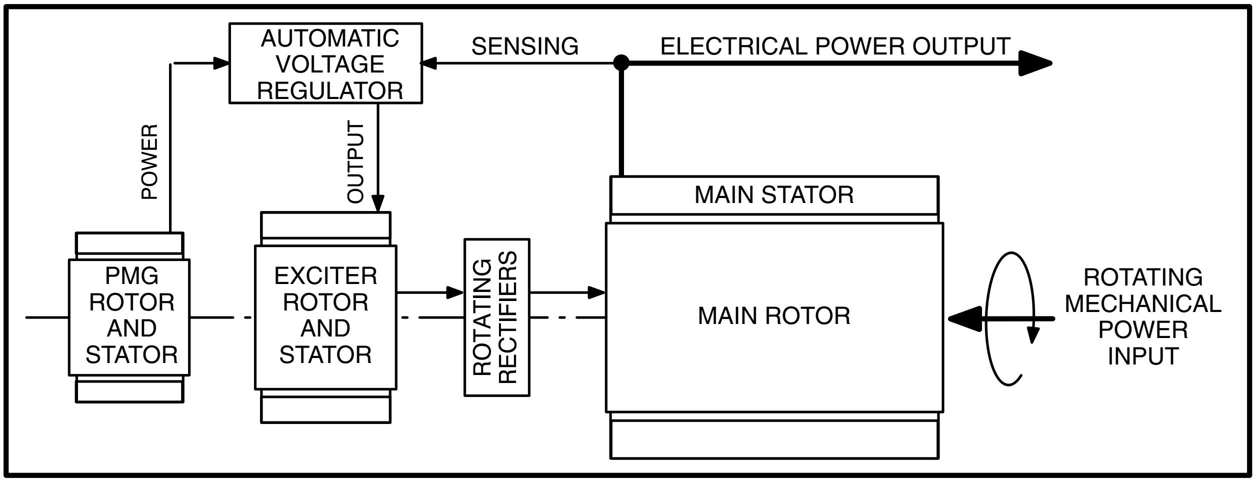


Figure 4–3. Separately-Excited (PMG) Generator

Separately–Excited Generators

The excitation system of a separately–excited generator is similar to that of a self–excited generator except that a separate permanent magnet generator (PMG) located on the end of the main generator shaft powers the voltage regulator. Refer to **Figure 4–3**. Because it is a separate source of power, the excitation circuit is not affected by the loads on the generator. The generator is capable of sustaining two to three times rated current for approximately ten seconds. For these reasons, separately–excited generator excitation systems are recommended for applications where enhanced motor starting capability, good performance with non–linear loads or extended duration short circuit performance are necessary.

With this excitation system it is necessary to protect the generator from fault conditions because the generator is capable of operating to destruction. The Power Command® Control System with AmpSentry™ provides this protection by regulating sustained short circuit current and shutting down the generator set in the event fault current persists but before the alternator is damaged. See *Electrical Design* for further information on this subject.

Transient Loading

A generator set is a limited power source both in terms of engine power (kW) and generator volt–amperes (kVA), regardless of the type of excitation system. Because of this, load changes will cause transient excursions in both voltage and frequency. The magnitude and duration of these excursions are affected principally by the characteristics of the load and the size of the alternator relative to the load. A generator set is a relatively high impedance source when compared to the typical utility transformer.

A typical voltage profile on load application and removal is shown in **Figure 4–4**. At the left side of the chart the steady–state no–load voltage is being regulated at 100 percent of rated voltage. When a load is applied the voltage dips immediately. The voltage regulator senses the voltage dip and responds by increasing the field current to recover rated voltage. Voltage recovery time is the duration between load application and the return of voltage to the envelope of voltage regulation (shown as ± 2%). Typically, initial voltage dip ranges from 15 to 45 percent of nominal voltage when 100 percent of generator set rated load (at 0.8 PF) is connected in one step. Recovery to nominal voltage level will occur in 1–10 seconds depending on the nature of the load and the design of the generator set.

The most significant difference between a generator set and a utility (mains) is that when a load is suddenly applied to a utility (mains) there is typically not a frequency variation. When loads are applied to a generator set the machine rpm (frequency) dips. The machine must sense the change in speed and readjust its fuel rate to regulate at its new load level. Until a new load and fuel rate match is achieved, frequency will be different than nominal. Typically, frequency dip ranges from 5 to 15 percent of nominal frequency when 100 percent of rated load is added in one step. Recovery may take several seconds.

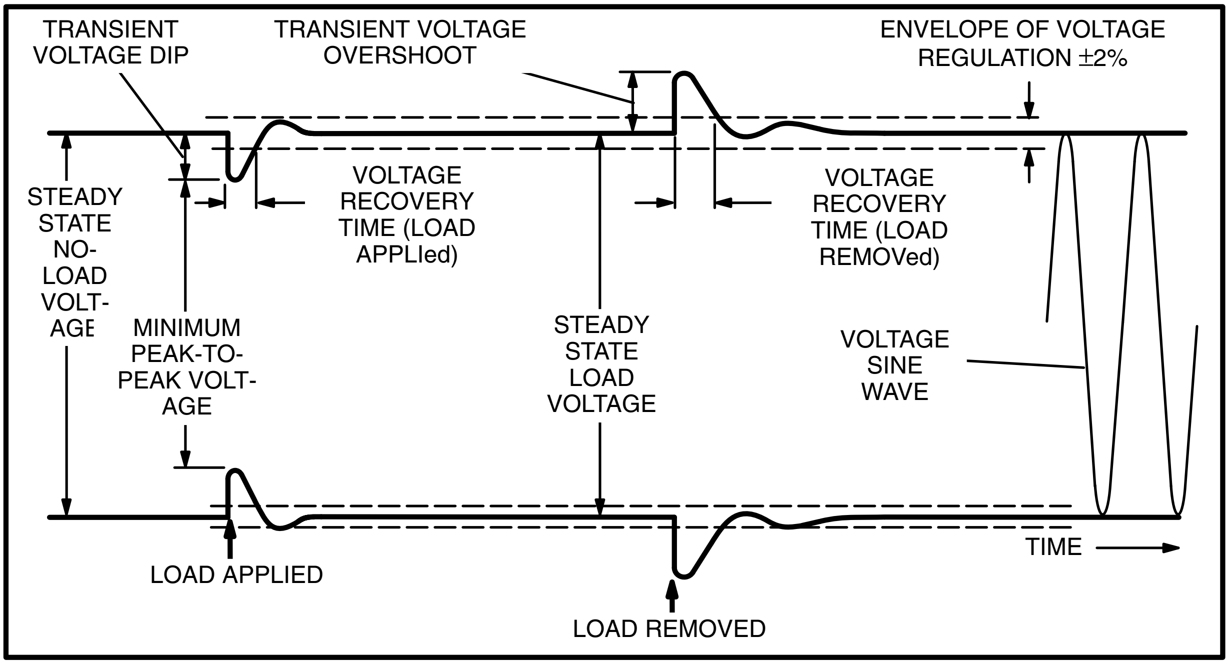


Figure 4–4. Typical Voltage Profile on Load Application and Removal

Note: Not all generator sets are capable of accepting 100% block load in one step.

Performance varies between generator sets because of differences in voltage regulator characteristics, governor response, fuel system design engine aspiration (natural or turbocharged), and how engines and generators are matched. An important goal in generator set design is limiting voltage and frequency excursions to acceptable levels.

Generator Saturation Curves

*G*enerator saturation curves plot generator output voltage for various loads as main field winding current is changed. For the typical generator shown, the no–load saturation curve **A** crosses the generator set rated voltage line when field current is approximately 18 amperes. In other words, approximately 18 amperes of field current is required to maintain rated no–load generator output voltage. The full–load saturation curve **B** shows that approximately 38 amperes of field current is required to maintain rated generator output voltage when the full–load power factor is 0.8. See **Figure 4–5.**

Excitation System Response

Field current cannot be changed instantaneously in response to load change. The regulator, exciter field, and main field all have time constants that have to be added. The voltage regulator has a relatively fast response, whereas the main field has a significantly slower response than the exciter field because it is many times larger. It should be noted that the response of a self–excited system will be approximately the same as that of a separately–excited system because the time constants for the main and exciter fields are the significant factors in this regard, and they are common to both systems.

Field forcing is designed in consideration of all excitation system components to optimize recovery time. It must be enough to minimize recovery time, but not so much as to lead to instability (overshoot) or overcome the engine (which is a limited source of power). See **Figure 4–6**.

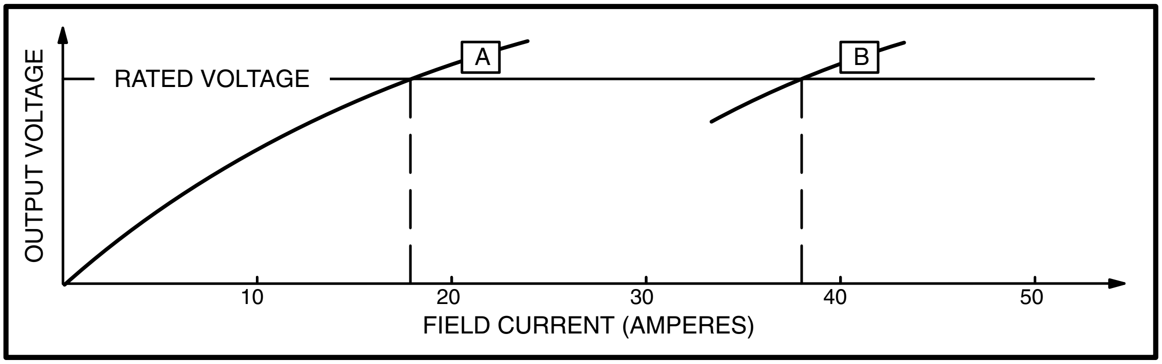


Figure 4–5. Typical Generator Saturation Curves

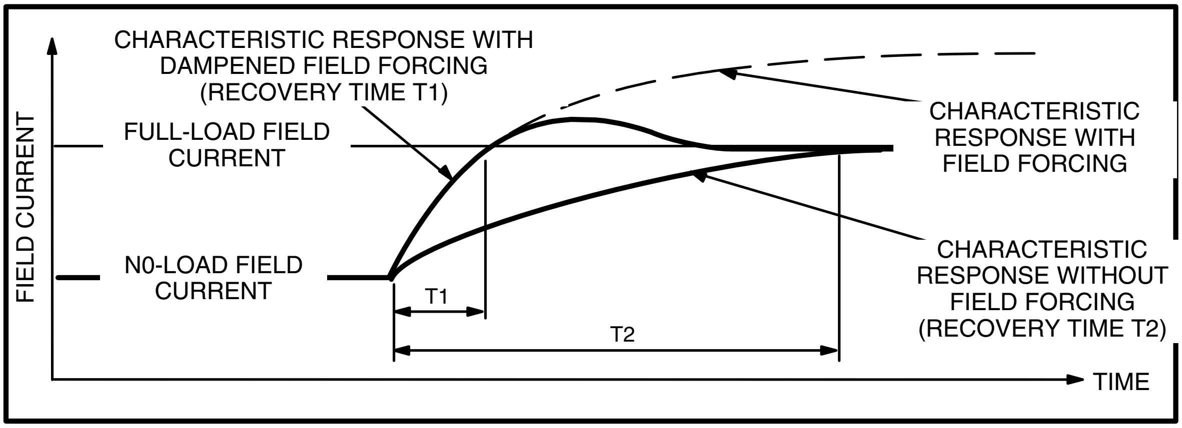


Figure 4–6. Excitation System Response Characteristics

Motor Starting Response

When motors are started, a starting voltage dip occurs which consists primarily of an instantaneous voltage dip plus a voltage dip as a result of excitation system response. **Figure 4–7** illustrates these two components which together, represent the transient voltage dip. The instantaneous voltage dip is simply, the product of motor locked rotor current and generator set sub–transient reactance. This occurs before the excitation system can respond by increasing field current and is therefore not affected by the type of excitation system. This initial voltage dip may be followed by further dip caused by the “torque matching” function of the voltage regulator which “rolls off” voltage to unload the engine if it senses a significant slowing down of the engine. A generator set must be designed to optimize recovery time while avoiding instability or lugging the engine.

Locked Rotor kVA

Motor starting current (locked rotor) is about six times rated current and does not drop off significantly until the motor nearly reaches rated speed as shown in **Figure 4–8**. This large motor “inrush” current causes generator voltage dip. Also, the engine power required to start the motor peaks at about three times rated motor power when the motor reaches approximately 80 percent of rated speed. If the engine does not have three times the rated power of the motor the voltage regulator will “roll off” generator voltage to unload the engine to a level it can carry. As long as motor torque is always greater than load torque during the period of acceleration, the motor will be able to accelerate the load to full speed. Recovery to 90 percent of rated voltage (81 percent motor torque) is usually acceptable because it results in only a slight increase in motor acceleration time.

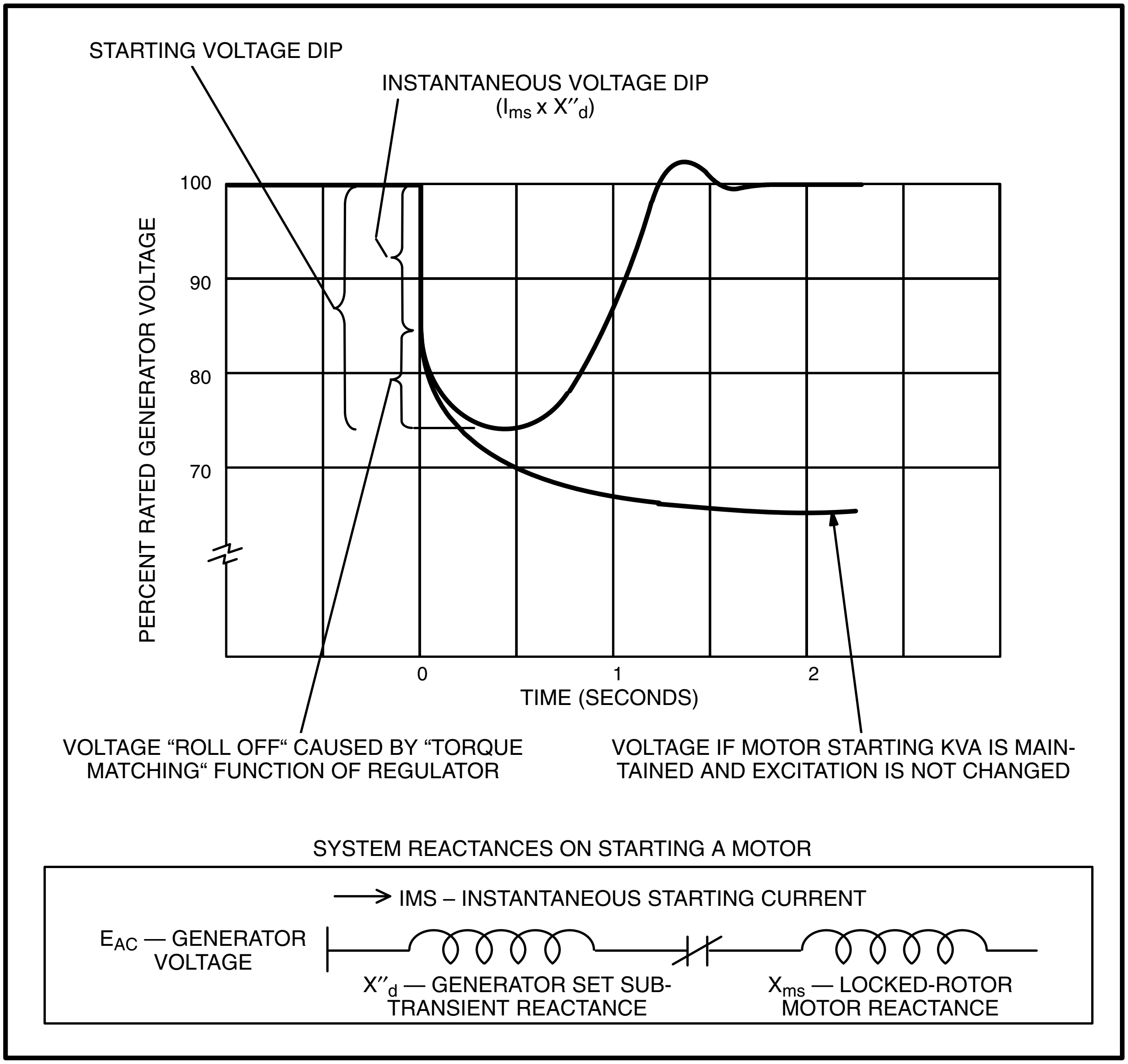


Figure 4–7. Transient Voltage Dip

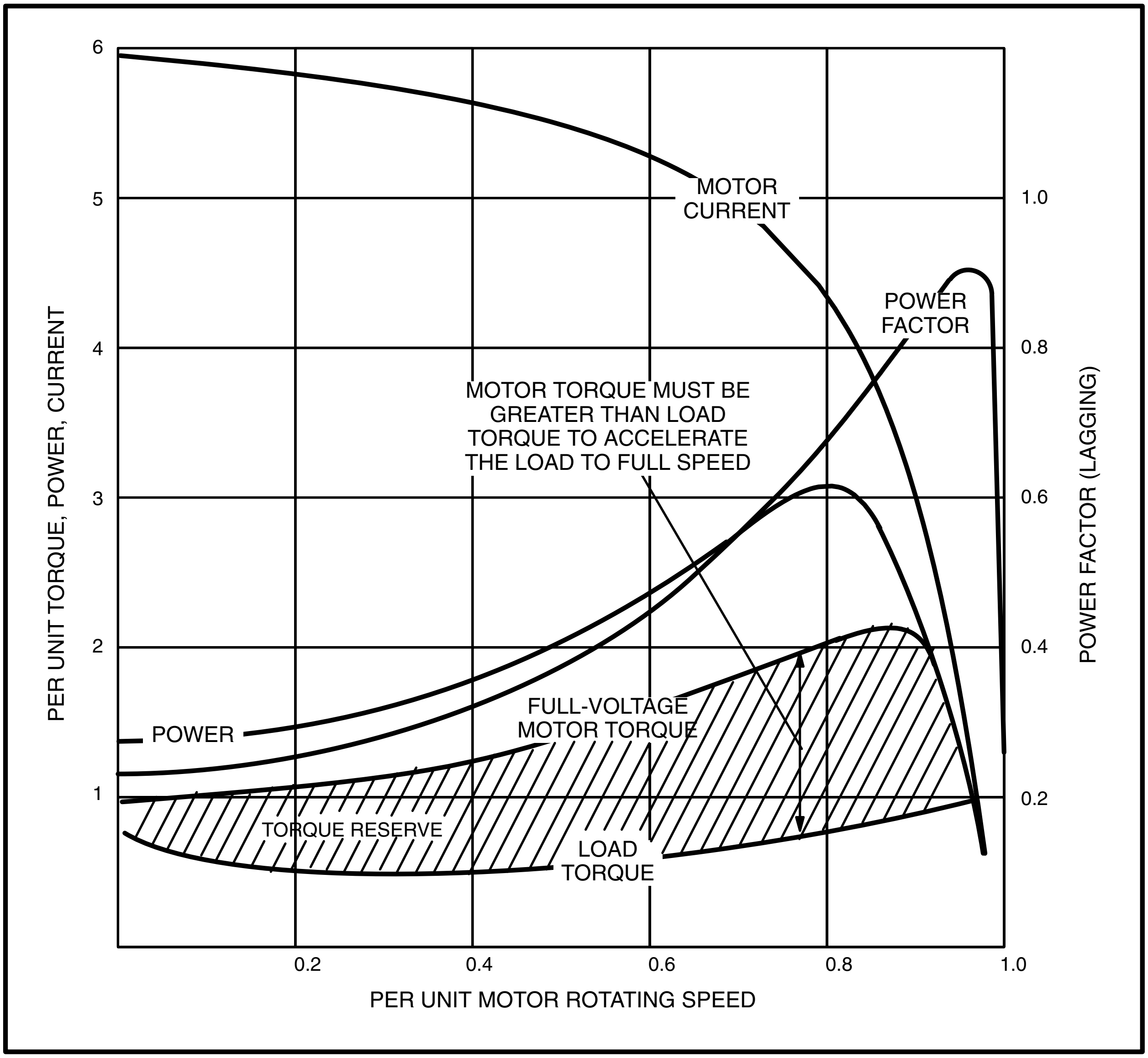


Figure 4–8. Typical Across-the-Line Motor Starting Characteristics (Assumes 100% of Nominal Voltage at Motor Terminals)

Sustained Voltage Dip

Following the relatively short (typically less than 10 cycles but as much as several seconds), steep transient voltage dip is a sustained period of voltage recovery as shown in **Figure 4–9**. The maximum motor starting kVA on the generator set Specification Sheet is the maximum kVA the generator can sustain and still recover to 90 percent of rated voltage, as shown by **Figure 4–10**. It should be noted that this is combined performance of the alternator, exciter, and AVR only. The motor starting performance of a particular generator set depends on the engine, governor and voltage regulator as well as the generator.

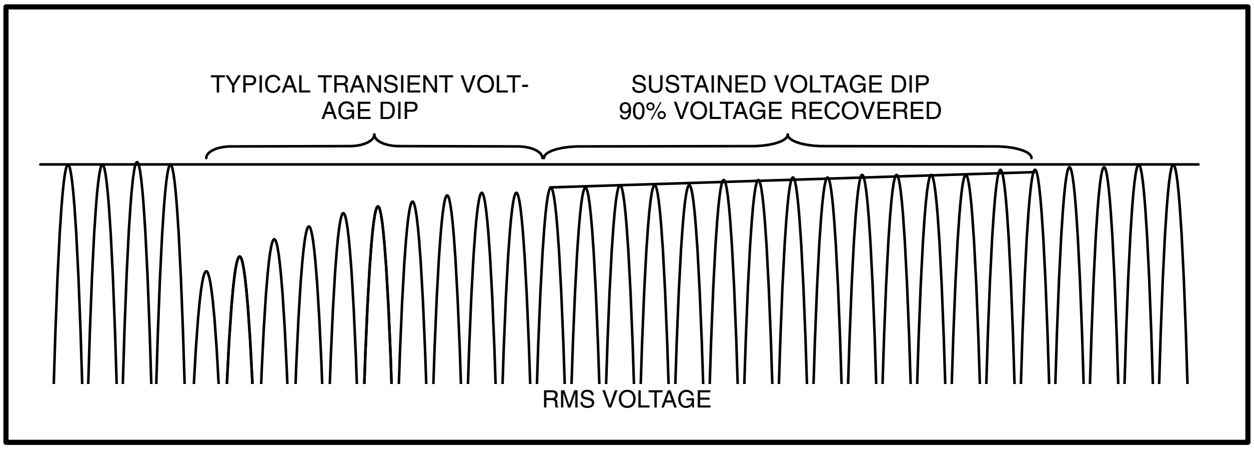


Figure 4–9. Sustained Voltage Dip

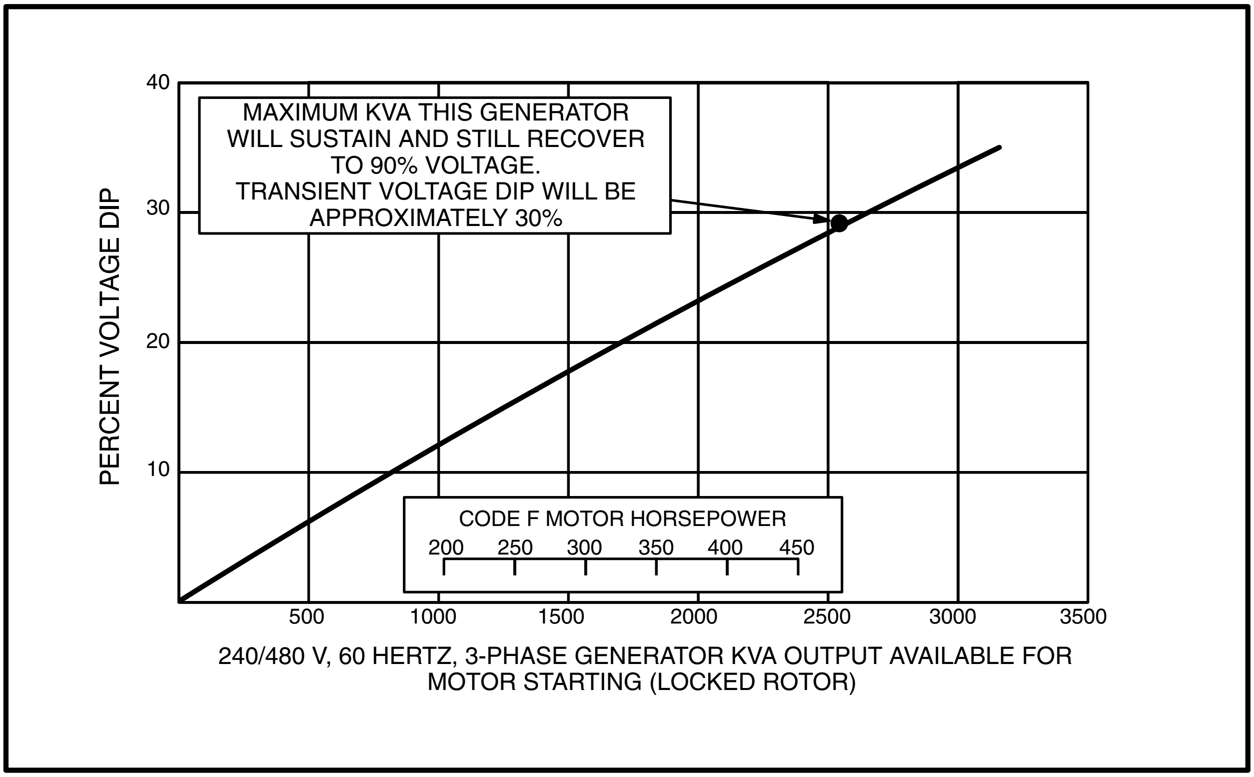


Figure 4–10. Typical NEMA Generator Chart of Transient Voltage Dip vs. Motor Starting KVA

Fault Response

The short circuit fault response of self– and separately–excited generators is different. A self–excited generator is referred to as a “collapsing field” generator because the field collapses when the generator output terminals are shorted (either 3 phase short or shorted L–L across the sensing phases). A separately–excited generator can sustain the generator field during a short circuit because excitation is provided by a separate permanent magnet generator. **Figure 4–11** shows the typical three–phase symmetrical short circuit current response of self– and separately–excited generators. Initial short circuit current is nominally 8 to10 times rated generator current and is a function of the reciprocal of the generator sub–transient reactance, $1/X''_d$. For the first few cycles (A), there is practically no difference in response between self–and separately–excited generators because they follow the same short circuit current decrement curve as field energy dissipates. After the first few cycles (B), a self–excited generator will continue to follow the short circuit decrement curve down to practically zero current. A separately–excited generator, because field power is derived independently, can sustain 2.5 to 3 times rated current with a 3–phase fault applied. This current level can be maintained for approximately 10 seconds without damage to the alternator.

Figure 4–12 is another way to visualize the difference in response to a three–phase fault. If the generator is self–excited, voltage and current will "collapse" to zero when current is increased beyond the knee of the curve. A separately–excited generator can sustain a direct short because it does not depend on generator output voltage for excitation power.

Short Circuit Winding Temperatures

The problem to consider in sustaining short circuit current is that the generator could be damaged before a circuit breaker trips to clear the fault. Short circuit currents can rapidly overheat generator stator windings. For example, an unbalanced L–N short on a separately excited generator designed to sustain three times rated current results in a current of about 7.5 times rated current. At that current level, assuming an initial winding temperature of about 155 °C, it can take less than five seconds for the windings to reach 300 °C—the approximate temperature at which immediate, permanent damage to the windings occurs. An unbalanced L–L short takes a few seconds longer to cause the windings to reach 300 °C, and a balanced three–phase short takes a little more time. See **Figure 4–13.** Also see Alternator Protection in the *Electrical Design* section.

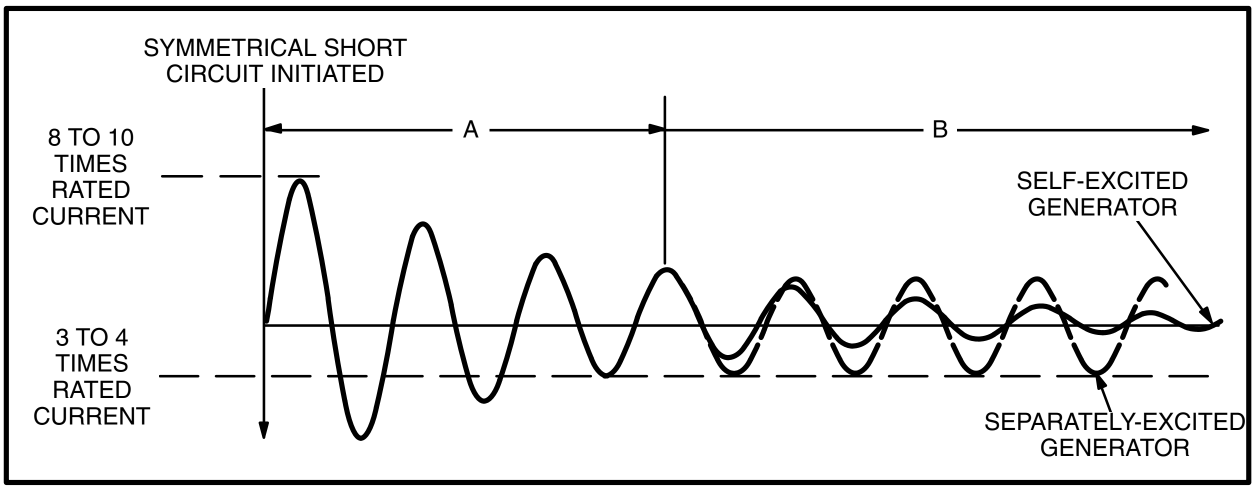


Figure 4–11. Symmetrical Three-Phase Short Circuit Response

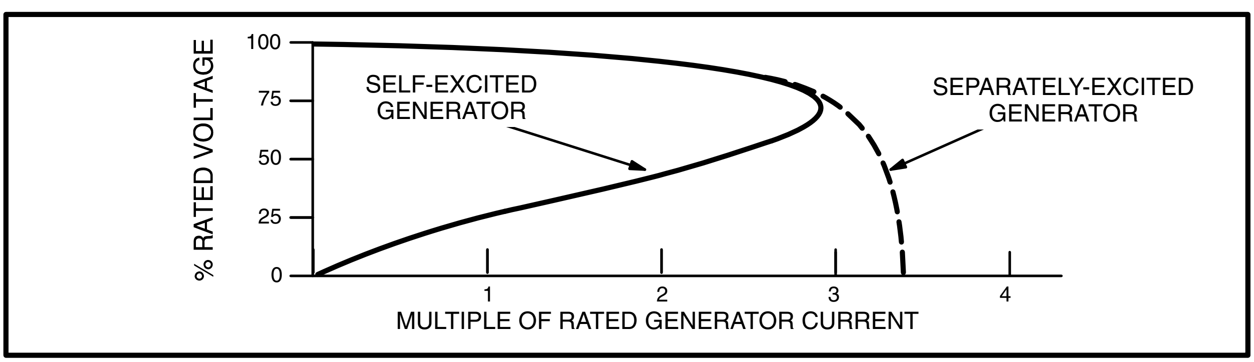


Figure 4–12. Short Circuit Capability

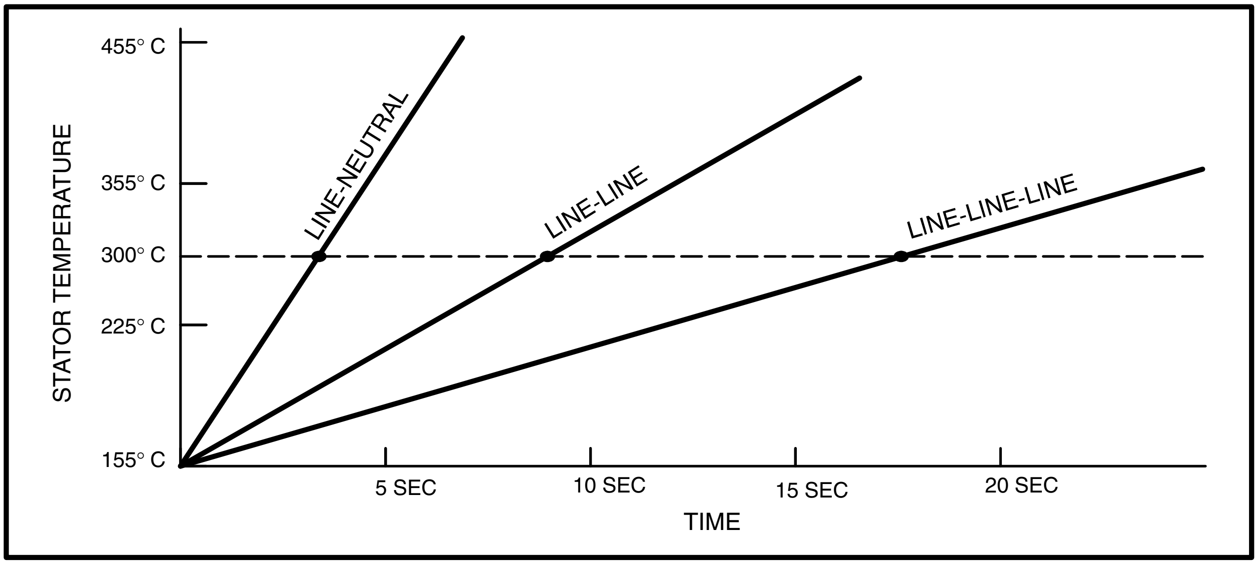


Figure 4–13. Approximate Short Circuit Winding Temperatures

As the reader can see from this lengthy subsection on fundamentals and excitation, only two basic forms of excitation systems influence a wide variety of performance characteristics. Steady state operation, transient conditions, motor starting, fault response and more are affected by this system. These characteristic effects are important in system performance studies. Below is a brief summary of the differentiating characteristics of self– and separately– excited systems.

- Self Excited
  - Higher Voltage Dips
  - Collapsing Field
  - Single Phase Average Sensing
  - Lower Tolerance for Non Linear Loads
  - Lesser Capable Motor Starter
- Separately Excited
  - Lower Voltage Dips
  - Sustained Fault Current
  - Three Phase RMS Sensing
  - Better Non–Linear Load Immunity
  - Better Motor Starter

Engines

Governors

Mechanical Governors

Mechanical governors, as the name suggests, control engine fueling based on mechanical sensing of engine RPM through flyweights or similar mechanisms. These systems exhibit about 3–5 percent speed droop from no load to full load inherent in the design. This type of system is generally the least expensive and is suitable for applications where the frequency droop is not a problem for the loads being served. Some but not all generator sets have optional mechanical governing available.

Electronic Governors

Electronic governors are used for applications where isochronous (zero droop) governing is required or where active synchronizing and paralleling equipment is specified. Engine RPM is usually sensed by electromagnetic sensor and the engine fueling controlled by solenoids driven by electronic circuits. These circuits, whether self contained controllers or part of a microprocessor generator set controller, utilize sophisticated algorithms to maintain precise speed (and so frequency) control. Electronic governors allow generator sets to recover faster from transient load steps than mechanical governors do. Electronic governors should always be used when the loads include UPS equipment.

Modern engines, especially diesel engines with full authority electronic fueling systems, are only available with electronic governing systems. The demand or regulation requirements to achieve increased fuel efficiency, low exhaust emissions and other advantages, require the precise control afforded by these systems.

Engine Starting Systems

Battery Starting

Battery starting systems for generator sets are usually 12 volt or 24 volt. Typically with smaller sets using 12 volt systems and larger machines using 24 volt systems. **Figure 4–14** illustrates typical battery–starter connections. Consider the following choosing or sizing batteries and related equipment:

- Batteries must have enough capacity (CCA, Cold Cranking Amps) to provide the cranking motor current indicated on the recommended generator set Specification Sheet. The batteries may be either lead–acid or nickel–cadmium. They must be designated for this use and may have to be approved by the local authority having jurisdiction.
- An engine–driven alternator with integral automatic voltage regulator is normally provided to recharge the batteries during operation.
- For most generator set power systems, auxiliary, float–type battery charger, powered by the normal power source, is desirable or required to keep the batteries fully charged when the generator set is not running. Float battery chargers are required for emergency standby systems.
- Codes usually specify a maximum battery charging time. The following rule–of–thumb can be used to size auxiliary battery chargers:

$$\text{Required Battery Charging Amps} = \frac{1.2 \times \text{Battery Amp–Hours}}{\text{Required Charging Hours}}$$

- Local codes may require battery heaters to maintain a minimum battery temperature of 50 °F (10 °C) if the generator set is subject to freezing ambient temperatures. See further information under Accessories and Options (this section), Standby Heating Devices for Generator Sets.
- Standard generator sets usually include battery cables, and battery racks are available.

Relocating of Starting Batteries

If batteries are mounted at a further distance from the starter than the standard cables allow, the cables must be designed accordingly. Total resistance, cables plus connections, must not result in an excessive voltage drop between the battery and the starter motor. Engine recommendations are that total cranking circuit resistance, cables plus connections, not exceed 0.00075 ohms for 12 volts systems and 0.002 ohms for 24 volt systems. See the following example calculation.

Example Calculation: A generator set has a 24–VDC starting system to be powered by two 12–volt batteries connected in series **(Figure 4–14)**. Total cable length is 375 inches, including the cable between the batteries. There are six cable connections. Calculate the required cable size as follows:

1. Assume a resistance of 0.0002 ohms for the starter solenoid contact ($R_{CONTACT}$).
2. Assume a resistance of 0.00001 ohms for each cable connection ($R_{CONNECTION}$), total of six.
3. Based on the formula that:
   Maximum Allowable Cable Resistance
   $= 0.002 - R_{CONNECTION} - R_{CONTACT}$
   $= 0.002 - 0.0002 - (6 \times 0.00001)$
   $= 0.00174$ ohms
4. Refer to **Figure 4–15** for AWG (American Wire Gauge) cable resistances. In this example, as shown by the dashed lines, the smallest cable size that can be used is 2–#1/0 AWG cables in parallel.

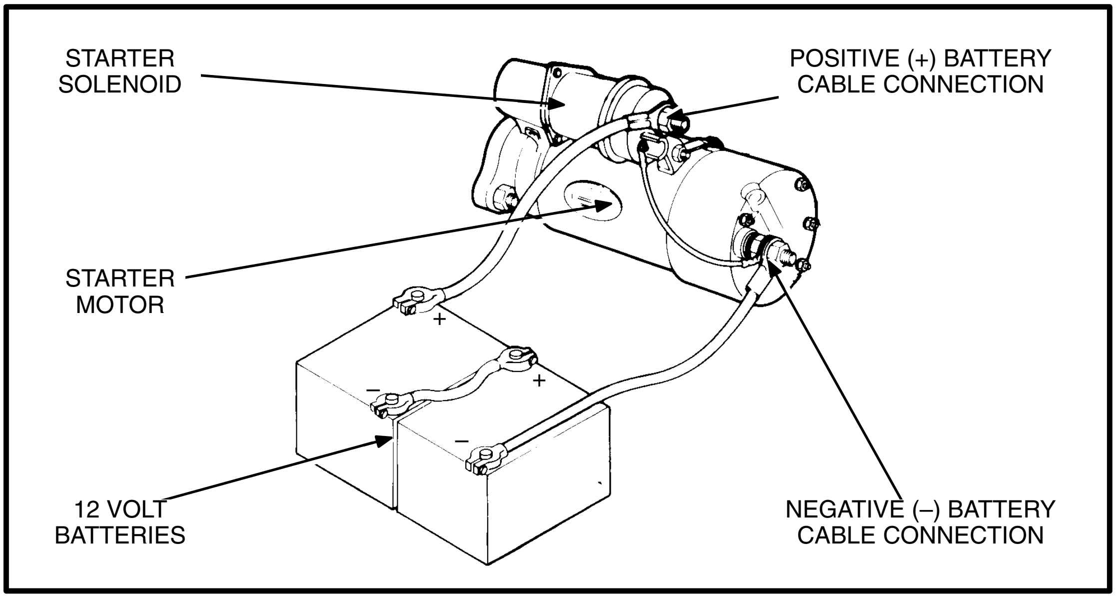


Figure 4–14. Typical Electric Starter Motor Connections (24 Volt System Shown)

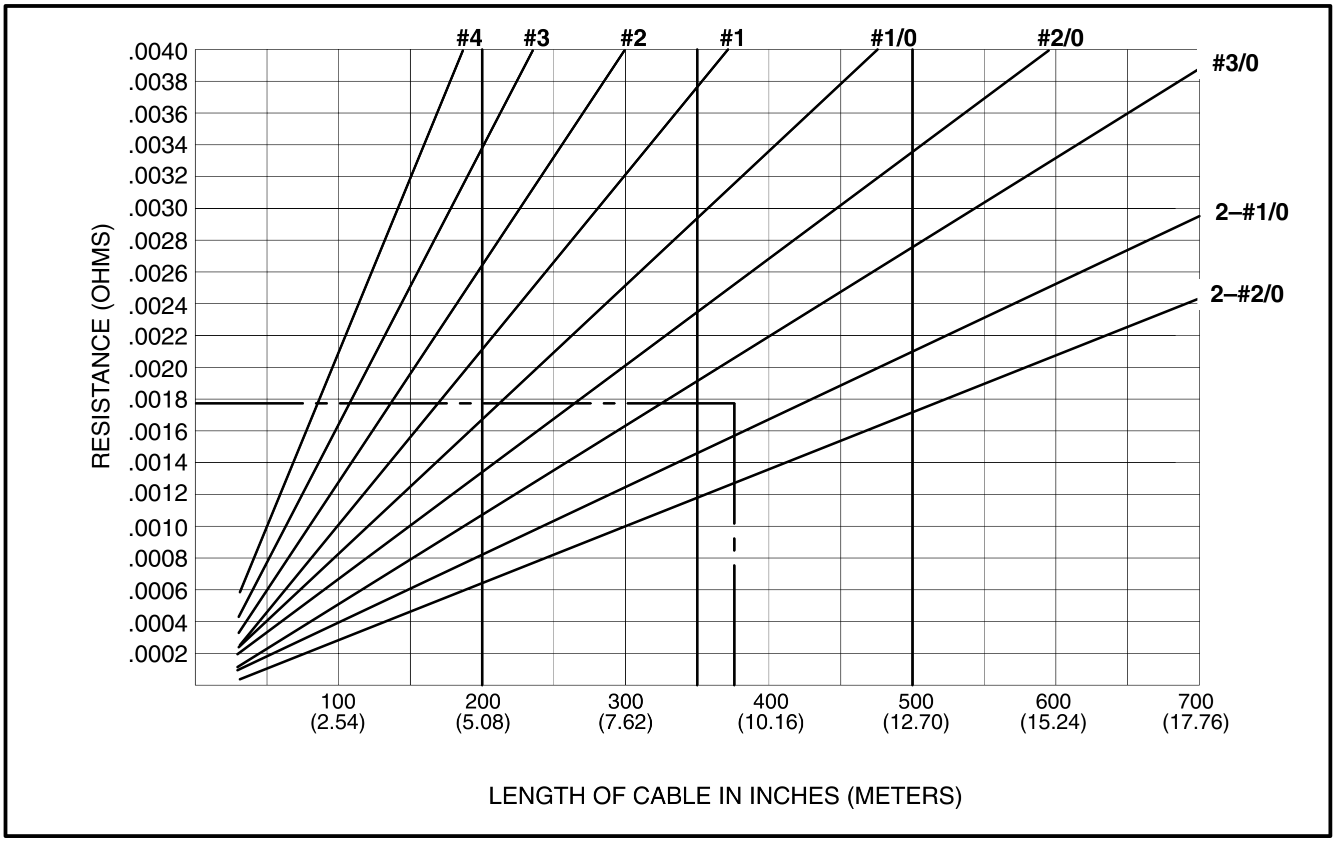


Figure 4–15. Resistance vs. Length for Various AWG Cable Sizes

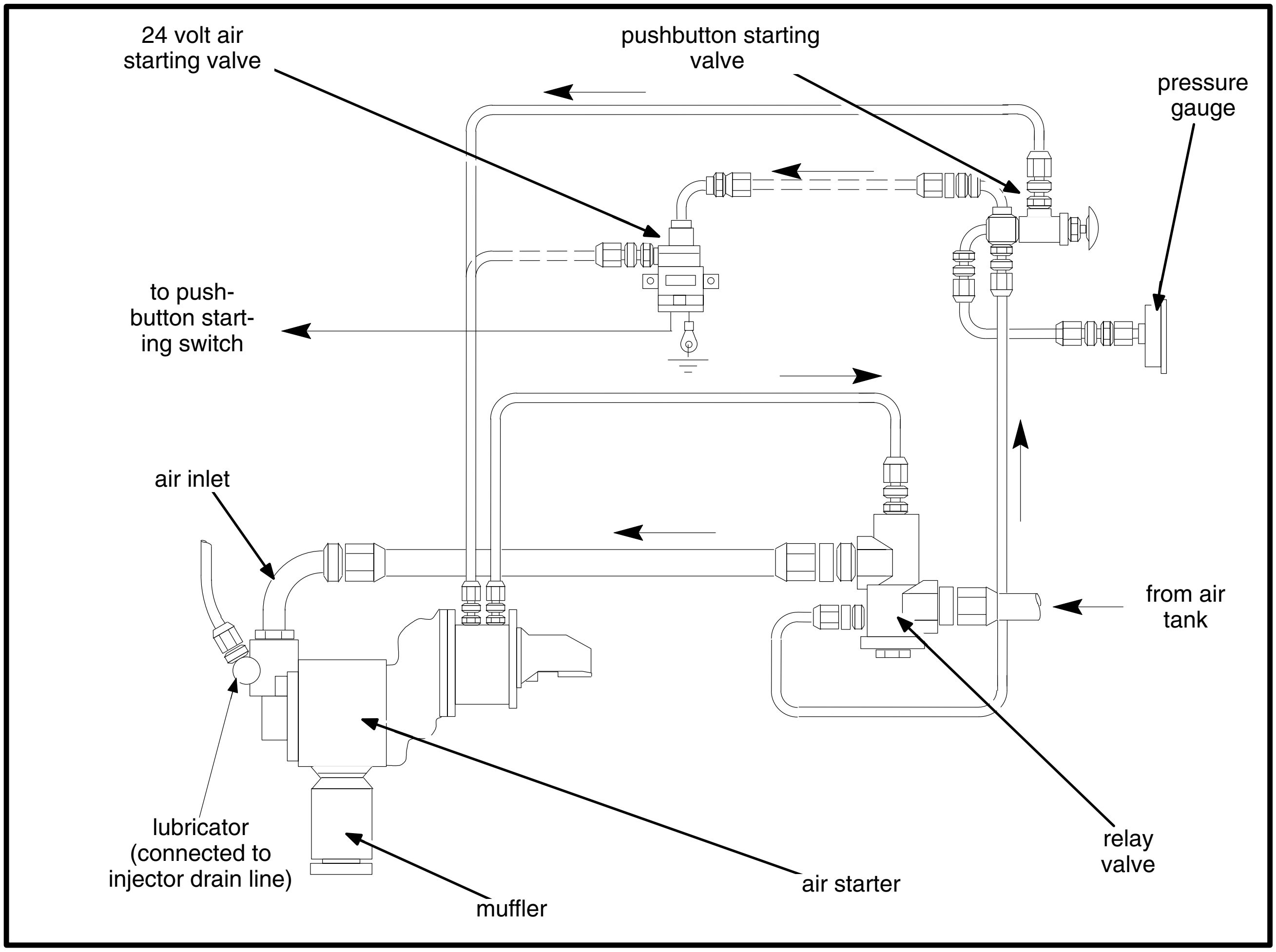


Figure 4–16. Typical Piping Arrangement for an Air Starter

Air Starting

Compressed air engine starting systems are available for some larger generator sets. Air starting may be preferred for some prime power applications assuming compressed air is readily available. **Figure 4–16** shows a piping arrangement for a typical air starter system. The following items should be considered for determination of equipment needs when installing an air starter system:

- The engine manufacturer should be consulted for recommendations regarding air hose size and the minimum tank volume required for each second of cranking. Tank size will depend on the minimum cranking time required. All of the starters available from Cummins Power Generation have a maximum pressure rating of 150 psig (1035 kPa).
- Air tanks (receivers) should be fitted with a drain valve of the screw–out, tapered–seat type (other types are unreliable and a common source of air leaks). Moisture can damage starter components.
- All valves and accessories in the system should be designed for diesel air starting service.
- Pipe fittings should be of the dry seal type and should be made up with thread sealant. Teflon tape is not recommended as it does not prevent thread loosening and can be a source of debris that can clog valves.

NOTE: Batteries, although of much less capacity, will still be required for engine control and monitoring systems when air starting is used.

Controls

Relay–Based

Until a few years ago relay–based control systems were common on nearly all generator sets. They can be designed to provide either manual or fully automatic starting plus basic generator protection functions. They may include sufficient equipment to meet local code requirements for generator sets.

Relay–based systems (see **Figure 4–17**) control engine starting and operational functions, monitor engine and alternator functions for failures or out–of–specification performance, and provide gauges, metering, and annunciation for user interface. Functions such as alternator voltage control are performed by a separate AVR circuit board. Similarly, a separate controller circuit operates electronic governing and other optional equipment. There are numerous optional features available to enhance performance and control to add functionality for special tasks such as interface to paralleling equipment and to monitor additional equipment functions such as fuel tanks, coolant, or batteries.

Figure 4–17. Two–Wire Control Interface Panel

Some generator sets are equipped with hybrid relay/solid–state control systems (see **Figure 4–18**). These controls provide more functionality than pure relay–based systems, but are still limited in their ability to provide complex control or advanced operation interfaces.

Figure 4–18. Detector 12™ Control Interface Panel

Electronic (Microprocessor) Based

Modern day demands for a high level of performance, enhanced functionality, control of sophisticated systems and network interfaces require the capabilities of microprocessor based control systems. The age of microprocessors and computers has enabled the development of fully integrated, electronic microprocessor based controls such as the Power Command (see **Figure 4–19**) control series from Cummins Power Generation. The Power Command system integrates engine operation, alternator control and monitoring functions of a fully equipped relay based control, plus electronic governing and voltage regulation along with many additional features and capabilities. Full monitoring of electrical output characteristics, kW, kVA, kVAR, over and under voltage, reverse power and more, allows for total control of the power producing system.

Figure 4–19. Power Command Microprocessor System

"Full Authority" Electronics

Advanced engine designs incorporate sophisticated fuel delivery systems, ignition or injection timing control, and active performance monitoring and adjustment. These systems and functions are required to achieve fuel efficiency and low exhaust emissions. "Full authority" engines as they are often referred to, require equally sophisticated microprocessor systems to operate and control these functions. A more advanced version of the Power Command control incorporates dynamic engine control capability with features and functionality of the previously mentioned version, plus many added features (see **Figure 4–20**). On generator sets with "full authority" electronic engines, this type of advanced control system is an integral part of the engine–generator package and there is no option for relay based or other control systems.

Figure 4–20. Power Command Full Authority Electronic

Control Options

Optional equipment for electronic control systems include all functions needed for control and monitoring for paralleling of multiple generator sets to each other and to utilities (mains). Intermediate type, paralleling upgradable controls are also available.

The available network interface capability for these types of controls can be an important feature to consider as optional equipment. The network capability provides for remote monitoring and control of the generator set as well as integration into building and power system automation systems.

Optional relay packages for control of peripheral equipment, are also available.

Accessories and Options

Control Safeties and Annunciators

Relay based control and monitoring systems available on many generator sets can include multiple warning and shutdown alarms for engine/generator protection. Optional equipment is usually required for full monitoring or remote annunciation as well on–set

AC metering. Additional equipment is required if network communications are desired, but this usually has limited capability. With the advent of complex electronic engine and alternator control requirements plus increased levels of diagnostic and service data, systems can run up against the capability limitations of these control system types.

Electronic control and monitoring systems, that are often standard equipment on many generator sets, include a full menu of integrated warning and shutdown alarms to protect the engine/generator equipment and communicate those alarms. Some of these alarms are customer selectable or programmable. All alarms can be displayed on the control panel or at a remote location. The remote annunciation is accomplished through various means:

1. Relay contact outputs for common or individual alarms.
2. Annunciator panels specifically designed for the control system, driven by various types of network interfaces.
3. Communication through Local Area Networks or modem connections to remote monitoring locations using PC based software.

Codes may require different levels of annunciation for different types of applications. Critical life safety (U.S. NFPA 110 Level 1) or all other emergency/standby (U.S. NFPA 110 Level 2) and equivalent codes specify the minimum annunciation required for those applications. Other codes may also have specific requirements. Refer to the individual codes in force for annunciation requirements. Power Command control from Cummins Power Generation are designed to meet or exceed these types of requirements and numerous additional other standards (Refer to the specification sheet for the Power Command control for details.)

Main–Line Circuit Breakers

Circuit breakers of both the molded case type and power circuit type may be used for generator sets. Molded case breakers are generally available mounted directly on the generator set. However, many circuit breakers must be mounted in a separate enclosure mounted on a wall or pedestal. Sizes can range from 10 to 2500 amperes and are suitable for mounting in an output box directly on the generator set. Power circuit breakers are available in sizes from 800 to 4,000 amps and are larger, faster–operating, and considerably more expensive than molded case breakers. Power circuit breakers are usually mounted on a free–standing panel next to the generator set instead of on the set because of their size and susceptibility to vibration damage. When main line breakers are needed for a project, the project specification should include the type of breaker, type of trip unit, and rating basis (continuous or non–continuous). See the Electrical Design section for more information regarding choices of circuit breakers.

Molded Case Switches

In cases where a disconnecting means is desired but protection for the generator or conductors is not required (i.e. this protection is afforded by AmpSentry™ or by using a self excited generator), a molded case switch is often used in place of a circuit breaker. These switches have the same contacts and switching mechanisms as circuit breakers but no trip current sensing. The switch will also provide a connection location and lugs for connection of load conductors.

Entrance Boxes

An entrance box is essentially a circuit breaker box without a CB. If no circuit breaker is needed or desired, the entrance box provides additional space for conductor entrance, routing and connection.

Multiple Circuit Breakers

Multiple breakers are often required and are available from the factory on most generator sets. Standard options available are two mounted circuit breakers (except on the largest alternator). On certain alternators and gensets it is simply not practical or there is no room to mount circuit breaker enclosures. Consult manufacturer representatives for availability on specific equipment. Special orders can be considered for mounting three or more breakers onto some generator sets but usually this drives the use of a wall mounted or free standing distribution panel.

Batteries and Battery Chargers

Perhaps the most critical sub–system, on a generator set, is the battery system for engine starting and generator set control. Proper selection and maintenance of batteries and battery chargers is essential for system reliability.

The system consists of batteries, battery racks, a battery charger powered by the normal electric power source during standby and an engine–driven battery charging alternator which recharges the batteries and provides DC power for the control system when the generator set is running.

When generator sets are paralleled, the battery banks for the individual sets are often paralleled to provide control power for the paralleling system. The manufacturer of the paralleling system should always be consulted to determine suitability of the engine control power system for this service because battery bank voltage dip may disrupt some paralleling control systems and require the use of separate–station batteries for the paralleling equipment.

Batteries should be located as close as possible to the generator set to minimize starting circuit resistance. The location should allow easy servicing of the batteries and minimize exposure to water, dirt and oil. A battery enclosure must provide ample ventilation so that explosive gases given off by the battery can dissipate. Codes in seismic zones require battery racks that have special features to prevent battery electrolyte spillage and breakage during an earthquake.

The systems designer should specify the type of battery system (usually limited to lead–acid or NiCad as explained below) and the battery system capacity. The required battery system capacity depends on the size of the engine (displacement), minimum engine coolant, lube oil and battery temperatures expected (see Standby Heating Devices for Generator Sets below), the engine manufacturer's recommended lube oil viscosity, and the required number and duration of cranking cycles[1]. The generator set supplier should be able to make recommendations based on this information.

Lead–acid batteries are the most commonly chosen type of battery for generator sets. They are relatively economical and provide good service in ambient temperatures between 0° F (–18° C) and 100° F (38° C). Lead–acid batteries can be recharged by conventional battery chargers which may be wall–mounted close to the generator set or in an automatic transfer switch (if the generator set is NOT part of a paralleling system). The charger should be sized to recharge the battery bank in approximately 8 hours while providing all the control power needs of the system.

A lead–acid battery may be of the sealed "maintenance–free" or flooded–cell type. Maintenance free batteries withstand maintenance neglect better but are not as easily monitored and maintained as flooded–cell batteries.

All lead–acid batteries are required to be charged at the job site prior to their initial use. Even maintenance–free batteries do not retain charge indefinitely. Flooded–cell batteries require addition of electrolyte at the job site and will rise to approximately 50 percent of the fully charged condition shortly after electrolyte is added to the battery.

NiCad (nickel–cadmium) battery systems are often specified where extreme high or low ambient temperature is expected because their performance is less affected by temperature extremes than that of lead–acid batteries. NiCad battery systems are considerably more expensive than lead–acid batteries but have a longer service life.

1 NFPA 110 applications require either two 45 second continuous cranking cycles with a rest period between, or two cycles of three 15 second cranking periods with 15 second rest between.

A major disadvantage of NiCad battery systems is that disposal may be difficult and expensive because the battery materials are considered hazardous. Also, NiCad batteries require special battery chargers in order to bring them to the full–charge level. These chargers must be provided with filters to reduce “charger ripple” which can disrupt engine and generator control systems.

Exhaust Systems and Mufflers

Two primary elements drive exhaust and muffler system choices, noise level, of course, and accommodating the relative movement between the exhaust system and the generator set.

Noise regulations or preferences are primary drivers for muffler choices. Exhaust system and muffler choices also obviously depend on whether the generator set is indoors or outdoors. An outdoor weather protective housing supplied by a generator set manufacturer usually will have various muffler options and usually with the muffler mounted on the roof. Muffler options are often rated as industrial, residential or critical depending on their attenuation. Acoustic housings usually include an integral muffler system as part of the overall acoustic package. For more information on noise and understanding sound levels see Section VI *Mechanical Design*.

A key element regarding the overall exhaust system is that the generator set vibrates, i.e. moves with respect to the structure it is housed within. Therefore a flexible piece of exhaust pipe or tube is required at the generator set exhaust outlet. Indoor systems with long runs of exhaust tube will also require allowance for expansion in order to avoid damage to both the exhaust system and to the engine exhaust manifolds or turbo chargers.

Another consideration for exhaust system equipment is in regard to measurement of the exhaust gas temperatures. The engine exhaust system may be fitted with thermocouples and monitoring equipment to accurately measure the engine exhaust temperature for the purpose of service diagnosis or to verify the engine is operating at load level sufficient to prevent light load operational problems. See Appendix E. *Maintenance and Service* for more information.

Housings (Canopies)

Housing generally can be categorized in three types, weather protective (sometimes referred to as skin–tight), acoustic, and walk–in enclosures. The names are for the most part self explanatory.

Weather Protective

Sometimes referred to as skin tight, these housings protect and can secure the generator set, often available with lockable latches. Incorporated louvers or perforated panels allow for ventilation and cooling air flow. Little, if any sound attenuation is achieved and sometimes there can be added vibration induced noise. These housing types will not retain heat or hold temperature above ambient.

Acoustic

Sound attenuating housings are specified based on a certain amount of noise attenuation or a published external sound level rating. Noise levels must be specified at a specific distance and to compare noise levels they all must be converted to the same distance base. Sound attenuation takes material and space so be certain that unit outline drawings applied include the proper acoustic housing information.

While some of these enclosure designs will exhibit some insulation capability to hold heat, this is not the intent of their design. If maintenance of above ambient temperatures are required, a walk–in enclosure is needed.

Walk–in

This term encompasses a wide variety of enclosures that are custom built to individual customer specifications. Often they include sound attenuation, power switching and monitoring equipment, lighting, fire extinguishing systems, fuel tanks, and other equipment. These types of enclosures are constructed both as drop over, single unit and as integral units with large doors or removable panels for service access. These enclosures can be built with insulation and heating capability.

Coastal Regions

Another consideration regarding housings is if the unit is in a coastal region. A coastal region is defined as within 60 miles of a saltwater body. In these areas steel housings, even when specially coated, skids, fuel tanks, etc. are more susceptible to corrosion from saltwater effects. The use of optional aluminum genset enclosures and skirts (where offered) are reocmmended in coastal regions.

Note: Placement of outdoor housings (especially acoustic housings) inside buildings is not a recommended practice for two primary reasons. One, acoustic housings utilize the excess fan restriction capability to achieve sound reduction through ventilation baffling. Therefore there is little or no restriction capability remaining for any air ducts, louvers or other equipment that will invariably add restriction. Two, the exhaust systems of outdoor housings are not necessarily sealed systems, i.e. they have clamped, slip fit joints in lieu of threaded or flanged fittings. These clamped fittings can let exhaust escape into the room.

Alternative Cooling and Ventilating Configurations

Liquid–cooled engines are cooled by pumping coolant (a mixture of water and anti–freeze) through passages in the engine cylinder block and heads by means of an engine–driven pump. The engine, pump and radiator or liquid–to–liquid heat exchanger form a closed, pressurized cooling system. It is recommended that, whenever possible, the generator set include this type of factory–mounted radiator for engine cooling and ventilation. This configuration results in the lowest system cost, best system reliability and best overall system performance. Further, the manufacturer of these generator sets can prototype test to verify system performance.

Cooling System Ratings

Most Cummins Power Generation generator sets have optional cooling system ratings available on the factory mounted radiator models. Cooling systems designed to operate in 40° C and 50° C ambient temperature are often available. Check individual unit specification sheets for performance or availability. These ratings have a maximum static restriction capability associated to them, see Ventilation in the *Mechanical Design* section for more information on this subject.

Note: Be cautious when comparing cooling system ratings that the rating is based on ambient temperature not air–on–radiator. An air–on–radiator rating restricts the temperature of the air flowing into the radiator and does not allow for air temperature increase due to the radiated heat energy of the engine and alternator. Ambient rated system accounts for this increase in temperature in their cooling capability.

Remote Cooling Alternatives

In some applications, the air flow restriction could be too great, because of long duct runs for example, for an engine–driven radiator fan to provide the air flow required for cooling and ventilation. In such applications, and where fan noise is a consideration, a configuration involving a remote radiator or a liquid–to–liquid heat exchanger should be considered. In these applications, a large volume of ventilating air flow is still required to remove the heat rejected by the engine, generator, muffler, exhaust piping and other equipment so as to maintain the generator room temperature at appropriate levels for proper system operation.

Remote Radiator

A remote radiator configuration requires careful system design to provide adequate engine cooling. Close attention must be paid to details such as the friction and static head limitations of the engine coolant pump and to proper deaeration, filling and draining of the coolant system, as well as containment of any anti–freeze leaks.

Heat Exchanger

A liquid–to–liquid heat exchanger configuration requires close attention to the design of the system that provides the medium for cooling the heat exchanger. It should be noted that local water conservation and environmental regulations may not permit city water to be used as the cooling medium and that in seismic risk regions city water could be disrupted during an earthquake.

See the *Mechanical Design* section for more detailed information regarding cooling alternatives.

Lubricating Oil Level Maintenance Systems:

Lubricating oil maintenance systems may be desirable for applications where the generator set is running under prime power conditions, or in unattended standby applications which may run for greater than the normal number of hours. Oil level maintenance systems do not extend the oil change interval for the generator set, unless special filtration is also added to the system.

Standby Heating Devices for Generator Sets

Cold Start and Load Acceptance

A critical concern of the system designer is the time it takes the emergency or standby power system to sense a power failure, start the generator set and transfer the load. Some codes and standards for emergency power systems stipulate that the generator set must be capable of picking up all the emergency loads within ten seconds of power failure. Some generator set manufacturers limit the cold starting performance rating to a percentage of the standby rating of the generator set. This practice recognizes that in many applications, only a portion of the total connectable load is emergency load (non–critical loads are permitted to be connected later), and that it is difficult to start and achieve full–load acceptance with diesel generator sets.

The Cummins Power Generation design criteria for cold starting and load acceptance is that the generator set be capable of starting and picking up all emergency loads up to the standby rating within ten seconds of power failure. This level of performance presumes that the generator set is located within a minimum ambient temperature of 40 °F (4 °C) and that the set is equipped with coolant heaters. This must be accomplished by installing the generator set in a heated room or enclosure. Outdoor, weather protective enclosures (including those termed “skin tight”) are generally not insulated and thus make it difficult to maintain a warm generator set in cooler ambient temperatures.

Below 40 °F (4 °C), and down to –25 °F (–32 °C), most Cummins Power Generation generator sets will start but may not accept load in one step within ten seconds. If a generator set must be installed in an unheated enclosure in a location with low ambient temperatures, the designer should consult with the manufacturer. The facility operator is responsible for monitoring operation of the generator set coolant heaters (a low coolant temperature alarm is required by NFPA 110 for this purpose) and obtaining the optimum grade of fuel for ambient conditions.

Generator sets in emergency power applications are required to start and pick up all emergency loads within 10 seconds of a power failure. Engine coolant heaters are usually necessary even in warm ambients, especially with diesel generator sets, to meet such requirements. NFPA 110 has specific requirements for Level 1 systems (where system failure can result in serious injury or loss of life):

- Coolant heaters are required unless the generator room ambient will never fall below 70° F (21° C).
- Coolant heaters are required to maintain the engine block at not less than 90° F (32° C) if the generator room ambient can fall to 40° F (4° C), but never below. Performance at lower temperatures is not defined. (At lower ambient temperatures the generator set may not start in 10 seconds, or may not be able to pick up load as quickly. Also, low temperature alarms may signal problems because the coolant heater is not maintaining block temperature at a high enough level for a 10–second start.)

- Battery heaters are required if the generator room ambient can fall below 32° F (0° C).
- A low engine temperature alarm is required.
- Coolant heaters and battery heaters must be powered by the normal source.

Coolant Heaters

Thermostatically controlled engine coolant heaters are required for fast starting and good load acceptance on generator sets that are used in emergency or standby applications[2]. It is important to understand that the coolant heater is typically designed to keep the engine warm enough for fast and reliable starting and load pick–up, not to heat the area around the generator set. So, in addition to the operating coolant heater on the engine, ambient air around the generator set should be maintained at a minimum of 40F (10C)[3]. If the ambient space around the generator set is not maintained at this temperature, considerations should be given to the use of special fuel type or fuel heating (for diesel gensets), alternator heaters, control heaters, and battery heaters.

Failure of the water jacket heater or reduction of the ambient temperature around the engine will not necessarily prevent engine starting, but will affect the time it takes for the engine to start and how quickly load can be added to the on–site power system. Low engine temperature alarm functions are commonly added to generator sets to alert operators to this potential system–operating problem.

Water jacket heaters (see **Figure 4–21**) are a maintenance item, so it can be expected that the heating element will be required to be changed at some times during the life of the installation. In order to replace the heater element without draining the entire cooling system of the engine, heater isolation valves (or other means) should be provided.

Jacket water heaters can operate at considerably higher temperatures than engine coolant lines, so it is desirable to use high quality silicon hoses, or braided hose to prevent premature failure of coolant hoses associated with the water jacket heater. Care should be taken in the design of the coolant heater installation to avoid overhead loops in the hose routing that can result in air pockets that might cause system overheating an failure.

Engine coolant heaters normally operate when the generator set is not running, so they are connected to the normal power source. The heater should be disabled whenever the generator set is running. This may be done by any number of means, such as an oil pressure switch, or with logic from the generator set control.

2 **US Code Note**: For Level 1 emergency power systems, NFPA 110 requires that engine coolant be kept at a minimum of 90° F (32° C). NFPA110 also requires that heater failure monitoring be provided in the form of a low engine temperature alarm.

3 **Canadian Code Note**: CSA282–2000 requires that generator sets used in emergency application are always installed in such a way that the generator set is in a 10C (40F) minimum environment.

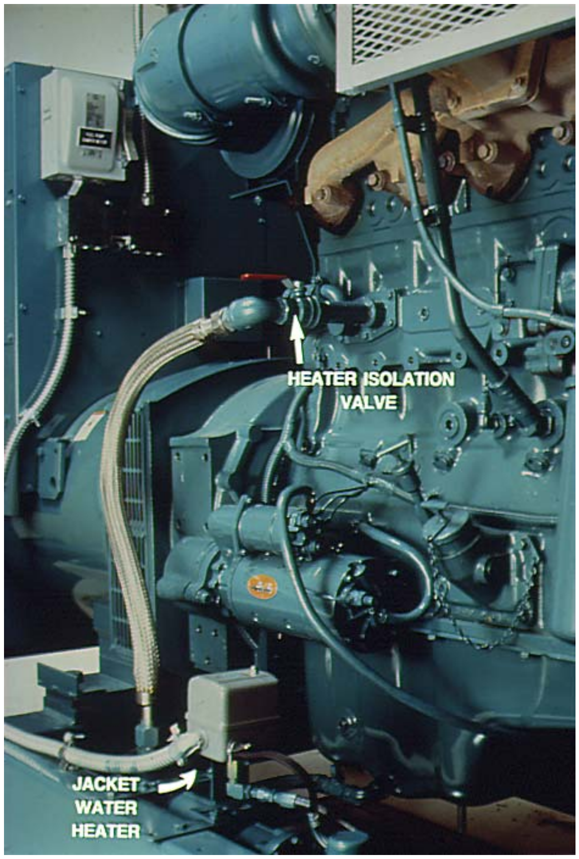


Figure 4–21. Water Jacket Heater Installation. Note Heater Isolation Valve, Hose Type, and Hose Routing.

Oil and Fuel Heaters

For applications where the generator set will be exposed to low ambient temperatures (less than 0° F [–18° C]), lube oil heaters and fuel line and fuel filter heaters for preventing fuel waxing may also be necessary.

Anti–Condensation Heaters

For applications where the generator set will be exposed to high humidity or fluctuating temperatures around the deploying, heaters for the generator and control box are recommended to prevent condensation. Condensation in the control box, on the control circuits or on generator windings can cause corrosion, deterioration of circuit paths and generator winding insulation and even cause short circuits and premature insulation failure.

Fuel Tanks (Diesels)

Day Tanks

Tanks at or near the generator set from which the generator set draws its fuel are called day tanks (although they do not necessarily contain sufficient fuel for a day's operation). These are used as a convenience or when it is not practical to draw directly from the primary fuel storage system. The distance to, the height above or below, or the size of the primary tank are reasons for using a day tank. All diesel engines have limitations as to fuel lift capability (or fuel draw restriction), fuel head pressure (both supply and return) and fuel supply temperature. The fuel is transferred from the primary tank to the day tank using a transfer pump often controlled by an automatic system utilizing level sensors in the day tank. If the tank is small, the fuel return is pumped back into the primary fuel tank to avoid overheating of the fuel. See fuel systems in the *Mechanical Design* section.

Sub–Base Tanks

Usually larger than day tanks, these tanks are either built into the base frame of the generator set or constructed so that the generator set chassis can be mounted directly onto it. These tanks hold an amount of fuel for a specified number of hours of operation such as 12 or 24 hour sub–base tank. Sub–base tanks are often dual–wall, incorporating a secondary tank around the fuel container for the purpose of fuel containment in case of a primary tank leak. Many local regulations require secondary fuel containment such as dual–wall construction along with full monitoring of primary and secondary containers.

Mounting Vibrations Isolators

To reduce vibrations transmitted to the building or mounting structure, often generator sets are mounted on vibration isolators. These isolators come in spring or rubber pad styles, the most common being spring type. Vibration isolation performance is generally 90% or higher and commonly in excess of 95%. Weight capacity and correct placement are critical to performance. In the case of larger generator sets with sub–base tanks the isolators are frequently placed between the tank and the base frame.

Power Switching Equipment

Power transfer or switching equipment such as transfer switches or paralleling gear, while not the subject of this manual, is an essential part of a standby power system. It is mentioned here to accentuate the importance of consideration and decisions about this equipment early in a project. The scheme of power switching for a project relates directly to the generator set rating (see Preliminary Design), the control configuration and the accessory equipment that may be required for the generator set. For more specific information regarding this subject, refer to other application manuals: *T011 – Power Transfer Systems* and *T016 – Paralleling and Paralleling Switchgear*.

Devices Required for Generator Set Paralleling

Generator sets in paralleling applications should be equipped with the following to enhance performance and protect the system from normally occurring faults:

- Paralleling suppressors to protect the generator excitation system from the effects of out–of–phase paralleling.
- Loss of field protection that disconnects the set from the system to prevent possible system failure.
- Reverse power protection that disconnects the set from the system so that engine failure does not cause a reverse power condition that could damage the generator set or disable the rest of the system.
- Electronic isochronous governing to allow use of active synchronizers and isochronous load sharing equipment.
- Equipment to control the reactive output power of the generator set and properly share load with other operating generator sets. This may include cross current compensation or reactive droop controls.
- Var/PF controller to actively control the reactive output power of the generator set in utility (mains) paralleling applications.

Relay based or relay/solid state integrated controls will require added equipment to accomplish the preceding requirements.

From the standpoint of convenience and reliability, a microprocessor based integrated control containing all of the above functions (such as the Cummins Power Generation Power Command control system) is desirable.

Additional Equipment Needs

In certain applications, such as prime or continuous power, medium voltage, utility paralleling and others, additional equipment may be desired or required and is generally available as optional or special order. Some of these include;

- RTDs, resistive temperature measurement devices in the alternator windings to monitor winding temperature directly.

- Thermistors on the end turns of the alternator to monitor winding temperature.
- Differential CTs to monitor for winding insulation breakdown.
- Ground fault monitoring and protection.
- Pyrometers for exhaust temperature measurement.
- Engine crankcase breather vapor recirculating systems.

CHAPTER 5 CONTENTS

5 – ELECTRICAL DESIGN

Overview

The electrical design and planning of the on–site generation system is critical for proper system operation and reliability. This chapter covers installation design of the generator and related electrical systems, their interface with the facility, and topics regarding load and generator protection. One key element for understanding and communication of the electrical system design is a one–line diagram such as the one depicted in **Figure 2–1**.

The electrical installation of the generator set and its accessories must follow the Electrical Code in use by local inspection authorities. Electrical installation should be done by skilled, qualified, and experienced electricians/contractors.

Typical Electrical System Designs

This section provides examples of typical electrical system designs used in low and medium/high voltage on–site power generation applications. It includes descriptions of different methods of generating at medium voltage such as the use of transformers in single and multiple generator configurations. While it is impossible to show every combination; the designs presented in this section are often used.

Several of the designs presented include paralleling capabilities and a brief discussion of the merits and risks associated with paralleling is provided.

- More information on paralleling of generators is discussed in Cummins Power Generation Application Manual T–016, which is available on request.

Because the use of transformers is widespread for medium voltage power generation, we have included a topic on these devices and the factors that are involved in choosing the right transformer.

Electrical System Designs tend to vary considerably based on the needs, or primary functions of the power generation equipment in the application. A system design that is optimized for emergency service situations will generally not be the best that it can be for interruptible service and is definitely not the same type of system design as might be seen in a prime power application. The one–line configuration differences are easy to see. For example, in prime applications the gensets are at the ”top” of the distribution system while in standby and especially in emergency applications the gensets are connected to loads toward the ”bottom” of the distribution system. Power transfer points in prime applications tend to be at the top of the distribution, switching large blocks of load, often with circuit breaker pairs while emergency and standby systems often utilize transfer switches located further down in the system.

Other differences are more subtle. Protection in a standby system is minimized in favor of greater reliability while in prime power we tend to move toward greater emphasis on protection of equipment. Coordination is often more of a concern in emergency applications. In standby applications grouping of loads might be commonly done based on location of loads within the facility, while in emergency applications, the grouping is based on priority of service.

In any system design, local codes and standards will have a significant impact on the overall system design, hardware, and other application details.

- Local codes and standards should always be consulted prior to undertaking any design or modification work.

This section is intended to cover these major points and other details, to provide general guidance on power system design.

General Guidelines

In view of the wide differences in applications, facilities, and conditions, the details of wiring and overcurrent protection of the electrical distribution system for on–site generation must be left to engineering judgement. There are however, some general guidelines to consider in the design.

- The design of the electrical distribution for emergency on–site generation systems should minimize interruptions due to internal problems such as overloads and faults. Subsets of this are providing for selective coordination of overcurrent protective devices and deciding on the number and location of the transfer switch equipment used in the system. To provide protection from internal power failures the transfer switch equipment should be located as close to the load utilization equipment as practical.
- Physical separation of the generator feeders from the normal wiring feeders to prevent possible simultaneous destruction as a result of a localized catastrophe such as a fire, flooding, or shear force.
- Bypass–isolation transfer switch equipment so that transfer switches can be maintained or repaired without disruption of critical load equipment.
- Provisions for permanent load banks or to facilitate connection to temporary load banks without disturbing permanent wiring, such as a conveniently located spare feeder breaker, to allow for exercising the generator set under a substantial load.

NOTE: Load banks installed in front of the genset radiator must be supported from the floor or other building structure, not from the radiator or duct adapter. These genset components may not be designed to support the weight or cantilever of the load bank.

- Load–shed circuits or load priority systems in case of reduced generator capacity or loss of a single unit in paralleled systems.
- Fire protection of conductors and equipment for critical functions, such as fire pumps, elevators for fire department use, egress lighting for evacuation, smoke removal or pressurization fans, communication systems, etc.
- The security and accessibility of switchboards and panelboards with overcurrent devices, and transfer switch equipment in the on–site generator distribution system.
- Provisions for the connection of temporary generators (portable rental generator sets) for periods when the permanently–installed generator set is out of service or when extended normal power outages make it necessary to provide power for other loads (space air conditioning, etc.).

Requirements

- In complex systems equipment that forms the distribution system may be under multiple ownerships. Ownership and responsibility for operation shall be clearly defined and must be adhered to. (See **Power Distribution**, page 5–21.)

Recommendations

- More information on paralleling of generators is discussed in Cummins Power Generation Application Manual T–016, which is available on request. (See **Typical Electrical System Designs**, page 5–3.)
- Local codes and standards should always be consulted prior to undertaking any design or modification work. (See **Typical Electrical System Designs**, page 5–3.)

- When evaluating total cost of ownership, the criticality of the installation will impact on the decision on the degree of redundancy that is built in to the system. Some local codes and standards require continuous service to legally required loads and the critical nature of some facilities may require similar service provisions. If generator sets are paralleled, the maintenance cost and temporary down time associated with temporary generator sets can be avoided. These considerations may also impact on the number of sets required for the installation (See **Single versus Parallel Generators**, page 5–17.)
- Although at first sight more economical, a single generator solution is also the least versatile and may be less efficient, particularly at partial loads. In prime power applications, high speed diesel generator sets may provide lower overall life cycle cost, due to higher efficiency and lower maintenance cost than larger lower speed machines. (See **Single versus Parallel Generators**, page 5–17.)
- Generators that parallel with the utility for less than 5 minutes per month are often not required to incorporate loss of utility protection. However, the risk of damage that can be caused in the event of a momentary utility supply failure should be assessed and the appropriate decision made (See **Combined Generator and Utility Systems**, page 5–19.)

Typical Low Voltage Systems

Many different system designs are possible, but for highest reliability, systems are typically configured so that generator set(s) are connected at low voltage, with the minimum number of transformers and circuit breakers between the generator set and load to be served. Local laws often require that emergency loads are electrically separated from non–emergency loads, and given preference in service so that overloads will result in the non–emergency loads are shed, because this provides the greatest reliability of service to the most critical loads in the system. In most cases a neutral conductor will be required; since many loads and their controls at low voltage will be single–phase, requiring a return conductor. Careful consideration must be given to the need for system neutral grounding and neutral switching requirements.

This design might also be used for a small prime power application.

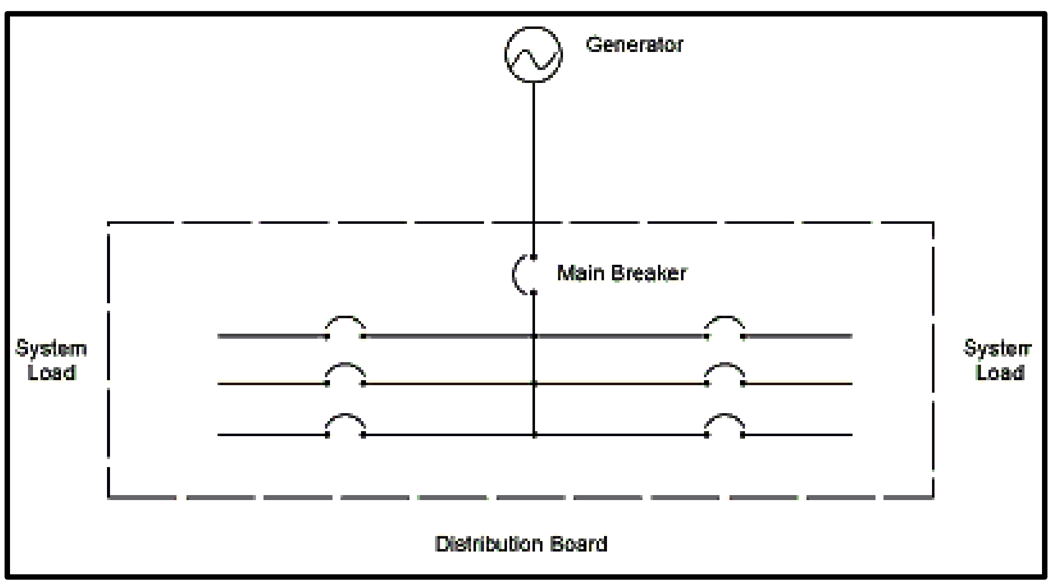


Figure 5–1. Generator Set Serving Common Loads

Generator sets are commonly provided with a main breaker that is mounted on the generator set and service to loads is provided through a separate distribution panel as shown in **Figure 5–1**. Generators are required to be provided with Overcurrent protection, and that can be provided in many forms, which include a breaker mounted in the distribution panel, as shown in **Figure 5–1**. Overcurrent protection is generally required for generator sets, but short circuit protection is not. (i.e., there is not required to be protection for a short circuit between the genset and the main breaker.) The significance of this is that the protection may be located at the generator set or in a remote panel. If the generator set circuit breaker is omitted, a disconnect switch may still be required by code at the generator set, to provide a point of isolation. Refer to local codes and standards for requirements for generator disconnects or isolation.

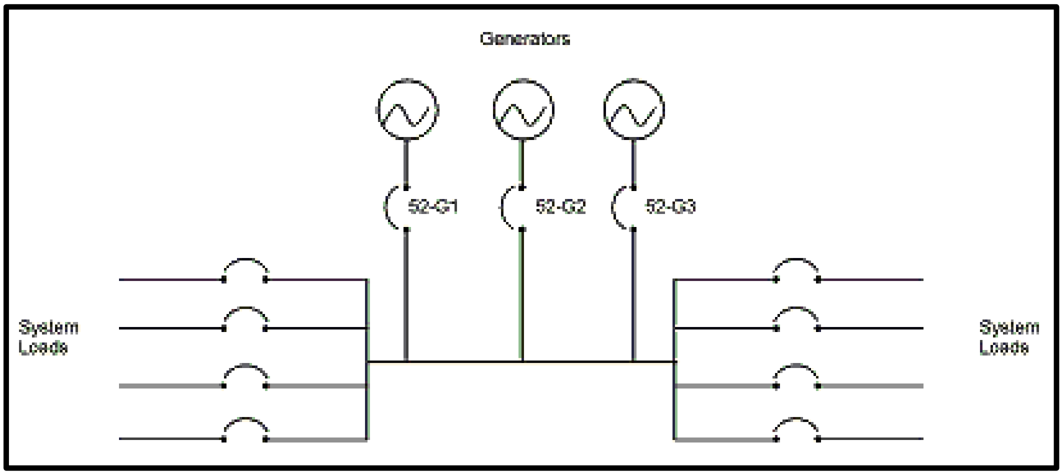


Figure 5–2. Multiple Generator Sets Serving Common Loads

Figure 5–2 shows a similar application with paralleling generators replacing the single generator set. In this situation the generator sets may be specifically selected to be of multiple sizes to allow for minimizing the fuel consumption at a site by closely matching the capacity of the operating equipment to the system loads. Use of dissimilar–sized generator sets may require specific system grounding (earthing) arrangements. See section 5.5 for more detailed information on grounding (earthing) requirements.

Figure 5–3 represents a typical single set power transfer scheme for one utility (mains) supply at low voltage, as may be applied to many domestic, commercial and small industrial applications. An automatic transfer switch (ATS), which may use contactors, circuit breakers or a dedicate transfer module, is used to transfer the electrical supply to the load from utility to generator. Three–pole generator and utility circuit breakers or fuse–switches are often used to limit the fault level present at the ATS. The ATS may be a 3–pole (solid, non–switched neutral) or 4–pole (switched neutral) device. Typically, 4–pole ATS equipment is used in applications where it is necessary to isolate the supply neutral from the generator neutral. The selection of switched neutral equipment may be related to either safety considerations, or if the system is required to incorporate ground fault detection devices. The utility service provider should be consulted to confirm the type of grounding (earthing) system used in the utility distribution system feeding a site, and verify that the proposed grounding arrangements at a customer site are appropriate. Power transfer switches and generator sets should not be connected to a utility service prior to this review (and utility approval, if required by local law).

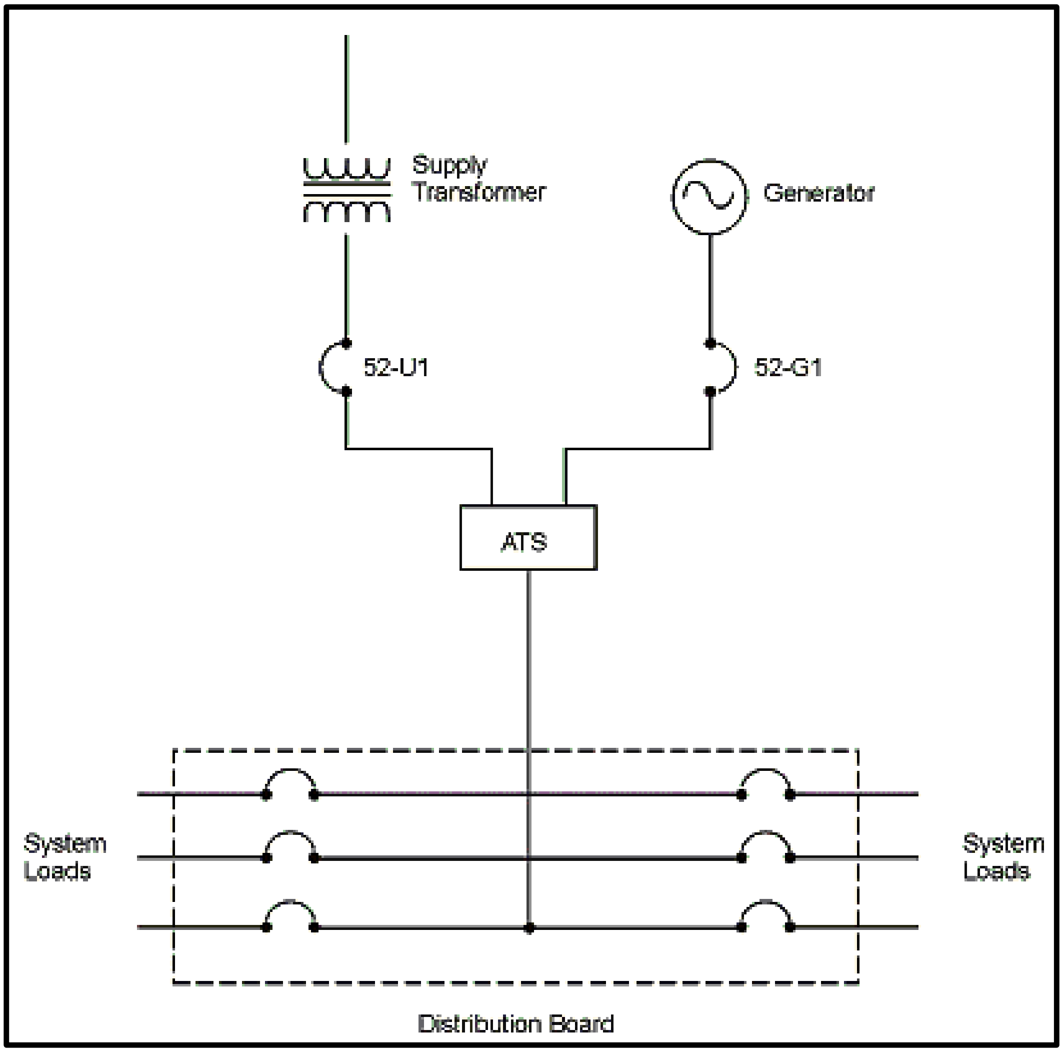


Figure 5–3. Single Generator Set Standby Applications

Note that some local codes and standards require the use of multiple transfer switches due to requirements to isolate emergency loads from standby loads. In these cases, the transfer switches may be located on the load side of the utility distribution panel, and the generator set may also need a distribution panel when the feeder breakers for the ATS equipment cannot be mounted on the generator set.

Larger systems can utilize multiple ATS units and protection located close to the loads. These are often considered to be more reliable than those employing a single large ATS, because faults in the distribution system are more likely to occur toward the load end of a distribution system and the use of multiple switches would result in less of the system being disrupted when a fault occurs. For more information on ATS products and applications, consult Cummins Power Generation Application Manual T–011.

Figure 5–4 illustrates a design suited to larger installations, particularly where multiple buildings are served by the same generator installation. In this system, three ATS units are used, supplied by a common utility and generator system. This scheme can be further adapted to operate from separate utility systems. Four–pole changeover devices are commonly used with three–pole generator and utility circuit breakers or fuse–switches. Each ATS has automatic utility failure sensing and will send a start signal to the generator system and will change over to the generator supply when this is within an acceptable tolerance. This scheme enables a versatile generation system to be constructed and can readily be adapted to multiple sets.

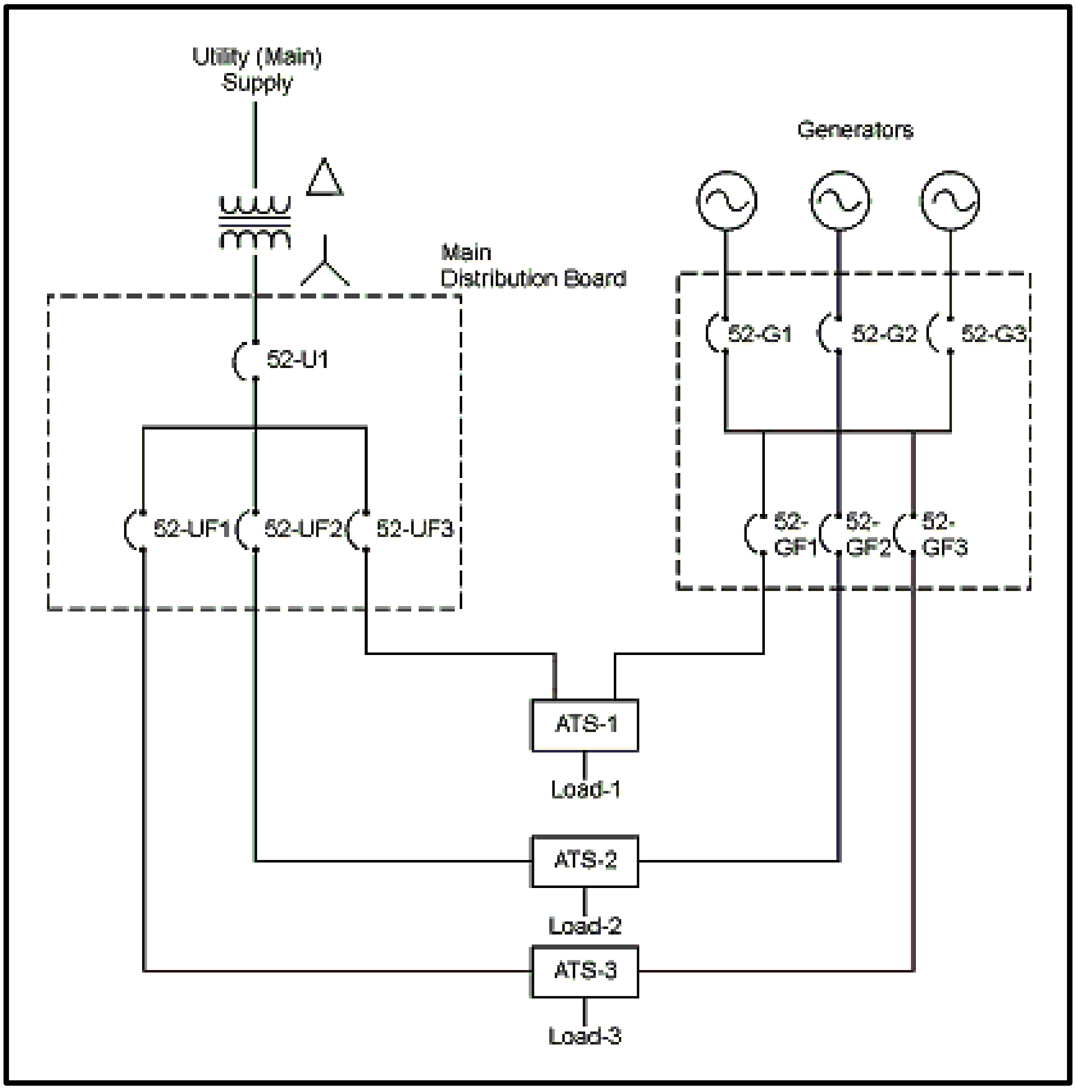


Figure 5–4. Multiple Generator Sets, Multiple ATS Applications

Typical Medium or High Voltage Systems

Medium (MV) or high voltage (HV) power generation is typically used where the power rating causes current at LV to exceed practical limits. In a practical sense, this occurs when the system capacity exceeds 4000 amps or more. It may also be desirable when power must be distributed to points at a significant distance from the generator set. Single generators rated at above 2.5 MVA and paralleling generators rated at above 2MVA are good examples of equipment that is commonly considered for MV application. MV alternators are not economically practical at less than approximately 1000 kW. At kW levels less than 1000kW, it is probably desirable to consider the use of a low voltage machine with a step up transformer.

When designing an MV or HV installation, consideration must be given to the training and qualifications of the personnel operating the system owing to the higher level of safety precautions required with these systems.

Figure 5–5 shows a simple generator scheme for a Prime Power installation that can employ single or multiple HV/MV generators. The system illustrated shows a single load transformer for simplicity; however additional load transformers may be added. MV/HV systems are usually configured as three–wire; since there are rarely any single–phase loads. The MV/HV neutral is not distributed and is normally grounded (earthed) as close to the source as is practical. Impedance can be inserted into the neutral–ground connection to limit the magnitude of ground (earth) fault current, which may take the form of a resistor or reactor. For further information on the subject of neutral grounding refer to Chapter 5.5.

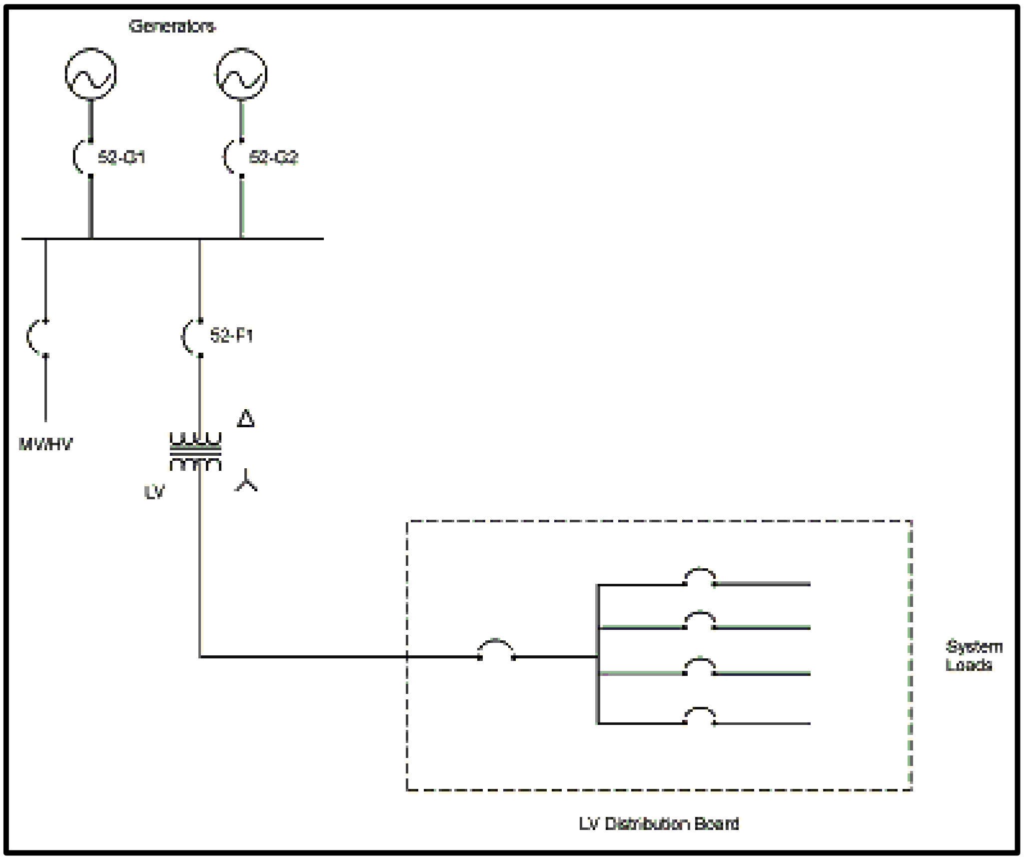


Figure 5–5. Simple MV/HV Generator System For Prime Power

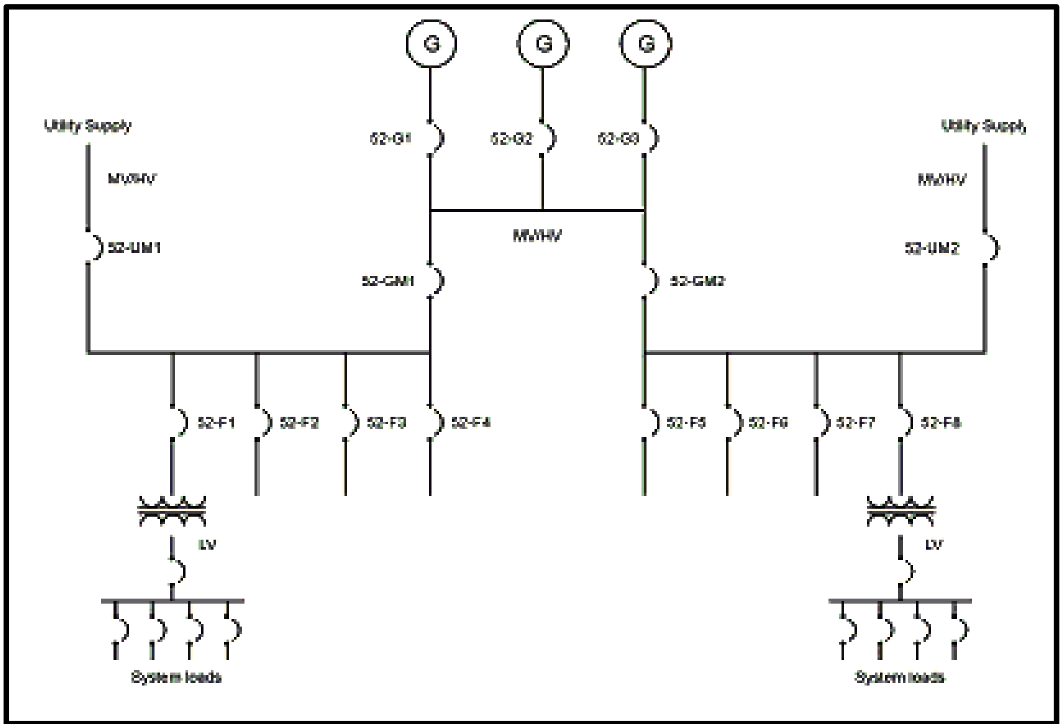


Figure 5–6. HV/MV Scheme For Multiple Generators / Utility Supplies And Loads

Figure 5–6 illustrates an HV/MV scheme for a large installation such as a high–rise building or computer center. The scheme has multiple utilities that are commonly operated in duty / standby mode. There is a utility and generator bus–tie circuit breaker and these can be configured to allow paralleling between utility and generators when either is supplying load. Careful consideration must be given to grounding considerations in this type of application. In many cases neutral impedance or controls to limit alternator field strength during single phase faults will probably be required.

This is a highly adaptable system that is extensively used throughout the world. Incorporation of the generator bus–tie circuit breaker allows the generators to be paralleled off–line. This results in rapid synchronization and load acceptance. In addition, the generators can be tested off–line assisting maintenance and fault finding procedures.

Where many transformers are being energized by the system, care should be taken to ensure that the appropriate overcurrent protection scheme chosen. In systems that feed a ring bus, care should be taken to be sure that the generator equipment can provide necessary energizing current for the system without nuisance tripping of protective devices. For more information on the types of over current protections and other related protection refer section 5.8.

Figure 5–7 depicts a LV generator being used on a MV application. A step–up transformer is used, allowing a standard LV generator to be used instead of a specially manufactured MV generator. In this case, the generator – transformer couple is treated essentially as an MV generator. The LV and MV systems should be treated as independent electrical systems and it is very important to note the configuration of the transformer windings as this is a common source of error. A delta winding should be chosen for the LV side – this helps limit third harmonics and allows the generator wye point to be the only point of reference for the LV system. The MV winding should be wye configured to allow the MV system to be referenced and this can be connected via impedance to the ground his is a typical practice but some systems demand other grounding arrangements. A good reference for these provisions is IEEE Standard 142 – ”IEEE Recommended Practices for Grounding of industrial and Commercial Power System ”.

This configuration is readily adaptable for multiple generator / transformer combinations which can be of unequal size. Transformers of identical rating and winding configuration may be operated with their wye–points coupled. When different size transformers are used, their wye–points can be coupled only when the transformer manufacturer confirms the operation. When dissimilar sized transformers are connected in parallel only one transformer neutral should be connected.

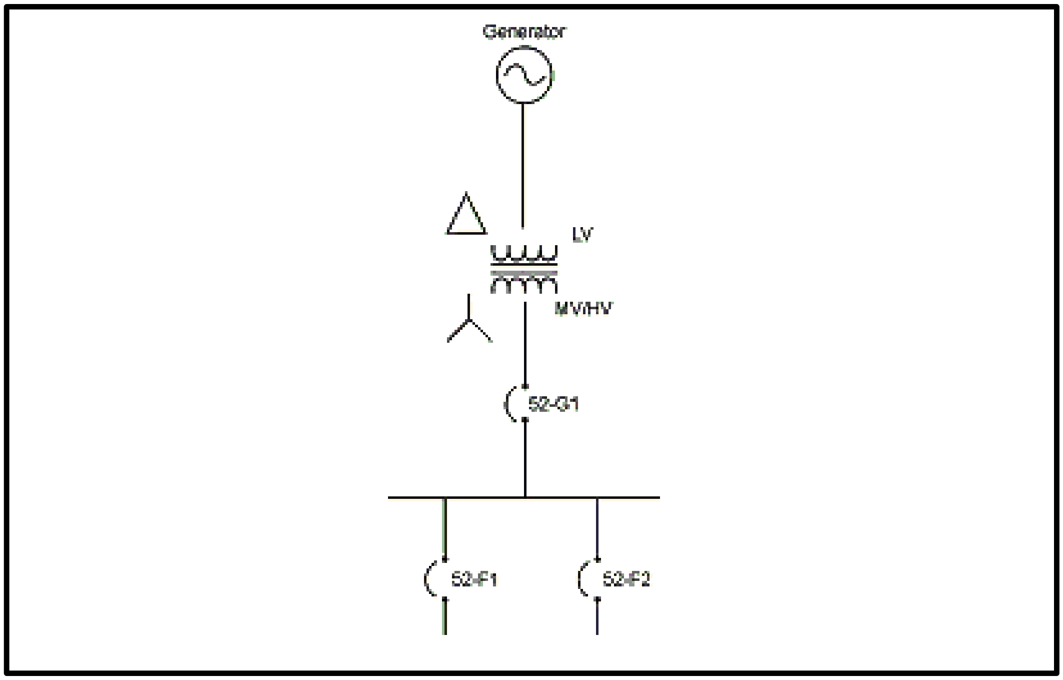


Figure 5–7. Low Voltage Generator For MV/HV Application

Choosing a Generator Transformer

Distribution class transformers come in a several configurations. Generally a transformer is classified by its application and by its cooling medium. In all cases the design criteria for the transformers is governed by ANSI C57.12.

Based on the application, the two broad categories are Substation type and Padmount type.

Substation Type – A transformer used in a switchgear line up that typically close–couples to both a medium voltage switch or breaker on the primary side and a low voltage breaker or switchgear assembly on the secondary side. A substation transformer must be located in a confined area that is restricted from public access. This is due to the fact that substation type transformers are not tamperproof and allows for access to live parts, fans, etc. Substation type transformers can be further sub–divided according to their cooling medium. There are two types of substations transformers –

- Dry Type
- Liquid filled

Dry Type Transformers

There are two major categories for Dry Type transformers – VPI and cast resin.

VPI – Vacuum Pressure Impregnated

This is the conventional dry type transformer that has been manufactured for the past few decades. The standard Insulation class is 220 degree C, with a temperature rise of 150 degree C over a 30 degree C ambient (AA). As an option fans can be added which allow for a 33% increase in the nominal KVA output (Typically stated as AA/FA on the KVA rating). This is the least expensive dry type transformer.

Conventional dry type transformers should only be used in continuous operation applications. The windings, even though encapsulated with a varnish type material, are susceptible to moisture.

Cast Resin

Another category of dry type transformers are the cast resin type. Cast resin transformers fall into two sub–categories – full cast and unicast.

Full Cast Transformers: In a full cast transformer each individual winding is completely encapsulated by a fiberglass epoxy resin. This is accomplished by using a vacuum chamber to pull the epoxy resin up through the windings. The result is that the epoxy acts both as a dielectric insulation medium and allows for superior mechanical strength during fault conditions. The standard insulation class is 185 degree C, with a temperature rise of 80 or 115 degree C above a 30 degree C ambient. As an option fans (FA) can be added which allow for up to 50% increase in nominal KVA output over the base AA rating.

Full cast transformers are the most expensive dry type transformer; however moisture is not an issue with full cast transformers so they are appropriate for non–continuously energized applications.

Unicast Transformers: This is a variation of the full cast design. Instead of a fully encapsulating each individual winding in epoxy, the primary and secondary cores are submerged in epoxy and an epoxy coating forms on the outside of the primary and secondary coils. The individual windings are typically insulated with varnish much like the conventional dry type transformer. The standard Insulation class is 185 degree C, with a temperature rise of 100 degree C over a 30 degree C ambient (AA). As an option fans (FA) can be added which allow for a 33% increase in KVA output.

Liquid Filled Transformers

Liquid filled transformers use the oil as the dielectric medium. Unlike conventional dry types they are impervious to moisture because the windings are completely covered in the dielectric oil. However, liquid filled transformers do require fire protection systems if used indoors.

- Mineral Oil
- High Fire Point

Mineral Oil

The least expensive of the oil filled is mineral oil. Liquid filled transformers have a standard temperature rise of 55 degree C over a 30 degree C ambient. Options are available for (55/65 degree C) which allows for a 12% increase over the nominal KVA rating. Forced air cooling can be applied which delivers an additional 15 to 25% increase over nominal KVA ratings

High Fire Point

Manufacturers typically offer either R–Temp (Cooper Industries) or Dow Corning 561 Silicone as high fire point liquids. Increasingly, the liquids get scrutinized by EPA as environmental hazards (such as PCB’s) and tend to go in and out of market favor as a result.

Padmounted Type Transformers

Padmounts are built to the same ANSI standards as listed for Substation type transformers. However, Padmounts are synonymous with a special type of construction. Typically, this means compartmentalized and tamperproof. The most common applications for Padmounts are outside in non–restricted areas where the public can and does have full access to the equipment. Padmounts are not available with a fan cooling option as this would negate the tamperproof construction. By far the most common Padmounts are liquid filled. This allows for some overload capabilities without the need for fans.

In addition to the above classifications, the choice of generator power transformer is governed by several factors:

- Winding configuration
- Rating
- Cooling medium
- Tap changer
- Impedance
- Connection

Winding Configuration

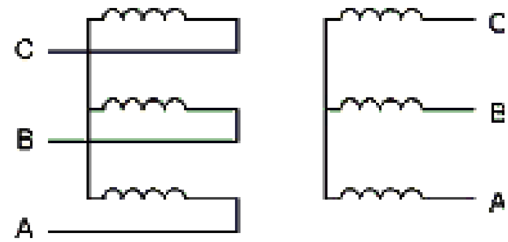
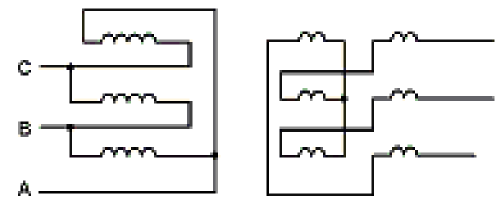
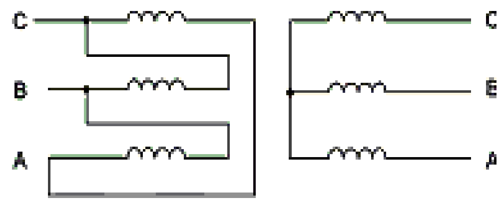
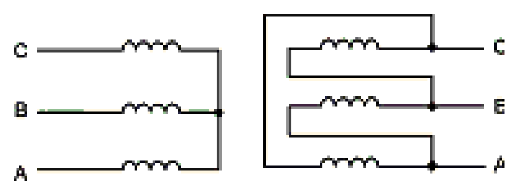
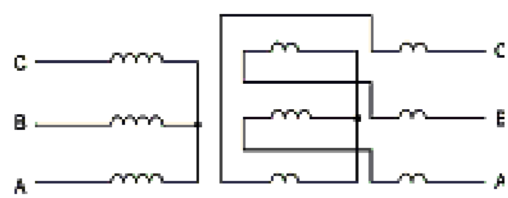
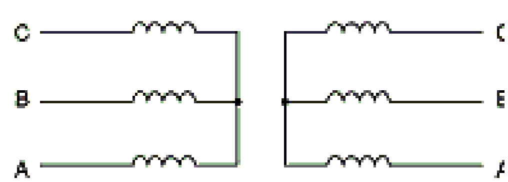
The winding configuration is generally governed by the need for referencing the electrical system to ground (earth). Conventionally, electrical systems are grounded at source and therefore, the winding of the transformer that is acting as the source of power for an electrical system can be expected to be provided with a reference point. Thus for a step–down transformer, where loads are being supplied from the lower voltage winding, this would be expected to be Star (Wye) connected with a provision for the common point between the three windings (the star point) to be connected to ground. For a step–up transformer, where load is being supplied from the higher voltage winding, this would again be expected to be connected in Star (Wye).

In many regions a typical transformer winding vector group may be shown as Dyn11, denoting that the transformer has a delta connected MV/HV winding and a wye connected low voltage winding with the star–point available for connection. The '11' denotes a 30–degree phase–shift anti–clockwise as depicted by the 11 O'clock position on a clock–face. Other common connections are YNd11 (wye connected MV/HV winding with neutral available, delta connected LB winding with an anticlockwise phase–shift), Dyn1 and YNd1 (as before but with clockwise phase–shifts) and YNyn0 (wye MV/HV and LV windings all with neutral points brought out and zero phase shift. The designation letter 'Z' represents a zigzag winding, while three groups of letters would indicate that a tertiary winding is fitted.

The most commonly used vector groups are shown below –

The vector group identifies the connection of the windings and the phase relation of the voltage phasors assigned to them. It consists of code letters that specify the connection of the phase windings and a code number that defines the phase displacement.

Code Number	Vendor Group	Circuit Configuration

0	Yy0	
0	Dz0	
5	Dy5	
5	Yd5	
5	Yz5	
6	Yy6	

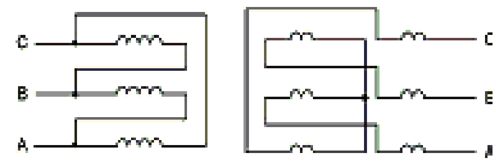
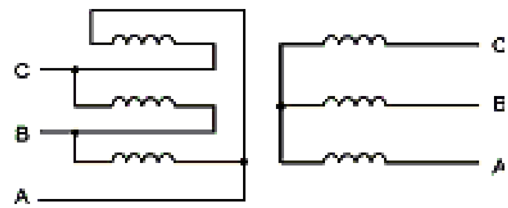
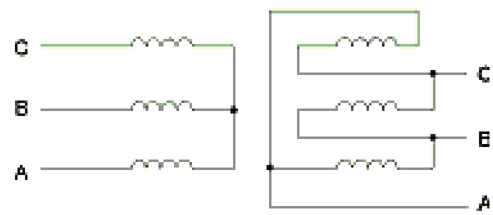
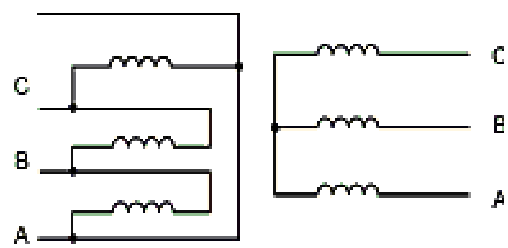
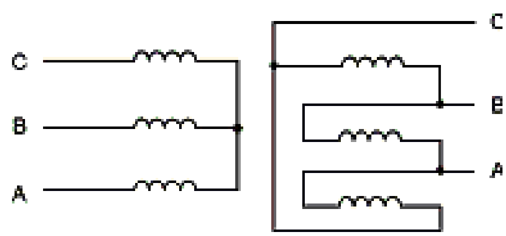
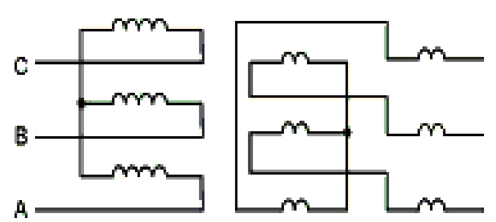
6	Dz6	
11	Dy11	
11	Yd1	
11	Dy1	
11	Yd11	
11	Yz11	

Table 5–1. Winding Configurations

Rating

Transformers are generally provided with a Continuous Maximum Rating (CMR) and a Continuous Emergency Rating (CER). The choice of rating will depend on the duty cycle expectations of the transformer and the electrical system. CMR rated transformers are generally bulkier and more costly than CER rated units; however the CER transformer will have a limited life if the CER limits are exploited, due to higher temperature rises. In general, it is recommended to choose CMR rated transformers for generators that are acting as the prime source of power. CER rated transformers may be applied to standby applications provided the duty cycle stated by the transformer manufacturer is not exceeded. Transformers are rated in kVA and useful gains in rating may be made if operating at power factors close to unity (1.0) power factor.

Cooling Medium

Many transformers use oil as a cooling and insulating medium. Oil filled transformers are generally more compact, but heavier than their cast–resin, air–insulated counterparts and are able to withstand severe environmental conditions. Fans are often incorporated to assist heat dissipation. Transformer cooling is classified as:

- Oil natural / Air natural (ONAN)
- Oil forced / Air natural (OFAN)
- Oil forced / Air forced (OFAF)

Oil is flammable and may cause severe pollution of the environment if not contained; therefore oil filled transformers should be installed within a containment area that is able to store up to 110% of the total capacity of the transformer. Low oil level alarm, explosion vents, winding and oil temperature and gas evolution detection protection are often provided for oil cooled transformers.

Tap Changers

Transformers are often provided with taps, usually on the higher voltage winding, to enable the output voltage to be adjusted, normally with the transformer isolated. Common tap values are +/– 5%, +/– 2.5% and 0. Tap Changers can be useful on a generator transformer if the utility system voltage is being operated toward the high or low end of the permitted range and a generator is required to parallel with the system. On–circuit tap changers are available but are generally costly. Often there are situations where the HV network is being operated considerably above the nominal voltage. Using a tap changer on the generator transformer can prevent the generator from exceeding its rated voltage when exporting under these conditions.

Impedance

In the event that high fault levels are estimated, increasing transformer impedance may provide a cost–effective solution, especially in limited run–hour applications. Care must be taken to ensure that the increased voltage increase across the transformer does not cause a generator to operate outside of its permitted voltage range, or prohibits voltage matching and synchronization. Consult the generator set manufacturer if voltage is expected to be more than 5% of nominal under any operating conditions.

Connection

The type of cable connection to each winding must be chosen in relation to the cables being installed. This is particularly true on high voltage circuits, where special termination techniques may be required and on low voltage circuits where a large number of cables are being connected. A basic choice between compound–filled and air–insulated cable boxes is available and various combinations may be obtained to allow connection of a wide range of cables and termination techniques. Cable entry is usually from below; if cable entry from above is planned, care is taken to ensure that moisture ingress is prevented.

In making the choice of transformer, it is vital that the above items are considered in relation to the site ambient conditions, which should include factors such as solar and ground heating as well as temperature and humidity.

Single versus Parallel Generators

Paralleling is the synchronous operation of two or more generator sets connected together on a common bus in order to provide power to common loads as shown in **Figure 5–8**. In deciding whether a single or multiple generators should be installed there are various factors to be considered, such as:

- Reliability
- Performance
- Cost
- Load types
- Generator and Room size
- Efficiency
- Load variation
- Flexibility

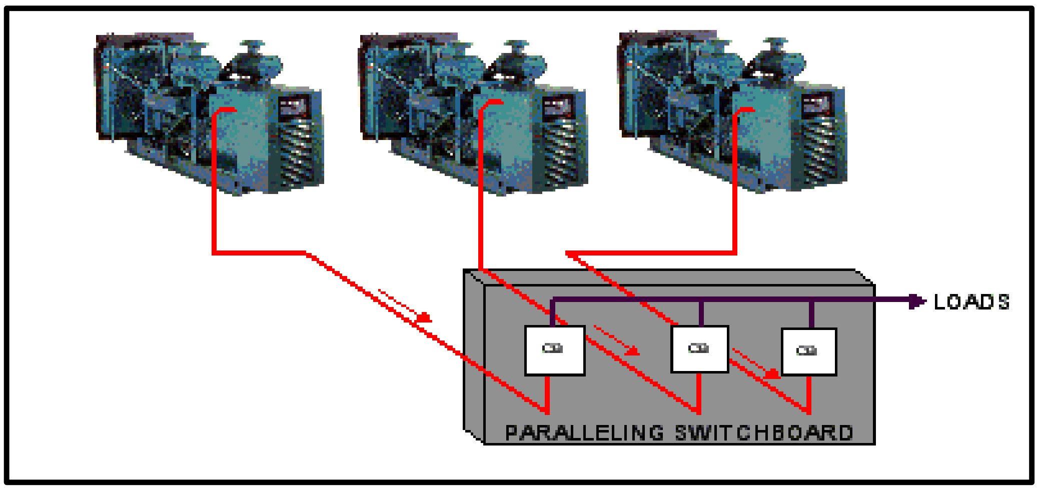


Figure 5–8. Parallel Generators

Reliability is the primary factor in the decision to use of paralleling in most emergency/standby applications, such as hospitals, computer centers and pumping stations; where the reliability of Power Supply is important since the loads connected are critical. In these cases, use of multiple generator sets and prioritized loading of the system allows the more critical loads to be served at the expense of less critical loads. In systems where all the loads are required for proper operation; redundant generator sets are provided, so that failure of a generator set will not disable the facility. Paralleling normally requires the ability to sequence loads in steps, and the ability to shed loads to allow the generator sets to operate within their load ratings in event of generator failure. A multiple set installation should be sized to allow a generator set to be taken out of the system for routine maintenance or repair without jeopardizing the supply to the load.

Performance of the on site power system can be more like the utility service when generators are paralleled, because the capacity of the aggregated generator sets relative to individual loads is much greater than it would be with single generator sets serving separate loads.. Because the bus capacity is greater, the impact of the transient loads applied to the generator sets by individual loads is minimized.

Cost. In general, multiple paralleled generator sets will cost more than a single genset of the same capacity, unless the capacity requirement forces the design to machines operating at less than 1500 rpm. The cost of a system should be evaluated as the total cost of ownership and must take into account factors such as the available building space, additional flues and pipe work, layout of cables, switchgear requirements and a system control for multiple installations. The required reliability and the benefit this brings must be set against the increased cost. Cost of maintenance is a key factor with generator sets that run for prime power or co–generation schemes. Although a single large set may have a seemingly high capital cost, this may be mitigated by other factors associated with the installation costs of a multiple generator system.

NOTE: *When evaluating total cost of ownership, the criticality of the installation will impact on the decision on the degree of redundancy that is built in to the system. Some local codes and standards require continuous service to legally required loads and the critical nature of some facilities may require similar service provisions. If generator sets are paralleled, the maintenance cost and temporary down time associated with temporary generator sets can be avoided. These considerations may also impact on the number of sets required for the installation.*

Generator and room size can be critical factors and may force a decision toward single or multiple set installations. A single generator set will typically be considerably heavier than a corresponding machine used in a paralleling situation. For roof–top installations or where the set has to be maneuvered into a basement or other confined space this may be prohibitive, leading to a decision toward smaller, lighter generators. However, space for access and maintenance must be allowed between the machines of a multiple installation and these inevitably use more room volume per electrical kilowatt generated.

Efficiency is a vital factor if the power generation scheme is producing base load power or if is being used for tariff reduction or co–generation. The versatility of the paralleling system, enabling generator sets to be run at optimal load and maximum efficiency will often pay back the initially higher installation costs in a short time in prime power situations.

Load is critical in deciding on the type of installation required. A single generator will typically be the most economical choice for loads below approximately 2000 kW as the cost of the paralleling control and switching equipment will be significant when compared to the cost of the generator. For small but essential installations, where the protection of two generators is essential but the cost of the paralleling equipment is prohibitive; a mutual standby installation may be a good alternative, where one generator acts as standby to the other. See T–011, Transfer Switch Application Manual, for more information on this design. For larger loads, the choice is less straightforward and around 2–3 MW, solutions using single or multiple generator sets are available. Above 3 MW, the choice is almost always multiple generator installations.

NOTE: *Although at first sight more economical, a single generator solution is also the least versatile and may be less cost–effective, particularly at partial loads and in long operating hour installations. In prime power applications, high speed diesel generator sets may provide lower overall life cycle cost, due to higher efficiency and lower maintenance cost than larger lower speed machines.*

Load variation should be considered in any generator application decision as many applications exhibit large differences between day and night and between summer and winter load profiles. A large manufacturing facility may have a daytime load of 2–3MW; but at night, unless used for continuous process application, the load may fall to just a few–hundred kW or even less. Installing a single large generator into this application could lead to many hours of light load running, which is detrimental to the engine. A typical installation of this type might use four – 1000 kW generators, with a 500 kW generator in a paralleling scheme, where the daytime load uses three of the four sets and where at night, only the smaller set is required to run.

Transient loads have a large effect on the required size of a generator and it is important to take into account all combinations of transient and steady state loads in any calculation to ensure that the power quality is maintained. Note that some loads present leading power factor load to generator sets, and this is also required to be considered in the generator set sizing and sequence of operation for the system. The Cummins 'GenSize' application sizing tool is helpful in these cases and can be accessed via our distributors.

Flexibility may be an important consideration where an installation may change in future. A single generator set installation is usually difficult to change, whereas sets can be added to a multiple set installation with relative ease, provided that allowance has been made in the initial design.

Risks

There are risks associated with the parallel operation of generator sets; both between sets and with the utility supply and these risks should be balanced with the benefits. The risks are:

- Where adequate load shedding has not been provided or where the load is maintained at a high level, there is a risk that, if one generator fails, the remaining generators on the system may not be able to support the system load. Load shedding should always be incorporated into a paralleling generation scheme and the reserve capacity at any time during operation should correspond with the amount of load that can be accepted if a running generator fails.
- Not all generators can be paralleled together – if sets of a different manufacturer or of a significantly different size are to be paralleled, consult the local Cummins distributor before proceeding.
- When paralleling with the utility, the generator effectively becomes a part of the utility system. If operation in parallel with the utility supply is specified, additional protection is required for the protection of the generator and utility system interconnection. This protection is commonly specified and approved by the utility service provider. Always consult local codes and standards when considering utility parallel operation.

Combined Generator and Utility Systems

Generators can be run in parallel with a utility supply to enable:

- No break changeover of load from utility to generator supply and vice versa.
- Peak shaving
- Peaking
- Co–generation

No–break changeover between generator and utility supplies can be accomplished by use of a closed transition (no–break) ATS, or by conventional paralleling and ramping of load. In the closed transition ATS the generator set is operated at a slightly different frequency than the utility so that the phase relationship between the generator and the utility is constantly changing. When the sources are synchronized, they are connected together for a period of less than 100 ms via a simple sync check device. While this system eliminates the total interruption of power when switching between live sources, it does not eliminate disturbances caused by sudden changes in load on the two sources. Disturbances can be minimized (but not eliminated) by using multiple switches in a system, so any switch only changes the load a small percentage of the generator capacity.

When using conventional switchgear for changeover, the generator is actively synchronized and paralleled with the utility; and load is ramped smoothly and relatively slowly from one to the other by controlling the fuel and excitation settings of the generator(s). These systems can be used to transfer load from utility to generator and vice–versa. Digital synchronizing systems can often operate over a wide voltage and frequency range, enabling paralleling to a utility operating even outside of acceptable operating levels. However, care should be taken to be sure that protective equipment does not trip during this synchronizing process.

Generators for peak shaving or peaking duty are normally run for long periods in parallel with the utility supply and care must be taken to select the correct duty rating, normally 'Continuous' or 'Limited Time Prime' for this purpose. This choice is governed by the amount of time to be run per annum. For more information on ratings see section 4. Generators used for peak shaving are generally started to correspond with periods of high tariff to reduce peak loading and may be configured to take a fixed load, or to allow the utility to take a fixed portion of the load, with the generator supplying the variance. Generators for peaking duty tend to run at maximum output when required and electricity is sold to the utility at times of high demand. Peak shaving may also be undertaken by taking over the site load completely in a no–break transfer and disconnecting the utility completely. Consult local codes and standards before proceeding with any design or modification work.

Protection for Utility (mains) Paralleled Generators

Note that where a generator system is being run in parallel with the utility supply, the two systems are combined and any incident on the utility system may also involve the generators. The requirements for utility parallel operation protection are highly variable according to the type of system being installed and the characteristics of the site and utility's distribution system. Additionally, regional codes and standards may vary between utility service suppliers. Consult the appropriate authorities before proceeding with the design for any utility paralleling interface.

Generator sets that operate in parallel with the utility are typically provided with sync–check (25) relay, over/under voltage (59/27) protection, reverse power relative to the grid (32), over current (51) protection, loss of grid protection and over/under frequency (81O/U) protection. Diode failure may be fitted but is not requirements by statute. In many regions equipment to detect 'island' condition and disconnect the gensets is also required.

An Island condition occurs when the utility power fails while a genset system is connected, and the protective system does not sense the failure and disconnect the generator system. As a result, the genset system may energize not only intended loads, but also the utility distribution system and other customers' loads. This causes danger to utility workmen, can disrupt utility distribution system protective devices, and can result in damage to utility and customer–owned equipment. Anti–island equipment varies with the nature of the application, the region of the world, and local codes and standards. For example, in Europe anti–island protection commonly includes rate of change of frequency (ROCOF) and vector–shift protection. This equipment may be specified when operating for more than 5 minutes per month in parallel with the grid. In the US, requirements vary considerably by state.

ROCOF and Vector Shift equipment both work by analyzing the rotation of the voltage vector and detecting a change, either in frequency (Hz/sec) or in degrees/sec. Other protections such as reverse kVAr, and directional current may also be used.

See T–016 for more information on interconnection requirements. Other helpful information is in IEEE1547, Standard for Interconnecting Distributed Resources with Electric Power Systems.

Following ANSI designations are used for the above protective functions:

25 – Sync check

27 – Undervoltage

32 – Reverse Power

40 – Field failure (reverse kVAr)

51 – AC Time Overcurrent

59 – Over voltage

78 – Vector shift

81 O/U – Over/under frequency / ROCOF

The protection system must also ensure that the quality of the utility supply to other customers is maintained, regardless of the status of the utility. Protection devices may require the same or similar functions as the generator side of the system, but will often have very different settings. Consult with the utility service provider to coordinate equipment requirements, settings, and commissioning requirements prior to paralleling a generator set to any utility service.

NOTE: Generators that parallel with the utility for short periods of time are often not required to incorporate loss of utility protection. However, the risk of damage that can be caused in the event of a momentary utility supply failure should be assessed and the appropriate decision made.

Power Distribution

Power Distribution equipment takes the single supply of power from the serving utility, on–site generator, or a combination of the two, and breaks it down into smaller blocks for utilization. Residential, commercial and smaller industrial users are usually served and metered by the utility at the utilization voltage. Larger premises are usually supplied and metered with bulk power at medium or even high voltage and this is stepped down to utilization voltage as required on the site.

Distribution schemes normally consist of four or less levels:

- Bulk supply at HV
- Transformation and bulk distribution at MV
- Transformation and bulk distribution at LV
- Final distribution and utilization at LV

A site may contain all four levels or just one, depending on circumstance.

Selecting a Distribution System

The distribution scheme is selected according to a number of criteria including:

- Energy availability requirements
- Size of the site (area and total power to be distributed)
- Load layout (equipment and power density)
- Installation flexibility requirements

In many small installations, distribution and generation will take place at the utilization voltage with no requirement to transform. However for larger sites, the high power densities may require that MV distribution is undertaken on the site, with individual smaller LV networks established at the point of usage.

Figure 2.9 shows a number of possibilities for the incorporation of power generation into a larger electrical system, such as a major industrial facility. For clarity, the diagram has been simplified to omit such features as MV ring–mains, etc., that are common in such situations. In North America power transfer functions are generally required to be provided via listed transfer switches rather than breaker pairs, as are shown in this drawing.

In this example the incoming supply to the premises is at medium or high voltage, typically 10–40 kV and this is normally stepped down and metered by the utility in a substation often near to the site boundary. The supply to the consumer is normally medium voltage at either 10–14 kV or 20–24 kV depending on region. This is therefore the primary source of power and distribution to the various areas of the site will often also be at medium voltage to reduce cable size and losses. Bulk power generation can be installed at this point – also at medium voltage – to provide standby power to the whole site; with the possibility of cogeneration and heat recovery. This may involve several large generators, with a total capacity of up to 10 MW or even more.

For individual premises on the same site, supply is taken at MV and is stepped down to LV for utilization in individual substations, which may have essential and non–essential LV loads segregated. Standby generation may be provided at this level, at LV, and will typically supply the essential loads only during a power outage.

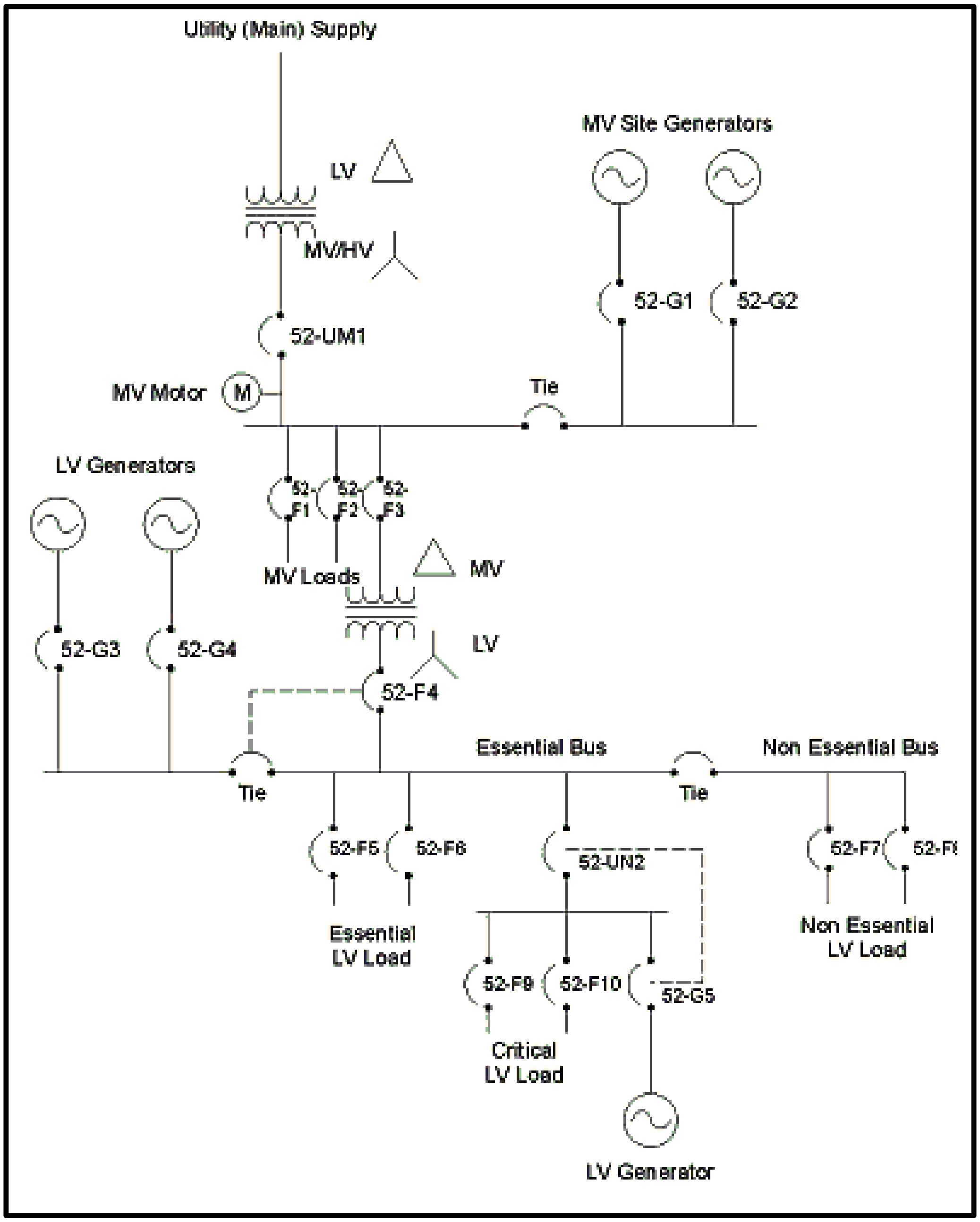


Figure 5–9. Sample HV/MV/LV Distribution System

The scheme for supplying critical loads using a smaller generator to back up the bulk generator system is also shown in this diagram. Refer to section 5.5 for discussion on grounding (earthing) and neutral connections. Refer to the section 5.6 for more details about the switchgear, its various types and the accessories that come with the breakers.

Electrical Connections

General

Vibration Isolation

All generator sets vibrate during normal operation, a simple fact that must be addressed. They are either designed with integral isolators or the entire skid is mounted on spring isolators to allow movement and to isolate vibrations from the building or other structure. Greater movement can also occur upon sudden load change or fault event and during startup or shutdown. Therefore, all connections to the generator set, mechanical and electrical, must be able to absorb the vibration movement and startup/shutdown movements. Power output, control function, annunciation, and accessory circuits all require stranded flexible leads and flexible conduits between the generator set and the building, mounting structure, or foundation.

Large stiff cables may not provide sufficient ability to bend even though they are considered flexible. This is also true of some conduit types, for example certain liquid–tight conduits that are quite stiff. Also keep in mind that cables or conduits are not compressible along their length so flexibility in that dimension must be accommodated with sufficient length, offsets or bends.

Further, the electrical connection points on the generator set – bushings, bus–bars, terminal blocks, etc. – are not designed to absorb these movements and related stresses. (This is again especially notable for large stiff cables or stiff “flexible” conduits. Failure to allow sufficient flexibility will result in damage to enclosures, leads, cables, insulation, or connection points.

Note: Simply adding flex conduit or cabling may not result in sufficient capability to absorb the vibration movement of a generator set. Cables and flexible conduits vary in flexibility and will not stretch or compress. This condition can be addressed by including at least one bend between the generator output enclosure and the structure (cement floor, raceway,wall, etc.) to allow for three dimensional movement.

Seismic Areas

In seismic risk areas, special electrical installation practices are required, including seismic mounting of equipment. The mass, center of gravity, and mounting dimensions of the equipment is indicated on the outline drawings.

Control Wiring

AC and DC control wiring (to the remote control equipment and remote annunciators) must be run in separate conduit from the power cables to minimize power circuit interference in the control circuit. Stranded conductors and a section of flexible conduit must be used for connections at the set.

Accessory Branch Circuits

Branch circuits must be provided for all accessory equipment necessary for operation of the generator set. These circuits must be fed either from the load terminals of an automatic transfer switch or from the generator terminals. Examples of accessories include the fuel transfer pump, coolant pumps for remote radiators, and motorized louvers for ventilation.

Branch circuits, fed from the normal power panelboard, must be provided for the battery charger and coolant heaters, if used. See **Figure 5–10.**

AC Power Connections at Generator

Verify a proper match of the number of conductors per phase and their size with the published lug capacities of the equipment (circuit breakers and transfer switches).

A main disconnect device (circuit breaker/switch) should be supervised and arranged to activate an alarm when it is open. Some suppliers will initiate a “not in auto” alarm when the CB is open.

Connection options at the generator can include the following:

Generator–Mounted Molded Case Circuit Breakers (Thermal–Magnetic or Solid–State)

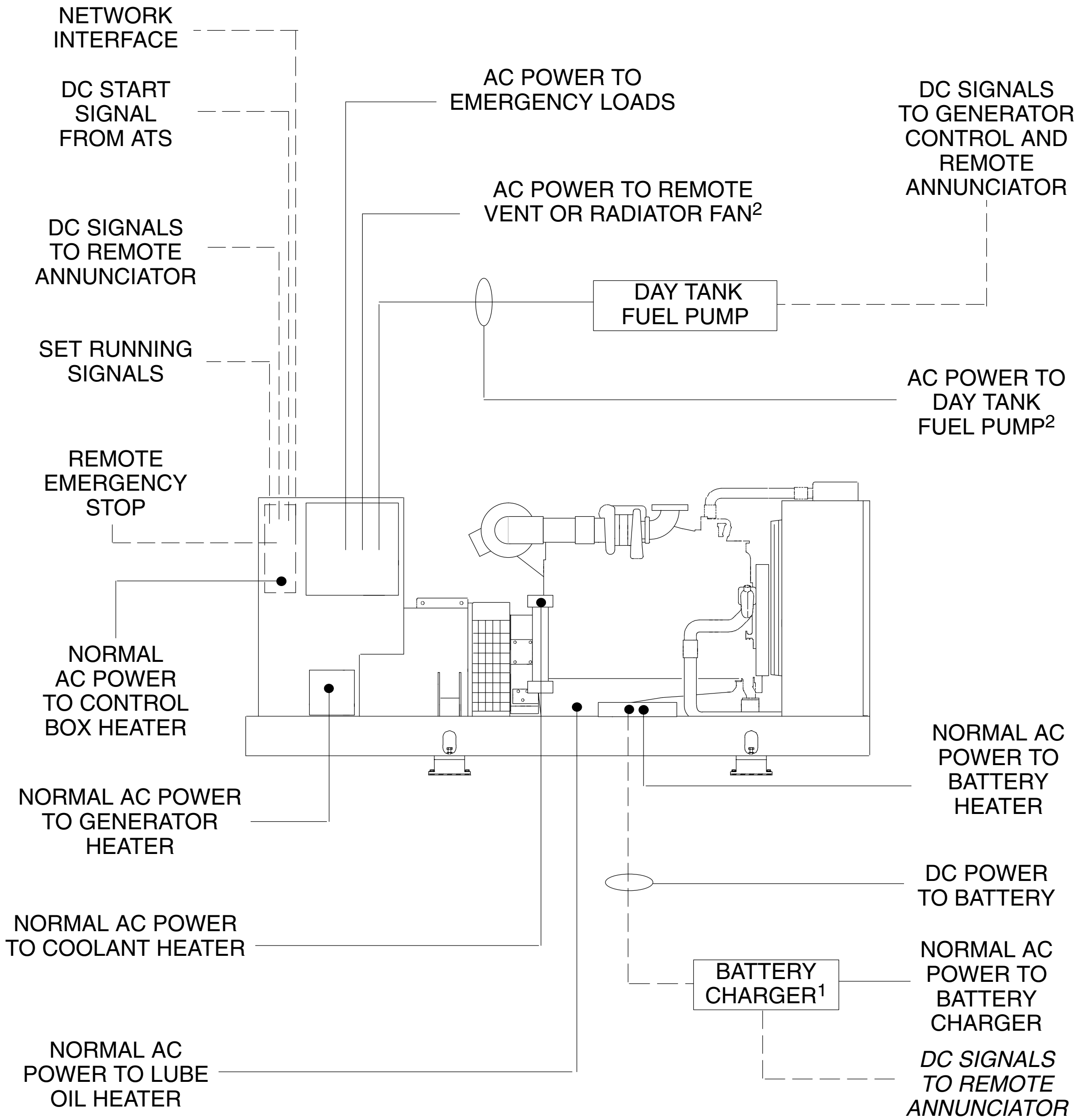
Connections can be made to a generator–mounted circuit breaker. The circuit breaker selected must have adequate interrupting capability based on the available short circuit current. With a single generator set the maximum available first cycle symmetrical short circuit current is typically in the range of 8 to 12 times the rated current. For a specific generator it equals the reciprocal of the generator per unit subtransient reactance, or $1/X''_d$. Use the minimum tolerance of subtransient reactance from the specific generator manufacturer's data for the calculation.

Generator–Mounted Disconnect (Molded Case) Switch

Connections can be made to a generator–mounted disconnect switch. This is allowable where the generator includes an inherent means of generator overcurrent protection, such as Power Command. The switch is not intended to interrupt fault level currents, having an interrupting rating sufficient only for the load currents.

Generator Terminals

Connections may be made to the generator terminals where no generator–mounted circuit breaker or disconnect switch is required and where the generator includes an inherent means of generator overload protection.



NOTES:
1. WHEN A CUMMINS POWER GENERATION ATS (AUTOMATIC TRANSFER SWITCH) IS USED, THE BATTERY CHARGER CAN BE SUPPLIED WITH THE ATS. ATS MOUNTED BATTERY CHARGERS CANNOT BE USED IN PARALLELING APPLICATIONS.
2. THESE LOADS CAN BE POWERED DIRECTLY OFF THE GENERATOR (WITH APPROPRIATE OVERCURRENT PROTECTION) OR FROM THE LOAD SIDE OF THE FIRST PRIORITY ATS.
3. THE ITEMS IN *ITALICS* ARE NOT ALWAYS USED.
4 NETWORK INTERCONNECT MAY REPLACE SIGNALS FOR SOME CONTROL INTERCONNECTIONS.

Figure 5–10. Typical Generator Set Control and Accessory Wiring

AC Power Conductors

The generator set AC output connects to field installed conductors sized as required by the load currents, the application, and codes. The conductors from the generator terminals to the first overcurrent device are considered tap conductors, and allowed to run short distances without short circuit protection. A generator circuit breaker may be provided at the load end of the generator supply conductors (for example, paralleling breakers in the paralleling switchboard or main breaker in a distribution panel) and still provide overload protection for the conductors.

If the generator set is not factory–supplied with a main–line circuit breaker, the ampacity of the field–installed AC phase conductors from the generator output terminals to the first overcurrent device should be at least equal to 115 percent of the rated full–load current, without temperature or altitude de–ratings. The ampacity of the conductors may be 100 percent of rated full–load current if the generator set is equipped with Power Command. The generator set manufacturer will specify line–ampere ratings of a specific generator set at the specific voltage required. If unknown, calculate using one of the following formulae:

$$I_{LINE} = \frac{kW \bullet 1000}{V_{L-L} \bullet 0.8 \bullet 1.73} \text{ OR } I_{LINE} = \frac{kVA \bullet 1000}{V_{L-L} \bullet 1.73}$$

Where:

I_{LINE} = Line Current (amps).
kW = Kilowatt rating of the genset.
kVA = kVA rating on the genset.
V_{L-L} = Rated line–to–line voltage.

See schematics (a) and (b) in **Figure 5–11.** The length of run for generator tap conductors to the first overcurrent device should be kept as short as possible (generally not more than 25 – 50 feet).

NOTE: If the generator is supplied with leads, the size of the leads may be smaller than required for field–installed conductors because generator leads have type CCXL or similar, high temperature insulation rated at or above 125 °C.

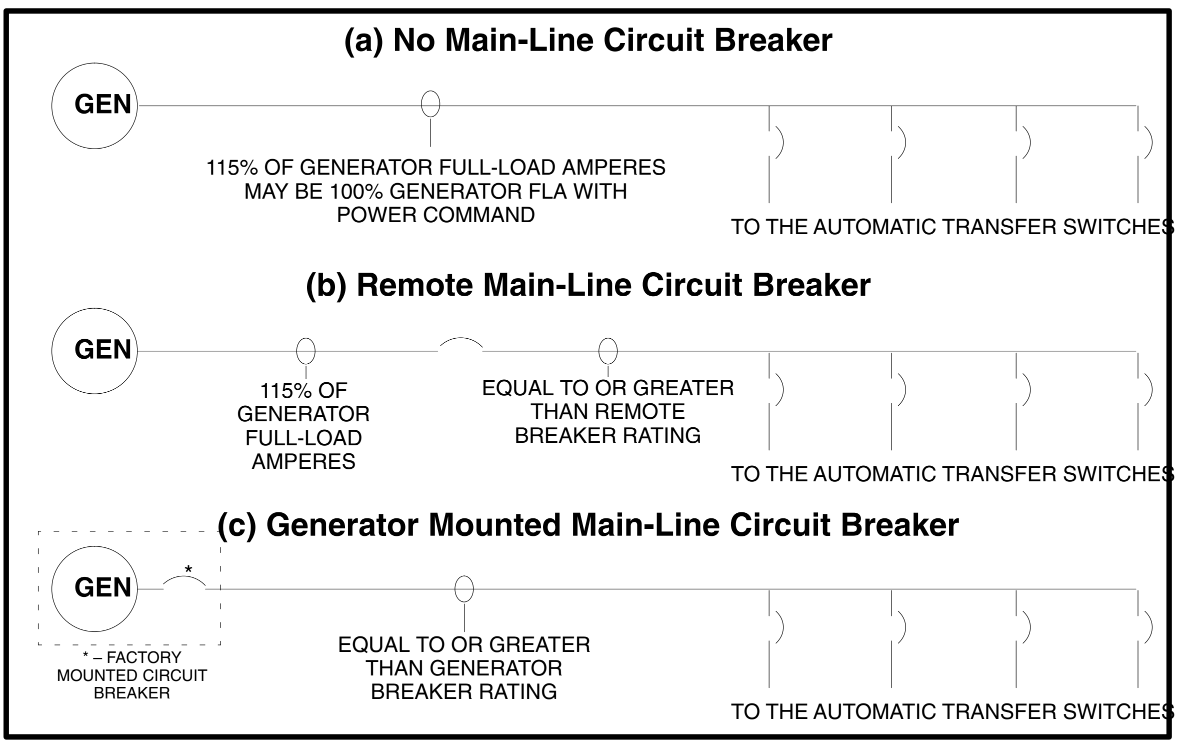


Figure 5–11. Feeder Ampacity

If the generator set is factory–equipped with a main–line circuit breaker, the ampacity of the field–installed AC phase conductors connected to the load terminals of the circuit breaker should be equal to or greater than the circuit breaker rating. See Schematic (c) in **Figure 5–11.**

The minimum ampacity of the neutral conductor is generally permitted to be equal to or greater than the calculated maximum single–phase unbalance of the load. Where a significant portion of the load is non–linear, the neutral should be sized in accordance with anticipated neutral current but never less than 100 percent rated. The generator neutral supplied by Cummins Power Generation is equal in ampacity to the phase conductors.

Note: Medium voltage cable (greater than 600 VAC) must be installed and terminated exactly as recommended by the cable manufacturer, by persons who have learned the procedures through training and practice under close supervision.

Voltage Drop Calculations

Conductor impedance due to resistance and reactance causes voltage to drop in an AC circuit. To obtain the performance expected of load equipment, conductors usually should be sized so that voltage does not drop more than 3 percent in a branch or feeder circuit or more than 5 percent overall between the service drop and the load equipment. While exact calculations are complex, reasonably close approximations can be made using the following relation:

$$V_{DROP} = \frac{(I_{PHASE} \bullet Z_{CONDUCTOR})}{V_{RATED}}$$

Example Calculation: Calculate percentage voltage drop in 500 feet of 1/0 AWG copper cable in steel conduit supplying a 3–phase, 100 kW, 480 volt, (line–to–line) load imposing a 0.91 PF (Power Factor).

$$Z(\text{ohms}) = \frac{L}{(1000 \bullet N)} [(R \bullet pf)+X\sqrt{(1-pf^2)}]$$

Where:

Z =	Impedance of conductor
R =	Resistance of conductor
X =	Reactance of conductor
L =	Conductor length in feet
N =	Number of conductors per phase
pf =	Power Factor
R =	0.12 ohms/1000 feet (NEC Chapter 9, Table 9, Resistance for 1/0 AWG copper conductors in steel conduit.)
X =	0.055 ohms/1000 feet (NEC Chapter 9, Table 9, Reactance for 1/0 AWG copper conductors in steel conduit.)

$$Z = \frac{500}{(1000 \bullet 1)} [0.12 \bullet 0.91) + 0.055 \sqrt{(1-0.91^2)}]$$

$$= 0.066 \text{ percent}$$

$$I_{PHASE} = \frac{kW}{kV \bullet 1.73} = \frac{100}{0.48 \bullet 1.73}$$

$$= 120.3 \text{ amps}$$

$$V_{DROP}(\%) = 100 \bullet \frac{120.3 \bullet 0.066}{480}$$

$$= 1.65 \text{ percent}$$

Allowable Single–Phase Load Unbalance

Single–phase loads should be distributed as evenly as possible between the three phases of a three–phase generator set in order to fully utilize the rated capacity (kVA and kW) of the set and to limit voltage unbalance. **Figure 5–12** can be used to determine the maximum permissible percentage of unbalanced single–phase load, as illustrated by the example calculation.

Single phase power can be taken up to 67 percent of the three–phase rating on Cummins Power Generation generator sets, up through 200/175 kW.

Generally, the larger the generator set, the lower the percentage of single–phase power that can be taken. **Figure 5–12** includes single–phase percentage lines for Cummins Power Generation intermediate–size Frame–4 and Frame–5 generators. Confirm the frame size by referring to the applicable Alternator Data Sheet referenced by the generator set Specification Sheet. Single–phase load unbalance should not exceed 10 percent.

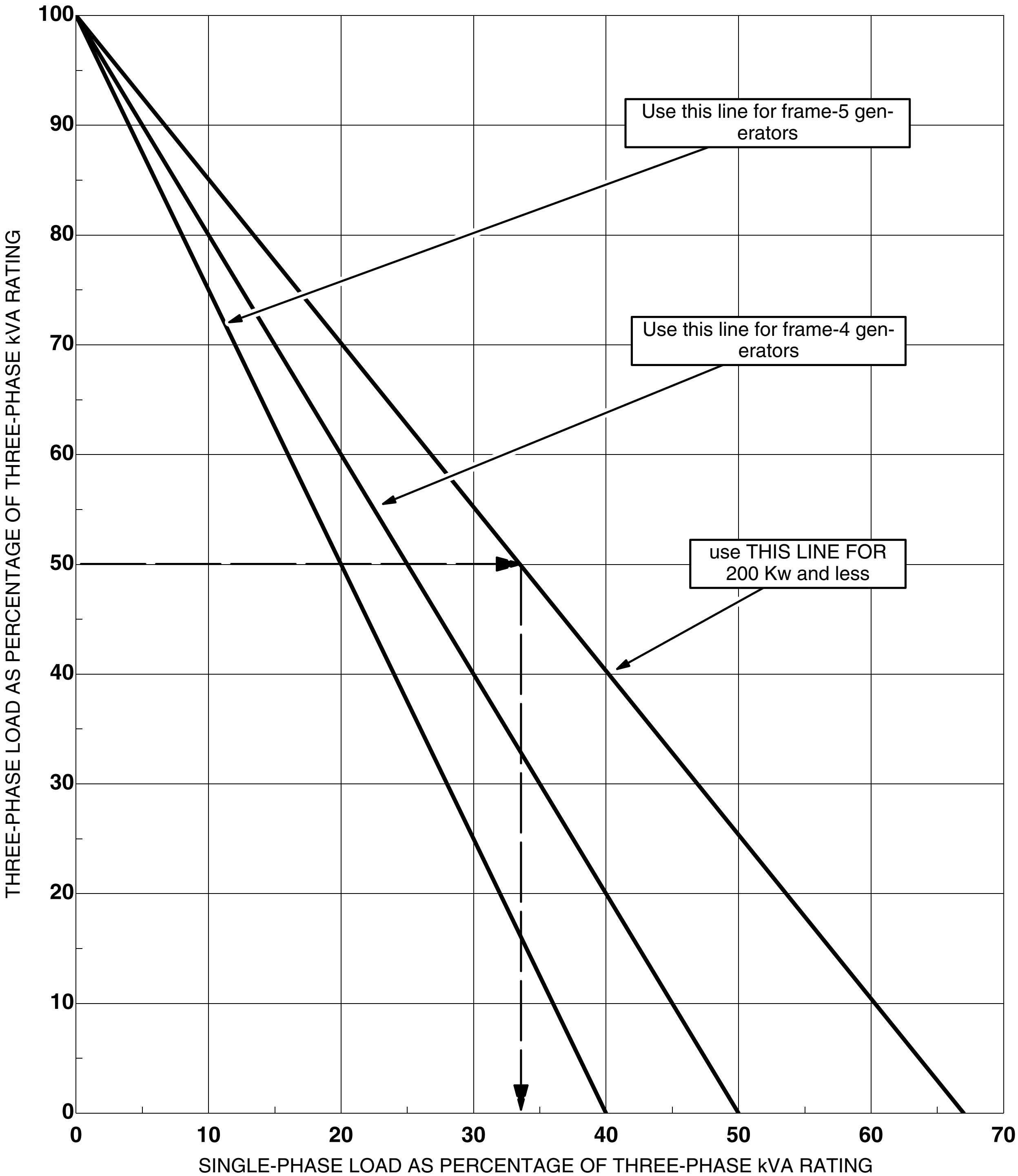


Figure 5–12. Allowable Unbalanced Single-Phase Load (Typical Three–Phase Generator From Cummins Power Generation)

Example Calculation: Find the maximum single–phase load that can be powered in conjunction with a total three–phase load of 62 kVA by a generator set rated 100kW/125 kVA.

1. Find the three–phase load as a percentage of the generator kVA rating:

$$\text{Three–Phase Load Percentage} = \left(\frac{62\ \text{kVA}}{125\ \text{kVA}}\right) \bullet 100\% = 50\%$$

2. Find the percentage of allowable single–phase load, as shown by the arrows in **Figure 5–12.** In this case, it is approximately 34 percent of the three–phase rating.

3. Find the maximum single–phase load:

$$\text{Maximum Single Phase Load} = \left(\frac{125\ \text{kVA} \bullet 34\%}{100\%}\right) = 42.5\ \text{kVA}$$

4. Note, as follows, that the sum of the three–phase and maximum permissible single–phase loads is less than the kVA rating of the generator set:

$$62\ \text{kVA} + 42.5\ \text{kVA} = 104.5\ \text{kVA}$$

and

$$104.5\ \text{kVA} < 125\ \text{kVA} \left(\text{Rating of the Generator Set}\right)$$

NOTE: Unbalanced loading of a generator set causes unbalanced phase voltages. The levels of load unbalance anticipated by these guidelines should not result in harm to the generator set itself. The corresponding levels of voltage unbalance, however, may not be acceptable for loads such as three–phase motors.

Because of unbalanced phase voltages, critical loads should be connected to the phase that the voltage regulator uses as the reference voltage (L_1–L_2 as defined in the generator set schematic) when only one phase is used as a reference.

Leading Power Factor Load

Three phase generator sets are rated for continuous operation at 0.8 PF (lagging) and can operate for short periods of time at lower power factors, such as when starting motors. Reactive loads that cause leading power factor can provide excitation power to the alternator, and if high enough, can cause alternator voltage to rise uncontrollably, damaging the alternator or loads or tripping protective equipment. **Figure 5–13** is a typical alternator curve of reactive power (kVAR) capability. A reasonable guideline is that a generator set can carry up to 10 percent of its rated kVAR capability in leading power factor loads without being damaged or losing control of output voltage.

The most common sources of leading power factor are lightly loaded UPS systems with input filters and power factor correction devices for motors. Loading the generator set with lagging power factor loads prior to the leading power factor loads can improve stability. It is also advisable to switch power factor correction capacitors on and off with the load. It is generally impractical to oversize a generator set (thus reducing the percentage of nonlinear load) to correct for this problem.

System and Equipment Grounding

The following is a general description of system and equipment grounding for AC generators permanently installed within a facility. While this is intended as a guide, it is important to follow local electrical code.

System Grounding (Earthing)

System grounding (earthing) is the intentional grounding of the neutral point of a wye–connected generator, the corner of a delta–connected generator, or the mid–point of one–phase winding of a delta–connected generator, to ground (earth). It is most common to ground the neutral point of a wye–connected generator and bring out the neutral (grounded circuit conductor) in a three–phase, four–wire system.

A corner–grounded delta system has a grounded circuit conductor that is not a neutral. It also has a “wild leg” that must be identified by orange color coding and connected to the middle pole of three–phase equipment.

Solid Grounding

A solidly grounded system is grounded directly by a conductor (the grounding electrode conductor) with no intentional impedance to earth (grounding electrode). This method is typically used and required by electrical code on all low voltage systems (600 volts and below) with a grounded circuit conductor (most often a neutral) that serves L–N loads.

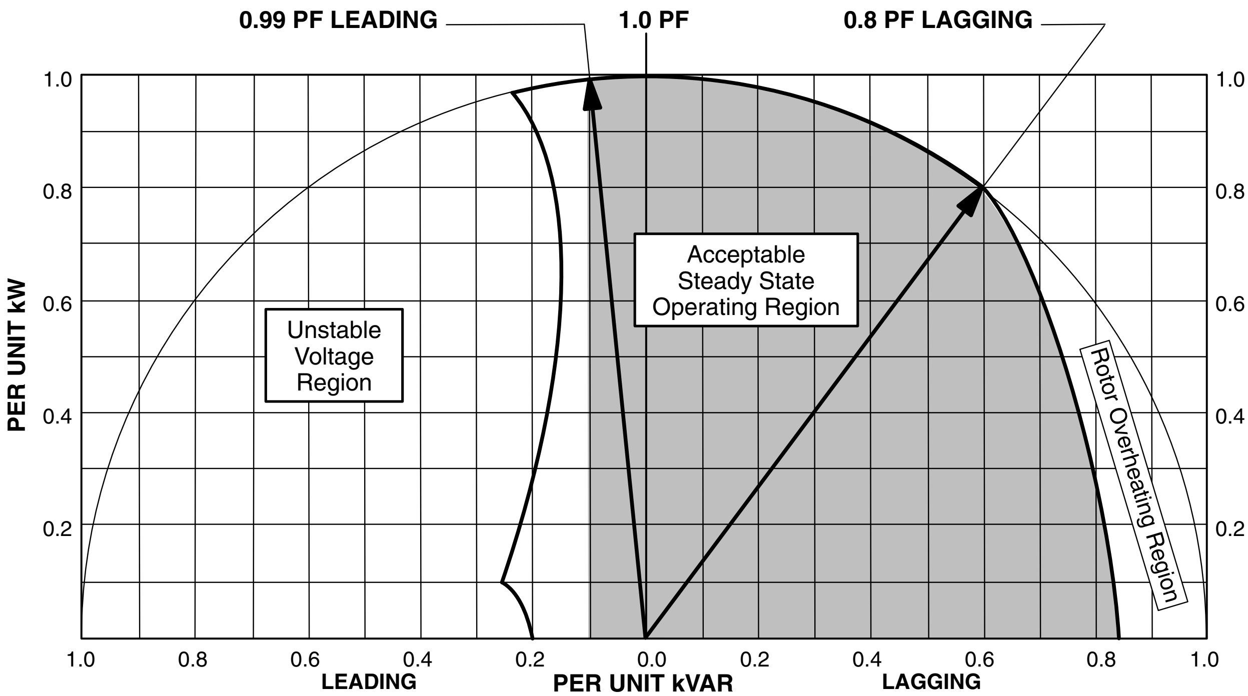


Figure 5–13. Typical Steady State Alternator Reactive Power Capability Curve

Correct grounding in standby systems that are solidly grounded is a function of the transfer switch equipment used (solid neutral or switched neutral). See **Figure 5–14**.

As shipped, the neutral terminal of a Cummins Power Generation generator is not bonded to ground. If the generator is a separately derived power source (i.e. 4–pole transfer switch) then the neutral will have to be bonded to ground and a grounding electrode conductor connected to the grounding electrode system by the installing electrician.

If the generator neutral connects to a service–supplied grounded neutral, typically at the neutral block of a 3–pole transfer switch, then the generator neutral should not be grounded at the generator. In this case, the electrical code may require a sign to be placed at the service supply indicating that the generator neutral is grounded at that location.

Impedance (Resistance) Grounding

A grounding resistor is permanently installed in the path from the neutral point of the generator to the grounding electrode. This method is occasionally used on three–phase, three–wire systems (no grounded circuit conductor) operating at 600 volts or below, where it is desirable to maintain continuity of power with the first and only accidental ground fault. Delta–wye transformers may be used in the distribution system to derive a neutral for line–to–neutral load equipment.

Typically, a high–resistance grounded, low voltage system uses a grounding resistor sized to limit ground fault current, at line–to–neutral voltage, to 25, 10, or 5 amps nominal (continuous time rating). Ground fault detection and alarm sysetms are also typically installed.

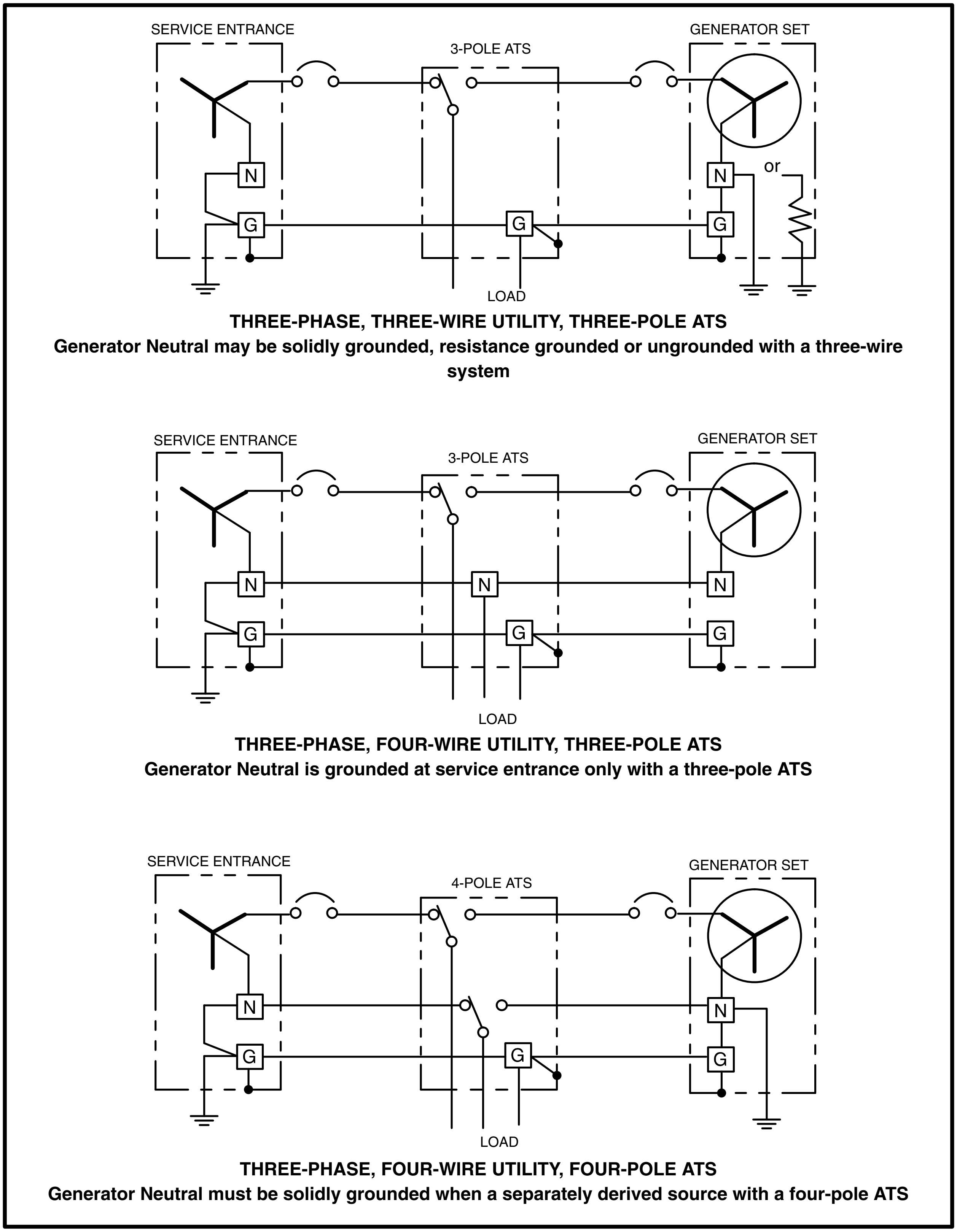


Figure 5–14. Typical One-Line Diagrams of Alternative System Grounding Methods

Select a grounding resistor based on:

1. Voltage Rating: Phase–to–phase voltage (system voltage) divided by the square root of three (1.73).
2. Current Rating: Low enough to limit damage but high enough to reliably operate the protective relaying.
3. Time Rating: Most often 10 seconds for protective relayed systems, and extended time for non–relayed systems.

NOTE: Low–resistance grounding is recommended on generator systems operating from 601 through 15,000 volts in order to limit the level of ground fault current (most often 200–400 amps) and permit time for selective coordination of protective relaying. See **Figure 5–15** *and Medium Voltage Grounding.*

Ungrounded

No intentional connection is made between the AC generator system and earth. This method is occasionally used on three–phase, three–wire systems (no grounded circuit conductor) operating at 600 volts or below, where it is required or desirable to maintain continuity of power with one ground fault, and qualified service electricians are on site. An example would be supplying a critical process load. Delta–wye transformers may be used in the distribution system to derive a neutral for line–to–neutral load equipment.

Equipment Grounding (Earthing)

Equipment grounding (earthing) is the bonding together and connection to ground (earth) of all non–current carrying (during normal operation) metallic conduit, equipment enclosures, generator frame, etc. Equipment grounding provides a permanent, continuous, low–impedance electrical path back to the power source. Proper grounding practically eliminates “touch potential” and facilitates clearing of protective devices during ground faults. A main bonding jumper at the source bonds the equipment grounding system to the grounded circuit conductor (neutral) of the AC system at a single point. A grounding connection location is provided on the alternator frame or, if a set–mounted circuit breaker is provided, a grounding terminal is provided inside the circuit breaker enclosure. See **Figure 5–16**.

Selective Coordination

Selective coordination is the positive clearing of a short circuit fault at all levels of fault current by the overcurrent device immediately on the line–side of the fault, and only by that device. “Nuisance clearing” of a fault by overcurrent devices upstream of the one closest to the fault causes unnecessary disruption of unfaulted branches in the distribution system and may cause the emergency system to start unnecessarily.

Electrical power failures include external failures, such as utility outage or brownout and internal failures within a building distribution system, such as a short circuit fault or overload that causes an overcurrent protection device to open the circuit. Because emergency and standby generator systems are intended to maintain power for selected critical loads, the electrical distribution system should be designed to maximize continuity of power in the event of a fault within the system. The overcurrent protection system should therefore be selectively coordinated.

Overcurrent protection for the equipment and conductors that are part of the emergency or standby power system, including the on–site generator, should follow applicable electrical codes. However, where the emergency power system serves loads that are critical to life safety, as in hospitals or high–rise buildings, more priority should be given to maintaining the continuity of power than to protecting the emergency system. For example, it would be more appropriate to have an alarm–only indication of an overload or ground fault than to have a circuit breaker open to protect the equipment if the result would be the loss of emergency power to loads critical for life–safety.

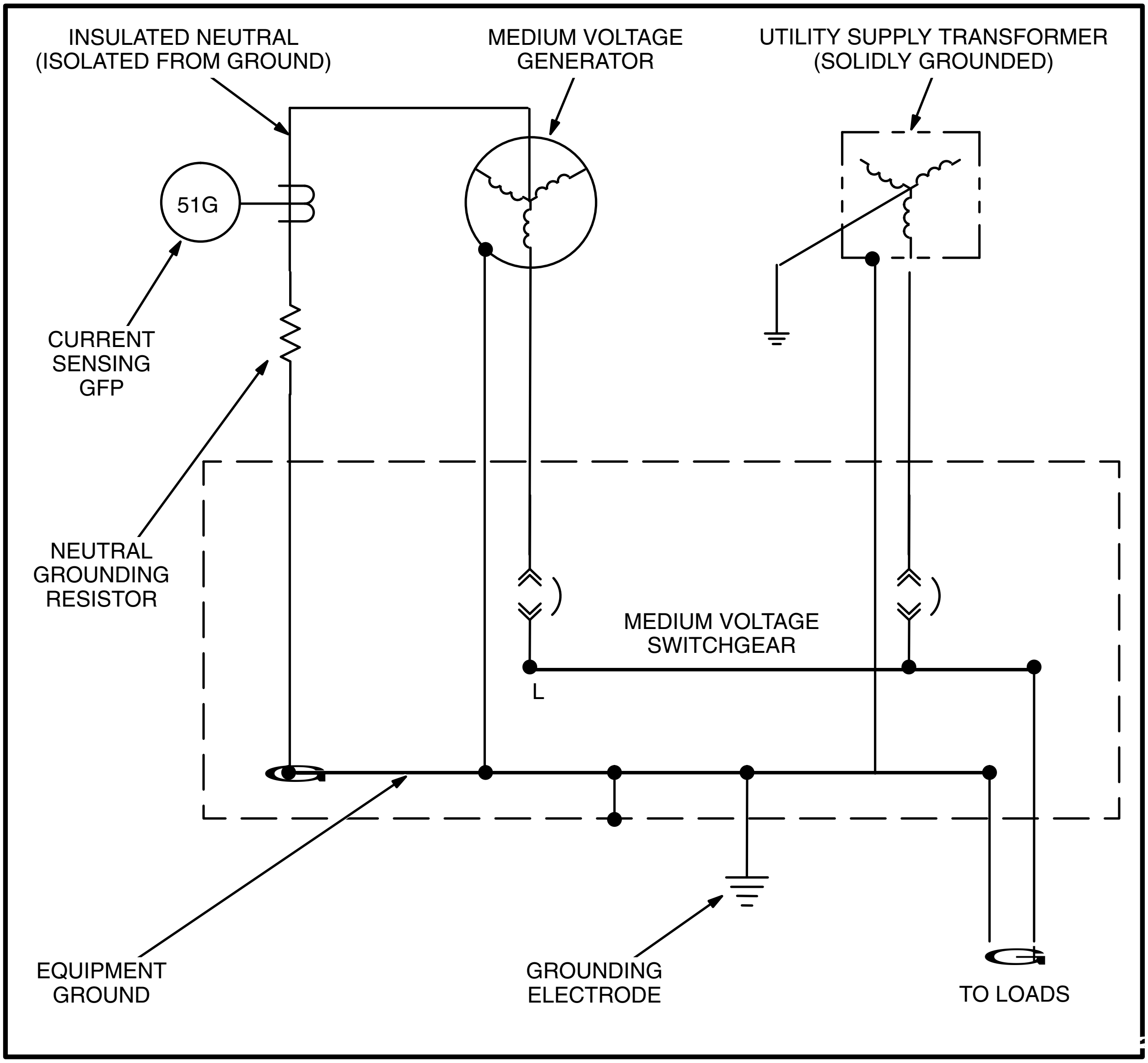


Figure 5–15. Typical Low-Resistance Grounding System for a Medium Voltage Generator Set and Load Transfer Equipment

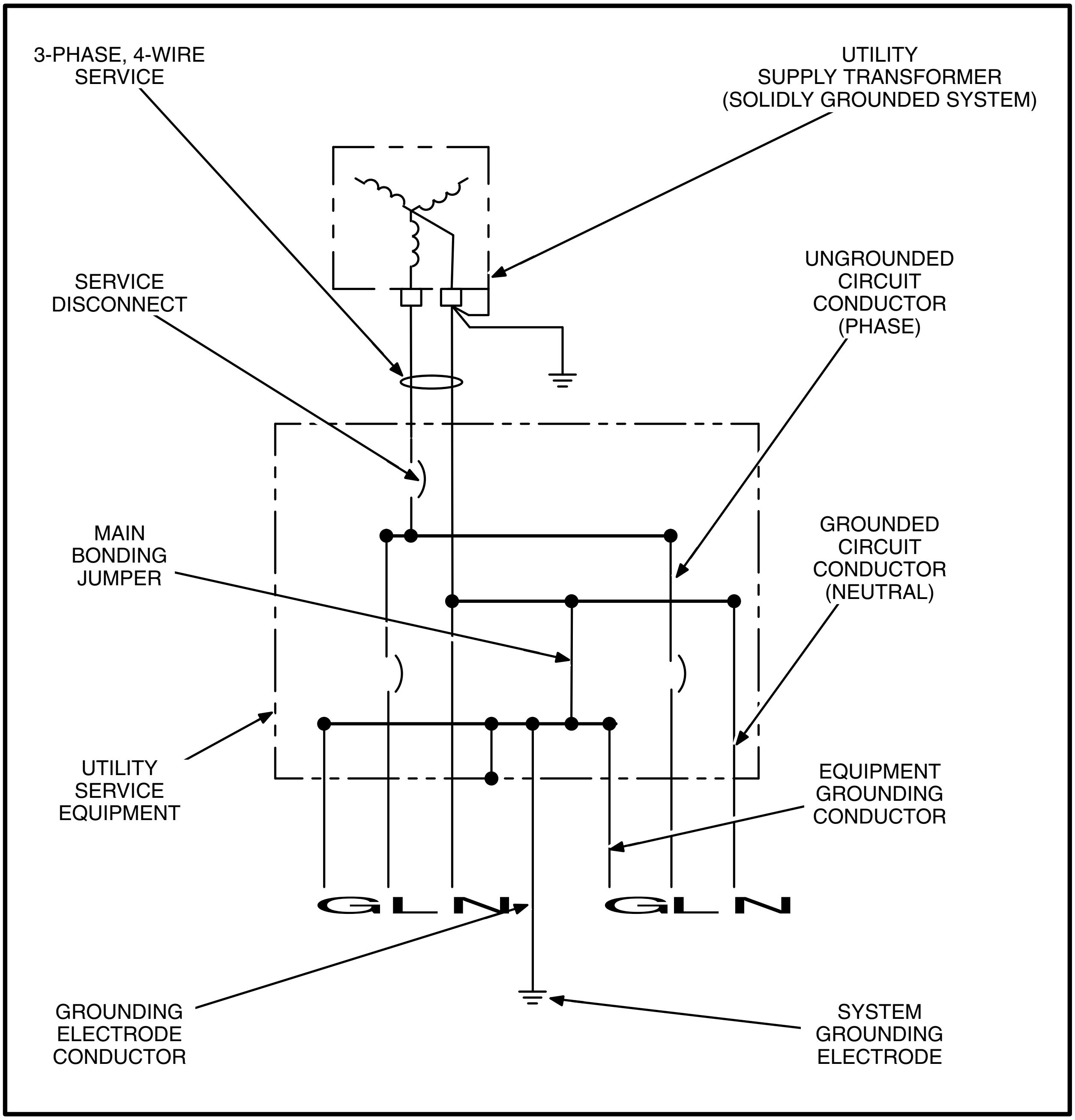


Figure 5–16. Typical System and Equipment Grounding Connections at the Utility Service Equipment

For the purposes of coordination, the available short circuit current in the first few cycles from a generator set is important. This current is independent of the excitation system and is solely dependent on the magnetic and electrical characteristics of the generator itself. The maximum first cycle bolted three–phase, symmetrical short circuit current (I_{SC}) available from a generator at its terminals is:

$$I_{SC}\ \text{P.U.} = \frac{1}{X''_d}$$

E_{AC} is the open circuit voltage and X''_d is the per–unit direct axis subtransient reactance of the generator. A typical Cummins Power Generation generator set will deliver 8 to12 times its rated current on a three–phase bolted fault, regardless of the type of excitation system used. (Refer to the generator set Specification Sheets and alternator data sheets for X''_d.)

Generator reactances are published in per unit to a specified base alternator rating. Generator sets, however, have various base ratings. Therefore, to convert per unit reactances from the alternator base to the generator set base use the following formula:

$$P.U.Z_{new} = P.U.Z_{given}\left(\frac{\text{base kV}_{given}}{\text{base kV}_{new}}\right)^2\left(\frac{\text{base kVA}_{new}}{\text{base kVA}_{given}}\right)$$

Example Calculation: Find X''_d (alternator subtransient reactance) for Cummins Power Generation Model 230DFAB diesel generator set rated 230 kW/288 kVA at 277/480 VAC. Bulletin S–1009a for this model references Alternator Data Sheet No. 303. ADS No. 303 indicates that $X''_d = 0.13$ for the alternator at a full–load rating point of 335 kW/419 kVA and 277/480 VAC (125 °C temperature rise). Substituting these values into the preceding equation:

$$X''_{d(Genset)} = X''_{d(ADS)}\left(\frac{kV_{ADS}}{kV_{Genset}}\right)^2\left(\frac{kVA_{Genset}}{kVA_{ADS}}\right)$$

$$X''_{d(Genset)} = 0.13\left(\frac{0.48}{0.48}\right)^2\left(\frac{288}{419}\right) = 0.089$$

Equipment Location Recommendations

It is recommended for selective coordination that transfer switches be located on the load side of the branch circuit overcurrent device, where possible on the line side of a branch circuit panel board. With the transfer switch located on the load side of the branch circuit overcurrent device, faults on the load side of the transfer switch will not result in unfaulted branches of the emergency system being transferred to the generator along with the faulted branch.

This recommendation is consistent with the recommendations for overall reliability to physically locate transfer switches as close to the load equipment as possible, and to divide the emergency system loads into the smallest circuits practical using multiple transfer switches.

A second recommendation is to use a sustaining generator (PMG excitation) to positively clear molded case branch circuit breakers. A sustaining generator can provide an advantage in clearing molded case circuit breakers of the same current rating but different time–current characteristics.

Fault and Overcurrent Protection with Generator Sets

Sizing a Main–Line Generator Circuit Breaker

Sizing a main–line generator circuit breaker usually follows one of three approaches:

The most common approach is to size the circuit breaker equal to or the next rating up from the generator full–load current rating. For example, an 800–ampere circuit breaker would be selected for a generator with a 751–ampere full load current rating. The advantage in this approach is one of cost; the cables and distribution panel or transfer switch can be sized to the breaker rating of 800 amperes. If the circuit breaker is standard rated (80% continuous) it may open automatically at levels below the generator full–load current rating. However, the generator set is not likely to be run near or at full kW load and at rated power factor long enough to trip the breaker in actual use. Alternatively, a 100% rated 800–ampere circuit breaker may be used that will carry 800 amperes continuously.

A second approach using standard (80% continuous) rated circuit breakers is to oversize the circuit breaker by 1.25 times the generator full load current. For example, a 1000–ampere circuit breaker would be selected for a generator with a 751–ampere full load current rating (751 amperes x 1.25 = 939 amperes, the next higher standard breaker rating equals 1000 amperes). A breaker selected this way should not trip under full kW load at rated power factor (rated kVA). The disadvantage of this approach is that the cables and distribution panel or transfer switch would need to be sized up to at least 1000 amperes.

Yet a third approach is to size the circuit breaker as the result of the design calculations for a feeder and its overcurrent device — recognizing that the principal purpose of the circuit breaker is to protect the feeder conductors. Feeder ampacity and overcurrent device rating are calculated by summing the load currents of the branch circuits multiplied by any applicable demand factors (DF) that are allowed by applicable electrical codes. *Without allowing for future capacity*, the minimum required feeder ampacity for a typical generator set application involving both motor and non–motor loads must equal or exceed:

- 1.25 x continuous non–motor load current, plus
- 1.00 x DF (demand factor) x non–continuous, non–motor load current, plus
- 1.25 x largest motor full–load current, plus
- 1.00 x sum of full–load currents of all other motors.

Because the generator set is sized for both starting (surge) and running load, and may also be sized to include future capacity, the generator set full–load current may be greater than the calculated ampacity of the generator feeder conductors and circuit breaker. If this is the case, consider increasing both the feeder conductor ampacity and the circuit breaker rating so that the breaker will not trip at full generator nameplate current. This would also provide future capacity for the addition of branch circuits.

NOTE: Feeder conductor ampacity is regulated and determined by codes, such as NFPA or CSA. While it is based on generator and CB capacity, other critical factors are also applied. Refer to applicable codes for correct feeder conductor sizing.

NOTE: Extended full–load testing may trip a main–line circuit breaker sized at or below the full–load current rating of the generator set.

Generator Set Sources

When the energy for the emergency system is provided by a generator set, it is necessary to provide branch circuit breakers (usually of the molded case type) with a high probability of tripping, regardless of the type of fault which could occur in a branch circuit.

When a generator set is subjected to a phase–to–ground fault, or some phase–to–phase faults, it will supply several times more than rated current, regardless of the type of excitation system. Generally, this trips the magnetic element of a branch circuit breaker and clears the fault. With a self–excited generator set, there are instances of three–phase faults and certain phase–phase faults where the output current of the generator will initially rise to a value of about 10 times rated current, and then rapidly decay to a value well below rated current within a matter of cycles. With a sustaining (PMG) generator set, the initial fault currents are the same, but the current decays to a sustained short circuit current ranging from about 3 times rated current for a three–phase fault to about 7–1/2 times rated current for a phase–to–ground fault.

The decay in fault current of a self–excited generator requires that branch circuit breakers unlatch and clear in the 0.025 seconds during which the maximum current flows. A branch circuit breaker that does not trip and clear a fault can cause the self–excited generator to collapse, interrupting power to the un–faulted branches of the emergency system. A sustaining (PMG) generator does not collapse and has the advantage of providing about three times rated current for several seconds, which should be sufficient for clearing branch circuit breakers.

Using the full load current ratings of the generator set and of the branch circuit breaker, the following method determines if a branch breaker will trip on a three–phase or phase–to–phase symmetrical fault. The method only determines if tripping is possible under short circuit conditions with the available fault current, and does not guarantee tripping for all values of fault current (in arcing faults, for instance, where fault impedance is high).

Because most circuit breaker charts express current as a percentage of the breaker rating, the available fault current must be converted to a percentage of the circuit breaker rating. Use the following formula to determine the available fault current as a percentage of the circuit breaker (CB) rating for an AC generator capable of delivering 10 times rated current initially ($X''_d = 0.10$), ignoring circuit impedance between the generator and the breaker:

$$\text{Fault Current as \% of CB rating} = \left(\frac{10 \bullet \text{Rated Generator Amps}}{\text{Rated CB Amps}}\right) \bullet 100\%$$

Consider the effect of a fault (short circuit) on a 100 ampere branch circuit breaker when power is supplied by a generator set having a rated current of 347 amperes. In this example, the fault current available for the first 0.025 seconds, regardless of excitation system, is:

$$\text{Fault Current as \% of CB rating} = \left(\frac{10 \bullet 347}{100}\right) \bullet 100\% = 3470\%$$

If the AC generator is of the type that can sustain three times rated current, use the following formula to determine the approximate current available as a percentage of the circuit breaker rating:

$$\text{Sustained Current as \% of CB rating} = \left(\frac{3 \bullet 347}{100}\right) \bullet 100\% = 1040\%$$

Figures 5–17 and **5–18** show the results with two 100 ampere thermal–magnetic molded case circuit breakers having different trip characteristics, “A” and “B.” With trip characteristic “A” (Figure 5–17), the initial fault current of 3470% will trip the breaker within 0.025 seconds. With trip characteristic “B” (Figure 5–18), the breaker may not trip with the 3470% current available initially, but will trip in approximately three seconds if fault current is sustained at 1040% of the breaker rating (three times the generator rating). The conclusion is that a sustaining (PMG) generator offers an advantage in providing sufficient fault current to clear branch circuit breakers.

The application of the generator, its excitation system, and operating voltage, determine the extent of overload protection provided for generators and the protective devices used.

NOTE: The following discussion applies for single–unit installations, 2000 kW and below. Refer to Cummins Power Generation publication T–016, Paralleling and Paralleling Switchgear, for protection requirements of multiple generators in parallel.

Overload Protection of Generators

In low voltage (600 volts and below) emergency/standby applications where critical loads are being served and the generator set runs a relatively small number of hours per year, the minimum protection requirements of applicable electrical codes should be met.

Beyond that, the specifying engineer should consider the tradeoff between equipment protection and continuity of power to critical loads, and may decide to provide more than the minimum level of protection.

In low–voltage prime power or interruptible applications, the loss of power that would result from operation of the protective devices may be tolerable and, therefore, a higher level of equipment protection would be appropriate.

Protection Zone

The zone of protection for generators includes the generator and the conductors from the generator terminals to the first overcurrent device; a main–line overcurrent device (if used), or the feeder overcurrent device bus. Overcurrent protection for the generator should include protection for short circuit faults anywhere within this zone.

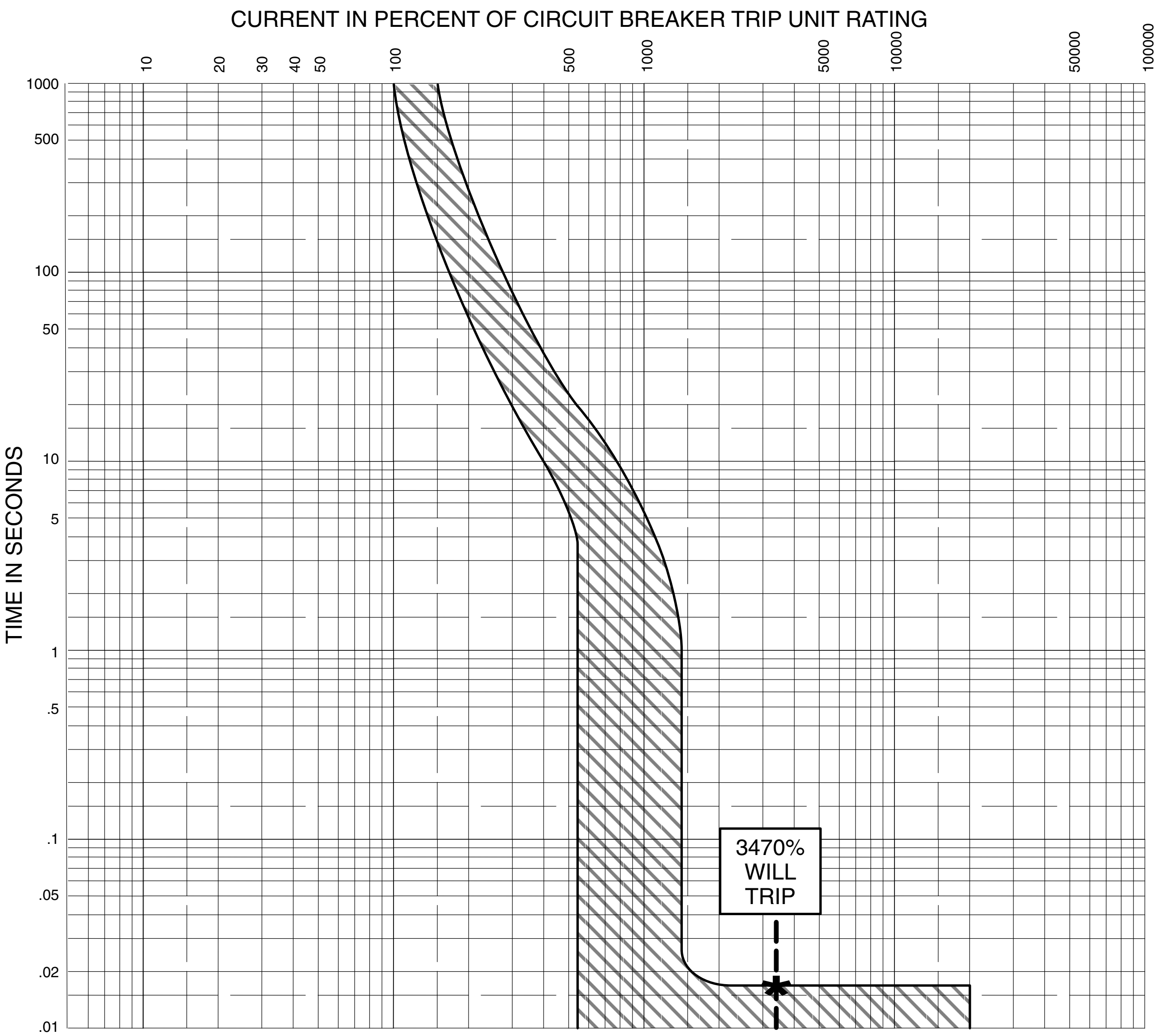


Figure 5–17. Fault Effect on a 100 Ampere Breaker with Trip Characteristic "A"

On the downstream side of the feeder bus, standard practice for overcurrent protection of conductors and equipment applies. The ratio of generator rated current to the rating of downstream overcurrent devices, multiplied by the short circuit current available from the generator in the first few cycles, should be sufficient for tripping these devices within one to two cycles.

Emergency/Standby Systems 600 Volts and Below

The minimum generator overload protection required by applicable electrical codes is recommended for Emergency/Standby applications 600 volts and below. Typically, this means the generator should be provided with phase overcurrent devices such as fuses or circuit breakers, or be protected by inherent design, such as PowerCommand AmpSentry™. In some applications, the electrical code may also require ground fault indication.

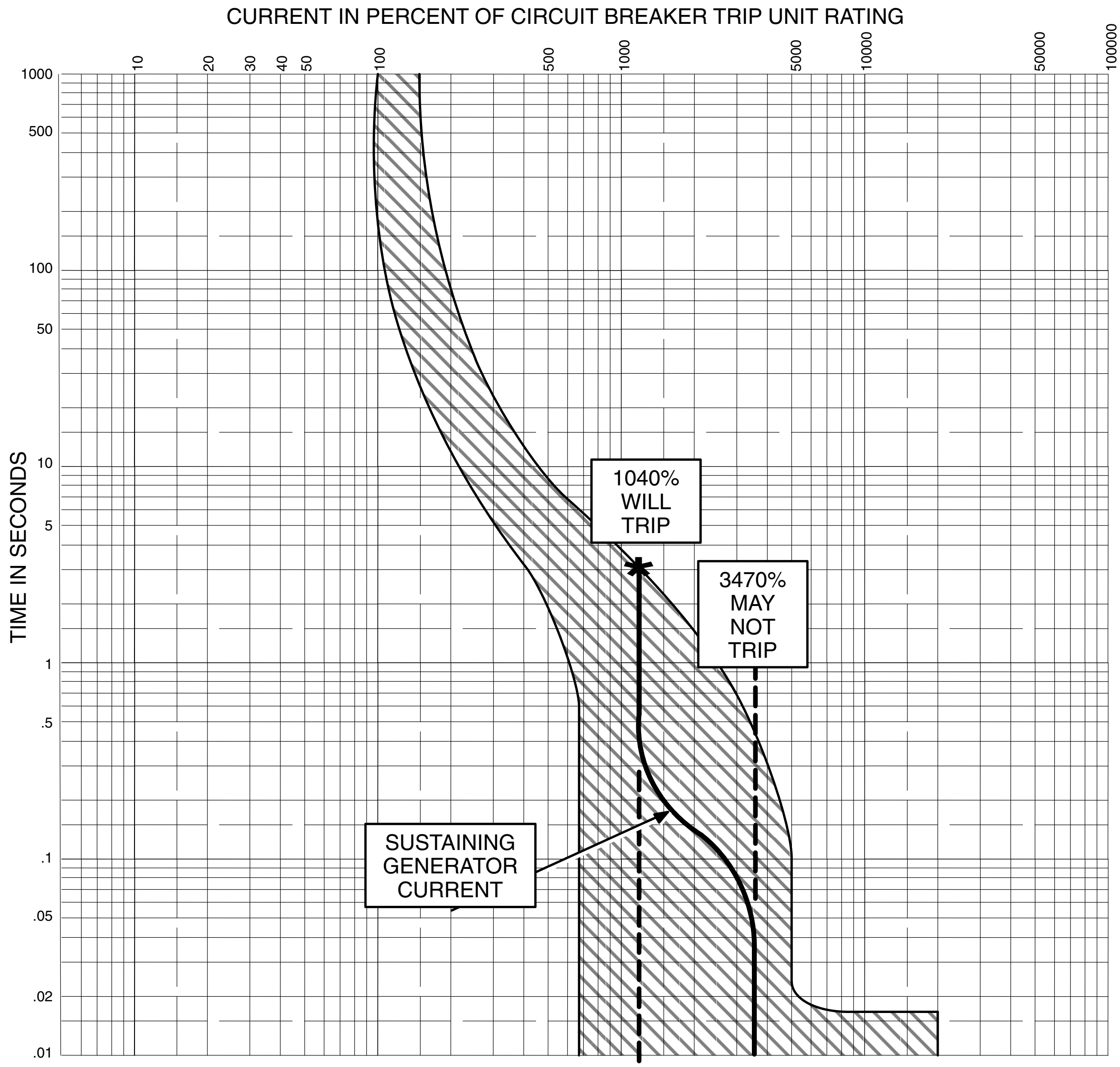


Figure 5–18. Fault Effect on a 100 Ampere Breaker with Trip Characteristic "B"

Generator Circuit Breaker

Conventional practice on generators without inherent overcurrent protection is to provide a molded case circuit breaker (MCCB), either thermal–magnetic or solid–state, sized to protect the generator feeder conductors, in order to satisfy electrical code requirements for generator overload protection. However, a typical thermal–magnetic MCCB sized to carry generator rated current does not provide effective generator protection. Generally, if circuit breakers are used for generator protection, a solid–state circuit breaker with full adjustments (Long time, Short time and Instantaneous, LSI) will be required to coordinate the breaker protection curve within the generator thermal capability curve. Where the generator is protected by inherent design, as generators with PowerCommand Amp Sentry , the use of a main–line circuit breaker for generator overload protection is not required.

There are other reasons to consider use of a circuit breaker; including protecting the generator feeder conductors, and to have a disconnecting means. In order to improve the overall reliability of the system, a disconnecting means may be provided by a molded case switch or other non–automatic means.

Inherent Design, Balanced Faults

A self–excited (Shunt) generator may be considered to be protected by inherent design since it is not capable of sustaining short circuit current into balanced three–phase faults long enough for serious damage to occur to the generator. Considering the need for high reliability of power to critical loads, use of shunt excitation is sometimes considered sufficient to meet the minimum generator protection required by electrical code by inherent design and make generator overcurrent protective devices (fuses or circuit breakers) unnecessary.

Note: In America, the electrical code permits generator feeder conductors, appropriately sized at 115 percent of generator rated current, to be run short distances without overcurrent protection for the conductors.

A generator with PMG excitation, but without PowerCommand, is capable of sustaining short circuit current with an unbalanced or balanced fault. If overcurrent devices downstream of the generator should fail to clear a **balanced** three–phase short circuit fault, the PMG excitation system includes an over–excitation shutdown function that will serve as “backup”. This over–excitation function will shut down the voltage regulator after about 8 to10 seconds. This backup protection is suitable for three–phase faults only and may not protect the generator from damage due to single–phase faults.

PowerCommand Controls and AmpSentry

PowerCommand uses a microcontroller (microprocessor) with three–phase current sensors to continuously monitor current in each phase. Under single– or three–phase fault conditions, current is regulated to approximately 300 percent of the generator rating. The microcontroller integrates current vs. time and compares the result to a stored generator thermal damage curve. Before reaching the damage curve, the microcontroller protects the generator by shutting down excitation and the engine. **Figure 5–19** shows the Amp Sentry protection curve[1] as available for use in protection and coordination studies. The alternator thermal damage curve is shown on the right side of the Amp Sentry protection curve. An overload current of 110 percent of rated for 60 seconds causes an overload alarm and operation of load shed contacts. An overload above 110% will cause the protective response at a time determined by the inverse time protection curve. These controls provide generator protection over the full range of time and current, from instantaneous short circuits, both single and three phase, to overloads of several minutes in duration. In terms of selective coordination one important advantage of Amp Sentry versus a main circuit breaker is that Amp Sentry includes an inherent delay of about 0.6 seconds for all fault currents above 4 per unit. This delay allows the instantaneous response of downstream breakers to clear faults without tripping the generator off–line, providing selective coordination with the first level of downstream breakers.

Ground Fault Indication/Protection

In America, the electrical code requires an indication of a ground fault on emergency and standby (life safety) generators that are solidly grounded, operating at more than 150 volts to ground, and with main overcurrent devices rated 1000 amperes or more. If required, standard practice in emergency/standby applications is to provide a latching

1 Power Command Amp Sentry protection curve is available from Cummins Power Generation representatives; order form R–1053.

indication only of a ground fault, and not to trip a circuit breaker. Although ground fault protection of equipment that opens a main generator circuit breaker may be provided, it is not required by code nor recommended on emergency (life safety) generators.

Proper operation of ground fault sensors on generator sets typically requires that the generator is separately–derived and the use of a 4–pole (switched neutral) transfer switch[2].

Prime Power and Interruptible, 600 Volts and Below

The generator overcurrent protection required by the North American electrical code is recommended for prime power and interruptible applications 600 volts and below. Typically, this means the generator should be provided with phase overcurrent devices such as fuses or circuit breakers, or be protected by inherent design.

2 See Cummins Power Generation publication T–016, Paralleling and Paralleling Switchgear.

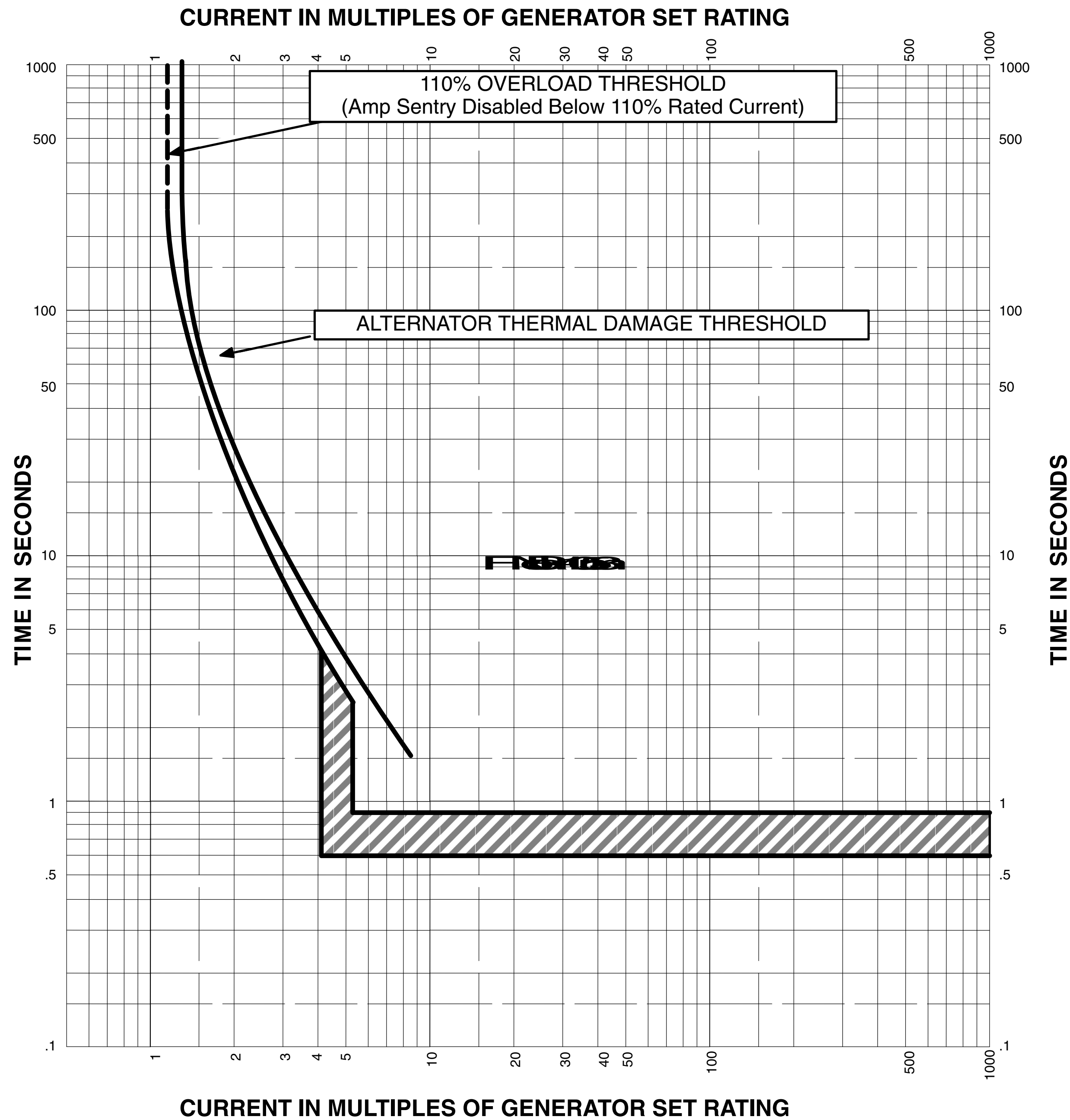


Figure 5–19. PowerCommand® Control AmpSentry™ Time-Over-Current Characteristic Curve Plus Alternator Damage Curve. *(Note: This curve is applicable to all Cummins PowerCommand□ Generator Sets.)*

Units equipped with the PowerCommand control with AmpSentry provide this protection. If a higher level of protection is desired, PowerCommand also provides the following inherent protections on all phases:

- Short circuit
- Over voltage
- Under voltage
- Loss of field
- Reverse power

As stated previously, PowerCommand control with AmpSentry provides the overcurrent and loss of field protection inherent in it design.

Medium Voltage, All Applications

In medium voltage applications (601 – 15,000 volts), the standard practice of providing generator protection will not typically compromise the reliability of the power supply since selectivity of devices is achievable. The cost of the investment in equipment also warrants a higher level of protection. The basic minimum protection includes (see **Figure 5–20**):

- Three phase backup overcurrent sensing (51V)
- One backup ground time–overcurrent relay (51G)
- Field loss sensing (40)
- Three phase instantaneous overcurrent sensing for differential protection (87).

NOTE: Refer to ANSI/IEEE Standard No. 242 for additional information about overcurrent protection of these generators.

Surge Protection of Medium–Voltage Generators

Consideration should be given to protecting medium–voltage generators against voltage surges caused by lightning strikes on the distribution lines and by switching operations. Minimum protection includes:

- Line arrestors on the distribution lines
- Surge arrestors at the terminals of the generator
- Surge capacitors at the terminals of the generator
- Strict adherence to good grounding practice.

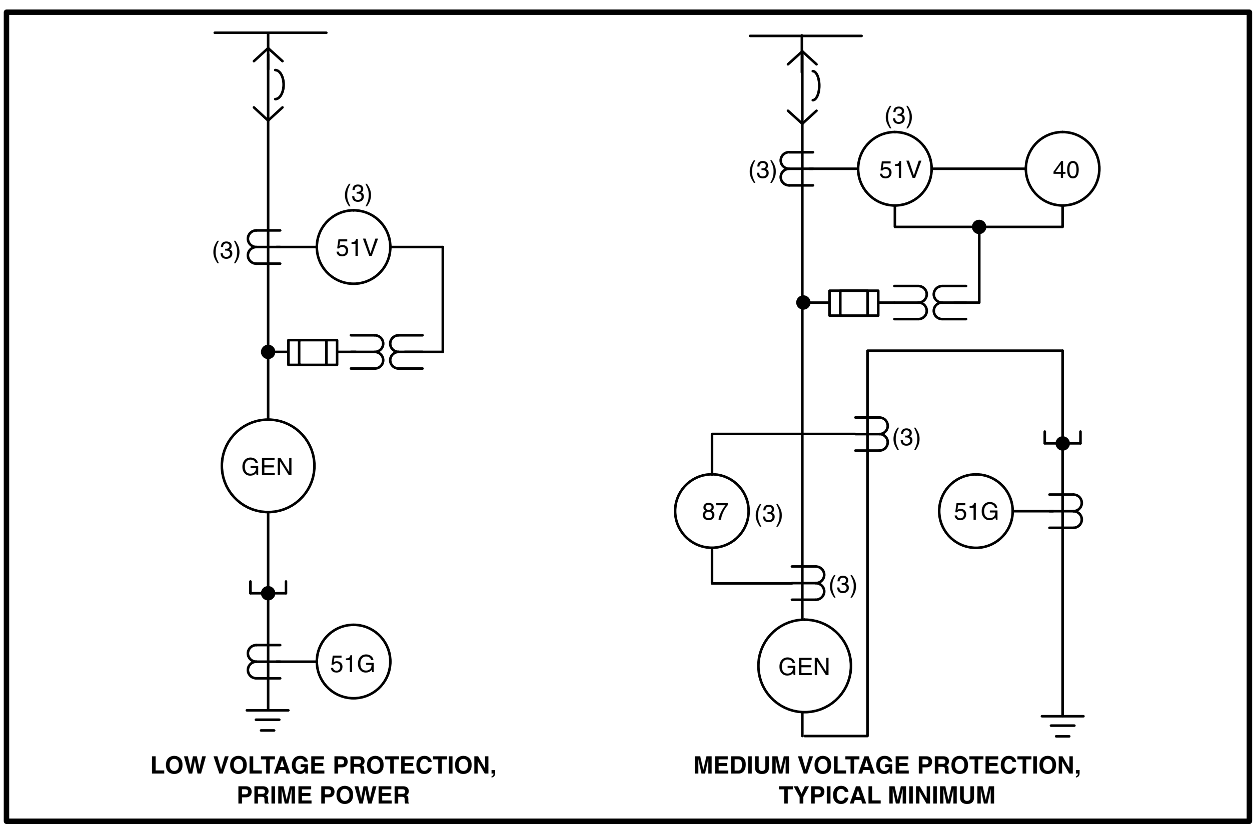


Figure 5–20. Typical Protective Scheme

CHAPTER 6 CONTENTS

6 – MECHANICAL DESIGN

Foundation and Mounting

Generator Set Mounting and Vibration Isolation

The installation design must provide a proper foundation to support the generator set, and to prevent damaging or annoying levels of vibration energy from migrating into the building structure. In addition, the installation should assure that the supporting infrastructure for the generator set does not allow vibration from the generator set to migrate into the stationary portion of the equipment.

All components that physically connect to the generator set must be flexible in order to absorb the vibration movement without damage. Components that require isolation include the engine exhaust system, fuel lines, AC power supply wiring, load wiring, control wiring (which should be stranded, rather than solid core), the generator set (from the mounting pad), and ventilation air ducts (for generator sets with skid–mounted radiators) (See **Figure 6–1**). Lack of attention to isolation of these physical and electrical interconnection points can result in vibration damage to the building or the generator set, and failure of the generator set in service.

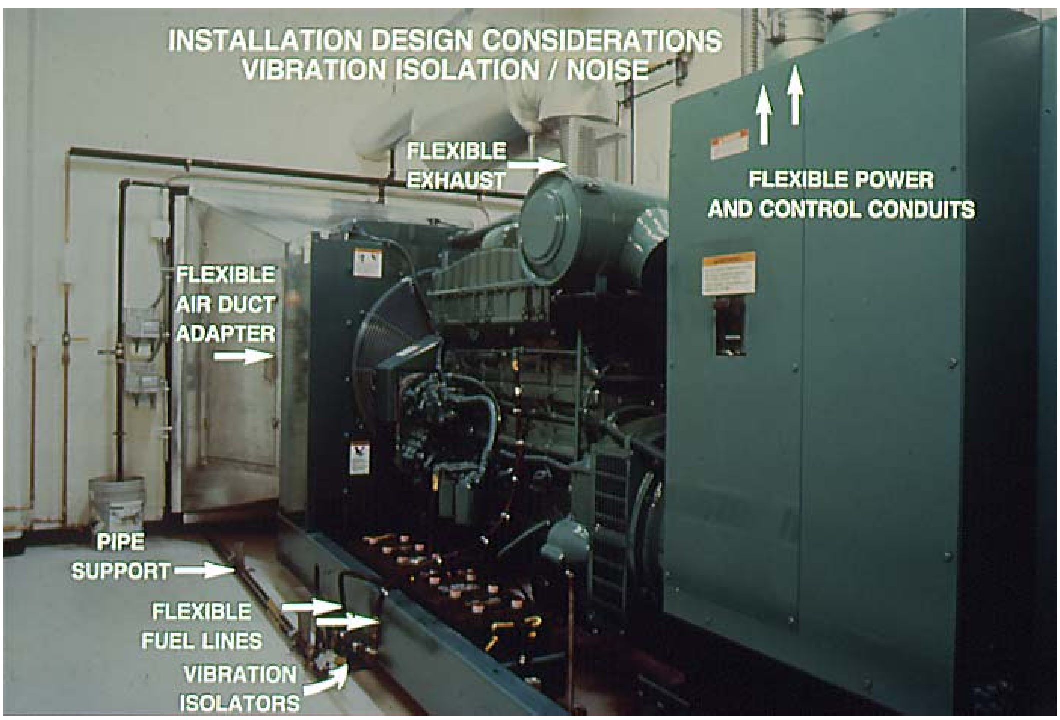


Figure 6–1. Anti–Vibration Provisions for a Typical Generator Set

The generator set engine, alternator, and other mounted equipment are typically mounted on a skid–base assembly. The skid–base assembly is a rigid structure that provides both structural integrity and a degree of vibration isolation. The foundation, floor, or roof must be able to support the weight of the assembled generator set and its accessories (such as a sub–base fuel tank), as well as resist dynamic loads and not transmit objectionable noise and vibration. Note that in applications where vibration isolation is critical the assembled weight of the package might include a massive mounting foundation (See Foundation Provisions in this section.)

Physical size, weight, and mounting configurations vary greatly between manufacturers and between various sizes of equipment. Consult the manufacturer's installation instructions for the specific model installed for detailed information on weights and mounting dimensions[1].

Foundation Provisions

Slab Floor

For many applications, a massive foundation is not necessary for the generator set. Gensets with integral vibration isolators can reduce transmitted vibrations by 60–80% and placing steel spring isolators between the genset and slab can isolate greater than 95% of vibrations (see vibration isolators later in this section). If vibration transmission to the building is not a critical concern, the major issue will be installing the generator set so that its weight is properly supported and so that the unit can be easily serviced. A concrete pad should be poured on top of a concrete floor to raise the generator set to a height that makes service convenient and to make housekeeping around the unit easier.

- The pad should be constructed of reinforced concrete with a 28–day compressive strength of at least 2500–psi (17,200 kPa).
- The pad should be at least 6 inches (150 mm) deep and extend at least 6 inches (150 mm) beyond the skid on all sides.

See generator set manufacturer's drawings for physical locations of fuel lines, control and power interconnections and other interfaces that are planned to be cast into the concrete. These interfaces vary considerably from supplier to supplier.

Vibration isolators should be secured to the mounting pad with Type J or L bolts (rag or rawl bolts) set into the concrete pad. Positioning of "cast in" bolts is problematic, since even small errors in location can cause time consuming redrilling of the skid base. Some generator set designs allow use of concrete anchor bolts. These would require the mounting points to be carefully laid out based on actual location of the mounting points on the generator set and isolators.

The mounting pad for the generator set should be level and flat to allow for proper mounting and adjustment of the vibration isolation system. Verify that the mounting pad is level lengthwise, widthwise, and diagonally.

Piers (Plinth)

Alternatively, the generator set can be mounted on concrete piers (plinth) oriented along the length of the skid of the generator set. This arrangement allows easy positioning of a drip pan underneath the generator set, and allows more room for servicing of the generator set. The piers should be physically attached to the floor.

Vibration Isolating Foundation

In applications where the amount of vibration transmission to the building is highly critical, mounting the generator set on a vibration isolating foundation may be required. In this case, additional considerations are necessary. **Figure 6–2** illustrates a typical vibration isolating foundation.

- The weight (W) of the foundation should be at least 2 times (and up to 5–10 times) the weight of the set itself to resist dynamic loading. (The weight of fuel in a sub–base fuel tank should not be considered to be contributing to the weight required of a vibration isolating foundation even though the isolators are between the tank and the generator set.)

1 Detailed information on Cummins Power Generation products can be found on the Cummins Power Suite, or may be obtained from any authorized distributor.

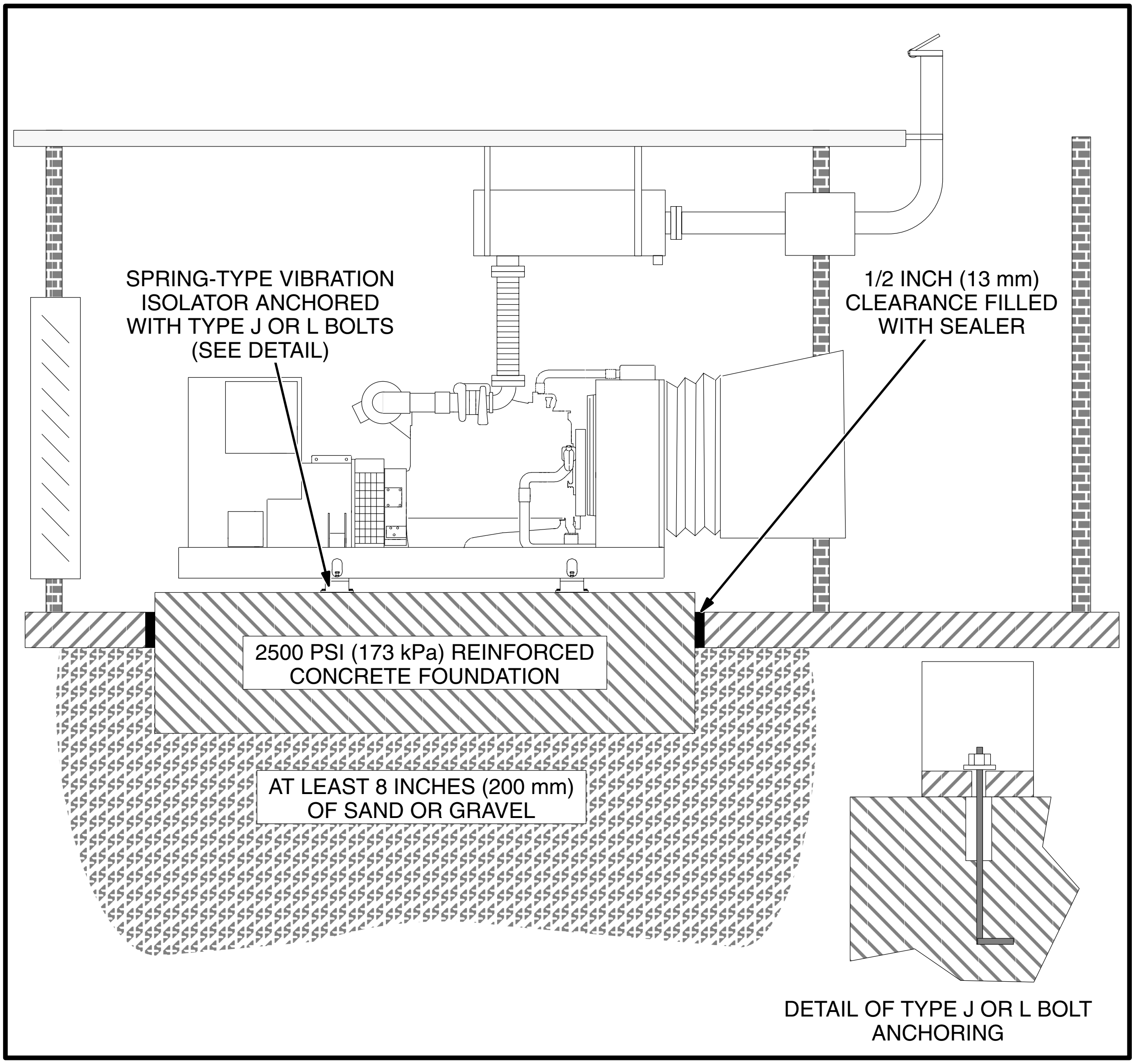


Figure 6–2 Typical Vibration Isolating Foundation

- The foundation should extend at least 6 inches (150 mm) beyond the skid on all sides. This determines the length (l) and width (w) of the foundation.
- The foundation should extend at least 6 inches (150 mm) above the floor to make service and maintenance of the generator set easier.
- The foundation must extend below the frost line to prevent heaving.
- The foundation should be reinforced concrete with a 28–day compressive strength of at least 2500 psi (17,200 kPa).
- Calculate the height (h) of the foundation necessary to obtain the required weight (W) by using the following formula:

$$h = \frac{W}{d \bullet l \bullet w}$$

Where:

h = Height of the foundation in feet (meters).
l = Length of the foundation in feet (meters).
w = Width of the foundation in feet (meters).
d = Density of Concrete – 145 lbs/f^3 (2322 kg/M^3)
W = Total wet weight of Genset in lbs (kg).

- The total weight of the generator set, coolant, fuel, and foundation usually results in a soil bearing load (SBL) of less than 2000 lbs/ft^2 (9800 kg/m^2)psi (96 kPa). Although this is within the load bearing capacity of most soils, always find out the allowable SBL by checking the local code and the soil analysis report for the building. Remember to include the weight of coolant, lubricant, and fuel (if applicable) when performing this calculation. Calculate the SBL by using the following formula:

$$\text{SBL (psi)} = \frac{W}{l \bullet w \bullet 144}$$

$$\text{SBL (kPa)} = \frac{W \bullet 20.88}{l \bullet w}$$

Sample Calculations (US units):

A 500kW genset weights approximately 10,000 pounds (4540 kg) wet (i.e., including coolant and lubricants). Skid dimension is 10 feet (3 meters) long and 3.4 feet (1 meter) wide.

l = 10 + (2 • 0.5) = 11 feet
w = 3.4 + (2 • 0.5) = 4.4 feet
Foundation weight = 2 • 10,000 = 20,000 lbs
Total weight = genset + foundation
=10,000 + 20,000 = 30,000 lbs

$$\textbf{SBL} = \frac{30{,}000}{11 \bullet 4.4} = \mathbf{620\ lbs/ft^2}$$

Vibration Isolators

The engine and alternator of a generator set must be isolated from the mounting structure where it is installed. Some generator sets, particularly smaller kW models, utilize neoprene/rubber vibration isolators that are inserted into the machine between the engine/alternator and the skid[2]. The skid of these generator sets usually can be bolted directly to the foundation, floor, or sub–structure. Other generator sets may be provided with a design that features the engine/alternator solidly attached to the skid assembly. Generator sets that do not include integral isolation should be installed using vibration isolation equipment such as pad, spring, or air isolators.

NOTE: Bolting a generator set that does not include integral isolators directly to the floor or foundation will result in excessive noise and vibration; and possible damage to the generator set, the floor, and other equipment. Vibrations can also be transmitted through the building structure and damage the structure itself.

2 Cummins Power Generation generator sets (200/175 kW and smaller) have rubber vibration isolators located between the skid and the engine–generator assembly and do not require use of external vibration isolators for most applications.

Pad Isolators

Pad–type isolators are comprised of layers of flexible materials designed to dampen vibration levels in non–critical applications, such as those on grade or for generator sets mounted in their own outdoor enclosure, or where integral isolators are used with a generator set. Pad isolators vary in their effectiveness, but are approximately 75% efficient. Depending on construction, they may also vary in effectiveness with temperature, since at cold temperatures the rubber isolating medium is much less flexible than at higher temperatures.

Spring Isolators

Figure 6–3 illustrates a steel spring vibration isolator of the type required for mounting generator sets that do not include integral vibration isolators. Depicted are the bottom rubber pad, isolator body, securing bolts, support spring, adjusting screw, and locking nut.

These steel spring isolators can damp up to 98 percent of the vibration energy produced by the generator set. Locate the isolators as shown on the generator set manufacturer's documentation. The isolators may not be located symmetrically around the perimeter of the generator set, because they are required to be located with consideration of the center of gravity of the machine. The number of isolators required varies with the ratings of the isolators and the weight of the generator set. See **Figure 6–4**.

When the machine is mounted on a sub–base fuel tank, the type of vibration isolators required to protect the sub–base fuel tank depends on the structure of the tank and the level of vibration force created by the machine. If synthetic rubber vibration isolators are installed between the engine/generator and the skid, additional vibration isolation is not usually required between the machine and the subbase tank. If the engine/alternator is solidly attached to the skid, additional vibration isolation between the skid and a sub–base tank is needed to protect the sub–base tank and adequately isolate the building from vibration. In all cases, follow the manufacturer's recommendations for the specific genset and sub–base tank combination.

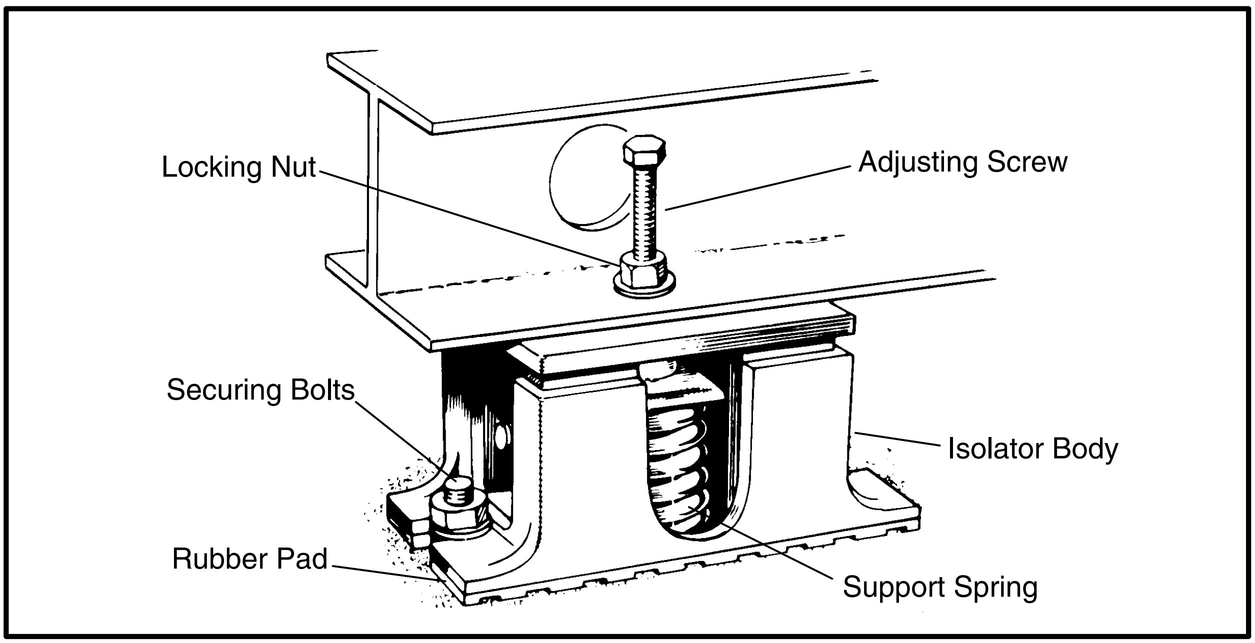


Figure 6–3. Typical Steel Spring Vibration Isolator

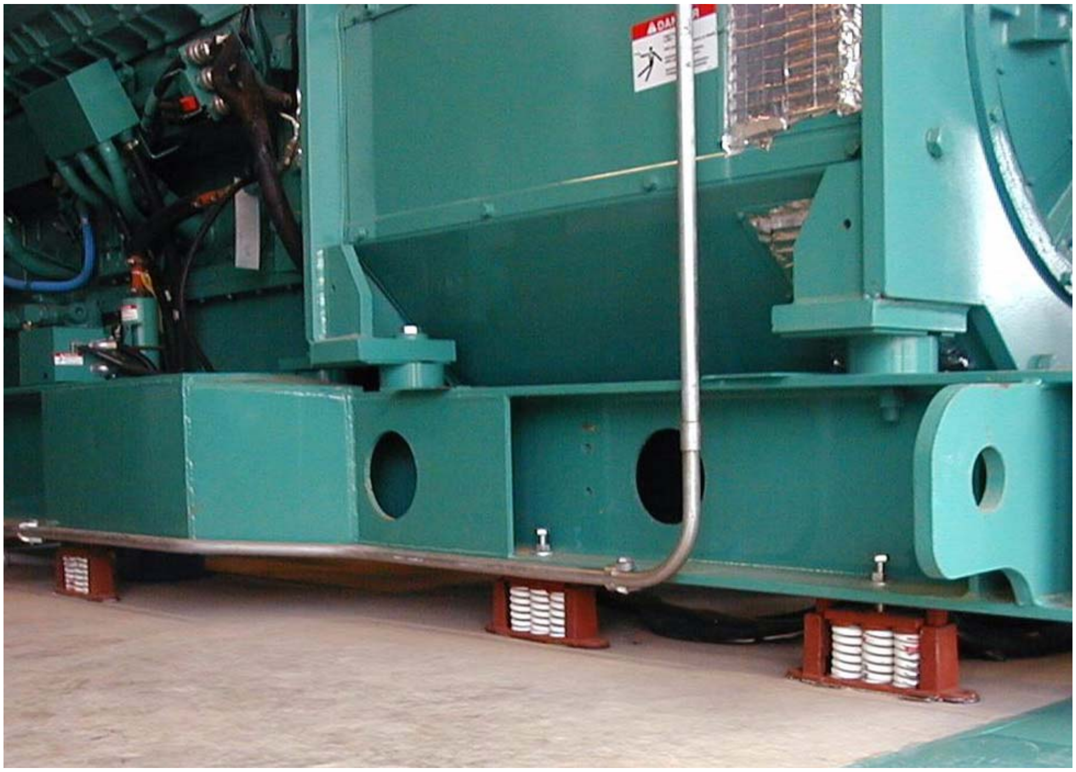


Figure 6–4. A Generator Set Mounted With Spring–Type Vibration Isolators

Spring–type vibration isolators must be properly selected and installed to provide effective isolation. The weight of the generator set should compress the isolator sufficiently to allow freedom of motion without allowing the isolator to “bottom out” during operation. This is accomplished by choosing the isolators and their number based on the isolator’s weight rating and the total weight of the generator set.

The isolator should be positively anchored to the mounting pad for the generator set using Rag (L or J bolts) or Rawl (concrete anchor) bolts.

Air Isolators

An air isolator (or air spring) is a column of gas confined in a container designed to utilize the pressure of the gas as the force medium of the spring. Air isolators can provide a natural frequency lower than can be achieved with elastomeric (rubber) and with special designs lower than helical steel springs. They provide leveling capability by adjusting the gas pressure within the spring.

Air isolators require more maintenance, and temperature limitations are more restrictive than for helical springs. Stiffness of air isolators varies with gas pressure and is not constant, as is the stiffness of other isolators. As a result, the natural frequency does not vary with load to the same degree as other methods of isolation. A failure of the air supply system or leak can cause the isolators to fail completely.

Dampening in air isolators is generally low with a critical dampening ratio in the order of 0.05 or less. This dampening is provided by flexure in the diaphragm or sidewall by friction, or by damping in the gas. Incorporating capillary flow resistance (adding an orifice to the flow) may increase damping between the cylinder of the air isolator and the connecting surge tanks.

Isolators Used in Seismic Locations

Additional factors must be considered for equipment installed in seismic areas. In addition to their typical role of protecting buildings or equipment from machine induced vibration, during a seismic event vibration isolators must also ensure that the equipment remains anchored and does not break free of the structure it is attached to.

In seismic areas, vibration isolators are often used between the genset skid–base and the structure it is attached to. Seismic isolator must be captive, meaning they restrain the generator set from excessive movement and must be strong enough to withstand the seismic forces encountered. Vibration isolators suitable for use in these applications are available in both synthetic rubber and steel spring types.

Vibration isolators, if installed between the engine/alternator and skid, must also adequately secure the engine/alternator to the skid. Normally these types of isolators are of the synthetic rubber type and must be of a “captive” design so as to adequately secure the equipment. The manufacturer or supplier of the equipment should be consulted to determine suitability to the specific application.

Whenever seismic events are a consideration, a qualified structural engineer should be consulted.

Earthquake Resistance

Cummins Power Generation generator sets, when properly mounted and restrained, are suitable for application in recognized seismic risk regions. Special design considerations are necessary for mounting and restraining equipment of the mass density typical of generator sets. Generator set weight, center of gravity, and mounting point locations are indicated on Cummins Power Generation generator set outline drawings.

Components such as distribution lines for electricity, coolant, and fuel must be designed to sustain minimal damage and to facilitate repairs should an earthquake occur. Transfer switches, distribution panels, circuit breakers and associated controls for critical applications[3] must be capable of performing their intended functions during and after the anticipated seismic shocks, so specific mounting and electrical connection provisions must be considered.

Power and Control Wiring Strain Relief

Power wiring and especially control wiring should be installed with the wiring supported on the mechanical structure of the generator set or control panel, and not the physical connection lugs or terminations. Strain relief provisions, along with the use of stranded control wiring rather than single core wiring help to prevent failure of the wiring or connections due to vibration. See Electrical Connections in *Electrical Design.*

Exhaust System

Exhaust System General Guidelines

The function of the exhaust system is to convey engine exhaust safely outside the building and to disperse the exhaust fumes, soot, and noise away from people and buildings. The exhaust system must be designed to minimize backpressure on the engine. Excessive exhaust restriction will result in increased fuel consumption, abnormally high exhaust temperature and failures related to high exhaust temperature as well as excessive black smoke.

See **Figure 6–5** and **6–6**. Exhaust system designs should consider the following:

- Schedule 40 black iron pipe may be used for exhaust piping. Other materials that are acceptable include prefabricated stainless steel exhaust systems.

3 **US CODE NOTE:** NFPA110 requires these features for Level 1 and Level 2 systems.

Figure 6–5: Typical Features of an Exhaust System for a Generator Installed Inside a Building.

- Flexible, seamless corrugated stainless steel exhaust tubing at least 24 inches (610 mm) long must be connected to the engine exhaust outlet(s) to allow for thermal expansion and generator set movement and vibration whenever the set is mounted on vibration isolators. Smaller sets with integral vibration isolation that are bolted directly to the floor must be connected by seamless corrugated stainless steel exhaust tubing at least 18 inches (457 mm) long. Flexible exhaust tubing must not be used to form bends or to compensate for incorrectly aligned exhaust piping.
- Generator sets may be provided with threaded exhaust, slip–type exhaust, or flange–type exhaust connections. Threaded and flanged connections are less likely to leak but more costly to install.
- Isolated non–combustible hangers or supports, NOT the engine exhaust outlet, must support mufflers and piping. Weight on the engine exhaust outlet can cause damage to the engine exhaust manifold or reduce the life of the turbocharger (when used), and can cause vibration from the generator set to be transmitted into the building structure. The use of mounts with isolators further limits vibration from being induced into the building structure.
- To reduce corrosion due to condensation, a muffler (silencer) should be installed as close as practical to the engine so that it heats up quickly. Locating the silencer close to the engine also improves the sound attenuation of the muffler. Pipe bend radii should be as long as practical.

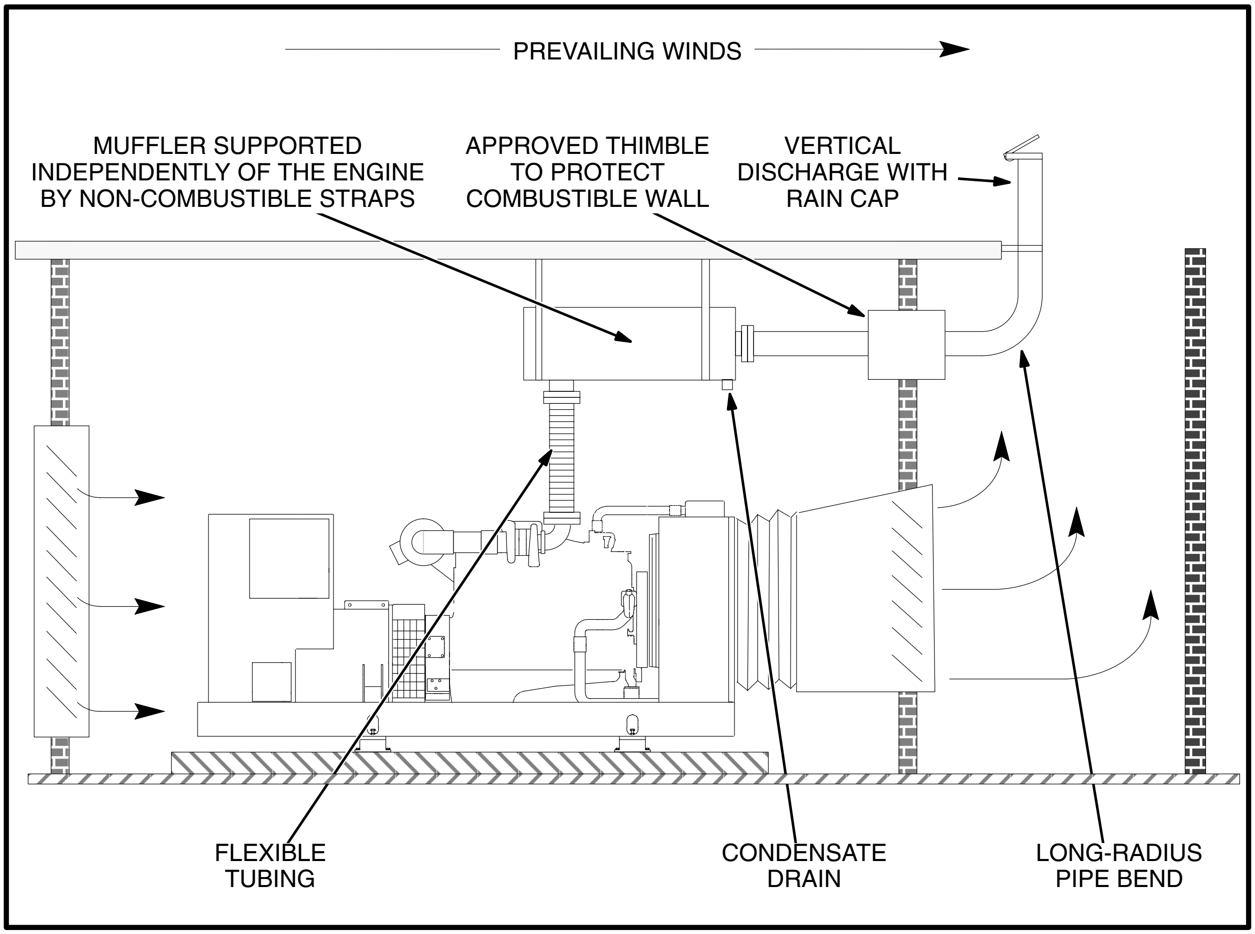


Figure 6–6. Typical Exhaust System

- Exhaust tubing and piping should be of the same nominal diameter as the engine exhaust outlet (or larger) throughout the exhaust system. Verify that the piping is of sufficient diameter to limit exhaust backpressure to a value within the rating of the specific engine used. (Different engines have different exhaust sizes and different backpressure limitations[4].) Piping of smaller diameter than the exhaust outlet must never be used. Piping that is larger than necessary is more subject to corrosion due to condensation than smaller pipe. Piping that is too large also reduces the exhaust gas velocity available for dispersing the exhaust gases up and into the outdoor wind stream.

4 Exhaust system size and other exhaust data for specific generator sets is described in the Cummins Power Suite.

- All engine exhaust system components should include barriers to prevent dangerous accidental contact. Exhaust piping and mufflers should be thermally insulated to prevent burns from accidental contact, prevent activation of fire detection devices and sprinklers, reduce corrosion due to condensation, and reduce the amount of heat radiated to the generator room. Expansion joints, engine exhaust manifolds, and turbocharger housings, unless water cooled, must never be insulated. Insulating exhaust manifolds and turbochargers can result in material temperatures that can destroy the manifold and turbocharger, particularly in applications where the engine will run a large number of hours. Routing of exhaust piping at least 8 feet (2.3 meters) above the floor will also help to prevent accidental contact with the exhaust system.
- Exhaust piping must be routed at least 9 inches (230 mm) from combustible construction. Use approved thimbles where exhaust piping must pass through combustible walls or ceilings (**Figure 6–7 and 6–8**).
- The exhaust system outlet direction should also be carefully considered. Exhaust should never be directed toward the roof of a building or toward combustible surfaces. Exhaust from a diesel engine is hot and will contain soot and other contaminants that can adhere to surrounding surfaces.
- Locate the exhaust outlet and direct it away from the ventilation air intakes.
- If noise is a factor direct the exhaust outlet away from critical locations.
- Exhaust pipe (steel) expands approximately 0.0076 inches per foot of pipe for every 100°F rise in exhaust gas above ambient temperature (1.14 mm per meter of pipe per 100° C rise). It is required that exhaust expansion joints be used to take up expansion in long, straight runs of pipe. Expansion joints should be provided at each point where the exhaust changes direction. The exhaust system should be supported so that expansion is directed away from the generator set. Exhaust temperatures are supplied by the engine or generator set manufacturer for the specific engine used[5].

5 Exhaust gas data for Cummins Power Generation products is available in the Power Suite CD package.

Figure 6–7: Generator Set Exhaust System Features. Dual Side Inlet Silencer, Flex Connectors, Exhaust Thimbles, and Mounting Hangers are Shown.

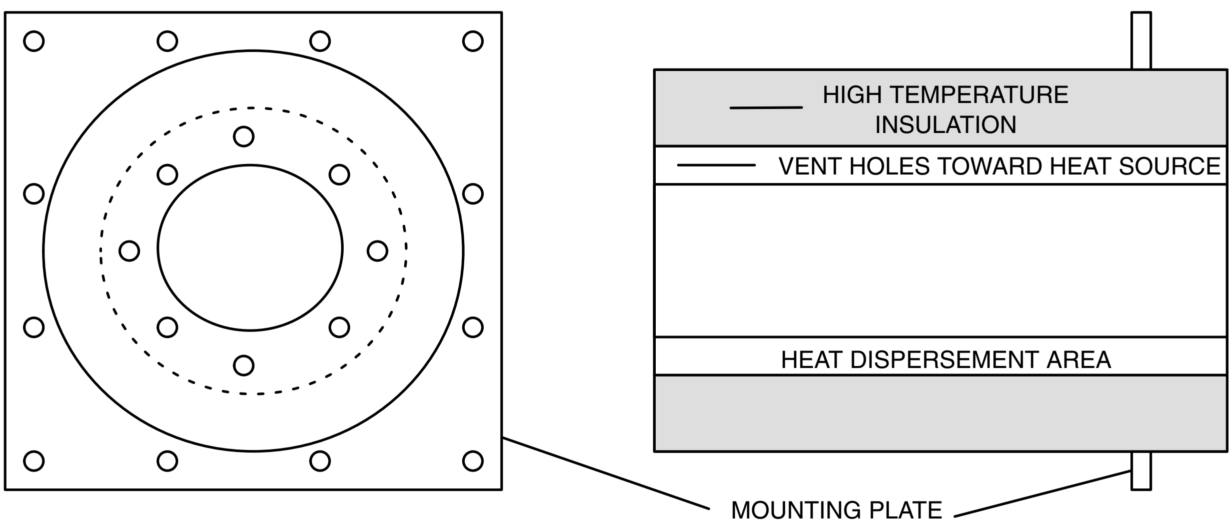


Figure 6–8: Typical Thimble Construction for Combustible Wall Installations.

- Horizontal runs of exhaust piping should slope downwards, away from the engine, to the out–of–doors or to a condensate trap.

- A condensate drain trap and plug should be provided where piping turns to rise vertically. Condensate traps may also be provided with a silencer. Maintenance procedures for the generator set should include regular draining of condensate from the exhaust system.
- Provisions to prevent rain from entering the exhaust system of an engine that is not operating should be provided. This might include a rain cap or exhaust trap (**Figure 6–9 and 6–10**) on vertical exhaust outlets. Horizontal exhaust outlets may be cut off at an angle and protected with birdscreen. Rain caps can freeze closed in cold environments, disabling the engine, so other protective devices may be best for those situations.
- A generator set should not be connected to an exhaust system serving other equipment, including other generator sets. Soot, corrosive condensate, and high exhaust gas temperatures can damage idle equipment served by a common exhaust system.
- Exhaust backpressure must not exceed the allowable backpressure specified by the engine manufacturer[6]. Excessive exhaust backpressure reduces engine power and engine life and may lead to high exhaust temperatures and smoke. Engine exhaust backpressure should be estimated before the layout of the exhaust system is finalized, and it should be measured at the exhaust outlet under full–load operation before the set is placed in service.
- See Exhaust Silencer Performance elsewhere in this section for information on exhaust silencers and various selection criteria for these devices.

WARNING: Engine exhaust contains soot and carbon monoxide, an invisible, odorless, toxic gas. The exhaust system must terminate outside the building at a location where engine exhaust will disperse away from buildings and building air intakes. It is highly recommended that the exhaust system be carried up as high as practical on the downwind side of buildings in order to discharge straight up to maximize dispersal. Exhaust should also discharge on the radiator air discharge side of the building to reduce the likelihood of exhaust gases and soot being drawn into the generator room with the ventilating air.

NOTE: Some codes specify that the exhaust outlet terminate at least 10 feet (3 meters) for the property line, 3 feet (1 meter) from an exterior wall or roof, 10 feet (3 meters) from openings into the building and at least 10 feet (3 meters) above the adjoining grade.

6 Exhaust backpressure information for specific Cummins Power Generation generator sets can be found in the Cummins Power Suite, or may be obtained from an authorized Cummins distributor.

Figure 6–9. A Simple Exhaust System Fitted With a Rain Cap to Prevent Rain From Entering the Exhaust.

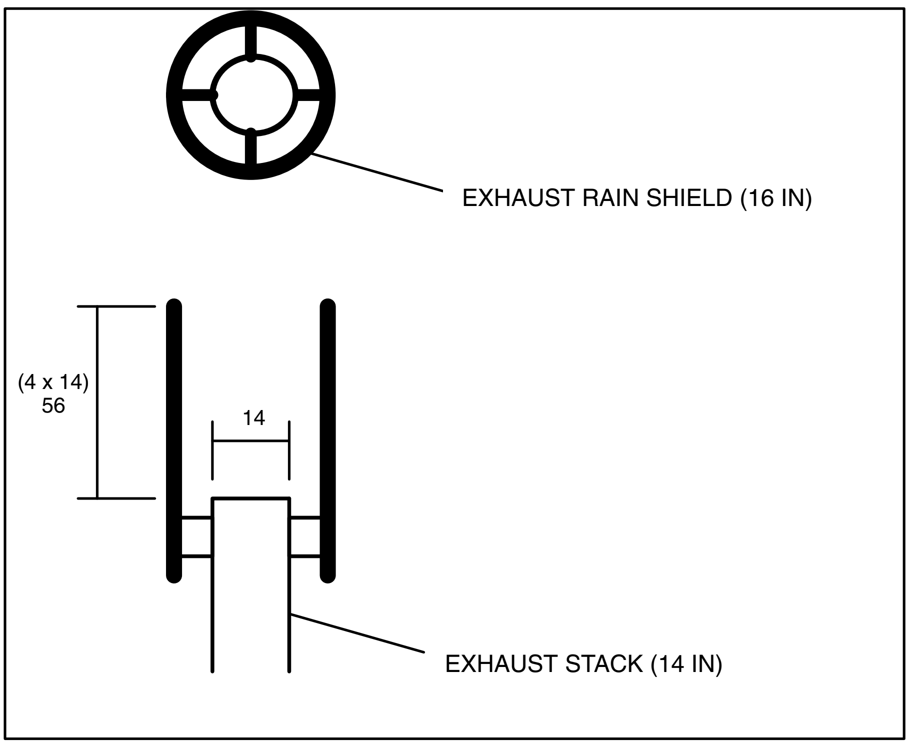


Figure 6–10. A Fabricated Rain Shield for Vertical Genset Exhaust Stack. Dimensions Shown are for a Typical 14–Inch Exhaust.

Exhaust System Calculations

Example Exhaust Backpressure Calculation (US Units)

The layout of an exhaust system in **Figure 6–11** specifies a 5–inch (125–mm) diameter by 24–inch (610 mm) long flexible tube at the engine exhaust outlet, a critical grade muffler with a 6–inch (150–mm) diameter inlet, 20 feet (610 m) of 6–inch (150–mm) diameter pipe and one 6–inch (150 mm) diameter long–radius elbow. The generator set Specification Sheet indicates that the engine exhaust gas flow is 2,715 cfm (cubic feet per minute)(76.9 m^3/min) and that the maximum allowable exhaust back pressure is 41 inches (1040 mm) WC (water column).

This procedure involves determining the exhaust back pressure caused by each element (flexible tubes, mufflers, elbows, and pipes) and then comparing the sum of the back pressures with the maximum allowable back pressure.

1. Determine the exhaust backpressure caused by the muffler. **Figure 6–12** is a graph of typical muffler exhaust backpressures. For more accurate calculations obtain data from the muffler manufacturer. To use **Figure 6–12**:

   a. Find the cross–sectional area of the muffler inlet using **Table 6–1** (0.1963 ft^2 in this example).

   b. Find the exhaust gas flow rate from the engine manufacturer[7]. For this example 2715 cfm is given.

   c. Calculate exhaust gas velocity in feet per minute (fpm) by dividing exhaust gas flow (cfm) by the area of the muffler inlet, as follows:

$$\text{Gas Velocity} = \frac{2715 \text{ cfm}}{0.1963 \text{ ft}^2} = 13{,}831 \text{ fpm}$$

   d. Using **Figure 6–12**, determine the back pressure caused by this flow in the specific muffler used. In this example, the dashed lines in **Figure 6–12** show that the critical grade muffler will cause a back pressure of approximately 21.5 inches W.C.

   3) 20 feet of 6–inch Pipe 20 ft

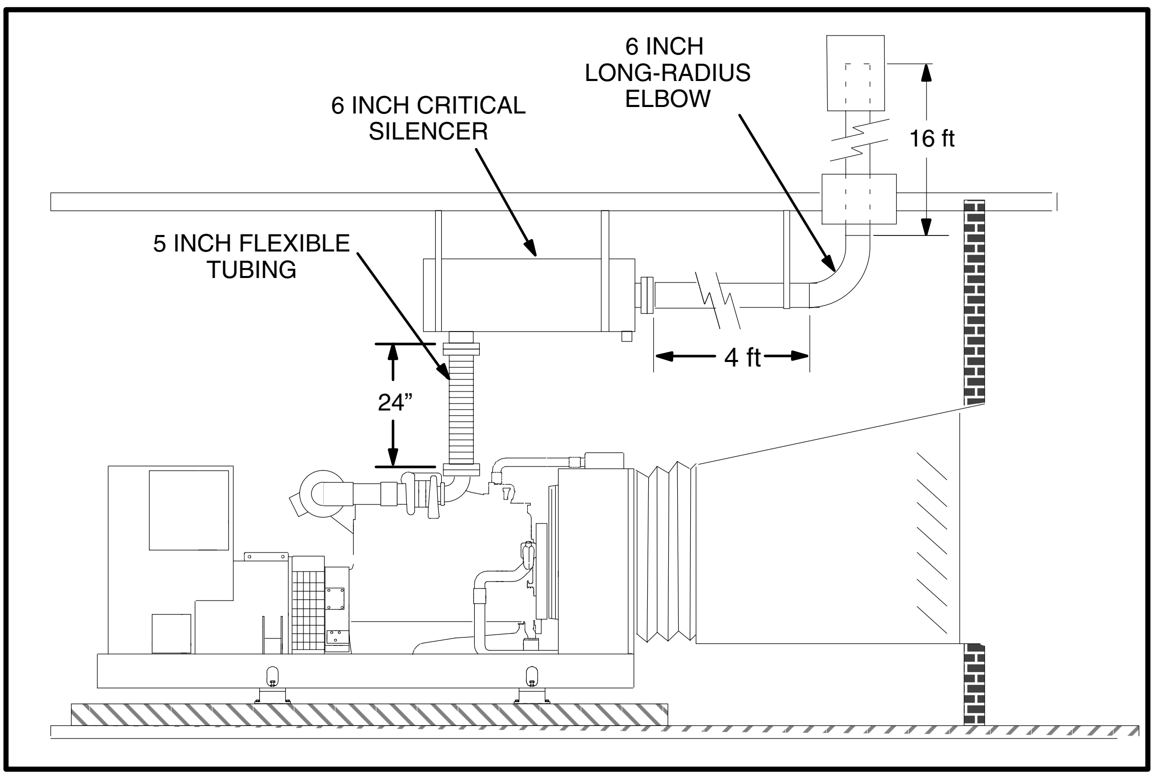


Figure 6–11. Sample Exhaust System for Calculation.

7 Exhaust gas data for Cummins Power Generation products is in the Cummins Power Suite.

2. Find the equivalent lengths of all fittings and flexible tube sections by using **Table 6–2**.
   1) 24 inch flexible tube 4 ft
   2) 6–inch long radius elbow 11 ft

3. Find the back pressure at the given exhaust flow per unit length of pipe for each nominal pipe diameter used in the system. In this example, 5 inch and 6 inch nominal pipe is used. Following the dashed lines in **Figure 6–13**, 5 inch pipe causes a back pressure of approximately **0.34** inches WC per foot and 6 inch pipe approximately **0.138** inches WC per foot.

4. Add the total back pressures for all elements of the example, as follows:
   1) 5 inch flexible tube (4•0.34) 1.4
   2) long–radius elbow (11•0.138) 1.5
   3) 20 feet of 6–inch pipe (20•0.138) 2.8
   4) muffler 21.5
   Total Restriction (inches WC) 27.2

The calculation indicates that the piping layout is adequate in terms of exhaust back pressure since the sum of the back pressures is less than the maximum allowable back pressure of 41 Inches WC.

NOTE: On engines with dual exhaust, the exhaust flow as listed on genset specification sheets from Cummins Power Generation is total flow of both banks. The listed value must be divided by 2 for correct calculation for dual exhaust systems.

DIAMETER OF MUFFLER INLET (INCHES)	AREA OF MUFFLER INLET (FT^2)	DIAMETER OF MUFFLER INLET (INCHES)	AREA OF MUFFLER INLET (FT^2)
2	0.0218	8	0.3491
2.5	0.0341	10	0.5454
3	0.0491	12	0.7854
3.5	0.0668	14	1.069
4	0.0873	16	1.396
5	0.1363	18	1.767
6	0.1963		

Table 6–1. Cross Sectional Areas of Openings of Various Diameter

TYPE OF FITTING	NOMINAL INCH (MILLIMETER) PIPE SIZE											
	2 (50)	2–1/2 (65)	3 (80)	3.5 (90)	4 (100)	5 (125)	6 (150)	8 (200)	10 (250)	12 (300)	14 (350)	16 (400)	18 (450)
90° Standard Elbow	5.2 (1.6)	6.2 (1.9)	7.7 (2.3)	9.6 (2.9)	10 (3.0)	13 (4.0)	15 (4.6)	21 (6.4)	26 (7.9)	32 (9.8)	37 (11.3)	42 (12.8)	47 (14.3)
90° Medium Radius Elbow	4.6 (1.4)	5.4 (1.6)	6.8 (2.1)	8 (2.4)	9 (2.7)	11 (3.4)	13 (4.0)	18 (5.5)	22 (6.7)	26 (7.9)	32 (9.8)	35 (10.7)	40 (12.2)
90° Long Radius Elbow	3.5 (1.1)	4.2 (1.3)	5.2 (1.6)	6 (1.8)	6.8 (2.1)	8.5 (2.6)	10 (3.0)	14 (4.3)	17 (5.2)	20 (6.1)	24 (7.3)	26 (7.9)	31 (9.4)
45° Elbow	2.4 (0.7)	2.9 (0.9)	3.6 (1.1)	4.2 (1.3)	4.7 (1.4)	5.9 (1.8)	7.1 (2.2)	6 (1.8)	8 (2.4)	9 (2.7)	17 (5.2)	19 (5.8)	22 (6.7)
TEE, Side Inlet or Outlet	10 (3.0)	12 (3.7)	16 (4.9)	18 (5.5)	20 (6.1)	25 (7.6)	31 (9.4)	44 (13)	56 (17)	67 (20)	78 (23.8)	89 (27.1)	110 (33.5)

18 Inch Flexible Tube	3 (0.9)	3 (0.9)	3 (0.9)	3 (0.9)	3 (0.9)	3 (0.9)	3 (0.9)	3 (0.9)	3 (0.9)	3 (0.9)	3 (0.9)	3 (0.9)	3 (0.9)
24 Inch Flexible Tube	4 (1.2)	4 (1.2)	4 (1.2)	4 (1.2)	4 (1.2)	4 (1.2)	4 (1.2)	4 (1.2)	4 (1.2)	4 (1.2)	4 (1.2)	4 (1.2)	4 (1.2)

Table 6–2. Equivalent Lengths of Pipe Fittings in Feet (Meters)

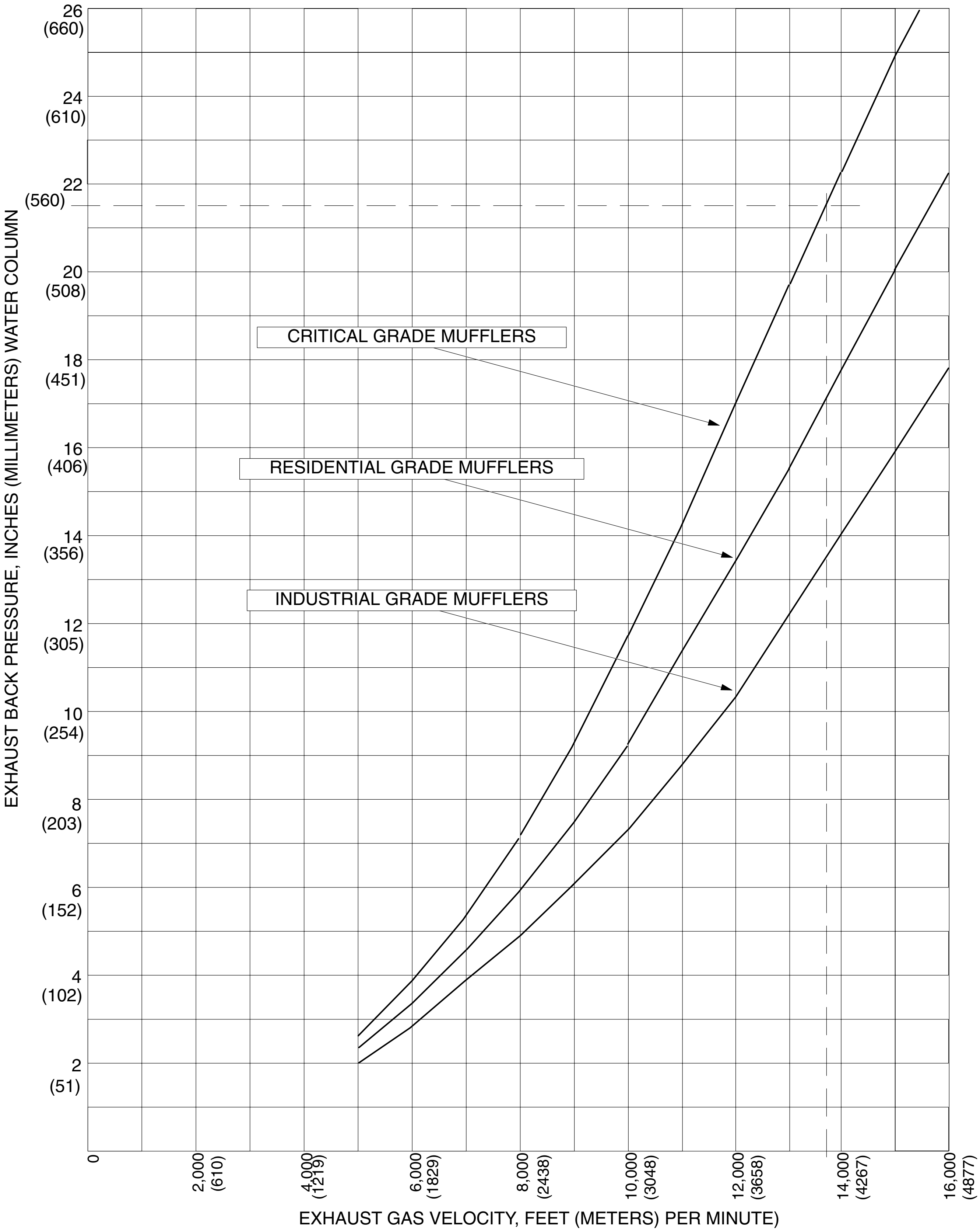


Figure 6–12. Typical Muffler Exhaust Back Pressure vs. Gas Velocity

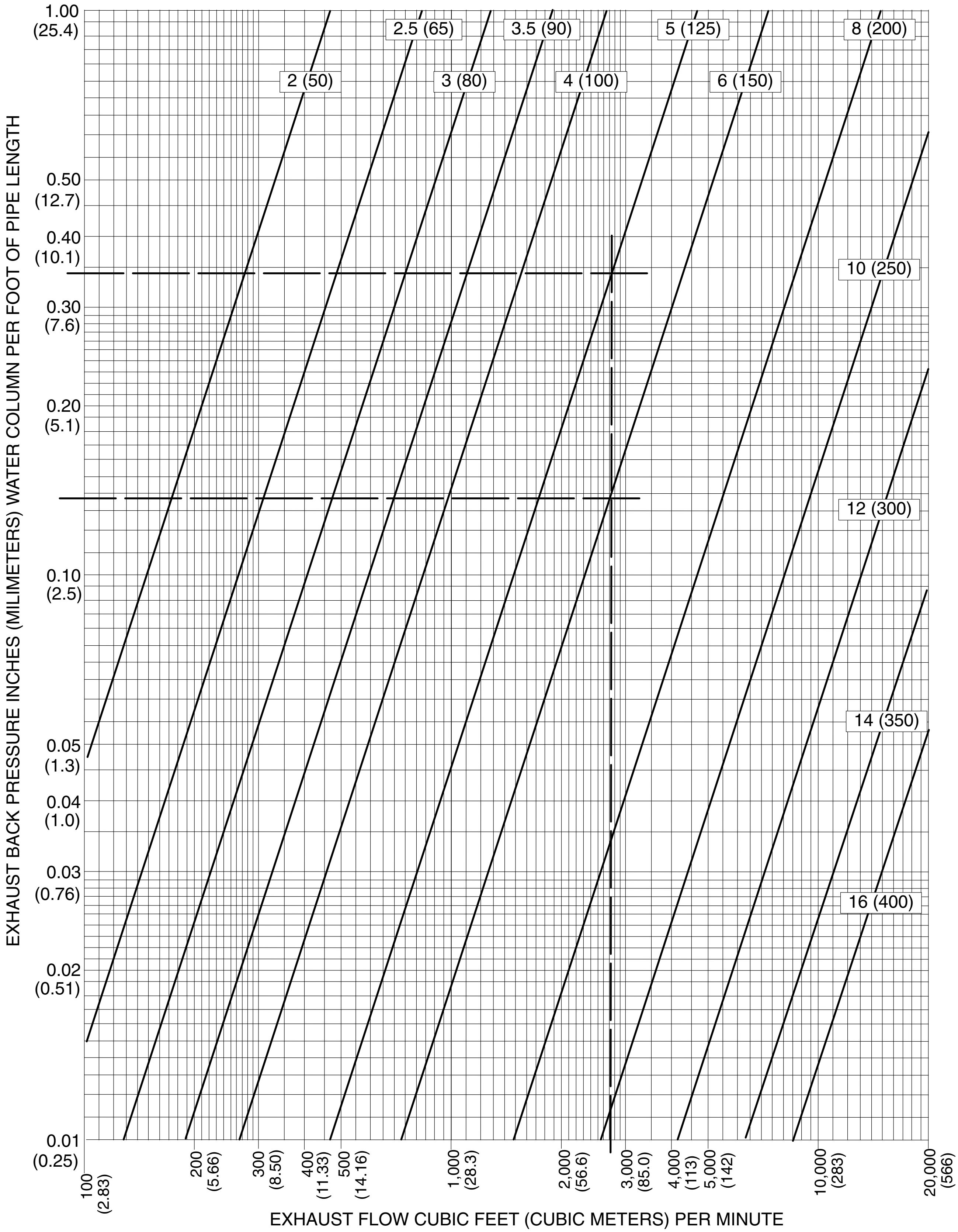


Figure 6–13. Exhaust Back Pressure in Nominal Inch (mm) Pipe Diameters

Engine Cooling

Liquid–cooled engines are cooled by pumping a coolant mixture through passages in the engine cylinder block and head(s) by means of an engine–driven pump. The most common generator set configuration has a mounted radiator and an engine–driven fan to cool the coolant and ventilate the generator room. Alternative methods for cooling the coolant include skid–mounted liquid–to–liquid heat exchangers, remote radiator, a remote liquid–to–liquid heat exchanger, and cooling tower configurations.

Requirements

All Systems

- Mixtures of either ethylene– or propylene–glycol and high–quality water shall be used for proper cooling and freeze / boil protection. (See **Coolant**, page 6–43.)
- Coolant heaters shall be installed in emergency / standby applications to ensure good engine starting (optional in tropical locations unless mandated by local ordinance). (See **Coolant Heaters**, page 6–44.)
- There shall be no loops in the coolant heater hose routing, and the hose shall run continuously uphill. (See **Coolant Heaters**, page 6–44.)
- Coolant heater connections shall be made using high quality silicon or braided hose. (See **Coolant Heaters**, page 6–44.)
- The coolant heater shall be disabled while the generator set is running. (See **Coolant Heaters**, page 6–44.)
- The cooling system shall be designed to accommodate installation site altitude and ambient temperature. (See **Altitude and Ambient Temperature**, page 6–45.)
- The radiator and other sensitive equipment shall be protected from dirt and debris. (See **Cooling System Fouling**, page 6–46.)
- Valves shall be clearly marked to identify “open” and “closed.” (See **Serviceability**, page 6–46.)
- Access shall be provided for cleaning and servicing all equipment (See **Serviceability**, page 6–46.).
- For mobile applications, special consideration shall be given to equipment durability and robustness. (See **Mobile Applications**, page 6–47.)

All Heat Exchanger Installations

- Installation shall satisfy raw water flow rate, pressure and temperature limits listed on the **Generator Set Data Sheet**.
- Raw water shall be protected from freezing.
- Local ordinances shall be consulted before designing or installing a system that draws from and / or discharges to a municipal water supply, river, or any other public water source.
- Installation shall have a sufficient generator set ventilation system.

All Non–Factory Supplied Cooling System Installations

- When placed back–to–back with the jacket water radiator with a single fan, the low temperature aftercooling (LTA) radiator shall be placed upstream in the airflow to access the coolest air. (See **Types of Cooling Systems**, page 6–25.)
- 2P2L systems shall have a thermostatic diverter valve and bypass loop to regulate intake manifold temperature. (See **Types of Cooling Systems**, page 6–25.)

- Remote–cooled installations shall have a sufficient generator set room ventilation system. (See **Non–Factory–Supplied Cooling Systems**, page 6–30.)
- System shall be designed to:
  - Limit the engine coolant outlet temperature to the 'Maximum Top Tank Temperature' value listed on the **Generator Set Data Sheet.** (See **General Requirements for All Non–Factory–Supplied Cooling Systems**, page 6–33.)
  - Maintain positive coolant head on the engine coolant pump. (See **General Requirements for All Non–Factory–Supplied Cooling Systems**, page 6–33.)
  - Stay within coolant pump static and friction head limits (See **System Connections and Plumbing**, page 6–35).
- LTA systems shall satisfy the aftercooler circuit requirements listed on the **Generator Set Data Sheet.** (See **General Requirements for All Non–Factory–Supplied Cooling Systems**, page 6–33.)
- Add electrical loads for the remote radiator fan, ventilating fans, coolant pumps and other accessories to the total load requirement of the generator set. (See **General Requirements for All Non–Factory–Supplied Cooling Systems**, page 6–33.)
- Coolant lines shall be appropriately designed rigid steel tubing or Schedule 40 pipe (with the exception of the connection requirements detailed below). (See **System Connections and Plumbing**, page 6–35.)
- Coolant piping external to the engine shall be of equal or larger diameter than the engine inlet and outlet connections. (See **System Connections and Plumbing**, page 6–35.)
- External coolant piping and connections shall be cleaned before connecting to the generator set. (See **System Connections and Plumbing**, page 6–35.)
- Consideration shall be given for thermal expansion of coolant pipes / tubes. (See **System Connections and Plumbing**, page 6–35.)
- System connections shall be designed to (See **System Connections and Plumbing**, page 6–35.):
  - Accommodate coolant pressures and temperatures.
  - Withstand vibration due to engine operation and movement during start–up and shutdown.
- Where used, connection hose shall conform to SAE J20R1 or equivalent and be rated for at least 75 psi (518 kPa) burst pressure and –40 °F (–40 °C) to 250 °F (121 °C). 100 psi (691 kPa) burst pressure capability is recommended for overhead radiator applications. (See **System Connections and Plumbing**, page 6–35.)
- Connection hose on suction side of the engine coolant pump shall resist collapse. SAE J20R1 hose meets this requirement for heavy–duty diesel engines. (See **System Connections and Plumbing**, page 6–35.)
- Coolant hose connections shall be secured with T–bolt or constant torque clamps. Worm screw–type clamps are unacceptable. If rigid steel tubing is used, it shall be beaded. (See **System Connections and Plumbing**, page 6–35.)
- System shall visibly clear itself of entrained air within 25 minutes of running time after system fill. (See **Deaerating Tank Requirements**, page 6–38.)
- Deaerating tank shall (See **Deaerating Tank Requirements**, page 6–38.):

- Be located at the highest point in the system.
- Have capacity of at least 17% of the total system coolant volume (11% drawdown capacity, 6% thermal expansion).
- Be equipped with:
- Fill / pressure cap
- Fill neck with minimum 0.125 inch (3 mm) diameter hole through one side, located as close as possible to the top of the tank
- Low coolant level shutdown switch (for 9 liter engines and above).
- Have vent lines connected above the coolant level.
- Have a dedicated connection point for each vent line. Do not tee any vent lines together.

- Engine coolant jacket and any high points in the system plumbing shall be vented to the deaerating tank. (See **Deaerating Tank Requirements**, page 6–38.)
- Generator set installation drawing shall be consulted for coolant jacket vent locations and connection sizes. (See **Deaerating Tank Requirements**, page 6–38.)
- Vent lines shall run continuously uphill to the deaerating tank. Loops / sags will cause air locks and are unacceptable. Lines shall not be pinched or constricted anywhere along their path. (See **Deaerating Tank Requirements**, page 6–38.)
- If venting valves that vent to atmosphere are used, drawdown capacity shall be increased from 11% to 14% (total tank capacity increases from 17% to 20%). (See **Deaerating Tank Requirements**, page 6–38.)
- System shall be capable of initial fill to at least 90% capacity at a minimum rate of 5 gpm (20 L/min), then topped off to 100%. (See **Deaerating Tank Requirements**, page 6–38.)
- System shall be equipped with a fill line (See **Deaerating Tank Requirements**, page 6–38.):
  - Line shall be routed directly from bottom of deaerating tank to straight section of engine coolant pump inlet piping near the engine.
  - Line shall have a continual rise from engine inlet pipe to deaerating tank.
  - No other lines may be connected to fill line
- Each generator set shall have its own dedicated complete cooling system. Do not manifold multiple generator sets to a common cooling system. (See **Interconnection of Cooling Systems**, page 6–43.)

Recommendations

All Heat Exchanger Installations

- Consideration should be given to heat exchanger tube or plate material dependent on quality of raw cooling water. (See **Set–Mounted Heat Exchanger**, page 6–28.)

All Non–Factory Supplied Cooling System Installations

- Air–to–air aftercooling (ATA) or one–pump two–loop (1P2L) systems should not be used for remote cooling applications. (See **Types of Cooling Systems**, page 6–25.)

- System should be designed for 115% cooling capability to account for system degradation. When cleaned according to manufacturer's recommended methods and frequency, a capacity of 100% should always be available. This is particularly important for generator sets installed in dusty / dirty environments. (See **General Requirements for All Non–Factory–Supplied Cooling Systems**, page 6–33.)
- Deaerating tank should be equipped with a sight glass for determining system coolant level. (See **Deaerating Tank Requirements**, page 6–38.)
- For vent line sizes not specified on the generator set installation drawing, it is recommended to use #4 hose (.25" ID – 6.35 mm ID) for vent lines less than 12 feet (3.7 m) in length. Use #6 hose (.375" ID – 9.5 mm ID) for vent lines greater than 12 feet (3.7 m) in length. (See **Deaerating Tank Requirements**, page 6–38.)
- Drain / isolation valves should be installed to allow service of the generator set without emptying the entire system of coolant. (See **Serviceability**, page 6–46.)

Overview

The heat energy rejected through the cooling system is roughly 25% of the total energy of the fuel burned in the engine (see **Figure 6–14**). The cooling system must be designed to handle this large amount of heat, or overheating and failure can occur.

Liquid–cooled generator sets are cooled by pumping a coolant mixture through passages in the engine cylinder block and head(s) by means of an engine–driven pump. The cooling system is a closed, pressurized system filled with a mixture of clean, soft (demineralized) water and ethylene or propylene glycol based antifreeze. (See **Coolant**, page 6–43.)

Read the appropriate sections of this chapter based on the type of cooling system utilized. The most common generator set configuration has a factory–supplied, set–mounted cooling system. Non–factory–supplied cooling systems are also used. Use the applicable sections of this chapter for each type of cooling system installation.

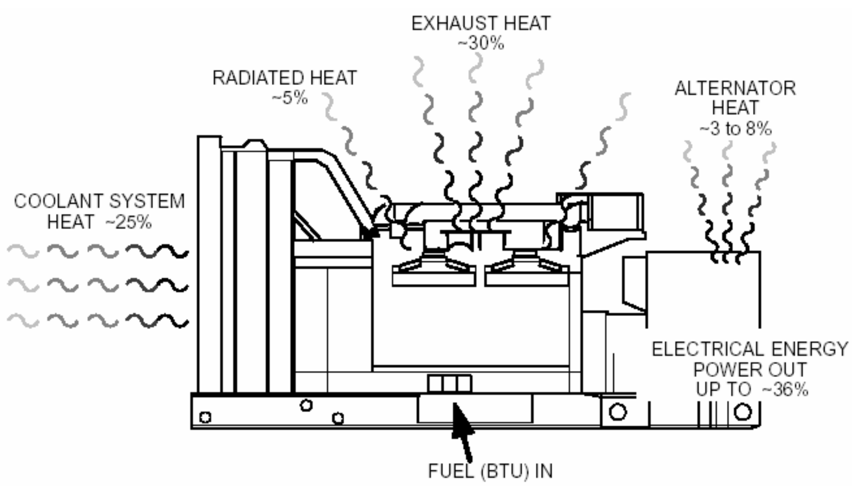


Figure 6–14. Typical Generator Set Heat Balance

Types of Cooling Systems

Generator–drive engines employ several different types of cooling systems. All engines utilize a jacket water cooling system for cooling the cylinder block and head(s). In addition, many generator sets use an aftercooling system to cool the combustion air exiting the turbocharger. This keeps intake manifold temperatures at the levels required to meet emission standards.

Generator set cooling systems include:

- non–aftercooled

- jacket water aftercooling (JWAC)
- air–to–air aftercooling (ATA)
- one–pump two–loop (1P2L)
- two–pump two–loop (2P2L).

For additional system details, contact the local Cummins distributor for access to the appropriate Application Engineering Bulletins (AEBs).

When placed back–to–back with the jacket water radiator with a single fan, the low temperature aftercooling (LTA) radiator shall be placed upstream in the airflow to access the coolest air.

Do not use ATA or 1P2L systems for remote cooling applications.

Non–Aftercooled

These engines do not require aftercooling to maintain low intake manifold temperatures. A jacket water cooling system is used for the cylinder block, cylinder head(s), and lubricating oil.

Jacket Water Aftercooling (JWAC)

With JWAC systems, the same coolant used to cool the engine block and cylinder head(s) is also used to cool the combustion air upstream of the intake manifold. The engine jacket and aftercooler coolant flows are combined, and a single engine coolant pump is utilized. This is the traditional cooling system design where the total engine coolant heat rejection is applied to a single external radiator or heat exchanger.

Air–to–Air Aftercooling (ATA)

ATA systems provide one approach to achieving low temperature aftercooling (LTA) necessary to meet current emissions standards. The charge air is routed to one or more radiator–mounted air–to–air cooler(s). See **Figure 6–15**.

These systems are not recommended for remote cooling for two reasons:

- The entire system piping and radiator are operated under turbocharged pressure (can exceed 40 psi (276 kPa) depending on the engine).
- The length of the air tube run to the radiator and back will create a time lag in turbocharging performance and could result in pressure pulses that impede proper performance.

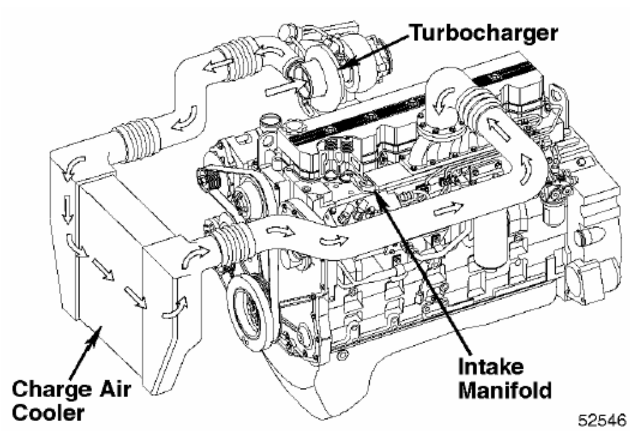


Figure 6–15. Typical Installation Of An Air–to–air Aftercooling System (jacket water system omitted for clarity)

One–Pump Two–Loop Cooling Systems (1P2L)

Another approach to achieving low temperature aftercooling (LTA) is the use of a 1P2L system. These systems utilize two cooling circuits and two radiator cores, but only one coolant pump. These systems are generally not recommended for remote cooling applications due to the difficulty of achieving balanced coolant flows and proper cooling of each circuit.

Two–Pump Two–Loop Cooling Systems (2P2L)

One more approach to achieving low temperature aftercooling (LTA) is the use of a 2P2L system. See **Figure 6–16** for a typical 2P2L system schematic. These systems utilize two completely separate cooling circuits, with two radiator cores, two coolant pumps and separate liquid coolant for each. One circuit cools the engine block and cylinder head(s), and the other cools the combustion air from the turbocharger. For remote systems, engines using this system require two separate radiator cores or heat exchangers. Each will have its own specifications for temperatures, pressure restrictions, heat rejection, etc.

2P2L systems shall have a thermostatic diverter valve and bypass loop to regulate intake manifold temperature.

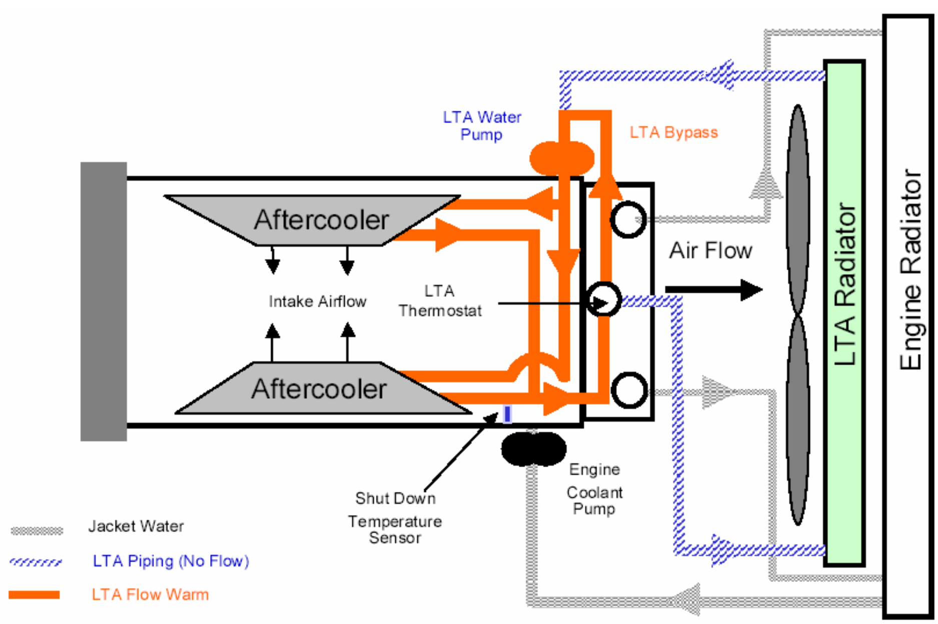


Figure 6–16. 2P2L Coolant Flow With Lta Thermostat Closed

Some generator sets are equipped with a specific type of cooling system that is referred to as “2P2L” but does not have two truly separate loops. These systems utilize one coolant pump with two impellers. Due to a small amount of coolant transfer that occurs in the pump, the system must either use one deaerating tank or two connected tanks. This is required to maintain coolant levels in each loop. See **Deaerating Tank Requirements**, page 6–38.

Factory–Supplied Cooling Systems

Factory–supplied cooling systems include both radiators and heat exchangers. A major advantage to installing a generator set with a factory–supplied cooling system is that a significant amount of design and installation work is already done. Customers installing a remote cooling system have to consider many requirements that are already satisfied by factory–installed systems.

A second advantage of factory–supplied systems is that they are prototype tested to verify overall performance.

Set–Mounted Radiator

A generator set with a set–mounted radiator has an integrated cooling and ventilation system. See **Figure 6–17**. The radiator fan is usually mechanically driven by the engine. Electric fans are used in some applications.

A requirement of the set–mounted radiator is to move a relatively large volume of air through the generator set area. Air must be provided to evacuate heat emitted from the equipment and support combustion of the fuel. This can be a large airflow requirement, and may lead to a decision to use a remote cooling system. However, even if a remote system is used, the airflow required to remove heat and provide combustion air is significant, and an adequate ventilation system will still be required. See the **Ventilation** section of this manual for additional details. With set–mounted radiator systems, the engine fan will often provide sufficient ventilation, eliminating the need for other ventilating devices and systems.

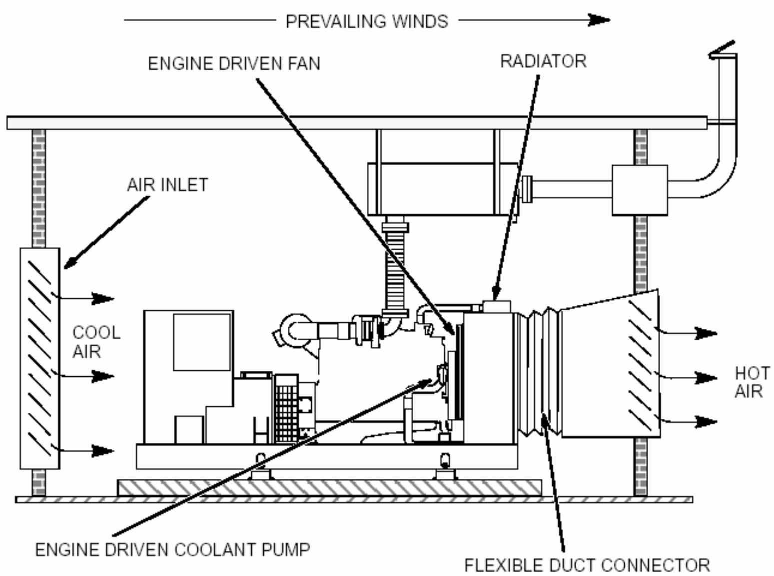


Figure 6–17. Factory–supplied, Set–mounted Radiator Cooling

Set–Mounted Heat Exchanger

With heat exchangers, heat is removed from the engine coolant in a closed system by raw water from an appropriate source. The engine, pump, and heat exchanger form a closed, pressurized cooling system. See **Figure 6–18**. The engine coolant and raw water do not mix.

- Installation shall satisfy raw water flow rate, pressure and temperature limits listed on the **Generator Set Data Sheet**.
- Raw water shall be protected from freezing.
- Local ordinances shall be consulted before designing or installing a system that draws from and / or discharges to a municipal water supply, river, or any other public water source.
- Installation shall have a sufficient ventilation system.
- Consideration should be given to heat exchanger tube or plate material dependent on quality of raw cooling water.

Additional considerations for the raw water side of the heat exchanger:

- A thermostatic water valve can be used to modulate water flow in response to coolant temperature.

- A normally closed battery–powered shut–off valve can be used to shut off the water when the set is not running (battery power should not be used to hold the valve closed).
- Potential sources for the raw water side of the heat exchanger include municipal supplies, rivers, lakes, wells, cooling towers, and others.
- Cooling tower applications will require extensive design and installation support from equipment suppliers and consulting engineers.

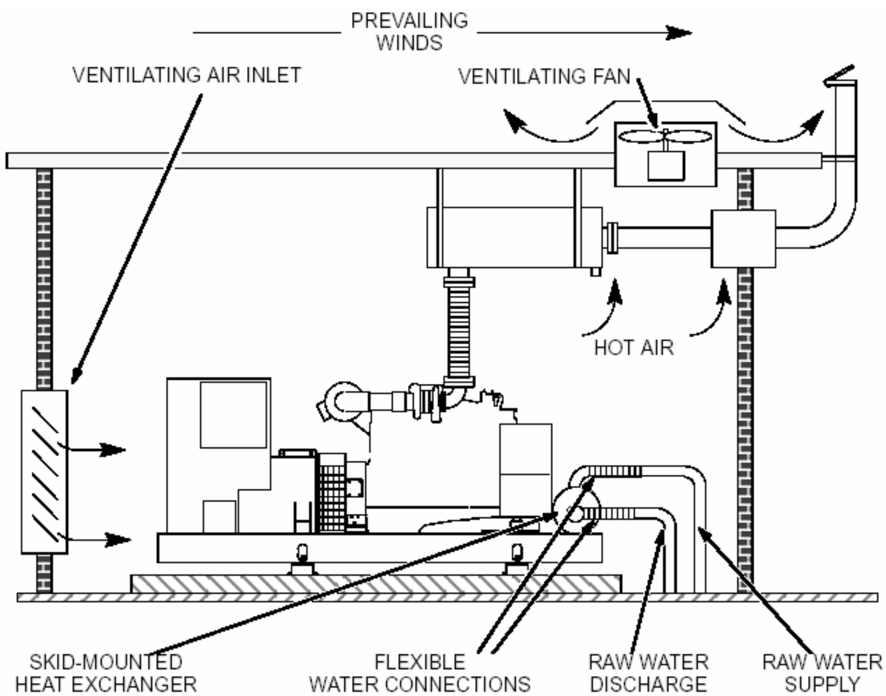


Figure 6–18. Set–mounted heat exchanger cooling.

The selection of a heat exchanger for generator set cooling eliminates the radiator fan from the set. The equipment room will therefore require a powered ventilating system to remove heat and provide the engine with combustion air. See the **Ventilation** section of this manual for additional details.

Heat exchangers are designed to work with a constant supply of clean water at a specified temperature. The quality of the raw water should be considered when specifying the heat exchanger, as impurities could lead to material degradation and reduced life. A heat exchanger made from higher–grade material may be necessary.

Calculations

There must be sufficient raw water flow to remove the **Heat Rejection to Coolant** indicated on the **Generator Set Data Sheet**.

$$RWR = \frac{HR}{(\Delta T)(c)}$$

where RWR = Raw Water Required, gallons/min (liters/min)
HR = Heat Rejection to Coolant, BTU/min (kJ/min)
?T = temperature rise of water across cooler core, °F (°C)
C = specific heat of water, 8 BTU/°F/gallon (4 kJ/°C/liter)

For example, assume the **Generator Set Data Sheet** indicates that the set rejects 15,340 BTU/minute (16,185 kJ/min), and the raw water inlet temperature is 80 °F (27 °C). Assume also that the raw water is discharged to a nearby river, and local ordinances restrict this discharge water temperature to 95 °F (35 °C). The required raw water supply flow is determined by the following:

$$RWR = \frac{15{,}340\ ^{BTU}\!/_{\min}}{(15\ ^{\circ}F)(8\ ^{BTU}\!/_{^{\circ}F \cdot gallon})} = 128\ \frac{gallon}{\min}$$

OR

$$RWR = \frac{16{,}185\ ^{kJ}\!/_{\min}}{(8\ ^{\circ}C)(4\ ^{kJ}\!/_{^{\circ}C \cdot liter})} = 506\ \frac{liter}{\min}$$

Remember that heat exchangers have minimum flow requirements (listed on the **Generator Set Data Sheet**). **These requirements must be satisfied, even if the calculation above indicates that a lower flow is sufficient.**

Non–Factory Supplied Cooling Systems

With non–factory–supplied cooling systems, there are several design elements to evaluate that are taken care of with factory–supplied cooling packages. These include, but are not limited to:

- Type of system to use
- Fuel cooling
- System deaeration, venting, etc.
- Remote–cooled installations shall have a sufficient generator set room ventilation system.

Remote systems are often used when it is not practical to get sufficient ventilation air to a set–mounted radiator system. Remote cooling systems do not eliminate the need for generator set ventilation, but they may reduce it. The generator set will still emit heat to the surroundings, and this heat must be evacuated. See the **Ventilation** section of this manual for additional details.

Characteristics of remote cooling systems include:

- Ability to get ambient temperature air to the radiator core
- Flexibility in site layout
- Improved serviceability, depending on the installation.

Determining the Remote Cooling Strategy to Use

Remote radiators (either in conjunction with the standard engine coolant pump, or with an auxiliary coolant pump) and heat exchangers can be used to remote cool the generator set.

The decision of which type of system to use is often dictated by the static and friction head limitations of the engine coolant pump, as given on the **Generator Set Data Sheet**. See **Figure 6–19** and **Figure 6–20** for examples.

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MIL STD 461C, Part 9 Radiated Emissions (EMI)

Cooling	Standby	Prime
Fan Load, HP (kW)	22.6 (16.9)	22.6 (16.9)
Coolant Capacity with radiator, US Gal (L)	24.0 (90.8)	24.0 (90.8)
Coolant Flow Rate, Gal/min (L/min)	196.0 (741.9)	196.0 (741.9)
Heat Rejection To Coolant, Btu/min (MJ/min)	16350.0 (17.3)	14350.0 (15.2)
Heat Radiated To Room, Btu/min (MJ/min)	6100.0 (6.5)	5540.0 (5.9)
Maximum Coolant Friction Head, psi (kPa)	10.0 (68.9)	10.0 (68.9)
Maximum Coolant Static Head, ft (m)	60.0 (18.3)	60.0 (18.3)

Air		
Combustion Air, scfm (m^3/min)	1517.0 (42.9)	1455.0 (41.2)
Alternator Cooling Air, scfm (m^3/min)	4156.0 (117.6)	4156.0 (117.6)
Radiator Cooling Air, scfm (m^3/min)	27200.0 (769.8)	27200.0 (769.8)
Max. Static Restriction, in H_2O (Pa)	0.5 (124.5)	0.5 (124.5)

Rating Definitions
...dby Rating based on: Applicable for supplying emergency power for the duration of normal power interruption. No ...load capability is available for this rating. (Equivalent to Fuel ... in accordan... 2789,

Figure 6–19. DFXX Generator Set Specification Sheet Showing 'Maximum Coolant Static Head'.

IEC 801.... Volta...
MIL STD 461C, Part 9 Radiated Emissions (EMI)

Cooling	Standby	Prime
Fan Load, HP (kW)	22.6 (16.9)	22.6 (16.9)
Coolant Capacity with radiator, US Gal (L)	24.0 (90.8)	24.0 (90.8)
Coolant Flow Rate, Gal/min (L/min)	196.0 (741.9)	196.0 (741.9)
Heat Rejection To Coolant, Btu/min (MJ/min)	16350.0 (17.3)	14350.0 (15.2)
Heat Radiated To Room, Btu/min (MJ/min)	6100.0 (6.5)	5540.0 (5.9)
Maximum Coolant Friction Head, psi (kPa)	10.0 (68.9)	10.0 (68.9)
Maximum Coolant Static Head, ft (m)	60.0 (18.3)	60.0 (18.3)

Air		
Combustion Air, scfm (m^3/min)	1517.0 (42.9)	1455.0 (41.2)
Alternator Cooling Air, scfm (m^3/min)	4156.0 (117.6)	4156.0 (117.6)
Radiator Cooling Air, scfm (m^3/min)	27200.0 (769.8)	27200.0 (769.8)
Max. Static Restriction, in H_2O (Pa)	0.5 (124.5)	0.5 (124.5)

Rating Definitions
...dby Rating based on: Applicable for supplying emergency power for the duration of normal power interruption. No ...load capability is available for this rating. (Equivalent to Fuel ... in accordan... 2789,

Figure 6–20. DFXX Generator Set Specification Sheet Showing 'Maximum Coolant Friction Head'.

Remote radiators are convenient because they do not require the continuous raw water flow that heat exchangers do. However, remote radiators are often impractical because they may need to be located a significant distance away from the generator set in order to access a continuous fresh air flow. This often leads to a violation of the static and/or friction head limitations of the engine coolant pump.

If the installation of a remote radiator would violate the engine coolant pump friction and/or static head limits, a heat exchanger can be installed. Keep in mind that the heat exchanger will need a continuous raw water supply that meets its flow, temperature and pressure requirements. The heat exchanger will need to be installed in a location that simultaneously satisfies the head limitations of the engine coolant pump and the raw water requirements of the heat exchanger itself. See **Set–Mounted Heat Exchanger,** page 6–28 and **Remote Heat Exchanger**, page 6–38.

Determining the Static Head on the Engine Coolant Pump

"Static head" refers to the static pressure on the engine coolant pump due to the height of the remote cooling system. The static head is simply the difference in height between the highest point of the cooling system and the engine crankshaft centerline. Consider the example shown in **Figure 6–21**. For the DFXX **Generator Set Data Sheet** shown in **Figure 6–19**, the vertical distance must be less than or equal to 60 ft (18.3 m).

Determining the Friction Head External to the Engine on the Engine Coolant Pump

"Friction head external to the engine" refers to the losses incurred in the coolant piping, valves, radiator core, heat exchanger, or any other cooling system equipment installed external to the engine. Calculations can be performed to estimate this value. These calculations involve determining the pressure loss caused by each individual element in the system, and then adding up all of the pressure losses to come up with the total friction head.

1. Determine the pressure loss in the radiator or heat exchanger by referring to the manufacturer's data. For example, assume a remote radiator is to be installed, and the pressure drop through the radiator is 1.5 psi (10.3 kPa) at a flow of 196 gpm (741.9 L/min).
2. Find the total length of all straight coolant pipe in the system. For this example, assume there is 80 feet (24.4 m) of 3–inch (80 mm) diameter straight pipe.

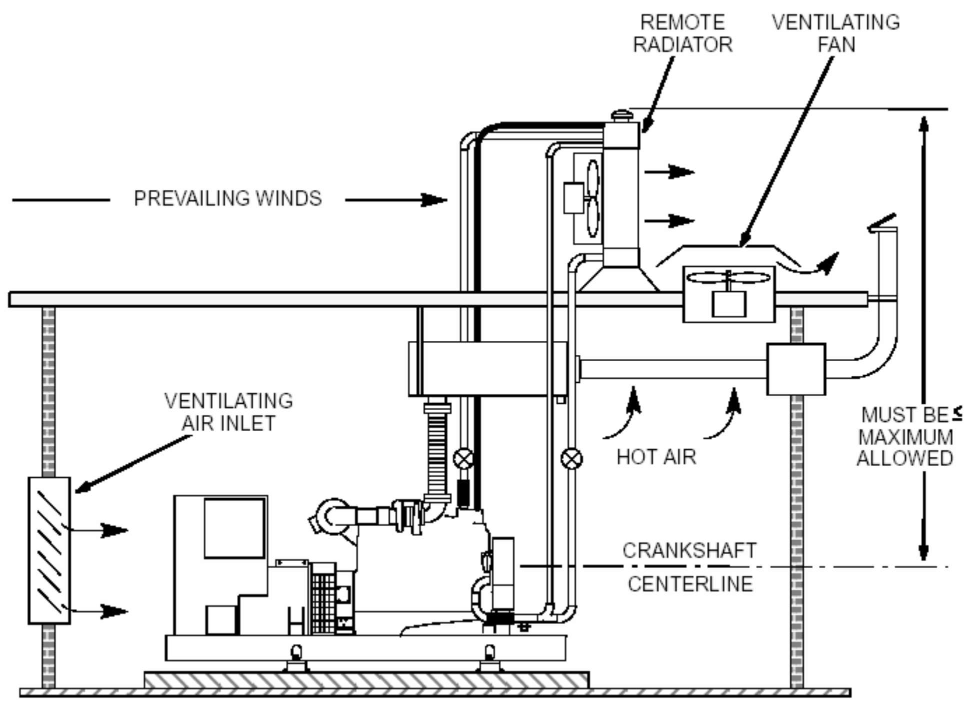


Figure 6–21. Example remote radiator system.

3. Find the estimated equivalent lengths of all fittings and valves by using **Table 6–3** and add to the total length of straight pipe. For this example, assume there are three long sweep elbows, two gate valves to isolate the radiator for engine servicing and a tee to connect the fill / make–up line.

Component	Equivalent Length, ft (m)
3 Long Sweep Elbows	3 x 5.2 ft = **15.6 ft** (3 x 1.6 m = **4.8 m**)
2 Gate Valves (Open)	2 x 1.7 ft = **3.4 ft** (2 x 0.5 m = **1.0 m**)
Tee (Straight Run)	**5.2 ft** (**1.6 m**)
80 Feet (24.4 m) Straight Pipe	**80 ft** (**24.4 m**)
Total Equivalent Length of Pipe	104.2 ft (31.8 m)

4. Find the pressure loss at the given flow per unit length of pipe for the nominal pipe diameter used in the system. In this example, 3–inch (80 mm) nominal pipe is used. From **Figure 6–23**, 3–inch (80 mm) pipe causes a pressure loss of approximately 4.0 psi per 100 feet of pipe (28 kPa per 30 m) at the required coolant flow rate of 196 gal/min (741.9 L/min). Obtain the required coolant flow rate from the **Generator Set Data Sheet**, as shown in **Figure 6–22**.

5. Calculate the pressure loss in the piping as follows:

$$PipingLoss = 104.2\,ft\left(\frac{4.0\,psi}{100\,ft}\right) = 4.2\,psi \quad \text{OR} \quad PipingLoss = 31.8\,m\left(\frac{28\,kPa}{30\,m}\right) = 29.7\,kPa$$

6. The total friction head is the sum of the piping and radiator losses. For example:

$$FrictionHead = 4.2\,psi + 1.5\,psi = 5.7\,psi \quad \text{OR} \quad FrictionHead = 29.7\,kPa + 10.3\,kPa = 40\,kPa$$

Compare the calculated value with the **Maximum Coolant Friction Head External to Engine** listed on the **Generator Set Data Sheet**. If the calculated value exceeds the maximum allowed, adjustments are required, and may include:

- Relocating the generator set and/or radiator/heat exchanger to reduce the distance between them
- Using larger diameter coolant pipes
- Redesigning the system to utilize fewer pipe bends
- Installing an auxiliary coolant pump.

For the example DFXX **Generator Set Data Sheet** shown in **Figure 6–20**, **Maximum Coolant Friction Head External to Engine** equals 10 psi (68.9 kPa). Since the calculated value is less than the maximum allowed, the system should be acceptable as designed. Upon system installation, this should be verified experimentally. Contact the local Cummins distributor for access to the appropriate system verification Application Engineering Bulletins (AEBs).

TYPE OF FITTING	NOMINAL INCH (MILLIMETER) PIPE SIZE										
	1/2 (15)	**3/4 (20)**	**1 (25)**	**1–1/4 (32)**	**1–1/2 (40)**	**2 (50)**	**2–1/2 (65)**	**3 (80)**	**4 (100)**	**5 (125)**	**6 (150)**
90° Std. Elbow or Run of Tee Reduced 1/2	1.5 (0.5)	2.1 (0.6)	2.6 (0.8)	3.5 (1.1)	4.3 (1.3)	5.5 (1.7)	6.5 (2.0)	8.0 (2.4)	11 (3.4)	14 (4.3)	16 (4.9)
90° Long Sweep Elbow or Straight Run Tee	1.0 (0.3)	1.4 (0.4)	1.6 (0.5)	2.4 (0.7)	2.7 (0.8)	3.5 (1.1)	4.2 (1.3)	5.2 (1.6)	7.0 (2.1)	9.0 (2.7)	11 (3.4)
45° Elbow	0.8 (0.2)	1.0 (0.3)	1.3 (0.4)	1.6 (0.5)	1.9 (0.6)	2.5 (0.8)	3.0 (0.9)	3.8 (1.2)	5.0 (1.5)	6.3 (1.9)	7.5 (2.3)
Close Return Bend	3.5 (1.1)	4.8 (1.5)	6.0 (1.8)	8.5 (2.6)	9.9 (3.0)	13 (4.0)	15 (4.6)	18 (5.5)	24 (7.3)	31 (9.4)	37 (11.3)
TEE, Side Inlet or Outlet	3.1 (0.9)	4.0 (1.2)	5.6 (1.7)	7.2 (2.2)	9.0 (2.7)	12 (3.7)	14 (4.3)	17 (5.2)	22 (6.7)	27 (8.2)	33 (10.1)
Foot Valve and Strainer	3.7 (1.1)	4.9 (1.5)	7.5 (2.3)	8.9 (2.7)	11 (3.4)	15 (4.6)	18 (5.5)	22 (6.7)	29 (8.8)	36 (11.0)	46 (14.0)
Swing Check Valve, Fully Open	3.8 (1.2)	5.0 (1.5)	6.5 (2.0)	9.0 (2.7)	10 (3.0)	13 (4.0)	15 (4.6)	19 (5.8)	26 (7.9)	33 (10.1)	40 (12.2)
Globe Valve, Fully Open	16 (4.9)	21 (6.4)	26 (7.9)	39 (11.9)	45 (13.7)	55 (16.8)	67 (20.4)	82 (25.0)	110 (33.5)	140 (42.7)	165 (50.3)
Angle Valve, Fully Open	8.3 (2.5)	11.5 (3.5)	15 (4.6)	18 (5.5)	22 (6.7)	27 (8.2)	33 (10.1)	41 (12.5)	53 (16.2)	70 (21.3)	85 (25.9)
Gate Valve, Fully Open	0.4 (0.1)	0.5 (0.2)	0.6 (0.2)	0.8 (0.2)	1.0 (0.3)	1.2 (0.4)	1.4 (0.4)	1.7 (0.5)	2.3 (0.7)	2.9 (0.9)	3.5 (1.1)

Table 6–3. Equivalent Lengths of Pipe Fittings and Valves in Feet (Meters)[8].

General Requirements for All Non–Factory Supplied Cooling Systems

Regardless of the type of system installed at the generator site to cool the set, the following requirements and recommendation apply. The first design requirement is to limit the engine coolant outlet temperature to the "Maximum Top Tank Temperature" listed

[8] Cummins employees can access Cummins Technical Report 9051–2005–005 for documentation of these values.

on the **Generator Set Data Sheet**. “Heat Rejection to Coolant” and “Coolant Flow Rate” values are also listed on the **Generator Set Data Sheet**, and all of this information will be required to specify an appropriate radiator or heat exchanger.

- System shall be designed to limit the engine coolant outlet temperature to the “Maximum Top Tank Temperature” listed on the **Generator Set Data Sheet**.
- Low Temperature Aftercooling (LTA) systems shall satisfy the aftercooler circuit requirements listed on the **Generator Set Data Sheet**.
- There shall always be positive coolant head on the engine coolant pump. Negative pressure can lead to cavitation and failure.
- Add electrical loads for the remote radiator fan, ventilating fans, coolant pumps and other accessories to the total load requirement of the generator set.
- Design the system for 115% cooling capability to account for system degradation. When cleaned according to manufacturer’s recommended methods and frequency, a capacity of 100% should always be available. This is particularly important for generator sets installed in dusty / dirty environments.

IEC 801.... Volta...
MIL STD 461C, Part 9 Radiated Emissions (EMI)

Cooling	Standby	Prime
Fan Load, HP (kW)	22.6 (16.9)	22.6 (16.9)
Coolant Capacity with radiator, US Gal (L)	24.0 (90.8)	24.0 (90.8)
Coolant Flow Rate, Gal/min (L/min)	196.0 (741.9)	196.0 (741.9)
Heat Rejection To Coolant, Btu/min (MJ/min)	16350.0 (17.3)	14350.0 (15.2)
Heat Radiated To Room, Btu/min (MJ/min)	6100.0 (6.5)	5540.0 (5.9)
Maximum Coolant Friction Head, psi (kPa)	10.0 (68.9)	10.0 (68.9)
Maximum Coolant Static Head, ft (m)	60.0 (18.3)	60.0 (18.3)

Air		
Combustion Air, scfm (m^3/min)	1517.0 (42.9)	1455.0 (41.2)
Alternator Cooling Air, scfm (m^3/min)	4156.0 (117.6)	4156.0 (117.6)
Radiator Cooling Air, scfm (m^3/min)	27200.0 (769.8)	27200.0 (769.8)
Max. Static Restriction, in H_2O (Pa)	0.5 (124.5)	0.5 (124.5)

Rating Definitions

...dby **Rating based on:** Applicable for supplying emergency power for the duration of normal power interruption. No ... load capability is available for this rating. (Equivalent to Fuel St... ...er in accordan... ...304... ...2789,

Figure 6–22. DFXX Generator Set Specification Sheet showing ’Coolant Flow Rate’

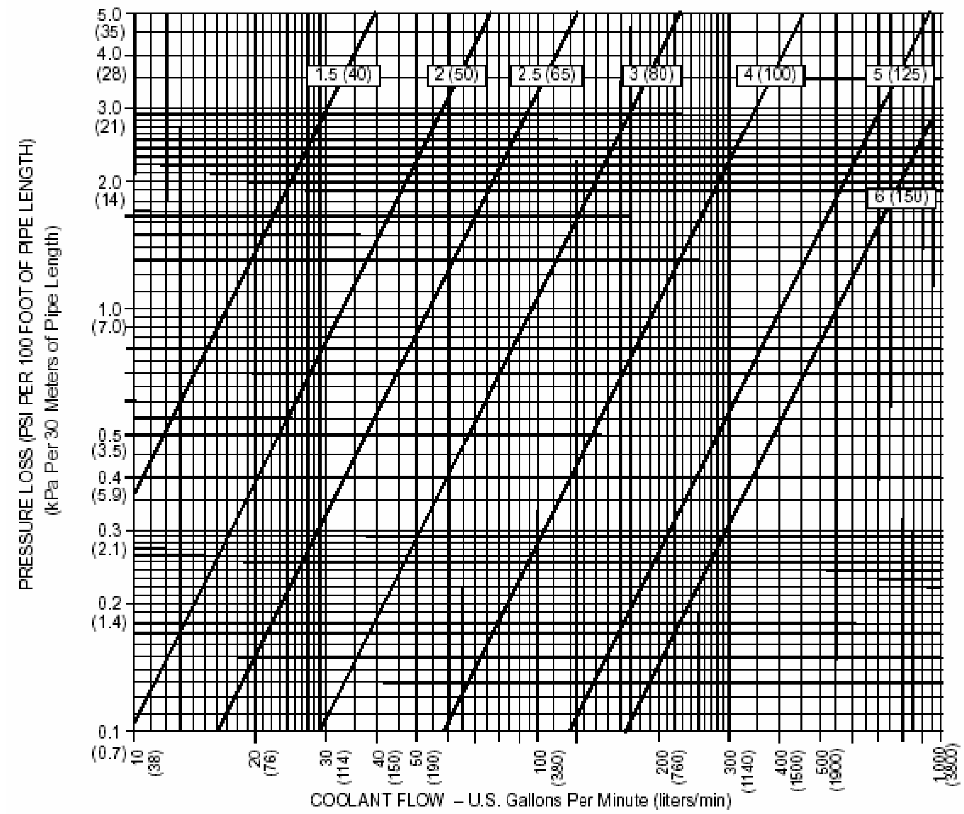


Figure 6–23. Frictional Pressure Losses For Inch (Mm) Diameter Pipes[9]

System Connections and Plumbing

Properly plumbing the remote cooling package to the engine is critical. The coolant must be able to flow freely through all piping and radiator / heat exchanger equipment external to the engine jacket. The friction or resistance generated by this flow is very important because it impairs engine coolant pump performance and the coolant flow through the engine jacket. The **Generator Set Data Sheet** shows engine coolant flow at two separate external restrictions. This is to show the system designer the relationship between coolant flow and external restriction, and takes some "guesswork" out of the design process. The following requirements apply.

- Maximum allowable values for coolant static and friction head shall not be exceeded. See **Determining the Remote Cooling Strategy to Use**, page 6–30.
- Coolant piping external to the engine shall be of equal or larger diameter than the engine inlet and outlet connections.
- External coolant piping and connections shall be cleaned before connecting to the generator set.
- Consideration shall be given for thermal expansion of coolant pipes/tubes.
- Coolant lines shall be appropriately designed rigid steel tubing or Schedule 40 pipe (with the exception of the connection requirements detailed below).
- Connections between generator set and remote system shall be designed to accommodate coolant pressures and temperatures.

[9] Cummins employees can access Cummins Technical Report 9051–2005–004 for documentation of these values.

- Connections shall also withstand vibration due to engine operation and movement during start–up and shutdown. Flexible stainless steel connections or double–clamped hoses should be used.
- Where used, connection hose shall conform to SAE J20R1 or equivalent and be rated for at least 75 psi (518 kPa) burst pressure and –40 °F (–40 °C) to 250 °F (121 °C). 100 psi (691 kPa) burst pressure capability is recommended for overhead radiator applications.
- Connection hose on the suction side of the engine coolant pump shall resist collapse. SAE J20R1 hose meets this requirement for heavy–duty diesel engines.
- Coolant hose connections shall be secured with T–bolt or constant torque clamps. Worm screw–type clamps are unacceptable. If rigid steel tubing is used, it must be beaded.

Remote Radiator

The application of a remote radiator to cool the generator set requires careful design. See **Figure 6–24** for an example system with a vertically mounted radiator, and **Figure 6–25** for a horizontal radiator.

Radiator location has a significant effect on performance. For example, rooftop (sand, parking lot, etc.) temperatures can be significantly hotter than the temperature given in local weather reports, and this must be considered. The radiator air–on–core temperature is often different than the ambient air temperature. (See **Altitude and Ambient Temperature**, page 6–45.)

The direction of prevailing winds must also be considered. Wind walls may be necessary to keep wind from opposing the cooling fan airflow. With rooftop installations, winds can be very strong and unpredictable due to neighboring structures.

Installation site conditions must be considered when selecting a radiator. Radiator cores with a high number of fins per inch are unacceptable for dirty (dusty, sandy, etc.) environments. Debris can easily be trapped in radiator cores with tight fin spacing, negatively impacting radiator performance. Wider fin spacing will allow sand, small dirt particles, etc. to pass through the core without becoming trapped.

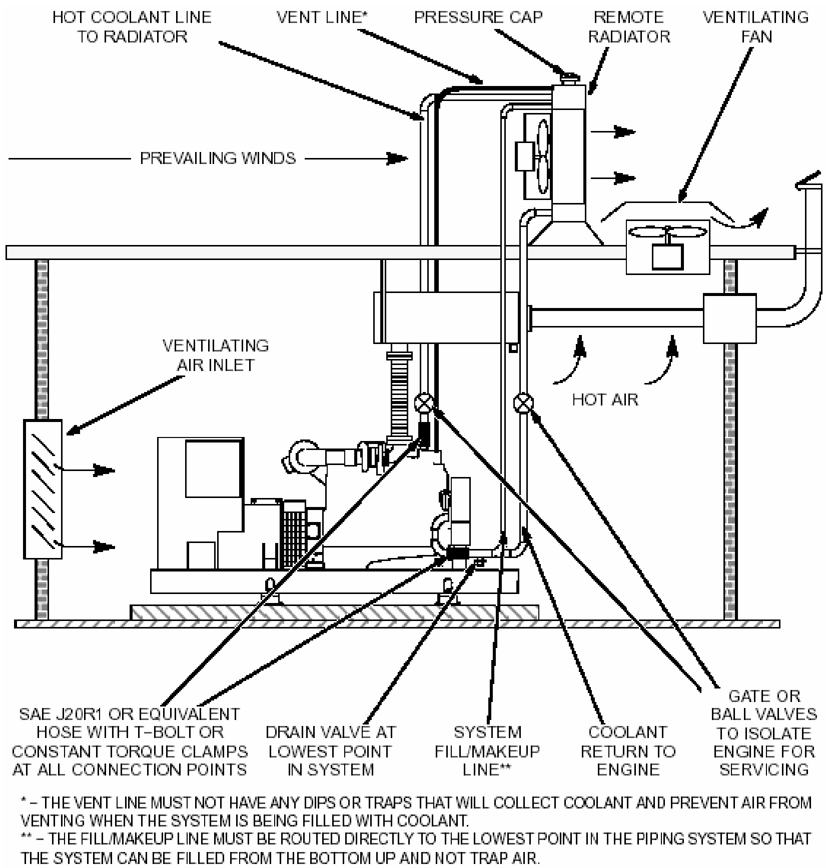


Figure 6–24. Typical Remote Radiator System

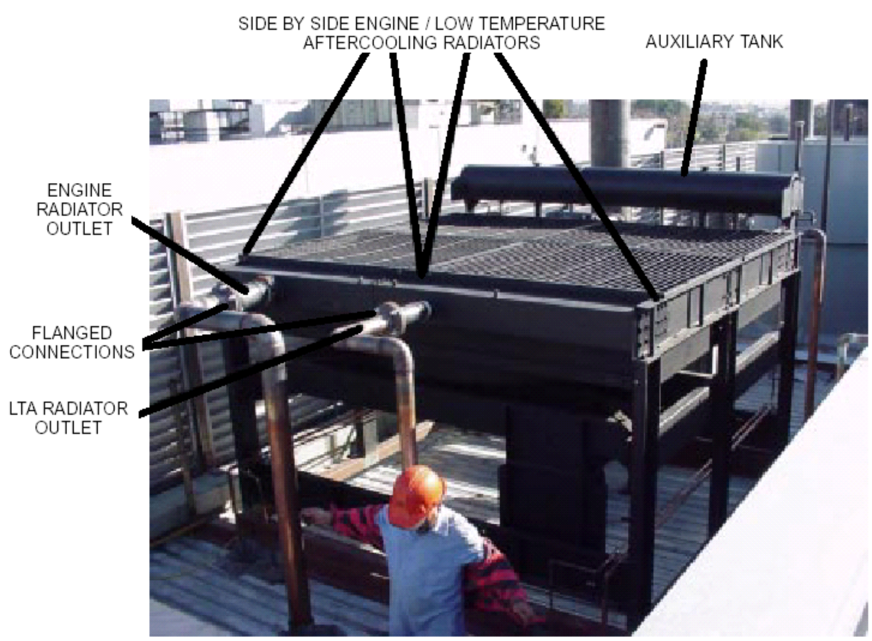


Figure 6–25. Horizontal remote radiator example.

Remote Heat Exchanger

A remote heat exchanger may be used as an alternative to installing a remote radiator. The details and requirements are the same as for a set–mounted heat exchanger. See **Set–Mounted Heat Exchanger,** page 6–28.

Dual Heat Exchanger Systems

Dual heat exchanger systems (see **Figure 6–26**) are recommended only when absolutely necessary to isolate the remote cooling system from the engine in situations where the static head limitations on the engine coolant pump are exceeded. These systems are difficult to design and implement, especially if a radiator is used to cool the heat exchanger raw water. In these situations, the radiator might be significantly larger than expected, and the factory–mounted heat exchanger will most likely be inadequate.

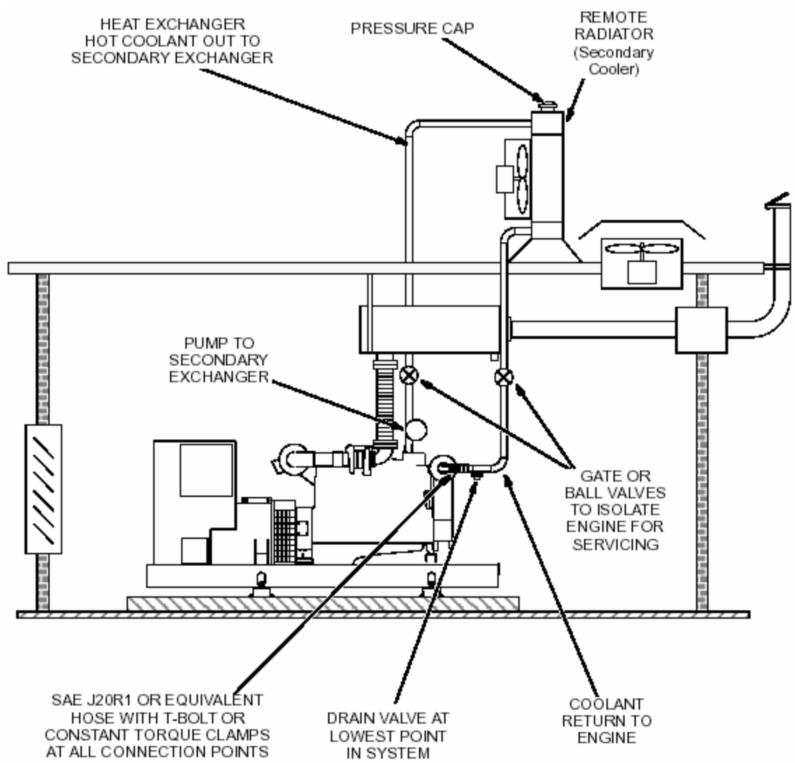


Figure 6–26. Dual Heat Exchanger System (with secondary remote radiator)

Deaerating Tank Requirements

Air entrained in the coolant can cause serious problems:

- Air accelerates erosion of water passages which in turn causes heat transfer and internal flow problems. These problems increase the likelihood of liner scoring, ring wear, and cylinder head cracking.
- Air in the system reduces the amount of heat transferred to the coolant.
- The air expands more than the coolant when heated and may cause loss of coolant from the system.
- In extreme cases air may cause loss of coolant pump prime resulting in major engine damage.

Normal generator set operation will introduce some air into the cooling system. Additional sources of air / exhaust in the cooling system include:

- Improper venting

- Turbulence in the deaerating tank
- Defective gaskets
- Faulty coolant pump seal
- Leaky injector sleeves.
- System shall visibly clear itself of entrained air within 25 minutes of running time after system fill.

Positive deaerating cooling systems utilize a sealed tank to provide an area for coolant deaeration. For details on which generator sets require a positive deaerating system, contact the local Cummins distributor for access to the appropriate Application Engineering Bulletin(s).

Deaerating tanks are used to remove entrained air from the system. These tanks function through bypassing a portion of the total coolant flow to a relatively non–turbulent area where the air separates from the coolant. Coolant from this area is then returned to the system to replace the bypassed coolant.

When a conventional downflow radiator is installed, common practice is to use an integral deaerating tank (also commonly referred to as a top tank) similar to **Figure 6–27** and **Figure 6–28**.

Installations can also use a non–integral deaerating tank (also commonly referred to as an auxiliary tank) to deaerate the coolant. A non–integral dearating tank system is shown in **Figure 6–29**.

- Deaerating tank shall be located at the highest point in the cooling system.
- Tank shall be equipped with: fill / pressure cap, means for filling at highest point, low coolant level shutdown switch (for 9 liter engines and above). The low coolant level shutdown switch will help minimize damage should the cooling system lose system pressure.
- Tank capacity shall be at least 17% of the total coolant volume in the system.
- Deaerating tank should have a sight glass to show the system coolant level.

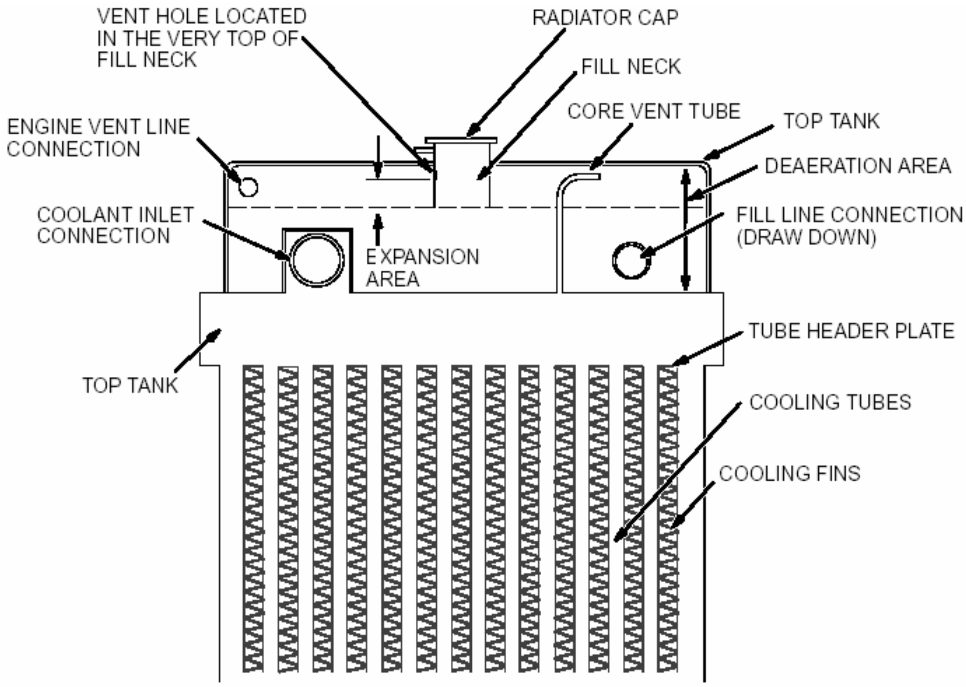


Figure 6–27. Typical Integral Deaerating Tank Configuration

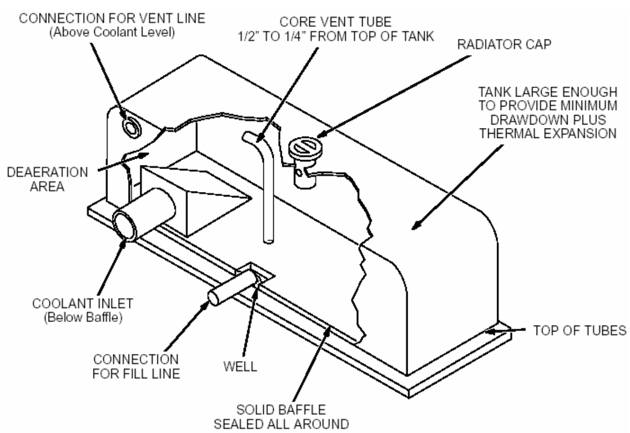


Figure 6–28. Typical Integral Deaerating Tank Configuration (radiator core omitted)

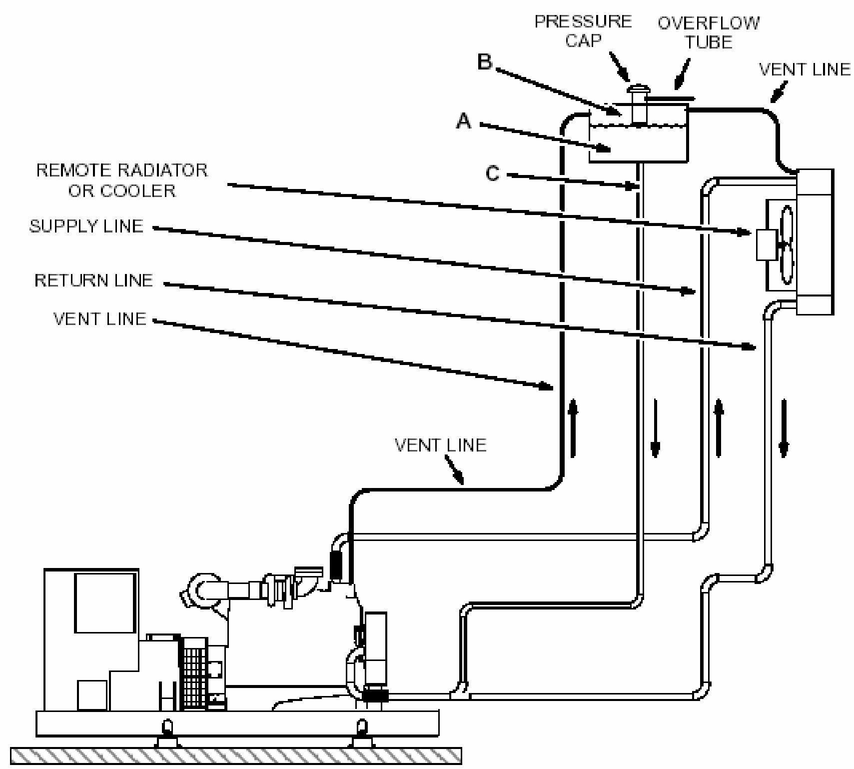


Figure 6–29. Remote Radiator System With Non–integral Deaerating Tank

Drawdown and Expansion

The deaerating tank capacity must be at least 17% of the total coolant volume in the system. This provides coolant drawdown capacity of 11%, plus 6% for thermal expansion.

Drawdown capacity is the amount of coolant that can be lost from the system before air will be drawn into the engine coolant pump.

The system must be designed so that when completely filled cold there is at least a 6% additional capacity to allow for thermal expansion. This extra volume is defined by proper location of the fill neck. See the “Expansion Area” in **Figure 6–27**. The bottom of the fill neck defines the top of the coolant level during cold–fill. The space between the underside of the roof of the tank and the bottom of the fill neck is the volume available for coolant expansion. A hole through the fill neck provides a path for vapor to escape out of the pressure cap as the coolant expands. Without the hole, coolant expands up the fill neck and out of the radiator cap.

- Fill neck shall have a minimum 0.125 inch (3 mm) diameter hole through one side, located as close as possible to the top of the tank.

Venting

System venting serves two important functions:

- Venting of air from the engine during fill
- Continual removal of air during generator set operation.

- Engine coolant jacket and any high points in the system plumbing shall be vented to the deaerating tank.
- Generator set installation drawing shall be consulted for coolant jacket vent locations and connection sizes.
- Vent lines shall be connected to the deaerating tank above the coolant level.
- Lines shall run continuously uphill to the deaerating tank. Loops / sags will cause air locks and are unacceptable.
- Lines shall not be pinched or constricted anywhere along their path.
- For systems requiring multiple vent lines, they may not be teed together. Dedicated connection points shall be provided for each line.
- If venting valves that vent to atmosphere are used, drawdown capacity shall be increased from 11% to 14% (total tank capacity increased from 17% to 20%).
- For vent line sizes not specified on the generator set installation drawing, it is recommended to use #4 hose (.25” ID – 6.35 mm ID) for vent lines less than 12 feet (3.7 m) in length. Use #6 hose (.375” ID – 9.5 mm ID) for vent lines greater than 12 feet (3.7 m) in length).

Venting valves that vent to atmosphere are sometimes used in applications where it is difficult to run the vent line upward all the way to the deaerating tank. Drawdown capacity must be increased when using this type of venting valve~~s are used~~ because the valves lose some coolant during operation.

Filling

Proper filling is critical to help prevent air locks. The installation of a fill line will permit the system to be filled from the bottom–up, and will help reduce the risk of entraining air during system fill.

- System shall be capable of initial fill to at least 90% capacity at a minimum rate of 5 gpm (20 L/min), then topped off to 100%.
- System shall be equipped with a fill line:
  - Line shall be routed directly from bottom of deaerating tank to straight section of engine coolant pump inlet piping near the engine.
  - Line shall have a continual rise from engine inlet pipe to deaerating tank.
  - No other lines may be connected to fill line.

Engines with a coolant flow rate less than 200 gal/min (757 L/min) usually use a connection of about 0.75 in (19 mm) ID. Engines with a coolant flow rate greater than 200 gal/min (757 L/min) use lines 1 to 1.5 in (25 mm to 38 mm) ID. These are given as general guidelines only. The installation must be checked for ability to fill in the time specified above. If the line is improperly sized or routed, the system will not fill properly. Reverse flow up the line may cause overflow of the deaerating tank.

System Cleanliness

Any foreign material in the system will degrade cooling performance and could result in major generator set damage.

- External coolant piping and connections shall be cleaned before connecting to the generator set.

Fuel Cooling

Many generator sets require the use of a fuel cooling system to maintain required fuel inlet temperatures. Consult the **Generator Set Data Sheet** to determine whether or not a fuel cooler is required, and for design requirements that will aid in cooler selection. If required, it must be accommodated in the cooling system design, and will add complexity to the system. It is often impractical or against code to pipe fuel to the remote cooling location. Two possibilities for handling the fuel cooling requirements:

- Include a fuel cooling radiator and fan within the generator set space and account for the heat rejection in the room ventilation design.
- Utilize a heat exchanger fuel cooler with a remote radiator or separate water supply for the coolant side.

Interconnection of Cooling Systems

For installation sites with multiple generator sets, it is unacceptable for more than one set to share a “central” cooling system.

- Each generator set shall have its own dedicated complete cooling system. Do not manifold multiple generator sets to a common cooling system.

Coolant

- Mixtures of either ethylene– or propylene–glycol and high–quality water shall be used for proper cooling and freeze / boil protection.
- Supplemental coolant additives (SCAs) are required for engines equipped with cylinder liners.

Generator sets must not be cooled by untreated water, as this will cause corrosion, cavitation, mineral deposits, and improper cooling. Mixtures of ethylene– or propylene–glycol and high–quality water must be used. For specific water quality requirements and other coolant details, see the latest version of “Cummins Coolant Requirements and Maintenance” service bulletin #3666132.

See **Table 6–4** for freezing and boiling point comparisons of different concentrations of coolant mixtures. Note that boiling temperatures increase with increasing system pressure. Pure water is included in this table for reference. Propylene–glycol based antifreeze is less toxic than ethylene based antifreeze while providing equivalent cooling system performance. However, as indicated in **Table 6–4**, it offers slightly less freeze / boil protection.

Property	Ethylene Glycol (% by Volume)			Propylene Glycol (% by Volume)			Pure Water
Glycol Concentration	40	50	60	40	50	60	0
Freezing Point °F (°C)	–12 (–24)	–34 (–37)	–62 (–52)	–6 (–21)	–27 (–33)	–56 (–49)	32 (0)
Boiling Point °F (°C) at Atmospheric Pressure	222 (106)	226 (108)	232 (111)	219 (104)	222 (106)	225 (107)	212 (100)
Boiling Point °F (°C) with 14 psi (96.5 kPa) Pressure Cap	259 (126)	263 (128)	268 (131)	254 (123)	257 (125)	261 (127)	248 (120)

Table 6–4. Antifreeze Mixture Properties

Coolant Heaters

Thermostatically controlled engine coolant heaters are used to improve starting and load acceptance. See **Figure 6–30**. As shown in **Figure 6–30**, a heater isolation valve can be installed to prevent draining the entire system of coolant for performing heater maintenance. If such a valve is installed, it shall only be closed for isolating the heater for maintenance. The valve must be locked open at all other times.

Local codes may require the installation of coolant heaters for generator sets used in emergency or standby applications. For example, in the US, NFPA 110 requires that engine coolant for Level 1 emergency power systems be kept at a minimum of 90 °F (32 °C). NFPA 110 also requires the installation of a low engine temperature alarm.

- Coolant heaters shall be installed in emergency / standby applications to ensure good engine starting (optional in tropical locations unless mandated by local ordinance).
- There shall be no loops in the coolant heater hose routing, and the hose shall run continuously uphill.
- Coolant heater connections shall be made using high quality silicon or braided hose.
- The coolant heater shall be disabled while the generator set is running.

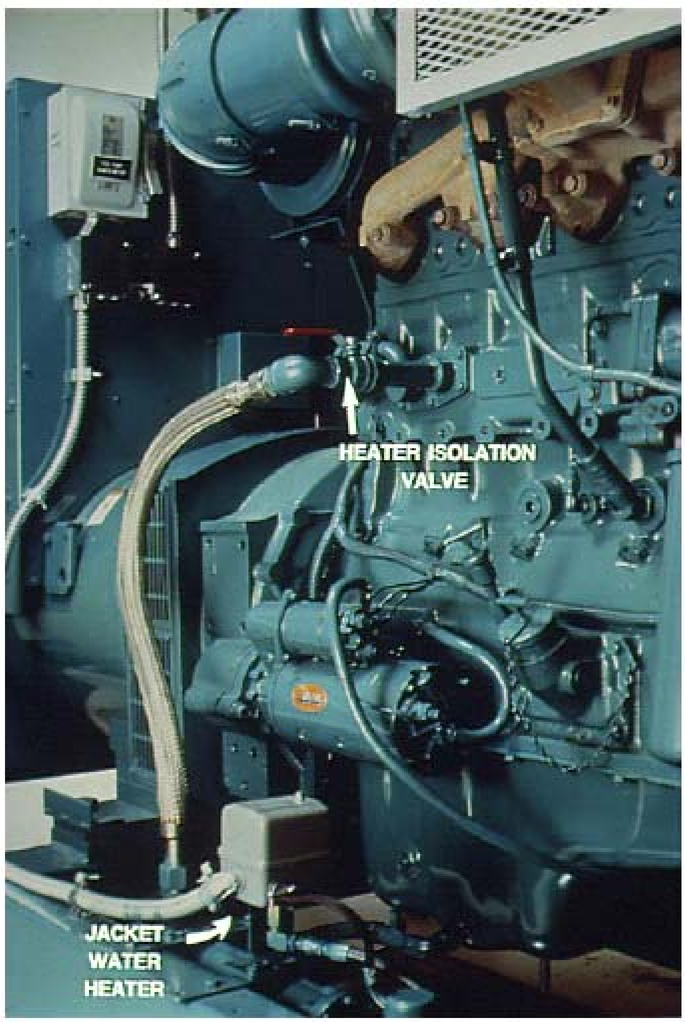


Figure 6–30. Coolant Heater Installation (note heater isolation valve, hose type, and hose routing)

Altitude and Ambient Temperature

Installation site altitude and temperature affect the density of the air surrounding the generator set, which in turn affects engine, alternator, and cooling system performance.

- The cooling system shall be designed to accommodate installation site altitude and ambient temperature.

The density of air decreases as altitude increases. This decrease in density may lead to problems achieving the required airflow and could force a system de–rate.

At high altitudes, reduced atmospheric pressure lowers coolant boiling temperatures. A higher–rated pressure cap may be required. See **Figure 6–31** for an example of altitude / system pressure effects on water. Effects on coolant mixtures are similar.

The system must be able to provide sufficient cooling at full load, even under maximum ambient temperature conditions. If a factory–supplied cooling system is installed, the suitability of this system at the site altitude and ambient temperature must be confirmed.

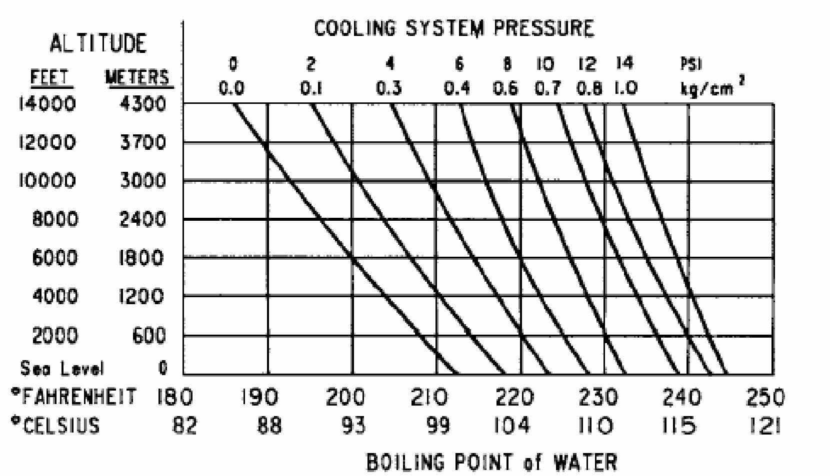


Figure 6–31. Water Boiling Temperature As A Function Of Altitude And System Pressure

It is important to understand the definition of ambient temperature and what it means for cooling system design and performance. For an open installation of a generator set (i.e. not installed in a container or housing) with a factory–supplied radiator, the ambient temperature is defined as the average temperature measured 3 feet off the corners of the generator end of the set (at 45°) and 3 feet off the floor. For housed or containerized sets, the ambient temperature is typically measured at the air inlet to the enclosure. Note that the air flowing through the radiator may be significantly warmer than this ambient temperature. Air temperature will increase as it flows into the room and across the set from rear to front (alternator end to radiator end). For this reason, many factory–supplied radiators are designed for an air–on–core temperature of 15 – 30 °F (8 – 17 °C) higher than the cooling package's rated ambient temperature. See **Figure 6–32** for a representation of the difference between ambient temperature and air–on–core temperature for a factory–supplied radiator cooling package.

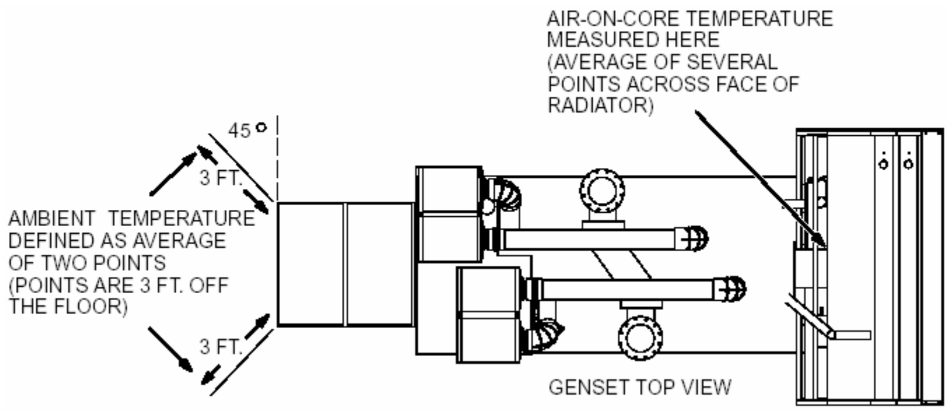


Figure 6–32. ”Ambient” vs. ”Air–on–Core” Temperature

For non–factory–supplied radiators, the critical temperature is the air–on–core temperature. The radiator should be selected to satisfy the cooling requirements at this air–on–core temperature, which can be significantly higher than the ambient temperature discussed above. It is the system designer's responsibility to ensure that this occurs. Note that the air–on–core temperature should be an average of several temperatures from different areas of the radiator face to avoid “hot” or “cold spots”. The air at the center of the face of the radiator, for example, may be significantly warmer than air near the edges of the radiator face.

In cold climates, coolant heaters can be used to improve starting and load acceptance. See **Coolant Heaters**, page 6–44.

For additional details regarding the effects of altitude and temperature on generator set operation, see the **Ambient Conditions** section of this manual.

System Limiting Ambient Temperature (LAT)

The cooling system's Limiting Ambient Temperature (LAT) is the ambient temperature up to which adequate cooling can be provided for the generator set running continuously at rated power. At ambient temperatures above LAT, the maximum top tank temperature listed on the **Generator Set Data Sheet** will eventually be exceeded if the generator set continues to be operated at full power.

For factory–supplied radiator systems, the LAT is listed as a function of airflow restriction on the **Generator Set Data Sheet**. For non–factory–supplied systems, contact the local Cummins distributor for access to the appropriate AEB(s) that discuss test procedures for determining system LAT.

Alternator Cooling

The alternator requires a steady flow of fresh ventilation air to avoid overheating. See the **Ventilation** section of this manual for details.

Cooling System Fouling

The radiator and other sensitive equipment shall be protected from dirt and debris. Dirty systems will not operate at peak efficiency, leading to poor generator set performance and fuel economy.

The radiator must be protected from dirt and debris as well as crankcase breather vapors that could foul or plug the radiator core. See the **Ventilation** section of this manual for additional details regarding filtration and engine crankcase ventilation.

Serviceability

- Valves shall be clearly marked to identify “open” and “closed”.
- Access shall be provided for cleaning and servicing all equipment.

- Drain / isolation valves should be installed to allow service of the generator set without emptying the entire system of coolant.

Drain / isolation provisions are especially important for remote systems. Draining all of the coolant in these systems can be costly. Illustrations throughout **Generator Set Cooling Systems** show locations of drains and isolation valves typically used in application. Note that all valves must be returned to operational mode once servicing is complete.

Access for cleaning / servicing should allow the removal of the radiator core. On some sets, this will require access for large equipment that may be necessary for core removal.

Mobile Applications

- For mobile applications, special consideration shall be given to equipment durability and robustness.

Mobile applications present unique challenges that do not exist in stationary generator set installations. Vibrations inherent to mobile applications can transmit forces to the generator set that can damage equipment. The radiator, coolant piping and hose connections, and other equipment must be designed and specified to withstand these forces. For additional details, see the **Special Applications – Mobile** section of this manual.

Engine Cooling

Cooling systems for reciprocating engine–driven generator sets have the following common characteristics, regardless of the heat exchanger used, to remove heat from the engine. These include:

- The engine portion of the cooling system is a closed, pressurized (10–14 psi/69.0–96.6 kPa) system that is filled with a mixture of clean, soft (demineralized) water, ethylene or propylene glycol, and other additives. Engines should not be directly cooled by untreated water, since this will cause corrosion in the engine and potentially improper cooling. The “cold” side of the cooling system can be served by a radiator, heat exchanger, or cooling tower.
- The engine cooling system must be properly sized for the ambient and components chosen. Typically the top tank temperature of the system (temperature at the inlet to the engine) will not exceed 220° F (104° C) for standby applications, and 200° F (93° C) for prime power installations.
- The cooling system must include deaeration and venting provisions to prevent build-up of entrained air in the engine due to turbulent coolant flow, and to allow proper filling of the engine cooling system. This means that in addition to the primary coolant inlet and outlet connections, there are likely to be at least one set of vent lines terminated at the “top” of the cooling system. Consult the engine manufacturer’s recommendations for the specific engine used for detailed requirements[10]. See **Figure 6–33** for a schematic representation of the cooling and vent lines on a typical engine.
- A thermostat on the engine typically is used to allow the engine to warm up and to regulate engine temperature on the “hot” side of the cooling system.
- The cooling system design should account for expansion in the volume of coolant as the engine temperature increases. Coolant expansion provisions for 6% over normal volume is required.

10 Requirements for venting and deaeration of specific Cummins engines are found in Cummins documents AEB.

- The system must be designed so that there is always a positive head on the engine coolant pump.
- Proper flows for cooling depend on minimizing the static and friction head on the engine coolant pump. The generator set will not cool properly if either the static or friction head limitations of the coolant pump are exceeded. Consult the engine manufacturer for information on these factors for the specific generator set selected. See Cooling Pipe Sizing Calculations in this section for specific instruction on sizing coolant piping and calculating static and friction head.
- Engine and remote cooling systems should be provided with drain and isolation provisions to allow convenient service and repair of the engine. See example drawings in this section for locations of drains and valves typically used in various applications.

Skid–Mounted Radiator

A generator set with a skid–mounted radiator (**Figure 6–34**) is an integral skid–mounted cooling and ventilating system. The skid–mounted radiator cooling system is often considered to be the most reliable and lowest cost cooling system for generator sets, because it requires the least amount of auxiliary equipment, piping, control wiring, and coolant, and minimizes work to be done at the jobsite on the generator set cooling system. The radiator fan is usually mechanically driven by the engine, further simplifying the design. Electric fans are used in some applications to allow more convenient control of the radiator fan based on the temperature of the engine coolant. This is particularly useful in severely cold environments.

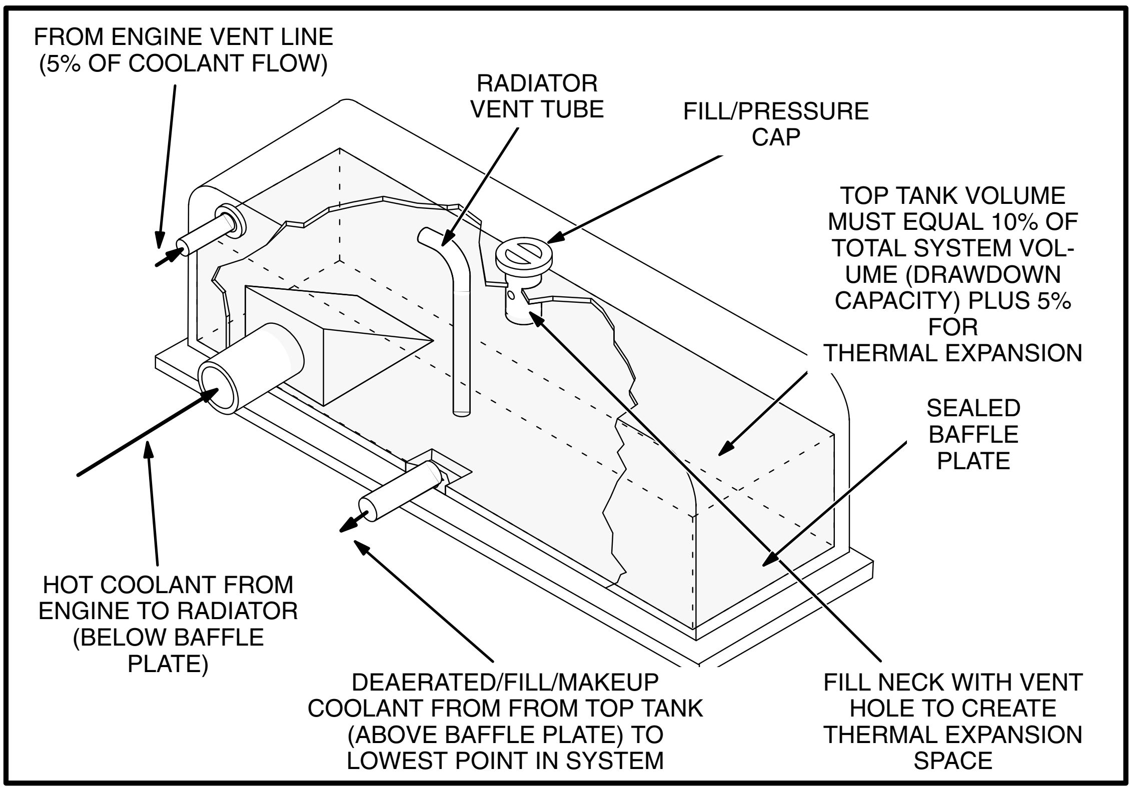


Figure 6–33. Deaeration Type of Radiator Top Tank

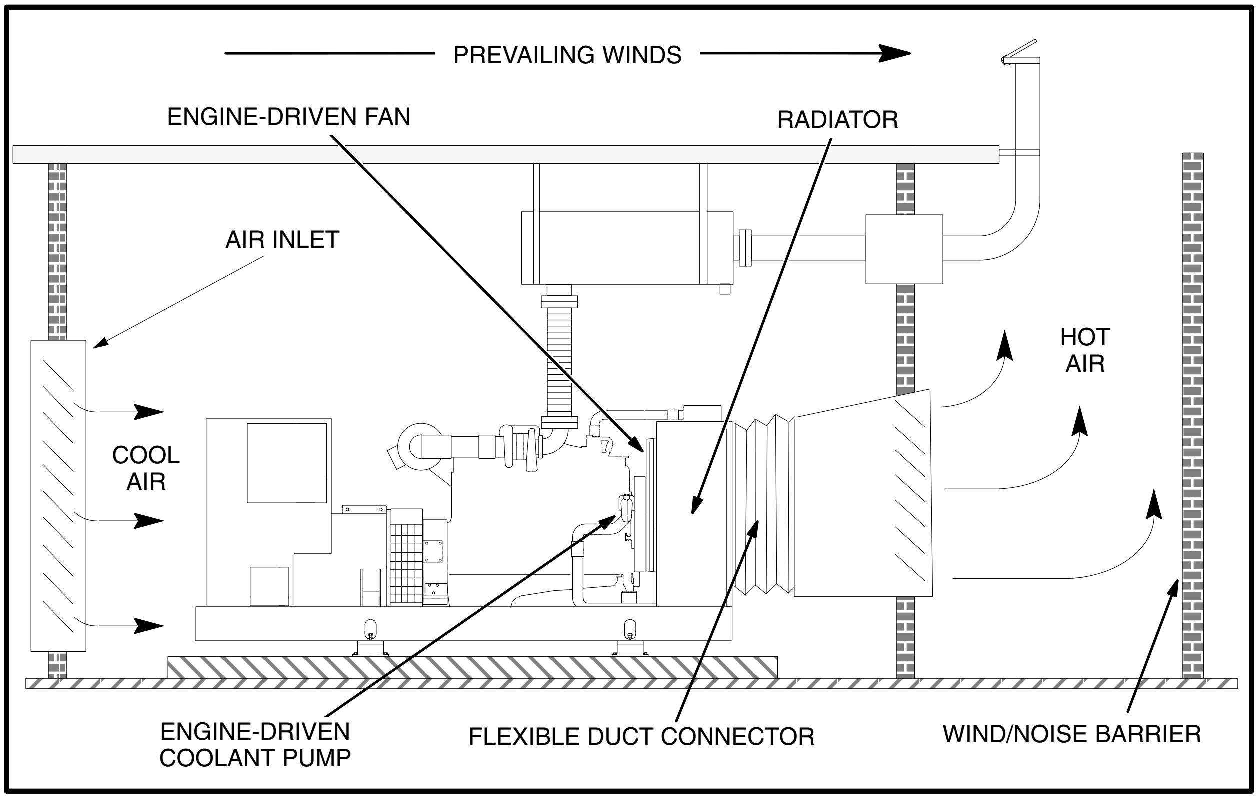


Figure 6–34. Factory-Mounted Radiator Cooling

Since the genset manufacturer typically designs skid–mounted cooling systems, the system can be prototype tested to verify the overall performance of the system in a laboratory environment. An instrumented, controlled, laboratory environment is useful in easily verifying the performance of a cooling system. Often physical limitations at a project site can limit the accuracy or practicality of design verification testing.

The major disadvantage of the skid–mounted radiator is the requirement to move a relatively large volume of air through the generator room, since the air flow through the room must be sufficient for evacuating heat radiated from the generator set and for removing heat from the engine coolant. See Ventilation in this section for details of ventilation system design and calculations related to ventilation system design. The engine fan will often provide sufficient ventilation for the equipment room, eliminating the need for other ventilating devices and systems.

Remote Radiator

Remote radiator systems are often used when sufficient ventilation air for a skid–mounting cooling system can not be provided in an application. *Remote radiators do not eliminate the need for generator set room ventilation, but they will reduce it.* If a remote radiator cooling system is required, the first step is to determine what type of remote system is required. This will be determined by calculation of the static and friction head that will be applied to the engine based on its physical location.

If calculations reveal that the generator set chosen for the application can be plumbed to a remote radiator without exceeding its static and friction head limitations, a simple remote radiator system can be used. See **Figure 6–35.**

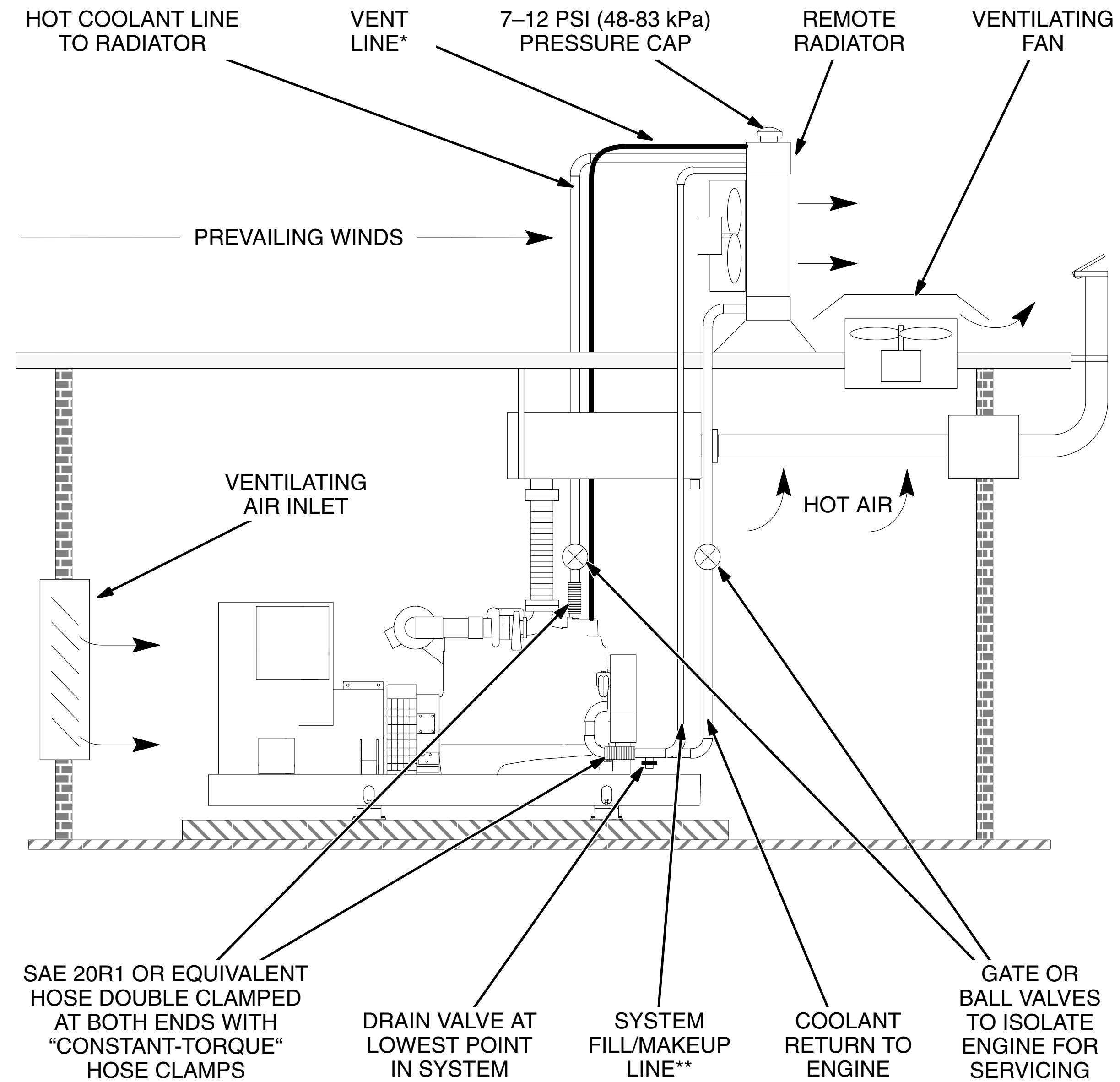
If the friction head is exceeded, but static head is not, a remote radiator system with auxiliary coolant pump can be used. See **Figure 6–33** and Remote Radiator With Auxiliary Coolant Pump, in this section.

If both the static and friction head limitations of the engine are exceeded, an isolated cooling system is needed for the generator set. This might include a remote radiator with hot well, or a liquid–to–liquid heat exchanger–based system.

Whichever system is used, application of a remote radiator to cool the engine requires careful design. In general, all the recommendations for skid mounted radiators also apply to remote radiators. For any type of remote radiator system, consider the following:

- It is recommended that the radiator and fan be sized on the basis of a maximum radiator top tank temperature of 200° F (93° C) and a 115 percent cooling capacity to allow for fouling. The lower top tank temperature (lower than described in Engine Cooling) compensates for the heat loss from the engine outlet to the remote radiator top tank. Consult the engine manufacturer for information on heat rejected to the coolant from the engine, and cooling flow rates[11].
- The radiator top tank or an auxiliary tank must be located at the highest point in the cooling system. It must be equipped with: an appropriate fill/pressure cap, a system fill line to the lowest point in the system (so that the system can be filled from the bottom up), and a vent line from the engine that does not have any dips or traps. (Dips and overhead loops can collect coolant and prevent air from venting when the system is being filled.) The means for filling the system must also be located at the highest point in the system, and a low coolant level alarm switch must be located there.
- The capacity of the radiator top tank or auxiliary tank must be equivalent to at least 17 percent of the total volume of coolant in the system to provide a coolant “drawdown capacity” (11percent) and space for thermal expansion (6 percent). Drawdown capacity is the volume of coolant that can be lost by slow, undetected leaks and the normal relieving of the pressure cap before air is drawn into the coolant pump. Space for thermal expansion is created by the fill neck when a cold system is being filled. See **Figure 6–33.**

11 Information on Cummins Power Generation products is provided in the Cummins Power Suite.



* – THE VENT LINE MUST NOT HAVE ANY DIPS OR TRAPS THAT WILL COLLECT COOLANT AND PREVENT AIR FROM VENTING WHEN THE SYSTEM IS BEING FILLED WITH COOLANT.

** – THE FILL/MAKEUP LINE MUST BE ROUTED DIRECTLY TO THE LOWEST POINT IN THE PIPING SYSTEM SO THAT THE SYSTEM CAN BE FILLED FROM THE BOTTOM UP AND NOT TRAP AIR.

Figure 6–35. Remote Radiator Cooling (Deaeration Type System, See **Figure 6–33**)

- To reduce radiator fin fouling, radiators that have a more open fin spacing (nine fins or less per inch) should be considered for dirty environments.

- Coolant friction head external to the engine (pressure loss due to pipe, fitting, and radiator friction) and coolant static head (height of liquid column measured from crankshaft centerline) must not exceed the maximum values recommended by the engine manufacturer[12]. See the example calculation in this section for a method of calculating coolant friction head. If a system configuration cannot be found that allows the engine to operate within static and friction head limitations, another cooling system type should be used.

NOTE: Excessive coolant static head (pressure) can cause the coolant pump shaft seal to leak. Excessive coolant friction head (pressure loss) will result in insufficient engine cooling.

- Radiator hose 6 to 18 inches (152 to 457mm) long, complying with SAE 20R1, or an equivalent standard, should be used to connect coolant piping to the engine to take up generator set movement and vibration.
- It is highly recommended that the radiator hoses be clamped with two premium grade “constant–torque” hose clamps at each end to reduce the risk of sudden loss of engine coolant due to a hose slipping off under pressure. Major damage can occur to an engine if it is run without coolant in the block for just a few seconds.
- A drain valve should be located at the lowest part of the system.
- Ball or gate valves (globe valves are too restrictive) are recommended for isolating the engine so that the entire system does not have to be drained to service the engine.
- Remember that the generator set must electrically drive remote radiator fan, ventilating fans, coolant pumps, and other accessories required for operation in remote cooling applications. So, the kW capacity gained by not driving a mechanical fan is generally consumed by the addition of electrical devices necessary in the remote cooling system. Remember to add these electrical loads to the total load requirement for the generator set.
- See Ventilation General Guidelines and Heat Exchanger or Remote Radiator Applications, both in this section, concerning generator room ventilation when remote cooling is used.

Deaeration Type Remote Radiator System

A deaeration type of radiator top tank (also know as a sealed top tank) or auxiliary tank must be provided. In this system, a portion of the coolant flow (approximately 5 percent) is routed to the radiator top tank, above the baffle plate. This allows air entrained in the coolant to separate from the coolant before the coolant returns to the system. Consider the following:

- Engine and radiator vent lines must rise without any dips or traps that will collect coolant and prevent air from venting when the system is being filled. Rigid steel or high density polystyrene tubing is recommended for long runs, especially if they are horizontal, to prevent sagging between supports.
- The fill/makeup line should also rise without any dips from the lowest point in the piping system to the connection at the radiator top tank or auxiliary tank. No other piping should be connected to it. This arrangement allows the system to be filled from bottom up without trapping air and giving a false indication that the system is full. With proper vent and fill line connections, it should be possible to fill the system at a rate of at least 5 gpm (19 L/Min) (approximately the flow rate of a garden hose).

12 Data for Cummins engines is in the Power Suite.

Remote Radiator with Auxiliary Coolant Pump

A remote radiator with an auxiliary coolant pump (**Figure 6–36**) can be used if coolant friction exceeds the engine manufacturer's maximum recommended value, and static head is within specifications. In addition to the considerations under Remote Radiators, consider the following:

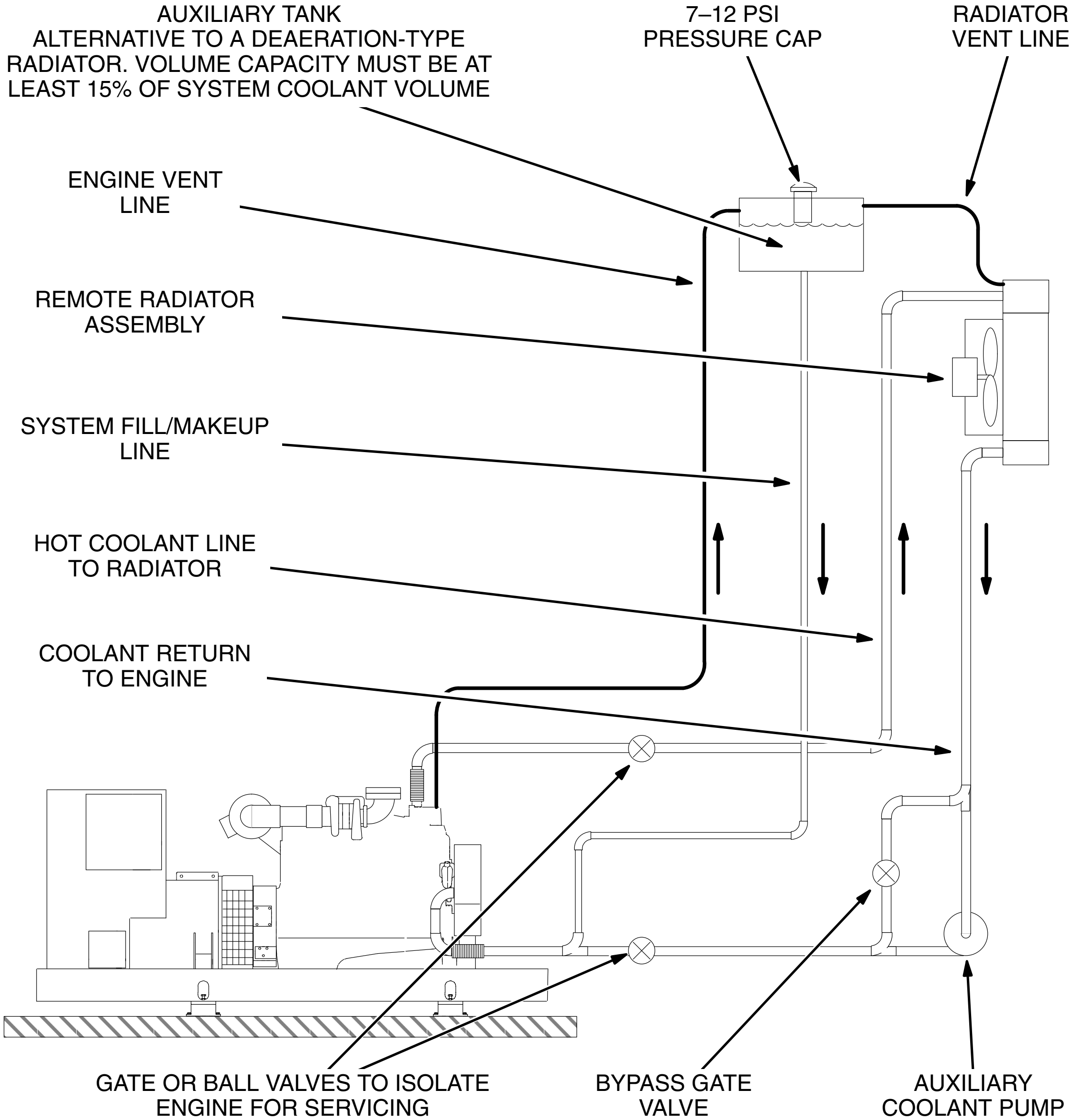


Figure 6–36. Remote Radiator With Auxiliary Coolant Pump and Auxiliary Tank

- An auxiliary pump and motor must be sized for the coolant flow recommended by the engine manufacturer and develop enough pressure to overcome the excess coolant friction head calculated by the method shown in the previous example.

NOTE: One foot of pump head (pump manufacturer's data) is equivalent to 0.43 PSI of coolant friction head (pressure loss) or one foot of coolant static head (height of liquid column).

- A bypass gate valve (globe valves are too restrictive) must be plumbed in parallel with the auxiliary pump, for the following reasons:
  - To allow adjustment of the head developed by the auxiliary pump (the valve is adjusted to a partially–open position to recirculate some of the flow back through the pump).
  - To allow operation of the generator set under partial load if the auxiliary pump fails (the valve is adjusted to a fully open position).
- Coolant pressure at the inlet to the engine coolant pump, measured while the engine is running at rated speed, must not exceed the maximum allowable static head shown on the recommended generator set Specification Sheet. Also, for deaeration type cooling systems (230/200 kW and larger generator sets), auxiliary pump head must not force coolant through the make–up line into the radiator top tank or auxiliary tank. In either case, the pump bypass valve must be adjusted to reduce pump head to an acceptable level.
- Since the engine of the generator set does not have to mechanically drive a radiator fan, there may be additional kW capacity on the output of the generator set. To obtain the **net power** available from the generator set, add the fan load indicated on the generator set Specification Sheet to the power rating of the set. Remember that the generator set must electrically drive the remote radiator fan, ventilating fans, coolant pumps, and other accessories required for the set to run for remote radiator applications. So, the kW capacity gained by not driving a mechanical fan is generally consumed by the addition of electrical devices necessary in the remote cooling system.

Remote Radiator with Hot Well

A remote radiator with a hot well (**Figure 6–37)** can be used if the elevation of the radiator above the crankshaft centerline exceeds the allowable coolant static head on the recommended generator set Specification Sheet. In a hot well system, the engine coolant pump circulates coolant between engine and hot well and an auxiliary pump circulates coolant between hot well and radiator. A hot well system requires careful design.

In addition to the considerations under Remote Radiator, consider the following:

- The bottom of the hot well should be above the engine coolant outlet.
- Coolant flow through the hot well/radiator circuit should be approximately the same as coolant flow through the engine. The radiator and the auxiliary pump must be sized accordingly. Pump head must be sufficient to overcome the sum of the static and friction heads in the hot well/radiator circuit.

NOTE: One foot of pump head (pump manufacturer's data) is equivalent to 0.43 PSI of coolant friction head (pressure loss) or one foot of coolant static head (height of liquid column).

- The liquid holding capacity of the hot well should not be less than the sum of the following volumes:
  - ¼ of the coolant volume pumped per minute through the engine (e.g., 25 gallons if the flow is 100 gpm) (100 liters if the flow is 400 l/min), plus
  - ¼ of the coolant volume pumped per minute through the radiator (e.g., 25 gallons if the flow is 100 gpm) (100 liters if the flow is 400 l/min), plus
  - Volume required to fill the radiator and piping, plus 5 percent of total system volume for thermal expansion.

- Careful design of the inlet and outlet connections and baffles is required to minimize coolant turbulence, allow free deaeration and maximize blending of engine and radiator coolant flows.
- Coolant must be pumped to the bottom tank of the radiator and returned from the top tank, otherwise the pump will not be able to completely fill the radiator.
- The auxiliary pump must be lower than the low level of coolant in the hot well so that it will always be primed.
- The radiator should have a vacuum relief check valve to allow drain down to the hot well.
- The hot well should have a high volume breather cap to allow the coolant level to fall as the auxiliary pump fills the radiator and piping.

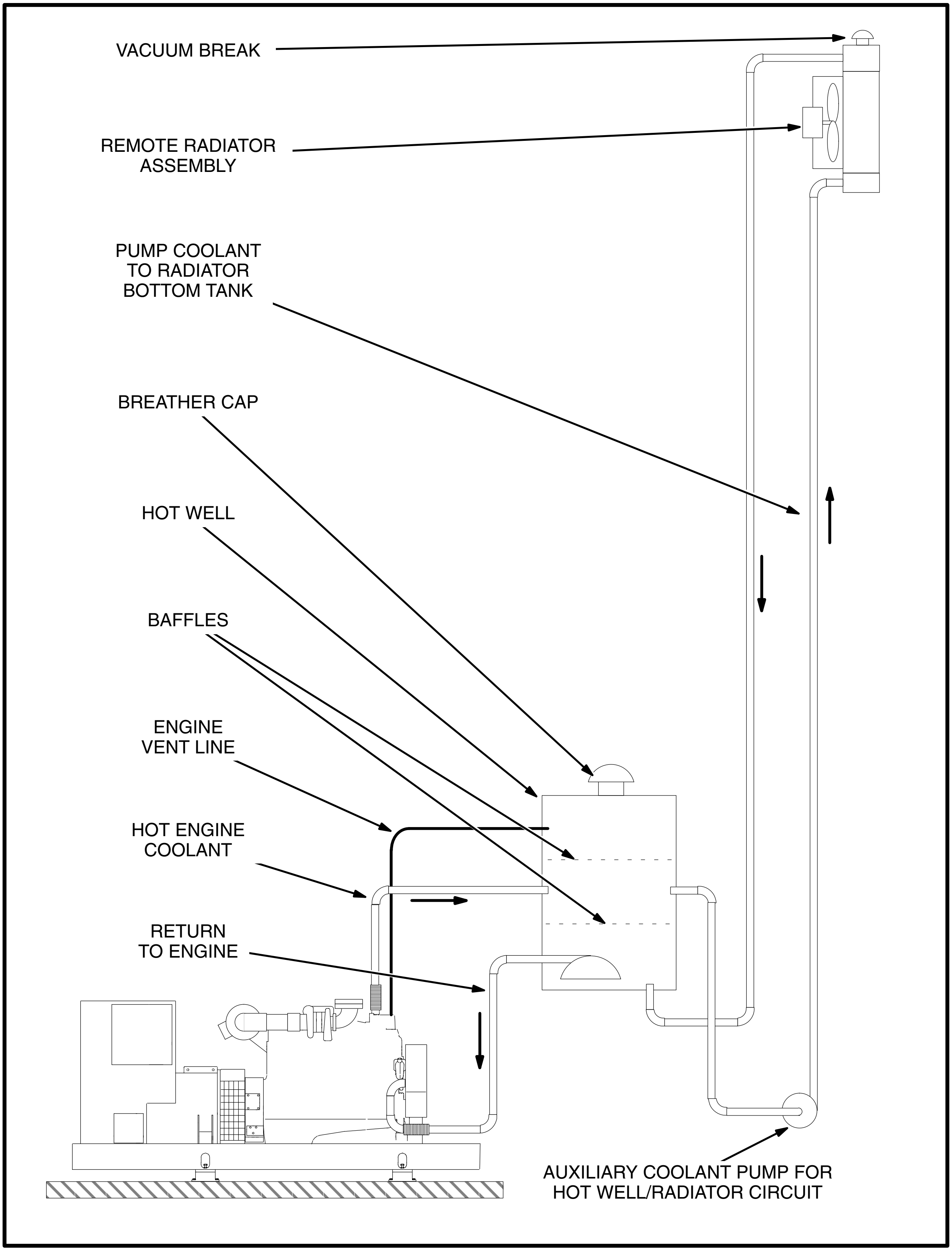


Figure 6–37. Remote Radiator With Hot Well and Auxiliary Coolant Pump

- Remember that the generator set must electrically drive remote radiator fan, ventilating fans, coolant pumps and other accessories required for operation in remote cooling applications. So, the kW capacity gained by not driving a mechanical fan is generally consumed by the addition of electrical devices necessary in the remote cooling system. Remember to add these electrical loads to the total load requirement for the generator set.

Multi–Loop Engine Cooling – Remote Radiators

Some engine designs incorporate more than one cooling loop and therefore require more than one remote radiator or heat exchanger circuit for remote cooling applications. These engines utilize various approaches to achieve Low Temperature Aftercooling (LTA) of the intake air for combustion. A primary reason behind the creation of these designs is their affect on improvement of exhaust emissions levels. Not all of these engine designs however are easily adaptable for remote cooling.

Two–Pump, Two–Loop

A common approach for low temperature aftercooling is to have two complete and separate cooling circuits with two radiators, two coolant pumps and separate liquid coolant for each. One circuit cools the engine water jackets, the other cools the intake combustion air after turbocharging. For remote cooling, these engines require two complete separate remote radiators or heat exchangers. Each will have its own specifications of temperatures, pressure restrictions, heat rejection, etc. that must be met in the remote systems. This data is available from the engine manufacturer. Essentially, two circuits must be designed, each **require** all the considerations of, and **must meet** all the criteria of a single remote system. See **Figure 6–38**.

Note: Radiator placement for the LTA circuit can be critical to achieving adequate removal of heat energy required for this circuit. When the LTA and jacket water radiators are placed back to back with a single fan, the LTA radiator should be placed upstream in the air flow so as to have the coolest air traveling over it.

One–Pump, Two–Loop

Occasionally engine designs accomplish low temperature aftercooling through the use of two cooling circuits within the engine, two radiators but only one coolant pump. These systems are not recommended for remote cooling applications due to the difficulty of achieving balanced coolant flows and thus proper cooling of each circuit.

Air–to–Air Aftercooling

Another approach to achieving low temperature aftercooling is to use an air–to–air radiator cooling circuit instead of an air–to–liquid design as described above. These designs route the turbocharged air through a radiator to cool it before entering the intake manifold(s). These systems are not generally recommended for remote cooling for two reasons. First, the entire system piping and radiator are operate under turbocharged pressure. Even the smallest pinhole leak in this system will significantly decrease turbo charger efficiency and is unacceptable. Second, the length of the air tube run to the radiator and back will create a time lag in turbocharging performance and potentially result in pressure pulses that will impede proper performance of the engine.

Radiators for Remote Radiator Applications

Remote Radiators

Remote radiators are available in a number of configurations for generator set applications. In all cases, the remote radiator uses an electric motor–driven fan that should be fed directly from the output terminals of the generator set. A surge tank must be installed at the highest point in the cooling system. The capacity of the surge tank must be at least 5% of the total system cooling capacity. The pressure cap installed there is selected based on the radiator sizing. Vent lines may also need to be routed to the surge tank. A sight glass is a desirable feature to display level of coolant in the system. It should be marked to show normal level cold and hot. A coolant level switch is a desirable feature to indicate a potential system failure when coolant level is low.

Some remote radiator installations operate with thermostatically controlled radiator fans. If this is the case, the thermostat is usually mounted at the radiator inlet.

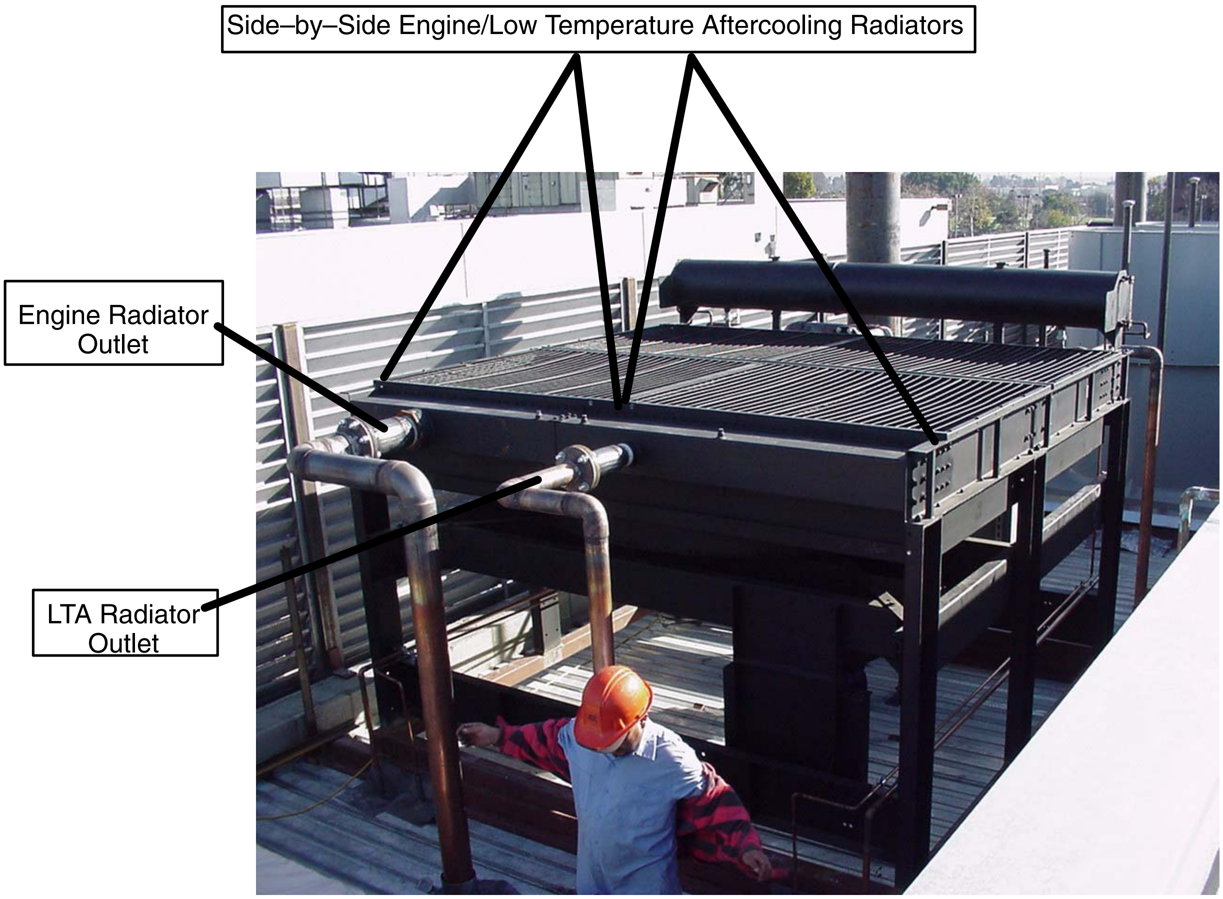


Figure 6–38. A Horizontal Remote Radiator and Aftercooler Radiator

Radiators may be either horizontal type (radiator core is parallel to mounting surface) or vertical type (radiator core is perpendicular to mounting surface) (**Figure 6–38**). Horizontal radiators are often selected because they allow the largest noise source in the radiator (the mechanical noise of the fan) to be directed up, where it is likely that there are no receivers that may be disturbed by the noise. However, horizontal radiators can be disabled by snow cover or ice formation, so they are often not used in cold climates.

Remote radiators require little maintenance, but when they are used, if they are belt driven, annual maintenance should include inspection and tightening of the fan belts. Some radiators may use re–greasable bearings that require regular maintenance. Be sure that the radiator fins are clean and unobstructed by dirt or other contaminants.

Skid–Mounted Heat Exchanger

The engine, pump and liquid–to–liquid heat exchanger form a closed, pressurized cooling system (**Figure 6–39**). The engine coolant and raw cooling water (the “cold” side of the system) do not mix. Consider the following:

- The generator set equipment room will require a powered ventilating system. See Ventilation in this section for information on the volume of air required for proper ventilation.

- Since the engine of the generator set does not have to mechanically drive a radiator fan, there may be additional kW capacity on the output of the generator set. To obtain the **net power** available from the generator set, add the fan load indicated on the generator set Specification Sheet to the power rating of the set. Remember that the generator set must electrically drive remote radiator fan, ventilating fans, coolant pumps and other accessories required for the set to run for remote radiator applications. So, the kW capacity gained by not driving a mechanical fan is generally consumed by the addition of electrical devices necessary in the remote cooling system.

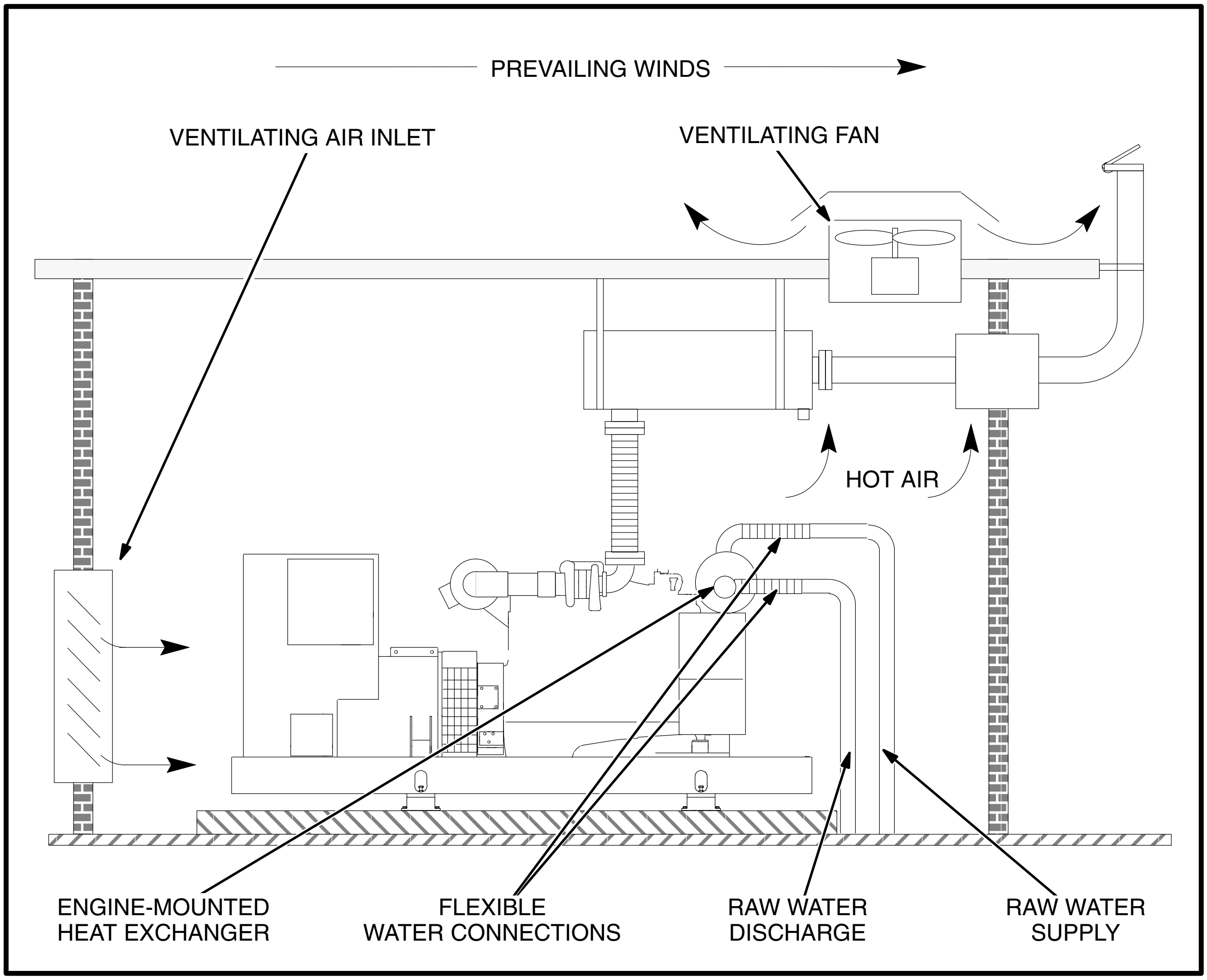


Figure 6–39. Factory-Mounted Heat Exchanger Cooling

- A pressure–reducing valve must be provided if water source pressure on the cold side of the system exceeds the pressure rating of the heat exchanger. Consult heat exchanger manufacturer for heat exchanger information[13].
- The heat exchanger and water piping must be protected from freezing if the ambient temperature can fall below 32 F (0 C).

13 Data for heat exchangers provided on Cummins Power Generation products that are provided with factory–mounted heat exchangers is available in the Cummins Power Suite.

- Recommended options include a thermostatic water valve (non–electrical) to modulate water flow in response to coolant temperature and a normally closed (NC) battery–powered shut off valve to shut off the water when the set is not running.
- There must be sufficient raw water flow to remove the **Heat Rejected To Coolant** indicated on the generator set Specification Sheet. Note that for each 1° F rise in temperature, a gallon of water absorbs approximately 8 BTU (specific heat). Also, it is recommended that the raw water leaving the heat exchanger not exceed 140° F (60° C). Therefore:

$$\text{Raw Water Required (gpm)} = \frac{\text{Heat Rejected}\left(\frac{\text{Btu}}{\text{min}}\right)}{\Delta\text{T (F)} \bullet \text{c}\left(\frac{\text{8 Btu}}{\text{F–Gallon}}\right)}$$

Where:
Δ T = Temperature rise of water across core
c = Specific heat of water

- If a set rejects 19,200 BTU per minute and the raw water inlet temperature is 80° F, allowing a water temperature rise of 60° F:

$$\text{Raw Water Required} = \frac{19{,}200}{60 \bullet 8} = 40 \text{ gpm}$$

Dual Heat Exchanger Systems

Dual heat exchanger cooling systems (**Figure 6–40**) can be difficult to design and implement, especially if a secondary cooling system such as a radiator is used to cool the heat exchanger. In these situations the remote device might be significantly larger than expected, since the change in temperature across the heat exchanger is relatively small. These systems should be designed for the specific application, considering the requirements of the engine, liquid to liquid heat exchanger, and remote heat exchanger device[14].

14 Skid–mounted heat exchangers provided by Cummins Power Generation are typically not suitable for use in dual heat exchanger applications. Dual heat exchanger arrangements require carefully matched components.

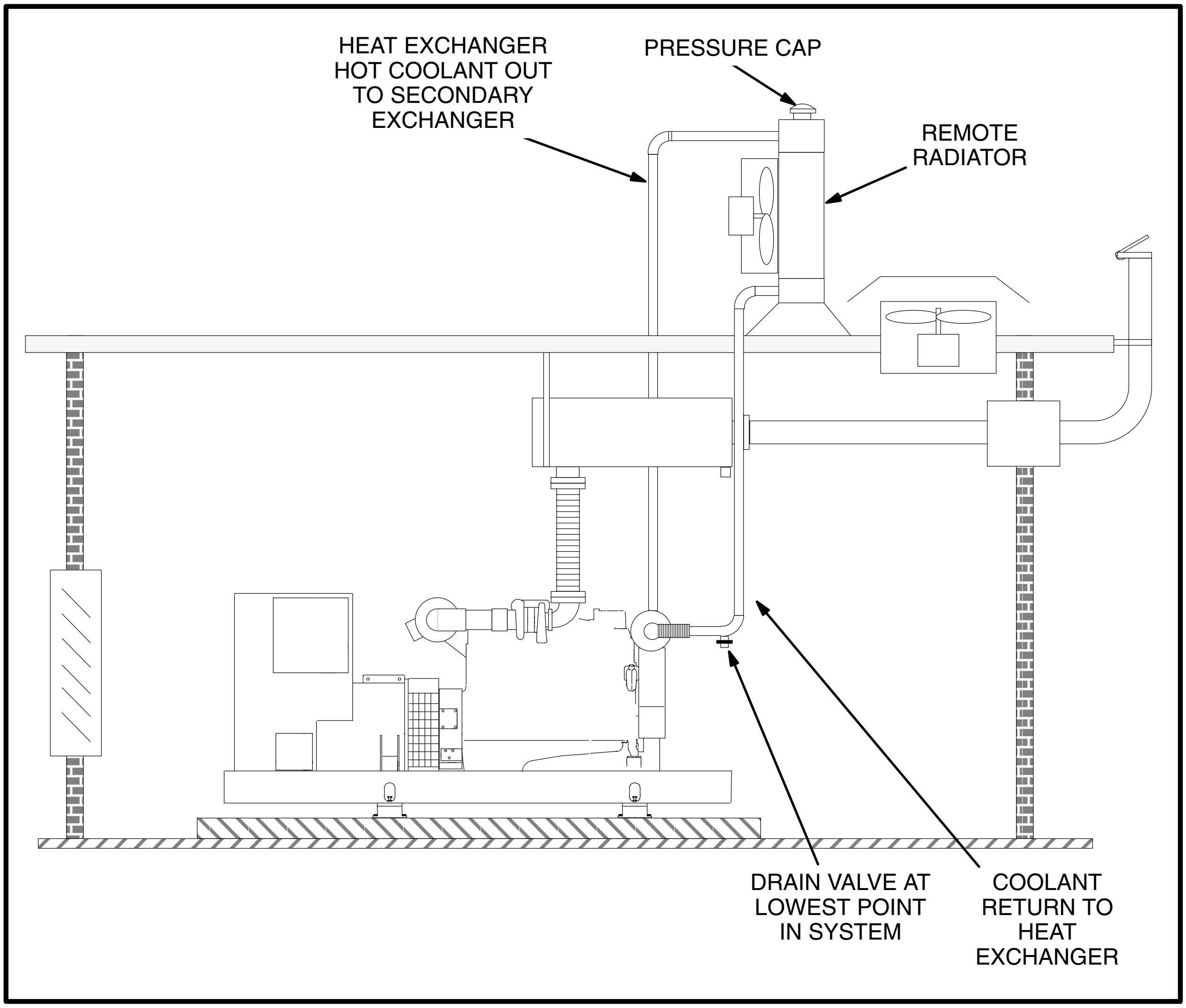


Figure 6–40. Dual Heat Exchanger System (With Secondary Liquid–to–Air Cooler)

Cooling Tower Applications

Cooling tower systems can be used in applications where the ambient temperature does not drop below freezing, and where the humidity level is low enough to allow efficient system operation. Typical arrangement of equipment is shown in **Figure 6–41.**

Cooling tower systems typically utilize a skid–mounted heat exchanger whose “cold” side to plumbed to the cooling tower. The balance of the system is composed of a “raw” water pump (the engine cooling pump circulates coolant on the “hot” side of the system) to pump the cooling water to the top of the cooling tower, where it is cooled by evaporation, and then returned to the generator set heat exchanger. Note that the system requires make–up water provisions, since evaporation will continuously reduce the amount of cooling water in the system. The “hot” side of the heat exchanger system is similar to that described earlier under skid mounted heat exchanger.

Fuel Cooling with Remote Radiators

Generator sets occasionally include fuel coolers to meet the requirements for specific engines. If an engine is equipped with a separate fuel cooler, these cooling requirements must be accommodated in the cooling system design. It is not often feasible to, and often against code to pipe fuel to a remote location. One approach would be to include a radiator and fan for fuel cooling within the generator space and account for the heat rejection in the room ventilation design. Another might be a heat exchanger type fuel cooling system utilizing a remote radiator or separate water supply for the coolant side.

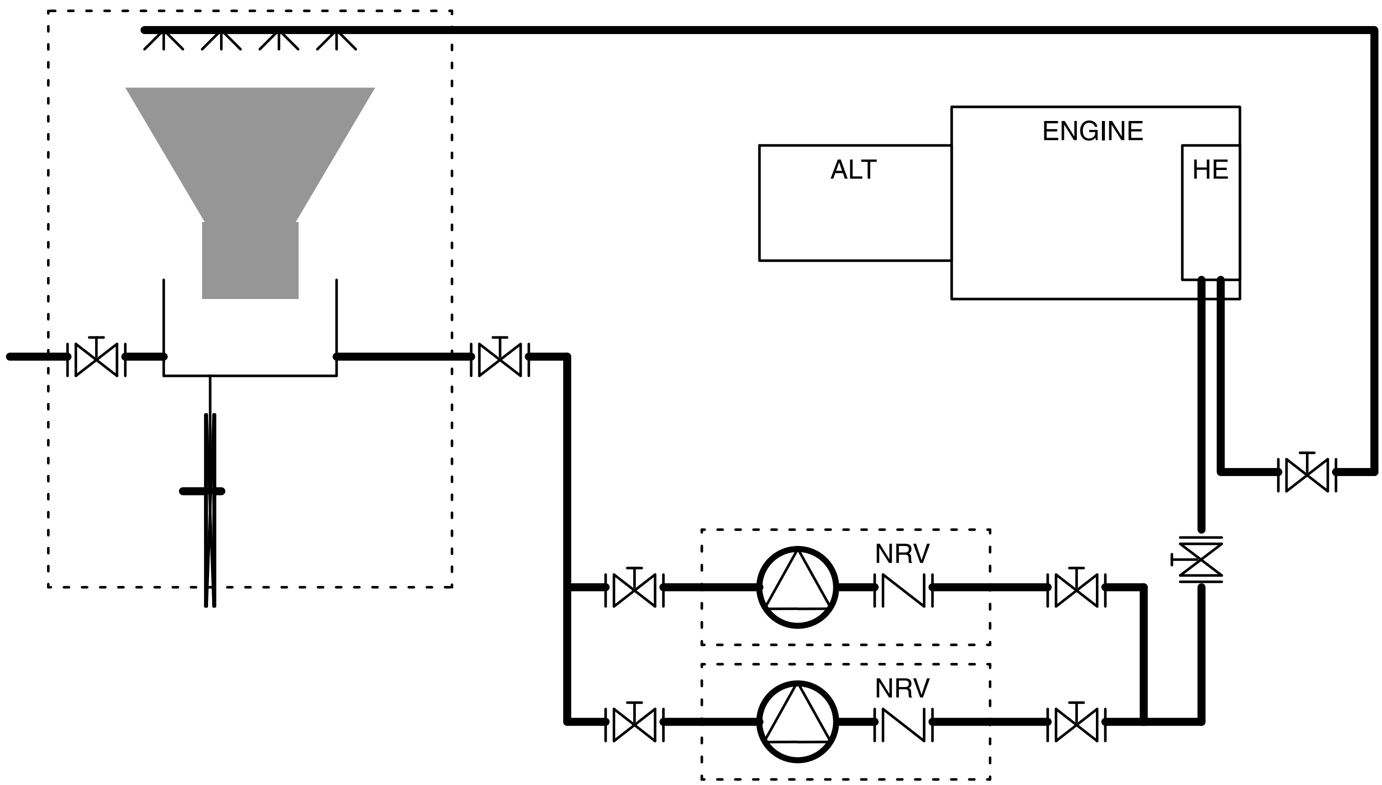


Figure 6–41. Diagram of Representative Cooling Tower Application

Cooling Pipe Sizing Calculations

The preliminary layout of piping for a remote radiator cooling system shown in **Figure 6–35** calls for 60 feet of 3–inch diameter pipe, three long sweep elbows, two gate valves to isolate the radiator for engine servicing and a tee to connect the fill/makeup line. The recommended generator set Specification Sheet indicates that coolant flow is **123 GPM** and that the allowable friction head is **5 PSI**.

This procedure involves determining the pressure loss (friction head) caused by each element and then comparing the sum of the pressure losses with the maximum allowable friction head.

1. Determine the pressure loss in the radiator by referring to the radiator manufacturer's data. For this example, assume the pressure loss is 1 psi at a flow of 135 gpm.
2. Find the equivalent lengths of all fittings and valves by using **Table 6–5** and add to the total run of straight pipe.

Three Long Sweep Elbows–3 x 5.2	15.6
Two Gate Valves (Open)–2 x 1.7	3.4
Tee (Straight Run)	5.2
60 Feet Straight Pipe	60.0
Equivalent Length of Pipe (Feet)	84.2

3. Find the back pressure at the given flow per unit length of pipe for the nominal pipe diameter used in the system. In this example, 3 inch nominal pipe is used. Following the dashed lines in **Figure 6–42**, 3 inch pipe causes a pressure loss of approximately **1.65 psi per 100 foot of pipe.**

4. Calculate the pressure loss in the piping as follows:

$$\text{Piping Loss} = 84.2 \text{ feet} \times \frac{1.65 \text{ psi}}{100 \text{ feet}} = 1.39 \text{ psi}$$

5. The total system loss is the sum of the piping and radiator losses:

   Total Pressure Loss = 1.39 psi piping + 1.00 psi radiator = 2.39 psi

6. The calculation for this example indicates that the layout of the remote radiator cooling system is adequate in terms of coolant friction head since it is not greater than the allowable friction head. If a calculation indicates excessive coolant friction head, repeat the calculation using the next larger pipe size. Compare the advantages and disadvantages of using larger pipe with that of using an auxiliary coolant pump.

TYPE OF FITTING	NOMINAL INCH (MILLIMETER) PIPE SIZE										
	1/2 (15)	**3/4 (20)**	**1 (25)**	**1–1/4 (32)**	**1–1/2 (40)**	**2 (50)**	**2–1/2 (65)**	**3 (80)**	**4 (100)**	**5 (125)**	**6 (150)**
90° Std. Elbow or Run of Tee Reduced ½	1.7 (0.5)	2.1 (0.6)	2.6 (0.8)	3.5 (1.1)	4.1 (1.2)	5.2 (1.6)	6.2 (1.9)	7.7 (2.3)	10 (3.0)	13 (4.0)	15 (4.6)
90° Long Sweep Elbow or Straight Run Tee	1.1 (0.3)	1.4 (0.4)	1.8 (0.5)	2.3 (0.7)	2.7 (0.8)	3.5 (1.1)	4.2 (1.3)	5.2 (1.6)	6.8 (2.1)	8.5 (2.6)	10 (3.0)
45° Elbow	0.8 (0.2)	1.0 (0.3)	1.2 (0.4)	1.6 (0.5)	1.9 (0.6)	2.4 (0.7)	2.9 (0.9)	3.6 (1.1)	4.7 (1.4)	5.9 (1.8)	7.1 (2.2)
Close Return Bend	4.1 (1.2)	5.1 (1.6)	6.5 (2.0)	8.5 (2.6)	9.9 (3.0)	13 (4.0)	15 (4.6)	19 (5.8)	25 (7.6)	31 (9.4)	37 (11.3)
TEE, Side Inlet or Outlet	3.3 (1.0)	4.2 (1.3)	5.3 (1.6)	7.0 (2.1)	8.1 (2.5)	10 (3.0)	12 (3.7)	16 (4.9)	20 (6.1)	25 (7.6)	31 (9.4)
Foot Valve and Strainer	3.7 (1.1)	4.9 (1.5)	7.5 (2.3)	8.9 (2.7)	11 (3.4)	15 (4.6)	18 (5.5)	22 (6.7)	29 (8.8)	36 (11.0)	46 (14.0)
Swing Check Valve, Fully Open	4.3 (1.3)	5.3 (1.6)	6.8 (2.1)	8.9 (2.7)	10 (3.0)	13 (4.0)	16 (4.9)	20 (6.1)	26 (7.9)	33 (10.1)	39 (11.9)
Globe Valve, Fully Open	19 (5.8)	23 (7.0)	29 (8.8)	39 (11.9)	45 (13.7)	58 (17.7)	69 (21.0)	86 (26.2)	113 (34.4)	142 (43.3)	170 (51.8)
Angle Valve, Fully Open	9.3 (2.8)	12 (3.7)	15 (4.6)	19 (5.8)	23 (7.0)	29 (8.8)	35 (10.7)	43 (13.1)	57 (17.4)	71 (21.6)	85 (25.9)
Gate Valve, Fully Open	0.8 (0.2)	1.0 (0.3)	1.2 (0.4)	1.6 (0.5)	1.9 (0.6)	2.4 (0.7)	2.9 (0.9)	3.6 (1.1)	4.7 (1.4)	5.9 (1.8)	7.1 (2.2)

Table 6–5. Equivalent Lengths of Pipe Fittings and Valves in Feet (Meters)

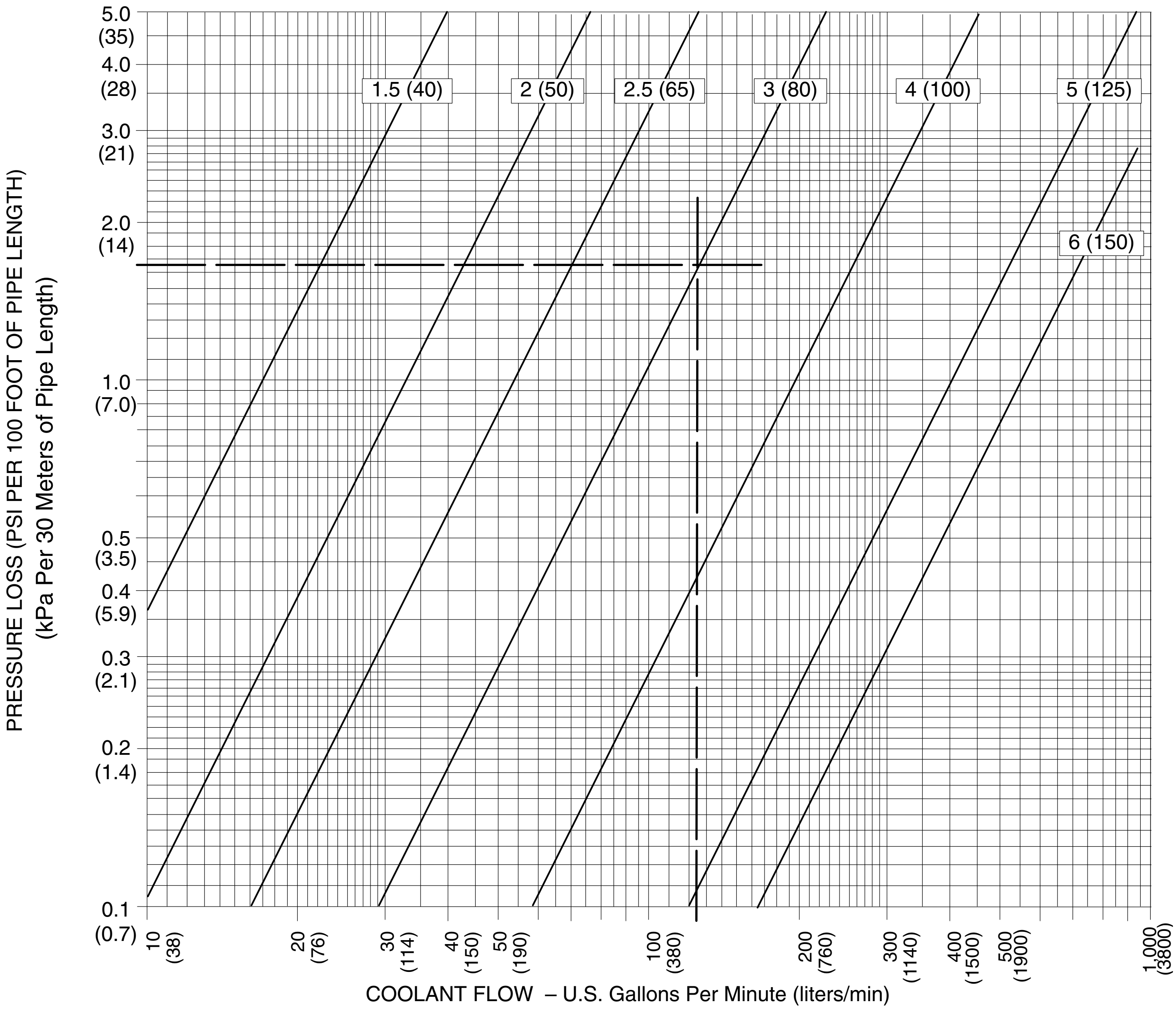


Figure 6–42. Frictional Pressure Losses for Inch (mm) Diameter Pipes

Coolant Treatment

Antifreeze (ethylene or propylene glycol base) and water are mixed to lower the freezing point of the cooling system and to raise the boiling point. Refer to **Table 6–7** for determining the concentration of ethylene or propylene glycol necessary for protection against the coldest ambient temperature expected. Antifreeze/water mixture percentages in the range of 30/70 to 60/40 are recommended for most applications.

NOTE: Propylene glycol based antifreeze is less toxic than ethylene based antifreeze, offers superior liner protection and eliminates some fluid spillage and disposal reporting requirements. However, it is not as effective coolant as ethylene glycol, so cooling system capacity (maximum operating temperature at full load) will be diminished somewhat by use of propylene glycol.

Cummins Power Generation generator sets, 125/100 kW and larger, are equipped with replaceable coolant filtering and treating elements to minimize coolant system fouling and corrosion. They are compatible with most antifreeze formulations. For smaller sets, the antifreeze should contain a corrosion inhibitor.

Generator sets with engines that have replaceable cylinder liners require supplemental coolant additives (SCAs) to protect against liner pitting and corrosion, as specified in the engine and generator set operator's manuals.

Ventilation

Overview

Ventilation of the generator set room is necessary to provide combustion air to the engine, remove the heat emitted from the generator set and any other equipment in the room, and to remove any fumes.

NOTE: The phrase "generator set room" and the term "room" are used throughout this section. However, the principles discussed here are applicable to any means of enclosing the generator set. For the purposes of this section, consider "room" synonymous with "powerhouse," "housing," "container," "enclosure," etc.

Poor ventilation system design and/or installation can lead to the following problems:

- Hazardous conditions for generator set room personnel (if applicable)
- High temperatures around the set that can lead to poor performance and overheating
- Poor operation in cold climates if the installation permits exposure of the unit to cold temperatures
- Issues with other equipment in the room that may be sensitive to high or low temperature.

Requirements

- Engine exhaust manifolds and turbochargers shall not be insulated. (See **Determining Airflow Requirements**, page 6–66.)
- Rigid insulation shall not be used on expansion joints. (See **Determining Airflow Requirements**, page 6–66.)
- Heat from other sources shall be considered in the ventilation system design. (See **Determining Airflow Requirements**, page 6–66.)
- Room inlet / outlet shall:
  - Accommodate the total combustion and ventilation airflow through the room. (See **Room Ventilation Inlet and Outlet Design Requirements**, page 6–73.)
  - Permit airflow across entire generator set from alternator end to radiator end. (See **Inlet and Outlet Design Guidelines**, page 6–74.)
  - Draw/discharge ventilation air directly from/to outdoors. (See **Inlet and Outlet Design Guidelines**, page 6–74.)
  - Permit the required amount of fresh air flow across each set in a multiple set installation. (See **Ventilating Multiple Generator Sets**, page 6–78.)
- The louver manufacturer shall be consulted for air velocity limits. (See **Calculating Inlet / Outlet Effective Flow Area,** page 6–74.)
- Radiator discharge ducts shall be self–supporting (See **Inlet and Outlet Design Guidelines**, page 6–74.).
- Ventilation system shall be designed for acceptable operation with all entry / service doors closed. All doors shall remain closed during generator set operation to maintain the designed ventilation flow. (See **Negative Pressure in the Generator Set Room**, page 6–75.)

- The crankcase breather line shall be routed such that vapors will not foul equipment. (See **Engine Crankcase Ventilation**, page 6–76.)
- If the crankcase breather is modified, crankcase pressure shall be measured at rated power. Pressure must be positive but not exceed 3 inches of water (0.75 kPa). (See **Engine Crankcase Ventilation**, page 6–76.)
- For set–mounted radiator / fan packages, generator set room total airflow restriction shall not exceed the maximum value listed on the **Generator Set Data Sheet.** (See **Airflow Restriction**, page 6–76.)
- Louvers shall open immediately upon generator set start–up for emergency / standby installations. In cold climates, louvers may open partially for combustion air only and controlled to modulate the temperature in the room. (See **Louver Operation**, page 6–78.)
- If a blocking wall is installed, it shall be located no closer than a distance equal to 1X the discharge louver height away from the building. For optimal performance, the wall should be located approximately 3X the discharge louver height away from the building. (See **Blocking Walls**, page 6–80.)
- A turning vane and drain shall be included with any blocking wall installation. (See **Blocking Walls**, page 6–80.)
- If ventilation system filters are installed, a system for detecting plugged filters shall be in place. (See **Ventilation Air Filtration**, page 6–81.)

Recommendations

- Exhaust piping and mufflers should be insulated. (See above requirement regarding manifolds and turbochargers – **Determining Airflow Requirements**, page 6–66.)
- Maximum outdoor temperature should be measured near the air inlet. (See **Determining Airflow Requirements**, page 6–66.)
- Air velocity should be limited to 500 – 700 feet/minute (150 – 220 meters/minute) to prevent rainwater / snow ingress. See above requirement regarding louver limits on air velocity. (See **Calculating Inlet / Outlet Effective Flow Area,** page 6–74.)
- Room inlet / outlet location recommendations (See **Inlet and Outlet Design Guidelines**, page 6–74.):
  - Inlet should not be located near engine exhaust outlet.
  - Inlet and outlet should not be located on the same wall.
  - Outlet should be located as high as possible and inlet should be located as low as possible, while maintaining fresh air flow across the entire set.
  - Outlet should be located on downwind side of the building.
- Additional combustion equipment should not be located in the generator set room. (See **Negative Pressure in the Generator Set Room**, page 6–75.)

Determining Airflow Requirements

Use the following method to determine the generator set room airflow requirements.

STEP 1: Determine Heat Emitted to Room from Generator Set

The engine and alternator will emit heat to the generator set room. In **Figure 6–43**, this heat is labeled Q_{GS}. Consult the **Generator Set Data Sheet** to determine the amount of heat, as shown in **Figure 6–44**. For the standby DFXX Cummins generator set example shown in **Figure 6–44**, Q_{GS} is 5530.0 Btu/min (5.9 MJ/min).

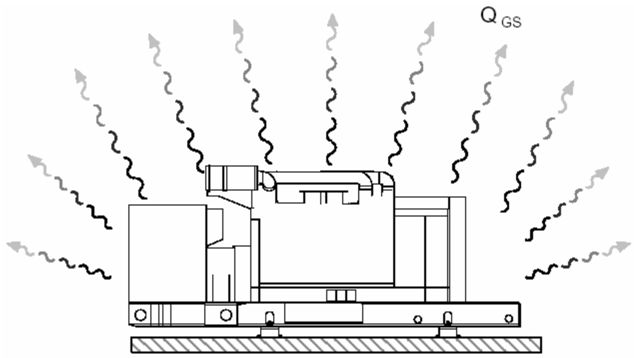


Figure 6–43. Heat Emitted To The Room From A Generator Set (Q_{GS})

STEP 2: Determine Heat Emitted to Room from Muffler and Exhaust Piping

The muffler and exhaust piping will emit heat to the generator set room, as shown in **Figure 6–45**. Use **Table 6–6** to estimate the amount.

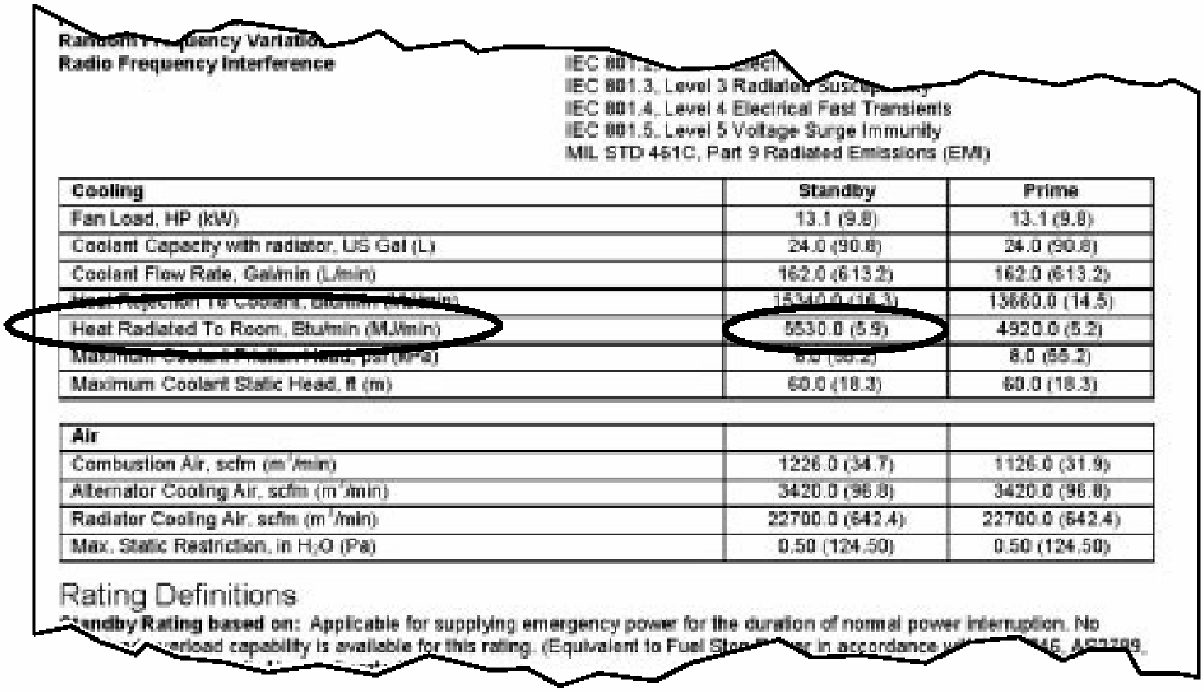
For the system shown in **Figure 6–45**, assume there is 10 feet of uninsulated 5–inch diameter (3 meters of 127 mm diameter) exhaust piping and an uninsulated muffler located in the generator set room. From **Table 6–6**, heat emitted from the piping (Q_P) and muffler (Q_M) can be determined:

$$Q_P = 10 feet * 139 \frac{Btu}{\min * ft} = 1390 Btu/\min$$

OR $$Q_P = 3.0 m * 481 \frac{kJ}{\min * m} = 1443 kJ/\min = 1.44 MJ/\min$$

$$Q_M = 1501 Btu/\min$$

OR $$Q_M = 1584 kJ/\min = 1.58 MJ/\min$$



Radio Frequency Interference

IEC 801.[illegible]
IEC 801.3, Level 3 Radiated [illegible]
IEC 801.4, Level 4 Electrical Fast Transients
IEC 801.5, Level 5 Voltage Surge Immunity
MIL STD 461C, Part 9 Radiated Emissions (EMI)

Cooling	Standby	Prime
Fan Load, HP (kW)	13.1 (9.8)	13.1 (9.8)
Coolant Capacity with radiator, US Gal (L)	24.0 (90.8)	24.0 (90.8)
Coolant Flow Rate, Gal/min (L/min)	162.0 (613.2)	162.0 (613.2)
[illegible]	[illegible]	13660.0 (14.5)
Heat Radiated To Room, Btu/min (MJ/min)	5530.0 (5.9)	4920.0 (5.2)
[illegible]	[illegible]	8.0 (55.2)
Maximum Coolant Static Head, ft (m)	60.0 (18.3)	60.0 (18.3)

Air		
Combustion Air, scfm (m^3/min)	1226.0 (34.7)	1126.0 (31.9)
Alternator Cooling Air, scfm (m^3/min)	3420.0 (96.8)	3420.0 (96.8)
Radiator Cooling Air, scfm (m^3/min)	22700.0 (642.4)	22700.0 (642.4)
Max. Static Restriction, in H_2O (Pa)	0.50 (124.50)	0.50 (124.50)

Rating Definitions

[illegible]ndby Rating based on: Applicable for supplying emergency power for the duration of normal power interruption. No [illegible] overload capability is available for this rating. (Equivalent to Fuel Stop [illegible] in accordance [illegible]

Figure 6–44. Example DFXX Generator Set Specification Sheet

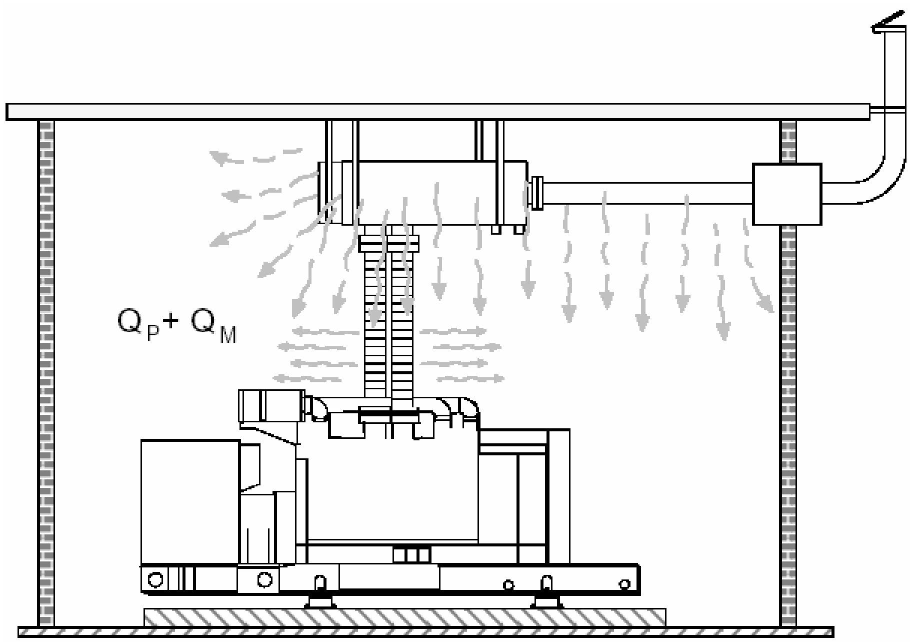


Figure 6–45. Heat Emitted to the Room from the Muffler and Exhaust Piping

Note that the values given in **Table 6–6** and the example equations are for uninsulated exhaust piping and mufflers. Cummins recommends insulating exhaust piping and mufflers to reduce the amount of heat emitted to the room. Factory–supplied, set–mounted radiator packages are designed and developed under the assumption that exhaust pipework will be lagged / insulated. As a rule of thumb, use 30% of the heat values given in **Table 6–6** for insulated systems[1].

Insulating engine exhaust manifolds and turbochargers can cause damage. In addition, rigid insulation cannot be used on expansion joints. For additional details, see the **Exhaust System** section of this manual, or contact the local Cummins distributor for access to AEB 60.05.

- Exhaust piping and mufflers should be insulated.
- Engine exhaust manifolds and turbochargers shall not be insulated.
- Rigid insulation shall not be used on expansion joints.

Pipe Diameter Inches (mm)	Heat From Pipe Btu/min/ft (kJ/min/m)	Heat From Muffler Btu/min (kJ/min)
3 (76)	87 (301)	922 (973)
3.5 (98)	99 (343)	1047 (1105)
4 (102)	112 (388)	1175 (1240)
5 (127)	139 (481)	1501 (1584)
6 (152)	164 (568)	1944 (2051)
8 (203)	213 (737)	2993 (3158)
10 (254)	268 (928)	3668 (3870)
12 (305)	318 (1101)	5463 (5764)
14 (356)	367 (1270)	8233 (8686)

Table 6–6. Estimated Heat Emitted from Uninsulated Exhaust Piping and Mufflers[15]

STEP 3: Determine Heat Emitted to Room from Other Heat Sources

- Heat from other sources shall be considered in the ventilation system design.

Other sources include switchgear, pumps, compressors, lighting, solar heat through windows, and any other heat–producing equipment. In the following equations, this heat is identified as Q_{AUX}.

For the example system, assume that there are no additional heat sources in the generator set room.

STEP 4: Calculate the Total Heat Emitted to Room from All Sources

To find the total heat emitted to the generator set room, sum all of the values from steps 1–3:

$$Q_{TOT} = Q_{GS} + Q_P + Q_M + Q_{AUX}.$$

For the example system,

$$Q_{TOT} = 5530 \,{}^{Btu}\!/_{\min} + 1390 \,{}^{Btu}\!/_{\min} + 1501 \,{}^{Btu}\!/_{\min} + 0 \,{}^{Btu}\!/_{\min} = 8421 \,{}^{Btu}\!/_{\min}.$$

STEP 5: Determine the Maximum Acceptable Room Temperature Rise

To determine the maximum acceptable generator set room temperature rise, first determine the maximum outdoor temperature (MAX T_{OUT}) and the maximum acceptable room temperature (MAX T_{ROOM}). The maximum outdoor temperature is the highest likely outdoor temperature in the geographic region. Ideally, this temperature will be measured near the generator set room air inlet. Temperatures near buildings can be significantly higher than temperatures in open spaces.

- Maximum outdoor temperature should be measured near the air inlet.

[15] Cummins employees can access Cummins Technical Report 9051–2005–003 for documentation of these values.

To determine the maximum acceptable room temperature, consult building codes, local ordinances, fire detection specifications, maximum generator set operating temperature before de–rate, cooling system capability, and other factors. Keep in mind that the generator set may not be the most temperature–sensitive equipment in the room. Maximum acceptable room temperatures may be defined by the operating limits of other equipment.

The maximum acceptable generator set room temperature rise is:

$$\Delta T = MaxT_{ROOM} - MaxT_{OUT}.$$

For the example system, assume that the generator set is located in a region where the highest outdoor temperature at the room inlet is 90 °F (32.2 °C), and the maximum acceptable room temperature is 104 °F (40 °C). The maximum acceptable generator set room temperature rise is:

$$\Delta T = 104\ ^{\circ}F - 90\ ^{\circ}F = 14\ ^{\circ}F \quad \text{OR} \quad \Delta T = 40\ ^{\circ}C - 32.2\ ^{\circ}C = 7.8\ ^{\circ}C$$

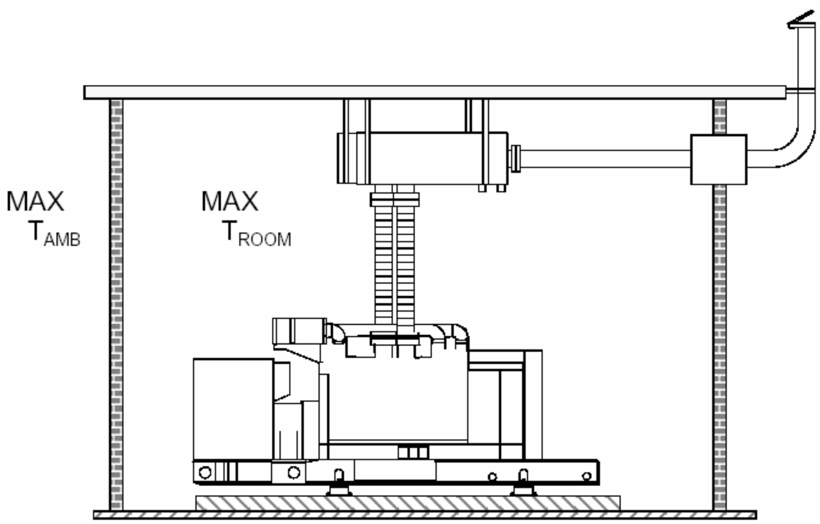


Figure 6–46. Maximum Acceptable Room And Ambient Temperatures

STEP 6: Determine the Combustion Airflow Requirement

Find the combustion airflow requirement on the **Generator Set Data Sheet**, as shown in **Figure 6–47**. For the standby DFXX Cummins generator set example shown, this value is 1226.0 cfm (34.7 m^3/min).

STEP 7: Calculate the Total Airflow Required through the Generator Set Room

First, the airflow required to provide the designed room temperature rise is calculated:

$$V_{ROOM} = \frac{Q_{TOT}}{(c_p)(\Delta T)(d)},$$

where V_{ROOM} = minimum forced ventilation airflow; cfm (m^3/min)

Q_{TOT} = total heat emitted to room (step 4); Btu/min (MJ/min)

c_p = specific heat; 0.241 Btu/lb/°F (1.01×10^{-3} MJ/kg/°C)

ÄT = generator set room temperature rise (step 5); °F (°C)

d = density of air; 0.0750 lb/ft^3 (1.20 kg/m^3).

For the example system,

$$V_{ROOM} = \frac{8421 \, ^{Btu}/_{\min}}{(0.241 \, ^{Btu}/_{lb \cdot ^{\circ}F})(14 \, ^{\circ}F)(0.075 \, ^{lb}/_{ft^3})} = 33278 \, cfm$$

OR

$$V_{ROOM} = \frac{8.92 \, ^{MJ}/_{\min}}{(1.01 x 10^{-3} \, ^{MJ}/_{kg \cdot ^{\circ}C})(7.8 \, ^{\circ}C)(1.20 \, ^{kg}/_{m^3})} = 944 \, ^{m^3}/_{\min}$$

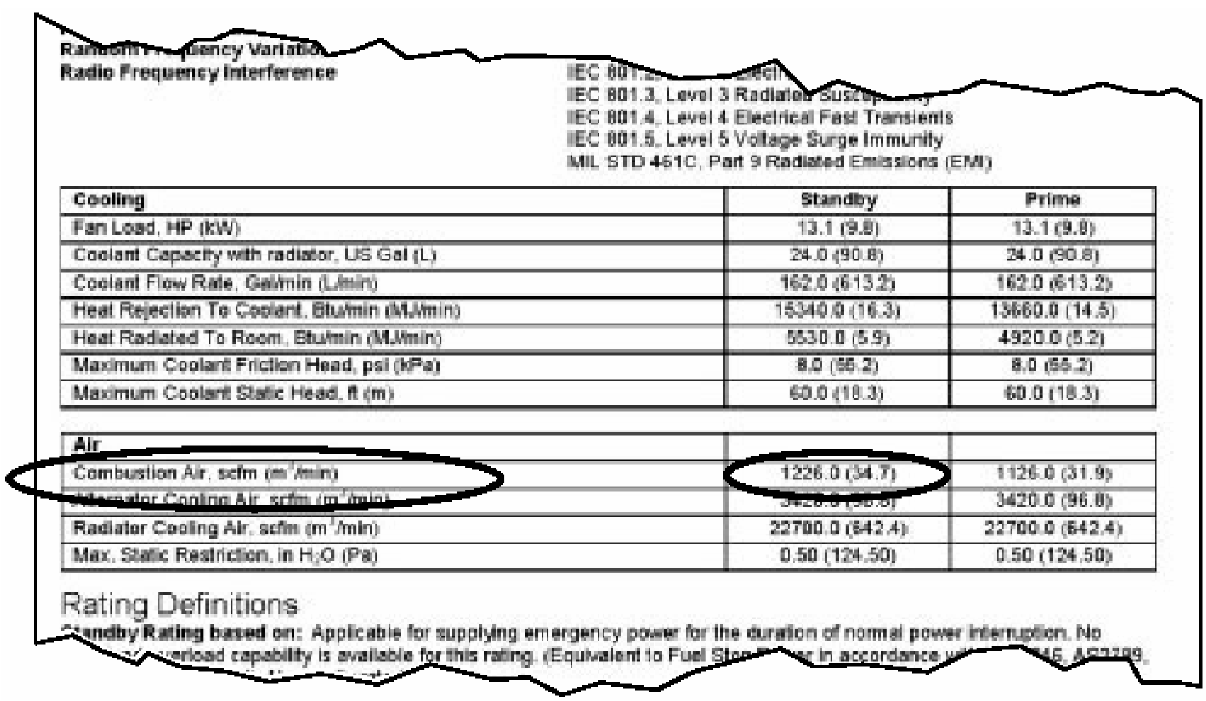
Next, add this value to the combustion air requirement from Step 6 to determine the required total airflow:

$$V_{TOT} = V_{ROOM} + V_{COMB}$$

For the example system,

$$V_{TOT} = 33278 \, cfm + 1226 \, cfm = 34504 \, cfm$$ OR

$$V_{TOT} = 944 \, ^{m^3}/_{\min} + 34.7 \, ^{m^3}/_{\min} = 979 \, ^{m^3}/_{\min}$$


Random Frequency Variation
Radio Frequency Interference — IEC 801.2, ... Electr...
IEC 801.3, Level 3 Radiated Susceptibility
IEC 801.4, Level 4 Electrical Fast Transients
IEC 801.5, Level 5 Voltage Surge Immunity
MIL STD 461C, Part 9 Radiated Emissions (EMI)

Cooling	Standby	Prime
Fan Load, HP (kW)	13.1 (9.8)	13.1 (9.8)
Coolant Capacity with radiator, US Gal (L)	24.0 (90.8)	24.0 (90.8)
Coolant Flow Rate, Gal/min (L/min)	162.0 (613.2)	162.0 (613.2)
Heat Rejection To Coolant, Btu/min (MJ/min)	15340.0 (16.3)	13660.0 (14.5)
Heat Radiated To Room, Btu/min (MJ/min)	5530.0 (5.9)	4920.0 (5.2)
Maximum Coolant Friction Head, psi (kPa)	8.0 (55.2)	8.0 (55.2)
Maximum Coolant Static Head, ft (m)	60.0 (18.3)	60.0 (18.3)

Air		
Combustion Air, scfm (m^3/min)	1226.0 (34.7)	1126.0 (31.9)
Alternator Cooling Air, scfm (m^3/min)	[illegible]	3420.0 (96.8)
Radiator Cooling Air, scfm (m^3/min)	22700.0 (642.4)	22700.0 (642.4)
Max. Static Restriction, in H_2O (Pa)	0.50 (124.50)	0.50 (124.50)

Rating Definitions

Standby Rating based on: Applicable for supplying emergency power for the duration of normal power interruption. No ... overload capability is available for this rating. (Equivalent to Fuel Stop Power in accordance with ...)

Figure 6–47. Example DFXX Generator Set Specification Sheet

STEP 8: Adjust Airflow for Altitude

Air density decreases as altitude increases. A generator set operating at high altitude requires more volumetric airflow than a generator set operating at sea level in order to maintain equivalent air mass flow. Increase airflow from Step 7 by 3% for every 1000 feet (305 meters) above sea level to maintain adequate ventilation. Use the following equation:

$$V_{ADJ} = (\frac{Alt}{Alt_{REF}})(.03)(V_{TOT}) + V_{TOT},$$

where V_{ADJ} = airflow adjusted for altitude; cfm (m^3/min)

Alt = altitude at installation site; ft (m)

Alt_{REF} = reference altitude; 1000 ft (305 m)

V_{TOT} = total airflow required from Step 7; cfm (m^3/min).

Assume the example system is to be installed at an altitude of 5000 feet (1524 meters).

$$V_{ADJ} = (\frac{5000ft}{1000ft})(.03)(34504cfm) + 34504cfm = 39680cfm.$$

OR

$$V_{ADJ} = (\frac{1524m}{305m})(.03)(979 m^3/\min) + 979 m^3/\min = 1126 m^3/\min.$$

This final value (V_{ADJ}) is the actual airflow required at the site conditions. Ventilation equipment suppliers may require additional details to specify appropriate equipment for the installation.

STEP 9: Determine Auxiliary Ventilation Fan Requirements

If the generator set has a factory–installed radiator and fan, obtain the "Radiator Cooling Air" or "Cooling System Airflow" value from the **Generator Set Data Sheet**. This is the airflow that the set–mounted fan will provide. For the standby DFXX Cummins generator set example shown in **Figure 6–48**, this value is 22700.0 cfm (642.4 m^3/min).

[illegible] Frequency Variation

Radio Frequency Interference — IEC 801.[illegible]
IEC 801.3, Level 3 Radiated Susc[illegible]
IEC 801.4, Level 4 Electrical Fast Transients
IEC 801.5, Level 5 Voltage Surge Immunity
MIL STD 461C, Part 9 Radiated Emissions (EMI)

Cooling	Standby	Prime
Fan Load, HP (kW)	13.1 (9.8)	13.1 (9.8)
Coolant Capacity with radiator, US Gal (L)	24.0 (90.8)	24.0 (90.8)
Coolant Flow Rate, Gal/min (L/min)	162.0 (613.2)	162.0 (613.2)
Heat Rejection To Coolant, Btu/min (MJ/min)	15340.0 (16.3)	13660.0 (14.5)
Heat Radiated To Room, Btu/min (MJ/min)	5530.0 (5.9)	4920.0 (5.2)
Maximum Coolant Friction Head, psi (kPa)	8.0 (55.2)	8.0 (55.2)
Maximum Coolant Static Head, ft (m)	60.0 (18.3)	60.0 (18.3)

Air		
Combustion Air, scfm (m^3/min)	1226.0 (34.7)	1126.0 (31.9)
[illegible]	3420.0 (96.8)	3420.0 (96.8)
Radiator Cooling Air, scfm (m^3/min)	22700.0 (642.4)	22700.0 (642.4)
[illegible]	[illegible]	0.50 (124.50)

Rating Definitions

[illegible]andby Rating based on: Applicable for supplying emergency power for the duration of normal power interruption. No [illegible]verload capability is available for this rating. (Equivalent to Fuel Sto[illegible] in accordance [illegible], AR[illegible]

Figure 6–48. Example DFXX Generator Set Specification Sheet

Compare the total airflow requirement (V_{ADJ}) obtained in Step 8 with the "Cooling System Airflow" value from the generator set technical information.

If V_{ADJ} is less than the "Radiator Cooling Air" value, the set–mounted fan will provide more than the necessary ventilation airflow, and no auxiliary fans are required. This assumes that the total airflow restriction is within limits. (See **Airflow Restriction**, page 6–76.)

If V_{ADJ} is greater than the "Radiator Cooling Air" value, the set–mounted fan will not provide the necessary ventilation airflow, and auxiliary fans are required. The auxiliary fans must make up the airflow difference between V_{ADJ} and the "Cooling System Airflow" value. The auxiliary fan must be sized and located such that it will complement the set–mounted fan, not compete with it for air.

If the example system were equipped with a factory–installed radiator and fan, V_{ADJ} = 39680 cfm (1126 m^3/min) is greater than the "Radiator Cooling Air" value of 22700.0 cfm (642.4 m^3/min), so auxiliary fans would be required for the generator set room. These fans would need to deliver 39680 cfm – 22700.0 cfm = 16980 cfm (1126 m^3/min – 642.4 m^3/min = 483.6 m^3/min).

Note: This example presents extreme circumstances. In most applications, set–mounted fans will be capable of providing the required airflow. However, these calculations must be done to verify that the fan is adequate.

If the generator set does not have a factory–installed radiator and fan, fans installed in the generator set room will be required to provide the total airflow calculated in Step 8.

If the example system were not equipped with a factory–installed radiator and fan, fans installed in the generator set room would need to provide 39680 cfm (1126 m^3/min) air flow.

Room Ventilation Inlet and Outlet Design Requirements

- Room inlet(s) and outlet(s) must accommodate the total airflow through the room.

If the generator set has a factory–installed radiator and fan, the total airflow through the generator set room is either the required ventilation airflow from Step 8 above (V_{ADJ}) or the "Cooling System Airflow" from Step 9, whichever value is greater. An example system is shown in Figure NO TAG.

If the generator set does not have a factory–installed radiator and fan, the total airflow through the generator set room is the required ventilation airflow from Step 8 above (V_{ADJ}). An example system is shown in **Figure 6–50**.

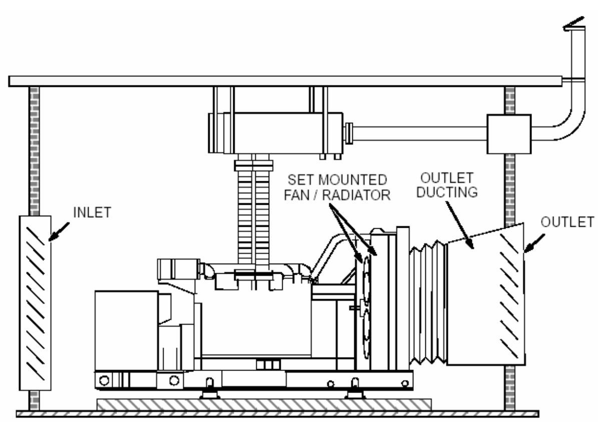


Figure 6–49. Example Ventilation System For Factory–installed Radiator and Fan

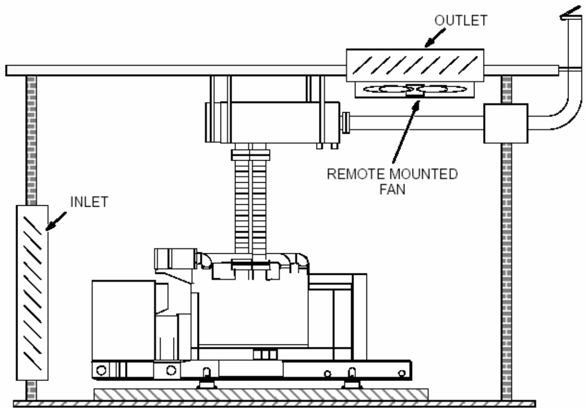


Figure 6–50. Example Ventilation System For Remote–cooled, Non–factory–installed Radiator and Fan (NOTE: cooling system is not shown in this illustration)

Calculating Inlet/Outlet Effective Flow Area

- Air velocity should be limited to 500 – 700 feet/minute (2.5 – 3.6 meters/second) to prevent rainwater / snow ingress.
- For louver installations, default to louver manufacturer for air velocity limits.

Typically, limiting the air velocity to 500 – 700 feet/minute (2.5 – 3.6 meters/second) will help keep rain and snow from entering the generator set room. For louver installations, be sure to check with louver manufacturer for specific air velocity requirements.

Louvers and screens over air inlet and outlet openings restrict airflow and vary widely in performance. A louver assembly with narrow vanes, for example, tends to be more restrictive than one with wide vanes. The effective open area specified by the louver or screen manufacturer should be used.

The required effective flow area of the inlet and/or outlet can be calculated:

$$A = \frac{V}{S},$$

where A = effective flow area; ft^2 (m^2)

V = volumetric flow; cfm (m^3/min)

S = air velocity; ft/min (m/min).

For the example system from part 1, assume inlet and outlet louvers are used, and the louver manufacturer requires the airflow velocity be limited to 400 feet/minute (122 meters/minute).

$$A = \frac{V}{S} = \frac{39680\,cfm}{400\,{}^{ft}/_{min}} = 99.2\,ft^2 \quad \text{OR} \quad A = \frac{V}{S} = \frac{1126\,{}^{m^3}/_{min}}{122\,{}^{m}/_{min}} = 9.2\,m^2$$

Louvers with an effective flow area of 99.2 ft^2 (9.2 m^2) would be required.

Inlet and Outlet Design Guidelines

These requirements and recommendations will help deliver the required amount of air across the generator set and maintain system integrity.

- Inlets and outlets shall be located such that air will flow across the entire generator set from alternator end to radiator end.
- Ventilation air shall be drawn directly from / discharged directly to the outdoors.
- Radiator discharge ducts shall be self–supporting.

- Inlet and outlet should not be located on the same wall.
- Inlet should not be located near the engine exhaust outlet.
- Outlets should be located as high as possible and inlets as low as possible, while maintaining fresh air flow across the entire set.
- Outlet should be located on the downwind side of the building.

"Top" views of recommended, acceptable, and unacceptable room layouts are shown in **Figure 6–51**. "Side" views of recommended and unacceptable room layouts are shown in **Figure 6–52**.

*Note: For generator sets with factory–supplied, set–mounted radiator packages, it will not be possible to locate the outlet high in the room. The recommended layout in **Figure 6–52** applies only to remote–cooled systems.*

Negative Pressure in the Generator Set Room

- Ventilation system shall be designed for acceptable operation with all entry / service doors closed. All doors shall remain closed during generator set operation to maintain the designed ventilation flow.
- Additional combustion equipment should not be located in the generator set room.

The ventilation system may cause a slight negative pressure in the generator set room. It is recommended that combustion equipment such as the building heating boilers not be located in the generator set room due to the possibility of negative pressure. If this is unavoidable, the possibility of impacts on cooling system performance and other detrimental effects such as flue backdraft must be examined. Extra large room inlet openings and/or ducts, pressurizing fans, etc. may be required to reduce the negative pressure to an acceptable level.

Regardless of the pressure in the generator set room, it must always be possible for personnel to open the door(s) to the room in case of emergency.

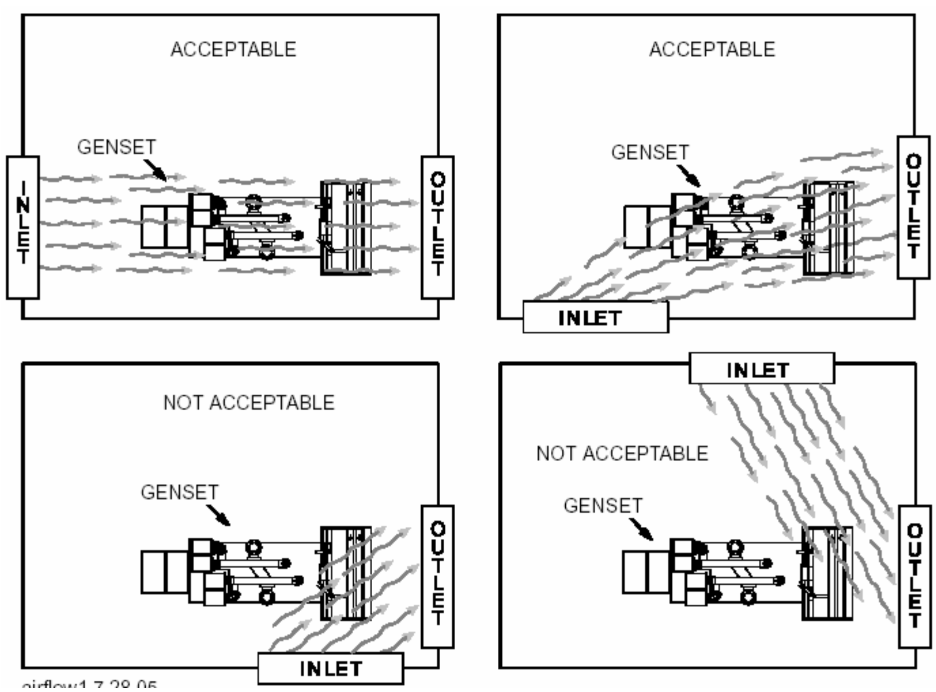


Figure 6–51. "Top" Views of Generator Set Room Layouts

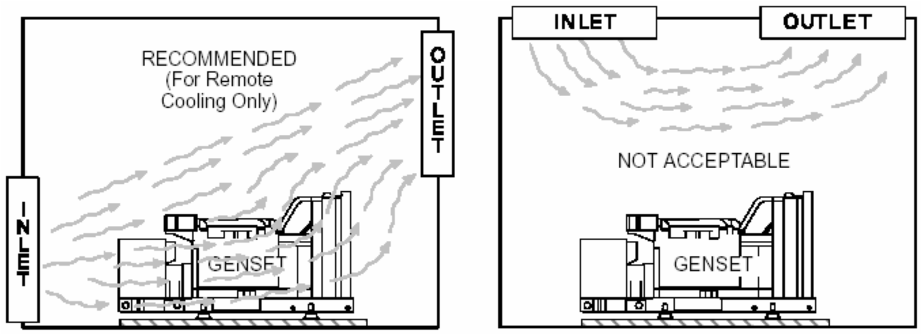


Figure 6–52. ”Side” Views Of Generator Set Room Layouts

Engine Crankcase Ventilation

- The crankcase breather line shall be routed such that vapors will not foul equipment.
- If the crankcase breather is modified, crankcase pressure shall be measured at rated power. Pressure must be positive but not exceed 3 inches of water (0.75 kPa).

Open engine crankcase ventilation systems will exhaust crankcase vapors into the generator set room. These vapors may contain an oil mist. The crankcase breather line shall be routed such that crankcase vapors cannot foul the radiator core, alternator, air cleaner, or any other equipment that may be sensitive to an oil mist. The potential for environmental pollution must also be considered when routing the line. Low spots or dips in the breather line are not permitted, and the line must be protected from freezing. The breather line must not add significant restriction to the system. If the breather is modified, the crankcase pressure must be measured at rated power. This value must be positive and not exceed 3 inches of water (0.75 kPa). Excessively long lines may cause over pressurization of the crankcase. A shorter route or larger diameter line may be required.

Airflow Restriction

- For set–mounted radiator / fan packages, generator set room total airflow restriction shall not exceed the listed maximum value.

If a set–mounted radiator/fan is used, the generator set room total airflow restriction cannot exceed the value listed in the generator set technical information. See **Figure 6–53**. For the DFXX generator set example, this value is 0.50 in H_20 (124.50 Pa).

Random Frequency Variation
Radio Frequency Interference

IEC 801.3, Level 3 Radiated Susceptibility
IEC 801.4, Level 4 Electrical Fast Transients
IEC 801.5, Level 5 Voltage Surge Immunity
MIL STD 461C, Part 9 Radiated Emissions (EMI)

Cooling	Standby	Prime
Fan Load, HP (kW)	13.1 (9.8)	13.1 (9.8)
Coolant Capacity with radiator, US Gal (L)	24.0 (90.8)	24.0 (90.8)
Coolant Flow Rate, Gal/min (L/min)	162.0 (613.2)	162.0 (613.2)
Heat Rejection To Coolant, Btu/min (MJ/min)	15340.0 (16.3)	13660.0 (14.5)
Heat Radiated To Room, Btu/min (MJ/min)	5530.0 (5.9)	4920.0 (5.2)
Maximum Coolant Friction Head, psi (kPa)	8.0 (55.2)	8.0 (55.2)
Maximum Coolant Static Head, ft (m)	60.0 (18.3)	60.0 (18.3)

Air		
Combustion Air, scfm (m^3/min)	1226.0 (34.7)	1126.0 (31.9)
Alternator Cooling Air, scfm (m^3/min)	3420.0 (96.8)	3420.0 (96.8)
Radiator Cooling Air, scfm (m^3/min)	22700.0 (642.4)	22700.0 (642.4)
Max. Static Restriction, in H_2O (Pa)	0.50 (124.50)	0.50 (124.50)

Rating Definitions

Standby Rating based on: Applicable for supplying emergency power for the duration of normal power interruption. No overload capability is available for this rating. (Equivalent to Fuel Stop Power in accordance with ... AS2789.

Figure 6–53. Example DFXX Generator Set Specification Sheet.

The generator set room inlet(s) and outlet(s) will cause airflow restriction. See **Figure 6–54**. The inlet restriction is the pressure drop labeled ÄP_i in **Figure 6–54**. The outlet restriction is the pressure drop across the outlet and any installed ducting, labeled ÄP_o in **Figure 6–54**. The sum of these two values must be less than the maximum allowed restriction listed in the generator set technical information:

ÄP_i + ÄP_o < Max. Static Restriction (from **Generator Set Data Sheet**).

If the total system restriction exceeds the maximum allowed, reduced airflow will result. Reduced airflow will prevent the cooling system from performing to its rated ambient temperature. Overheating and shutdown are possible.

Additional cooling system performance details can be found on the generator set model's **Cooling System Data Sheet**. Consider the example shown in **Figure 6–55**. Assume an example 50 Hz standby generator set is installed in a room with a total airflow restriction of 0.25 in water (6.4 mm water). For the 50 °C ambient system shown, the actual ambient capability of this system is 47 °C.

Pressure drop data for inlets, outlets, louvers, dampers, ducting, etc., should be obtained from the manufacturer for the volume flow rates predicted. For installations in North America, refer to ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers) publications for recommendations on duct design if air ducts are required.

Once all equipment is installed in the room, the airflow restriction must be verified to insure that it is within limits. See **Airflow Restriction** in **System Verification**, page 6–81.

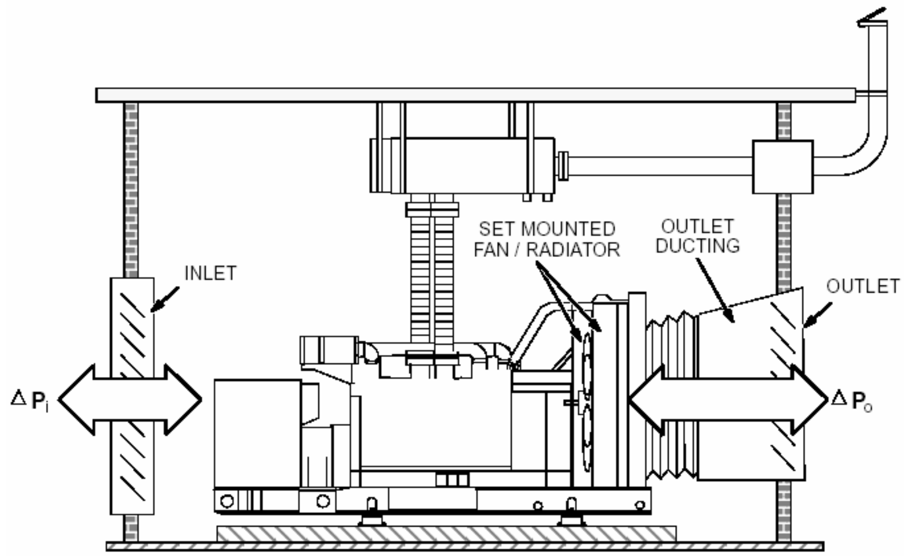


Figure 6–54. Room inlet and outlet airflow restriction.

50 Degree C Ambient Radiator Cooling System

Duty		Rating (kW)	Max Cooling @ Air Flow Static Restriction, Unhoused (inches water/mm water)				Housed in Free Air, No Air Discharge Restriction				
			0.0 /0.0	0.25 /6.4	0.5 /12.7	0.75/19.1	F183	F184	F200	F201	F202
			Maximum Allowable Ambient Temperature, Degree C								
60 Hz	Standby	300	50	50	48.2	N/A	43.9	N/A	45	45	44
	Prime	270	52.5	52	50.5	N/A	45	N/A	N/A	N/A	N/A
50 Hz	Standby	275	50	47	42.8	N/A	40	N/A	N/A	N/A	N/A
	Prime	250	51.6	51.3	46.2	N/A	40.8	N/A	N/A	N/A	N/A

Figure 6–55. Example DXXX Cooling System Data Sheet

If a set–mounted radiator/fan is not used, the auxiliary fans must deliver the required amount of air against the restrictions imposed by the inlets and outlets in order to maintain designed room temperature. Consult equipment suppliers for assistance.

Ventilating Multiple Generator Sets

- Each generator set in a multiple set installation shall receive the required amount of fresh air flow.

For applications where multiple generator sets are installed in the same room, the ventilation system must be designed so that the required amount of air will flow across each generator set. The goal in such installations is to have uniform flow across all units. There are several methods to achieve this, including:

- Proper location of room inlets and outlets
- Ducting.

With multiple set installations, additional care is required to make sure that hot expelled ventilation air from one set is not recirculated into the inlet of any other set. Examples of good and poor designs are shown in **Figure 6–56**.

Louver Operation

- Louvers shall open immediately upon generator set start–up for emergency / standby installations. In cold climates, louvers may open partially for combustion air only and controlled to modulate the temperature in the room.

Generator sets used for emergency or standby power are expected to handle full load immediately upon start–up. For these situations, make sure that the louvers are open and permit full air flow as soon as the set is started.

In cold climates, or when the generator set is operated or tested under light or no load, the full air flow through the site may result in overcooling. In these instances, louvers can be thermostatically controlled to keep the room temperature at an acceptable level and permit proper cooling. Be cautious of creating a negative pressure that may be a health hazard to generator set room personnel.

Ventilation air can be recirculated to modulate the temperature in the generator set room for cold climate operation. This will help the generator set warm up faster and keep fuel temperatures higher than the fuel cloud point. This recirculation system should be thermostatically controlled to maintain an appropriate temperature in the room. See **Figure 6–57**.

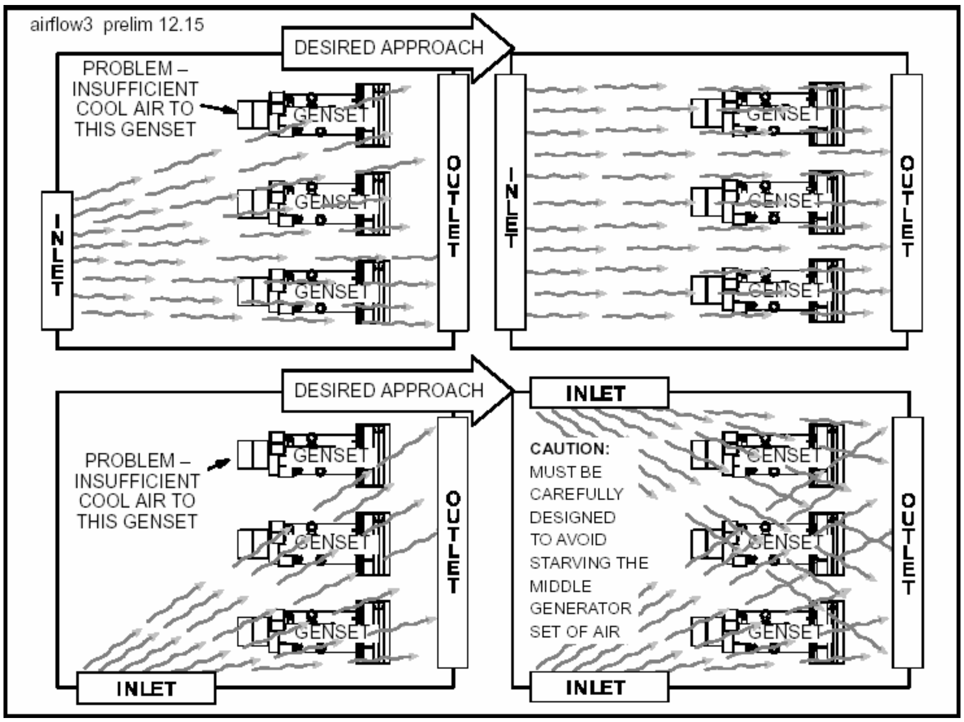


Figure 6–56. Multiple Generator Set Installation

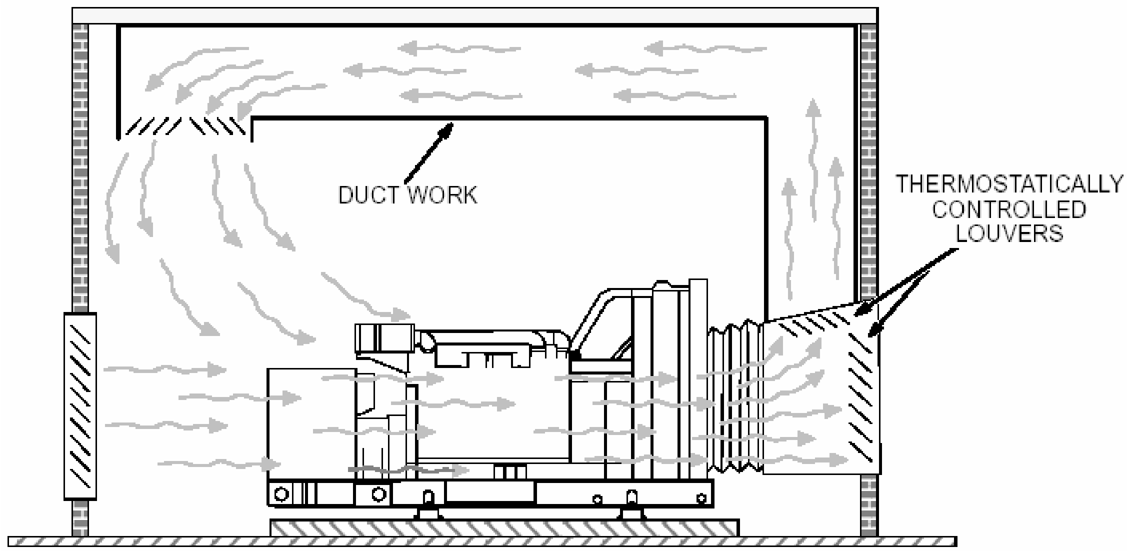


Figure 6–57. Room Recirculation System

Blocking Walls

- If a blocking wall is installed, it shall be located no closer than a distance equal to 1X the discharge louver height away from the building. For optimal performance, the wall should be located approximately 3X the discharge louver height away from the building.
- A turning vane and drain shall be included with any blocking wall installation.

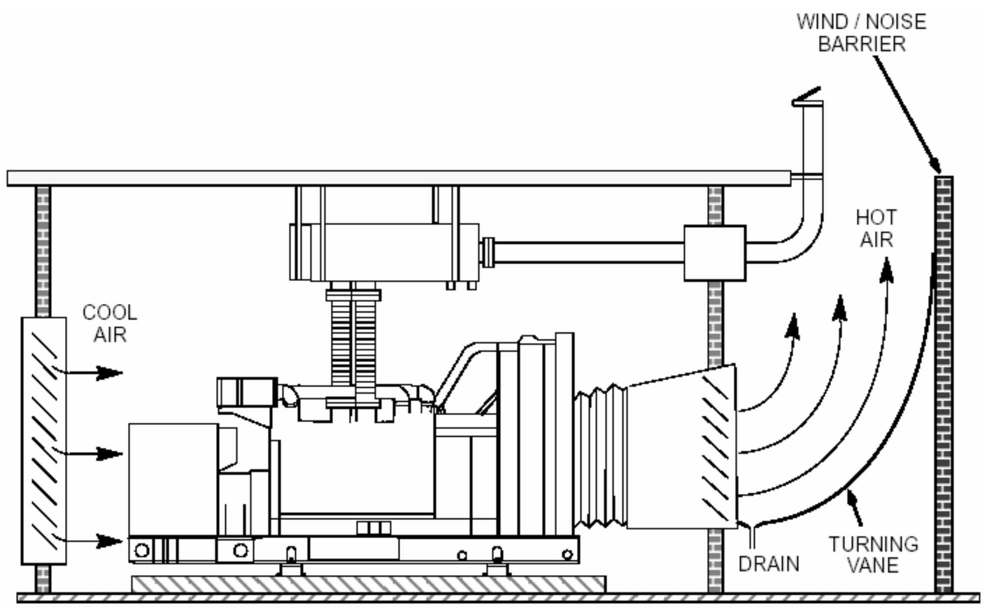


Figure 6–58. Blocking Wall and Turning Vane

Blocking walls can be constructed to prevent wind from blowing into the ventilation outlet. See **Figure 6–58**. The blocking wall should be located a distance at least equal to the radiator outlet away from the outlet. Better performance is achieved at a distance of approximately 3 times the radiator air outlet. A turning vane should be used to help reduce the restriction caused by the wall. A drain should be included with the turning vane to prevent rain water from entering the generator set room.

Ventilation Air Filtration

The generator set room must be kept free from dirt and debris. Ventilating air that is polluted with dust, fibers, salt, or other chemicals or materials may require special filters on the room ventilation system, engine, or alternator. If filters are used, their airflow restriction must be considered. For generator sets with set–mounted radiators, the filter restriction must be included in the total airflow restriction calculation. The total restriction, including filters, must remain below the total allowed restriction listed in the generator set technical information. (See **Airflow Restriction**, page 6–76.)

- If ventilation system filters are installed, a system for detecting plugged filters shall be in place.

If filters are used, there should be provisions in place to monitor their condition and detect clogged filters. Pressure drop indicators can be installed on the room ventilation system. Other solutions may also be acceptable.

Altitude and Ambient Temperature

Installation site altitude and temperature affect the density of the air surrounding the generator set, which in turn affects engine, alternator, and cooling system performance. For additional details, including a discussion of Limiting Ambient Temperature (LAT), see the **Generator Set Cooling Systems** and **Ambient Conditions** sections of this manual.

System Verification

Upon system installation, field tests should be performed to make sure that design criteria have been met.

Room Temperature Rise

The following procedure can be used to compare actual versus designed room temperature rise:

1. Run the generator set at full load (1.0 power factor is acceptable) long enough for the engine coolant or oil temperature to stabilize. This will take approximately 1 hour.
2. With the generator set still running at rated load, measure the air temperature of the generator set room at the air cleaner inlet.
3. Measure the outdoor air temperature in the same location that was used in Step 5 (from **Determining Airflow Requirements**, page 6–66.)
4. Calculate the temperature difference between the outdoors and the generator set room.
5. Verify that the design room temperature rise is not exceeded.

If the design room temperature rise is exceeded, more detailed testing of the facility or corrections in the system design will be required.

Airflow Restriction

Before the generator set is placed in service, the room airflow restriction should be measured to confirm that the system does not exceed the maximum allowed airflow restriction listed in the generator set technical information. Room airflow restriction should be measured according to **Figure 6–59** and **Figure 6–60**.

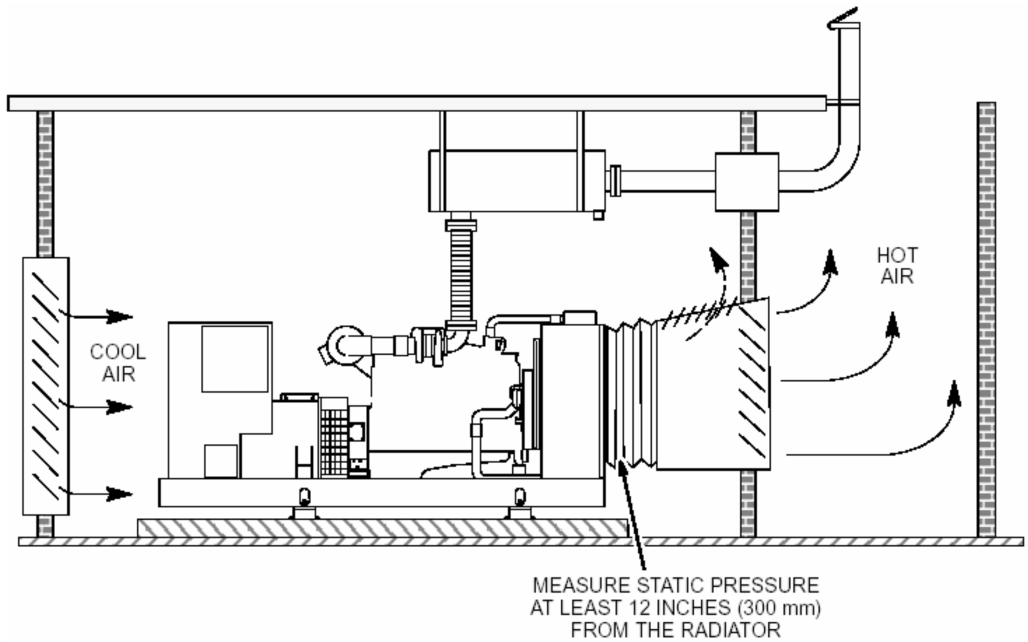


Figure 6–59. Measuring Airflow Restriction

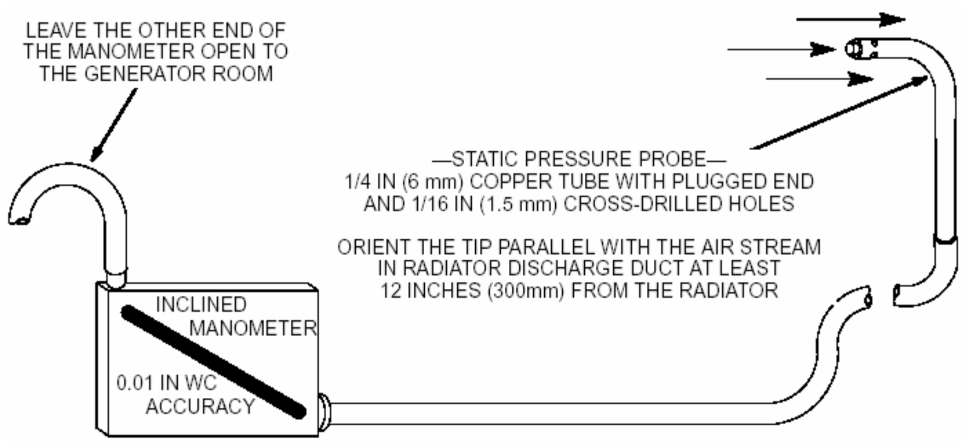


Figure 6–60. MEasuring Airflow Restriction

General Guidelines

Ventilation of the generator room is necessary to remove the heat expelled from the engine, alternator and other heat generating equipment in the genset room, as well as to remove potentially dangerous exhaust fumes and to provide combustion air. Poor ventilation system design leads to high ambient temperatures around the generator set that can cause poor fuel efficiency, poor generator set performance, premature failure of components, and overheating of the engine. It also results in poor working conditions around the machine.

Selection of the intake and exhaust ventilation locations is critical to the proper operation of the system. Ideally, the inlet and exhaust allow the ventilating air to be pulled across the entire generator room. The effects of prevailing winds must be taken in to consideration when determining exhaust air location. These effects can seriously degrade skid–mounted radiator performance. If there is any question as to the wind speed and direction, blocking walls can be used to prevent wind blowing into the engine exhaust air outlet (See **Figure 6–61**). Care should also be taken to avoid ventilation exhausting into a recirculation region of a building that forms due to prevailing wind direction.

MIXTURE BASE		MIXTURE PERCENTAGES (ANTIFREEZE/WATER)					
		0/100	30/70	40/60	50/50	60/40	95/5
ETHYLENE GLYCOL	FREEZING POINT	32° F (0° C)	4° F (–16° C)	–10° F (–23° C)	–34° F (–36° C)	–65° F (–54° C)	8° F (–13° C)
	BOILING POINT	212° F (100° C)	220° F (104° C)	222° F (106° C)	226° F (108° C)	230° F (110° C)	345° F (174° C)
PROPYLENE GLYCOL	FREEZING POINT	32° F (0° C)	10° F (–12° C)	–6° F (–21° C)	–27° F (–33° C)	–56° F (–49° C)	–70° F (–57° C)
	BOILING POINT	212° F (100° C)	216° F (102° C)	219° F (104° C)	222° F (106° C)	225° F (107° C)	320° F (160° C)

Table 6–7. Freezing and Boiling Points vs. Concentration of Antifreeze

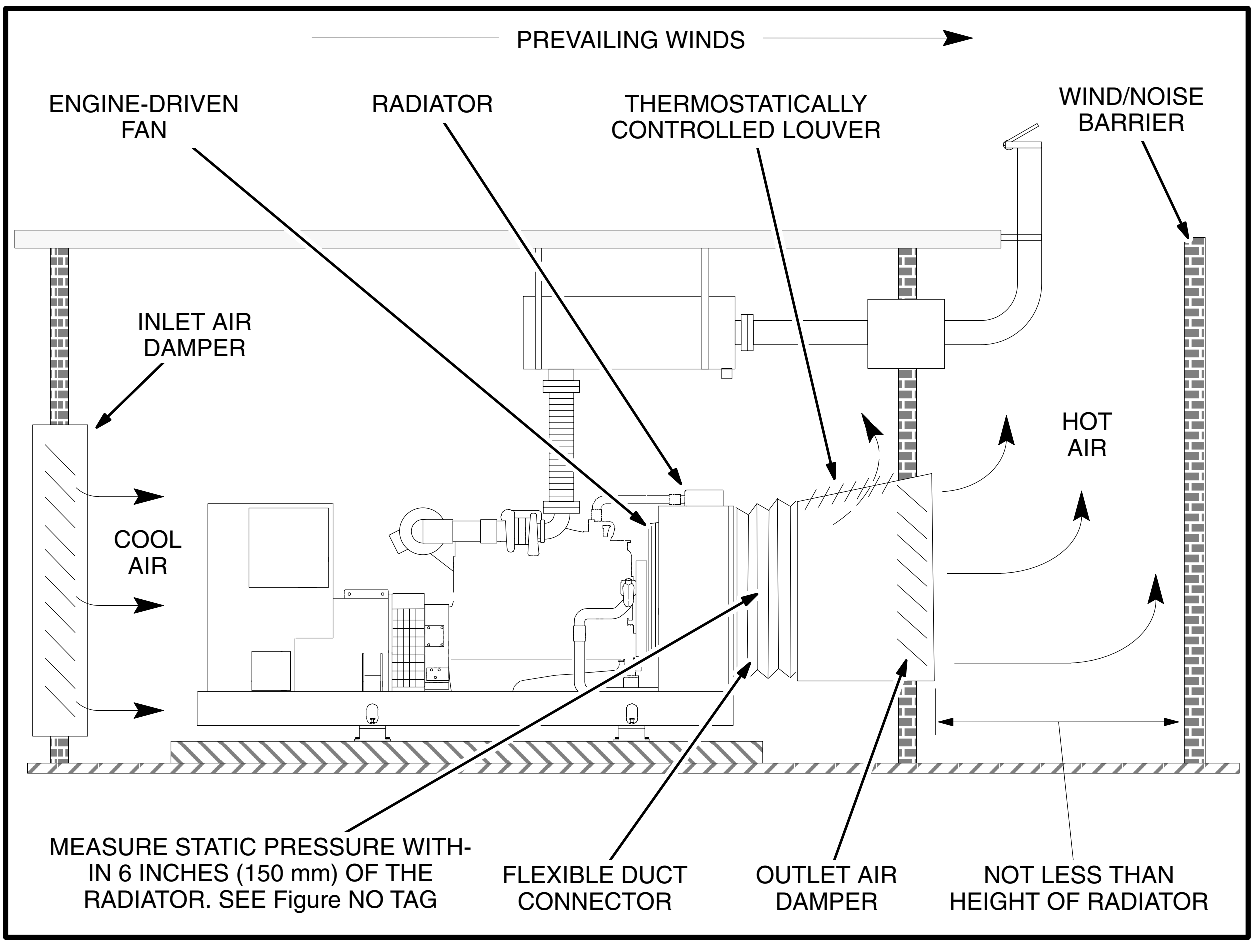


Figure 6–61. Factory-Mounted Radiator Cooling

Ventilating air that is polluted with dust, fibers, or other materials may require special filters on the engine and/or alternator to allow proper operation and cooling, particularly in prime power applications. Consult the factory for information on use of generator sets in environments that include chemical contamination.

Engine crankcase ventilation systems can exhaust oil–laden air into the generator set room. The oil can then be deposited on radiators or other ventilation equipment, impeding their operation. Use of crankcase ventilation breather traps or venting of the crankcase to outdoors is best practice.

Attention should be give to the velocity of intake air brought into the generator set room. If the air flow rate is too high, the generator sets will tend to pull rain and snow into the generator set room when they are running. A good design goal is to limit air velocity to between 500–700 f/min (150–220 m/min).

In cold climates, the radiator exhaust air can be recirculated to modulate the ambient air temperature in the generator set room. This will help the generator set warm up faster, and help to keep fuel temperatures higher than the cloud point of the fuel. If recirculation dampers are used, they should be designed to “fail closed”, with the main exhaust dampers open, so that the generator set can continue to operate when required. Designers should be aware that the generator set room operating temperature will be very close to the outdoor temperature, and either not route water piping through the generator set room, or protect it from freezing.

As ventilating air flows through an equipment room, it gradually increases in temperature, particularly as it moves across the generator set. See **Figure 6–62**. This can lead to confusion as to temperature ratings of the generator set and the overall system. Cummins Power Generation practice is to rate the cooling system based on the ambient temperature around the alternator. The temperature rise in the room is the difference between the temperature measured at the alternator, and the outdoor temperature. The radiator core temperature does not impact the system design, because radiator heat is moved directly out of the equipment room.

A good design goal for standby applications is to keep the equipment room at not more than 125° F (50° C). However, limiting generator set room temperature to 100° F (40° C) will allow the generator set to be provided with a smaller, less expensive skid–mounted radiator package, and eliminate the need for engine de–rating due to elevated combustion air temperatures[16]. Be sure that the design specifications for the generator set fully describe the assumptions used in the design of the ventilation system for the generator set.

The real question then becomes, “What is the maximum temperature of outdoor air when the generator set will be called to operate?” This is simply a question of the maximum ambient temperature in the geographic region where the generator set is installed.

In some areas of the northern United States for example, the maximum temperature is likely to not exceed 90° F. So, a designer could select the ventilation system components based on a 10° F temperature rise with a 100° F generator set cooling system, or based on a 35° F temperature rise with a 125° F generator cooling system.

The key to proper operation of the system is to be sure that the maximum operating temperature and temperature rise decisions are carefully made, and that the generator set manufacturer designs the cooling system (not just the radiator) for the temperatures and ventilation required.

The result of improper system design is that the generator set will overheat when ambient temperatures and load on the generator set is high. At lower temperatures or lower load levels the system may operate properly.

16 .Check the engine manufacturer’s data for information on derating practice for a specific engine. Information on Cummins Power Generation products is on the Power Suite.

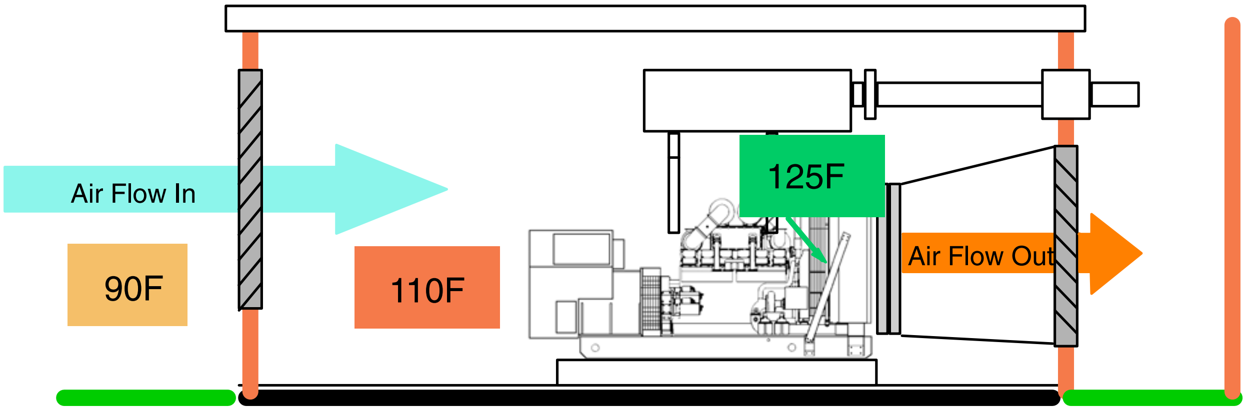


Figure 6–62. Typical Air Temperature Surrounding an Operating Genset

Air Flow Calculations

The required air flow rate to maintain a specific temperature rise in the generator room is described by the formula:

$$m = \frac{Q}{c_p \, T \, d}$$

Where: m = Mass flow rate of air into the room; ft^3/min (m^3/min)

Q = Heat rejection into the room from the genset and other heat sources; BTU/min (MJ/min).

c_p = Specific heat at constant pressure; 0.241 BTU/lb–° F ($1.01x10^{-3}$ MJ/kg–° C).

ΔT = Temperature rise in the generator set room over outdoor ambient; ° F (° C).

d = Density of air; 0.0754 lb/ft^3 (1.21 kg/m^3).

Which can be reduced to:

$$m = \frac{Q}{0.241 \bullet 0.0754 \bullet \Delta T} = \frac{55.0Q}{\Delta T} \; (ft^3/min)$$

OR:

$$m = \frac{Q}{(1.01 \bullet 10^{3)} \bullet 1.21 \bullet \Delta T} = \frac{818Q}{\Delta T} \; (m^3/min)$$

The total airflow required in the room is the calculated value from this equation, plus the combustion air required for the engine[17].

In this calculation the major factors are obviously the heat radiated by the generator set (and other equipment in the room) and the allowable maximum temperature rise.

17 Data required for calculations for specific Cummins Power Generation generator sets can be found on the Cummins Power Suite. There may be significant differences in the variables used in these calculations for various manufacturer's products.

Since the heat rejection to the room is fundamentally related to the kW size of the generator set and that rating is controlled by building electrical load demand, the major decision to be made by the designer regarding ventilation is what allowable temperature rise is acceptable in the room.

Field Testing of Ventilation Systems

Since it is difficult to test for proper operation, one factor to view in system testing is the temperature rise in the room under actual operating conditions, vs. the design temperature rise. If the temperature rise at full load and lower ambient temperatures is as predicted, it is more probable that it will operate correctly at higher ambients and load levels.

The following procedure can be used for preliminary qualification of the ventilation system design:

1. Run the generator set at full load (1.0 power factor is acceptable) long enough for the engine coolant temperature to stabilize. This will take approximately 1 hour.
2. With the generator set still running at rated load, measure the ambient air temperature of the generator set room at the air cleaner inlet.
3. Measure the outdoor air temperature (in the shade).
4. Calculate the temperature difference between the outdoor temperature and the generator set room.
5. Verify that the design temperature rise of the generator room is not exceeded, and that the maximum top tank temperature of the engine is not exceeded.

If either the design temperature rise or top tank temperature is exceeded, more detailed testing of the facility or corrections in the system design will be required to verify proper system design.

Skid–Mounted Radiator Ventilation

In this configuration (**Figure 6–61**), the fan draws air through inlet air openings in the opposite wall and across the generator set and pushes it through the radiator which has flanges for connecting a duct to the outside of the building.

Consider the following:

- The location of the generator room must be such that ventilating air can be drawn directly from the outdoors and discharged directly to the outside of the building. Ventilation air should not be drawn from adjacent rooms. Exhaust should also discharge on the radiator air discharge side of the building to reduce the likelihood of exhaust gases and soot being drawn into the generator room with the ventilating air.
- Ventilating air inlet and discharge openings should be located or shielded to minimize fan noise and the effects of wind on airflow. When used, the discharge shield should be located not less than the height of the radiator away from the ventilation opening. Better performance is achieved at approximately 3 times the radiator height. In restricted areas, turning vanes will help to reduce the restriction caused by the barriers added to the system. When these are used, make provisions for precipitation run–off so that it is not routed into the generator room.
- The airflow through the radiator is usually sufficient for generator room ventilation. See the example calculation (under Air Flow Calculations in this section) for a method of determining the airflow required to meet room air temperature rise specifications.

- Refer to the recommended generator set Specification Sheet for the design airflow through the radiator and allowable airflow restriction. **The allowable air flow restriction must not be exceeded.** The static pressure (air flow restriction) should be measured, as shown in **Figures 6–61, 6–63, and 6–64**, to confirm, before the set is placed in service, that the system is not too restrictive This is especially true when ventilating air is supplied and discharged through long ducts, restrictive grilles, screens, and louvers.
- Rules of thumb for sizing ventilation air inlets and outlets have been applied or even published in the past but have more recently been largely abandoned. Due to large variation in louver performance and greater demands on installations for space, noise, etc., these rules of thumb have proven to be unreliable at best. Generally, louver manufacturers have charts of restriction versus airflow readily available. These charts combined with duct design and any other restriction can be easily compared to the published specifications for the generator set for a reliable method of determing acceptable restriction levels.
- For installations in North America, refer to the ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers) publications for recommendations on duct design if air ducts are required for the application. Note that the inlet duct must handle combustion airflow (see the Specification Sheet) as well as ventilating airflow and must be sized accordingly.
- Louvers and screens over air inlet and outlet openings restrict airflow and vary widely in performance. A louver assembly with narrow vanes, for example, tends to be more restrictive than one with wide vanes. The effective open area specified by the louver or screen manufacturer should be used.
- Because the radiator fan will cause a slight negative pressure in the generator room, it is highly recommended that combustion equipment such as the building heating boilers not be located in the same room as the generator set. If this is unavoidable, it will be necessary to determine whether there will be detrimental effects, such as backdraft, and to provide means (extra large room inlet openings and/or ducts, pressurizing fans, etc.) to reduce the negative pressure to acceptable levels.
- In colder climates, automatic dampers should be used to close off the inlet and outlet air openings to reduce heat loss from the generator room when the generator set is not running. A thermostatic damper should be used to recirculate a portion of the radiator discharge air to reduce the volume of cold air that is pulled through the room when the set is running. The inlet and outlet dampers must fully open when the set starts. The recirculating damper should close fully at 60° F (16° C).
- Other than recirculating radiator discharge air into the generator room in colder climates, all ventilating air must be discharged directly outside the building. It must not be used to heat any space other than the generator room.
- A flexible duct connector must be provided at the radiator to prevent exhaust air recirculation around the radiator, to take up generator set movement and vibration, and prevent transmission of noise.

Note: Duct adapters or radiator shrouds may not be designed to support weight or structure beyond that of the flexible duct adatper. Avoid supporting additional weight/equipment with the duct adapter or radiator shroud without sufficient analysis of strength and vibration considerations.

- Typically a generator set with a Skid–Mounted radiator is designed for full–power cooling capability in an ambient temperature of 40° C while working against an external cooling air flow resistance of 0.50 inch WC (Point A, **Figure 6–64**). External airflow resistance is that caused by ducts, screens, dampers, louvers, etc. Operation in ambient temperatures higher than the design temperature can be considered (Point B, **Figure 6–64**, for example) if derating is acceptable and/or resistance to cooling airflow is less than the resistance under which the cooling capability was tested. (Less resistance means greater airflow through the radiator, offsetting the effect of higher air temperature on radiator cooling capability.) Close consultation with the factory is required to attain acceptable generator set cooling capability in an elevated ambient temperature.

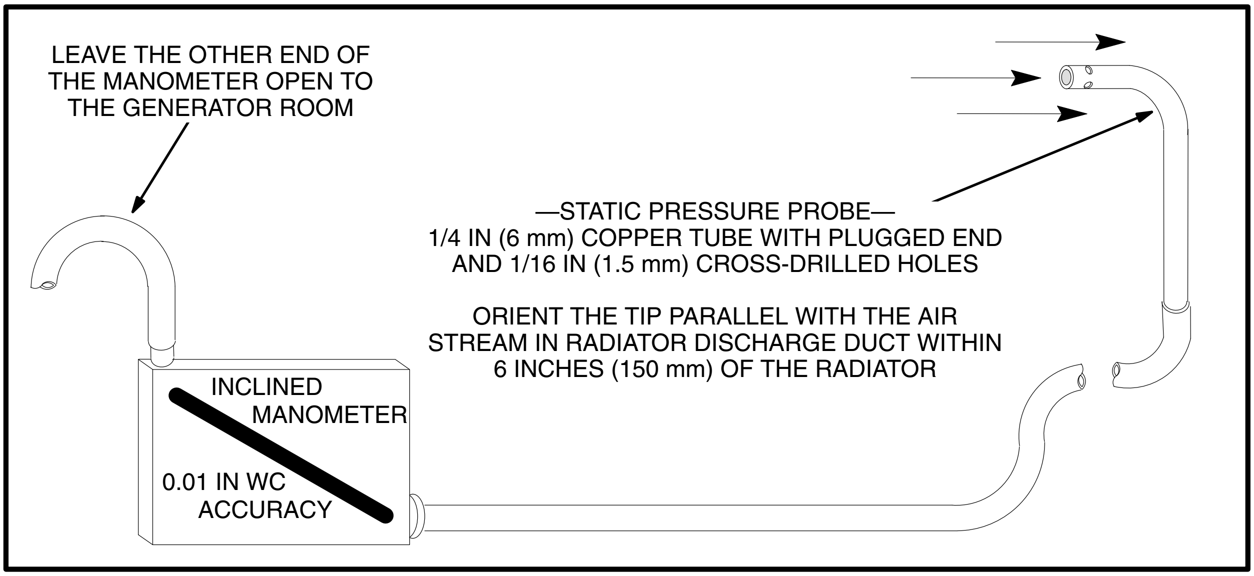


Figure 6–63. Recommended Instrumentation for Measuring Air Flow Restriction

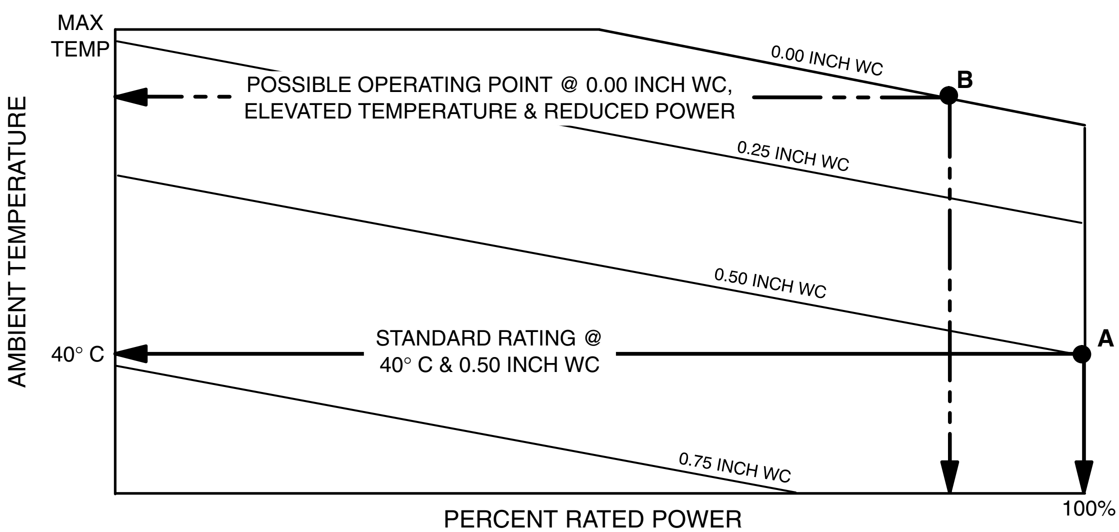


Figure 6–64. Figure Cooling Capability in Elevated Ambients

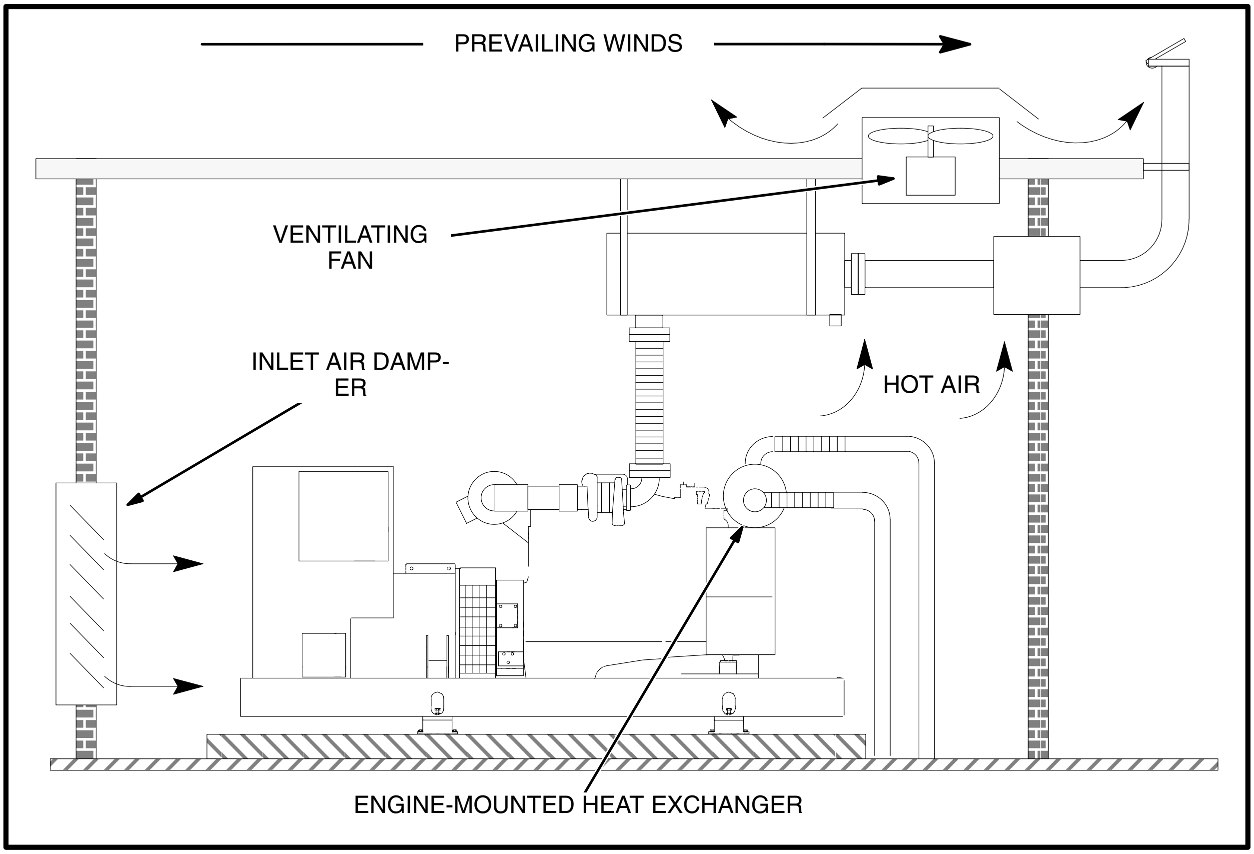


Figure 6–65. Ventilation for a Heat Exchanger Cooling System

Ventilating Heat Exchanger or Remote Radiator Applications

A heat exchanger (**Figure 6–65)**, or remote radiator cooling system might be selected because of noise considerations or because the air flow restriction through long ducts would be greater than that allowed for the engine–driven radiator fan. Consider the following:

- Ventilating fans must be provided for the generator room. The ventilating fans must have the capacity of moving the required flow of ventilating air against the airflow restriction. See the following example calculation for a method of determining the airflow required for ventilation.
- A remote radiator fan must be sized primarily to cool the radiator. Depending on its location, it might also be used to ventilate the generator room.
- The fan and air inlet locations must be such that the ventilating air is drawn forward over the set.

In general, remote cooling systems have more parasitic loads, so slightly less kW capacity is available from the generator set in those applications. Remember to add the parasitic loads to the total load requirements for the generator set.

Example Ventilating Air Flow Calculation

The recommended generator set Specification Sheet indicates that the heat radiated to the room from the generator set (engine and generator) is 4,100 BTU/min. The muffler and 10 feet of 5–inch diameter exhaust pipe are also located inside the generator room. Determine the airflow required to limit the air temperature rise to 30° F.

1. Add the heat inputs to the room from all sources. **Table 6–8** indicates that the heat loss from 5–inch exhaust pipe is 132 BTU/min per foot of pipe and 2,500 BTU/min from the muffler. Add the heat inputs to the room as follows:

Heat rejection from generator set	4,100
Heat from Exhaust Pipe–10 x 132	1,320
Heat from Muffler	2,500
Total Heat to Generator Room (BTU/Min)	7,920

PIPE DIAMETER INCHES (mm)	HEAT FROM PIPE BTU/MIN-FOOT (kJ/Min-Meter)	HEAT FROM MUFFLER BTU/MIN (kJ/Min)
1.5 (38)	47 (162)	297 (313)
2 (51)	57 (197)	490 (525)
2.5 (64)	70 (242)	785 (828)
3 (76)	84 (291)	1,100 (1,160)
3.5 (98)	96 (332)	1,408 (1,485)
4 (102)	108 (374)	1,767 (1,864)
5 (127)	132 (457)	2,500 (2,638)
6 (152)	156 (540)	3,550 (3,745)
8 (203)	200 (692)	5,467 (5,768)
10 (254)	249 (862)	8,500 (8,968)
12 (305)	293 (1,014)	10,083 (10,638)

Table 6–8. Heat Losses From Uninsulated Exhaust Pipes and Mufflers

2. The required airflow to account for heat rejection in the room is proportional to the total heat input divided by the allowable room air temperature rise (See Ventilation earlier in this section):

$$m = \frac{55 \bullet Q}{\Delta T} = \frac{55 \bullet 7920}{30} = 14{,}520 \text{ ft}^3\text{/min}$$

Fuel Supply

Diesel Fuel Supply

Diesel engine–driven generator sets are generally designed to operate on ASTM D975 number 2 diesel fuel. Other fuels may be suitable for short term operation, if the fuel meets the quality and physical characteristics described in **Table 6–9**. Consult engine manufacturer for use of other fuels.

Care should be taken in the purchase of fuel and filling of tanks to prevent ingress of dirt and moisture into the diesel fuel system. Dirt will clog injectors and cause accelerated wear in the finely machined components of the fuel system. Moisture can cause corrosion and failure of these components.

Diesel generator sets consume approximately 0.07 gal/hr per rated–kW (0.26 liters/hr per rated–kW) of fuel at full load, based on their standby rating. For example, a 1000 kW standby generator set will consume approximately 70 gal/hr (260 liters/hr) of fuel. The main fuel tank for a diesel generator set may be either a sub–base tank (mounted under the generator set skid), or a remote fuel tank. If the main (bulk) fuel tank is remote from the generator set, an intermediate (day) tank may be required to properly supply the generator set. There are considerable differences in engine capabilities between suppliers, so the fuel system design should be reviewed for the specific generator set installed at a site.

The primary advantage of sub–base fuel tanks is that the system can be factory designed and assembled to minimize site work. However, they may not be a practical (or possible) selection based on main fuel tank capacity requirements and code limitations, and the ability to access the tank for re–filling. When selecting a sub–base fuel tank, be aware that the generator set control system and other service maintenance points may be raised to an impractical height. This may require structures to be added to the installation to allow convenient service or meet operational requirements.

Because of the limitations of the mechanical fuel pumps on most engines, many installations that require remote main (bulk) fuel tanks will also require intermediate (day) tanks. The main tank may be either above the generator set, or below it, and each of these installations will require slightly different intermediate tank designs and fuel control systems.

Figures 6–66 and 6–67 illustrate typical diesel fuel supply systems.

PROPERTY	SPECIFICATIONS	GENERAL DESCRIPTION
Viscosity (ASTM D445)	1.3–1.5 centisokes (mm/sec) at 40° C (104° F)	The injection system works most effectively when the fuel has the proper ”body” or viscosity. Fuels that meet the requirements of ASTM 1–D or 2–D fuels are satisfactory with Cummins fuel systems.
Cetane Number (ASTM D613)	42 minimum above C (32° F) 45 minimum below 0° C (32° F)	Cetane number is a measure of the starting and warm–up characteristics of a fuel. In cold weather or in service with prolonged low loads, a higher cetane number is desirable.
Sulphur Content (ASTM D129 or 1552)	Not to exceed 0.5 mass percent (see note)	Diesel fuels contain varying amounts of various sulphur compounds which increase oil acidity. A practical method of neutralizing high acids from higher sulphur is to change oil more frequently or use a higher TBN oil (TBN = 10 to 20) or both. The use of high sulphur fuel (above 0.5 mass percent)will result in sulfate formation in the exhaust gas under high load continuous conditions. High sulphur fuel will also shorten the life of certain components in the exhaust system, including the oxidation catalyst.
Active Sulphur (ASTM D130)	Copper strip corrosion not to exceed No.2 rating after three hours at 50° C (122° F)	Some sulphur compounds in fuel are actively corrosive. Fuels with a corrosion rating of three or higher can cause corrosion problems.
Water and Sediment (ASTM D1796)	Not to exceed 0.05 volume percent	The amount of water and solid debris in the fuel is generally classified as water and sediment. It is good practice to filter the fuel while it is being put into the fuel tank. More water vapor condenses in partially filled tanks due to tank breathing caused by temperature changes. Filter elements, fuel screens in the fuel pump, and fuel inlet connections on injectors, must be cleaned or replaced whenever they become dirty. These screens and filters, in performing their intended function, will become clogged when using a poor or dirty fuel and will need replacing more often.
Carbon Residue (Ramsbottom, ASTM D254 or Conradson, ASTM D189)	Not to exceed 0.35 mass percent on 10 volume percent residuum	The tendency of a diesel fuel to form carbon deposits in an engine can be estimated by determining the Ramsbottom or Conradson carbon residue of the fuel after 90 percent of the fuel has been evaporated.
Density (ASTM D287)	42–30 degrees API gravity at 60° F (0.816–0.876 g/cc at 15° C)	Gravity is an indication of the high density energy content of the fuel. A fuel with a high density (low API gravity) contains more BTUs per gallon than a fuel with a low density (higher API gravity). Under equal operating conditions, a higher density fuel will yield better fuel economy than a low density fuel.
Cloud Point (ASTM D97)	6° C (10° F) below lowest ambient temperature at which fuel expected to operate.	The cloud point of the fuel is the temperature at which crystals of paraffin wax first appear. Crystals can be detected by a cloudiness of the fuel. These crystals will cause a filter to plug.
Ash (ASTM D482)	Not to exceed 0.02 mass percent (0.05 percent with lubricating oil blending)	The small amount of non–combustible metallic material found in almost all petroleum products is commonly called ash.
Distillation (ASTM D86)	The distillation curve must be smooth and continuous.	At least 90 percent of the fuel must evaporate at less than 360° C (680° F). All of the fuel must evaporate at less than 385° C (725° F).
Acid Number (ASTM D664)	Not to exceed 0.1 Mg KOH per 100ML	Using fuel with higher acid numbers can lead to higher levels of wear than is desirable. The total acid number is located in ASTM D664
Lubricity	3100 grams or greater as measured by US Army scuffing BOCLE test or Wear Scar Diameter (WSD) less than 0.45mm at 60° C (WSD less than 0.38mm at 25° C) as measured by HFRR method.	Lubricity is the ability of a liquid to provide hydrodynamic and/or boundary lubrication to prevent wear between moving parts.
NOTE: Federal or local regulations may require a lower sulphur content than is recommended in this table. Consult all application regulations before selecting a fuel for a given engine application.		

Table 6–9. Diesel Fuel Specifications

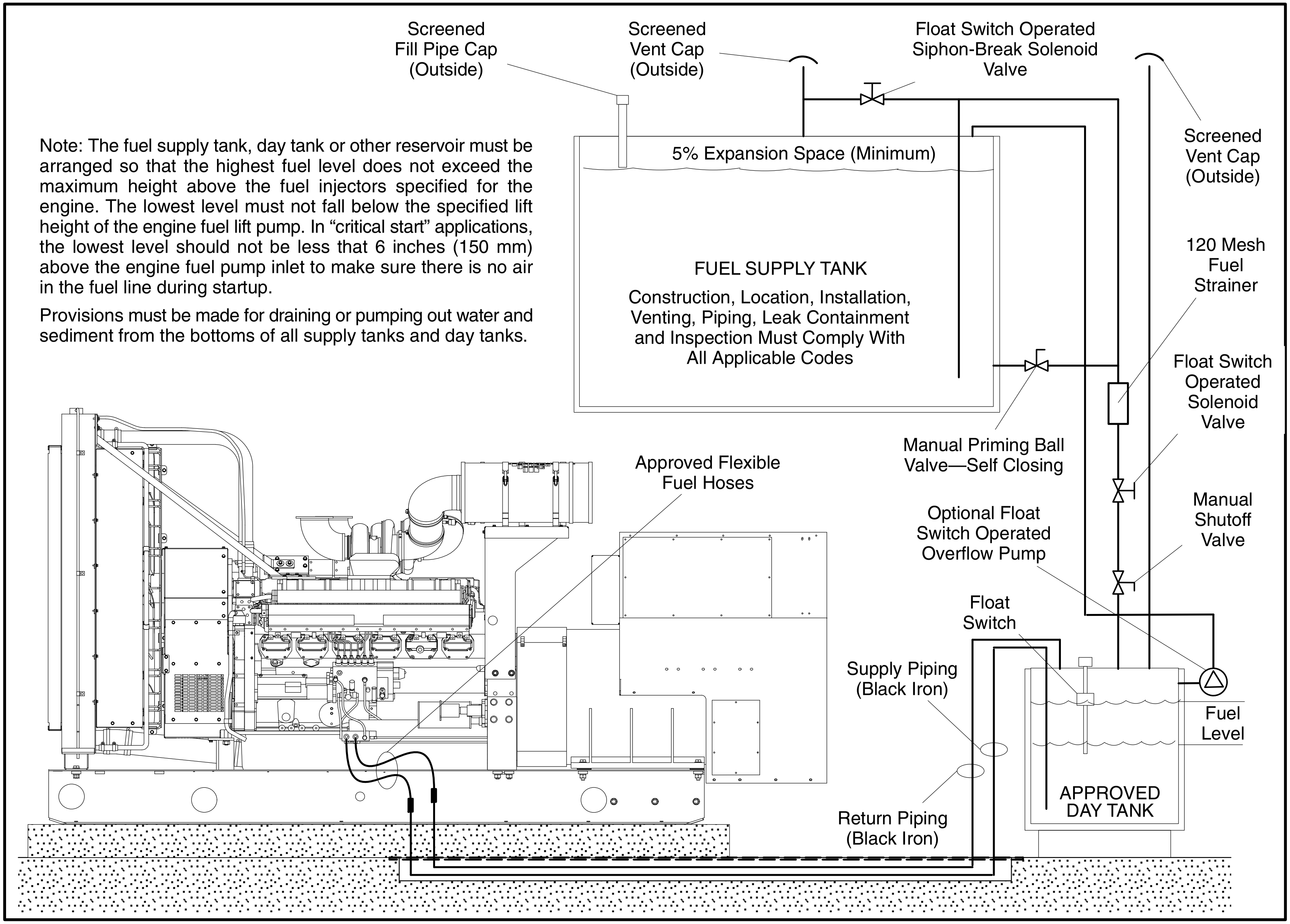
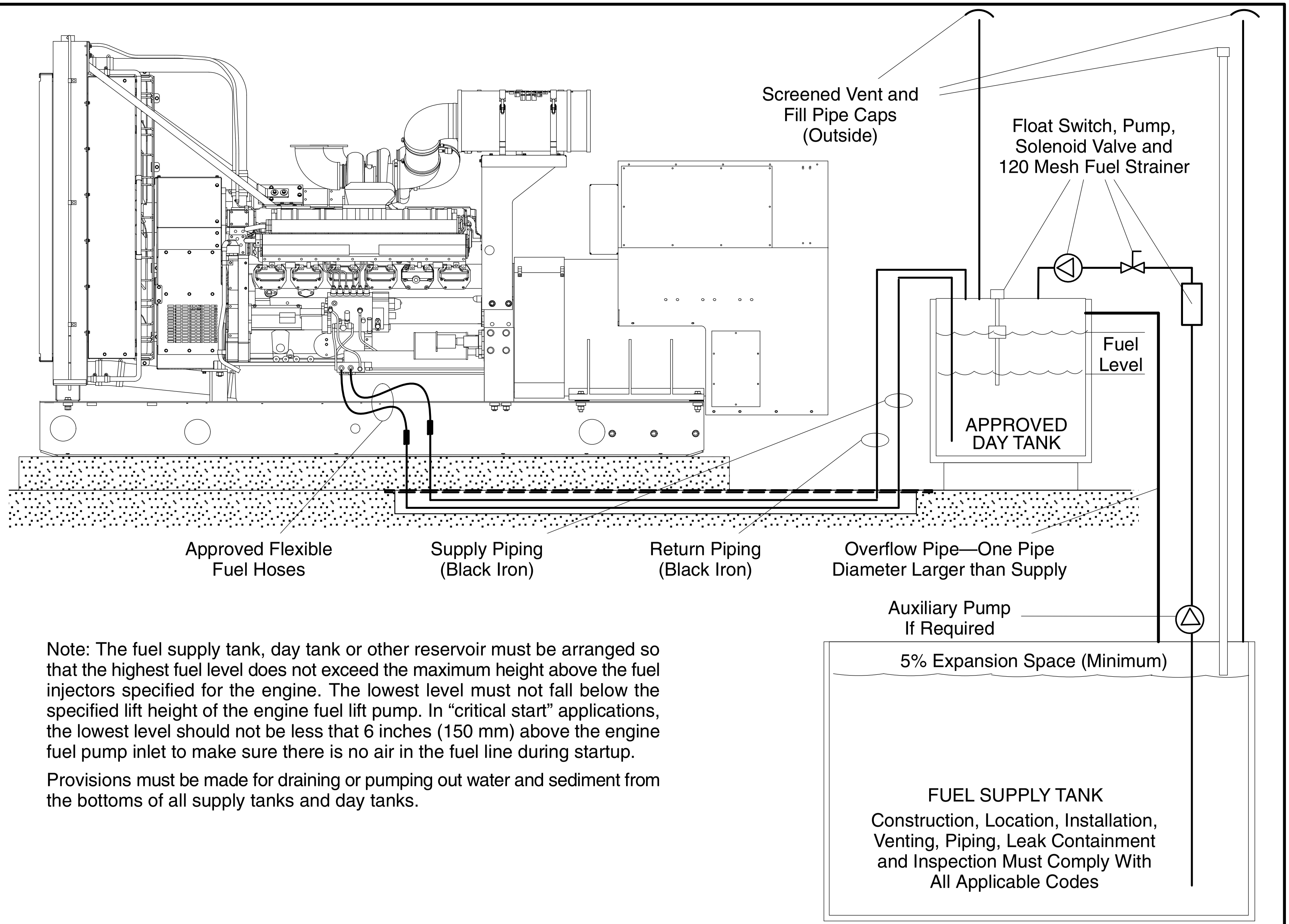


Figure 6–66. Typical Fuel Supply System—Supply Tank Above Generator Set



Note: The fuel supply tank, day tank or other reservoir must be arranged so that the highest fuel level does not exceed the maximum height above the fuel injectors specified for the engine. The lowest level must not fall below the specified lift height of the engine fuel lift pump. In “critical start” applications, the lowest level should not be less that 6 inches (150 mm) above the engine fuel pump inlet to make sure there is no air in the fuel line during startup.

Provisions must be made for draining or pumping out water and sediment from the bottoms of all supply tanks and day tanks.

Figure 6–67. Typical Fuel Supply System—Supply Tank Below Generator Set

The following should be considered when designing and installing any diesel fuel supply system:

- Fuel supply tank capacity, construction, location, installation, venting, piping, testing, and inspection must comply with all applicable codes and their local interpretation[18]. Local environmental regulations generally require secondary containment (called a "rupture basin", "dike", or "bund") to prevent leaking fuel from entering the soil or the sewer system. The secondary containment area will normally include features to sense and sound an alarm when the main tank is leaking.
- Location should be chosen with consideration for accessibility for refilling and whether supply lines will need to be heated (in cold climates).
- The fuel supply tank must hold enough fuel to run the set for the prescribed number of hours[19] without refueling. Tank sizing calculations can be based on the hourly fuel consumption rates, tempered with the knowledge that full load operation of most generator sets is rare. Other considerations for tank sizing include the duration of expected power outages vs. availability of fuel deliveries and the storage life of the fuel. The storage life for diesel fuel is 1–1/2 to 2 years, when properly maintained.
- Fuel supply tanks must be adequately vented to prevent pressurization. There may be both primary and emergency venting requirements in a tank, depending on local codes and interpretations. They also must have provisions for manually draining or pumping out water and sediment, and have at least a five–percent expansion space to prevent spillage when the fuel warms up.
- The fuel lift pump, day tank transfer pump or float valve seat should be protected from fuel supply tank debris by a pre–filter or sediment bowl with a 100 to 120 mesh element.
- For emergency power systems, codes might not permit the fuel supply to be used for any other purpose, or may specify a draw–down level for other equipment that guarantees the fuel supply for emergency power use.
- The Cetane rating of No. 2 heating oil is not high enough for dependable starting of diesel engines in cold weather. Therefore, separate supply tanks for emergency power and building heating systems might be required.
- Separate fuel return lines to the day tank or supply tank must be provided for each generator set in a multiple–set installation to prevent pressurizing the return lines of idle sets. Also, a fuel return line must not include a shutoff device. Engine damage will occur if the engine is run with the line shut off.
- A day tank is required whenever pipe friction and/or supply tank elevation, either below the fuel pump inlet or above the fuel injectors, would cause an excessive fuel inlet or return restriction. Some generator set models are available with an integral skid–mounted or sub–base day tank.

NOTE: Where generator sets are paralleled or must satisfy short emergency start–time requirements, it is a requirement that a fuel tank or reservoir be located such that the lowest possible fuel level is not less than 6 inches (150 mm) above the fuel pump inlet. This will prevent air from accumulating in the fuel line while the set is not running, eliminating the period during startup when the air has to be purged. Options are available on some models for eliminating this requirement.

18 **US CODE NOTE:** In North America, NFPA Standards No. 30 and No. 37 are typical.

19 **US CODE NOTE:** NFPA110 defines number of required operating hours as the *Class* of an installation. Typical requirements are 2 hours if for emergency egress from the building, 8 hours for the duration of most outages.

- Day tank fuel temperature limits may be exceeded in some applications when the warm fuel from the engine is returned to the day tank. As fuel temperature increases, fuel density and lubricity decrease, reducing maximum power output and lubrication of fuel handling parts such as pumps and injectors. One solution is to pipe the fuel back to the supply tank rather than to the day tank. Other designs might require a fuel cooler to reduce the return fuel temperature to a safe level for return to the day tank. Consult the engine manufacturer for more information on the engine used, and its return fuel requirements[20].
- The day tank fuel transfer pump capacity and supply piping should be sized on the basis of the maximum fuel flow indicated on the recommended generator set Specification Sheet.
- Use **Table 6–9** as a guide for diesel fuel selection to obtain best performance.
- All fuel systems should have provisions for containment of fuel if a tank leaks, and also for situations where it is “overfilled”.
- Consider means to manually fill tanks if auto tank filling system fails.
- The supply pump from the main tank may be a duplex type to improve system reliability.
- Local fire codes may include specific requirements for the generator set, such as means to prevent fuel flow into the generator set room if a fire is sensed, and means to return fuel to the main tank if a fire occurs in the generator set room.

Diesel Fuel Piping

- Diesel fuel lines should be constructed from black iron pipe. Cast iron and aluminum pipe and fittings must not be used because they are porous and can leak fuel. Galvanized fuel lines, fittings, and tanks must not be used because the galvanized coating is attacked by the sulfuric acid that forms when the sulfur in the fuel combines with tank condensate, resulting in debris that can clog fuel pumps and filters. Copper lines should not be used because fuel polymerizes (thickens) in copper tubing during long periods of disuse and can clog fuel injectors. Also, copper lines are less rugged than black iron, and thus more susceptible to damage.

Note: Never use galvanized or copper fuel lines, fittings or fuel tanks. Condensation in the tank and lines combines with the sulfur in the diesel fuel to produce sulfuric acid. The molecular structure of the copper or galvanized lines or tanks reacts with the acid and contaminates the fuel.

- Approved flexible fuel hose must be used for connections at the engine to take up generator set movement and vibration.
- Piping from a day tank to the engine should run “down hill” all the way from the tank to the engine, with no overhead loops that can allow air to be entrained in the system.
- Fuel system piping should be properly supported to prevent vibration and breakage due to vibration. The piping should not run close to heating pipes, electrical wiring, or engine exhaust system components. The piping system design should include valves at appropriate locations to allow isolation of system components for repair without draining the entire fuel system.
- Piping systems should be regularly inspected for leaks and general condition. The piping system should be flushed before operation of the engine to remove dirt and other impurities that could damage the engine. Use of plugged “T” connections rather than elbows allows for easier cleaning of the piping system.

20 In general, Cummins engines may be installed with the fuel return plumbed to the day tank. The location of the return line varies with the engine provided.

- The engine manufacturer's data indicates the maximum fuel inlet and return restrictions, the maximum fuel flow, supply and return, and the fuel consumption. **Table 6–10** indicates minimum hose and pipe sizes for connections to a supply tank or day tank when it is within 50 feet (15 meters) of the set and at approximately the same elevation.

Hose and pipe size should be based on the maximum fuel flow rather than on the fuel consumption. It is highly recommended that the fuel inlet and return restrictions be checked before the generator set is placed in service.

Max Fuel Flow Rate GPH (L/hr)	Flex Hose No.*	NPS Pipe Size (in)	DN Pipe Size (mm)
Less than 80 (303)	10	1/2	15
81–100 (304–378)	10	1/2	15
101–160 (379–604)	12	3/4	20
161–230 (605–869)	12	3/4	20
231–310 (870–1170)	16	1	25
311–410 (1171–1550)	20	1–1/4	32
411–610 (1550–2309)	24	1–1/2	40
611–920 (2309–3480)	24	1–1/2	40

* Generic fuel hose suppliers' size specification.

Table 6–10. Minimum Fuel Hose and Pipe Sizes; Up to 50 Feet (15 Meters) Equivalent Length.

Sub–Base Fuel Tank

When a generator set is mounted on a sub–base fuel tank, the vibration isolators must be installed between the generator set and the fuel tank. The fuel tank must be able to support the weight of the set and resist the dynamic loads. It is required that the tank be mounted such that an air space is provided between the bottom of the tank and the floor underneath to reduce corrosion and permit visual inspections for leaks.

Day Tanks

When an intermediate day tank is required in an application, it is typically sized for approximately 2 hours of operation for the generator set at full load. (Subject to code limitations for fuel in the generator set equipment room.) Multiple generator sets may be fed from one day tank, but it is preferred that there be one day tank for each generator set in the system. The day tank should be located as close to the generator set as is practical. Position the tank to allow for manually filling the tank, should it become necessary.

The height of the day tank should be sufficient to put a positive head on the engine fuel pump. (Minimum level in tank not less than 6 inches [150 mm] above engine fuel inlet.) The maximum height of fuel in the day tank should not be sufficient to put a positive head on the engine fuel return lines.

Fuel return line location in the day tank is different depending on the type of engine used. Some engines require the fuel to be returned above the maximum tank level, others require fuel to be returned to the tank at the bottom (or below the minimum tank level). The engine manufacturer supplies these specifications.

Important features, either required or desired, of day tanks include:

- Rupture basin or bund. (Option, but required by law in many areas.)
- Float switch used for tank filling to control: a solenoid valve, if the bulk tank is above the day tank, or a pump, if the bulk tank is below the day tank.
- Vent pipe, same size as fill, routed to highest point in system.
- Drain valve.

- Level gage or sight glass.
- Low level alarm (option).
- High level float switch to control: the solenoid, if the bulk tank is above the day tank, or the pump control, if the bulk tank is below the day tank.
- Overflow to bulk tank if the tank is below the day tank.

Local laws and standards often control day tank construction as well as federal codes so it is essential to check with the local authority.

Gaseous Fuel Supply

See section 2 of this manual for information regarding general advantages and disadvantages of gaseous fuel systems compared to other available alternatives.

Gaseous fueled generator sets (also called “spark–ignited generator sets”) may utilize natural gas or liquid–propane (LP) gas, or both. Dual fuel systems with natural gas as primary fuel and propane as a backup can be used in seismic risk areas and where there is concern that a natural event could disrupt a public utility gas system.

Regardless of the fuel used, the primary factors in successful installation and operation of a gas fuel system are:

- The gas supplied to the generator set must be of acceptable quality.
- The gas supply must have sufficient pressure. Care must be taken to be sure that the gas supply *at the generator set*, not just at the source, is of proper pressure for operation. The specified pressure must be available while the generator set is running at full load.
- The gas must be supplied to the genset in sufficient volume to support operation of the generator set. This is normally a matter of selecting fuel line size to be large enough to transport the volume of fuel needed. For LP vapor–withdrawal fuel systems the size and temperature of the fuel tank also affects this requirement.

Failure to meet the minimum requirements of the generator set in these areas will result in the inability of the generator set to operate, or inability to carry rated load, or poor transient performance.

Gaseous Fuel Quality

Gaseous fuels are actually a mixture of several different hydrocarbon gases such as methane, ethane, propane, and butane; other gaseous elements such as oxygen and nitrogen; vaporized water; and various contaminants, some of which are potentially damaging to an engine over time. The quality of the fuel is based on the amount of energy per unit volume in the fuel and the amount of contaminants in the fuel.

Energy Content

One of the most important characteristics of the gaseous fuel used in a generator set is the heat value of the fuel. The heat value of a fuel describes how much energy is stored in a specific volume of the fuel. Gaseous fuel has a low heat value (LHV) and a high heat value (HHV). The low heat value is the heat available to do work in an engine after the water in the fuel is vaporized. If the low heat value of a fuel is too low, even if a sufficient volume of fuel reaches the engine, the engine will not be able to maintain full output power, because sufficient energy is not available in the engine to convert to mechanical energy. If the LHV is below 905 BTU/ft^3 the engine may not produce rated power at standard ambient temperature conditions.

If the local fuel has a higher energy content than 1000 BTU/ft^3, the actual flow requirements in cu ft/min will be lower and the pressure requirements drop slightly. Conversely if the local fuel has a lower energy content than 1000 BTU/ ft^3, the actual flow requirements in ft^3/min will be higher and a higher minimum supply pressure will be needed to meet published performance for any given generator set

Each engine may have slightly different performance characteristics based on the type of fuel provided, due to differences in engine compression ratio, and whether the engine is naturally aspirated or turbocharged.

Pipeline Natural Gas

The most common fuel for generator sets is called “Pipeline natural gas”. In the US, “dry pipeline natural gas” has specific qualities, based on federal requirements. In other countries, pipeline gas may vary in content, so fuel characteristics should be verified prior to use with a generator set. US pipeline gas is a mixture composed of approximately 98% methane and ethane with the other 2% being hydrocarbons such as propane and butane, nitrogen, carbon dioxide, and water vapor. “Dry” means that it is free of liquid hydrocarbons such as gasoline, but NOT that it is free of water vapor. Dry pipeline gas typically has a LHV of 936 BTU/ft^3, and a HHV of 1,038 BTU/ft^3.

Field Gas

The composition of “Field natural gas” varies considerably by region and by continent. Careful analysis is necessary prior to using field natural gas in an engine. Field natural gas can contain “heavier” hydrocarbon gases such as pentane, hexane, and heptane, which may require derating of the output of the engine. Other contaminants, such as sulfur, may also be present in the fuel. A typical field gas might have a LHV of 1203 BTU/ft^3, and a HHV of 1,325 BTU/ft^3.

Propane (LPG)

Propane is available in two grades, either commercial, or special duty. Commercial propane is used where high volatility is required. Not all spark–ignition engines will operate acceptably with this fuel due to its volatility. Special duty propane (also called HD5) is a mixture of 95% propane and other gases such as butane that allow better engine performance due to the reduction pre–ignition due to reduced volatility. Special duty propane fuel gas that meets the ASTM D 1835 specification for special–duty propane (equivalent to HD–5 propane of Gas Producers Association Standard 2140) is suitable for most engines. Propane has a LHV of approximately 2,353 BTU/ft^3, and an HHV of 2,557 BTU/ft^3. The higher heating value of the fuel necessitates mixing of different volumes of air in the fuel system for propane vs. natural gas applications, so dual fuel engines essentially have two fuel arrangements for this purpose.

Contaminants

The most harmful contaminants in gaseous fuels are water vapor and sulfur.

Water vapor is damaging to an engine because it may cause uncontrolled burning, pre–ignition, or other effects that can damage an engine. Liquid vapor or droplets must be removed from the fuel prior to entry into the engine by use of a “dry filter” that is mounted in the fuel system prior to the primary fuel pressure regulator. The dew point of fuel gas should be at least 20F (11C) below the minimum ambient temperature at the installation site.

Sulfur and hydrogen sulfides will cause corrosion and serious damage to an engine over a relative short period of time. Different engines have different levels of tolerance to sulfur contamination, and some engines simply should not be operated with fuel that contains significant sulfur content. Contact the engine manufacturer for approval of specific engines with specific fuels. The effects of sulfur in the fuel can be counteracted in part by use of high–ash natural gas lubricating oils. In general, engines should not be operated with fuels in excess of 10 parts per million (ppm).

Certain fuels, such as those derived from land fill applications, can have useful chemical energy content, but very high sulfur levels (>24 ppm). These fuels are often termed “sour gas”. If this fuel is scrubbed of the sulfur content, it can be used as a fuel for many engines, provided that it has sufficient BTU content.

Fuel Analysis

The gaseous fuel supplier can provide a fuel analysis that describes the chemical makeup of the fuel to be provided. This fuel analysis can be used to be certain that the fuel is suitable for use in the specific engine proposed for a specific application, and also to verify that the BTU content of the fuel is sufficient to provide necessary kW output of the machine. Gas suppliers may change the pipeline natural gas composition without notice, so there is no long–term guarantee of performance, but the process of evaluation of the fuel can be briefly described as:

1. List the percent of each gas constituent in the fuel.
2. Calculate the percent of the total fuel that is combustible. The combustible portion of the fuel is 100% less the inert component percentages. Inert components include oxygen, carbon dioxide and water vapor.
3. Calculate the percent of each combustible component of the fuel.
4. Verify acceptability of the fuel by checking the percent of each combustible element vs. the recommendations of the engine manufacturer.

   For example, for a gas analysis of:

   90% Methane
   6% Ethane
   2% Hydrogen
   1% Normal Pentane
   1% Nitrogen

   - Total percent inert elements = 1%.
   - Total combustible =100%–1% = 99%.
   - % Methane = 90%/99% = 91%.
   - % Ethane = 6%/99% = 6.1%.
   - % Hydrogen = 2%/99% = 2%.
   - % Normal Pentane = 1%/99% = 1%.

   See **Table 6–11** for a typical listing of Maximum Permissible Combustibles in Cummins Gas generator sets. Note that in this example, the analysis shows the fuel will be acceptable for a lower compression ratio engine (typically around 8.5:1) but not for a higher compression engine. A higher compression engine will have more stringent fuel composition requirements but may operate satisfactorily with a derating of its output – consult the engine manufacturer.
5. Verify the rating of the generator set based on use of the proposed fuel.

The total BTU content of the fuel will determine the rating of the generator set when using fuel of a specific composition. If any component of the fuel has more than the specific value allowed derating will be required. Consult the engine manufacturer for fuel requirements and derating instructions.

Note that the fuel derating and the altitude/temperature derating[21] are not additive. Only the maximum value of the fuel derate or the altitude/temperature derate need be applied.

Turbocharged engines have unique fuel composition requirements due to higher cylinder pressures. To avoid problems with pre–ignition or detonation, power output derating is required if propane and/or Iso–Butane content exceed the percentages listed in **Table 6–12**.

21 Consult the engine or generator set manufacturer for temperature/altitude derating factors.

	8.5:1 Compression Ratio	10.5:1 Compression Ratio
Methane (C_1)	100	100
Ethane (C_2)	100	100
Propane (C_3)	10	2
ISO–Butane (IC_4)	7	0.2
Hydrogen (H_2)	7	trace
Normal Butane (NC_4)	3	0.2
ISO–Pentane (IC_5)	3	0.2
Normal Pentane (NC_5)	1	0.1
Hexane (C_6)	1	0.1
Heptane (C_7)	1	0.1

Table 6–11. Maximum Allowable Percentages for Engine Fuel Combustibles

	8.5:1 Compression Ratio	10.5:1 Compression Ratio
Methane	NA	NA
Ethane	NA	NA
Propane	5%	*
Iso-butane	2%	*
*High compression ratio turbocharged engines cannot consume any propane or iso–butane.		

Table 6–12. Maximum Allowable Percentages of Constituent Gases Before Derating Turbocharged Engines

Generator Set Fuel System Design

Figure 6–68 illustrates the typical gas line components in an automatic–transfer, dual–fuel system (natural gas and LPG). Single fuel systems (natural gas or LPG) use the noted portions of the components on this drawing. Not shown is the LPG vaporizer supplied with Cummins Power Generation generator sets equipped for liquid withdrawal of LPG (engine–mounted on outdoor sets only). Service pressure regulators, dry gas filters and manual shutoff valves are typically provided by the installer but are available as accessories from Cummins Power Generation.

Site Fuel System Design

The following should be considered when installing a natural gas and/or LPG fuel system:

- Gaseous–fuel supply system design, materials, components, fabrication, assembly, installation, testing, inspection, operation and maintenance must comply with all applicable codes[22].
- The layout and sizing of gas piping must be adequate for handling the volume of gas required by the generator set and all other equipment, such as building heating boilers, supplied by the same source. Full–load gas flow (see the recommended generator set Specification Sheet) must be available at not less than the minimum required supply pressure, typically from 5 to 10 inches WC (water column), depending on model. Final determination of pipe sizes must, however, be based upon the method approved by the authority having jurisdiction (see NFPA No. 54).

22 In North America, NFPA Standards No. 30, No. 37, No. 54 and No. 58 are typical.

- Most installations will require a service gas pressure regulator. Gas supply pressure should not exceed 13.8 or 20 inches WC, depending on model, at the inlet to the generator set. Depending on distribution gas pressure, more than one stage of pressure regulation may be required. High–pressure gas piping is not permitted inside buildings (5 psig for natural gas and 20 psig for LPG, unless higher pressures are approved by the authority having jurisdiction). Gas pressure regulators must be vented to the outdoors according to code.

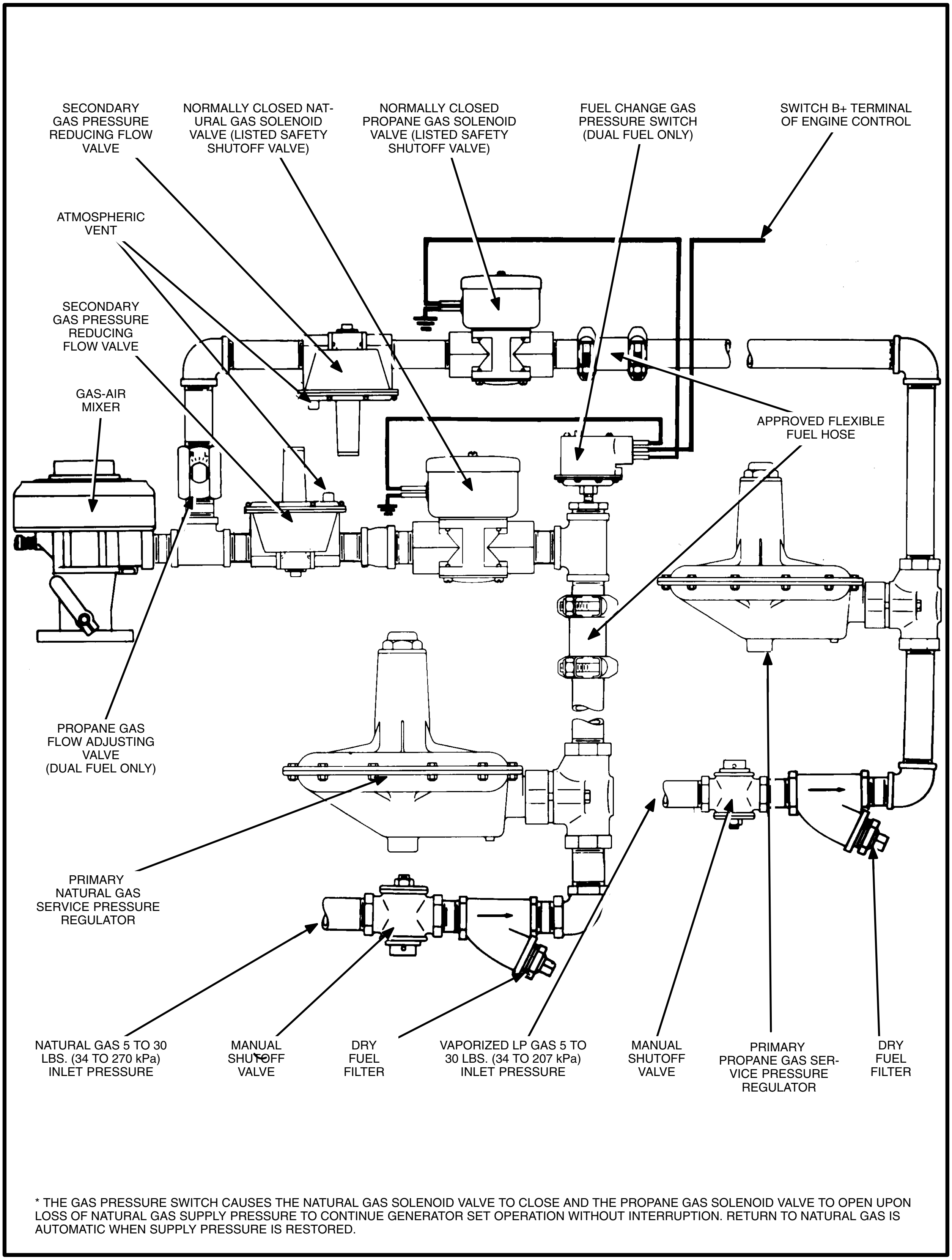


Figure 6–68. Typical Gaseous Fuel System

- The pressure regulator installed on the supply line at the gas source for generator applications should never be a "pilot" regulator. A "pilot" style regulator is the type where the regulator requires a pressure line from the regulator housing to the downstream gas pipe to "sense" when downstream pressure has dropped. Pilot regulators do not work because the response time is unacceptable compared to the large–instantaneous changes in demand from the generator set.
- Approved flexible fuel hose must be used for connections at the engine to take up generator set movement and vibration.
- Most codes require both manual and electric (battery–powered) shutoff valves ahead of the flexible fuel hose(s). The manual valve should be of the indicating type.
- A dry fuel filter should be installed in each line as shown in **Figure 6–68** to protect the sensitive pressure regulating components and orifices downstream from harmful foreign substances carried along in the gas stream (rust, scale, etc.).
- An LPG fuel supply system must be dedicated for the emergency power system if it is the required alternative fuel.
- An LPG vaporizer heated by engine coolant is factory installed on Cummins Power Generation generator sets equipped for a liquid–withdrawal of LPG. Because high pressure (20 psig or greater) gas piping is not permitted inside buildings, generator sets equipped for liquid withdrawal of LPG must not be installed inside the building. (Weather–protective housings for outdoor installation are available for most LPG models.)
- The rate of vaporization in an LPG tank depends upon the outdoor air temperature, unless the tank is equipped with a heater, and the quantity of fuel in the tank. Even on cold days outdoor air heats and vaporizes LPG (mostly through the wetted tank surface) when air temperature is higher than LPG temperature. Withdrawing vapor causes tank temperature and pressure to drop. (At –37° F [–38° C] LPG has zero vapor pressure.) Unless there is enough fuel and enough heat available from ambient air, the vaporization rate will drop off, as the generator set runs, to less than that required to continue running properly.

Gaseous Fuel System Calculations Fuel Pressure

Tank Size

Use **Figure 6–69** as a quick reference for sizing an LPG tank on the basis of the lowest ambient temperature expected. For example, on a 40F day, withdrawal at 1000 ft^3/h requires a 2000 gallon tank at least half full. Note: In many instances the amount of fuel required for proper vaporization is far greater than that required for the number of hours of operation stipulated by code.

For instance, in an NFPA 110 Class 6 application, there must be enough fuel for the generator set to run for 6 hours before refilling the tank. LPG yields approximately 36.5 cubic feet of gas per gallon of liquid. If the generator set withdrawal rate is 1000 ft^3/h:

$$\text{Fuel Consumed in 6 hours} = \frac{1000\ ft^3/hr \bullet 6\ hours}{36.5\ ft^3/gal} = 164\ \text{gallons}$$

In this instance the tank must be sized for at least 2000 gallons based on the lowest expected temperature rather than on the fuel consumed in 6 hours (164 gallons).

Gas Pipe Sizing

Sizing of gas piping for proper fuel delivery, both flow and pressure, can become quite complex. However, a simplified method, as with other piping for exhaust and coolant, is to convert all fittings, valves, etc. to equivalent lengths of pipe in the diameter(s) being considered. The total equivalent length can then be related to flow capacity.

Table 6–5, Equivalent Lengths of Pipe Fittings and Valves applies to gas as well as liquid piping. **Tables 6–13 through 6–17** show maximum gas capacity for equivalent length for various pipe sizes. Tables 6–10 through 6–14 are reproduced from NFPA 54–2002, National Fuel Gas Code, and are selected considering the general fuel system operating requirements for generator sets. Tables are included for natural gas, propane liquid withdrawal and propane vapor withdrawal under specified conditions. Consult NFPA 54 or other applicable codes for other operating conditions or other fuel system installation requirements.

A calculation of minimum pipe size is fairly straightforward:

- Make a list of al the fittings and valves in a proposed system and sum their equivalent lengths using the table.
- Add to this total, all lengths of straight pipe to arrive at a total equivalent length.
- Choose the applicable table based on the fuel system.
- Obtain the maximum fuel requirements for the specific generator set(s) from the manufacturer's specification sheets. Convert to ft^3/hr as needed (Be cognizant of BTU content as discussed earlier in this section.)
- Locate the equivalent length of pipe (or next larger equivalent length) in the left hand column. Move across to the columns to where the number is as large or larger than the total equivalent length calculated above. At the top of that column is the minimum nominal pipe size or tubing size required for the system as designed.

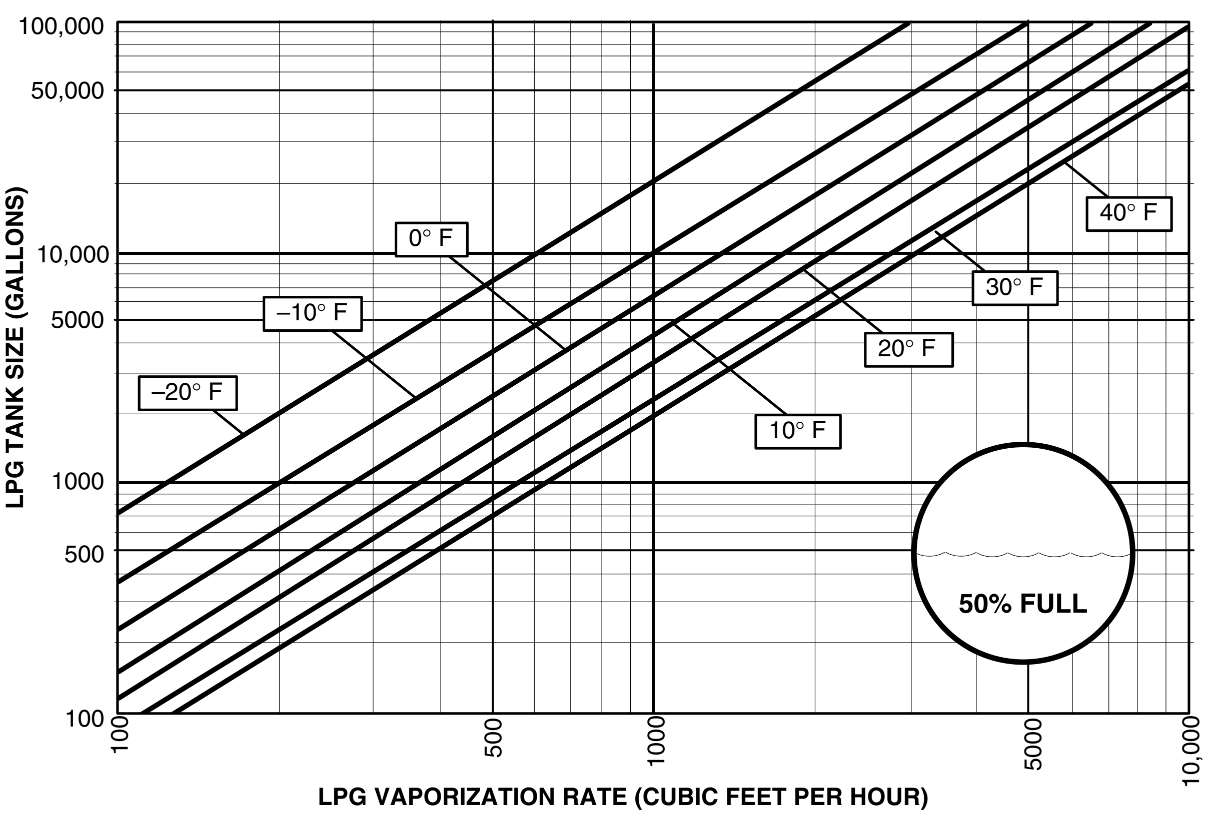


Figure 6–69. Minimum LPG Tank Size (50% Full) Required to Maintain 5 PSIG at Specific Withdrawal Rate and Minimum Expected Winter Temperature

Gas: Natural **Inlet Pressure:** 0.5 psi or less **Pressure Drop:** 0.5 in. w.c. **Specific Gravity:** 0.60											
	Pipe Size (in.)										
Nominal	1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	4
Actual ID	(0.364)	(0.493)	(0.622)	(0.824)	(1.049)	(1.380)	(1.610)	(2.067)	(2.469)	(3.068)	(4.026)
Length (ft)	**Maximum Capacity in Cubic Feet of Gas per Hour**										
10	43	95	175	360	680	1400	2100	3950	6300	11000	23000
20	29	65	120	250	465	950	1460	2750	4350	7700	15800
30	24	52	97	200	375	770	1180	2200	3520	6250	12800
40	20	45	82	170	320	660	990	1900	3000	5300	10900
50	18	40	73	151	285	580	900	1680	2650	4750	9700
60	16	36	66	138	260	530	810	1520	2400	4300	8800
70	15	33	61	125	240	490	750	1400	2250	3900	8100
80	14	31	57	118	220	460	690	1300	2050	3700	7500
90	13	29	53	110	205	430	650	1220	1950	3450	7200
100	12	27	50	103	195	400	620	1150	1850	3250	6700
125	11	24	44	93	175	360	550	1020	1650	2950	6000
150	10	22	40	84	160	325	500	950	1500	2650	5500
175	9	20	37	77	145	300	460	850	1370	2450	5000
200	8	19	35	72	135	280	430	800	1280	2280	4600

Table 6–13. Natural Gas Schedule 40 Iron Pipe Sizing[23]

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Gas: Natural
Inlet Pressure: 0.5 psi or less
Pressure Drop: 0.5 in. w.c.
Specific Gravity: 0.6

	Tube Size (in.)										
Nominal	K & L	1/4	3/8	1/2	5/8	3/4	1	1 1/4	1 1/2	2	2 1/2
	ACR	3/8	1/2	5/8	3/4	7/8	1 1/8	1 3/8	1 5/8	2 1/8	2 5/8
Outside		0.375	0.500	0.625	0.750	0.875	1.125	1.375	1.625	2.125	2.625
Inside*		0.305	0.402	0.527	0.652	0.745	0.995	1.245	1.481	1.959	2.435
Length (ft)		Maximum Capacity in Cubic Feet of Gas per Hour									
10		27	55	111	195	276	590	1062	1675	3489	6173
20		18	38	77	134	190	406	730	1151	2398	4242
30		15	30	61	107	152	326	586	925	1926	3407
40		13	26	53	92	131	279	502	791	1648	2916
50		11	23	47	82	116	247	445	701	1461	2584
60		10	21	42	74	105	224	403	635	1323	2341
70		9.3	19	39	68	96	206	371	585	1218	2154
80		8.6	18	36	63	90	192	345	544	1133	2004
90		8.1	17	34	59	84	180	324	510	1063	1880
100		7.6	16	32	56	79	170	306	482	1004	1776
125		6.8	14	28	50	70	151	271	427	890	1574
150		6.1	13	26	45	64	136	245	387	806	1426
175		5.6	12	24	41	59	125	226	356	742	1312
200		5.2	11	22	39	55	117	210	331	690	1221
250		4.7	10	20	34	48	103	186	294	612	1082
300		4.2	8.7	18	31	44	94	169	266	554	980

* Table capacities are based on Type K copper tubing inside diameter (shown), which has the smallest inside diameter of the copper tubing products.

Table 6–14. Natural Gas Semi–Rigid Copper Tubing Sizing[24]

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Gas: Undiluted Propane
Inlet Pressure: 11.0 in. w.c.
Pressure Drop: 0.5 in. w.c.
Specific Gravity: 1.50
Special Use: Pipe sizing between single or second stage (low pressure regulator) and appliance.

	Pipe Size (in.)								
Nominal Inside	1/2	3/4	1	1 1/4	1 1/2	2	3	3 1/2	4
Actual:	0.622	0.824	1.049	1.38	1.61	2.067	3.068	3.548	4.026
Length (ft)	**Maximum Capacity in Thousands of Btu per Hour**								
10	291	608	1145	2352	3523	6786	19119	27993	38997
20	200	418	787	1616	2422	4664	13141	19240	26802
30	160	336	632	1298	1945	3745	10552	15450	21523
40	137	287	541	1111	1664	3205	9031	13223	18421
50	122	255	480	984	1475	2841	8004	11720	16326
60	110	231	434	892	1337	2574	7253	10619	14793
80	94	197	372	763	1144	2203	6207	9088	12661
100	84	175	330	677	1014	1952	5501	8055	11221
125	74	155	292	600	899	1730	4876	7139	9945
150	67	140	265	543	814	1568	4418	6468	9011
200	58	120	227	465	697	1342	3781	5536	7712
250	51	107	201	412	618	1189	3351	4906	6835
300	46	97	182	373	560	1078	3036	4446	6193
350	42	89	167	344	515	991	2793	4090	5698
400	40	83	156	320	479	922	2599	3805	5301

Table 6–15. Propane Vapor Schedule 40 Iron Pipe Sizing[25]

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Gas: Undilute Propane
Inlet Pressure: 11.0 in w.c.
Pressure Drop: 0.5 in. w.c.
Specific Gravity: 1.50
Special Use: Sizing between single or second stage (low pressure regulator) and appliance

		Tube Size (in.)									
Nominal	K & L	1/4	3/8	1/2	5/8	3/4	1	1 1/4	1 1/2	2	2 1/2
	ACR	3/8	1/2	5/8	3/4	7/8	1 1/8	1 3/8	1 5/8	2 1/8	2 5/8
Outside		0.375	0.500	0.625	0.750	0.875	1.125	1.375	1.625	2.125	2.625
Inside*		0.305	0.402	0.527	0.652	0.745	0.995	1.245	1.481	1.959	2.435
Length (ft)		Maximum Capacity in Thousands of Btu per Hour									
10		45	93	188	329	467	997	1795	2830	5895	10429
20		31	64	129	226	321	685	1234	1945	4051	7168
30		25	51	104	182	258	550	991	1562	3253	5756
40		21	44	89	155	220	471	848	1337	2784	4926
50		19	39	79	138	195	417	752	1185	2468	4366
60		17	35	71	125	177	378	681	1074	2236	3956
70		16	32	66	115	163	348	626	988	2057	3639
80		15	30	61	107	152	324	583	919	1914	3386
90		14	28	57	100	142	304	547	862	1796	3177
100		13	27	54	95	134	287	517	814	1696	3001
125		11	24	48	84	119	254	458	722	1503	2660
150		10	21	44	76	108	230	415	654	1362	2410
175		10	20	40	70	99	212	382	602	1253	2217
200		8.9	18	37	65	92	197	355	560	1166	2062
225		8.3	17	35	61	87	185	333	525	1094	1935
250		7.9	16	33	58	82	175	315	496	1033	1828
275		7.5	15	31	55	78	166	299	471	981	1736
300		7.1	15	30	52	74	158	285	449	936	1656

* Table capacities are based on Type K copper tubing inside diameter (shown), which has the smallest inside diameter of the copper tubing products.

Table 6–16. Propane Vapor Semi–Rigid Copper Tubing Sizing[26]

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Equivalent Length of Pipe, ft.	Schedule 40 Iron Pipe Size, in.: Nominal (Inside Diameter)								
	1/2 (0.622)	3/4 (0.824)	1 (1.049)	1 1/4 (1.38)	1 1/2 (1.61)	2 (2.067)	3 (3.068)	3 1/2 (3.548)	4 (4.026)
30	733	1532	2885	5924	8876	17094	48164	70519	98238
40	627	1311	2469	5070	7597	14630	41222	60355	84079
50	556	1162	2189	4494	6733	12966	36534	53492	74518
60	504	1053	1983	4072	6100	11748	33103	48467	67519
70	463	969	1824	3746	5612	10808	30454	44589	62116
80	431	901	1697	3484	5221	10055	28331	41482	57787
90	404	845	1593	3269	4899	9434	26583	38921	54220
100	382	798	1504	3088	4627	8912	25110	36764	51216
150	307	641	1208	2480	3716	7156	20164	29523	41128
200	262	549	1034	2122	3180	6125	17258	25268	35200
250	233	486	916	1881	2819	5428	15295	22395	31198
300	211	441	830	1705	2554	4919	13859	20291	28267
350	194	405	764	1568	2349	4525	12750	18667	26006
400	180	377	711	1459	2186	4209	11861	17366	24193
450	169	354	667	1369	2051	3950	11129	16295	22700
500	160	334	630	1293	1937	3731	10512	15391	21442
600	145	303	571	1172	1755	3380	9525	13946	19428
700	133	279	525	1078	1615	3110	8763	12830	17873
800	124	259	488	1003	1502	2893	8152	11936	16628
900	116	243	458	941	1409	2715	7649	11199	15601
1000	110	230	433	889	1331	2564	7225	10579	14737
1500	88	184	348	713	1069	2059	5802	8495	11834
2000	76	158	297	611	915	1762	4966	7271	10128

Table 6–17. Propane Schedule 40 Iron Pipe Sizing, Liquid Withdrawal – Maximum Capacity of Pipe in Cubic Feet of Gas per Hour. Pipe size recommendations are based on schedule 40 black iron pipe.

Reducing Noise in Generator Set Applications

The Science of Noise

Noise Level Measurement and Decibel/dB(A) Units: One unit of measurement for sound is the decibel (dB). The decibel is a convenient number on a logarithmic scale expressing the ratio of two sound pressures, comparing the actual pressure to a reference pressure.

Noise regulations are generally written in terms of “decibels ‘A’ scale” or dB(A). The “A” denotes that the scale has been “adjusted” to approximate how a person perceives the loudness of sound. Loudness depends on sound pressure level (amplitude) and frequency. **Figure 6–70** shows typical noise levels associated with various surroundings and noise sources.

Accurate and meaningful sound level data are preferably measured in a “free field site” to collect noise data. A “free field”, as distinguished from a “reverberant field”, is a sound field in which the effects of obstacles or boundaries on sound propagated in that field are negligible. (Generally this means the objects or barriers are far away, do not reflect toward the test area and/or are covered with adequate sound absorption materials.) Accurate noise measurements also require that the microphone be placed outside the "near field." "Near field" is defined as the region within one wave length, or two times the largest dimension of the noise source, whichever is greater. Noise measurements for community regulations should not be made in the near field. Engineers' noise specifications should call for sound pressure level measurements in the free field, 7 meters (21 feet) or greater.

Noise measurements should be made using a sound level meter and an octave band analyzer for more detailed analysis by acoustical consultants. The microphones are placed in a circle of 7 meters (21 feet) radius centered on the generator set; a sufficient distance for this type and size of equipment. Refer to the Sound Performance data sheets available on the Power Systems Software Suite CD for data on Cummins Power Generation products.

Additive Sound Levels

The noise level at a given location is the sum of the noise levels from all sources, including reflecting sources. For example, the noise level at a point in a free field equidistant from two identical generator sets is double when both sets are running. A doubling of the noise level is represented as an increase of approximately 3 dB(A). In this case, if the noise level from either set is measured as 90 dB(A), one could expect to measure 93 dB(A) when both sets are running.

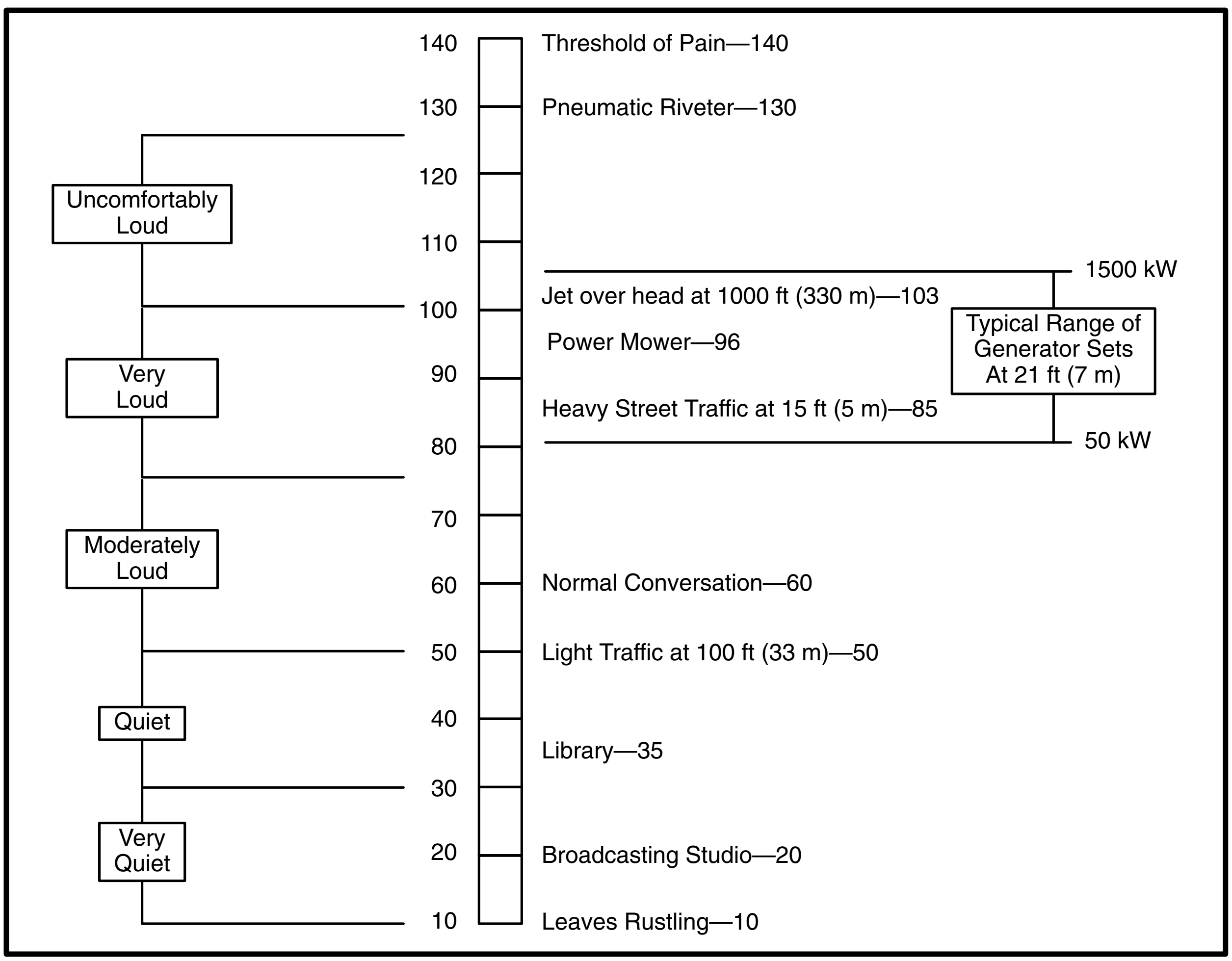


Figure 6–70. Typical Noise Levels

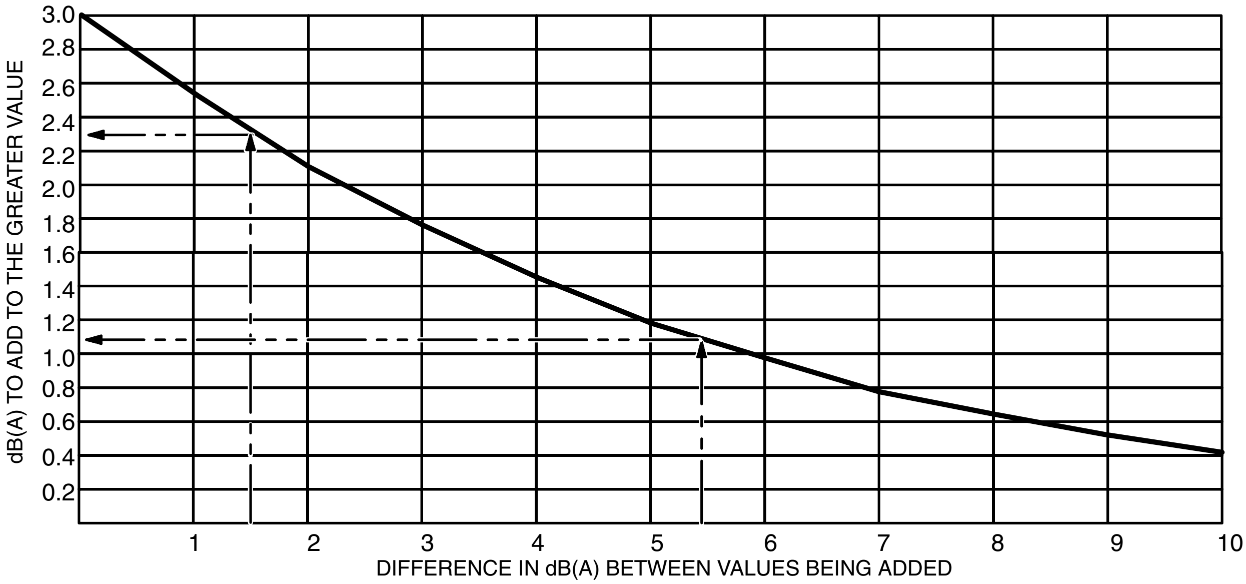


Figure 6–71. Graph Of Values For Adding Noise Levels

Figure 6–71 can be used, as follows, to estimate the noise level from multiple noise sources:

1. Find the difference in dB(A) between two of the sources (any pair). Locate that value on the horizontal scale as shown by the vertical arrow, move up to the curve and over to the vertical scale as shown by the horizontal arrow. Add this value to the larger dB(A) value of the pair.
2. Repeat Step 1 between the value just determined and the next value. Keep repeating the process until all sources have been accounted for.

For example, to add 89 dB(A), 90.5 dB(A), and 92 dB(A):

- Subtract 90.5 dB(A) from 92 dB(A) for a difference of 1.5 dB(A). As the arrows show in **Figure 6–71**, corresponding to the difference of 1.5 dB(A) is the value of 2.3 dB(A) which should be added to 92 dB(A) for a new value of 94.3 dB(A).
- Likewise, subtract 89 dB(A) from the new value of 94.3 dB(A) for a difference of 5.3 dB(A).
- Finally, add the corresponding value of 1.1 dB(A) to 94.5 dB(A) for a total of 95.6 dB(A).

Alternatively, the following formula can be used to add sound pressure levels measured in dB(A):

$$dBA_{total} = 10 \bullet \log_{10}\left(10^{\left(\frac{dBA_1}{10}\right)} + 10^{\left(\frac{dBA_2}{10}\right)} + ... + 10^{\left(\frac{dBA_n}{10}\right)}\right)$$

Effect of Distance

In a “free field,” sound level decreases as distance increases. If, for example, a second sound measurement is taken twice as far from the source, the second reading will be approximately 6 dB(A) less than the first (four times less). If the distance is cut in half, the second reading will be approximately 6 dB(A) greater (four times greater). For the more general case, if the sound pressure level (SPL_1) of a source at distance d_1 is known, the sound pressure level (SPL_2) at distance d_2 can be found as follows:

$$SPL_2 = SPL_1 - 20 \bullet \log_{10}\left(\frac{d_2}{d_1}\right)$$

For example, if the sound pressure level (SPL_1) at 21 meters (d_1) is 100 dB(A), at 7 meters (d_2), the sound pressure level (SPL_2) will be:

$$SPL_2 = 100dBA - 20 \bullet \log_{10}\left(\frac{7}{21}\right)$$

$$= 100 - 20 \bullet (-0.477)$$

$$= 100 + 9.5 = 109.5 \text{ dBA}$$

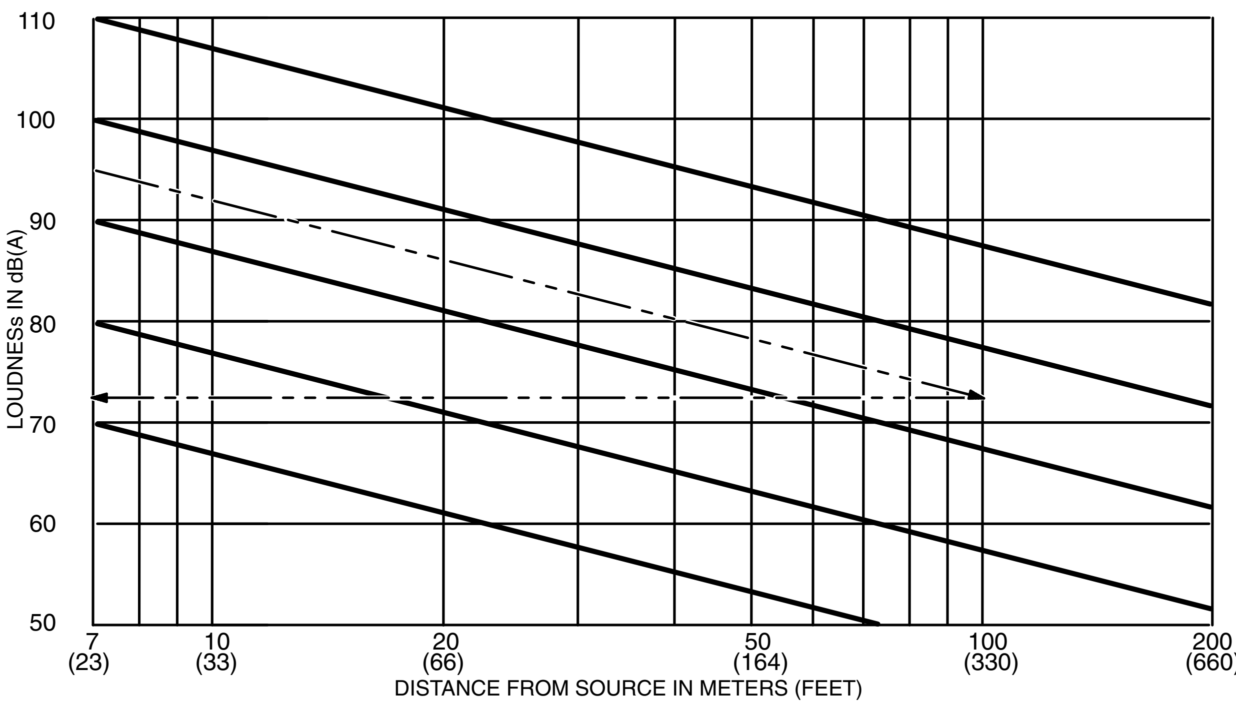


Figure 6–72. Decrease In Loudness As Distance Increases (Free Field)

To apply the distance formula (above) to generator set data published by Cummins Power Generation, the background noise level must be at least 10 dB(A) below the noise level of the generator set and the installation must approximate a free field environment.

Figure 6–72 can be used as an alternative to the formula for estimating the sound level at various distances, such as to the property line. For example, as shown by the dashed arrows, if the noise rating on the recommended generator set Specification Sheet is 95 dB(A) (at 7 meters), the noise level 100 meters away will be approximately 72 dB(A).

To use **Figure 6–72**, draw a line parallel to the slanted lines from the known dB(A) value on the vertical scale line to the vertical line for the specified distance. Then draw a horizontal line back to the vertical scale line and read the new dB(A) value.

Generator Set Noise

Generator set applications are susceptible to problems associated with noise levels, due to the inherent high levels of noise produced by operating generator sets. Codes and standards have been enacted to protect property owners or users from objectionable levels of noise from other properties.

In general, required noise levels at a property line are often in the low 60s or high 50s (depending on time of day), while untreated generator set noise levels can approach 100dBA. The generator set noise may be amplified by site conditions, or the ambient noise level existing at the site may prevent the generator set from meeting required noise performance levels. (In order to accurately measure the noise level of any source, the noise source must be more than 10 dBA louder than the ambient around it.)

The noise level produced by a generator set at a property line is predictable if the generator set is installed in a *free field* environment. In a free field environment, there are no reflecting walls to magnify the noise produced by the generator set, and the noise level follows the “6 dBA reduction for doubling distance” rule. If the property line is within the *near field* of a generator set the noise level may not be predictable. A near field environment is any measurement taken within twice the largest dimension of the noise source.

Reflecting walls and other hard surfaces magnify the noise level that may be sensed by a receiver. For example, if a generator set is placed next to a hard surfaced wall, the noise level perpendicular to the wall will be approximately twice the expected sound power of the generator set in a free field environment (i.e., a generator set operating with a 68 dBA noise level would measure 71 dBA next to a reflecting wall). Putting a generator set in a corner further magnifies the noise level sensed.

Noise ordinances are often only enforced by complaint, but the high cost of retrofitting a site for noise reduction makes it a good idea to assess noise performance requirements early in the design cycle, and designing into the site the most cost effective sound attenuation provisions.

See section **Table 2–2** for representative outside noise data.

Reducing Structure – Transmitted Noise

Vibrating structures create sound pressure waves (noise) in the surrounding air. Connections to a generator set can cause vibrations in the building structure, creating noise. Typically, these include the skid anchors, radiator discharge air duct, exhaust piping, coolant piping, fuel lines, and wiring conduit. Also, the walls of a generator set housing can vibrate and cause noise. **Figure 6–1** shows ways of minimizing structure–transmitted noise by proper vibration isolation.

Mounting a generator set on spring–type vibration isolators effectively reduces vibration transmission. Vibration isolation practice is described in Vibration Isolators at the beginning of this chapter.

Flexible connections to exhaust pipe, air duct, fuel line, coolant pipe (remote radiator or heat exchanger systems) and wiring conduit effectively reduce vibration transmission. All generator set applications require the use of flexible connections to the generator set.

Reducing Airborne Noise

Airborne noise has a directional characteristic and is usually the most apparent at the high end of the frequency range.

- The simplest treatment is to direct the noise, such as a radiator or exhaust outlet, away from receivers. For example, point the noise up vertically so that people at grade level will not be in the sound path.
- Line–of–sight barriers are effective in blocking noise. Barriers made of materials with high mass materials such as concrete, filled cement block, or brick, are best. Be careful to eliminate sound paths through cracks in doors or room (or enclosure) access points for exhaust, fuel, or electrical wiring.

- Sound absorbing (acoustic) materials are available for lining air ducts and covering walls and ceilings. Also, making noise travel through a 90–degree bend in a duct reduces high frequency noise. Directing noise at a wall covered with sound absorbing material can be very effective. Fiberglass or foam may be suitable, based on factors such as cost, availability, density, flame retardance, resistance to abrasion, aesthetics and cleanability. Care should be taken to select materials that are resistant to the effects of oil and other engine contaminants.
- A concrete block enclosure is an excellent barrier to all noise. The blocks may be filled with sand to increase the mass of the wall and thus increase noise attenuation.
- Remote radiator arrangements can be used to limit air flow and to move the radiator fan noise source to a location that is less likely to be objectionable to receivers. Remote radiator installations can be supplied with low speed fans to minimize noise from the assembly.

Sound Attenuated Enclosures (Canopies)

Generator sets that are installed out of doors may be provided with integral sound attenuated enclosures. These enclosures effectively form an enclosed space around the generator set and can effectively reduce the noise level produced by the machine.

In general, the price of the enclosure is directly related to the sound attenuation required. So, the greater the level of sound attenuation required, the greater the cost of the enclosure. It is not uncommon for enclosure costs to approach the cost of the generator set that it protects.

It should also be recognized that there may be a price in terms of generator set performance by use of high levels of sound attenuation. Carefully test sound attenuated machines for proper ventilation system and load–carrying performance.

NOTE: Be cautious when comparing cooling system ratings that the rating is based on ambient temperature not air–on–radiator. An air–on–radiator rating restricts the temperature of the air flowing into the radiator and does not allow for air temperature increase due to the radiated heat energy of the engine and alternator. Ambient rated system accounts for this increase in temperature in their cooling capability.

Exhaust Silencer Performance

Generator sets are almost always provided with an exhaust silencer (muffler) to limit exhaust noise from the machine. Exhaust silencers come in a wide variety of types, physical arrangements, and materials.

Silencers are generally grouped into either chamber–type silencers, or spiral type devices. The chamber type devices can be designed to be more effective, but the spiral types are often physically smaller, and may have suitable performance for the application.

Silencers may be constructed of cold–rolled steel or stainless steel. Cold–rolled steel silencers are less expensive, but more susceptible to corrosion than stainless steel silencers. For applications where the silencer is mounted indoors, and protected with insulation (lagging) to limit heat rejection, there is little advantage for the stainless variety.

Silencers can be provided in the following physical configurations:

- End in/end out; probably the most common configuration.
- Side in/end out; often used to help to limit ceiling height requirements for a generator set.
- Dual side inlet/end out; used on “V” engines to eliminate need for an exhaust header, and minimize ceiling height requirements.

Silencers are available in several different noise attenuation “grades”; commonly called: “industrial”, “residential”, and “critical”. Note that the exhaust noise from a generator set may not be the most objectionable noise source on the machine. If the mechanical noise is significantly greater than the exhaust noise, selection of a higher performance silencer may not improve the noise level present at the site.

In general, the more effective a silencer is at reducing exhaust noise, the greater the level of restriction on the engine exhaust. For long exhaust systems, the piping itself will provide some level of attenuation.

Typical Silencer Attenuation
Industrial Silencers: 12–18 dBA
Residential Silencers: 18–25 dBA
Critical Silencers: 25–35 dBA

Fire Protection

The design, selection and installation of fire protection systems is beyond the scope of this manual due to of the wide range of factors to consider, such as building occupancy, codes, and the efficacy of various fire protection systems. Consider the following, however:

- The fire protection system must comply with the requirements of the authority having jurisdiction, such as the building inspector, fire marshal or insurance carrier.
- Generator sets that are used for emergency and standby power should be protected from fire by location or by the use of fire–resistant construction in the generator set room. In some locations, generator room construction for installations that are considered to be necessary for life safety must have a two–hour fire resistance rating[27],[28]. Some locations will also require feeder fire protection. Consider use of automatic fire doors or dampers for the generator set room.

The generator set room must be ventilated adequately to prevent buildup of engine exhaust gases or flammable fuel supply gas.

- The generator room should not be used for storage purposes.
- Generator rooms should not be classified as hazardous locations (as defined by the NEC) solely by reason of the engine fuel.
- The authority having jurisdiction will usually classify the generator set as a low heat appliance when use is only for brief, infrequent periods, even though exhaust gas temperature may exceed 1000° F (538° C). Where exhaust gas temperature may exceed 1000° F (538° C), some diesels and most gas engines may be classified as high heat appliances and may require exhaust systems rated for 1400° F (760° C) operation. Consult the engine manufacturer for information on exhaust temperatures.
- The authority having jurisdiction may specify the quantity, type, and sizes of approved portable fire extinguishers required for the generator room.
- A manual emergency stop station outside the generator room or remote from a generator set in an outside enclosure would facilitate shutting down the generator set in the event of a fire or other type of emergency.

27 **CODE NOTE:** In the US, NFPA110 requires that generator sets used in Level 1 emergency systems be installed in a room with a 2–hour fire resistance rating. Other emergency systems are required to have 1–hour fire resistance ratings.

28 **CODE NOTE:** In Canada, CSA282–2000 requires that a room with 1–hour fire resistance rating protect emergency power systems that are installed in buildings.

- Typical liquid fuel systems are limited to 660 gallons (2498 liters) inside of a building. However, the authority having jurisdiction may enforce much more stringent restrictions on the amount of fuel that can be stored inside a building. Also, exceptions may be made to allow use of larger amounts of fuel in a generator set room, especially if the generator set room has properly designed fire protection systems.
- Fuel tanks located inside buildings and above the lowest story or basement should be diked in accordance with NFPA standards and environmental regulations.
- The generator set should be exercised periodically as recommended under at least 30 percent load until it reaches stable operating temperatures. It should also be run under nearly full load at least once a year to prevent fuel from accumulating in the exhaust system.

Equipment Room Design

General Considerations

Generator sets should be installed according to instructions provided by the generator set manufacturer, and in compliance with applicable codes and standards.

General guidelines for room design:

- Most generator sets will require access for service to both sides of the engine as well as the control/alternator end of the machine. Local electrical codes may require specific working space for electrical equipment, but in general, allow for working space equal to the width of the genset on both sides and rear.
- Location of fuel system, or electrical distribution system components may require additional working space. See fuel supply requirements elsewhere in this section for more information on that subject.
- There should be access to the generator set room (or outdoor enclosure) that allows the largest component in the equipment to be removed (almost always the engine). Access may be through wide doorways, or via removable inlet or exhaust air louvers. An ideal design will allow moving the generator set as a package into the equipment room.

Roof–top Installations

With more pressure on building cost, it is becoming more common to locate generator sets on roof–tops. These installations can be successfully accomplished if the building structure can support the weight of the generator set and associated componentry. General advantages and disadvantages of these installations:

Advantages

- Unlimited ventilation air for system.
- No (or little) need for ventilation duct work.
- Short exhaust runs
- Fewer Noise issues (may still require sound attenuated enclosure).
- Fewer space limitations
- Generator set is isolated from normal service, for better system reliability.

Disadvantages

- Roof structure may need to be strengthened to support generator set.
- Moving equipment to roof may be expensive. (crane or disassembly)
- Code restrictions

- Longer cable runs
- Limited fuel storage at generator set; fuel supply (and possibly return) must run through building.
- More difficult to service generator set

Note: Even though the generator set is mounted on the roof, care must still be taken with engine exhaust, to avoid contamination of air inlet ducts into the building or adjacent properties. See Ventilation General Guidelines earlier in this section for more information.

It is recommended that generator sets that have limitations in their service access be provided with a load bank connection within the building distribution system. This will allow load banks to be temporarily connected in a convenient location. Otherwise, the difficulty of connecting a load bank may hinder or even prevent proper testing of the generator set.

APPENDIX A CONTENTS

APPENDIX A

Sizing Generator Sets with GenSize ™

Overview

GenSize ™ is a software application (available on the Power Suite CD from Cummins Power Generation) for determining the proper size (capacity) of generator sets for your standby or prime power applications. All of the information needed to order an appropriate generator set configuration from your local distributor is included in the recommendation prepared by the software.

In the Library CD that accompanies the Power Suite CD, you can also view and print an array of product information necessary to properly design a complete power generation system. Information on the Library CD includes: generator set specification sheets, technical support information (alternator data, generator set exhaust emissions data, generator set acoustic data, generator set prototype test summaries) and key drawings (outline, schematic, wiring diagrams, and accessory installation drawings).

With GenSize you can create, save, retrieve, modify, and delete information within a project. Load information can be copied and pasted within or between multiple projects. GenSize handles most load types including various lighting types, HVAC, Battery Charging, UPS, motors, Fire Pumps and general loading. A user–defined load area is available for the user to input characteristics of a unique load. GenSize correctly handles welding, cyclic, and medical imaging loads (where load surge occurs after all loads have been started and not during the starting sequence itself).

NOTE: When GenSize is used as the basis for sizing a generator set from a manufacturer other than Cummins Power Generation, be aware that competitive generator sets of the same kW rating may not be suitable for a given application due to differences in performance. The power system designer can minimize risk in this situation by specifying a generator set with similar alternator temperature rise, alternator per unit subtransient reactance, harmonics, and governor transient performance.

In addition to being a tool for viewing generator set performance data, GenSize includes an easy–to–use graphical interface for entering information about the loads placed on the generator set, the starting step sequence of the loads, and parameters for the generator set itself. Although there is no separate manual for GenSize, its context–sensitive Help files should be sufficient for running the application.

Applications

There are four Applications within the Power Suite: GenSize, Library, GenCalc and GenSpec.

In GenSize, the project as a whole is displayed on the left side, while the right shows the contents of any node selected from the left side. This is the core of the application where loads and sequence are input and defined.

The Library Application allows the user to explore product specifications and data, application drawings and other pertinent information, and to incorporate this data into a project report. The Library is accessed through a Library Contents CD. The Library contents CD may be copied to a PC hard drive for access convenience.

The GenCalc Application includes a Decrement Curve Calculator for the alternators used on Cummins generator sets. This application is designed to include several future applications for assistance in designing exhaust and fuel systems as well as other facets of power systems.

The GenSpec Application contains a selection of Word documents featuring sample specifications for generator sets, paralleling equipment, and transfer switches. More information about these Applications can be found in the GenSize Help area.

Installing Power Suite

Insert the Power Suite CD in the CD–ROM drive and follow the software installation instructions on the screen, or select Start/Run from the Windows desktop, select the CD ROM drive and run Setup.exe. The GenSize software is designed to run in a Windows NT, 95, 98, or 2000 operating system environment. The browser function for the Library CD is optimized for Internet Explorer 5.0 and Adobe Acrobat 4.0 (included on the CD). After installation is complete, a New Project dialog box will appear – Select New Project.

Project Parameters

The first step in sizing and selecting an engine–generator set is to establish project parameters. At a minimum, the generator set must be sized to supply the maximum load starting steady–state running requirements of the connected load equipment.

To set the default project parameters, select Projects from the top tool bar, then New Project Default Parameters at the bottom of the pull–down menu. The resulting dialog box, **Figure A–1**, shows New Project Parameters that are applied to all new projects and can be altered to suit your preferences. The project parameters for a single or an existing project can be changed without altering the default parameters by highlighting the project name then selecting Projects, Edit, and then the parameters tab.

Following is an explanation of the project parameters and the default entries shown in the dialog box.

Number of Generator Sets Running In Parallel

The default value is 1. If the total load is greater than the capacity of a single generator set, insert 2, 3, or more as appropriate. If the total load is above 1000 kW, it may be advantageous to parallel generator sets for higher reliability and operational flexibility. When the total load is 300 kW or less, however, it is usually not cost–effective to parallel generator sets – although it is technically feasible.

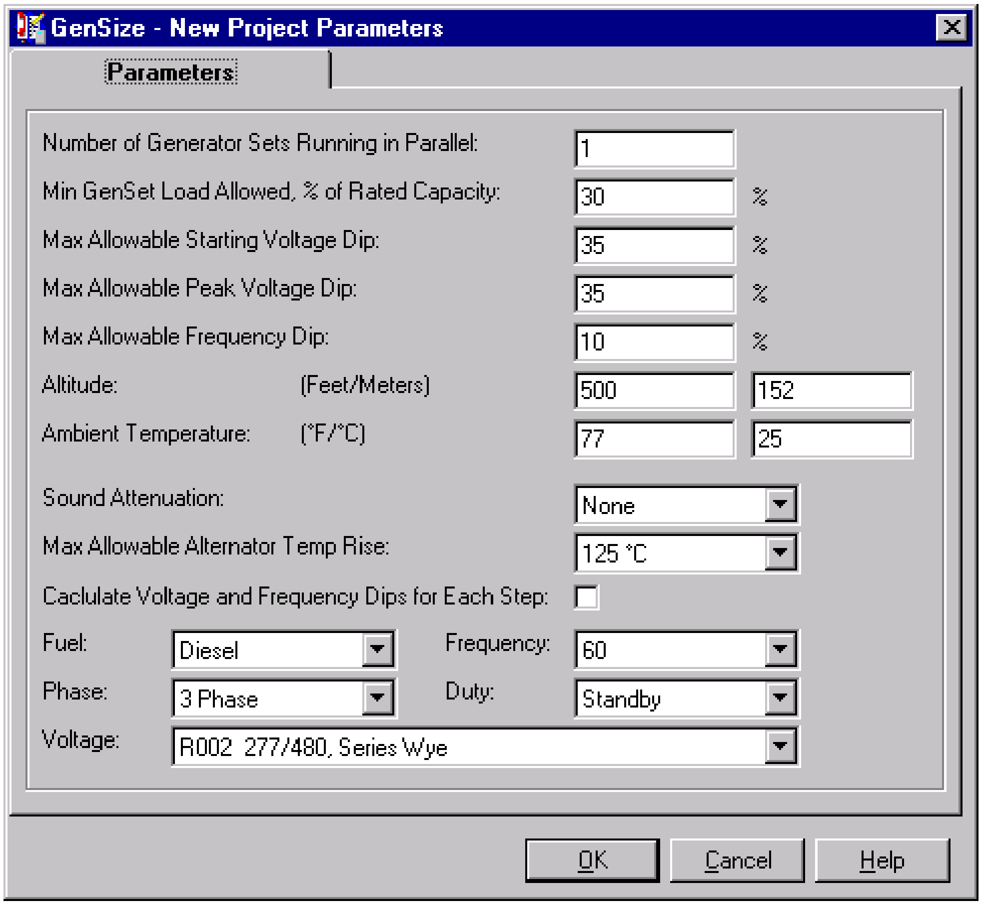


Figure A–1. GenSize–New Project Parameters Dialog Box

Minimum Genset Load/Capacity

Running a generator set under light load can lead to engine damage and reduced generator set reliability. Cummins Power Generation does not recommend running generator sets at less than 30 percent of rated load — this is the default setting in GenSize. Load banks should be used to supplement the regular loads when loading falls below the recommended value. A generator set should not run at less than 10 percent of rated load for any extended period.

Maximum Voltage Dip (Starting and Peak)

As you reduce the maximum allowable voltage dip during initial startup, or when loads cycle under automatic controls or have high peak surges, the size of the recommended generator set increases. Choosing a lower allowable voltage dip results in a larger recommended generator set. However, setting allowable voltage dips of more than 40 percent can lead to relay and contactor malfunctions. The default Maximum Voltage Dip in GenSize is 35 percent.

Maximum Frequency Dip

As you reduce the maximum allowable frequency dip, you increase the size of the recommended generator set. Since a generator set is a limited power source (compared to a utility), voltage and frequency excursions will occur during transient loading events. The generator set must be sized to limit these excursions to an appropriate level for proper load performance. The default Maximum Frequency Dip in GenSize is 10 percent. This number may have to be set lower when supplying frequency–sensitive loads, such as UPS systems. Check with the UPS manufacturer for information on the UPS system's sensitivity to frequency excursions when operating on a standby generator set.

Altitude and Ambient Temperature

Based on geographic location, the size of the generator set the software recommends may be increased for a given level of performance as altitude and/or ambient temperature increase. The default values are an altitude of 500 feet (152 meters) and an ambient temperature of 77° F (25° C).

Sound Attenuation

The default setting is None. However, a Quiet Site generator set may be selected. Quiet Site units include special exhaust silencers, a sheet metal housing with sound attenuating insulation, and/or intake and discharge dampers. Not all models are available in a Quiet Site configuration. When selecting Sound Attenuation, GenSize generator set recommendations will be limited to standard optional packages available from the factory. Your local distributor, however, should be consulted for any other sound attenuation needs.

Maximum Alternator Temperature Rise

A maximum allowable temperature rise over an ambient of 40° C (104° F) can be specified for the alternator windings. GenSize will recommend engine–alternator combinations that limit the alternator temperature rise to the specified temperature when powering the specified connected loads. It may be desirable to use lower temperature rise alternators in applications that contain significant non–linear loads, where better motor starting is required, or in prime duty applications. The default setting is 125° C. Note that, when you select a lower temperature rise alternator, you may increase the size of the recommended generator set to accommodate a larger alternator.

Fuel

The default fuel is Diesel. Other choices of available fuels are Natural gas and Liquid Propane Gas. An “Any Fuel” choice is available which allows GenSize to compare the performance of all available fuel choices.

Note: For gaseous fuels requirements above approximately 150/140 kW, consult the distributor.

Frequency

Specify the required operating frequency. Generator sets are configured for either 50 Hz or 60 Hz. The default value is 60 Hz.

Phase

Select either a single– or three–phase generator set. The default setting is three–phase. If selecting single–phase, only single–phase loads are allowed. Selecting single–phase will also limit the number of available models since larger generator sets are not available with single–phase generators. The default three–phase selection permits single–phase loads but GenSize assumes that the single–phase loads will be balanced across the three phases.

Duty

GenSize makes a recommendation based on the standby or prime power rating of the generator set, derating appropriately for site conditions. The default setting is Standby. For further discussion and illustration of system and generator set ratings see Preliminary Design section.

A *standby power system* is an independent power system that supplies a facility in the event of a failure of the normal power source. (It is assumed that the generator set is isolated from the utility service.) The standby power rating is applicable for emergency power duty for the duration of a typical power interruption. No overload capability is available for this rating.

A *prime power system* is an independent power system for supplying electric power in lieu of purchasing power from a commercial utility. (It is assumed that the generator set is isolated from the utility service, or that utility service is unavailable.) The prime power rating is the maximum power available at variable load for an unlimited number of hours.

A minimum of 10 percent overload capability is available for prime power ratings per engine rating standards BS 5514 and DIN 6271. Not every generator set configuration is available for prime duty.

When generator sets are paralleled with a utility service for an extended period of time, they should not be operated in excess of their base load rating. Generally the base load rating of a generator set is significantly lower than its prime power rating. Base load ratings for generator sets are available from the factory or your local Cummins Power Generation distributor.

Voltage

Available voltage choices are a function of selected frequency. Default values are 277/480, Series Wye.

Entering Loads

The next and most important step in sizing a generator set is identifying every type and size of load the generator set will power. As with most operations in GenSize, the loads can be entered either from the menu under Projects, Add New Load, or from the icons located on the tool bar. After selecting a load type, the load entry form will appear. Each load form will open with load characteristic defaults which can all be changed. Enter all of the required information. If you are unsure what any of the items are, check the online Help for an explanation. As each load is entered, they will appear in a list on the left side of the screen under the project you are working on. Selecting (with a mouse click) one of the loads in the list will display the load operating characteristics on the right of the screen. Double clicking a load icon will open the load entry form for that load and you can edit the load from here. The following is intended to help you understand load parameters and the way they are calculated by GenSize.

Identify all of the different type and size loads the generator set will need to support. If you have more than one load of a given size and type, you only need to enter it once, unless you want each of the loads to carry a different description. The quantity of each load can be set when you enter the load in the step starting sequence. As described later in this section

Cummins Power Generation has researched the starting and running characteristics of many of the common loads and have included defaults for these load characteristics in GenSize. You can choose to use the defaults or, if you know the characteristics of your load are different, change the load characteristic. If you have a load type other than what is identified in GenSize, use a miscellaneous load to define the load starting and running requirements.

Based on the load characteristics, GenSize calculates values for running kW (RkW), running kVA (RkVA), starting kVA (SkVA), starting kW (SkW), starting power factor (SPF), peak kVA (PkVA), peak kW (PkW), and running amps (RAmps). When non–linear loads are present, it may be necessary to over–size the alternator, and GenSize calculates a value for the alternator kW (AkW) for the load.

Note that when entering single–phase loads on a three–phase generator set, GenSize assumes that all three phase loads will be balanced among the three phases. Therefore, the single–phase loads are converted to an equivalent three–phase load for sizing purposes. This results in the single–phase load current being distributed across the three phases so the single–phase load current is divided by 1.73. When a single phase load is entered for a three phase set application, the actual single phase current will be displayed in the load entry form, but when the load is entered into a step (the step load is the balanced load applied to the generator), the step load current is converted to the equivalent three phase current.

Definition of Terms

The following abbreviations are used in GenSize for calculating individual load running and starting requirements, step load requirements, and transient surge load requirements. These abbreviations are used on load forms and reports in the application and in the following discussion intended to document some of the calculations performed in GenSize.

Load Running Requirements (Individual Load Steady–State Running)

- Running kVA (RkVA) – the running kilovolt–amperes load.
- Running kW (RkW) – the running kilowatt load.
- Alternator kW (AkW) – the alternator capacity provided to compensate (to oversize) for non–linear distortion.
- Running PF (RPF) – the steady–state running power factor of the load.
- Efficiency – the ratio of output power to input power.
- Running Amps (RAmps) – the running amperes for a load or step.

Load Starting Requirements (Individual Load Starting)

- Starting kW (SkW) – starting kilowatts of a load.
- Starting kVA (SkVA)– starting kilovolt–amperes of a load.
- Starting PF (SPF) – starting power factor is the power factor of the load at the time it is initially energized or started.

Transient Step Load Requirements (Combined Load in Each Step Load Application)

- Maximum Step kW – the maximum step load in kW (sum of individual load starting kilowatts (SkW)) in the step.
- Maximum Step kVA – the maximum step load in kVA (sum of individual load starting kilovolt–amperes (SkVA)) in the step.
- Cumulative Step kW – the Maximum Step kW added to the running kW of the previous step(s).
- Cumulative Step kVA – the Maximum Step kVA added to the running kVA of the previous step(s).
- Effective Step kW – the Cumulative Step kW times a multiplier to account for the reduced load effect due to sustained reduced output voltage during the transient step load.
- Effective Step kVA – the Cumulative Step kVA times a multiplier to account for the reduced load effect due to sustained reduced output voltage during the transient step load.

Transient Surge Load Requirements (Combined Load for all Loads that Require Random Peak Operating Power)

- Peak kW (PkW) – the sudden increase of power in kW demanded by a cyclical load as it starts, or by other surge loads like welders and medical imaging equipment when they operate.
- Peak kVA (PkVA) the sudden increase of power in kVA demanded by a cyclical load as it starts, or by other surge loads like welders and medical imaging equipment when they operate.
- Cumulative Surge kVA – the Peak kVA added to the running kVA of all other non–surge loads.
- Cumulative Surge kW – the Peak kW added to the running kW of all other non–surge loads.

- Effective Surge kW – the Cumulative Peak kW times a multiplier to account for the reduced load effect due to sustained reduced output voltage during the transient surge load.
- Effective Surge kVA – the Cumulative Peak kVA times a multiplier to account for the reduced load effect due to sustained reduced output voltage during the transient surge load.

Detailed Load Calculations

The following documents all of the individual load requirements calculations. Load running, starting and peak surge requirements are calculated for each load based on assumed default operating characteristics as displayed on the individual load entry forms.

Light Load Calculations

Three different light load types can be entered:

Fluorescent – A low–pressure mercury type discharge lamp where most of the light is emitted by an excited layer of fluorescent material. The same load characteristics are used for ballast or electronic types. Both are non–linear loads, but GenSize ignores the non–linearity for this load type since this is usually a small part of the total connected load.

Incandescent – Standard bulb type lamp assemblies, which use a filament to create light.

Discharge (HID) – Lamps that produce light by passing a current through a metal vapor; includes high pressure sodium, metal halide, and mercury vapor discharge lighting.

RkW If kVA entered: RkW = kVA x RPF
If Ramps entered: 1∅ RkW = (Ramps x voltage x RPF) ÷ 1000
3∅ RkW = (Ramps x voltage x RPF x 1.73) ÷ 1000
RkVA If RkW entered: RkVA = RkW ÷ RPF
If Ramps entered: 1∅ RkVA = (Ramps x voltage) ÷ 1000
3∅ RkVA = (Ramps x voltage x 1.73) ÷ 1000
RPF Running power factor as entered or default
SkW SkW = RkW for incandescence and florescence
SkW = 0.75 x RkW for HID
SkVA SkVA = SkW ÷ SPF
SPF SPF = RPF, except for HID where default SPF = 0.85
AkW AkW = RkW
Ramps 1∅ Ramps = (RkW x 1000) ÷ (voltage x RPF)
3∅ Ramps = (RkW x 1000) ÷ (voltage x RPF x 1.73)

Air Conditioner Load Calculations

GenSize simply converts tons to horsepower for sizing air conditioning loads at 2 HP/ton as a conservative estimate of the total load for a lower efficiency unit. If you want a more exact size and know the individual component motor loads in the A/C equipment, enter them individually and come up with a demand factor for what loads are likely to start simultaneously.

RkW RkW = AC Tons x 2 x 0.746
RkVA RkVA = RkW ÷ RPF
RPF Running power factor as entered or default from database
SkW High Inertia SkW = SkVA x SPF
Low Inertia SkW = SkVA x SPF x 0.6
SkVA SkVA = HP x (LRkVA/HP) x SkVA factor, where
LRkVA/HP is the average kVA/HP for the NEMA Code letter of the motor, and SkVA factor is 1.0 for full voltage starting, or from reduced voltage starting table (see Reduced Voltage Starting Method)
SPF As entered, or default values from database by HP and starting method

For loads that are designated to automatically cycle on and off:

	PkW	PkW = SkW
	PkVA	PkVA = SkVA
AkW	(non–VFD) AkW = RkW except solid–state starter where AkW = 2.0 x RkW unless a bypass contactor is used, then AkW = RkW	
AkW	(VFD) Conventional AC Inverter: AkW = 2.0 x RkW Pulse Width Modulated: AkW = 1.4 x RkW DC Drive: AkW = 2.0 x RkW	
Ramps	1∅ Ramps = (HP x 746) ÷ (voltage x Eff. x RPF) 3∅ Ramps = (HP x 746) ÷ (1.73 x voltage x Eff. x RPF)	

Battery Charger Load Calculations

A battery charger is a silicon–controlled rectifier (SCR) assembly used to charge batteries. A battery charger is a non–linear load requiring an oversized alternator.

RkW	RkW = RkVA x RPF
RkVA	RkVA = (Output kVA x Recharge Rate) ÷ Efficiency
RPF	Running power factor as entered or default
SkW	SkW = RkW
SkVA	SkVA = RkVA
SPF	SPF = RPF
AkW	For 3 pulse, AkW = 2.5 x RkW For 6 pulse, AkW = 1.4 x RkW For 12 pulse, AkW = 1.15 x RkW With input filter, AkW = 1.15 x RkW
Ramps	1∅ Ramps = (RkVA x 1000) ÷ voltage 3∅ Ramps = (RkVA x 1000) ÷ (voltage x 1.73)

Medical Imaging Load Calculations

GenSize calculates a peak voltage dip for when a medical imaging load is operated. This dip must be limited to 10% to protect the quality of the image. If the peak voltage dip is set higher in the project parameters, GenSize will automatically lower it and notify you. The generator set is then sized to limit the voltage dip to 10% when the medical imaging equipment is operated with all other loads running. If multiple medical image loads are used, the peak voltage dip is calculated for the single largest load and assumes only the single largest load will be operated at any one time.

Note that GenSize assumes that the medical imaging equipment is not being operated while loads are starting, so the starting voltage dip is calculated separately and is allowed to exceed 10%.

RkW	If RkVA entered: RkW = RkVA x RPF If Ramps entered: 1∅ RkW = (Ramps x voltage x RPF) ÷ 1000 3∅ RkW = (Ramps x voltage x RPF x 1.73) ÷ 1000
RkVA	If Ramps entered: RkVA = RkW ÷ RPF
RPF	Running power factor as entered or default
SkW	SkW = RkW
SkVA	SkVA = SkW ÷ SPF
PkW	PkW = PkVA x SPF
PkVA	As entered, or 1∅ PkVA = (Pamps x voltage) ÷ 1000 3∅ PkVA = (Pamps x voltage x 1.73) ÷ 1000
SPF	SPF = SkVA ÷ SkW
AkW	AkW = RkW
Ramps	1∅ Ramps = (RkVA x 1000) ÷ voltage 3∅ Ramps = (RkVA x 1000) ÷ (voltage x 1.73)

Motor Load Calculations

If the motor load is powered by a variable speed or variable frequency drive or is an AC drive on a DC motor, select Variable Frequency Drive (VFD). A VFD is a non–linear load requiring an oversized alternator to match the running load requirements. On the other hand, since VFDs ramp the load on, the starting requirements will be reduced compared to a motor started across the line. Select PWM if the VFD is of the pulse width modulated type. PWM type VFDs require less oversizing than non–PWM types.

Motor starting requirements can be reduced by applying some type of reduced voltage or solid state starter. Application of these devices can result in smaller generator set recommendations. However, caution must be used when applying any of these starting methods. First of all, motor torque is a function of the applied voltage and all of these methods result in lower voltage during starting. These starting methods should only be applied to low inertia motor loads unless it can be determined the motor will produce adequate accelerating torque during starting. Additionally, these starting methods can produce very high inrush currents when they transition from start to run if the transition occurs prior to the motor reaching very near operating speed, resulting in starting requirements approaching an across the line start. GenSize assumes the motor reaches near rated speed before this transition, ignoring these potential inrush conditions. If the motor does not reach near rated speed prior to transition, excessive voltage and frequency dips can occur when applying these starters to generator sets. If unsure how your starter and load will react, use across–the–line starting.

For across–the–line motor starting, select low inertia load if you know the load requires low starting torque at low speeds. This will reduce the starting kW requirements for the generator set and can result in a smaller set. Low inertia loads are typically centrifugal fans and pumps. If unsure, use high inertia (leave low inertia unselected).

RkW	If HP entered: RkW = (HP x 0.746) ÷ Running Efficiency If kW entered: RKW = kW ÷ Running Efficiency If Ramps entered: 1∅ RkW = (Ramps x voltage x RPF x Efficiency) ÷ 1000 3∅ RkW = (Ramps x voltage x RPF x Efficiency x 1.73) ÷ 1000
RkVA	RkVA = RkW ÷ RPF
RPF	Running power factor as entered or default from database
SkW	High Inertia SkW = SkVA x SPF Low Inertia SkW = SkVA x SPF x 0.6
SkVA	SkVA = HP x (LRkVA/HP) x SkVA factor, where LrkVA/HP is the average kVA/HP for the NEMA Code letter of the motor, and SkVA factor is 1.0 for full voltage starting, or from reduced voltage starting table (see Reduced Voltage Starting Method)
SPF	As entered, or default values from database by HP and starting method

For loads that are designated to automatically cycle on and off:

PkW	PkW = SkW
PkVA	PkVA = SkVA
AkW	(non–VFD) AkW = RkW except solid–state starter where AkW = 2.0 x RkW unless a bypass contactor is used, then AkW = RkW
AkW	(VFD) Conventional AC Inverter: AkW = 2.0 x RkW Pulse Width Modulated: AkW = 1.4 x RkWDC Drive: AkW = 2.0 x RkW
Ramps	1∅ Ramps = (HP x 746) ÷ (voltage x Efficiency x RPF) 3∅ Ramps = (HP x 746) ÷ (1.73 x voltage x Efficiency x RPF)

Fire Pump Load Calculations

GenSize will size the generator limiting the peak voltage dip to 15% when starting the fire pump,with all other non–surge loads running. This is to meet North American fire code requirements. The generator set does not have to be sized to provide the locked rotor kVA of the fire pump motor indefinitely. That would result in an oversized generator set, which could experience maintenance and reliability issues from being under–utilized.

Whenever a reduced voltage starter is used for a fire pump motor, the user should consider sizing for across–the–line starting because the fire pump controller includes either a manual–mechanical, manual–electrical, or automatic means to start the pump across–the–line in the case of a controller malfunction. GenSize will not disallow use of reduced voltage starters for fire pumps, however.

RkW	If HP entered: RkW = HP x 0.746 ÷ Running Efficiency If kW entered: RkW = kW ÷ Running Efficiency If Ramps entered: 1∅ RkW = (Ramps x voltage x RPF x Efficiency) ÷ 1000 3∅ RkW = (Ramps x voltage x RPF x Efficiency x 1.73) ÷ 1000
RkVA	RkVA = RkW ÷ RPF
RPF	Running power factor as entered or default from database
SkW	High Inertia SkW = SkVA x SPF Low Inertia SkW = SkVA x SPF x 0.6
SkVA	SkVA = HP x (LRkVA/HP) x SkVA factor, where LrkVA/HP is the average kVA/HP for the NEMA Code letter of the motor, and SkVA factor is 1.0 for full voltage starting, or from reduced voltage starting table (see Reduced Voltage Starting Method)
SPF	As entered, or default values from database by HP and starting method
PkW	PkW = SkW
PkVA	PkVA = SkVA
AkW	(non–VFD) AkW = RkW except solid–state starter where AkW = 2.0 x RkW unless a bypass contactor is used, then AkW = RkW
AkW	(VFD) Conventional AC Inverter: AkW = 2.0 x RkW Pulse Width Modulated: AkW = 1.4 x RkW DC Drive: AkW = 2.0 x RkW
Ramps	1∅ Ramps = (HP x 746) ÷ (voltage x Efficiency x RPF) 3∅ Ramps = (HP x 746) ÷ (1.73 x voltage x Efficiency x RPF)

UPS Load Calculations

A static UPS uses silicon controlled rectifiers (SCR) or another static device to convert AC voltage to DC for charging batteries, and an inverter to convert DC to conditioned AC power to supply the load. A UPS is a non–linear load and may require an oversized alternator. Some incompatibility problems between generator sets and static UPSs have led to many misconceptions about sizing the generator set for this type of load. Past problems did occur, and the recommendation from UPS suppliers at that time was to oversize the generator set from two to five times the UPS rating. Even then some problems persisted, and since then those incompatibility problems have been addressed by most UPS manufacturers. It is more cost effective to require generator compatibility of the UPS supplier than to oversize the generator.

If the batteries are discharged when the UPS is operating on the generator set, the generator set must be capable of supplying the rectifier for battery charging and the inverter to supply the load. A second reason to use the full UPS rating is that additional UPS load may be added in the future up to the nameplate rating. The non–linear load sizing factors used by GenSize are based on the level of harmonics the UPS induces in the generator output with the UPS fully loaded. Since the harmonics increase at lighter loads, selecting the larger capacity alternator helps to offset this effect.

For multiple redundant UPS systems, size the generator set for the combined nameplate ratings of the individual UPSs. Redundant system applications are those where one UPS is installed to back up another and the two are on–line at all times with 50% or less load.

UPS equipment often has varying power quality requirements depending on the operating mode. When the rectifier is ramping up, often relatively broad frequency and voltage swings can occur without disrupting equipment operation. However, when the bypass is enabled, both frequency and voltage must be very constant, or an alarm condition will occur. This occurs when rapidly changing UPS input frequency results from a sudden transient load change on a generator set. During this transient event, static UPSs with solid–state bypass switches must break synch with the source and disable the bypass.

RkW	RkW = RkVA x RPF		
RkVA	RkVA = (Output kVA x Recharge Rate) ÷ Efficiency		
RPF	Running power factor as entered or default		
SkW	SkW = RkW		
SkVA	SkVA = RkVA		
SPF	SPF = RPF		
AkW	For 3 pulse, AkW = 2.5 x RkW		
	For 6 pulse, AkW = 1.4 x RkW		
	For 12 pulse, AkW = 1.1.5 x RkW		
	With input filter,	AkW = 1.15 x RkW for 6 and 12 pulse	
		AkW = 1.40 x RkW for 3 pulse	
Ramps	1∅ Ramps = (RkVA x 1000) ÷ voltage		
	3∅ Ramps = (RkVA x 1000) ÷ (voltage x 1.73)		

Miscellaneous Load Calculations

Described below are the types and calculations GenSize uses for the various miscellaneous loads:

Welder Load Calculations

RkW	If RkVA entered: RkW = RkVA x RPF	
	If Ramps entered:	1∅ RkW = (Ramps x voltage x RPF) ÷ 1000
		3∅ RkW = (Ramps x voltage x RPF x 1.73) ÷ 1000
RkVA	If Ramps entered: RkVA = RkW ÷ RPF	
RPF	Running power factor as entered or default	
SkW	SkW = RkW	
SkVA	SkVA = SkW ÷ SPF	
PkW	PkW = PkVA x SPF	
PkVA	As entered, or	1∅ PkVA = (Pamps x voltage) ÷ 1000
		3∅ PkVA = (Pamps x voltage x 1.73) ÷ 1000
SPF	SPF = SkVA ÷ SkW	
AkW	AkW = RkW	
Ramps	1∅ Ramps = (RkVA x 1000) ÷ voltage	
	3∅ Ramps = (RkVA x 1000) ÷ (voltage x 1.73)	

General Receptacle Load Calculations

RkW	RkW = Entered kW
RkVA	RkVA = RkW ÷ RPF
RPF	Running power factor as entered or default
SkW	SkW = RkW
SkVA	SkVA = SkW ÷ SPF
SPF	SPF = RPF
PkW	PkW = RkW
PkVA	PkVA = RkVA
AkW	AkW = RkW
Ramps	1∅ Ramps = (RkW x 1000) ÷ (voltage x RPF)
	3∅ Ramps = (RkW x 1000) ÷ (voltage x RPF x 1.73)

User Defined Load Calculations

RkW	If kW entered: RkW = Kw	
	If kVA entered: RkW = kVA x RPF	
	If Ramps entered:	1∅ RkW = (Ramps x voltage x RPF) ÷ 1000
		3∅ RkW = (Ramps x voltage x RPF x 1.73) ÷ 1000
RkVA	If kW entered: RkVA = RkW ÷ RPF	
	If RkVA entered: RkVA = kVA	
	If Ramps entered:	1∅ RkVA = (Ramps x voltage) ÷ 1000
		3∅ RkVA = (Ramps x voltage x 1.73) ÷ 1000

RPF	Running power factor as entered or default
SkW	If kW entered: SkW = kW If kVA entered: SkW = SkVA x SPF If Starting amps entered:1∅ SkW = (Ramps x voltage x RPF) ÷ 1000 3∅ SkW = (Ramps x voltage x RPF x 1.73) ÷ 1000
SkVA	SkVA = SkW ÷ SPF
SPF	SPF = RPF, except for HID where default SPF = 0.85 and RPF = 0.90
PkW	PkW = SkW
PkVA	PkVA = SkVA
AkW	AkW = RkW
Ramps	1∅ Ramps = (RkW x 1000) ÷ (voltage x RPF) 3∅ Ramps = (RkW x 1000) ÷ (voltage x RPF x 1.73)

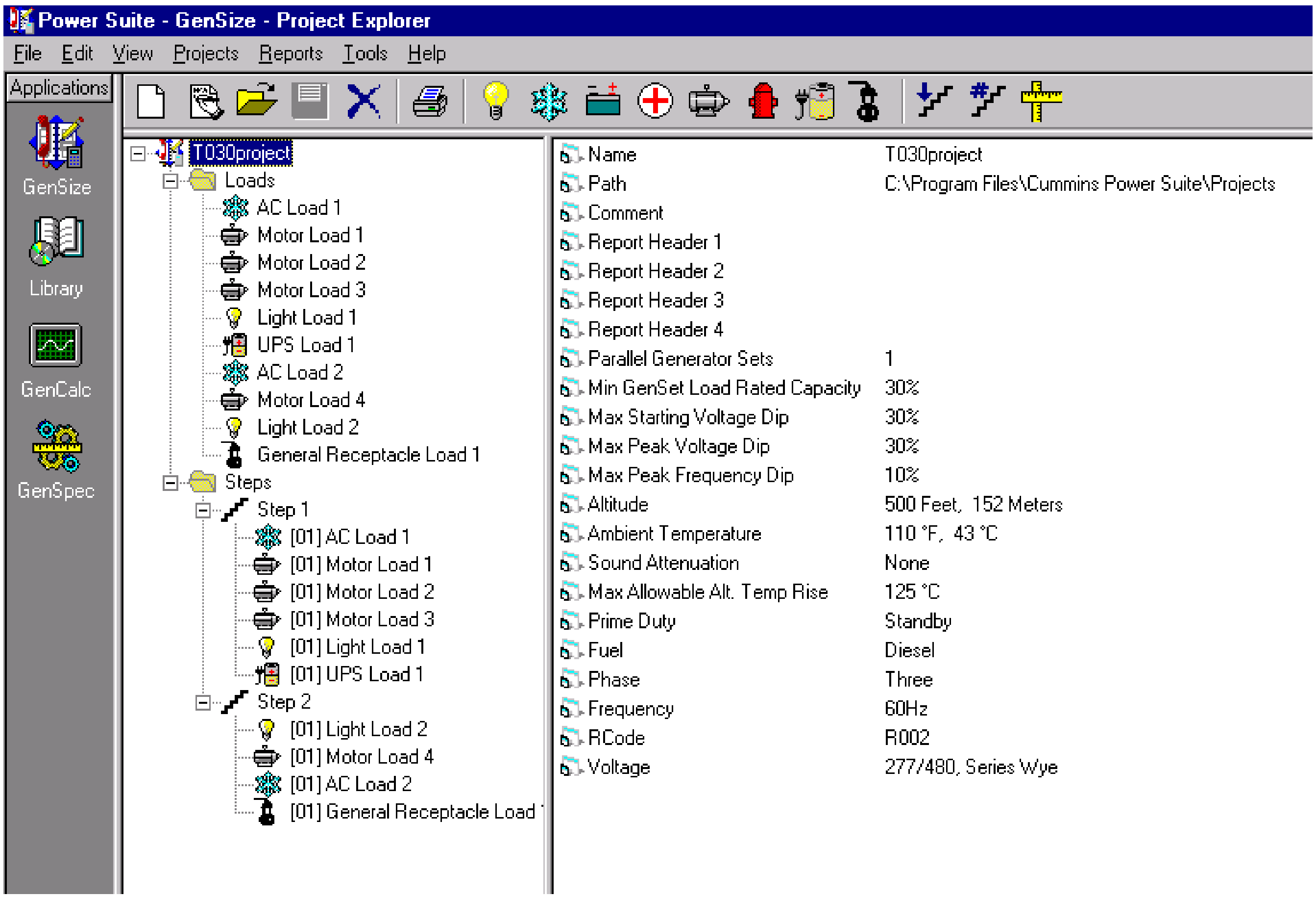


Figure A–2. GenSize Application Project Window

Entering Loads into Steps

After entering the loads, you need to enter all of the project loads into Load Steps. Open the first load step by clicking on the Steps folder on the left of the screen. Note that initially, there are no loads in the Step. Step sequence loading can reduce the size of generator set required when using multiple steps. Multiple transfer switches can be used to connect load to the generator set at different times, simply by adjusting the transfer time delays on the individual switches. Simply allow a few seconds between steps to allow the generator set to stabilize with each load step.

To enter individual loads into the step, simply click and drag the load over the step. Once the load is placed into a step, you can set the load quantity in the step by right clicking and selecting Set Quantity from the drop down menu. Alternatively, each time you click and drag a load into the step, the quantity will increase.

To enter multiple loads into the step, click on the loads folder and all loads are listed on the right side of the screen. Using the Shift or Ctrl key and the mouse, select the desired loads, click on any of the selected loads on the right, and drag to the step. All of the selected loads should appear in the step.

Use the tool bar to add one or more additional steps, as desired. You can view the loads and steps using View on the menu to find out either which steps individual loads were placed in or to get a summary of all the loads in each step.

Load Step Considerations

For many applications, the generator set will be sized to be able to pick up all of the loads in a single step. For some applications it is advantageous to start the loads with the larger starting surge requirements first, then after those loads are running, to start the rest of the loads in different steps. The starting sequence of loads might also be determined by codes in which the emergency loads must come on first, then the standby equipment, then the optional loads.

Starting step sequencing of generator sets may be accomplished with transfer switches using transfer time delays, load sequencer, or other controller, such as a PLC. You may use this application to tell your distributor how many starting steps your application requires. Remember, even though there is a controlled initial loading sequence, there may be uncontrolled load stopping and starting of certain loads and you may wish to check surge loading under those conditions.

Step Sequence Guidelines

Single Step Simultaneous Starting: One commonly used approach is to assume that all connected loads will be started in a single step, regardless of the number of transfer switches used. This assumption will result in the most conservative (largest) generator set selection. Use a single step load unless something will be added, such as multiple transfer switches with staggered time delays or a step load sequencer.

Single Step with a Diversity Factor: This is similar to simultaneous starting in a single step, except that an estimated diversity factor, of perhaps 80%, is applied to reduce the SkVA and SkW totals to account for whatever automatic starting controls may be provided with the load equipment.

Multiple Step Sequence: Sequenced starting of loads (where possible) will often permit the selection of a smaller generator set. GenSize assumes that adequate time is allowed between load steps for the generator set voltage and frequency to stabilize, typically 5–10 seconds.

Consider the following when controls or delays are provided to step sequence the loads onto the generator set:

- Start the largest motor first.
- When starting motors that use electronic drives (VFD or VSD) the largest motor first rule may not apply. Using electronic drives for starting and running motors allows the designer to better control the actual load applied to the generator set by controlling the maximum current load, rate of load application, etc. The thing to remember about these loads is that they are more sensitive to voltage variation than motors that are started ”across–the–line.”
- Load the UPS last. UPS equipment is typically frequency sensitive, especially to the rate of change of frequency. A pre–loaded generator set will be more stable in accepting UPS load.
- For each step, the SkW required is the total of the RkW of the previous step(s) plus the SkW for that step.

Recommendations and Reports

The following is intended to help you understand the GenSize recommendation for a generator set and available reports that can be printed. **Figure A–3** illustrates the default screen on which GenSize makes its recommendation for the single Cummins Power Generation generator set model that most closely matches the current project parameters. This screen can be toggled with the screen illustrated in **Figure A–4** on which all generator set models that match the parameters can be viewed. You may find it helpful to view the latter display to appreciate the differences in performance between all of the models that could do the job, any of which you could select for the project. You can also print out Reports for distribution and review.

The recommended model(s) will be highlighted in ***green*** in the upper half of the screen. In the lower half of the screen are displayed the parameters for the recommended generator set. These include:

- *Generator Set Requirements:* This tab summarizes the Duty, Voltage, Altitude, Phase, Voltage Dips, and other parameters.
- *Load Running/Surge Requirements:* This tab summarizes all of the load requirements for the project. Pct. Rated Load provides a quick way of determining how much generator set running capacity is being used.
- *Generator Set Configuration:* This tab enumerates the alternator frame size, number of leads, whether the alternator is reconnectable, whether the alternator has an increased capacity for motor starting, the voltage range, whether the alternator has an extended stack, and whether the alternator can provide full single–phase output. It also lists the engine model, displacement, number of cylinders, fuel, and the altitude and ambient temperature derating knees and slope values.

The report grid displays information about the recommended generator set and allows comparison with other generator sets. Following is a discussion of some of the important headings on this grid:

Site Rated Standby (Prime) kW

Displays the site rated standby or prime kW (prime power duty is already derated 10 percent). If the display is **red**, the site rated kW is less than the load running kW, or the running load kW is less than 30 percent of the site rated set kW. A recommended generator set must meet the running load requirement and run at least 30 percent of rated capacity to be recommended.

If the display is ***yellow***, the load running *kW* is less than 30 percent of the site rated set kW. Running generator sets at less than 30 percent of rated load can be accomplished by lowering the minimum percent rated load value in the New Project Parameters.

Site Rated Alternator Max kW (Temperature Rise)

Displays the site–rated alternator kW for the temperature rise selected in the current project parameters. If the display is **red**, the alternator cannot maintain the temperature rise for your connected load requirement, either Running kW or Alternator kW.

Site Rated Alternator Max kVA (Temperature Rise)

Displays the site rated alternator kVA for the temperature rise set in the New Project Parameters. If the display/column is **red**, the alternator cannot maintain your temperature rise for the load Running kVA requirement. The maximum alternator rated kVA capacity is shown in the grid.

The altitude knee for alternators, however, is 1000m (3280 ft) and the temperature knee 40° C (104° F). Alternator Max kW will be derated 3% per 500m (1640 ft) of altitude above the knee and 3% per 5° C (9° F) of ambient temperature over the knee.

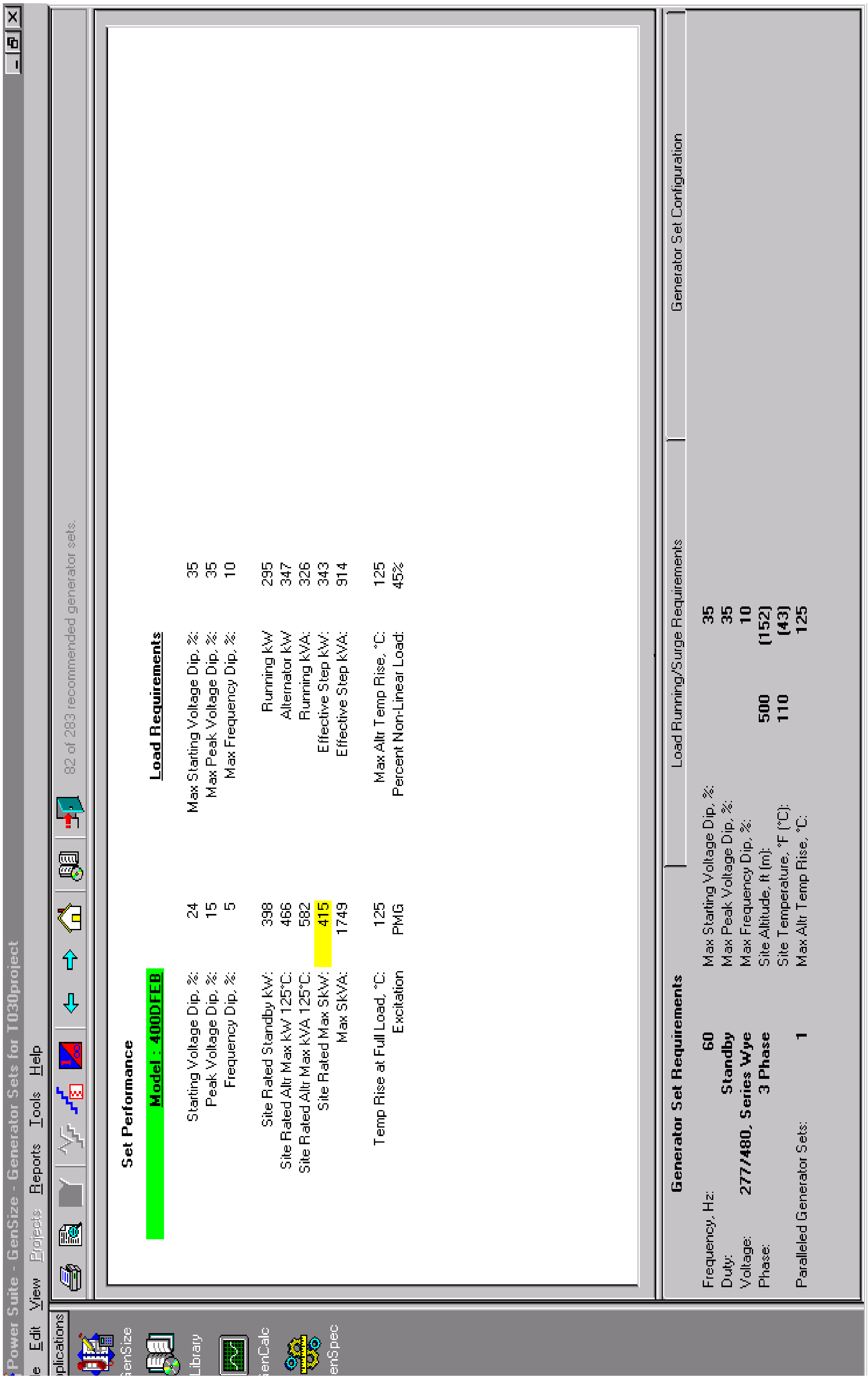
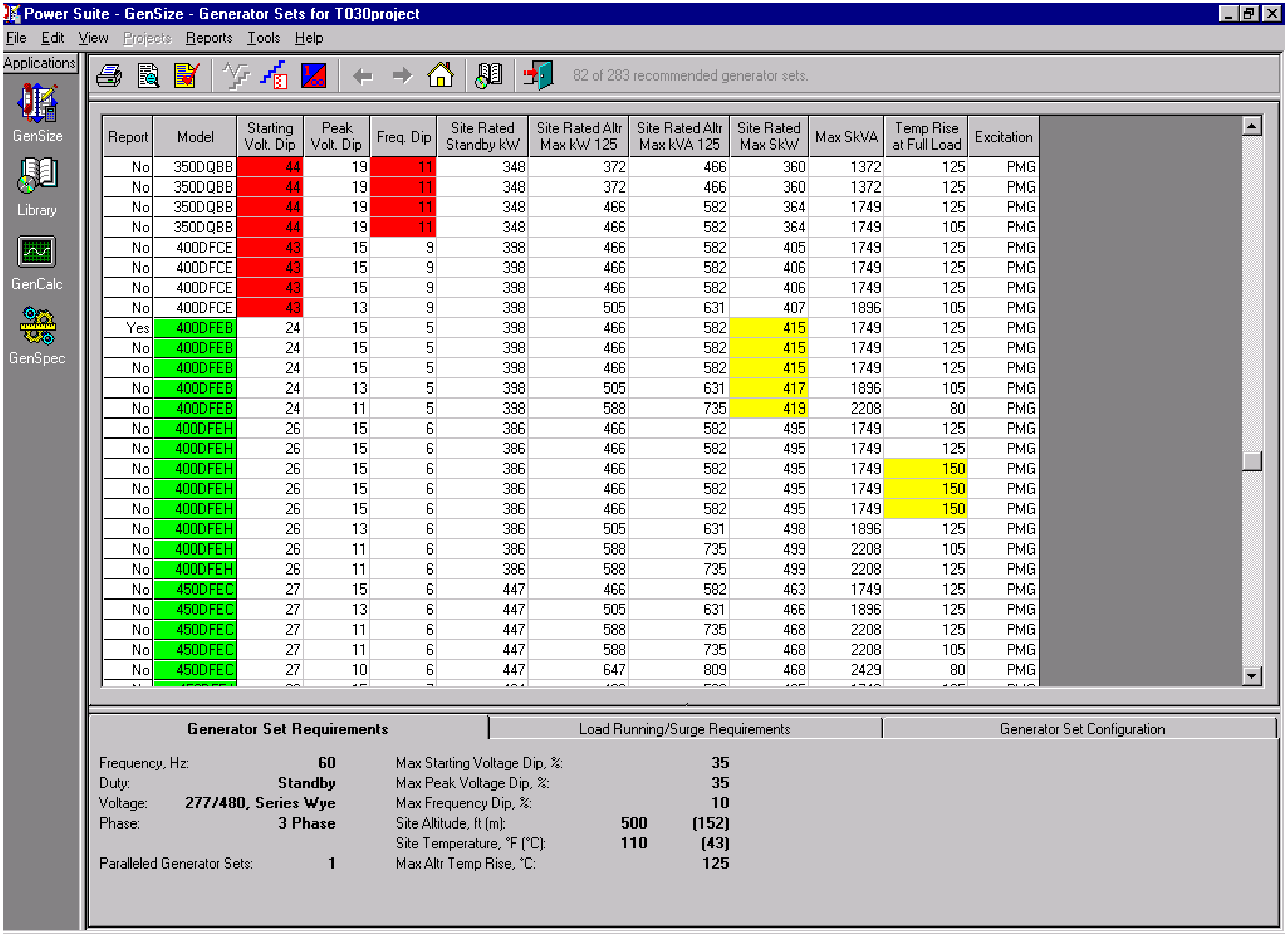


Figure A–3. Recommended Generator Set Window



Report	Model	Starting Volt. Dip	Peak Volt. Dip	Freq. Dip	Site Rated Standby kW	Site Rated Altr Max kW 125	Site Rated Altr Max kVA 125	Site Rated Max SkW	Max SkVA	Temp Rise at Full Load	Excitation
No	350DQBB	44	19	11	348	372	466	360	1372	125	PMG
No	350DQBB	44	19	11	348	372	466	360	1372	125	PMG
No	350DQBB	44	19	11	348	466	582	364	1749	125	PMG
No	350DQBB	44	19	11	348	466	582	364	1749	105	PMG
No	400DFCE	43	15	9	398	466	582	405	1749	125	PMG
No	400DFCE	43	15	9	398	466	582	406	1749	125	PMG
No	400DFCE	43	15	9	398	466	582	406	1749	125	PMG
No	400DFCE	43	13	9	398	505	631	407	1896	105	PMG
Yes	400DFEB	24	15	5	398	466	582	415	1749	125	PMG
No	400DFEB	24	15	5	398	466	582	415	1749	125	PMG
No	400DFEB	24	15	5	398	466	582	415	1749	125	PMG
No	400DFEB	24	13	5	398	505	631	417	1896	105	PMG
No	400DFEB	24	11	5	398	588	735	419	2208	80	PMG
No	400DFEH	26	15	6	386	466	582	495	1749	125	PMG
No	400DFEH	26	15	6	386	466	582	495	1749	125	PMG
No	400DFEH	26	15	6	386	466	582	495	1749	150	PMG
No	400DFEH	26	15	6	386	466	582	495	1749	150	PMG
No	400DFEH	26	15	6	386	466	582	495	1749	150	PMG
No	400DFEH	26	13	6	386	505	631	498	1896	125	PMG
No	400DFEH	26	11	6	386	588	735	499	2208	105	PMG
No	400DFEH	26	11	6	386	588	735	499	2208	125	PMG
No	450DFEC	27	15	6	447	466	582	463	1749	125	PMG
No	450DFEC	27	13	6	447	505	631	466	1896	125	PMG
No	450DFEC	27	11	6	447	588	735	468	2208	125	PMG
No	450DFEC	27	11	6	447	588	735	468	2208	105	PMG
No	450DFEC	27	10	6	447	647	809	468	2429	80	PMG

Figure A–4. All Generator Set Window

Site Rated Max SkW and Max SkVA

Displays the site–rated (derated when necessary for altitude and ambient temperature) maximum SkW and SkVA the generator set configuration can accommodate. If the display is **red**, the generator set cannot recover to a minimum of 90 percent of rated voltage with required Step or Peak load. One of the sizing philosophies for surge loading is that, with the surge load applied, the generator set must be able to recover to 90 percent of rated voltage so that motors can develop adequate accelerating torque. If the generator set recovers to 90 percent of rated voltage, a motor will develop 81 percent of rated torque, which has been shown by experience to provide acceptable motor starting performance.

If the display is ***yellow***, the generator set can recover to a minimum of 90 percent of rated voltage with required surge load, but only because the surge requirement has been reduced. GenSize will reduce the surge requirement in recognition of the fact that the generator set output voltage is reduced while loads having starting power requirements approaching the maximum generator set capacity are starting.

Temperature Rise At Full Load

Displays the temperature rise the alternator will not exceed while supplying load up to and including the generator set full–load rating. Each individual generator set model will have one or more of the following temperature rise alternators available which may be specified in the current project parameters: 80° C, 105°C, 125° C and 150° C. Of course, the actual temperature rise of an alternator is a function of actual connected load. Therefore, GenSize may recommend a generator set with a lower or higher temperature rise option than specified in the New Project Parameters since the set recommendation is based on connected load. Connected load may be less than the full generator set capacity or, in the case of non–linear loads, the alternator may be required to be rated at greater than the set capacity. In any case, the set recommendation will limit the alternator temperature rise to that specified in the New Project Parameters.

Excitation

Displays the type of excitation system to be supplied with a generator set. If the display is **red**, the generator set is shunt excited and the percentage of non–linear load exceeds 25 percent of the load running requirement, RkW. The PMG excitation system is recommended for applications that have a high–linear load content. Unless the PMG option is unavailable, Cummins Power Generation does not recommend using shunt excited generator sets if the non–linear load requirement is more than 25 percent of the total load requirement.

The non–linear load requirement is calculated by adding the Running kW from all of the loads where *Alternator kW* exceeds *Running kW*. This will be the case for UPS loads, variable frequency motors, and solid state motor starters which are not equipped with an automatic bypass. This Alternator *kW* sum is then divided by the sum of the Running *kW* from all of the loads.

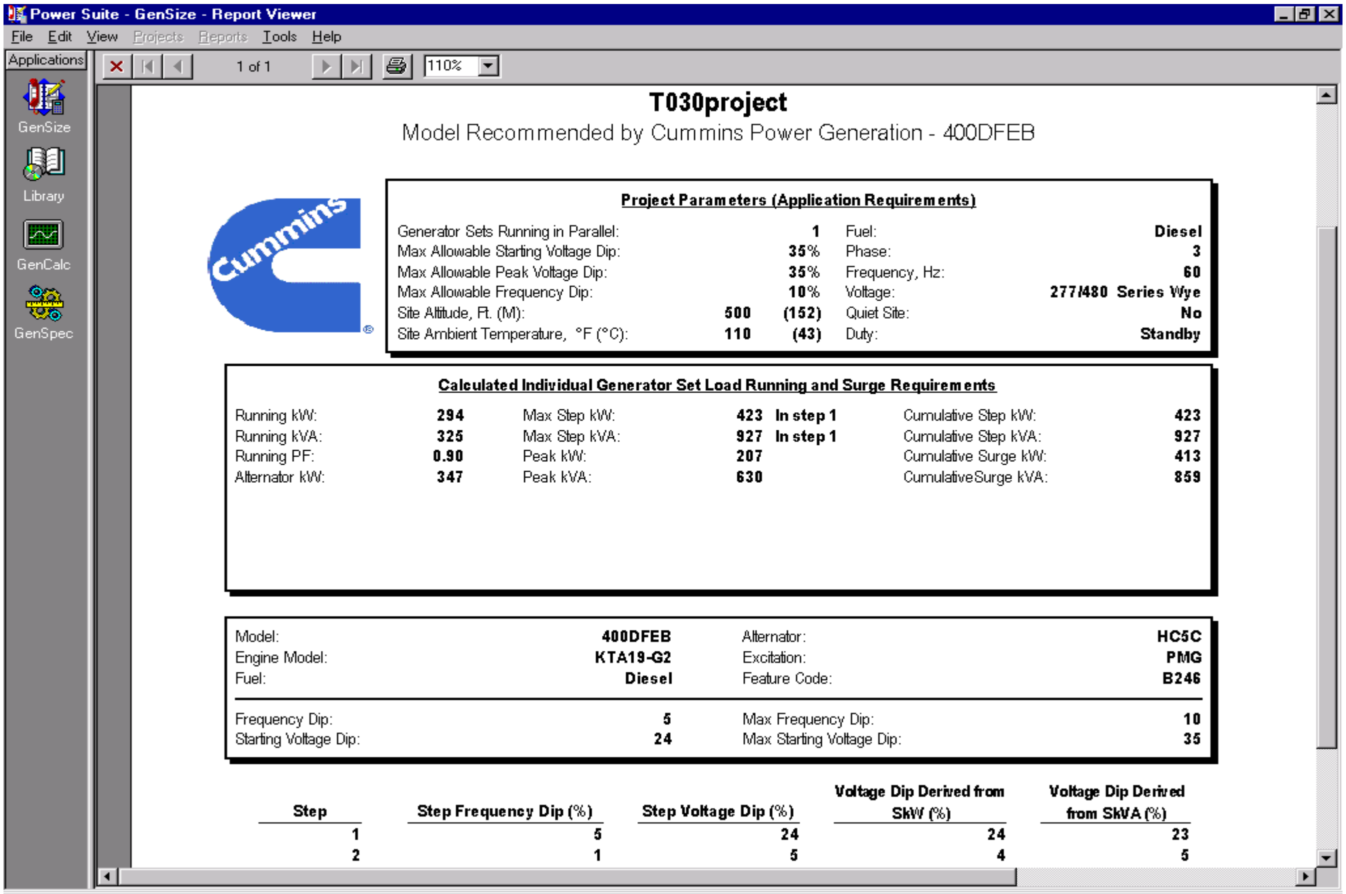
Why a generator set may not be recommended: Several factors can cause a generator set to not be recommended.

- Running kW requirement may exceed the rating of the generator set. Project parameters such as altitude, ambient temperature and prime power duty may cause the generator set to be derated and fall below project requirements.
- The Running kW may be below the minimum of 10 to 30 percent of rated generator set capacity, as specified in the current project parameters (30 percent is default, as recommended by Cummins Power Generation).
- The surge kW requirement may exceed generator capacity, which may have fallen below project requirements because of derating for altitude and ambient temperature. GenSize uses the greater Cumulative kW and Peak kW to determine the load surge kW.

- The surge kVA exceeds generator set capacity. The surge kVA requirement is similar to the surge kW requirement except that there is no derating for altitude or ambient temperature. GenSize uses the greater of cumulative kVA and Peak kVA (if any) to determine the load surge kVA requirement.
- The alternator kW required exceeds the alternator capacity, which may be derated for altitude and ambient temperature by the project parameters. The altitude knee for alternators, however, is 1000m (3280 ft) and the temperature knee 40° C (104° F). Alternator *kW* will be derated 3% per 500m (1640 ft) of altitude above the knee and 3% per 5° C (9° F) of ambient temperature over the knee.
- The alternator kVA required exceeds alternator capacity, which can be derated by altitude and temperature in the same way as the alternator kW.
- The total non–linear load requirement exceeds 25 percent of the total load requirement. This will exclude shunt–excited generators where PMG excitation is not available. The total non–linear load requirement is the sum of the Alternator kW values of all of the non–linear loads.
- The calculated voltage and frequency dips exceed the limits set in the current project parameters.
    - Starting voltage dip is calculated using the higher of two values: dip based on the maximum Step kW or on the maximum step kVA.
    - Peak voltage dip is calculated only if loads in the project exhibit a running surge (cyclic loads or loads like medical imaging that have a high peak power requirement when they are operated.
    - Frequency dip is calculated using the higher of two values: maximum Step kW or Peak kW from loads which exhibit running surge.
- The message, "No generator set is available that meets your running load requirements" usually means that something in the New Project Parameters has been changed after having specified the running load. For instance, you will get the message if you change from diesel to natural gas fuel or from no sound attenuation to Quite Site and the running load you had specified exceeds the capacity of the largest natural gas or Quite Site generator set available. It may also mean that your project falls into a "gap" in the Cummins Power Generation product line. At this point, lowering the minimum percent rated load in the project parameters could allow a recommended set. If this is the case, contact your local Cummins Power Generation distributor for help.
- The message, "No generator set is available which meets your frequency or voltage dip requirements" generally means that the surge requirement of some load step is forcing selection of such a large generator set that the steady state running load falls below 30 percent of the generator set capacity. Since Cummins Power Generation does not recommend running at less than 30 percent of rated capacity, no set can be recommended. At this point, you may have several choices:
    - Increase the allowable voltage or frequency dip.
    - Reduce the minimum percent rated load to less than 30 percent.
    - Apply loads in more steps to lower the individual step surge load.
    - Provide reduced–voltage motor starting.
    - Parallel generator sets.
    - Add loads that do not have a high starting surge (lights, resistive loads, etc.).

Reports

Several type of reports can be generated for the project that is open, a Step/Load Detail, Steps and Dips Detail, and a Recommended Generator report. These can be viewed on screen for review prior to completion, saved for submittal or printed. **Figure A–5** is an example of the Recommended Generator report.



T030project

Model Recommended by Cummins Power Generation - 400DFEB

Project Parameters (Application Requirements)

Generator Sets Running in Parallel:	1		Fuel:	Diesel
Max Allowable Starting Voltage Dip:	35%		Phase:	3
Max Allowable Peak Voltage Dip:	35%		Frequency, Hz:	60
Max Allowable Frequency Dip:	10%		Voltage:	277/480 Series Wye
Site Altitude, Ft. (M):	500	(152)	Quiet Site:	No
Site Ambient Temperature, °F (°C):	110	(43)	Duty:	Standby

Calculated Individual Generator Set Load Running and Surge Requirements

Running kW:	294	Max Step kW:	423 In step 1	Cumulative Step kW:	423
Running kVA:	325	Max Step kVA:	927 In step 1	Cumulative Step kVA:	927
Running PF:	0.90	Peak kW:	207	Cumulative Surge kW:	413
Alternator kW:	347	Peak kVA:	630	CumulativeSurge kVA:	859

Model:	400DFEB	Alternator:	HC5C
Engine Model:	KTA19-G2	Excitation:	PMG
Fuel:	Diesel	Feature Code:	B246
Frequency Dip:	5	Max Frequency Dip:	10
Starting Voltage Dip:	24	Max Starting Voltage Dip:	35

Step	Step Frequency Dip (%)	Step Voltage Dip (%)	Voltage Dip Derived from SkW (%)	Voltage Dip Derived from SkVA (%)
1	5	24	24	23
2	1	5	4	5

Figure A–5. Recommended Generator Report in View Mode

APPENDIX B CONTENTS

APPENDIX B

Reduced Voltage Motor Starting

Although voltage dip often causes various problems, a controlled reduction in voltage at the motor terminals can be beneficial when it is used to reduce the starting kVA of a motor in applications where the reduced motor torque is acceptable. Reducing motor starting kVA can reduce the size of the required generator set, lessen the voltage dip, and provide a softer start for the motor loads. Make sure, however, that the motor will develop sufficient torque to accelerate the load under reduced voltage conditions. Also, any starter that makes a transition between "start" and "run" can cause an inrush condition nearly as severe as across–the–line starting — unless the motor is at or near synchronous speed at transition. This may cause unacceptable voltage dip and potentially starter drop–out.

A Comparison of Motor Starting Methods

Table B–1 compares the effects of full voltage, auto–transformer, and resistor starting on a 50 horsepower, Design B, Code G motor. As can be seen, autotransformer starting requires less motor starting capacity from the generator set. Resistor starting actually requires more kW (engine power) than across–the–line starting.

	TYPE OF STARTER		
	AUTOTRANS-FORMER	**RESISTOR**	**FULL VOLTAGE**
% of applied voltage (tap)	65	50	100
% of full voltage (multiplier)*	0.42	0.50	1.0
Starting kVA with reduced voltage starter	295** x 0.42 = 123.9	295** x 0.50 = 147.5	295** x 1.0 = 295
Starting kW with reduced voltage starter (kVA x PF)	123.9 x 0.36***= 43.4	147.5 x 0.8****= 118	295x 0.36***= 106.9
Run kVA	46	46	46
Run kW	41	41	41

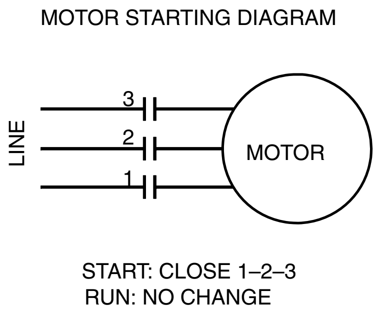
* See Table 3–4
** See Table 3–5 and multiply horsepower of 50 by the factor of 5.9 for Code Letter G.
*** See Table 3–6
**** See SPF for Resistor in Table 3–4

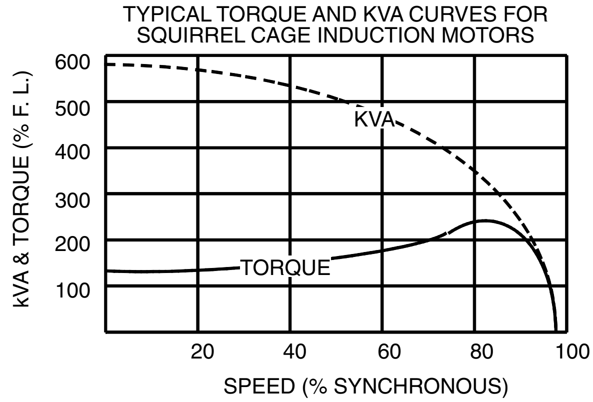
Table B–1. Reduced Voltage Motor Starting Comparison

Full Voltage Motor Starting

Starting: Full voltage, across–the–line starting is typical unless it is necessary to reduce motor starting kVA because of the limited capacity of the generator set or to limit voltage dip during motor starting. There is no limit to the HP, size, voltage, or type of motor.

Application Notes: This method is most common because of its simplicity, reliability, and initial cost. Note on the kVA and torque curves that starting kVA remains fairly constant until the motor almost reaches full speed. Also note that kW peaks at about 300 percent of rated kW near 80 percent of synchronous speed.

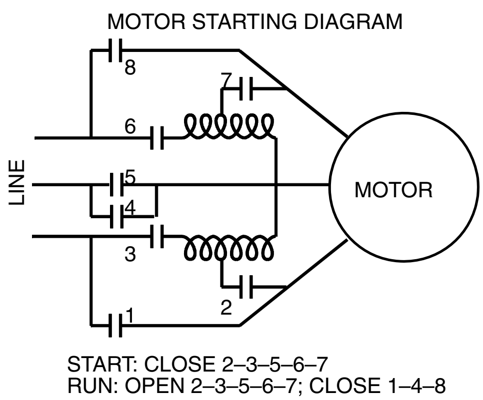


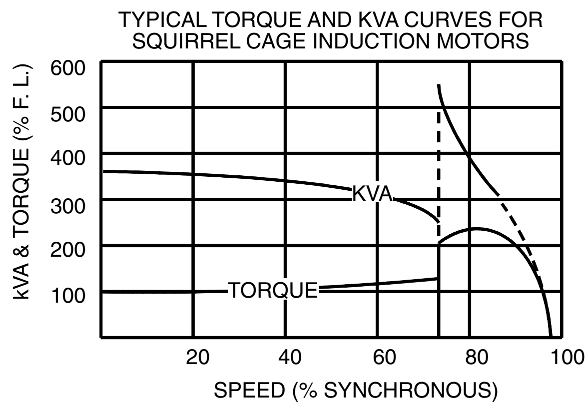


Autotransformer Motor Starting, Open Transition

Starting: The autotransformer is in the circuit only during starting to reduce voltage to the motor. The opening of the circuit during transition can cause severe transients, which may even be able to cause nuisance tripping of circuit breakers.

Application Notes: Open transition switching of reduced voltage starters should be avoided in generator set applications, especially when the motors are not brought up to full speed at the time of transition. The reason for this is that the motor slows down and gets out of synchronization during the switching transition. The result is similar to paralleling generator sets out of phase. The kVA drawn immediately after switching can exceed starting kVA. Also note that the starting power factor is lower when an autotransformer is used.



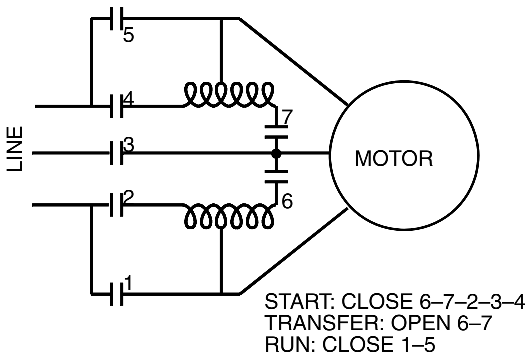


Autotransformer Motor Starting, Closed Transition

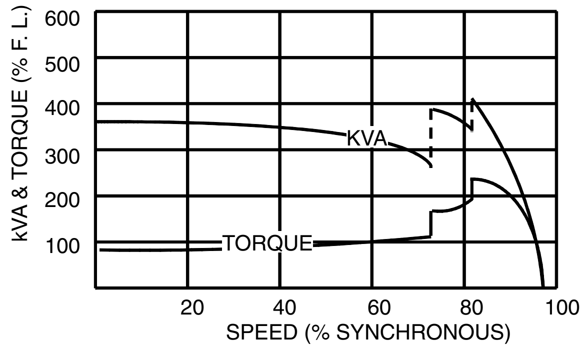
Starting: The circuit is not interrupted during starting. During transfer, part of the autotransformer winding remains in the circuit as a series reactor with the motor windings.

Application Notes: Closed transition is preferred over open transition because of less electrical disturbance. The switching, however, is more expensive and complex. It is the most commonly used reduced voltage starting method for large motors with low load torque requirements, such as sewage lift pumps and chillers. The principle advantage is more torque per current than with other reduced voltage starting methods. Operation can be automatic and/or remote. Also note that the starting power factor is lower when an autotransformer is used.

MOTOR STARTING DIAGRAM



TYPICAL TORQUE AND KVA CURVES FOR SQUIRREL CAGE INDUCTION MOTORS

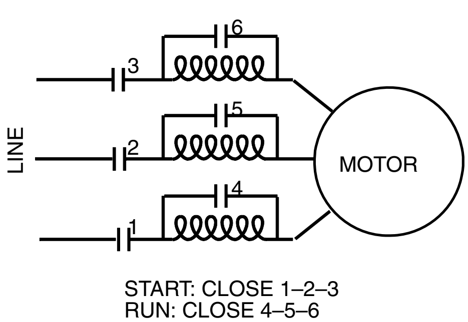


Reactor Motor Starting, Closed Transition

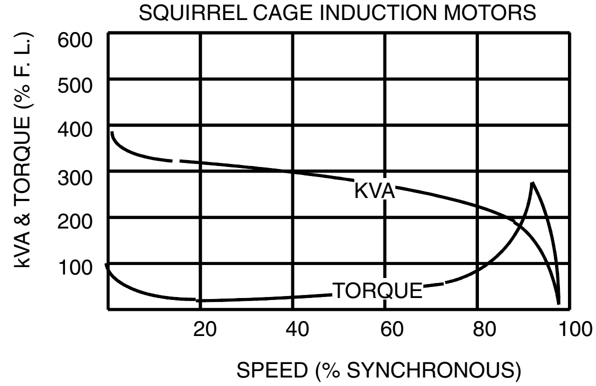
Starting: Reactor starting has the advantage of simplicity and closed transition, but results in lower starting torque per kVA than with autotransformer starting. Relative torque, however, improves as the motor accelerates.

Application Notes: Reactor starting is generally not used except for large, high–voltage or high–current motors. The reactors must be sized for HP and voltage and may have limited availability. Typically, reactor starting costs more than autotransformer starting for smaller motors, but is simpler and less expensive for larger motors. Starting power factor is exceptionally low. Reactor starting allows a smooth start with almost no observable disturbance on transition and is well suited for applications such as centrifugal pumps or fans.

MOTOR STARTING DIAGRAM



TYPICAL TORQUE AND KVA CURVES FOR SQUIRREL CAGE INDUCTION MOTORS

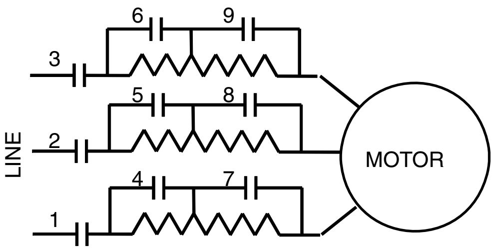


Resistor Motor Starting, Closed Transition

Starting: Resistor starting is occasionally used for smaller motors where several steps of starting are required and no opening of motor circuits between steps is allowed.

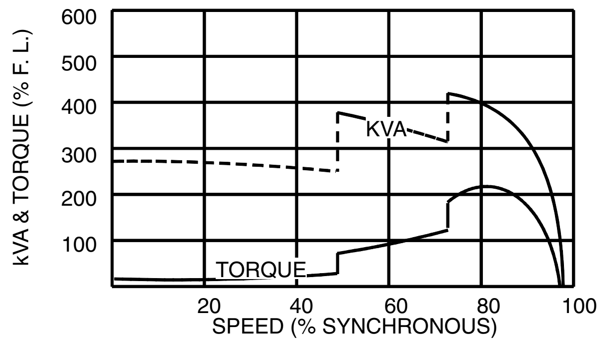
Application Notes: Also available as a stepless transition starter which provides a smoother start. Resistor starting is usually the least expensive with small motors. Accelerates loads faster because the voltage increases with a decrease in current. Has a higher starting power factor.

MOTOR STARTING DIAGRAM



START: CLOSE 1–2–3
SECOND STEP: CLOSE 4–5–6
THIRD STEP: CLOSE 7–8–9

TYPICAL TORQUE AND KVA CURVES FOR SQUIRREL CAGE INDUCTION MOTORS



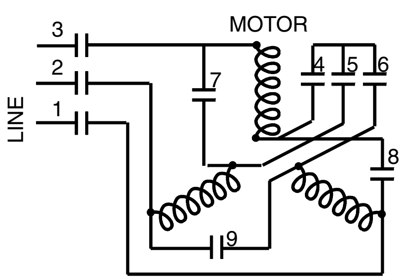
Star–Delta Motor Starting, Closed Transition

Starting: Star–Delta starting requires no autotransformer, reactor, or resistor. The motor starts star–connected and runs delta–connected.

Application Notes: This starting method is becoming more popular where low starting torques are acceptable. It has the following disadvantages:

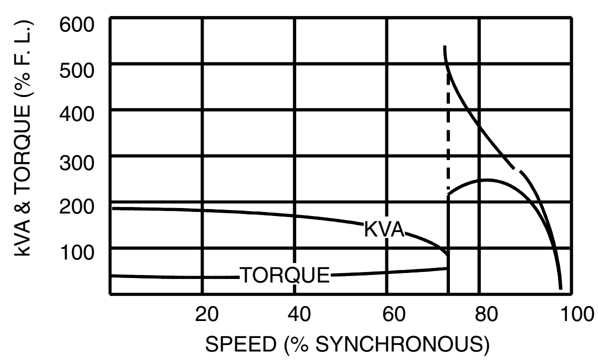
1. Open transition. Closed transition is available at extra cost.
2. Low torque.
3. No advantage when the motor is powered by a generator set unless the motor reaches synchronous speed before switching. In applications where the motor does not reach synchronous speed, the generator set must be sized to meet the surge.

MOTOR STARTING DIAGRAM



START: CLOSE 1–2–3–4–5–6
RUN: OPEN 4–5–6; CLOSE 7–8–9

TYPICAL TORQUE AND KVA CURVES FOR SQUIRREL CAGE INDUCTION MOTORS

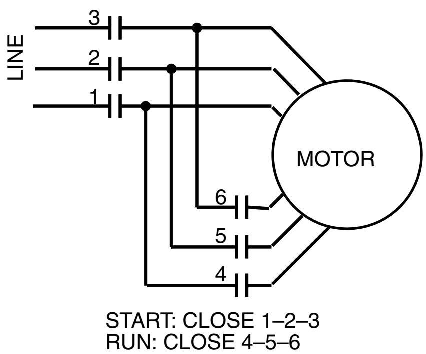


Part Winding Motor Starting, Closed Transition

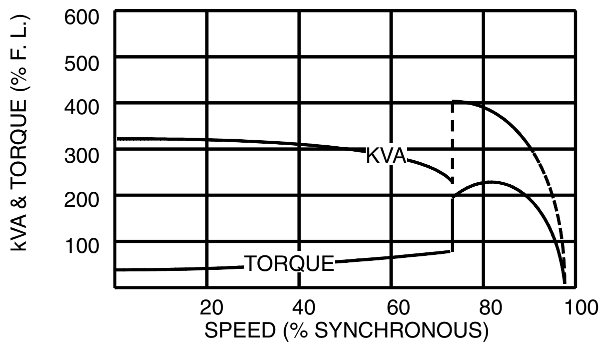
Starting: Part winding starting is less expensive because it requires no autotransformer, reactor, or resistor and uses simple switching. Available in two or more starting steps depending on size, speed, and voltage of motor.

Application Notes: Automatically provides closed transition. First, one winding is connected to the line; after a time interval, the second winding is paralleled with the first. Starting torque is low and is fixed by the motor manufacturer. The purpose of part winding is not to reduce starting current but to provide starting current in smaller increments. There is no advantage to this method if the motor is powered by a generator set unless the motor can reach synchronous speed before transition to the line.

MOTOR STARTING DIAGRAM



TYPICAL TORQUE AND KVA CURVES FOR SQUIRREL CAGE INDUCTION MOTORS

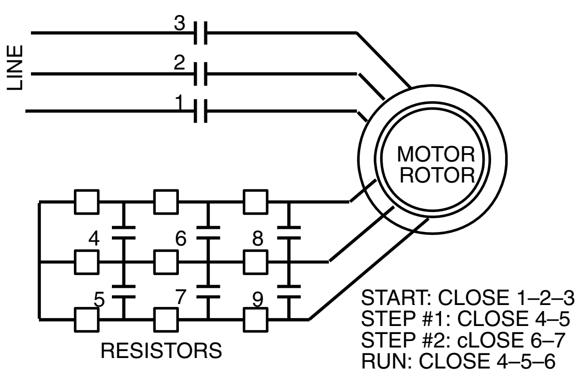


Wound Rotor Motor Starting

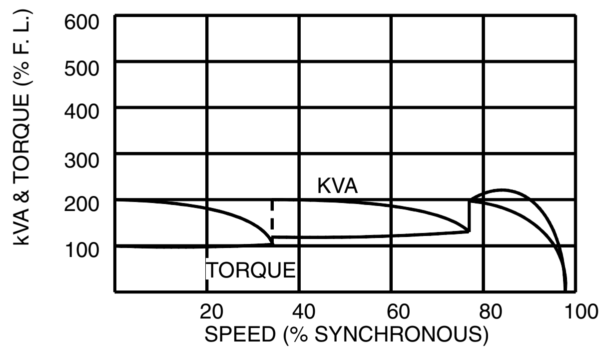
Starting: A wound rotor motor can have the same starting torque as a squirrel cage motor but with less current. It differs from squirrel cage motors only in the rotor. A squirrel cage motor has short circuit bars, whereas a wound rotor motor has windings, usually three–phase.

Application Notes: Starting current, torque, and speed characteristics can be changed by connecting the proper amount of external resistance into the rotor. Usually, wound rotor motors are adjusted so that the starting kVA is about 1.5 times running kVA. This is the easiest type of motor for a generator set to start.

MOTOR STARTING DIAGRAM



TYPICAL TORQUE AND KVA CURVES FOR WOUND ROTOR MOTORS



Synchronous Motor Starting

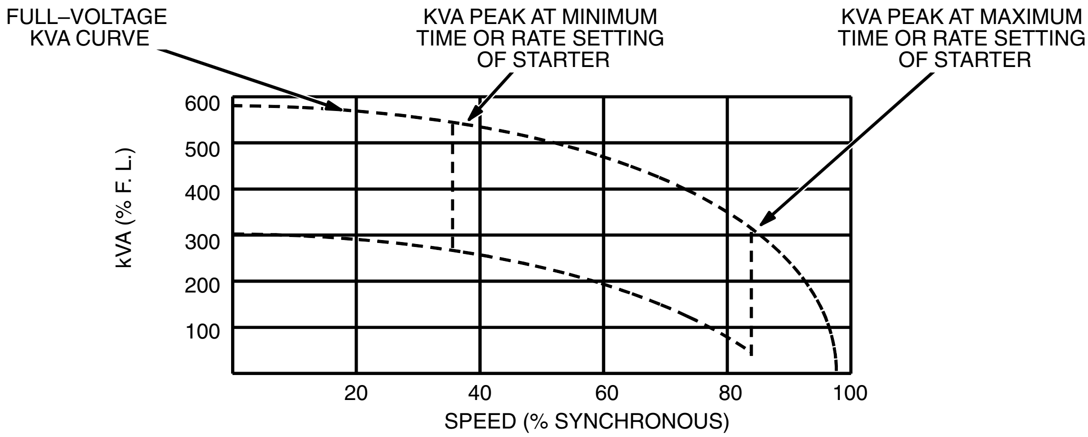
Starting: Synchronous motors can use most of the starting methods discussed. Synchronous motors rated 20 HP and greater have starting characteristics similar to wound rotor motors.

Application Notes: Synchronous motors are in a class by themselves. There are no standards for performance, frame size, or connections. Motors rated 30 HP or less have high locked rotor currents. They can be used in applications where power factor correction is desired. (Use the standard code letter when the actual letter is not known.)

General Application Note

If the reduced voltage motor starter has a time or rate adjustment, adjust the settings to obtain about two seconds between taps. This allows time for the motor to approach rated speed and thus reduce the peak kVA at the time of switching, as shown below. Note that at the minimum setting there is not much improvement over full voltage starting.

In some applications the inrush current is so low that the motor shaft will not start to turn on the first tap, nor even the second. For those applications there is little reduction of starting kVA from the standpoint of the generator set.


FULL–VOLTAGE KVA CURVE
KVA PEAK AT MINIMUM TIME OR RATE SETTING OF STARTER
KVA PEAK AT MAXIMUM TIME OR RATE SETTING OF STARTER
600
500
400
300
200
100
kVA (% F. L.)
20
40
60
80
100
SPEED (% SYNCHRONOUS)

APPENDIX C CONTENTS

APPENDIX C

World Voltages and Supplies

Country	*Frequency (Hz)*	*Supply Voltage Levels in Common Use (V)*
Abu Dhabi (United Arab Emirates)	50	415/250
Afghanistan	50;60	380/220;220
Algeria	50	10 kV; 5.5 kV; 380/220; 220/127
Angola	50	380/220; 220
Antigua	60	400/230;230
Argentina	50	13.2 kV; 6.88 kV; 390/225; 339/220;220
Australia	50	22 kV; 11 kV; 6.6 kV; 440/250; 415/240; 240
Austria	50	20 kV; 10 kV; 5 kV; 380/220; 220
Bahamas	60	415/240; 240/120; 208/120; 120
Bahrain	50;60	11 kV; 400/230; 380/220;230; 220/110
Bangladesh	50	11 kV; 400/230; 230
Barbados	50	11 kV; 3.3 kV; 230/115; 200/115
Belgium	50	15 kV; 6kV; 380/220; 220/127, 220
Belize	60	440/220; 220/110
Bermuda	60	4.16/2.4 kV; 240/120; 208/120
Bolivia	50;60	230/115; 400/230/220/110
Botswana	50	380/220;220
Brazil	50;60	13.8 kV; 11.2 kV; 380/220, 220/127
Brunei	50	415/230
Bulgaria	50	20 kV; 15 kV; 380/220; 220
Burma	50	11 kV; 6.6 kV; 400/230; 230
Burundi		
Cambodia (Khmer Republic)	50	380/220; 208/120; 120
Cameroon	50	15 kV; 320/220; 220
Canada	60	12.5/7.2 kV; 600/347; 240/120; 208/120; 600; 480; 240
Canary Islands	50	380/220; 230
Cape Verde Islands	50	380/220; 127/220
Cayman Islands	60	480/240; 480/227; 240/120; 208/120
Central African Republic	50	380/220
Chad	50	380/220; 220
China	50	380/220 50Hz
Chile	50	380/220; 220
Colombia	60	13.2 kV; 240/120; 120
Costa Rica	60	240/120; 120
Cuba	60	440/220; 220/110
Cyprus	50	11 kV; 415/240; 240
Czechoslovakia	50	22 kV; 15 kV; 6 kV; 3 kV; 380/220; 220
Dahomey	50	15 kV; 380/220; 220
Denmark	50	30 kV; 10 kV; 380/220;220
Dominica (Windward Islands)	50	400/230
Dominican Republic	60	220/100; 110
Dubai (United Arab Emirates)	50	6.6 kV; 330/220; 220
Ecuador	60	240/120; 208/120; 220/127; 220/110

Country	*Frequency (Hz)*	*Supply Voltage Levels in Common Use (V)*
Egypt (United Arab Republic)	50	11 kV; 6.6 kV; 380/220; 220
Eire (Republic of Ireland)	50	10 kV; 380/220; 220
El Salvador	60	14.4 kV; 2.4 kV; 240/120
Ethiopia	50	380/220; 220
Faeroe Islands (Denmark)	50	380/220
Falkland Islands (UK)	50	415/230; 230
Fiji	50	11 kV; 415/240; 240
Finland	50	660/380; 500; 380/220; 220
France	50	20 kV; 15 kV; 380/220; 380; 220; 127
French Guiana	50	380/220
French Polynesia	60	220; 100
Gabon	50	380/220
Gambia	50	400/230; 230
Germany (BRD)	50	20 kV; 10 kV; 6 kV; 380/220; 220
Germany (DDR)	50	10 kV; 6kV; 660/380; 380/220; 220/127; 220; 127
Ghana	50	440/250; 250
Gibraltar	50	415/240
Greece	50	22 kV; 20 kV; 15 kV; 6.6 kV; 380/220
Greenland	50	380/220
Grenada (Windward Islands)	50	400/230; 230
Guadeloupe	50;60	20 kV; 380/220; 220
Guam (Mariana Islands)	60	13.8 kV; 4 kV; 480/277; 480; 240/120; 207/120
Guatemala	60	13.8 kV; 240/120
Guyana	50	220/110
Haiti	60	380/220; 230/115; 230; 220; 115
Honduras	60	220/110; 110
Hong Kong (and Kowloon)		50 11 kV; 346/200; 200
Hungary	50	20 kV; 10 kV; 380/220; 220
Iceland	50	380/220; 220
India	50; 25	22 kV; 11kV; 440/250; 400/230; 460/230; 230
Indonesia	50	380/220; 2201127
Iran	50	20 kV; 11kV; 400/231; 380/220; 220
Iraq	50	11 kV; 380/220; 220
Israel	50	22kV; 12.6 kV; 6.3 kV; 400/230; 230
Italy	50	20 kV; 15 kV; 10 kV; 380/220; 220/127; 220
Ivory Coast	50	380/220; 220
Jamaica	50	4/2.3 kV; 220/110
Japan	50; 60	6.6 kV;200/100; 22 kV; 6.6 kV; 210/105; 200/100; 100
Jordan	50	380/220; 220
Kenya	50	415/240; 240
Korea Republic (South)	60	200/100; 100
Kuwait	50	415/240; 240
Laos	50	380/220
Lebanon	50	380/220; 190/110; 220; 110
Lesotho	50	380/220; 220
Liberia	60	12.5/7.2 kV; 416/240; 240/120; 208/120

Country	Frequency (Hz)	Supply Voltage Levels in Common Use (V)
Libyan Arab Republic	50	400/230; 220/127; 230; 127
Luxembourg	50	20 kV; 15 kV; 380/220; 220
Manila	60	20 kV; 6.24 kV; 3.6 kV; 240/120
Martinique	50	220/127; 127
Mauritania	50	380/220
Mauritius	50	400/230; 230
Macao	50	380/220; 220/110
Malagassy Republic (Madagascar)	50	5 kV; 380/220; 220/127
Malawi	50	400/230; 230
Malaysia (West)	50	415/240; 240
Mali	50	380/220; 220/127; 220; 127
Malta	50	415/240
Mexico	60	13.8 kV; 13.2 kV; 480/277; 220/127; 220/120
Monaco	50	380/220; 220/127; 220; 127
Montserrat	60	400/230; 230
Morocco	50	380/220; 220/127
Mozambique	50	380/220
Muscat and Oman	50	415/240; 240
Naura	50	415/240
Nepal	50	11 kV; 400/220; 220
Netherlands	50	10 kV; 3 kV; 380/220; 220
Netherlands Antilles	50; 60	380/220; 230/115; 220/127; 208/120
New Caledonia	50	220
New Zealand	50	11 kV; 415/240; 400/230; 440; 240; 230
Nicaragua	60	13.2 kV; 7.6 kV; 240/120
Niger	50	380/220; 220
Negeria	50	15 kV; 11 kV; 400/230; 380/220; 230; 220
Norway	50	20 kV; 10 kV; 5 kV; 380/220; 230
Pakistan	50	400/230
Panama	60	12 kV; 480/227; 240/120; 208/120
Papua New Guinea	50	22 kV; 11 kV; 415/240; 240
Paraguay	50	440/220; 380/220; 220
Peru	60	10 kV; 6 kV; 225
Philippines	60	13.8 kV; 4.16 kV; 2.4 kV; 220/110
Poland	50	15 kV; 6 kV; 380/220; 220
Portugal	50	15 kV; 5 kV; 380/220; 220
Portuguese Guinea	50	380/220
Puerto Rico	60	8.32 kV; 4.16 kV; 480; 240/120
Qatar	50	415/240; 240
Reunion	50	110/220
Romania	50	20 kV; 10 kV; 6 kV; 380/220; 220
Rwanda	50	15 kV; 6.6 kV; 380/220; 220
Sabah	50	415/240; 240
Sarawak (East Malaysia)	50	415/240; 240
Saudi Arabia	60	380/220; 220/127; 127
Senegal	50	220/127; 127
Seychelles	50	415/240
Sierra Leone	50	11 kV; 400/230; 230
Singapore	50	22 kV; 6.6 kV; 400/230; 230

Country	Frequency (Hz)	Supply Voltage Levels in Common Use (V)
Somali Republic	50	440/220; 220/110; 230; 220; 110
South Africa	50; 25	11 kV; 6.6 kV; 3.3 kV; 433/250; 400/230; 380/220; 500; 220
Southern Yemen (Aden)	50	400/230
Spain	50	15 kV; 11 kV; 380/220; 220/127; 220; 127
Spanish Sahara	50	380/220; 110; 127
Sri Lanka (Ceylon)	50	11 kV; 400/230; 230
St. Helena	50	11 kV; 415/240
St. Kitts Nevis Anguilla	50	400/230; 230
St. Lucia	50	11 kV; 415/240; 240
Saint Vincent	50	3.3 kV; 400/230; 230
Sudan	50	415/240; 240
Surinam	50; 60	230/115; 220/127; 220/110; 127; 115
Swaziland	50	11 kV; 400/230; 230
Sweden	50	20 kV; 10 kV; 6 kV; 380/220; 220
Switzerland	50	16 kV; 11 kV; 6 kV; 380/220; 220
Syrian Arab Republic	50	380/220; 200/115; 220; 115
Taiwan (Republic of China)		60 22.8 kV; 11.4 kV; 380/220; 220/110
Tanzania (Union Republic of)	50	11 kV; 400/230
Thailand	50	380/220; 220
Togo	50	20 kV; 5.5 kV; 380/220; 220
Tonga	50	11 kV; 6.6 kV; 415/240; 240; 210
Trinidad and Tobago	60	12kV; 400/230; 230/115
Tunisia	50	15 kV; 10 kV; 380/220; 220
Turkey	50	15 kV; 6.3 kV; 380/220; 220
Uganda	50	11 kV 415/240; 240
United Kingdom	50	22 kV; 11 kV; 6.6 kV; 3.3 kV; 400/230; 380/220; 240; 230; 220
Upper–Yolta	50	380/220; 220
Uruguay	50	15 kV; 6 kV; 220
USA	60	480/277; 208/120; 240/120
USSR	50	380/230; 220/127 and higher voltages
Venezuela	60	13.8 kV; 12.47 kV; 4.8 kV; 4.16 kV; 2.4 kV; 240/120; 208/120
Vietnam (Republic of)	50	15 kV; 380/220; 208/120; 220; 120
Virgin Islands (UK)	60	208; 120
Virgin Islands (US)	60	110/220
Western Samoa	50	415/240
Yemen, Democratic (PDR)	50	440/250; 250
Yugoslavia	50	10 kV; 6.6 kV; 380/220; 220
Zaire (Republic of)	50	380/220; 220
Zambia	50	400/230; 230
Zimbabwe	50	11 kV; 390/225; 225

APPENDIX D CONTENTS

APPENDIX D

Useful Formulas

TO OBTAIN:	SINGLE–PHASE AC POWER	THREE–PHASE AC POWER
kilowatts (kW)	$\frac{\text{Volts x Amps x PF}}{1000}$	$\frac{\text{Volts x Amps x PF x 1.732}}{1000}$
kVA	$\frac{\text{Volts x Amps}}{1000}$	$\frac{\text{Volts x Amps x 1.732}}{1000}$
Amps (kVA unknown)	$\frac{\text{kW x 1000}}{\text{Volts x PF}}$	$\frac{\text{kW x 1000}}{\text{Volts x PF x 1.732}}$
Amps (kW unknown)	$\frac{\text{kVA x 1000}}{\text{Volts}}$	$\frac{\text{kVA x 1000}}{\text{Volts x 1.732}}$
Frequency (Hertz)	$\frac{\text{\# poles x rpm}}{120}$	$\frac{\text{\# poles x rpm}}{120}$
Reactive Power (kVAR)	$\frac{\text{Volts x Amps x } \sqrt{1 - PF^2}}{1000}$	$\frac{\text{Volts x Amps x 1.732 x } \sqrt{1 - PF^2}}{1000}$
% Voltage regulation (for steady loads, from No–Load to Full–Load)	$\left(\frac{V_{NL} - V_{FL}}{V_{FL}}\right) \text{x } 100$	$\left(\frac{V_{NL} - V_{FL}}{V_{FL}}\right) \text{x } 100$
% Frequency Regulation (for steady loads from No–Load to Full–Load)	$\left(\frac{F_{NL} - F_{FL}}{F_{FL}}\right) \text{x } 100$	$\left(\frac{F_{NL} - F_{FL}}{F_{FL}}\right) \text{x } 100$
Horsepower required to drive a generator	$\frac{\text{kW}}{\text{0.746 X Generator Efficiency}}$	$\frac{\text{kW}}{\text{0.746 X Generator Efficiency}}$
First cycle RMS short circuit current (±10%)	$\frac{\text{Rated Amperes}}{\text{pu X}''_d}$	$\frac{\text{Rated Amperes}}{\text{pu X}''_d}$

- “PF” refers to power factor, which is expressed as a decimal fraction. For example, 80% power factor = 0.8 for the purposes of calculations. In general, single–phase generator sets are rated at 100% power factor and three–phase generator sets at 80% power factor.
- “Volts” refers to line–to–line voltage.
- “Amps” refers to line current in amperes.
- “F” refers to frequency. 0% frequency regulation is defined as isochronous.

APPENDIX E CONTENTS

APPENDIX E

Maintenance and Service

A well–planned program of preventative maintenance and service should be integral to the design of an on–site power system. Failure of a standby generator set to start and run could lead to loss of life, personal injury, property damage, and loss of business income. Failure to start and run due to low battery charge because of improper maintenance is the most common type of failure. A comprehensive program carried out on a scheduled basis by qualified persons can prevent such failures and their possible consequences. The maintenance and service programs most generator set distributors offer on a contract basis should be considered. Typically, they include performance of scheduled maintenance, repairs, parts replacement, and service documentation.

The maintenance schedule for prime power sets should be on the basis of running time, as published by the manufacturer. Since standby sets run infrequently, the maintenance schedule is usually in terms of daily, weekly, monthly, or longer term tasks. See the manufacturer's instructions for details. In any case, scheduled maintenance should include:

Daily

- Check for oil, coolant, and fuel leaks.
- Check operation of the engine coolant heater(s). If the block is not warm, the heaters are not working and the engine might not start.
- Check to see that the switchgear is in the AUTOMATIC position and the generator circuit breaker, if used, is closed.

Weekly

- Check engine oil and coolant levels.
- Check the battery charging system.

Monthly

- Check for air cleaner restrictions.
- Exercise the generator set by starting and running it for at least 30 minutes under not less than 30% rated load. Lower load levels are acceptable if the exhaust gas temperature reaches a level sufficient to prevent engine damage. See **Table E–1** for minimum exhaust gas temperatures for Cummins engines. Check for unusual vibrations, noises, and exhaust, coolant and fuel leaks while the set is running. (Regular exercising keeps engine parts lubricated, improves starting reliability, prevents oxidation of electrical contacts, and consumes fuel before it deteriorates and has to be discarded.)
- Check for radiator restrictions, coolant leaks, deteriorated hoses, loose and deteriorated fan belts, non–functioning motorized–louvers and proper concentration of engine coolant additives.
- Check for holes, leaks, and loose connections in the air cleaner system.
- Check fuel level and fuel transfer pump operation.
- Check for exhaust system leaks and restrictions, and drain the condensate trap.
- Check all meters, gauges, and indicator lamps for proper operation.
- Check the battery cable connections and battery fluid level and recharge the batteries if specific gravity is less than 1.260.
- Check for ventilation restrictions in the inlet and outlet openings of the generator.

- Check that all required service tools are readily available.

Engne Family	Exhaust Stack Temperatures Calibrated Thermocouple
B Series	550
C Series	600
LTA10	650
M11	650
NT(A)855	650
N14	650
QSX15	700
KTA19	650
VTA28	650
QST30	650
KTA38	650
QSK45	700
KTA50	700
QSK60	700
QSK178	700

Table E–1. Recommended Minimum Exhaust Stack Temperatures. (Exhaust gas temperature is measured by thermocouple. Use of external temperature sensing is not sufficiently accureate to verify exhaust temperature.)

Semi–Annually

- Change engine oil filters.
- Change the filter(s) in the coolant conditioner circuit.
- Clean or replace the crankcase breather filter(s).
- Change the fuel filter(s), drain sediment from fuel tanks, check flexible fuel hoses for cuts and abrasions and check the governor linkage.
- Check electrical safety controls and alarms.
- Clean up accumulations of grease, oil, and dirt on the generator set.
- Check power distribution wiring, connections, circuit breakers, and transfer switches.
- Simulate a utility power outage. This will test the ability of the set to start and assume the rated load. Check the operation of the automatic transfer switches, related switchgear and controls, and all other components in the standby power system.

Annually

- Check the fan hub, pulleys, and water pump.
- Clean the day tank breather.
- Check and torque the exhaust manifold and turbocharger fasteners.
- Tighten the generator set mounting hardware.
- Clean the generator power output and control boxes. Check for and tighten all loose wiring connectors. Measure and record generator winding insulation resistances. Check the operation of the generator heater strips and grease the bearings.

- Check the operation of the main generator circuit breaker (if used) by manually operating it. Test the trip unit according to the manufacturer's instructions.
- If the set is normally exercised at no–load or carries only light loads, run the generator set for at least three hours, including one hour at near rated load.
- Conduct generator insulation tests annually throughout the life of the generator set. Initial tests done before final load connections are made will serve as benchmarks for annual tests. These tests are mandatory for generator sets rated above 600 VAC. Review ANSI/IEEE Standard 43, Recommended Practice for Testing Insulation Resistance of Rotating Machinery.

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Codes and Standards

Related Product Standards

Applicable performance standards for generator sets include:

- *International Electrotechnical Committee*: Standard for Rotating Electrical Machines, Part 1 (Rating and Performance), IEC 34–1.
- *International Standards Organization*: Standard for Reciprocating Internal Combustion Engine Driven Alternating Current Generator Sets, Parts 1 through 9, ISO 8528.
- *National Electrical Manufacturer's Association:* Standard for Motors and Generators, NEMA MG1–1.
- *Canadian Standards Association:* CSA 22, Canadian Electrical Code. CSA 282, Emergency Electrical Power Supply for Buildings.
- *Underwriters Laboratories*: UL 2200 Stationary Engine Generator Assemblies.

In North America, many safety (and environmental) issues related to generator set applications are addressed by the following standards of the *National Fire Protection Association (NFPA)*:

- Flammable and Combustible Liquids Code–NFPA 30
- Standard for the Installation and use of Stationary Combustion Engines and Gas Turbines–NFPA 37
- National Fuel Gas Code–NFPA 54
- Storage and Handling of Liquified Petroleum Gas—NFPA 58
- National Electrical Code–NFPA 70
- Health Care Facilities Code–NFPA 99
- Life Safety Code–NFPA 101
- Emergency and Standby Power Systems–NFPA 110.

Modification of Products

Generator sets and other related products are sometimes Certified, Listed, or otherwise assured to be compliant to specific standards or codes. This generally applies to the product as manufactured and shipped from the original manufacturer. Often these products are labeled or in some way marked as such. Subsequent modifications to the product could alter or violate the specific code compliance or listing. Product modifications should be, and in some cases must be submitted to the local authority having jurisdiction for approval.

APPENDIX G CONTENTS

APPENDIX G

Glossary

AC (Alternating Current)
Alternating current is electric current that alternates between a positive maximum value and a negative maximum value at a characteristic frequency, usually 50 or 60 cycles per second (Hertz).

AC Generator
AC generator is the preferred term for referring to a generator that produces alternating current (AC). See Alternator and Generator.

Acoustic Material
Acoustic material is any material considered in terms of its acoustic properties, especially its properties of absorbing or deadening sound.

Active Power
Active power is the real power (kW) supplied by the generator set to the electrical load. Active power creates a load on the set's engine and is limited by the power of the engine and efficiency of the generator. Active power does the work of heating, lighting, turning motor shafts, etc.

Air Circuit Breaker
An air circuit breaker automatically interrupts the current flowing through it when that current exceeds the trip rating of the breaker. Air is the medium of electrical insulation between electrically live parts and grounded (earthed) metal parts. Also see Power Circuit Breaker.

Annunciator
An annunciator is an accessory device used to give remote indication of the status of an operating component in a system. Annunciators are typically used in applications where the equipment monitored is not located in a portion of the facility that is normally attended. The NFPA has specific requirements for remote annunciators used in some applications, such as hospitals.

Alternator
Alternator is another term for AC generator.

Amortisseur Windings
The amortisseur windings of a synchronous AC generator are the conductors embedded in the pole faces of the rotor. They are connected together at both ends of the poles by end rings. Their function is to dampen waveform oscillations during load changes.

Ampacity
Ampacity is the safe current–carrying capacity of an electrical conductor in amperes as defined by code.

Ampere
The ampere is a unit of electric current flow. One ampere of current will flow when a potential of one volt is applied across a resistance of one ohm.

Apparent Power
Apparent power is the product of current and voltage, expressed as kVA. It is real power (kW) divided by the power factor (PF).

Armature
The armature of an AC generator is the assembly of windings and metal core laminations in which the output voltage is induced. It is the stationary part (stator) in a revolving–field generator.

Authority Having Jurisdiction
The authority having jurisdiction is the individual with the legal responsibility for inspecting a facility and approving the equipment in the facility as meeting applicable codes and standards.

Backup Protection
Backup protection consists of protective devices which are intended to operate only after other protective devices have failed to operate or detect a fault.

Base Load
Base load is that portion of a building load demand which is constant. It is the “base” of the building demand curve.

Black Start
Black start refers to the starting of a power system with its own power sources, without assistance from external power supplies.

Bumpless Transition
Bumpless transition is make–before–break transfer of an electrical load from one source to another where voltage and frequency transients are kept to a minimum.

Bus
Bus can refer to the current–carrying copper bars that connect the AC generators and loads in a paralleling system, to the paralleled output of the AC generators in a system or to a feeder in an electrical distribution system.

Circuit
A circuit is a path for an electric current across a potential (voltage).

Circuit Breaker
A circuit breaker is a protective device that automatically interrupts the current flowing through it when that current exceeds a certain value for a specified period of time. See Air Circuit Breaker, Main Breaker, Molded Case Circuit Breaker, and Power Circuit Breaker.

Contactor
A contactor is a device for opening and closing an electric power circuit.

Continuous Load
A continuous load is a load where the maximum current is expected to continue for three hours or more (as defined by the NEC for design calculations).

Cross Current Compensation
Cross current compensation is a method of controlling the reactive power supplied by AC generators in a paralleling system so that they share equally the total reactive load on the bus without significant voltage droop.

CT (Current Transformer)
Current transformers are instrument transformers used in conjunction with ammeters, control circuits and protective relaying. They usually have 5 ampere secondaries.

Current
Current is the flow of electric charge. Its unit of measure is the ampere.

Current Limiting Fuse
A current limiting fuse is a fast–acting device that, when interrupting currents in its current–limiting range, will substantially reduce the magnitude of current, typically within one–half cycle, that would otherwise flow.

Cycle
A cycle is one complete reversal of an alternating current or voltage—from zero to a positive maximum to zero again and then from zero to a negative maximum to zero again. The number of cycles per second is the frequency.

dB/dB(A) Scale
The decibel (dB) scale used in sound level measurements is logarithmic. Sound level meters often have several decibel weighting scales (A, B,C). The A–scale, dB(A), is the most commonly used weighting scale for measuring the loudness of noise emitted from generator sets.

Delta Connection
Delta connection refers to a three–phase connection in which the start of each phase is connected to the end of the next phase, forming the Greek letter Δ.. The load lines are connected to the corners of the delta.

Demand Factor
The demand factor is the ratio of actual load to the potential total connected load.

Deviation Factor
The deviation factor is the maximum instantaneous deviation, in percent, of the generator voltage from a true sine wave of the same RMS value and frequency.

Dielectric Strength
Dielectric strength is the ability of insulation to withstand voltage without rupturing.

Direct Current (DC)
Direct current is current with no reversals in polarity.

Differential Relay
A differential relay is a protective device which is fed by current transformers located at two different series points in the electrical system. The differential relay compares the currents and picks up when there is a difference in the two which signifies a fault in the zone of protection. These devices are typically used to protect windings in generators or transformers.

Earthing
Earthing is the intentional connection of the electrical system or electrical equipment (enclosures, conduit, frames, etc.) to earth or ground.

Efficiency (EFF)
Efficiency is the ratio of energy output to energy input, such as the ratio between the electrical energy input to a motor and the mechanical energy output at the shaft of the motor.

Emergency System
An emergency system is independent power generation equipment that is legally required to feed equipment or systems whose failure may present a life safety hazard to persons or property.

Energy
Energy is manifest in forms such as electricity, heat, light and the capacity to do work. It is convertible from one form to another, such as in a generator set, which converts rotating mechanical energy into electrical energy. Typical units of energy are kW•h, BTU (British thermal unit), Hp•h, ft•lbf, joule, and calorie.

Exciter
An exciter is a device that supplies direct current (DC) to the field coils of a synchronous generator, producing the magnetic flux required for inducing output voltage in the armature coils (stator). See Field.

Fault
A fault is any unintended flow of current outside its intended circuit path in an electrical system.

Field
The generator field (rotor) consists of a multi–pole electromagnet which induces output voltage in the armature coils (stator) of the generator when it is rotated by the engine. The field is energized by DC supplied by the exciter.

Flicker
A term describing visible brightening and dimming of lights caused by a voltage surge or oscillation.

Free Field (Noise Measurements)
In noise measurements, a free field is a field in a homogeneous, isotropic medium (a medium having the quality of transmitting sound equally in all directions) which is free of boundaries. In practice, it is a field in which the effects of the boundaries are negligible in the region of interest. In the free field, the sound pressure level decreases 6 dB each doubling of the distance from a point source.

Frequency
Frequency is the number of complete cycles per unit of time of any periodically varying quantity, such as alternating voltage or current. It is usually expressed as (Hz) Hertz or CPS (cycles per second).

Frequency Regulation
Frequency regulation is a measure that states the difference between no–load and full–load frequency as a percentage of full–load frequency.

Generator
A generator is a machine which converts rotating mechanical energy into electrical energy. See AC generator.

GFP (Ground Fault Protection)
A ground fault protection system is a system designed to limit the damage to equipment from line–to–ground fault currents.

Governor
A governor is a device on the engine which controls fuel to maintain a constant engine speed under various load conditions. The governor must have provision for adjusting speed (generator frequency) and speed droop (no load to full load).

Ground
A ground is a connection, either intentional or accidental, between an electrical circuit and the earth or some conducting body serving in place of the earth.

Grounding
Grounding is the intentional connection of the electrical system or the electrical equipment (enclosures, conduit, frames etc.) to earth.

Grounded Neutral
A grounded neutral is the intentionally grounded center point of a Y–connected, four–wire generator, or the mid–winding point of a single phase generator.

Ground Return
Ground return is a method of ground fault detection that employs a single sensor (CT) encircling the main bonding jumper between the power system neutral and ground. This device in itself is not capable of locating the faulted circuit but when used in conjunction with ground fault sensors on all feeders and source connections, can provide bus fault protection when properly coordinated (delayed).

Harmonics
Harmonics are voltage or current components which operate at integral multiples of the fundamental frequency of a power system (50 or 60 Hertz). Harmonic currents have the effect of distorting the shape of the voltage wave form from that of a pure sine wave.

Hertz (Hz)
The term Hertz is the preferred designation for cycles per second (CPS).

Hunting
Hunting is a phenomenon that can occur upon load changes in which the frequency or the voltage continues to rise above and fall below the desired value without reaching a steady–state value. It is caused by insufficient damping.

Insulation
Insulation is non–conductive material used to prevent leakage of electric current from a conductor. There are several classes of insulation in use for generator construction, each recognized for a maximum continuous–duty temperature.

Jerk
Rate of change of acceleration. Often used as a measure of performance in elevator systems.

kVA (kilo–Volt–Amperes)
kVA is a term for rating electrical devices. A device's kVA rating is equal to its rated output in amperes multiplied by its rated operating voltage. In the case of three–phase generator sets, kVA is the kW ouput rating divided by 0.8, the rated power factor. KVA is the vector sum of the active power (kW) and the reactive power (kVAR) flowing in a circuit.

kVAR (kilo–Volt–Amperes Reactive)
KVAR is the product of the voltage and the amperage required to excite inductive circuits. It is associated with the reactive power which flows between paralleled generator windings and between generators and load windings that supply the magnetizing currents necessary in the operation of transformers, motors, and other electromagnetic loads. Reactive power does not load the generator set's engine but does limit the generator thermally.

kW (kilo–Watts)
KW is a term used for power rating electrical devices and equipment. Generator sets in the United States are usually rated in kW. KW, sometimes called active power, loads the generator set's engine.

kW• h (kilo–Watt–hour)
This is a unit of electric energy. It is equivalent to one kW of electric power supplied for one hour.

Lagging Power Factor
Lagging power factor in AC circuits (a power factor of less than 1.0) is caused by inductive loads, such as motors and transformers, which cause the current to lag behind the voltage. See Power Factor.

Leading Power Factor
Leading power factor in AC circuits (0.0 to –1.0) is caused by capacitive loads or overexcited synchronous motors which cause the current to lead the voltage. See Power Factor.

Leg
A leg is a phase winding of a generator, or a phase conductor of a distribution system.

Line–To–Line Voltage
Line–to–line voltage is the voltage between any two phases of an AC generator.

Line–To–Neutral Voltage
In a 3–phase, 4–wire, Y–connected generator, line–to–neutral voltage is the voltage between a phase and the common neutral where the three phases are tied together.

Load Factor
The load factor is the ratio of the average load to the generator set power rating.

Low Voltage
In the context of this manual, low voltage refers to AC system operating voltages from 120 to 600 VAC.

Lugging
Attaching lugs (terminations) to the end of wires.

Main Breaker
A main breaker is a circuit breaker at the input or output of the bus, through which all of the bus power must flow. The generator main breaker is the device, usually mounted on the generator set, that can be used to interrupt generator set power output.

Mains
Mains is a term used extensively outside the United States to describe the normal power service (utility).

Medium Voltage
In the context of this manual, medium voltage refers to AC system operating voltages from 601 to 15,000 VAC.

Molded Case Circuit Breaker
A molded case circuit breaker automatically interrupts the current flowing through it when the current exceeds a certain level for a specified time. *Molded case* refers to the use of molded plastic as the medium of electrical insulation for enclosing the mechanisms and for separating conducting surfaces from one another and from grounded (earthed) metal parts.

Motoring
In paralleling applications, unless a generator set is disconnected from the bus when its engine fails (usually as a result of a fuel system problem), the generator will drive (motor) the engine, drawing power from the bus. Reverse power protection which automatically disconnects a failed set from the bus is essential for paralleling systems. Also, in certain applications such as elevators, the load can motor the generator set if insufficient additional load is present.

NEC (National Electrical Code)
This document is the most commonly referenced general electrical standard in the United States.

NEMA
National Electrical Manufacturers Association

Neutral
Neutral refers to the common point of a Y–connected AC generator, a conductor connected to that point or to the mid–winding point of a single–phase AC generator.

NFPA
National Fire Protection Association

Nonattainment Areas
Areas of the country that consistently do not meet U.S. Environmental Protection Agency (EPA) air quality standards.

Nonlinear Load
A nonlinear load is a load for which the relationship between voltage and current is not a linear function. Some common nonlinear loads are fluorescent lighting, SCR motor starters, and UPS systems. Nonlinear loads cause abnormal conductor heating and voltage distortion.

Octave Band
In sound pressure measurements (using an octave band analyzer), octave bands are the eight divisions of the measured sound frequency spectrum, where the highest frequency of each band is twice that of its lowest frequency. The octave bands are specified by their center frequencies, typically: 63, 125, 250, 500, 1,000, 2,000, 4,000 and 8,000 Hz (cycles per second).

Ohm
The ohm is a unit of electrical resistance. One volt will cause a current of one ampere to flow through a resistance of one ohm.

One–Line Diagram
A one–line diagram is a schematic diagram of a three–phase power distribution system which uses one line to show all three phases. It is understood when using this easy to read drawing that one line represents three.

Out–Of–Phase
Out–of–phase refers to alternating currents or voltages of the same frequency which are not passing through their zero points at the same time.

Overload Rating
The overload rating of a device is the load in excess of the nominal rating the device can carry for a specified length of time without being damaged.

Overshoot
Overshoot refers to the amount by which voltage or frequency exceeds the nominal value as the voltage regulator or governor responds to changes in load.

Parallel Operation
Parallel operation is the operation of two or more AC power sources whose output leads are connected to a common load.

Peak Load
Peak load is the highest point in the kilowatt demand curve of a facility. This is used as the basis for the utility company's demand charge.

Peak Shaving
Peak shaving is the process by which loads in a facility are reduced for a short time to limit maximum electrical demand in a facility and to avoid a portion of the demand charges from the local utility.

Phase
Phase refers to the windings of an AC generator. In a three–phase generator there are three windings, typically designated as A–B–C, R–S–T or U–V–W. The phases are 120 degrees out of phase with each other . That is, the instants at which the three phase voltages pass through zero or reach their maximums are 120 degrees apart, where one complete cycle is considered 360 degrees. A single–phase generator has only one winding.

PMG (Permanent Magnet Generator)
A permanent magnet generator is a generator whose field is a permanent magnet as opposed to an electro–magnet (wound field). Used to generate excitation power for separately excited alternators.

Phase Angle

Phase angle refers to the relation between two sine waves which do not pass through zero at the same instant, such as the phases of a three–phase generator. Considering one full cycle to be 360 degrees, the phase angle expresses how far apart the two waves are in relation to a full cycle.

Phase Rotation

Phase rotation (or phase sequence) describes the order (A–B–C, R–S–T or U–V–W) of the phase voltages at the output terminals of a three–phase generator. The phase rotation of a generator set must match the phase rotation of the normal power source for the facility and must be checked prior to operation of the electrical loads in the facility.

Pitch

Pitch is the ratio of the number of generator stator winding slots enclosed by each coil to the number of winding slots per pole. It is a mechanical design characteristic the generator designer may use to optimize generator cost verse voltage wave form quality.

Pole

Pole is used in reference to magnets, which are bipolar. The poles of a magnet are designated North and South. Because magnets are bipolar, all generators have an even number of poles. The number of poles determines how fast the generator will have to be turned to obtain the specified frequency. For example, a generator with a 4–pole field would have to be run at 1800 rpm to obtain a frequency of 60 Hz (1500 rpm for 50 Hz).

Pole can also refer to the electrodes of a battery or to the number of phases served by a switch or breaker.

Power Circuit Breaker

A power circuit breaker is a circuit breaker whose contacts are forced closed via a spring–charged, over–center mechanism to achieve fast closing (5–cycle) and high withstand and interrupting ratings. A power circuit breaker can be an insulated case or power air circuit breaker.

Power

Power refers to the rate of performing work or of expending energy. Typically, mechanical power is expressed in terms of horsepower and electrical power in terms of kilowatts. One kW equals 1.34 hp.

Power Factor (PF)

The inductances and capacitances in AC circuits cause the point at which the voltage wave passes through zero to differ from the point at which the current wave passes through zero. When the current wave precedes the voltage wave, a leading power factor results, as in the case of capacitive loads or overexcited synchronous motors. When the voltage wave precedes the current wave, a lagging power factor results. This is generally the case. The power factor expresses the extent to which the voltage zero differs from the current zero. Considering one full cycle to be 360 degrees, the difference between the zero points can then be expressed as an angle. Power factor is calculated as the cosine of the angle between zero points and is expressed as a decimal fraction (.8) or as a percentage (80%). It is the ratio of kW and kVA. In other words kW = kVA x PF.

Radio Interference

Radio interference refers to the interference with radio reception caused by a generator set.

Radio Interference Suppression

Radio interference suppression refers to the methods employed to minimize radio interference.

Reactance

Reactance is the opposition to the flow of current in AC circuits caused by inductances and capacitances. It is expressed in terms of ohms and its symbol is X.

Reactive Power
Reactive power is the product of current, voltage and the sine of the angle by which current leads or lags voltage and is expressed as VAR (volts–amperes–reactive).

Real Power
Real power is the product of current, voltage and power factor (the cosine of the angle by which current leads or lags voltage) and is expressed as W (watts).

Resistance
Resistance is the opposition to the flow of current in DC circuits. It is expressed in ohms and its symbol is R.

RMS (Root Mean Square)
The RMS values of a measured quantity such as AC voltage, current and power are considered the “effective” values of the quantities. See Watt.

Rotor
A rotor is the rotating element of a motor or generator.

RPM
Revolutions Per Minute

SCR (Silicon Controlled Rectifier)
An SCR is a three–electrode solid–state device which permits current to flow in one direction only, and does this only when a suitable potential is applied to the third electrode, called the gate.

Selective Coordination
Selective coordination is the selective application of overcurrent devices such that short circuit faults are cleared by the device immediately on the line side of the fault, and only by that device.

Self–Excited
An alternator whose excitation system draws its power from its own main AC output.

Separately Excited
An alternator whose excitation system draws its power from a separate source (not its own output).

Service Entrance
The service entrance is the point where the utility service enters the facility. In low voltage systems the neutral is grounded at the service entrance.

Service Factor
Service factor is a multiplier that is applied to a motor’s nominal horsepower rating to indicate an increase in power output (overload capacity) the motor is capable of providing under certain conditions.

Short Circuit
A short circuit is generally an unintended electrical connection between current carrying parts.

Shunt Excited
An alternator that uses (shunts) a portion of its AC output for excitation current.

Shunt Trip
Shunt trip is a feature added to a circuit breaker or fusible switch to permit the remote opening of the breaker or switch by an electrical signal.

Sine Wave
A sine wave is a graphical representation of a sine function, where the sine values (usually the y axis) are plotted against the angles (x axis) to which they correspond. AC voltage and current wave shapes approximate such a curve.

Soft Loading
Soft loading refers to the ramping of load onto or off of a generator in a gradual fashion for the purpose of minimizing voltage and frequency transients on the system.

Slow Rate
Rate of change of frequency.

Sound
Sound is considered both in terms of the sound pressure waves travelling in air (pressures superimposed on the atmospheric pressure) and the corresponding aural sensation. Sound can be “structure–borne”, that is, transmitted through any solid elastic medium, but is audible only at points where the solid medium “radiates” the pressure waves into the air.

Sound Level Meter
A sound level meter measures sound pressure level. It has several frequency–weighted decibel (dB) scales (A, B, C) to cover different portions of the range of measured loudness. Sound level meters indicate RMS sound, unless the measurements are qualified as instantaneous or peak sound level.

Sound Pressure Level (SPL)
Sound pressure level refers to the magnitude of the pressure differential caused by a sound wave. It is expressed on a dB scale (A,B,C) referenced to some standard (usually 10^{-12} microbars).

Standby System
A standby system is an independent power system that allows operation of a facility in the event of normal power failure.

Star Connection
See Wye Connection.

Starting Current
The initial value of current drawn by a motor when it is started from standstill.

Stator
The stator is the stationary part of a generator or motor. See Armature.

Surge
Surge is the sudden rise in voltage in a system, –usually caused by load disconnect.

Surge Suppressor
Surge suppressors are devices capable of conducting high transient voltages. They are used for protecting other devices that could be destroyed by the transient voltages.

Synchronization
In a paralleling application, synchronization is obtained when an incoming generator set is matched with and in step to the same frequency, voltage, and phase sequence as the operating power source.

Telephone Influence Factor (TIF)
The higher harmonics in the voltage wave shape of a generator can cause undesirable effects on telephone communications when power lines parallel telephone lines. The telephone influence factor is calculated by squaring the weighted RMS values of the fundamental and the non–triple series of harmonics, adding them together and then

taking the square root of the sum. The ratio of this value to the RMS value of the no–load voltage wave is called the Balanced TIF. The ratio of this value to three times the RMS value of the no–load phase–to–neutral voltage is called the Residual Component RIF.

Transformer
A transformer is a device that changes the voltage of an AC source from one value to another.

Undershoot
Undershoot refers to the amount by which voltage or frequency drops below the nominal value as the voltage regulator or governor responds to changes in load.

Utility
The utility is a commercial power source that supplies electrical power to specific facilities from a large central power plant.

Volt
The volt is a unit of electrical potential. A potential of one volt will cause a current of one ampere to flow through a resistance of one ohm.

Voltage Dip
Voltage dip is the dip in voltage that results when a load is added, occurring before the regulator can correct it, or resulting from the functioning of the voltage regulator to unload an overloaded engine–generator.

Voltage Regulation
Voltage regulation is a measure that states the difference between maximum and minimum steady–state voltage as a percentage of nominal voltage.

Voltage Regulator
A voltage regulator is a device that maintains the voltage output of a generator near its nominal value in response to changing load conditions.

Watt
The watt is a unit of electric power. In direct current (DC) circuits, wattage equals voltage times amperage. In alternating current (AC) circuits, wattage equals effective (RMS) voltage times effective (RMS) amperage times power factor times a constant dependent on the number of phases. 1,000 watts equal one kW.

Wye Connections
A Wye connection is the same as a star connection. It is a method of interconnecting the phases of a three–phase system to form a configuration resembling the letter Y. A fourth (neutral) wire can be connected at the center point.

Zero Sequence
Zero sequence is a method of ground fault detection that utilizes a sensor (CT) that encircles all the phase conductors as well as the neutral conductors. The sensor will produce an output proportional to the imbalance of current ground fault in the circuit. This output is then measured by a relay to initiate circuit breaker tripping or ground fault alarm.

Zones of Protection
Zones of protection are defined areas within a distribution system that are protected by specific groups.

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APPENDIX H

List of Figures

APPENDIX I CONTENTS

APPENDIX I

List of Tables