Cummins Power Generation

Chapter 4
Equipment Selection

Our energy working for you.™

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

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 <u>S</u>tandby rating, within 105° C rise at the <u>P</u>rime rating and within 80° C rise at the <u>C</u>ontinuous rating.

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

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

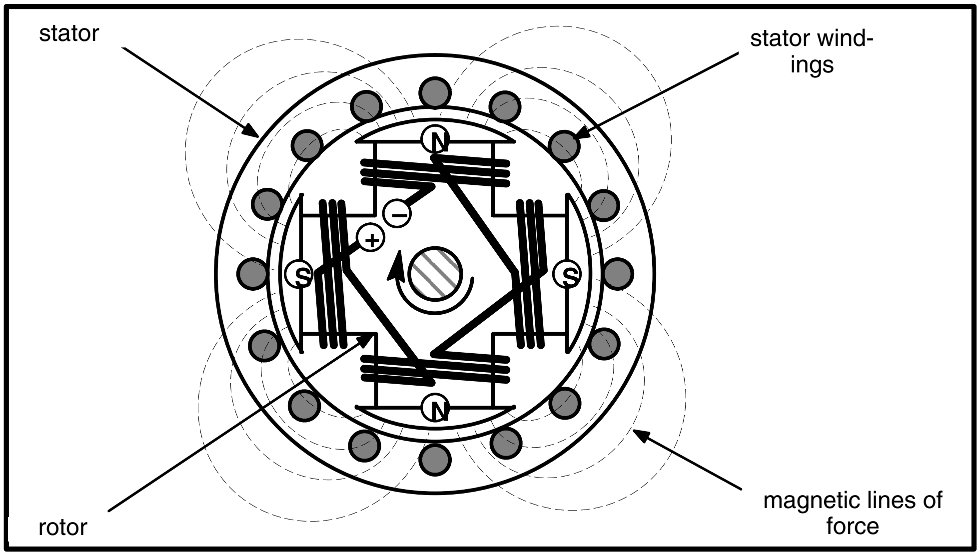

Figure 4–1. Four-Pole Generator Cross Section

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.

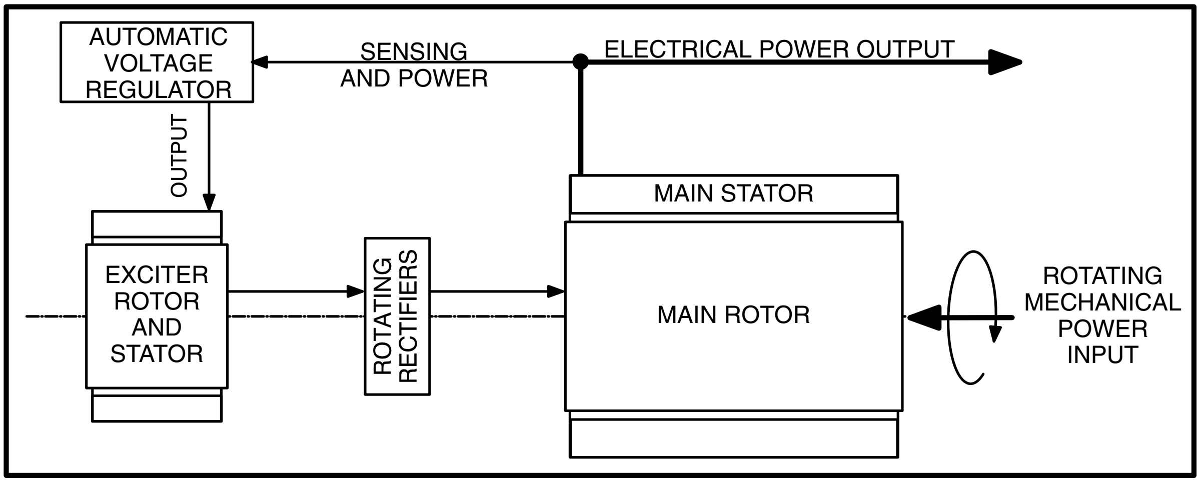

Figure 4–2. Self-Excited Generator

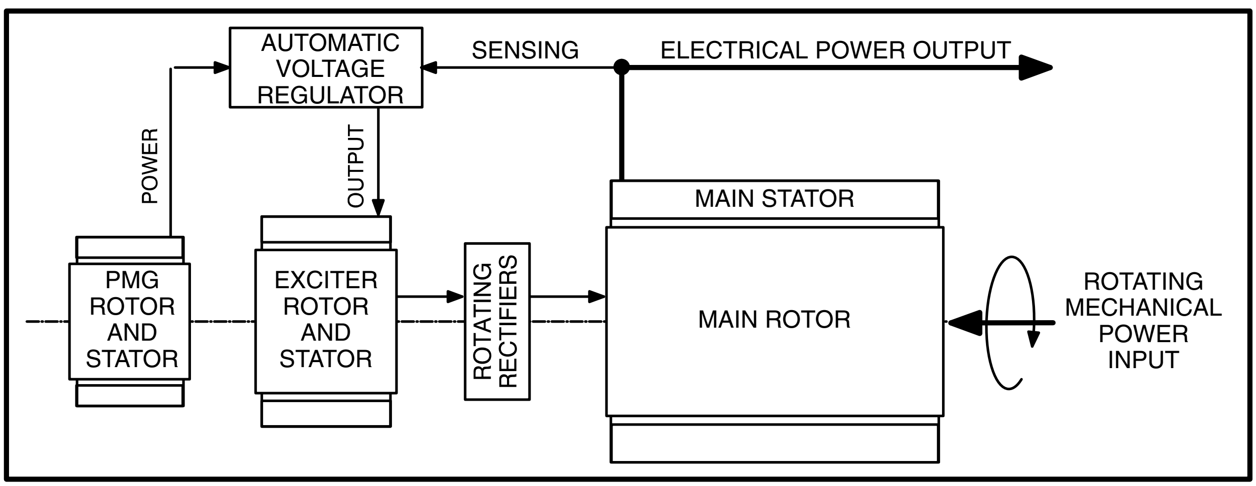

Figure 4–3. Separately-Excited (PMG) Generator

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.

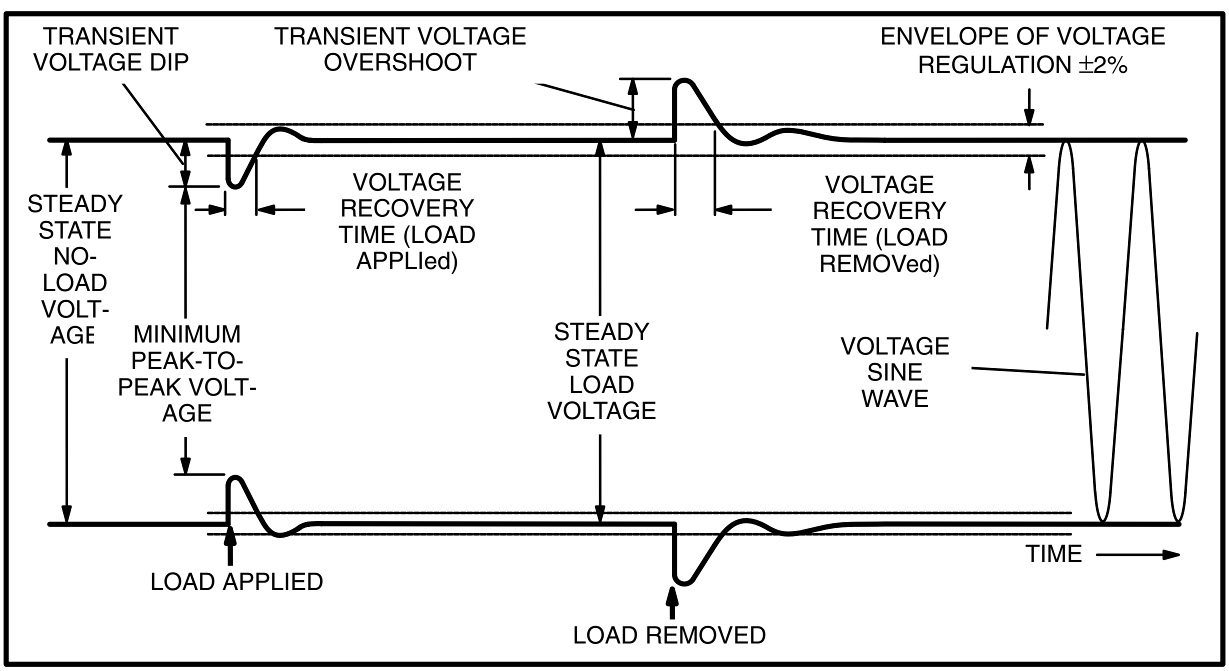

Figure 4–4. Typical Voltage Profile on Load Application and Removal

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**.

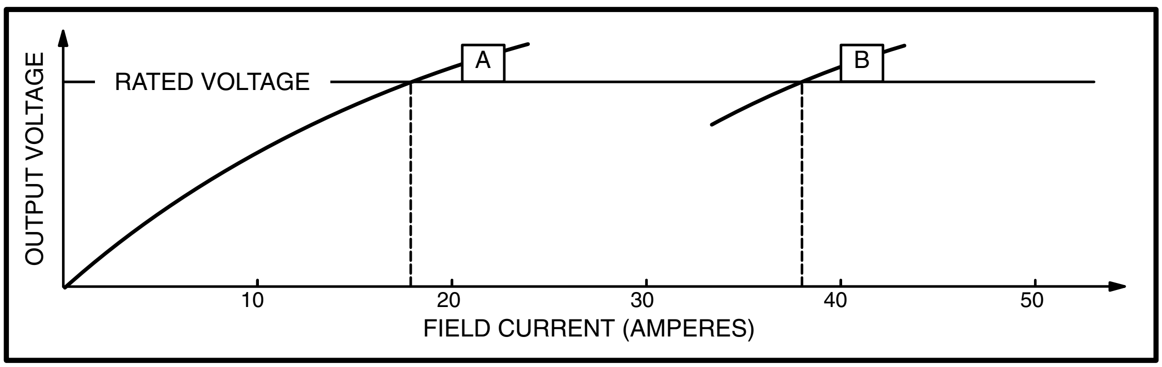

Figure 4–5. Typical Generator Saturation Curves

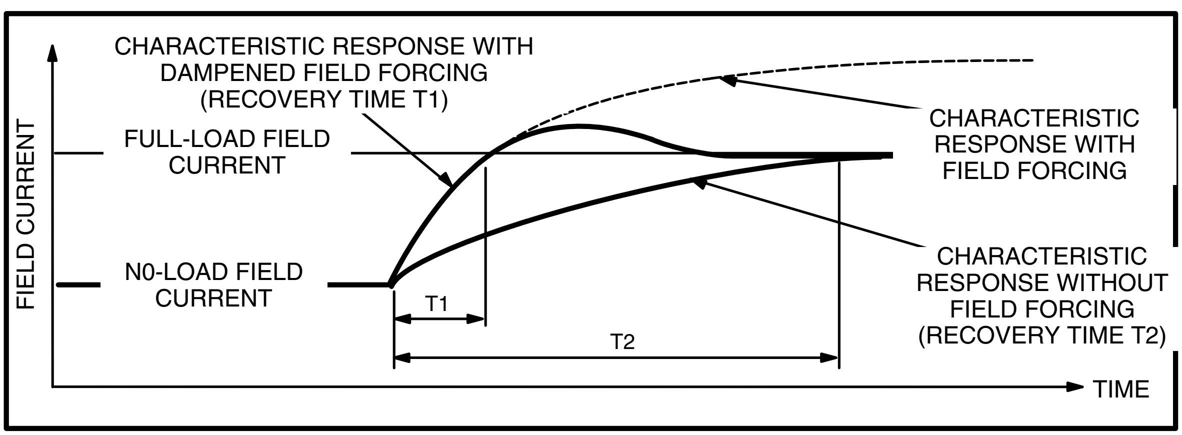

Figure 4–6. Excitation System Response Characteristics

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.

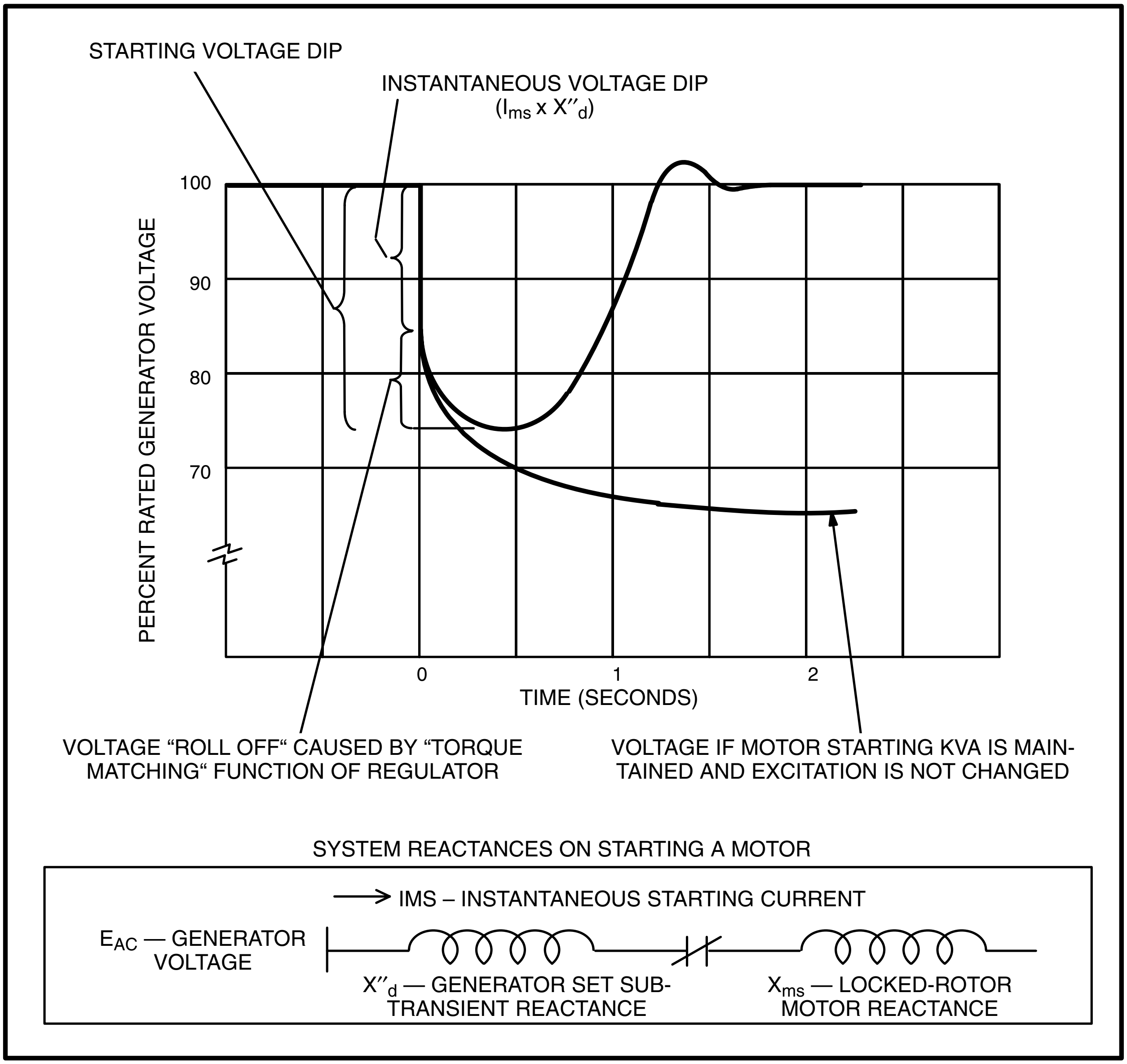

Figure 4–7. Transient Voltage Dip

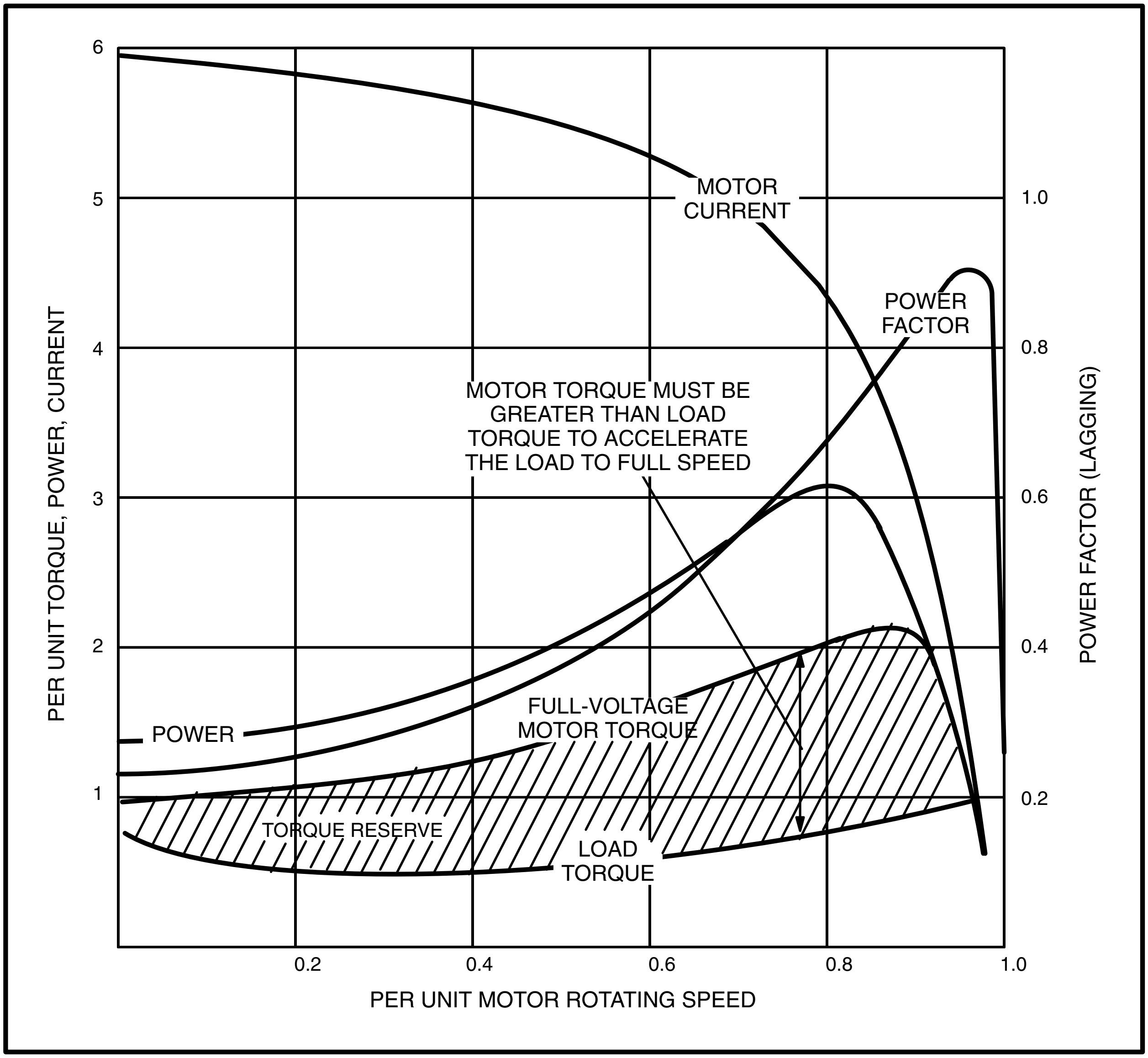

Figure 4–8. Typical Across-the-Line Motor Starting Characteristics (Assumes 100% of Nominal Voltage at Motor Terminals)

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.

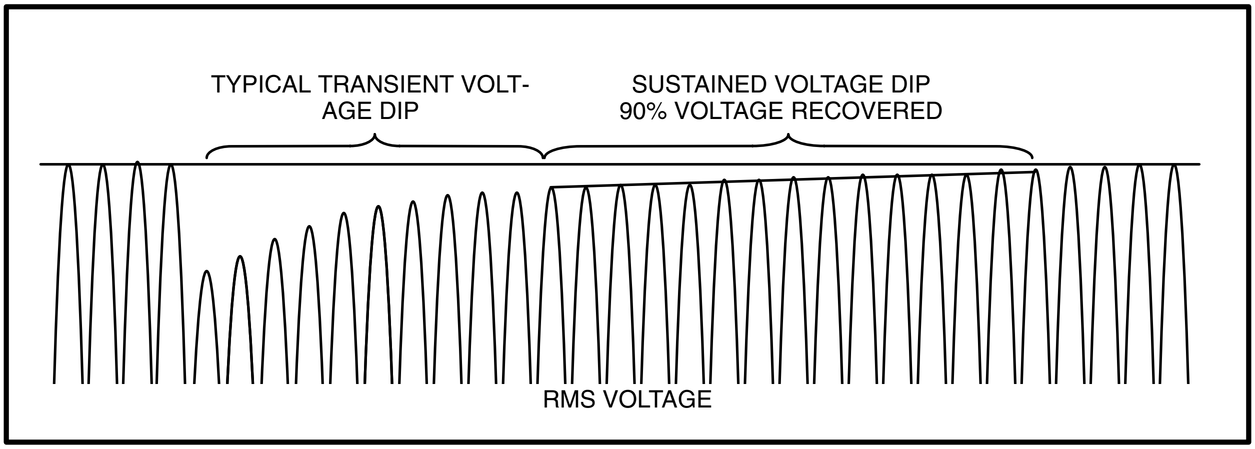

Figure 4–9. Sustained Voltage Dip

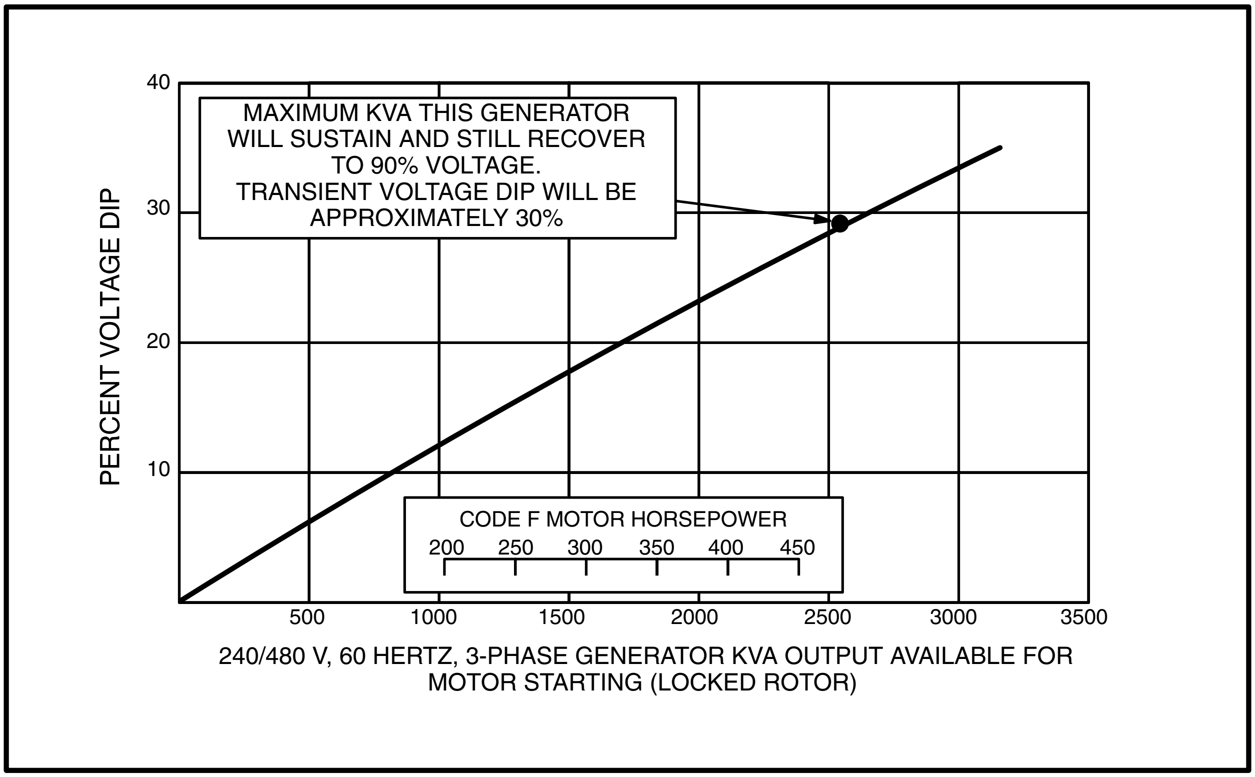

Figure 4–10. Typical NEMA Generator Chart of Transient Voltage Dip vs. Motor Starting KVA

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.

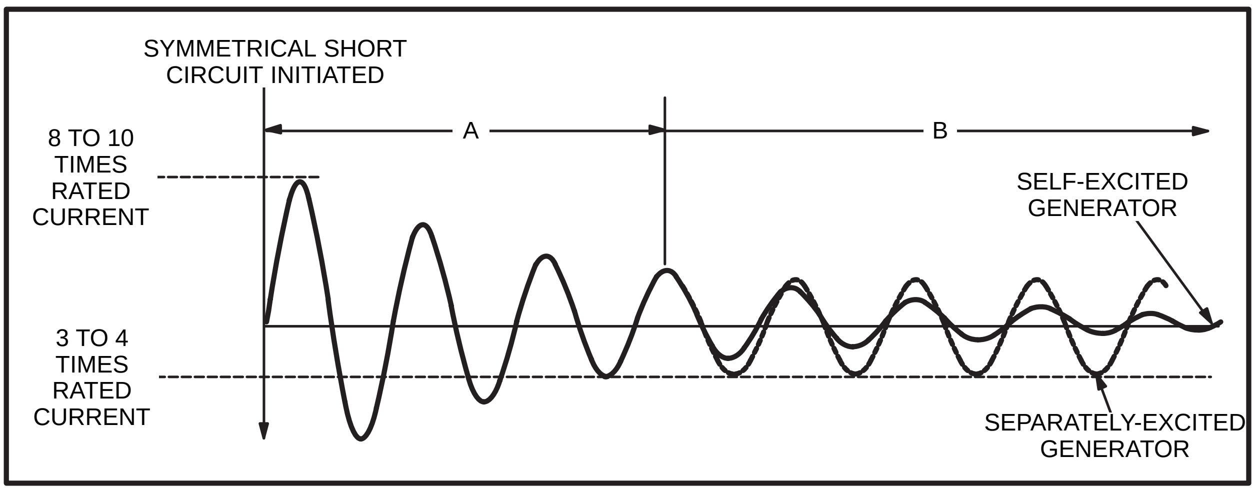

Figure 4–11. Symmetrical Three-Phase Short Circuit Response

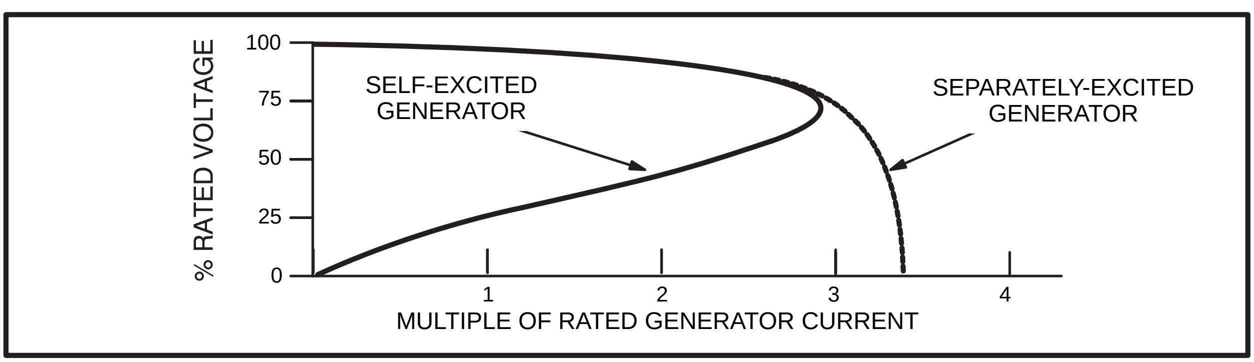

Figure 4–12. Short Circuit Capability

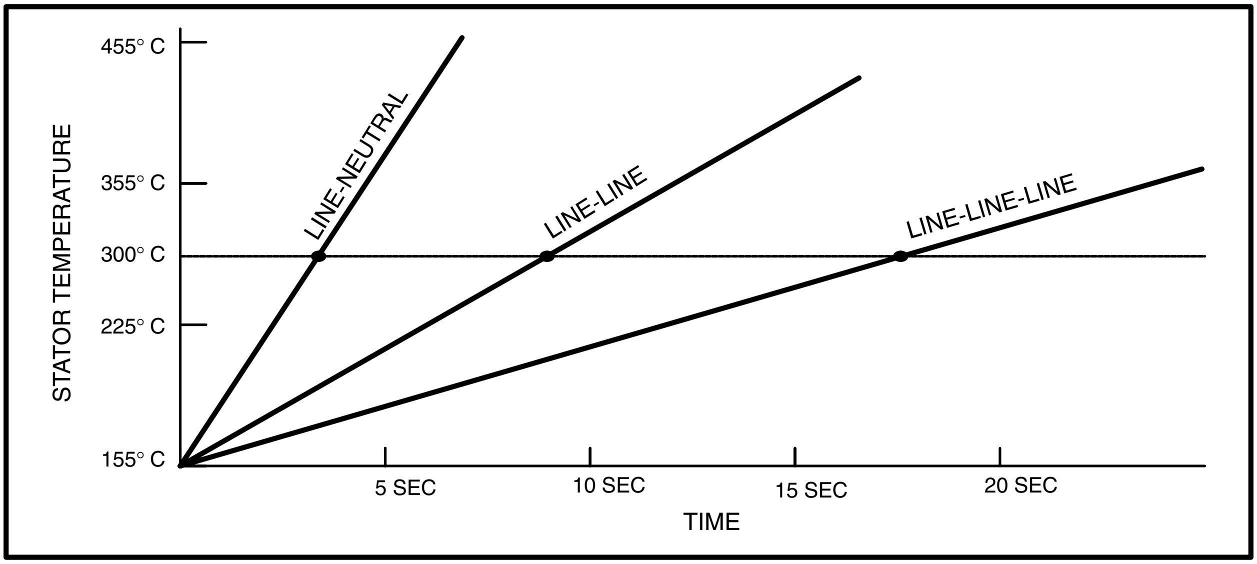

Figure 4–13. Approximate Short Circuit Winding Temperatures

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.

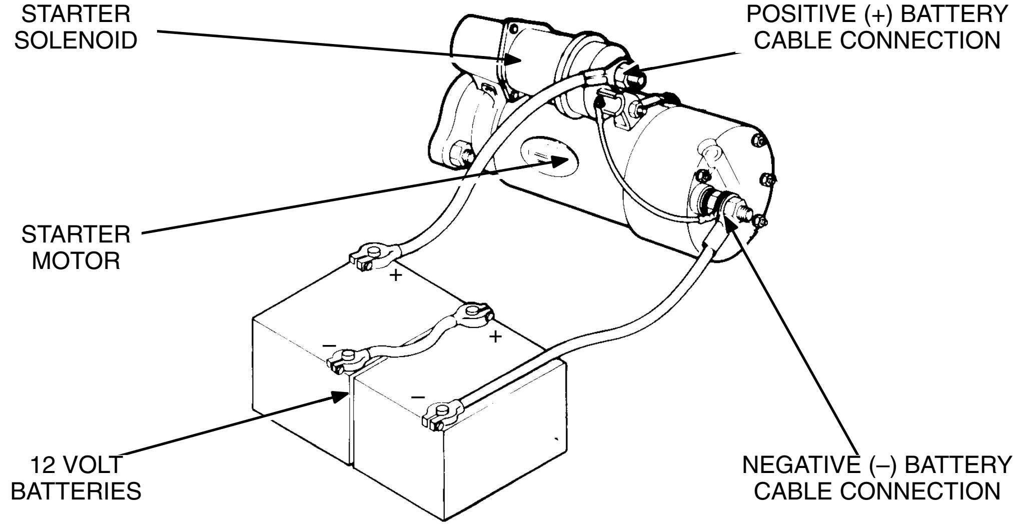

Figure 4–14. Typical Electric Starter Motor Connections (24 Volt System Shown)

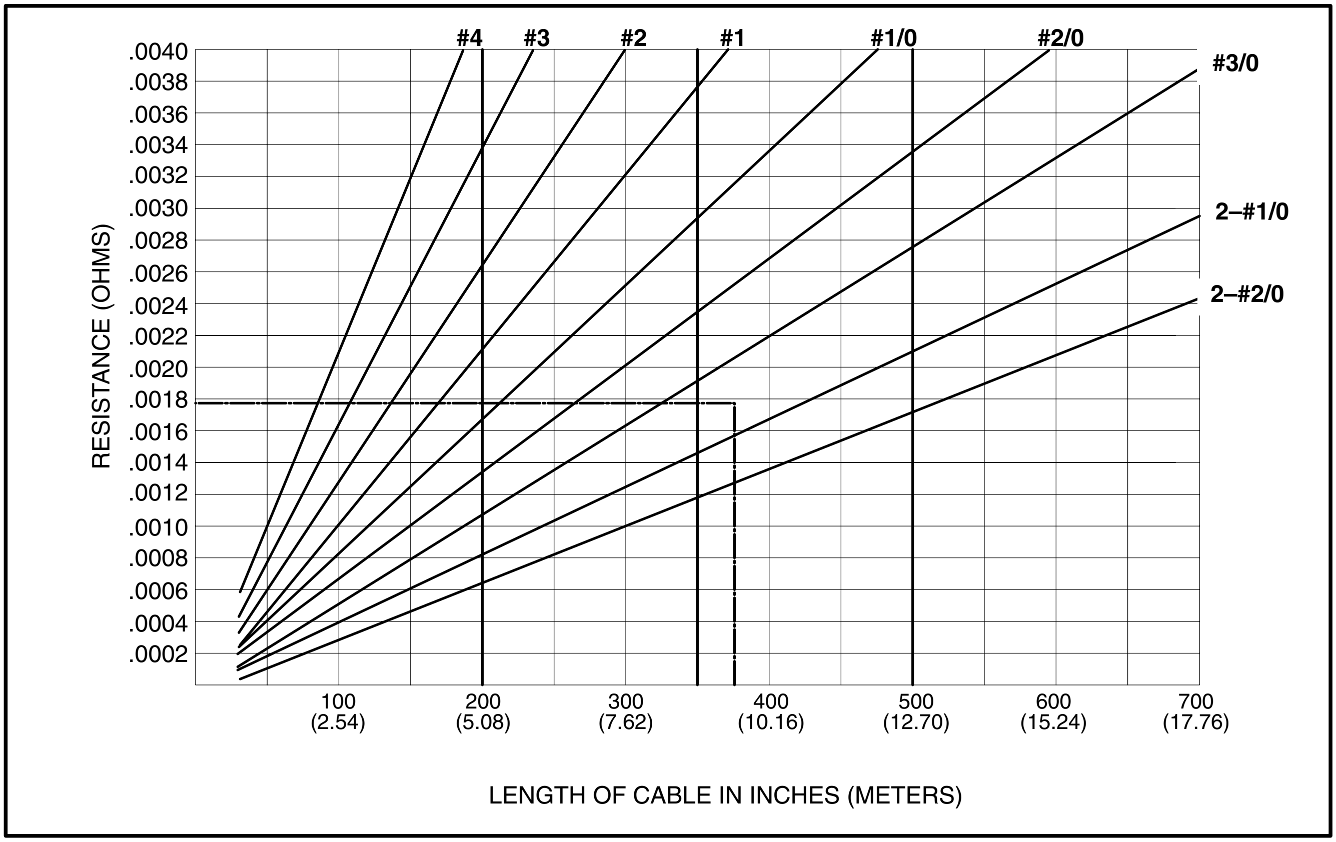

Figure 4–15. Resistance vs. Length for Various AWG Cable Sizes

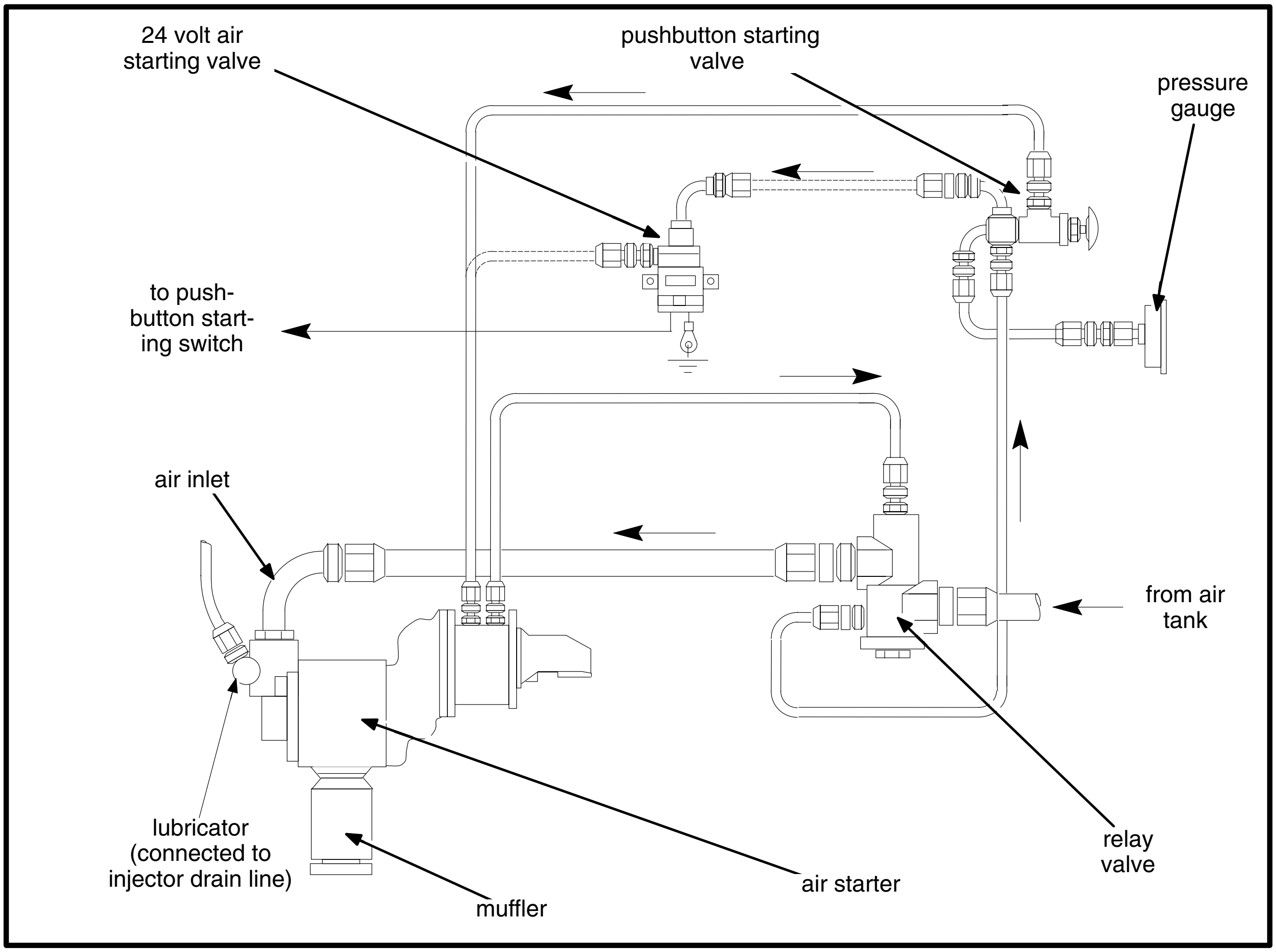

Figure 4–16. Typical Piping Arrangement for an Air Starter

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.

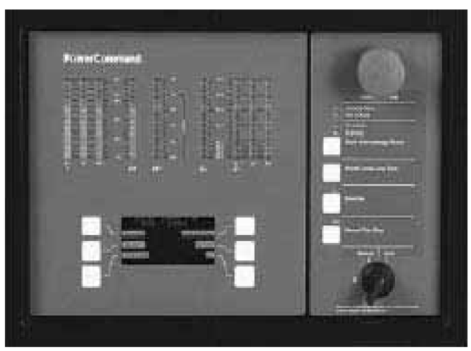

Figure 4–20. Power Command Full Authority Electronic

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.

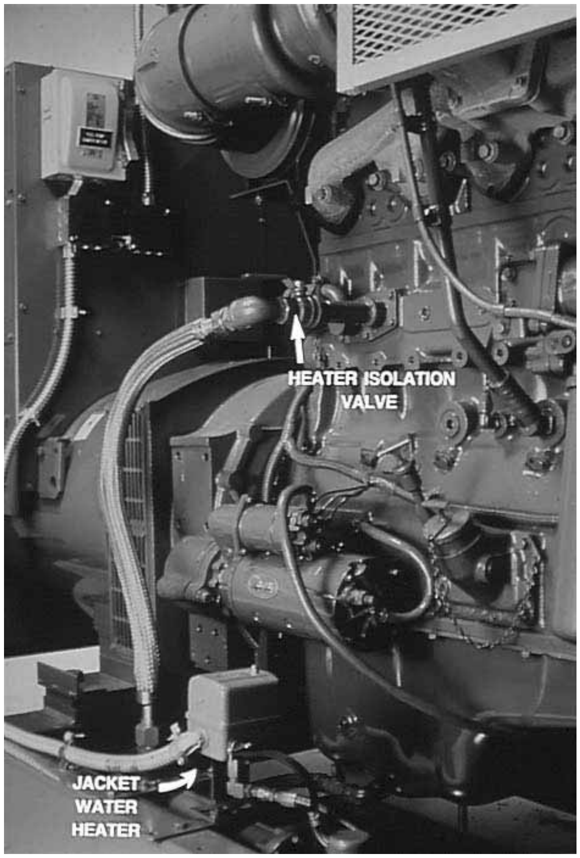

Figure 4–21. Water Jacket Heater Installation. Note Heater Isolation Valve, Hose Type, and Hose Routing.

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.