Chapter 5
Electrical Design
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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.

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).
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 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

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](image)

Choose a Generator Transformer

Distribution class transformers come in 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.
<table>
<thead>
<tr>
<th>Code Number</th>
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<th>Circuit Configuration</th>
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<tbody>
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</tr>
<tr>
<td>0</td>
<td>Dz0</td>
<td><img src="image2" alt="Circuit Diagram 2" /></td>
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<tr>
<td>6</td>
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<tr>
<td>11</td>
<td>Yz11</td>
<td><img src="image6" alt="Circuit Diagram" /></td>
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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.
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.

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.

![Diagram of HV/MV/LV Distribution System](image)

**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.
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.

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.
### 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.

**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.

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

\[ I_{\text{LINE}} = \frac{kW \times 1000}{V_{L-L} \times 0.8 \times 1.73} \quad \text{OR} \quad I_{\text{LINE}} = \frac{kVA \times 1000}{V_{L-L} \times 1.73} \]

Where:
- \( I_{\text{LINE}} \) = 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.

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![Diagram](image)

**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:

\[
V_{DROP} = \left(\frac{I_{PHASE} \cdot Z_{CONDUCTOR}}{V_{RATED}}\right)
\]

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).

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

Where:

- \(Z\) = Impedance of conductor
- \(R\) = Resistance of conductor
- \(X\) = Reactance of conductor
- \(L\) = Conductor length in feet
- \(N\) = Number of conductors per phase
- \(\text{pf}\) = 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.)

\[
Z = \frac{500}{(1000 \cdot 1)} \left[(0.12 \cdot 0.91) + 0.055 \sqrt{(1–0.91^2)}\right]
= 0.066 \text{ percent}
\]

\[
I_{PHASE} = \frac{kW}{kV \cdot 1.73} = \frac{100}{0.48 \cdot 1.73}
= 120.3 \text{ amps}
\]

\[
V_{DROP} (%) = 100 \cdot \frac{120.3 \cdot 0.066}{480}
= 1.65 \text{ percent}
\]
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.
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:
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:

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

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

\[
104.5 \text{ kVA} < 125 \text{ kVA} \text{ (Rating of the Generator Set)}
\]

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 (L1–L2 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.

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 and Equipment Grounding

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.

**PER UNIT kVAR**

**PER UNIT kW**

0.2

0.4

0.6

0.8

1.0

0.2

0.4

0.6

0.8

1.0

0.99 PF LEADING

1.0 PF

0.8 PF LAGGING

Acceptable
Steady State
Operating Region

Unstable
Voltage Region

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 systems are also typically installed.
THREE-PHASE, THREE-WIRE UTILITY, THREE-POLE ATS
Generator Neutral may be solidly grounded, resistance grounded or ungrounded with a three-wire system

THREE-PHASE, FOUR-WIRE UTILITY, THREE-POLE ATS
Generator Neutral is grounded at service entrance only with a three-pole ATS

THREE-PHASE, FOUR-WIRE UTILITY, FOUR-POLE ATS
Generator Neutral must be solidly grounded when a separately derived source with a four-pole ATS

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<sub>AC</sub> is the open circuit voltage and X<sub>d</sub><sup>′′</sup> is the per–unit direct axis subtransient reactance of the generator. A typical Cummins Power Generation generator set will deliver 8 to 12 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<sub>d</sub><sup>′′</sup>.)

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:

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

Example Calculation: Find X<sub>d</sub><sup>′′</sup> (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<sub>d</sub><sup>′′</sup> = 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:

\[
X_{d(Genset)} = X_{d(ADS)} \left( \frac{\text{kVA}_{\text{ADS}}}{\text{kVA}_{\text{Genset}}} \right)^2 \frac{\text{kVA}_{\text{Genset}}}{\text{kVA}_{\text{ADS}}} \]

\[
X_{d(Genset)} = 0.13 \left( \frac{0.48}{0.48} \right)^2 \frac{288}{419} = 0.089
\]

**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.*

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:

\[
\text{Fault Current as } \% \text{ of CB rating} = \left( \frac{10 \cdot \text{Rated Generator Amps}}{\text{Rated CB Amps}} \right) \times 100\%
\]

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:

\[
\text{Fault Current as } \% \text{ of CB rating} = \left( \frac{10 \cdot 347}{100} \right) \times 100\% = 3470\%
\]

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:

\[
\text{Sustained Current as } \% \text{ of CB rating} = \left( \frac{3 \cdot 347}{100} \right) \times 100\% = 1040\%
\]

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.

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.

**CURRENT IN PERCENT OF CIRCUIT BREAKER TRIP UNIT RATING**

![Image of a graph showing the relationship between time in seconds and current in percent of circuit breaker trip unit rating.](image)

**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 to 10 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 curve1 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

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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.

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 its design.

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](image-url)