5 – ELECTRICAL DESIGN

Overview

The electrical design and planning of the on−site generation system is critical for proper system operation and reliability. This chapter covers installation design of the generator and related electrical systems, their interface with the facility, and topics regarding load and generator protection.

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

Typical Electrical System Designs

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

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

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

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

Electrical System Designs tend to vary considerably based on the needs, or primary functions of the power generation equipment in the application. A system design that is optimized for emergency service situations will generally not be the best fit for interruptible service and is definitely not the same type of system design as a prime power application. The one−line configuration differences are easy to see. For example, in prime applications the generator sets are at the ”top” of the distribution system while in standby and especially in emergency applications the generator sets 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. This also means 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 of 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: Generator set components are not designed to support the weight or cantilever of a load bank. Load banks, when installed, must always be supported by the floor or other building structures that have adequate load bearing capacity.

- 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 5–19.)

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 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 5–16.)
- 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 5–16.)
- Generator sets that parallel to the utility only for a short period of time generally require less protection than those that parallel for unlimited periods of time. However, it should be recognized that paralleling to the utility for any period of time, even fractions of a second, carry risks of equipment damage that are not present in non–parallel applications. (See **Combined Generator and Utility Systems**, page 5–18.)

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 being 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. A key element for understanding and communication of the electrical system design is a one–line diagram such as the one depicted in **Figure 5–1**.

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

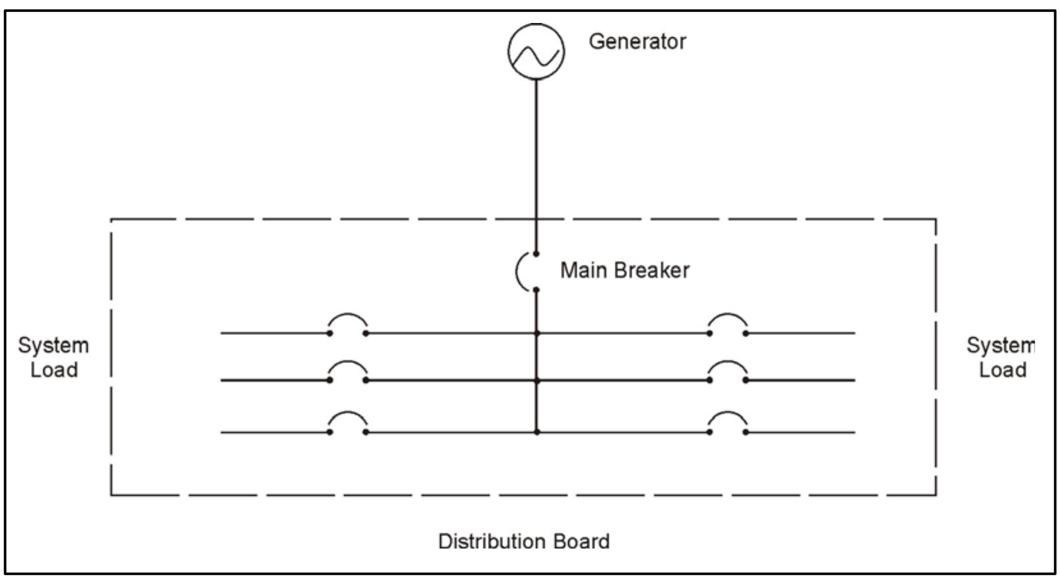


Figure 5–1. Generator Set Serving Common Loads

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 this can be provided in many forms, such as 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 no requirement for protection of 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.

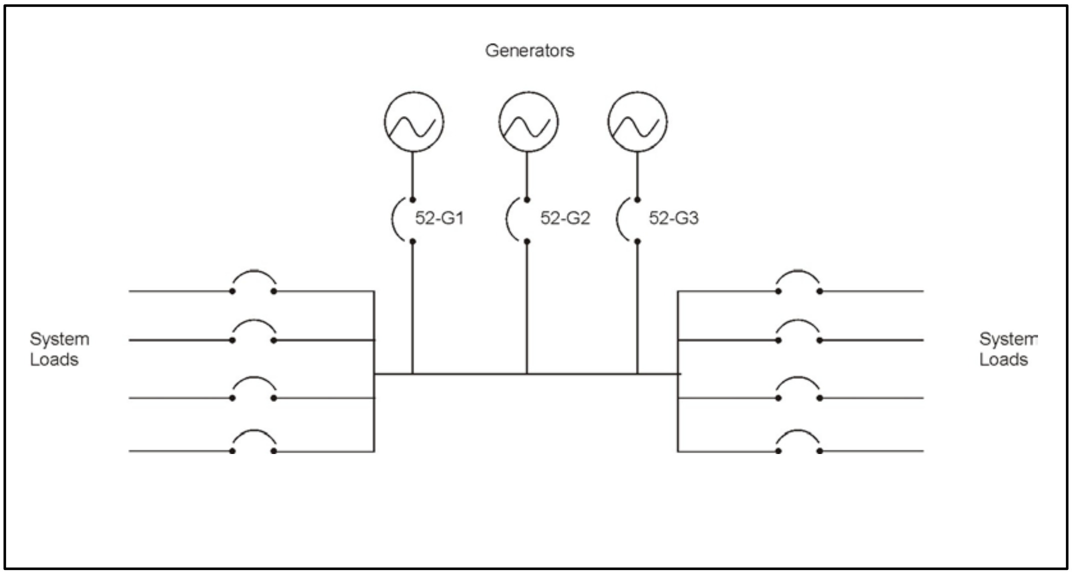


Figure 5–2. Multiple Generator Sets Serving Common Loads

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 minimize 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 page 5–28 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 dedicated transfer module, is used to transfer the electrical supply to the load from utility to generator. Three–pole generator and utility circuit breakers or fuse–switches are often used to limit the fault level present at the ATS. The ATS may be a 3–pole (solid, non–switched neutral) or 4–pole (switched neutral) device. Typically, 4–pole ATS equipment is used in applications where it is necessary to isolate the supply neutral from the generator neutral. The selection of switched neutral equipment may be related to either safety considerations, or if the system is required to incorporate ground fault detection devices. The utility service provider should be consulted to confirm the type of grounding (earthing) system used in the utility distribution system feeding a site, and verify that the proposed grounding arrangements at a customer site are appropriate. Power transfer switches and generator sets should not be connected to a utility service prior to this review (and utility approval, if required by local law).

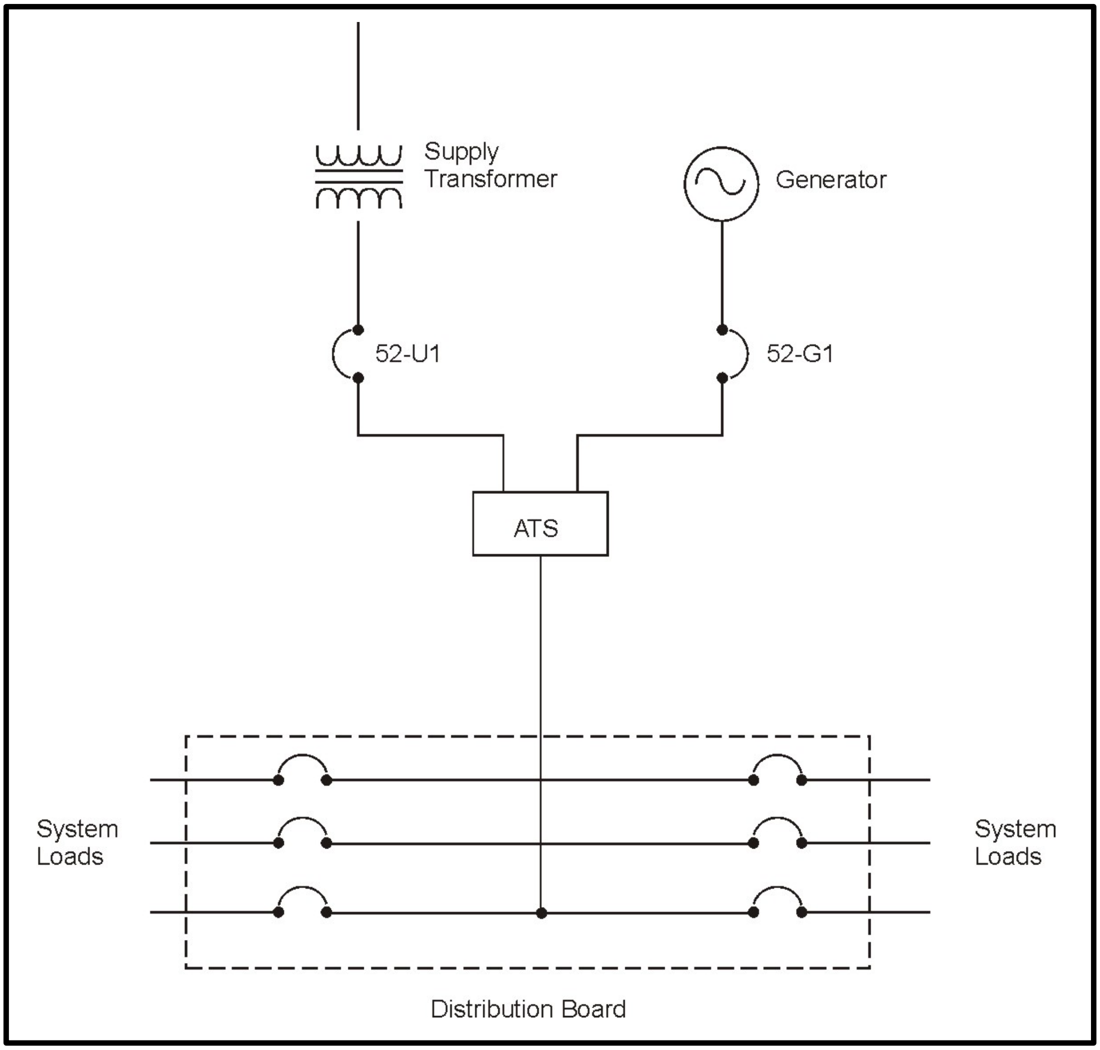


Figure 5–3. Single Generator Set Standby Applications

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

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

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

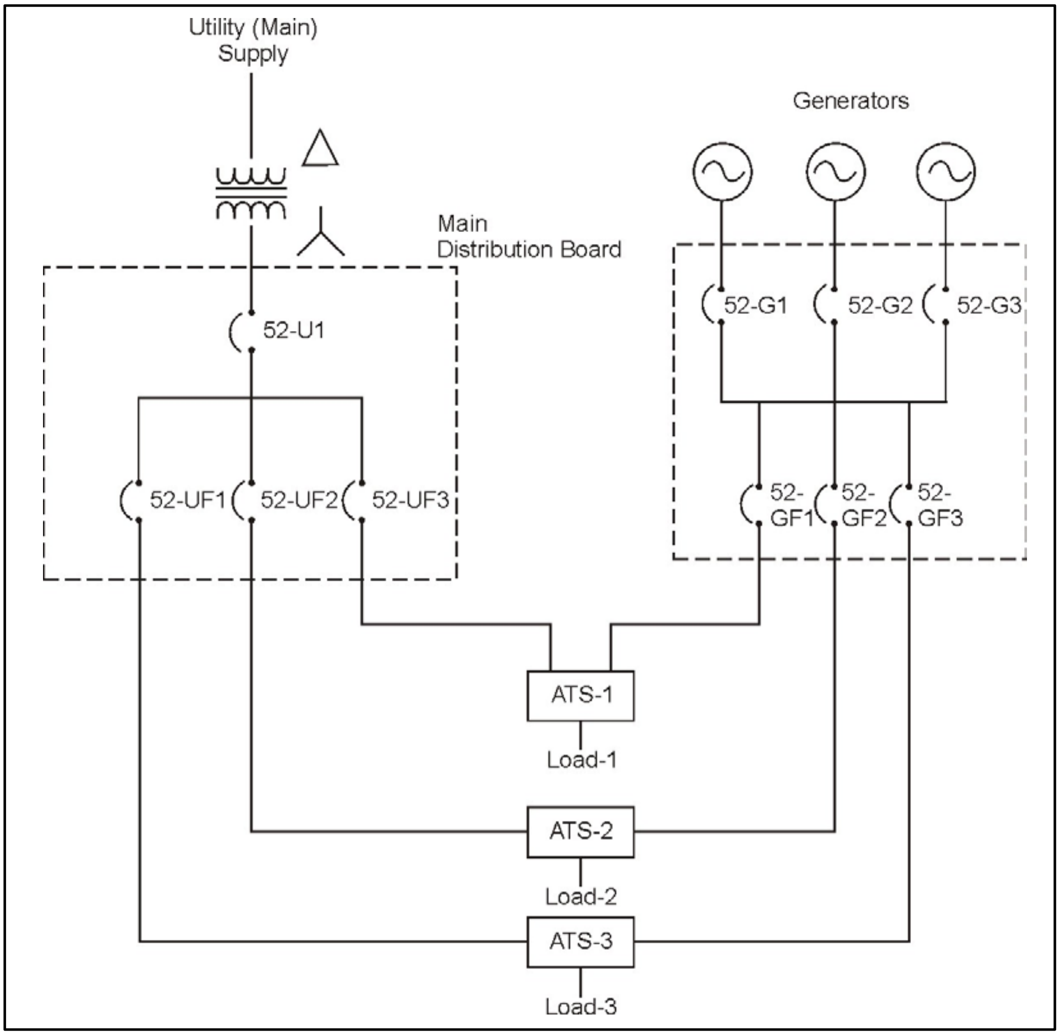


Figure 5–4. Multiple Generator Sets, Multiple ATS Applications

Typical Medium or High Voltage Systems

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

When designing an MV or HV installation, consideration must be given to the training and qualifications of the personnel operating the system owing to the higher level of safety precautions and different work procedures 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 page 5−28.

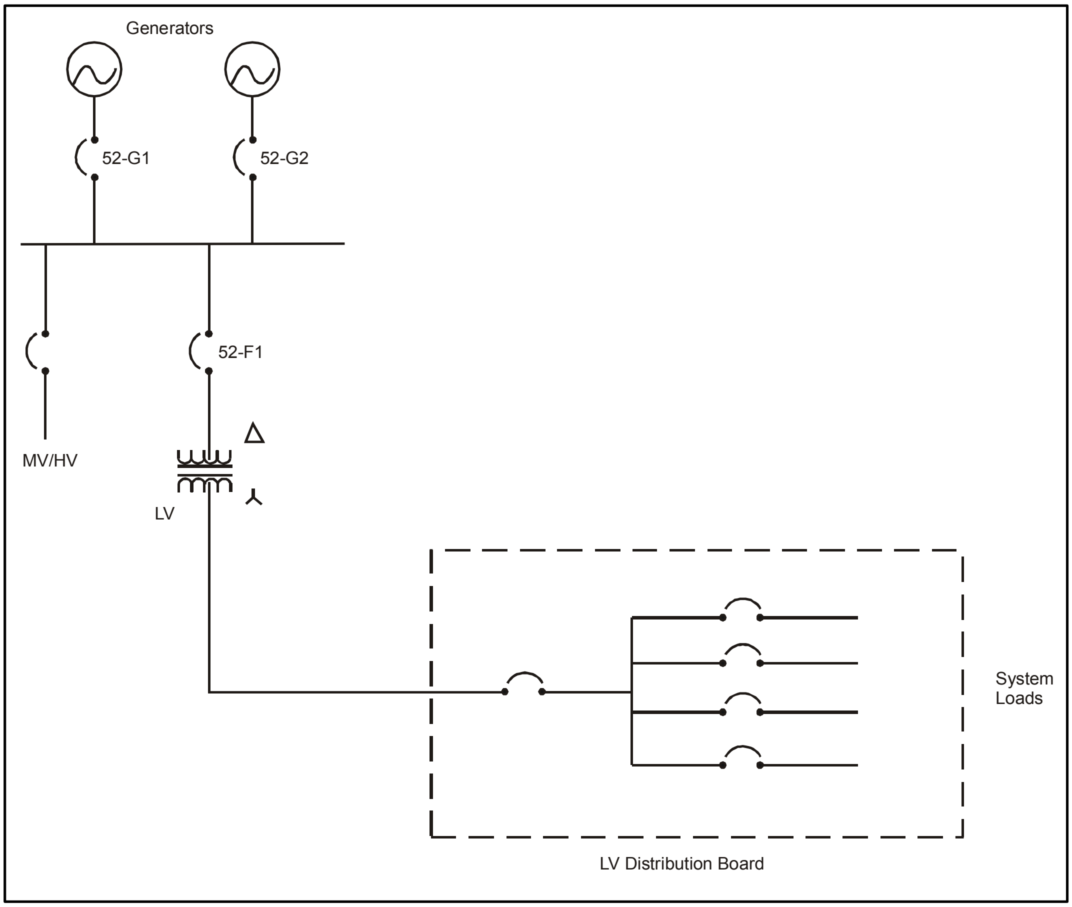


Figure 5−5. Simple MV/HV Generator System For Prime Power

Figure 5−6 illustrates an HV/MV scheme for a large installation such as an industrial facility 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.

*Note: There are multiple mains present in the configuration shown in **Figure 5−6**.*

This is a highly adaptable system that is extensively used throughout the world. Incorporation of the generator bus main circuit breakers 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, simplifying maintenance and fault finding procedures.

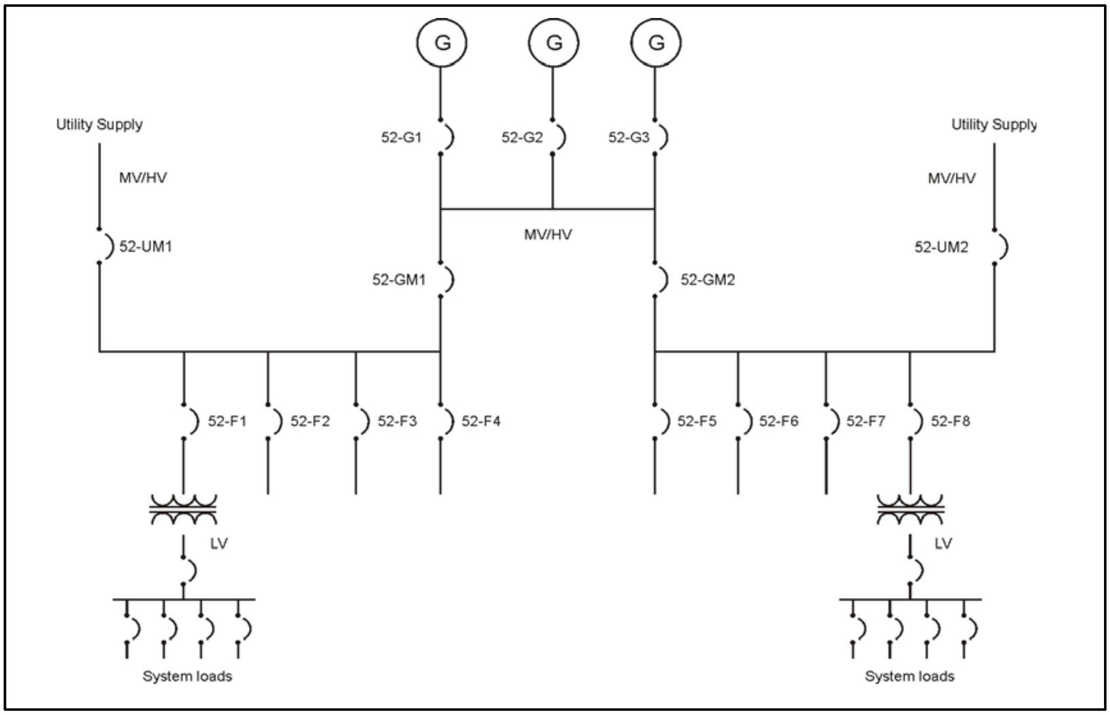


Figure 5–6. HV/MV Scheme For Multiple Generators / Utility Supplies And Loads

Where many transformers are being energized by the system, care should be taken to ensure that the appropriate overcurrent protection scheme is chosen. Applications that require a single generator set to energize a large number of unloaded transformers as a part of their sequence of operation (such as emergency power for a ring bus configuration) should be reviewed to verify that protective functions in the system, including overcurrent protection, will not nuisance trip during the process of energizing the transformer(s). In addition, the generator set used in this type of application should include a permanent magnet generator(PMG), and the alternator's ability to energize the transformer(s) should be verified. For Cummins machines with PMG, if the total transformer kVA exceeds 10 times the rated kVA of the alternator, the factory should be consulted for guidance.

For more information on the types of over current protections and other related protection refer to page 5–34.

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. This is a typical practice but some systems require other grounding arrangements. A good reference for these provisions is IEEE Standard 142 – "IEEE Recommended Practices for Grounding of industrial and Commercial Power System ".

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

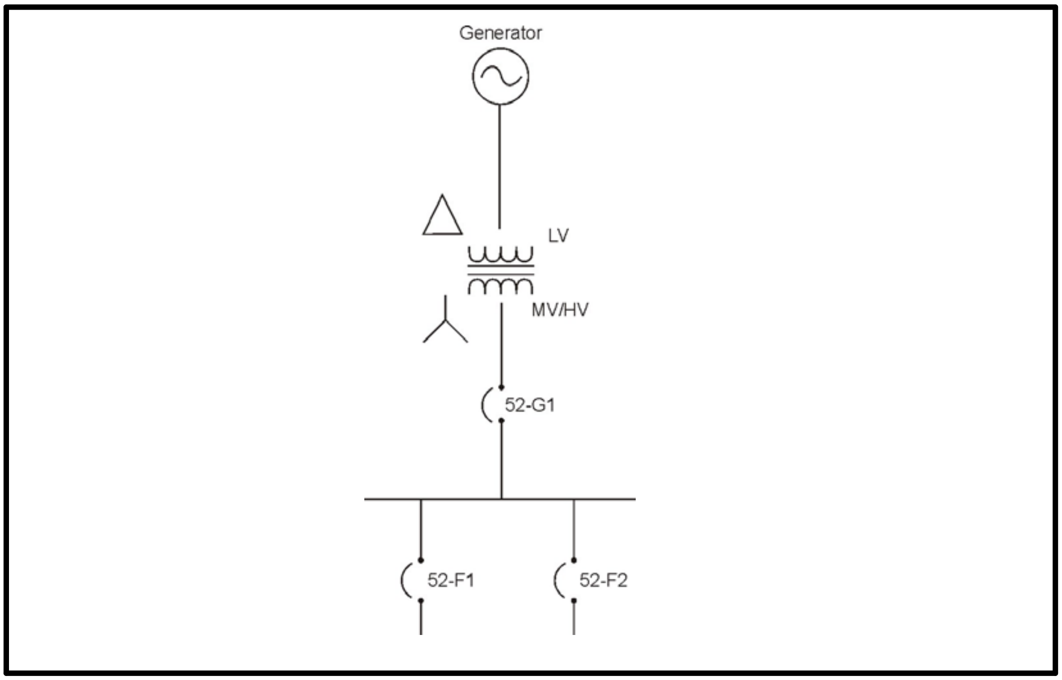


Figure 5–7. Low Voltage Generator For MV/HV Application

Choosing a Generator Transformer

Distribution class transformers come in a several configurations. Generally a transformer is classified by its application and by its cooling medium. In North America the design criteria for the transformers is governed by ANSI C57.12, while in Europe, Central Asia and Asia Pacific, the standards is IEC 60076.

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

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 restricts public access. This is due to the fact that substation type transformers are not tamperproof and live parts, fans, etc are exposed. Substation type transformers can be further sub–divided according to their cooling medium. There are two types of substation transformers:

- Dry Type
- Liquid filled

Padmounted Type Transformers

Padmounts are built to the same ANSI standards as listed for Substation type transformers. However, Padmounts are typically compartmentalized and tamperproof. The most common applications for Padmounts are outdoors installations in non–restricted areas, where members of the public can come into contact with the transformer. 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.

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 oil or other liquid as the dielectric medium. Unlike conventional dry types, liquid filled transformers are impervious to moisture because the windings are completely covered in dielectric oil. However, liquid filled transformers do require fire protection systems if used indoors. There are two types of liquid in common use:

- Mineral Oil
- High Fire Point

Mineral Oil

Mineral oil is the least expensive of all oils that are used as filling. 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

<u>High Fire Point</u>

Manufacturers typically offer either R–Temp (Cooper Industries) or Dow Corning 561 Silicone as high fire point liquids. These liquids are being increasingly scrutinized by environmetal protection agencies as environmental hazards (such as PCBs) and tend to go in and out of market favor as a result.

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

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

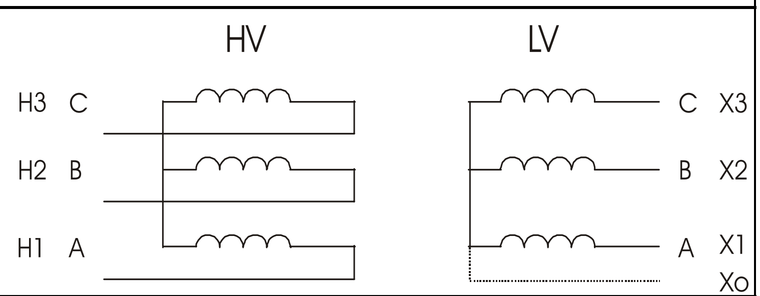
Winding Configuration

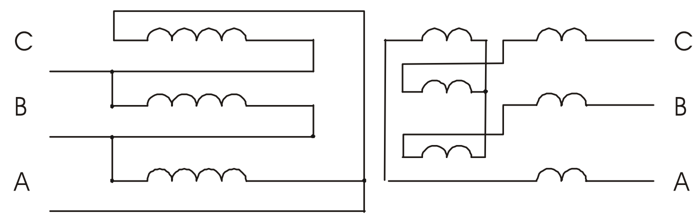
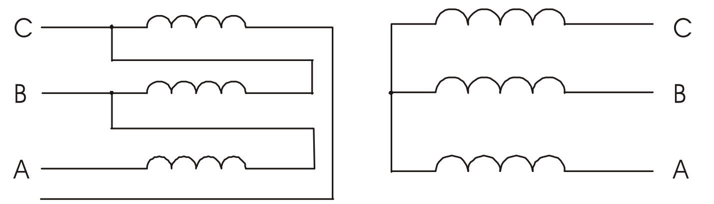
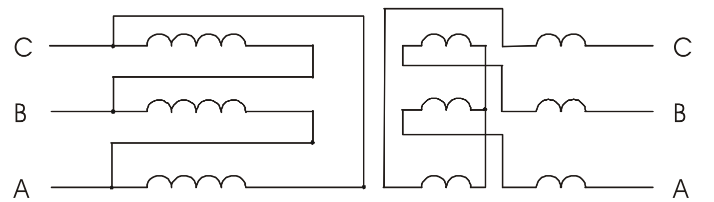
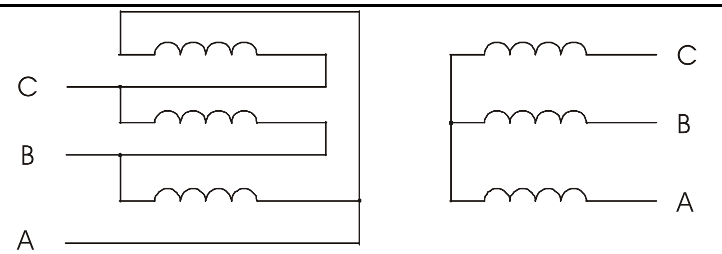
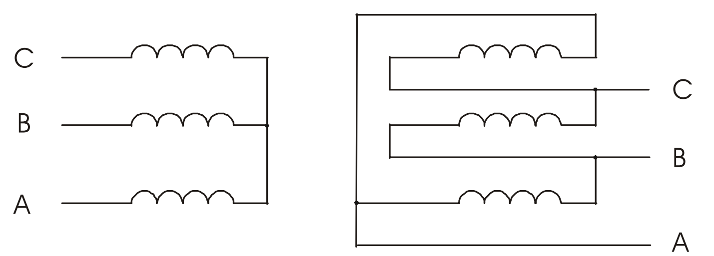
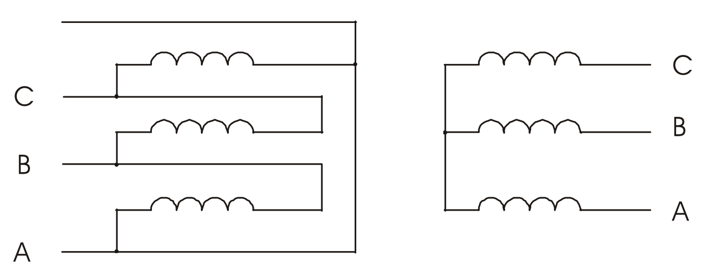
The winding configuration is generally governed by the need for referencing the electrical system to ground (earth). Conventionally, electrical systems are grounded at source and therefore, the winding of the transformer that is acting as the source of power for an electrical system can be expected to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

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

The most commonly used vector groups are shown below:

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

Code Number	Vector Group	Circuit Configuration
0	Yy0	

Code Number	Vector Group	Circuit Configuration
0	Dz0	
5	Dy5	
6	Dz6	
11	Dy11	
1	Yd1	
1	Dy1	

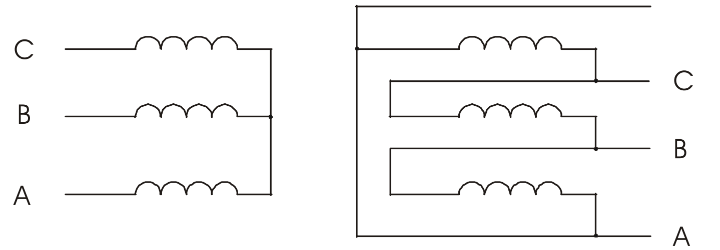
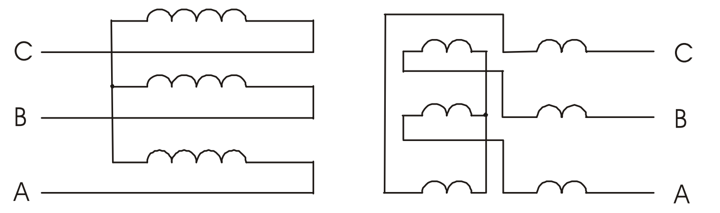
Code Number	Vector Group	Circuit Configuration
11	Yd11	
11	Yz11	

Table 5-1. Winding Configurations

Rating

Transformers are generally provided with a Continuous Maximum Rating (CMR) and a Continuous Emergency Rating (CER). The choice of rating will depend on the duty cycle expectations of the transformer and the electrical system. CMR rated transformers are generally bulkier and more costly than CER rated units; however the CER transformer will have a limited life if the CER limits are reached, 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).

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 the voltage is expected to be more than 5% of nominal under any operating conditions.

Connection

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

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

Single versus Parallel Generators

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

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

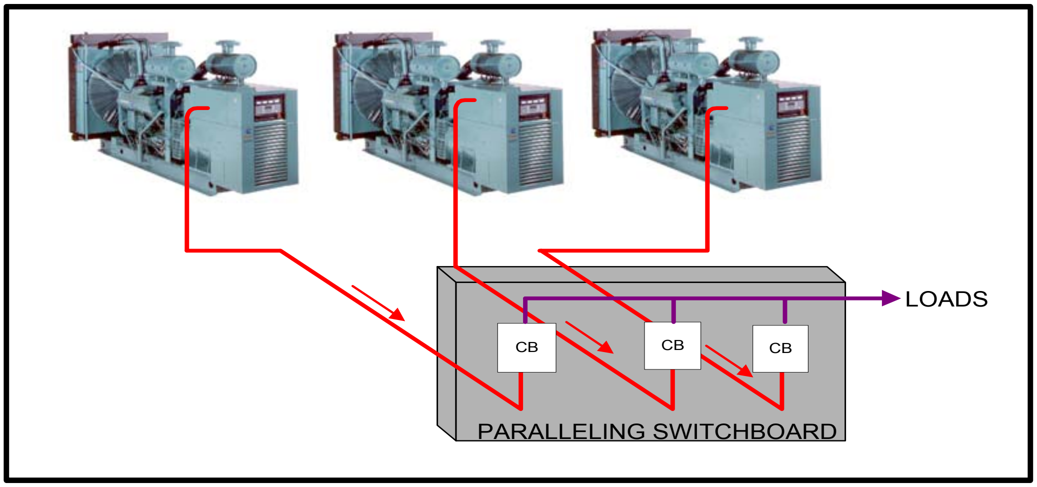


Figure 5–8. Parallel Generators

Reliability is the primary factor in the decision to use paralleling in most emergency/standby applications, such as hospitals, computer centers and pumping stations. 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.

Note: To achieve higher levels of reliability, the reliablity of standard generator set controls must be maintained, even though paralleling adds componentry that can make systems more complex and can tend to make the individual genset less reliable.

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.

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.

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. See Appendix A for information on Gensize.

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. these risks should be evaluated against the benefits obtainable by paralleing. 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 if one of the running generators should fail at any time during operation, the remaining generators should have sufficient reserve capacity to be able to satisfy the resulting load increase.
- 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.

Note: Additional controls are required to control load adding and load shedding capability, compatibility between paralleling generator sets, and paralleling to utility.

Combined Generator and Utility Systems

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

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

No–break changeover between generator and utility supplies can be accomplished by use of a closed transition (no–break) ATS, or by conventional paralleling and ramping of load. In the closed transition ATS the generator set is operated at a slightly different frequency than the utility so that the phase relationship between the generator and the utility is constantly changing. When the sources are synchronized, they are connected together for a period of less than 100 ms via a simple sync check device. While this system eliminates the total interruption of power when switching between live sources, it does not eliminate disturbances caused by sudden changes in load on the two sources. Disturbances can be minimized (but not eliminated) by using multiple switches in a system, so any closing switch only changes the load by 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 the section titled **Guidelines for Generator Set Ratings** in Chapter 2. 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.

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 5–9 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 that may have essential and non–essential LV loads segregated. Standby generation may be provided at this level, at LV, and will typically supply the essential loads only during a power outage.

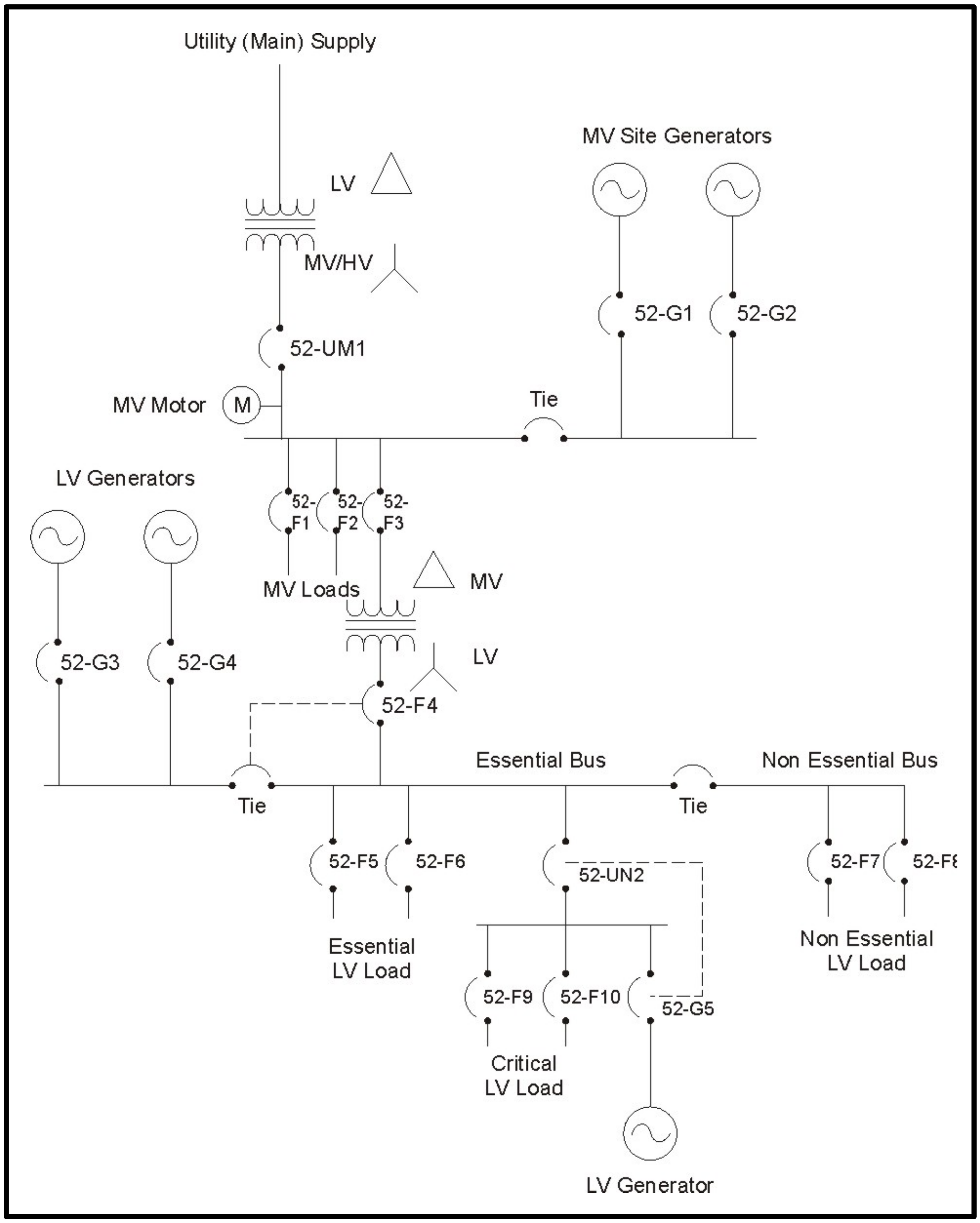


Figure 5–9. Sample HV/MV/LV Distribution System

The scheme for supplying critical loads using a smaller generator to back up the bulk generator system is also shown in this diagram. Refer to page 5–28 for information on grounding (earthing) and neutral connections. Refer to page 5–34 for more detailed information on switchgear, types of switchgear and the accessories supplied with breakers.

The next section, Electrical Connections, can be found in Part 2. To view Part 2, click the link below the one you used to view this file.