Application Considerations

Inductive Loads

Transferring motor loads between two sources requires special consideration. Even though the two sources may be synchronized at the start of transfer, the motor will tend to slow down upon loss of power during transfer, thus causing the motor residual voltage to be out of phase with the oncoming source when the transfer is completed. The speed of transfer, total inertia, and motor and system characteristics are involved. On transfer, the vector difference and resulting high abnormal inrush current could cause serious damage to the motor, and the excessive current drawn by the motor may trip the overcurrent protective device. Both motor loads with relatively low load inertia in relation to torque requirements, such as pumps and compressors, and large inertia loads, such as induced draft fans, etc., that keep turning near synchronous speed for a longer time after loss of power, are subject to the hazard of out–of–phase switching.

A common application involves switching induction motor loads (or other inductive load such as a transformer) from one energized power source to another energized power source. Such is the case when re–transferring motor loads after an outage or when transferring motor loads to the generator during system testing. An inductive load stores magnetism in its steel core, resulting in residual voltage present at the load terminals for some finite time after the load is disconnected from a power source. For motors, this residual voltage decays as a function of the motor open circuit time constant. As shown in **Figure 21**, this decay may take several cycles to a few seconds, depending on motor size.

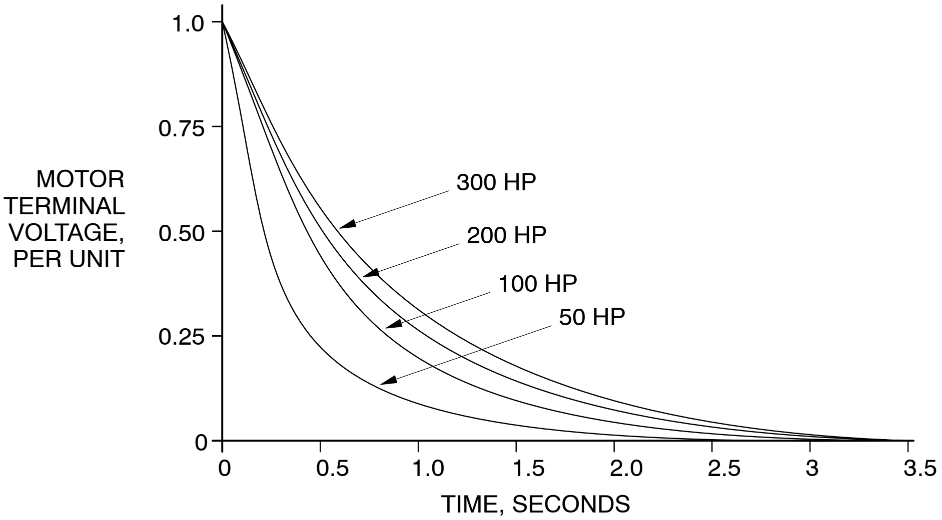


Figure 21. Induction Motor Open Circuit Voltage Decay

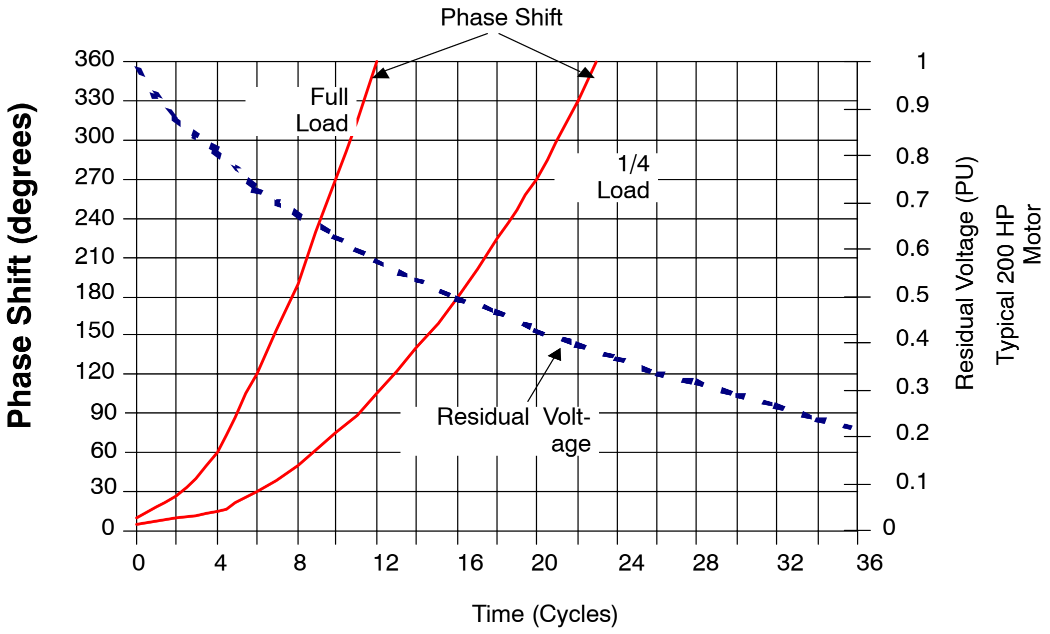
Reconnection of these inductive loads with an out–of–phase residual voltage present of more than .25 per unit can result in transient currents high enough to trip overcurrent devices and/or transient torque high enough to damage the load equipment. Several transfer switch control and construction considerations are applied as discussed below.

Inductive Loads (cont'd)

There are three common situations to consider where inductive load transfer may be between energized sources:

1) With the normal source at full voltage, transfer between energized sources will always be the case during system testing, exercise, and retransfer operation.
2) If just one phase is lost on a three–phase normal source, motors may continue to rotate holding up the voltage on the faulted phase, so that transfer would be between energized sources.
3) If the normal source voltage has dropped below the setting of the voltage sensors, but not gone completely, creating a similar situation.

When a running induction motor is disconnected from its power source, the motor generates residual internal voltage, present across its terminals, until the stored residual magnetism dissipates due to losses in the iron and as the motor loses speed due to shaft load and losses. The rate of change in frequency of the residual voltage is a complex function of the shaft load, inertia (angular momentum), the residual voltages generated by other motors on the same bus, and capacitive or resistive loads that also may be on the same bus. Thus, the relative phase angle between the residual AC voltage of a disconnected motor and an oncoming power source is uncontrollable and difficult to predict. The frequency of the motor residual voltage will slip in and out of synchronism with the power source at an increasing rate as the motor slows down until the motor voltage decays to zero. A very simple graphical view showing motor voltage and frequency versus time is shown in **Figure 22**.



Source: GE Industrial Power Systems Data Book

Figure 22. Motor Voltage and Phase Shift

Time "0" represents when the motor is disconnected from the source. Motor terminal voltage is shown by the dashed line. Note that it takes about ½ second for

Inductive Loads (cont'd)

the voltage to decay to around 25% of rated. Motor voltage phase shift is shown for two different motor load conditions. This represents the phase shift of the terminal voltage with respect to the source voltage from which the motor was disconnected, assuming the source voltage frequency remains constant. As the motor slows down after being disconnected, the phase angle changes, more rapidly for a heavily loaded motor. The band shown from 3 to 8 cycles represents the time range typical for the contact open time of open transition mechanical switches with no additional intentional time delay.

If time "0" is the point at which a motor load is to be transferred between a generator and a utility source, a heavily loaded 200 HP motor voltage would decay to about 75% of rated and be 120 degrees out of phase with the utility voltage 6 cycles later, at the time of connection to the utility source. This also assumes the generator and utility were operating near the same frequency just prior to transfer. As the frequency differential gets larger, the rate of change of phase shift increases.

Because the total transfer time is considerably shorter than most motor open circuit time constants, fast transfer can result in reconnection with motor residual voltages from approximately 75 to almost 100% rated voltage, and with up to a 180 degree phase angle between the residual motor voltage and the oncoming source. If power is reapplied before the residual voltage has decayed to a safe level of 0.25 per unit, the applied power source and the residual voltage can be significantly out of phase, resulting in excessively high inrush current and a corresponding increase (10 to 20 times) in torque. High transient currents may trip overcurrent protection devices. Abnormally high torque can also put unacceptable stress on shafts, couplings, and electrical insulation. The mechanical damage to the motor may or may not be immediate, but is cumulative with repetitive out–of–phase reconnections. The damage may also result in an insulation failure, which may not be readily attributable to the actual problem of out–of–phase reconnection.

Residual magnetism in a lightly–loaded transformer will result in a very brief DC residual voltage across its terminals, which should be allowed to decay to zero before reconnection to an AC source. Generally, 10–15 cycles is sufficient time for the residual DC voltage to decay to zero.

Several methods can be considered as discussed below:

Programmed Transition (Delayed Neutral)

As a simple and reliable solution to out–of–phase transfer of motors and all other loads, Cummins recommends a feature called Programmed Transition, which uses the well established practice of slowing down the contact transfer time sufficiently to allow the residual motor voltage to decay to 25 percent of rated and permit safe reconnection. As shown in **Figure 23**, the Cummins Programmed Transition option uses an adjustable time delay to control the contact transfer time of the contact mechanism.

Programmed Transition (Delayed Neutral) (cont'd)

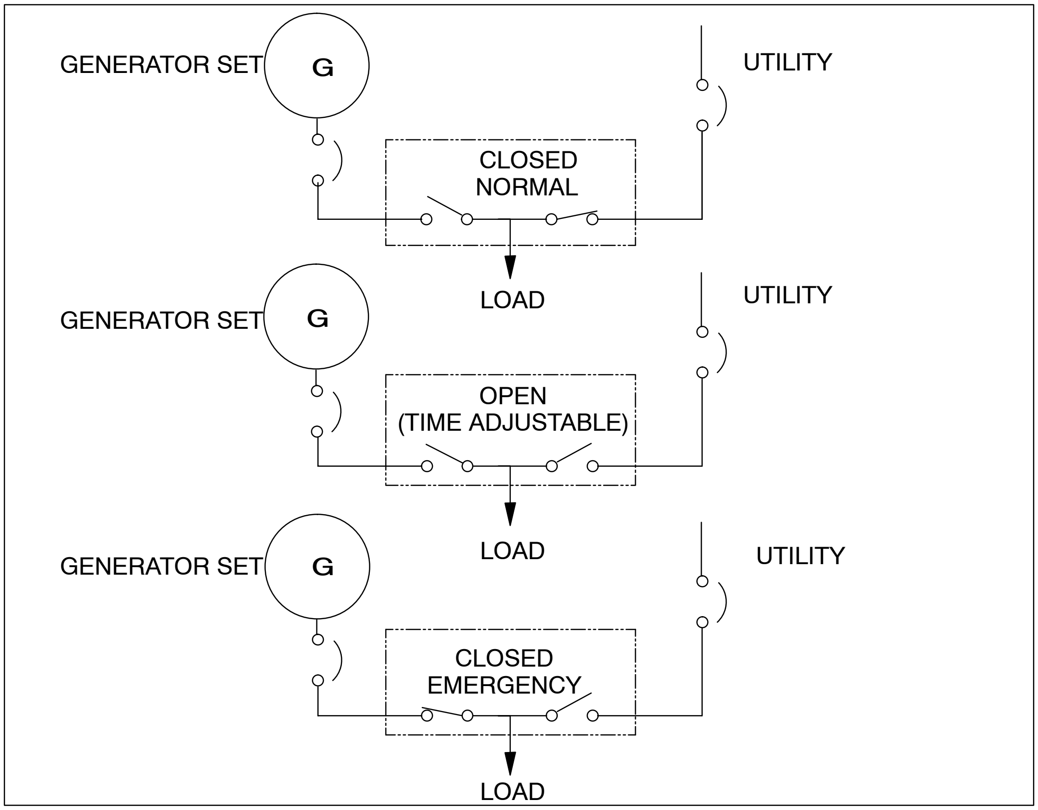


Figure 23. Programmed Transition Operation

The appropriate setting of the delay depends on the open circuit time constant of the motor. The motor open circuit time constant is a function of motor design, size, and type. An open circuit time constant is defined as the time it takes for the motor's residual voltage to decay to 38% of its rated voltage with no shaft load and the power terminals open circuited. A conservative approximation of the appropriate time delay setting would be 1.5 times the motor's open circuit time constant. For example, the residual voltage of a typical 200 HP motor will decay to 25% in about 0.5 seconds. Generally, a setting of from 0.5 to 1.5 seconds over the range of 25 to 200 HP would be sufficient delay. Motors less than 25 HP should not be a problem. Motors larger than 200 HP may require slightly longer delays. Several motors (of different sizes and time constants), as well as other loads, are frequently connected to one transfer switch. If more than one motor is connected to the transfer switch, use 1.5 times the open circuit time constant of the largest motor. Smaller motors and resistive loads reduce the circuit time constant, accelerating the decay. Two or more identical motors connected together will decay in essentially the same time as a single motor; for example, four 50–HP motors will decay as fast as one 50–HP motor. Synchronous motors have a longer time constant than induction motors. Capacitance retards the voltage decay, so if power factor correction has been applied and will remain connected to the bus, it may be reasonable to use additional delay.

Motor Starter Disconnect

Motor starter control circuit disconnect is another approach to out–of–phase reconnection of motors that uses the same well established approach of allowing residual motor voltage to decay to a safe level. Where a number of different

Motor Starter Disconnect (cont'd)

types of loads are connected to a transfer switch, one of which is a large motor, a motor starter disconnect function permits safe transfer of the motor between energized sources without extending the brief power interruption to the other loads during contact transfer, as would be the case with Programmed Transition.

Instead of introducing a deliberate delay between breaking and making operations of the transfer switch phase pole contacts, the disconnect feature signals the motor contactor to drop out before transfer operation takes place. The disconnect provides a Form–C contact that is field wired into the contactor holding coil circuit of the motor controller. Following a time delay, the disconnect restores the Form–C contact to permit the motor controller to reset. For these applications, the motor controller must reset automatically. A simplified diagram of the motor load disconnect circuit is shown in **Figure 24**.

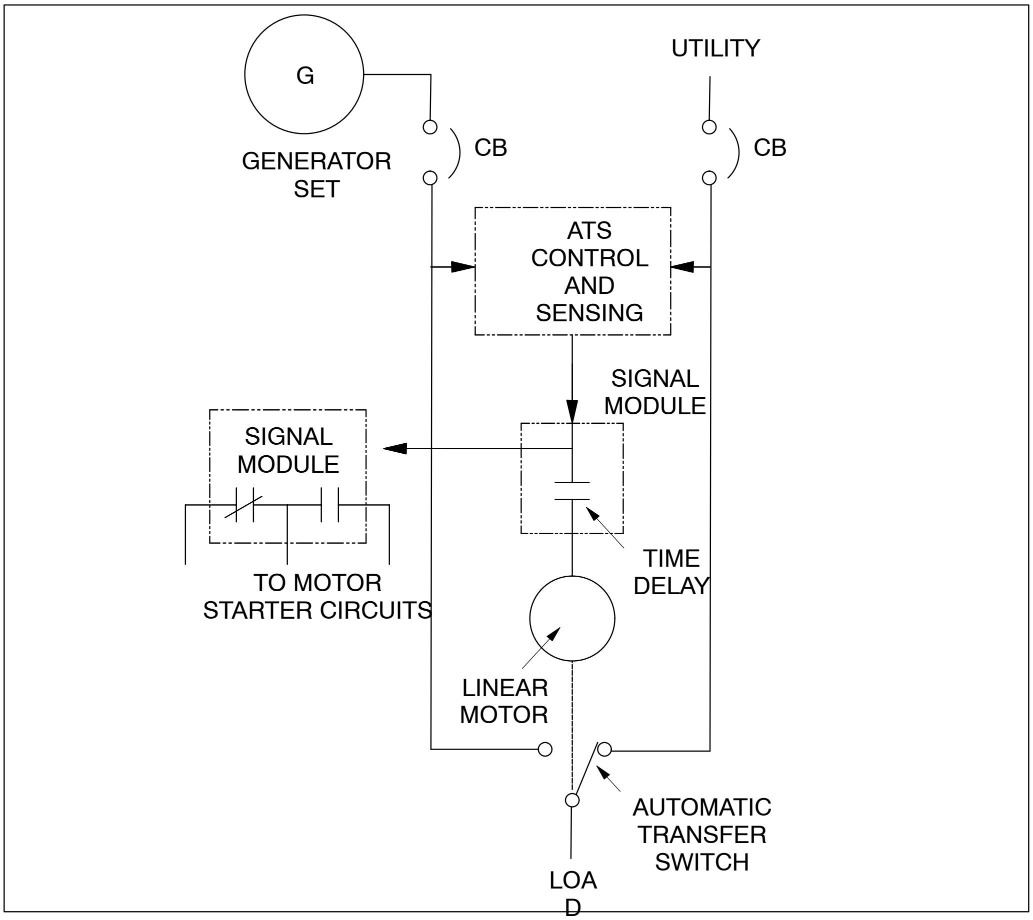


Figure 24. Motor Load Disconnect Circuit.

In–phase Monitor

Another approach uses an in–phase monitor that senses the relative phase angle between the two power sources. When the relative phase angle difference between the two sources is less than approximately 20° and approaching zero, the transfer switch contact mechanism is actuated. The in–phase monitor anticipates the change in phase angle that will occur during the time required for the contact mechanism to transfer. Because residual voltage will remain high, the switching operation from source to source must be fast, generally 6 cycles or

In–phase Monitor (cont'd)

less, before the relative phase angle of the residual motor voltage can move out–of–phase by more than about 20 electrical degrees at the instant of reconnection to a power source. The rate of change in frequency of the residual voltage is a complex function of several factors, including the shaft load, the residual voltages generated by other motors on the same bus, and capacitive or resistive loads that also may be on the same bus. Thus the relative phase angle between the residual AC voltage of a disconnected motor and an oncoming power source is constantly changing. Because of the complexity and number of variables involved in using fast transfer schemes and the possibility of cumulative motor or driven load damage, NEMA MG1–20.85 recommends a comprehensive study on a case by case basis before applying any fast transfer or reclosing approach.

The in–phase monitor approach has practical limitations, being suited principally for low–slip motors with high inertia constant loading. An in–phase monitor is not be recommended for:

1) transfer of multiple motors, such as a motor control center,
2) lightly loaded transformers,
3) UPS and other SCR–controlled equipment, and
4) equipment requiring a minimum OFF time, such as small computers operating directly on power source power(not on UPS).

Closed Transition Switch

Closed transition switches are effective in eliminating out–of–phase motor load transfer since the motor is not disconnected from a power source during transfer. However, load transfer can cause objectionable disturbances to the oncoming power source if the load being transferred is large enough compared to the capacity of the source. This is more likely when transferring to a generator source. A generator is relatively high impedance source and it takes a finite amount of time for the engine fuel system to respond to load changes. In order to limit the voltage and frequency disturbance to load tolerable levels, it is necessary to limit the load change to less than approximately 25% of the generator rating or include controls in the closed transition switch to slowly ramp the load onto the generator.

Solid State Switch

Solid state switches are effective in minimizing out–of–phase motor load transfer since the motor is disconnected from a power source for such a short duration (less than ¼ cycle). However, just like with closed transition switching, load transfer can cause objectionable disturbances to the oncoming power source if the load being transferred is large enough compared to the capacity of the source. This is more likely when transferring to a generator source. A generator is relatively high impedance source and it takes a finite amount of time for the engine fuel system to respond to load changes. In order to limit the voltage and frequency disturbance to load tolerable levels, it is necessary to limit the load change to less than approximately 25% of the generator rating.

Solid State Loads (UPS and VFD)

Uninterruptible power supplies and variable frequency drives that use silicon controlled rectifiers (SCRs) may malfunction or be damaged if transferred rapidly to an out–of–phase source. Generally, it is desirable to introduce a delay when transferring these types of loads to, effectively allow the load controls to “reset” by experiencing a loss of input power. Other equipment requires either UPS backup or a minimum off time during a power transfer to allow an orderly shutdown, such as retail bar–code equipment and electronic boiler controls.

System Grounding and Switched Neutral

Cummins transfer switch equipment is available with either a solid neutral terminal block, or a switched neutral pole. Determination of which type to use will depend on the way the facility distribution system is grounded and whether ground fault protection is used.

Grounding Methods

Service–Supplied Neutral Single Ground Point – The solid neutral connection terminal block is used most commonly in on–site generator systems. These systems are not considered separately derived systems, because the normal source neutral and the generator source neutral are solidly interconnected. [1999 NEC Article 250–20 (d) (FPN No. 1): ”An alternate alternating current power source such as an on–site generator is not a separately derived system if the neutral is solidly interconnected to a service–supplied system neutral.”]

In the system shown in **Figure 25**, the neutral conductor is grounded at the service equipment. Ground fault protection for equipment (GFP) may be added to the normal service equipment. The only path for ground fault current is on the grounding conductor outside of the GFP sensors. The generator neutral is not bonded to ground, because to do so would create multiple ground fault current paths; one of which would be through the sensor, the other outside the sensor. With multiple paths the ground fault current would split according to the impedance of each path, as shown in **Figure 26**. The ground fault current sensed by the GFP will be the difference between the actual ground fault current and that part of the ground fault current returning through the sensor on the neutral. As a result of the multiple neutral–to–ground connections, the GFP equipment will be rendered ineffective.

Grounding Methods (cont'd)

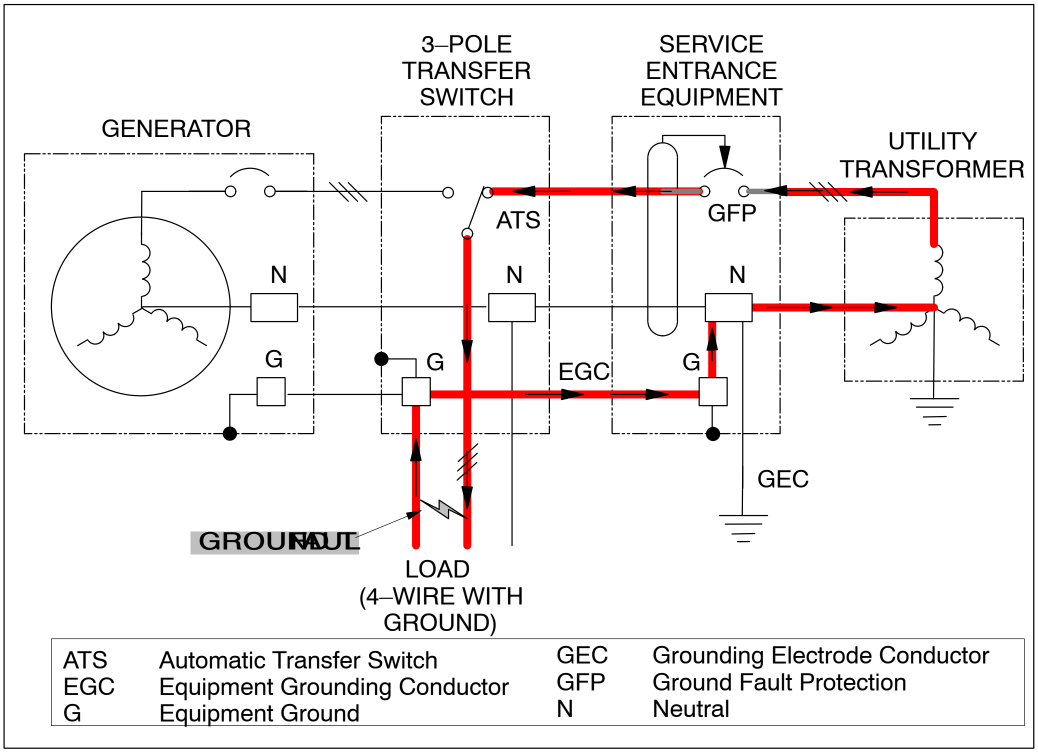


Figure 25. Single System Ground at Utility Service Entrance.

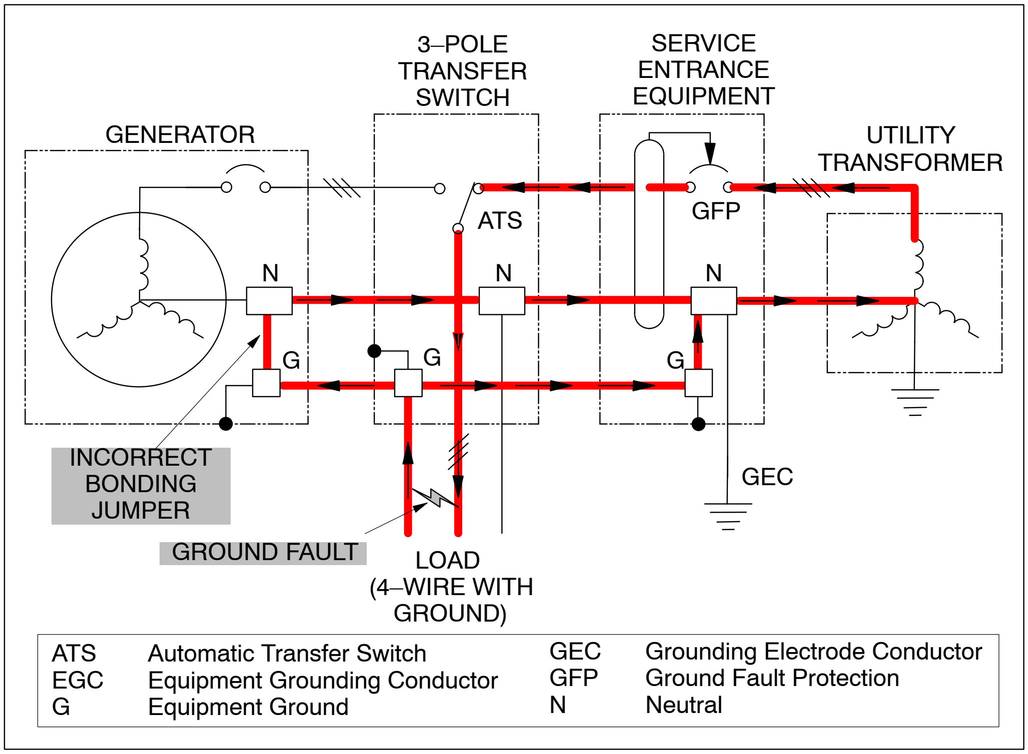
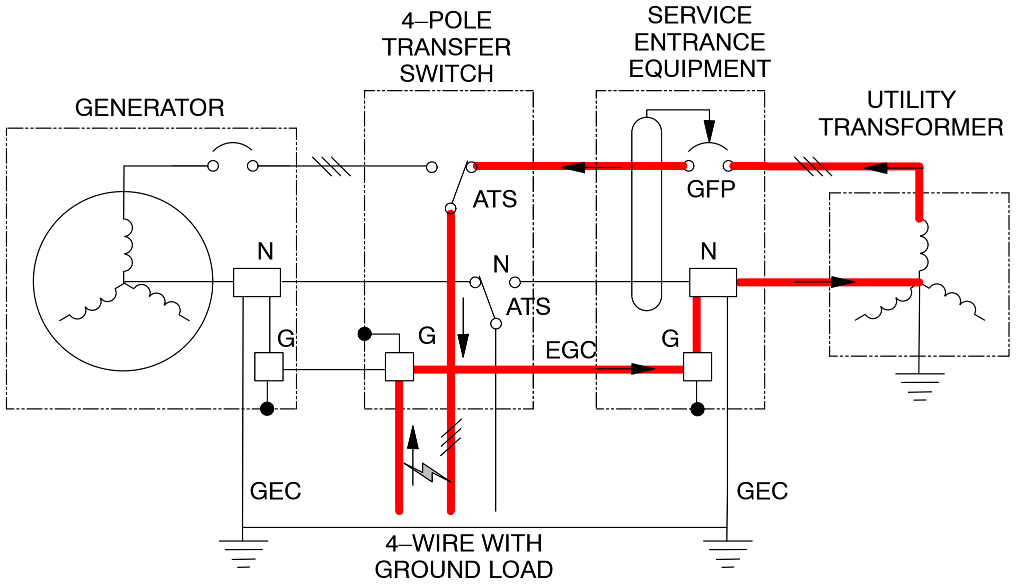


Figure 26. Multiple System Grounds (Neutral to Ground Bond Improperly Installed).

Grounding Methods (cont'd)



ATS	Automatic Transfer Switch	GEC	Grounding Electrode Conductor
EGC	Equipment Grounding Conductor	GFP	Ground Fault Protection
G	Equipment Ground	N	Neutral

Figure 27. Separately Derived Generator with a Switched Neutral Transfer Switch.

Separately Derived Generator – A switched neutral pole as shown in **Figure 27** is used in applications where it is necessary for accurate sensing of ground fault current. When used, the on–site generator set is a separately derived system. Where the transfer equipment includes a switched neutral pole and the generator is a separately derived system, its neutral must be bonded to an effective ground. For simplicity and reliability, the switched neutral pole in Cummins transfer equipment is driven by the same actuator shaft that drives the phase poles, so that the neutral pole is switched simultaneously with the phase poles in a break–before–make action.

Following are cases where it is necessary to use a switched neutral.

Case 1. Ground Fault Indication on Generator. If the emergency generator set is rated 277/480 wye, and the generator main circuit protective device is rated 1000 amperes or more, the NEC Article 700–7 (d) will require a ground fault indication on the generator main disconnect. The zero–sequence or residual ground fault sensing equipment requires the generator to be separately derived for proper operation. The visual indication of a ground fault may be located on the generator set control panel.

Ground fault protection (GFP) for equipment that would disconnect the generator main is not required on any capacity emergency generator. [Reference: NEC 700–26, 701–17]

Case 2. Parallel Paths for Neutral Current. If the normal service has GFP and additional levels of GFP are also provided for feeders, then switched neutral transfer equipment and a separately–derived and grounded generator are

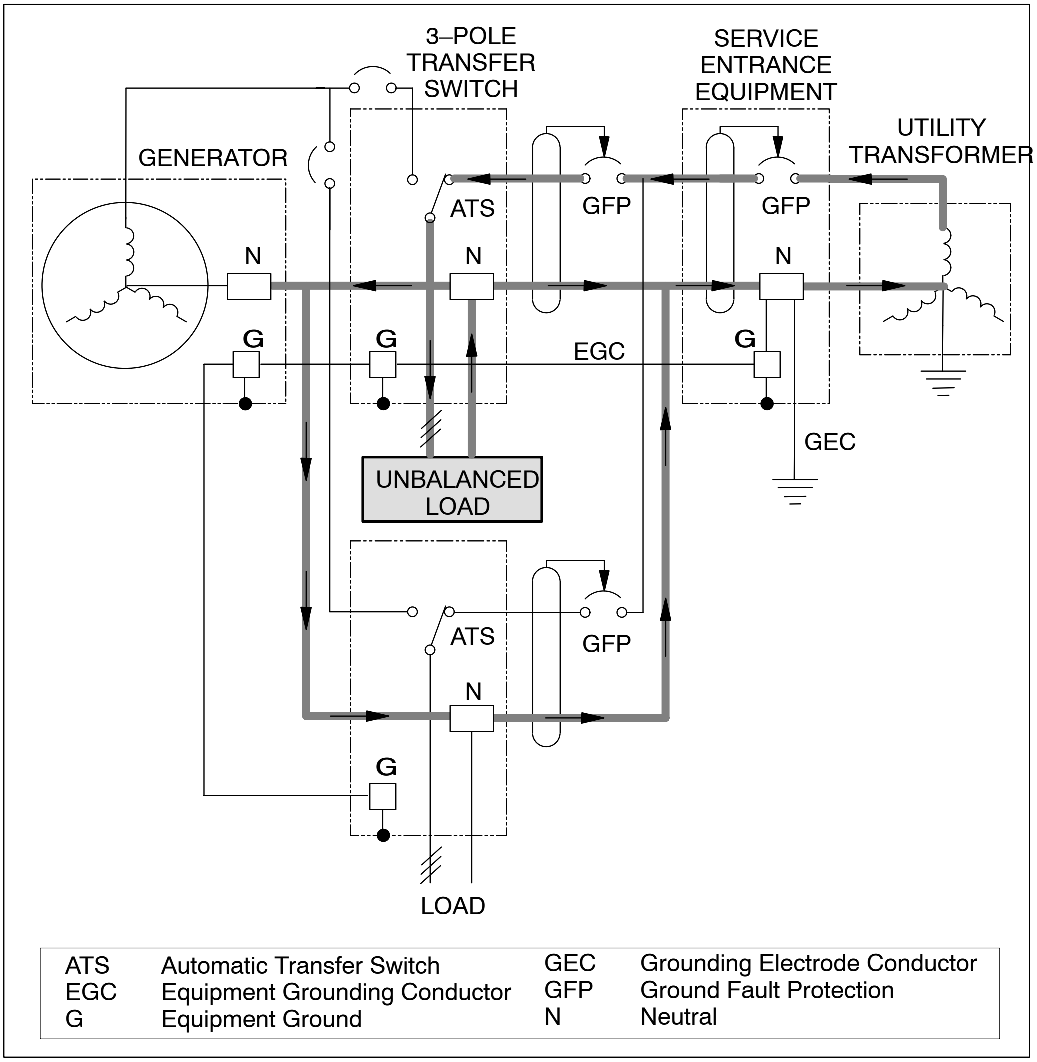
Grounding Methods (cont'd)

necessary so that the GFP system equipment will operate as intended. In **Figure 28**, the normal distribution has GFP on the service and on the feeders, and the neutral conductors are solidly interconnected in multiple transfer equipment. In this situation, parallel paths exist for neutral current. A part of the neutral current will find a return path on the generator neutral bypassing the feeder level GFP sensor. A nuisance trip of one or more feeder GFP may result. **Figure 29** shows correctly applied switched neutral switches to prevent the paralleled path.

Case 3. **Figure 30** shows an application that is becoming more common, one standby generator set serving two separate buildings. In this application switched neutral transfer equipment should be used to eliminate a parallel return path on the neutral for ground fault current. The generator set is a separately–derived source in this application. Note that the two utility service neutrals are tied together by the grounding conductor. While this creates a second grounding point for either neutral, the GFP sensors will work properly.

Figure 31 shows the same arrangement as **Figure 30**, except that transfer equipment with a switched neutral pole has replaced the solid neutral terminal block equipment. The alternate paths for ground fault and neutral current described above have been eliminated. Because there is no solid interconnection with the service–supplied neutral, the generator set is a separately–derived system and its neutral must be grounded.

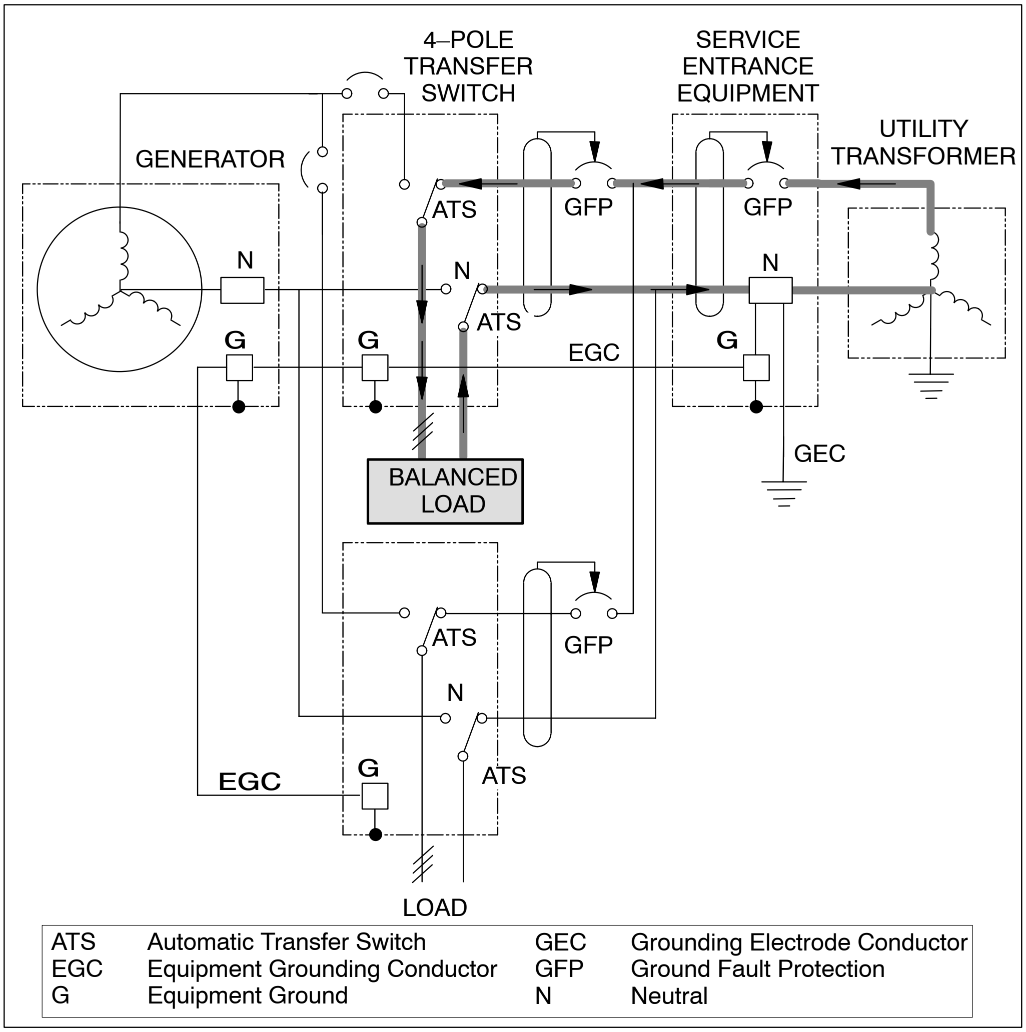
Grounding Methods (cont'd)



ATS	Automatic Transfer Switch	GEC	Grounding Electrode Conductor
EGC	Equipment Grounding Conductor	GFP	Ground Fault Protection
G	Equipment Ground	N	Neutral

Figure 28. Unbalanced Neutral Current.

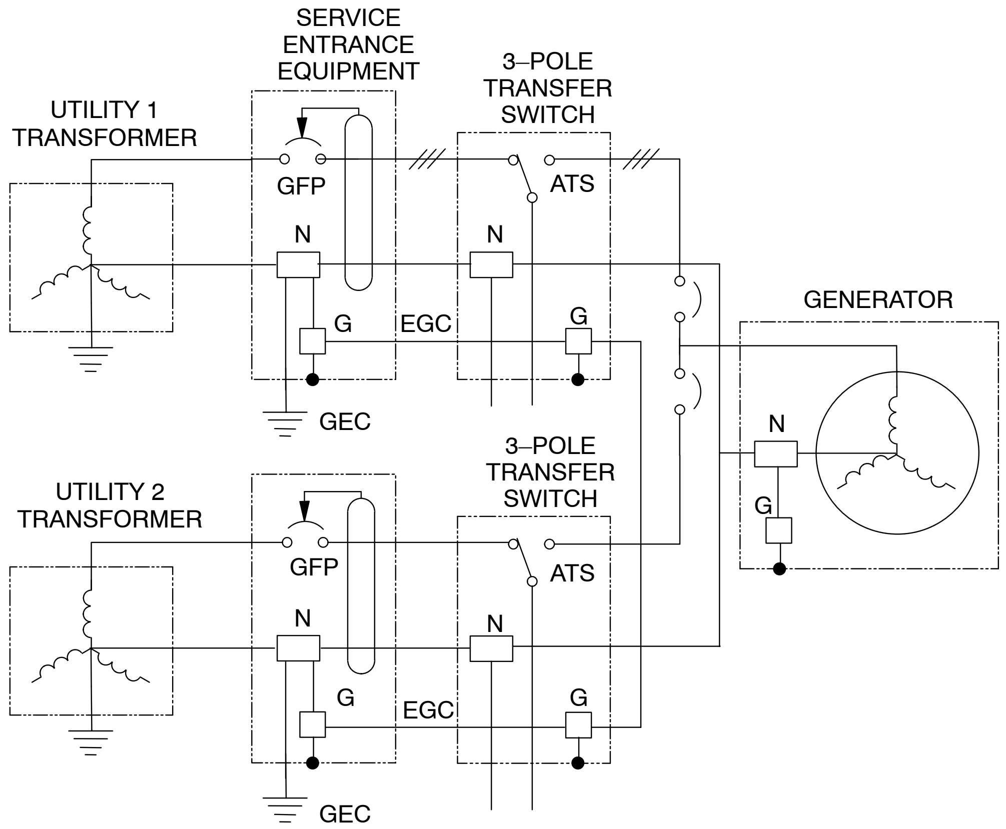
Grounding Methods (cont’d)



ATS	Automatic Transfer Switch	GEC	Grounding Electrode Conductor
EGC	Equipment Grounding Conductor	GFP	Ground Fault Protection
G	Equipment Ground	N	Neutral

Figure 29. Neutral Pole Switches Applied in Multiple level GFP Systems.

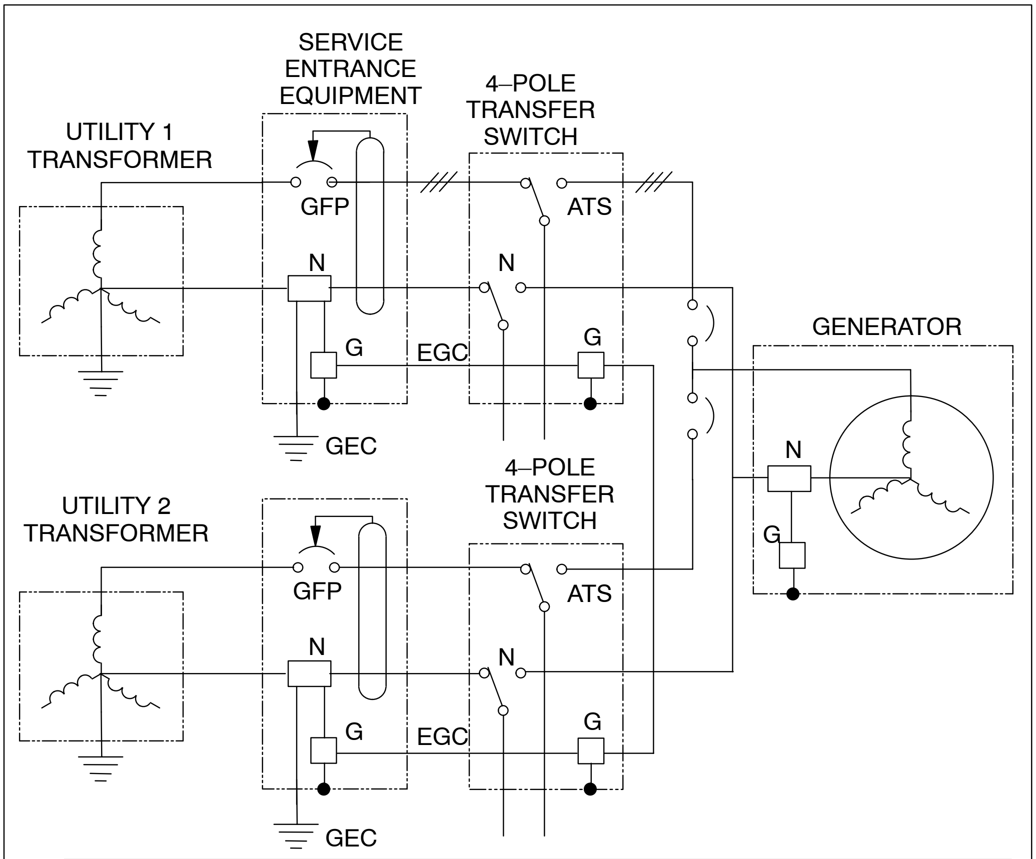
Grounding Methods (cont'd)



ATS	Automatic Transfer Switch	GEC	Grounding Electrode Conductor
EGC	Equipment Grounding Conductor	GFP	Ground Fault Protection
G	Equipment Ground	N	Neutral

Figure 30. One Separately Derived Generator Serves Two Buildings with Three Pole Switches.

Grounding Methods (cont'd)



ATS	Automatic Transfer Switch	GEC	Grounding Electrode Conductor
EGC	Equipment Grounding Conductor	GFP	Ground Fault Protection
G	Equipment Ground	N	Neutral

Figure 31. Single Separately Derived Generator Serving Two Buildings with Switched Neutral Switches.

In hospitals with an essential electrical system, NEC Article 517–17 requires two–level ground fault protection equipment for feeders when the service has been provided with GFP. Hospital essential electrical systems require a minimum of three transfer switches; and thus, hospital systems serve as an example of an application where switched neutral transfer equipment may be required.

Neutral Switching Methods

Simultaneously Switched Neutral – Two methods of switching the neutral are available commercially; simultaneous switching and overlapping switching. With simultaneous switching (available from Cummins), the neutral pole is mounted on a common crossbar with the phase poles, and thus is switched at the same time as the phase conductors in a break–before–make action. The grounded neutrals of the two power sources are not connected together, even momentarily.

Overlapping Neutral – With overlapping switching (not available from Cummins), the neutral pole is momentarily closed to the grounded neutrals of both power sources in a make–before–break action. A temporary solid neutral connection is created with multiple grounds similar to situations described earlier. Neutral current has, therefore, two paths of return to the source during the overlapping make–before–break switching action and a nuisance trip could result

Neutral Switching Methods (cont'd)

when no ground fault exists. As a result it may become necessary to increase GFP current settings or extend time delays to avoid nuisance tripping, which would reduce protection for single–phase ground faults. In low voltage bare busbar equipment, an unbalanced arcing single–phase ground fault may escalate into a balanced arcing multiphase fault within as little as 1 to 2 cycles. Once balanced the fault current will not be detectable by a GFP sensor. Therefore GFP used to protect bare busbar equipment should be set to initiate a trip instantaneously, or zone interlocking GFP systems should be used to be effective. Use of an overlapping neutral pole, which may require the GFP delay to be set anywhere from 6 cycles up to 24 cycles (100 to 400 milliseconds), would significantly reduce the protection afforded by the GFP. Use of an overlapping neutral is incompatible with zone interlocking GFP or other instantaneous ground fault relays.

Fire Pumps

In North America, transfer equipment feeding fire pumps must be specifically listed (in accordance to NEC and NFPA 20) for fire pump service. Each electric driven fire pump must have an alternate source of power and be connected by a dedicated transfer switch. The transfer switch must be located in the same room as the fire pump. The required transfer switch rating must be at least 115% of the pump motor full load current rating. In addition, if the Normal Utility source side of the transfer switch includes overcurrent protection (either integral or separate), the overcurrent device must be sized to hold fire pump motor locked rotor current (typically 600%) indefinitely. This may require the full load current rating of the switch to be higher in order to comply with the maximum allowable overcurrent device rating dictated by the transfer switch design. Other features incorporated in fire pump listed transfer switches include:

- Voltage and frequency sensing on all phases of the emergency source
- Provisions for an emergency source isolating means (either integral or separate)
- Phase sequence monitoring of the utility source
- Water tight enclosure

Health Care Facilities

Typical examples of both life safety and life support emergency power requirements are found in large health care facilities.

The acceptable duration for an interruption of normal power service to critical hospital loads is the subject of many state codes and regulations. National standards often referenced by the states and specifically addressing this issue are NFPA 99 and the NEC, Article 517.

NFPA 99 requires that all health care facilities maintain an alternate source of electrical power. With few exceptions, this source must be an on–site generator capable of servicing both essential major electrical equipment and emergency systems.

For hospitals, NFPA 99 provides the following criteria with respect to the emergency system: “Those functions of patient care, depending on lighting or appliances that are permitted to be connected to the Emergency System are divided into two mandatory branches; the Life Safety and the Critical. The branches of the Emergency System shall be installed and connected to the alternate power source…so that all functions specified…shall be automatically restored to operation within 10 seconds after interruption of the normal power.”

Health Care Facilities (cont'd)

To meet the "10 second criteria" the emergency system must include independent distribution circuits with automatic transfer to the alternate power source. Two–way bypass and isolation transfer switches are recommended for the emergency branches. The hospital emergency system installation must follow Articles 518 and 700 of the NEC.

The *life safety branch* of the emergency system, as described in NFPA 99–1996, includes illumination for means of egress and exit signs (ANSI/NFPA 101–1994 requirement), fire alarms and systems, alarms for nonflammable medical gas systems, hospital communication systems, and task illumination selected receptacles at the emergency generator set location.

NFPA 99 contains a complete listing of circuits to be connected to the critical branch feed areas and functions related to patient care. For most of these critical loads the "10 second criteria" is considered to be sufficient. However, an instantaneous restoration of minimal task lighting, using battery systems, is recommended in operating, delivery, and radiology rooms where the loss of lighting due to power failure might cause severe and immediate danger to a patient undergoing surgery or an invasive radiographic procedure.

Nonlinear Loads

Harmonic currents induced by nonlinear loads may require special consideration. Be sure to include the harmonics in load calculations to ensure adequate switch ampacity for both phase and neutral poles. With the predominance of nonlinear loads fully rated neutral poles are recommended. Check with the manufacturer to be sure the control source monitoring, especially voltage and frequency monitoring is not adversely affected by the harmonics. Voltage sensing should only respond to the RMS voltage and frequency detection should not be impaired by additional harmonics zero crossing.

Bypass Isolation

Bypass–Isolation automatic transfer switch equipment is configured with a manual bypass transfer switch in parallel with an automatic transfer switch. The parallel connections between the bypass switch and ATS are made with isolating contacts such that the automatic transfer switch can be drawn out for service and repair and power is fed to the load through the bypass switch. The bypass–Isolation automatic transfer equipment available from Cummins is the non–load break type, meaning there is no power interruption to the load when the equipment operates. Also available from other manufacturers is load break isolation–bypass equipment, which isolates the load from both power sources before bypassing the ATS. The bypass–isolation equipment available from Cummins is two–source bypass, meaning the bypass switch can be operated to either source (if power is available). Also available from other manufacturers is single–source bypass, meaning the bypass can be operated to only one source, typically the normal source.

In many installations, performing regular testing or detailed inspections on the emergency system is difficult because some or all of the loads connected to the system are vital to human life or are critical in the operation of continuous processes. De–energizing these loads for any length of time is also difficult. This situation often results in a lack of maintenance. For such installations, a means can be provided to bypass the critical loads directly to a reliable source of power without downtime of the loads. The transfer switch can then be isolated for safe inspection and maintenance.

Bypass Isolation (cont'd)

Two–way bypass isolation switches are available to meet this need. These switches perform three functions:

a) Shunt the service around the transfer switch without interrupting power to the load. When the bypass (BP) handle (upper handle) is moved to the bypass–to–normal (BP–NORM) position, the closed transfer switch contacts are shunted by the right–hand BP contacts. The flow of current then divides between the bypass and transfer contacts. This assures there will not be even a momentary interruption of power to the load should current no longer flow through the transfer switch, in which case the full current is immediately carried by the bypass contacts.
b) Allow the transfer switch to be electrically tested and operated without interrupting power to the load. With the isolation (IS) handle (lower handle) moved to the test position, the load terminals of the transfer switch are disconnected from the power source. The transfer switch is still energized from the normal and emergency sources and can be electrically tested without interrupting the load. The closed right–hand BP contacts carry the full load.
c) Electrically isolate the transfer switch form both sources of power and load conductors to permit inspections and maintenance of the transfer switch. With the isolation handle moved to the open position, the automatic transfer switch (ATS) is completely isolated. The load continues to be fed through the BP contact. With drawout capability, the transfer switch can now be completely removed without interrupting the load. In this mode, the bypass switch has a dual function. In addition to bypass, it also operates as a manual backup transfer switch.

Although the foregoing illustrates bypass to the normal source, the transfer switch can also by bypassed to the emergency source without interrupting power to the load, provided bypass is made to the source feeding the critical load. When bypassing to the emergency source, the same three functions can be performed after the transfer switch has transferred to emergency. While two–way bypass isolation switch arrangements have been available for many years, only recently has it become possible to combine a two–way, noninterruption bypass function with the automatic transfer function all in one interconnected assembly.

The bypass and isolation portions of the switch assembly should incorporate zero maintenance design. This design concept avoids system shutdown during maintenance or repair. To achieve zero maintenance design, bypass contacts should be in the power circuit only during the actual bypass period. The objection to retaining the bypass contacts in the circuit at all times is that they, along with the bus bars, are also subject to damage from fault currents. While the transfer switch is repairable without disruption of service, the bypass switch is not.

Providing a combination automatic transfer and bypass isolation switch in lieu of an automatic transfer switch more than doubles the cost.

Closed Transition

Closed transition transfer is used in many applications for many different purposes but the most common reason to apply them is to avoid any power interruption to the load while transferring the load between two available sources of power. Many different control schemes are also available and caution should be exercised when applying them to be sure design objectives are met safely. Following are several key considerations.

Utility Approval

Whenever closed transition is used, approval to parallel with the local electric utility must be obtained. Utility requirements vary widely, even at different geographic locations (electrical grid interconnect locations) within the same utility system. Even if “fast” or “hard” closed transition is anticipated (where the total interconnect time is limited to 100 msec), the utility may require added protective controls. The utility may be concerned over the potential for extended parallel operation in the event of transfer switch misoperation. Protection requirements will usually be limited to utility system protection to guard against things like islanding. Additional protective functions for the generator may also be desirable.

Synchronizing Controls

Both passive and active synchronizing controls are used to permit connection of the generator to the utility. Passive controls operate in a very similar fashion to a transfer switch in–phase monitor control. These controls simply monitor the source conditions and only permit parallel operation when the generator and utility are synchronized within a certain phase angle and frequency acceptance window. This type of control requires very reliable fast contact switching (5 cycles) and tight phase angle (less than 15 degrees) and frequency difference (less than 0.5 Hz) windows.

Active synchronizing controls look for synchronism of the two sources but include control of the generator set engine governor to force the generator to synchronize with the utility. These controls also require reliable fast contact switching (5 cycles) and tight phase angle (less than 15 degrees) and frequency difference (less than 0.5 Hz) windows. However, since the switch is controlling the governor, the controls can be adjusted to limit gain, controlling the rate of change of frequency of the generator during synchronizing. This minimizes the possibility of connecting the generator to the utility in an out–of–phase condition.

Load Disturbances

Closed transition switching is often applied to not only eliminate power interruption to the load during transfer, but to make the transfer transparent. That is, limit any voltage or frequency disturbance to an undetectable level. This may be difficult to accomplish with 100 msec transfer, particularly when transferring a load from a utility to a generator source. An engine driven generator requires considerably longer to adjust excitation and governing levels to the changing load, particularly on larger generators. Generally, this requires a “soft” transfer device. This type closed transition control includes an adjustable paralleling time, up to several seconds (even minutes) and governor controls that slowly ramp the load onto the generator prior to disconnecting from the utility. Active synchronizing combined with load ramping allows seamless load transfer between sources.

Optional Utility Paralleling Controls

When paralleling an engine driven generator to a utility source, strong consideration should be given to including additional controls and protective functions, regardless of the duration of utility parallel operation (even if only 100 msec). Considerable damage to the generator can occur if either excitation is lost or the engine runs out of fuel. Loss of Excitation and Reverse Power protection are recommended. VAR/Power Factor control is recommended to prevent interchange of VARS at point of interconnection when the utility voltage varies from the generator setpoint (such as may happen with utility load changes and during power factor correction).

Extended Parallel Operation

A very common application for closed transition switches is where extended utility paralleling is used for utility interruptible, peak shaving, cogeneration or other

Extended Parallel Operation (cont'd)

utility demand side opportunities. These switches will need to include import/export controls to control power flow at the point of interconnection. These applications will frequently involve higher capacity generators, often at higher voltages. Consideration should be given to including additional generator protective functions including generator differential, phase and ground overcurrent (possibly directional), phase sequence, loss of phase. The utility may require islanding protection, usually satisfied by including over/under frequency and over/under voltage protection.

Interrupting Capability

Including any of the protective controls referenced above requires a device be included somewhere in the system that provides the means to interrupt up to fault level currents at the connected voltage. It is desirable to include this functionality as part of the closed transition switch rather than rely on control interconnections to some external device furnished by another supplier. This requires the closed transition switch be a circuit breaker type switch.

Service Entrance

Service entrance rated transfer switches are generally circuit breaker type switches. The circuit breakers not only provide the transfer function but are inherently protected against utility available fault current and provide integral protection for load feeder conductors. These switches also include provisions for system grounding and optional ground fault protection as required. Just a reminder to consider the implications of interconnecting the transfer function at this point in the distribution system as discussed in section 2. Although this may be an acceptable arrangement for fairly simple systems with minimal branch circuits, it may not offer the power reliability desired in more complex distribution systems.

Short Circuit Protection

Available Fault Current

In order to apply transfer switch equipment correctly within its short circuit or withstand and closing rating (WCR), it is first necessary to determine the maximum available fault current from each source at the switch location. Any potential contribution from load sources (motors) must also be considered. Typically a utility source will have higher available short circuit current, but generator sources, particularly multiple generators, must also be considered. If the transfer switch equipment is capable of closed transition operation, where both sources are paralleled even momentarily, the WCR of the transfer equipment must be equal to or greater than the sum of available short circuit current from both sources and any potential load sources. If the maximum available fault current calculated at the line terminals of the upstream overcurrent device is less than the WCR of the transfer switch equipment, proper application is assured since the additional cable impedance can only further reduce the available current at the transfer switch equipment. If the WCR of the transfer switch is equal to or greater than the interrupting rating of a properly applied upstream overcurrent device, the transfer switch equipment is properly protected. Alternatively, the available short circuit current at the transfer switch terminals may be calculated using the cable impedance. If the available fault current at the transfer switch terminals is equal to or less than the WCR, the transfer switch equipment is properly protected.

Short Circuit X/R Ratio

It is also necessary to determine the X/R ratio at the point of application of the transfer switch equipment. The X/R ratio at the transfer switch equipment loca-

Short Circuit X/R Ratio (cont'd)

tion should not exceed the X/R ratio of the test circuit used in determining the switch WCR. **Table 2** lists standard WCR ratings and the corresponding testing X/R ratio. Underwriter's Laboratories also uses these X/R ratios for testing current limiting fuses and molded case circuit breakers, so if the overcurrent devices are properly applied within rating, coordination with the transfer switch equipment WCR is automatic.

Withstand and Closing Current Rating (RMS symmetrical Amperes	Maximum Test Power Factor	Minimum Corresponding X/R Ration
5,000	0.5	1.73
7,500	0.5	1.73
10,000	0.5	1.73
14,000	0.30	3.18
18,000	0.30	3.18
22,000	0.20	4.90
25,000	0.20	4.90
30,000	0.20	4.90
35,000	0.20	4.90
42,000	0.20	4.90
50,000	0.20	4.90
65,000	0.20	4.90
100,000	0.20	4.90
125,000	0.20	4.90
150,000	0.20	4.90
200,000	0.20	4.90

Table 2. Standard Withstand and Closing Ratings and X/R Ratios.

ANSI/UL 1008 presents specific test requirements to ensure the withstand capabilities of switches. Included are methods and types of overcurrent device application, available short–circuit currents required, and allowable damage criteria while still remaining operable. Also, power factor requirements of the test circuit are given. Manufacturers should be consulted to determine the method of testing applied to transfer switches. Determining whether a fuse or circuit breaker (and what size and type) was used, and determining the X/R ratio of the test circuit are both important aids in judging whether or not the switch is suitable for its intended application. Current limiting fuses or current limiting circuit breakers, for example, would considerably limit the duration of short–circuit current compared to the application of ordinary circuit breakers. Normally, symmetrical rms amperes should be used when coordinating time–current characteristics of switches and protective devices.

It is the X/R ratio of a circuit that determines the maximum available peak current and thus the maximum magnetic stresses that can occur. As the X/R ratio in-

Short Circuit X/R Ratio (cont'd)

creases, both the fault withstand ability of the switch and the capability of an overcurrent protective device must also increase. In many instances a circuit breaker symmetrical current interrupting rating or a transfer switch withstand rating must be reduced if applied at an X/R ratio greater than what the device safely withstood at test. Optionally, higher continuous current rated switches may be required to achieve the necessary withstand capability at higher X/R ratios.

Magnitude and Duration of Short Circuit Current

Of the many areas of concern for protection of components that make up an emergency or standby power system, one needing special consideration is that of magnitude and duration of short–circuit current available from the emergency or standby power source. Fault conditions have a direct impact on the availability of the power supply to serve its intended purpose. Studies should be made to determine available short–circuit current throughout the system supplied by an emergency or standby power supply, especially at switching and current interrupting devices.

In evaluating the performance of an emergency or standby generator under fault conditions, a critical concern is whether sufficient fault current is available for sufficient duration to selectively trip overcurrent devices in a properly coordinated system. In most cases emergency or standby power sources do not produce as much fault current as the normal source. When both sources are designed to supply a distribution system, through automatic or manual switching devices, the magnitude of the fault current available from the normal supply usually determines the required interrupting or withstand rating of the system components. Careful planning is necessary to design a system that assures optimum selectivity and coordination with both power sources. An emergency or standby generator's available short–circuit current should be compared to the ratings of system overcurrent devices to determine how this coordination is to be achieved. Normally the emergency or standby power source should be connected into the power system so as to be physically and electrically as close to the loads as practical. This will minimize the number and size of distribution system circuit breakers involved and the number of coordination levels required.

Proper operation of transfer switches are a vital part of the proper operation of the system making careful application of the switches extremely important, maybe more so than other branch–circuit devices. The design, normal duty, and fault–current ratings of the switch play an important part in its application and protection scheme. It must be capable of closing into high inrush currents, of withstanding fault currents, and of severe duty cycle in switching normal–rated load. All are important capability characteristics and thus important to protection, but emphasis in this chapter will be mainly on fault withstand ability. The coordination of overcurrent protection devices with transfer switch ratings, under fault conditions, is one of the most important aspects of maintaining the integrity and reliability necessary in the operation of a standby or emergency power system.

The destructive effects of high fault currents consist mainly of two components: (1) magnetic stresses that attempt to pry open the switch contacts and bend bus bars, and (2) heat energy developed that can melt, deform, or otherwise damage the switch. Either or both of these components can cause switch failure.

A fault involving high short–circuit currents usually causes a substantial voltage drop that will be sensed by the voltage sensing relays in the automatic transfer

Magnitude and Duration of Short Circuit Current (cont'd)

switch. It is imperative for protection that the switch contacts remain closed until protective devices can clear the fault. Separation of contacts, prior to protective device operation, can develop enough arcing and heat to damage the switch. Normally employed time delay to prevent immediate transfer of mechanically held mechanisms and contact structures specifically designed with high contact pressure, in some cases utilizing electromagnetic forces to increase contact pressure, combine to provide the reliability and protection necessary in automatic transfer switch operation. It follows that proper application of the switch within its withstand rating is important to prevent contacts from welding together and to prevent any other circuit path joints and connections from overheating or deforming, thus prolonging the life and increasing reliability of the switch.

Additionally, ANSI/UL 1008 establishes withstand ratings for transfer switches using either integrally designed overcurrent protection or external overcurrent protective devices. In the case where circuit breakers are integrally incorporated into the design, it should be noted that the transfer switch contacts will not remain closed for the duration of a short circuit, but instead will interrupt the current. Thus the withstand rating can be considered the same as the interrupt rating. This interchange of the terms interrupting and withstand can lead to confusion, especially when transfer switches of the integral circuit breaker type with the trip units removed are used with external overcurrent protective devices. Caution is advised when evaluating the withstand rating for this case, since eliminating the trip unit can reduce the interrupting rating and therefore the withstand rating by as much as 2 or 3 times.

Line Side Protective Devices

Fault–current magnitude and time of duration determine the heat energy and thermal stress developed during a fault, and this energy is normally designated as I^2t. In addition to current magnitude withstand ratings, automatic transfer switches have I^2t ratings that, if exceeded, can damage or possible even destroy a switch.

Available I^2t at a switch will vary with the magnitude of fault current and the clearing time of the overcurrent device protecting the switch. Thus, to know the available I^2t, the type of overcurrent protective device must be known since different protective devices allow different magnitudes of fault–current let–through and have different clearing times. Clearing time of a fuse will differ from that of a circuit breaker, and each will differ among different specific types. Current–limiting fuses introduce an additional parameter to be considered, called peak let–through current. When applying current–limiting fuses, the time factor reduces to a fraction of a cycle.

ANSI/UL 1008 permits an automatic transfer switch to be tested without an overcurrent protective device so long as the time of the test is at least as long as the opening time of a specified protective device at a specified level of fault current. Although the switch under these conditions may be capable of withstanding several cycles of the specified fault current, it might not be labeled as rated for this number of cycles. In actual applications, it is not uncommon for switches to be required to carry fault current for several cycles. If this is the case, the user is bound to assure that the available fault current does not cause the I^2t rating of the switch to be exceeded.

Circuit Breakers – Principals of coordination and selectivity between the breakers and devices to be protected in the distribution system follow those of most

Line Side Protective Devices (cont'd)

typical systems (assuming adequate fault–current availability). Reliability of power to critical loads will depend on selective breaker tripping. Two areas of concern regarding breakers and automatic transfer switches are evident: protecting the switch according to its withstand rating and, at the same time, achieving proper selectivity for service reliability. Selectivity becomes more of a problem when transfer switching and overcurrent protection are combined as an integral unit. The integral protective device fault clearing characteristics must be known to allow coordination with external overcurrent devices.

In most instances, available fault current from an emergency or standby generator will be substantially less than that of the normal source. When this is the case, the emergency or standby source should be located as close as possible to the critical load from a distribution standpoint to minimize the number of coordination levels and breaker sizes. As previously stated, proper selectivity in breaker operation is no different from that in most distribution systems.

When applying circuit breakers for protection, the transfer switch I^2t rating must correlate with the maximum clearing time of the breaker protecting it even with instantaneous tripping. For instance, it is possible for a transfer switch to have a withstand rating of 100 000 symmetrical amperes when used with a specific current–limiting fuse, but may only have a withstand rating of 30 000 symmetrical amperes when used with a specific circuit breaker with an instantaneous trip. The same reasoning applies for breakers with different fault–clearing times, especially considering time–delayed trips versus instantaneous trips. ANSI C37.19–1988 recognizes this by requiring reduced short–circuit interrupting ratings of circuit breakers for a short–time delay applications. For example, a 225 A frame low–voltage power circuit breaker, with an instantaneous trip unit, has a 22 000 symmetrical amperes interrupting rating at 480 V. The same breaker without an instantaneous trip has a reduced rating of 14 000 symmetrical amperes at 480 V.

It is often difficult to predict future expansion with the present emphasis on cost–effective systems. It is especially difficult to justify added capital expenditures for speculated load growth. A situation not so unusual is for available short–circuit current to eventually exceed breaker and transfer switch interrupting and withstand ratings when the normal supply transformer bank is increased in rating to accommodate unexpected load growth. A solution is to add current–limiting fuses in line with the existing breakers in accord with UL series ratings to protect the equipment whose rating has been exceeded. The fuses should be applied in accordance with recommendations from the circuit breaker manufacturers. This offers an economical compromise of limiting short–circuit current and I^2t let through and still maintaining some operating flexibility. However, coordination can be compromised. An alternative solution is to apply current–limiting reactors whereby overcurrent device coordination can be maintained, providing X/R ratios do not become excessive.

Fuses – First cost may favor fuses over circuit breakers. Another advantage is that fuses can safely interrupt higher short circuit currents than breakers and with faster clearing times. A disadvantage is the requirement to replace fuses after fault clearing. Breakers offer an advantage where loads include three–phase motors, since their operation will not create a single–phase condition.

Line Side Protective Devices (cont'd)

When fuses are used, peak let–through current and I^2t energy let–through should be coordinated with the same characteristics of the transfer switch to be protected. These characteristics vary among fuse manufacturers and types of fuses and, therefore, the manufacturer should be consulted for each particular fuse considered. Additionally, transfer switches may be rated for operation in series with a specific fuse for which they were tested. If another class of fuse with the same ampere rating and interrupting rating is substituted, the transfer switch could possibly fail under fault conditions if the substitute fuse permits a higher peak current and I^2t energy let–through. The same reasoning applies when comparing a current–limiting fuse to a circuit breaker equipped with an instantaneous trip with a clearing time as fast as 1–1/2 cycles. The circuit breaker will permit a higher peak current and I^2t energy let–through than the current–limiting fuse, which can clear in a fraction of a cycle.

Surge Withstand Capability

In addition to current–carrying capabilities, automatic transfer switches must be able to withstand voltage surges to satisfy their reliability requirements. Control devices in an automatic transfer switch initiate the operation of transfer or retransfer and thus heavily affect the reliability of the switch. However, these control devices do not have the physical size and dielectric space inherent in the main load current–carrying parts of the switch. For this reason, it is important that high–quality products suitable for emergency equipment use are employed in the switch.

ANSI/UL 1008 requires dielectric voltage withstand tests of 1000 V plus twice–rated voltage. But the requirements are unclear as to what specific devices are to be tested and whether or not control devices are to be included. ANSI/UL 1008 requirements are intended mainly for safety, but to satisfy the reliability requirements of an emergency or standby power system, consideration should be given to additional surge protection depending on the exposure of the switch to voltage surges. Some considerations helpful in protecting the dielectric strength of an automatic switch are

- Arc–breaking capability to minimize flashover between sources and deterioration of dielectric.
- Contact construction to minimize heat generated at high currents.
- Readily accessible contacts and components for easy visual inspection and replacement.

Some common causes of voltage transients in AC systems that might affect automatic transfer switches are switching inductive loads, energizing and de–energizing transformers, and lightning and commutation transients. In most cases, it is impossible to eliminate all the causes of transients, and thus the transients themselves, so the next step is to assume they will occur and then take measures to protect sensitive equipment. It is recommended that transfer switches meet impulse withstand voltage test requirements as designated in ANSI/NEMA ICS 1 and voltage surge withstand capability as designated in IEEE std C37.90. This is particularly important if solid–state voltage and frequency sensing is used.

IEEE Std 141 provides an in–depth analysis of causes and effects of carious kinds of overvoltages.