



Automatic or Manual?

Fast or Delayed Transfer?

Bypass Isolation?

Solid State or Mechanical?

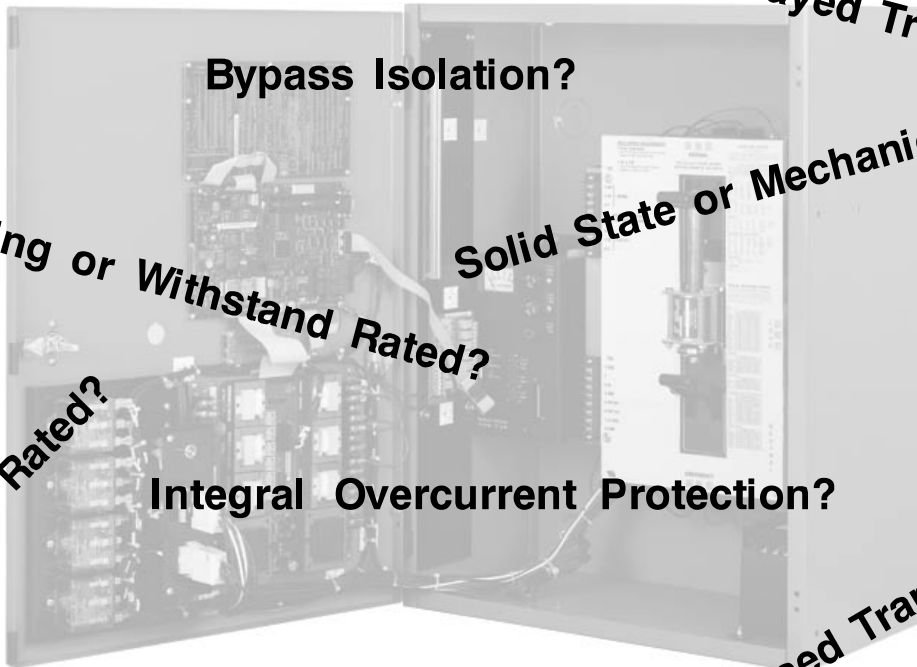
Interrupting or Withstand Rated?

Fire Pump Rated?

Integral Overcurrent Protection?

3 or 4 Pole?

Open or Closed Transition?



Rev a to b summary.

- Automatic Control Modes section, Generator Set to Generator Set has been rewritten.
- Appendix B has been reformatted, with some additions.

Table of Contents

Warranty	i
Introduction	1
Definitions	1
Transfer Equipment Purpose	4
Related Codes and Standards	4
Electrical System Design	5
Power Reliability	5
Electrical Interconnection Location	5
Load Power Interruption	13
Load Sensitivity	14
Electrical Code Requirements	16
Equipment Type	18
Automatic	18
Nonautomatic	19
Open Transition	19
Closed Transition	20
Bypass Isolation	20
Equipment Ratings	21
Continuous Current	21
Voltage	22
Switching Duty	22
Phase	22
Short Circuit	23
Transfer Equipment Switching Means	26
Mechanical Switches	26
Contactor Type	26
Circuit Breaker Type	26
Definite Purpose Type	27
Solid State	28
Alternative Arrangements and Configurations	30
Bypass Isolation	30
Closed Transition	31
Automatic Mains Failure	32
Transfer Equipment Controls	33
Control Types	33
Manual Transfer Switches	33
Nonautomatic Transfer Switches	33
Automatic Transfer Switches	33
Automatic Control Modes	34
Utility to Generator	34
Generator to Generator	35
Utility to Utility	36
Source Monitoring	37
Undervoltage	37
Overvoltage	39

Over/Under Frequency	40
Loss of Phase	41
Voltage Unbalance	41
Phase Rotation	42
Time Delays	42
Start	42
Stop	42
Transfer	42
Retransfer	43
Exercise and Test	43
Operator Interface	43
Indicator Lamps	43
Test Switch	43
Retransfer Override Switch	44
Not-In-Automatic Indication	44
Metering	44
Security Key	44
Fault Monitoring	44
Communication	44
Closed Transition Transfer Control	44
Application Considerations	45
Inductive Loads	45
Programmed Transition (Delayed Neutral)	47
Motor Starter Disconnect	48
In-phase Monitor	49
Closed Transition Switch	50
Solid State Switch	50
Solid State Loads (UPS and VFD)	50
System Grounding and Switched Neutral	51
Grounding Methods	51
Neutral Switching Methods	58
Fire Pumps	59
Health Care Facilities	59
Nonlinear Loads	60
Bypass Isolation	60
Closed Transition	61
Utility Approval	62
Synchronizing Controls	62
Load Disturbances	62
Optional Utility Paralleling Controls	62
Extended Parallel Operation	62
Interrupting Capability	63
Service Entrance	63
Short Circuit Protection	63
Available Fault Current	63
Short Circuit X/R Ratio	63
Magnitude and Duration of Short Circuit Current	65
Line Side Protective Devices	66
Surge Withstand Capability	68
Manual Operation	69

Installation Considerations	70
Physical Location	70
Enclosures	70
Inspection, Testing and Maintenance	72
Weekly Inspection	72
Monthly Testing	72
Annual Maintenance and Testing	72
Annual Maintenance	72
Annual Testing	73
Thermography	73
Appendix A	74
Bibliography	74
Appendix B	75
Alternative Power Generation System Arrangements	75
Basic Standby	75
Redundant Standby	76
Dual Standby Operation	77
Automatic Priority Selection	78
Prime Power (Plant to Plant) Operation	79
Sequential Prime Power	80
Dual Utility With Standby Generator	81
Automatic Transfer Switch with Dual Remote Switches	82
Figure Number Index	83
Table Number Index	83
Word Index	84

Warranty

Warranty: This manual is published solely for information purposes and should not be considered all inclusive. If further information is required, consult Cummins Power Generation. Sale of product shown or described in this literature is subject to terms and conditions outlined in appropriate Cummins Power Generation selling policies or other contractual agreement between the parties. This literature is not intended to and does not enlarge or add to any such contract. The sole source governing the rights and remedies of any purchaser of this equipment is the contract between the purchaser and Cummins Power Generation.

NO WARRANTIES, EXPRESSED OR IMPLIED, INCLUDING WARRANTIES OF FITNESS FOR A PARTICULAR PURPOSE OR MERCHANTABILITY, OR WARRANTIES ARISING FROM COURSE OF DEALING OR USAGE OF TRADE, ARE MADE REGARDING THE INFORMATION, RECOMMENDATIONS AND DESCRIPTIONS CONTAINED HEREIN. Each customer is responsible for the design and functioning of its building systems. We cannot ensure that the specifications of Cummins Power Generation products are the proper and sufficient ones for your purposes. You must satisfy yourself on that point.

In no event will Cummins Power Generation be responsible to the purchaser or user in contract, in tort (including negligence), strict liability or otherwise for any special, indirect, incidental or consequential damage or loss whatsoever, including but not limited to damage or loss of use of equipment, plant or power system, cost of capital, loss of power, additional expenses in the use of existing power facilities, or claims against the purchaser or user by its customers resulting from the use of the information, recommendations and descriptions contained herein.

Introduction

This Manual is intended to provide guidance in the selection and application of transfer switch equipment in a variety of power generation situations. Transfer equipment is available in many configurations, all sharing the same basic function, that of providing a means to connect electrical loads to either of two independent power sources. Equipment is also available to connect loads to more than two sources but most of the discussion in this manual is directed to two source transfer. This equipment is used to increase the availability and reliability of power to serve the load equipment. In many cases, this equipment may be required by codes and standards, developed and enforced on a national and local level. Proper selection and application of this equipment is the ultimate responsibility of qualified facility designers and engineers.

NOTE: By publishing this reference manual, Cummins does not ensure anyone using the information it contains against any liability arising from that use. Users of the information in this manual should make independent investigation of the validity of that information for their particular use of any items referred to herein. The contents of this manual are subject to revision at any time.

Compliance with all applicable local codes and standards is the responsibility of other qualified professionals accountable for facility design and installation. In any installation where transfer equipment will be used to establish a parallel connection between facility on-site generation with the normal utility source, apply equipment designed for that purpose and approved by the utility.

Definitions

The following terms are pertinent to the design and application of transfer switch equipment and are used in this Manual. Where possible, definitions are extracted from sources that developed them with industry consensus such as IEEE, NEMA and NFPA.

Ampacity – The current, in amperes, that a conductor or equipment can carry continuously under the conditions of use without exceeding its temperature rating.

Approved – As used in this document, acceptable to the authority having jurisdiction for permitting equipment installation in a facility.

Arc chute – A structure affording a confined space or passageway, lined with arc resisting material, into or through which, an arc is directed to extinction.

Arcing contacts – The contacts of a switching device on which the arc is drawn after the main contacts have parted.

Automatic transfer switch – Self acting, operating by its own mechanism when actuated by some impersonal influence (such as a voltage sensor).

Branch circuit – The circuit between the final overcurrent device protecting the circuit and the load.

Bypass isolation switch – See switch, bypass isolation.

Definitions (cont'd)

Closed transition – In transfer equipment, a method of switching the load between sources without interrupting power to the load.

Closing rating – The RMS symmetrical current a transfer switch can safely close into and conduct during short circuit conditions.

Enclosure – A surrounding case or housing used to protect the contained conductor or equipment against external conditions and to prevent operating personnel from accidentally contacting live parts.

Equipment ground – A ground connection to noncurrent-carrying metal parts of a wiring installation or of electric equipment, or both.

Equipment grounding conductor – The conductor used to connect the noncurrent-carrying metal parts of equipment, raceways, and other enclosures to the service equipment, the service power source ground, or both.

Feeder circuit – All circuit conductors between the service equipment (or the generator switchboard) and the final branch circuit overcurrent device.

Ground – A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth or some conducting body that serves in place of the earth.

Ground fault protection – A system intended to provide protection of equipment from damaging ground faults by operating to cause a disconnecting means to open all ungrounded conductors of the faulted circuit.

Grounded conductor – A system or circuit conductor that is intentionally grounded.

Grounding conductor – A conductor used to connect equipment or the grounded circuit of a wiring system to a grounding electrode or electrodes.

In-phase monitor – A device that monitors the relative phase angle between the two power sources serving a transfer switch. This device is used with the controls of an automatic transfer switch as a permissive control to allow transfer between the two power sources only upon the condition of the two sources achieving a near synchronous condition.

Interrupting rating (capacity) – The highest current at rated voltage that a device can safely interrupt.

Isolating switch – See switch, isolating.

Listed – Equipment, materials or services included in a list published by an organization that is acceptable to an authority (inspector) having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that the equipment, material or services either meets appropriate designated standards or has been tested and found suitable for a specified purpose.

Neutral conductor – The conductor that is intended to be so energized, that, in the normal steady state, the voltages from every other conductor to the neutral conductor are definitely related and usually equal in amplitude.

Definitions (cont'd)

Neutral ground – An intentional ground applied to the neutral conductor or neutral point of a circuit, transformer, machine, apparatus, or system.

Nonautomatic switch – A switch that requires personal intervention for its control.

Nonlinear load – Any electrical load where, when a sinusoidal voltage is applied, a nonsinusoidal current results. Typically solid state type loads which, when connected to a sinusoidal power source, induce harmonic currents in the power system, causing voltage distortion of the power source and may cause current to flow in the neutral conductor.

Open transition – In transfer equipment, a method of switching the load between sources, where power to the load is intentionally interrupted during switching.

Overcurrent – Any current in excess of the rated current of equipment or the ampacity of a conductor.

Overlapping neutral pole – In a four-pole switch, the fourth or neutral pole that is switched in an overlapping fashion with the main phase poles. Commonly, the neutral pole is operated to close the neutral before opening phase poles and maintain the two source neutrals connected until after the phase poles have been switched.

Overload – Operation of equipment in excess of normal, full load rating, or of a conductor in excess of rated ampacity.

Pole – That portion of a device associated exclusively with one electrically separated conducting path (whether phase or neutral) of the main circuit of the device. If a switch has more than one pole, it may be called multi-pole (three-pole, four-pole, etc.) provided the poles are coupled in such a manner as to operate together.

Program(med) transition – A transfer switch control function that causes an intentional delay, during load transfer, in the open position. This function is normally used to allow voltage at the load terminals to decay prior to reconnecting the load to an energized source.

Separately derived system – A premises wiring system whose power is derived from a battery, from a solar voltaic system, or from a generator, transformer or converter windings, and that has no electrical connection, including a solidly connected grounded circuit conductor, to supply conductors originating in another system.

Service – The conductors and equipment for delivering electric energy from the serving utility to the wiring system of the premises served.

Service (rated) equipment – The necessary equipment usually consisting of a circuit breaker(s) or switch(es) and fuse(s) and accessories, connected to the load end of service conductors to a building or other structure, or an otherwise designated area, and intended to constitute the main control and cutoff of the supply. This includes ground fault protection where required.

Short circuit – An overcurrent resulting from a fault of negligible impedance between live conductors having a difference in potential under normal operating conditions.

Definitions (cont'd)

Switch, bypass isolation – A manually operated device used in conjunction with a transfer switch to provide a means of directly connecting load conductors to a power source and of disconnecting the transfer switch.

Switch, isolating – A switch intended for isolating an electric circuit from the source of power. It has no interrupting rating and is intended to be operated only after the circuit has been opened by some other means.

Switch, transfer – An automatic or nonautomatic device for transferring one or more load conductor connections from one power source to another.

Switched neutral pole – In a four pole switch, the fourth or neutral pole that is switched simultaneously with the main phase poles.

Transfer switch – See switch, transfer.

Withstand rating – The RMS symmetrical current a transfer switch can safely conduct during short circuit conditions.

Transfer Equipment Purpose

Although there are many variations of transfer equipment with different construction, operating modes, and controls, the basic purpose of this equipment, as discussed in this manual, is to provide a means to switch electrical loads between available power sources. This equipment is used to increase availability and reliability of power to the load equipment. This equipment can be manually or automatically operated, open or closed transition, include feeder and load overcurrent protection, employ mechanical or electronic switching means. This manual is intended to provide guidance for the application of this equipment in a variety of uses, where mandated by governing codes or desired for critical processes. Frequently, this equipment is used to transfer the load from the normal utility source to a back-up generator and is supplemented by either a rotary or static UPS to achieve uninterruptible power.

Related Codes and Standards

The following codes and standards are applicable to the design, application and installation of transfer equipment. This is intended for reference only and not intended to be all inclusive. Be sure to check with the local authorities having jurisdiction for the installation location.

IEC 947	NFPA 70
UL 1008	NFPA 110
CSA 282	NFPA 99
NEMA ICS10	CEC

Electrical System Design

Applying transfer equipment in electrical systems affects many design considerations. The basic function of a transfer switch is to enhance availability of power to critical electrical loads, providing a means to switch the load between two or more available sources of power. The switches can be either manually or automatically operated. In either case, the switches should be connected as near the load utilization equipment as practical, preferably downstream of any devices that may operate to disconnect power to the load (disconnects, breakers, fuses,). Many factors will dictate this including costs, circuit arrangements, physical space, load power requirements, load operating requirements, and many other factors.

Power Reliability

Electrical Interconnection Location

Although economic and physical layout considerations impact where transfer equipment is electrically connected in a facility, recommended practice is to install switches as near to the load as possible. The switch is then available to transfer the load to the alternate source for most abnormal conditions including, failure of the normal source, feeder failure, and circuit breaker and fuse operation. In general, more and smaller, dedicated switches, improve reliability of power to critical loads. In some applications (most notably health care), multiple, dedicated switches are required by code to achieve separation of circuits and increase power reliability. Multiple smaller transfer switches also provide a convenient means to step load the alternate source generator set and make it easier to achieve coordination of overcurrent devices, both on the line and load side of the switch.

Installation of transfer equipment nearer the normal utility source service may require several considerations involving:

- Type of applicable transfer equipment
- Service entrance rating
- Voltage
- Downstream overcurrent device coordination

All of these considerations are interrelated and may force the use of power frame low voltage breakers or medium voltage breakers. In larger facilities, the utility power is taken at distribution voltages above 600 VAC. If the switching takes place at these voltages, medium voltage equipment is required. This equipment is designed for high capacity and the continuous ratings may exceed that required by emergency loads because the equipment must be sized to carry full normal service capacity. It may be more economical to use distribution transformers and switch at lower voltage. Of course, if the loads are medium voltage, there is no choice but to switch at the higher voltage.

Electrical Interconnection Location (cont'd)

Higher available fault current is present at locations closer to the normal utility source. These available fault currents also may dictate the use of power frame breakers in order to achieve the necessary short circuit withstand capability. Low voltage transfer switches have short circuit ratings ranging from 10,000 amps to 100,000 amps depending on continuous rating when protected by low voltage breakers equipped with instantaneous trip units. These switches carry up to 200,000 amp ratings when protected by either current limiting fuses or current limiting breakers. Most of these low voltage transfer switches are required to be protected by fast acting overcurrent devices that contain no intentional time delays typically included with larger molded case and power frame breakers. These delays are necessary to achieve coordination with downstream protection, allowing the smaller downstream branch breakers to trip first, limiting the outage to the individual faulted branch.

Several figures below help to illustrate many of these points.

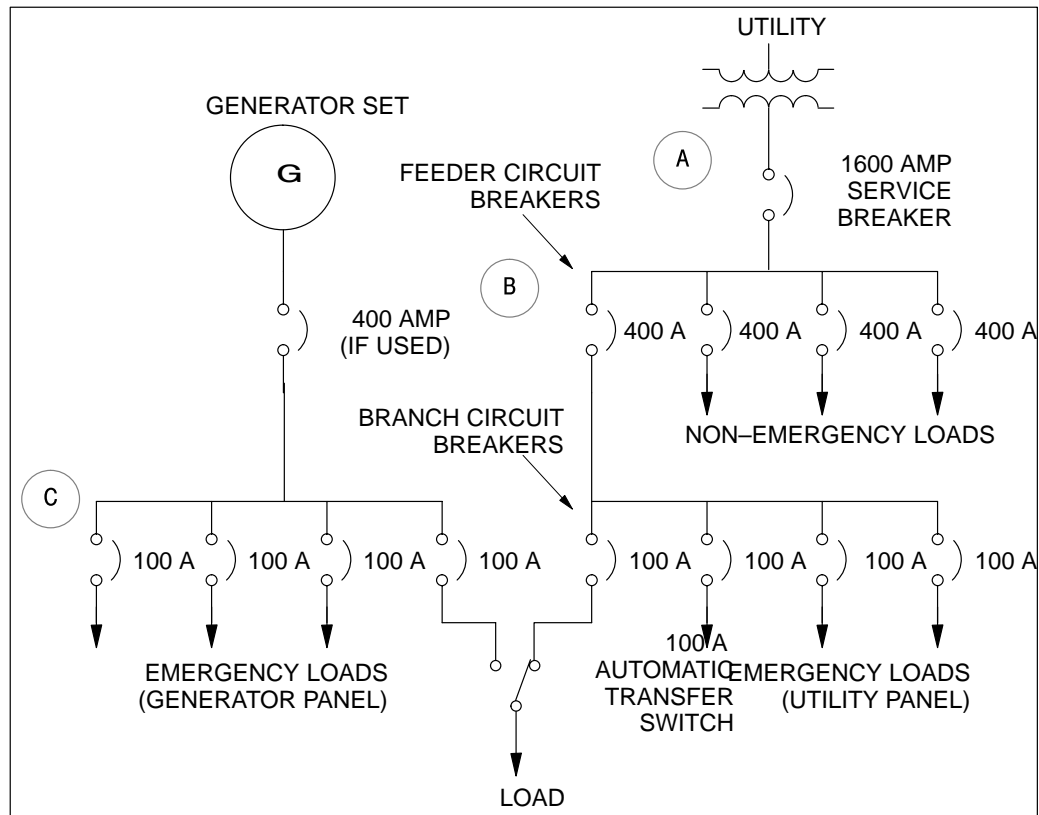


Figure 1. Transfer Switch Connected Near the Load.

Figure 1 illustrates a system where the transfer switch equipment is interconnected nearest the load utilization equipment. The loads can be selected or grouped as required by code or desired for the application. In this case, it is assumed that there are four unique 100 amp loads. These may be individual loads, like a 100 amp lighting panel, or multiple loads which may require additional load side circuit panels and conductor protection. The smallest single load will likely be no smaller than commonly available sized transfer switches, as small as 30 amps from Cummins. All of the emergency loads are served from either a utility

**Electrical
Interconnection
Location
(cont'd)**

or generator panel through a transfer switch. The incoming utility connects to the utility emergency panel and other facility loads (not required to be served by the generator). The generator connects to the generator emergency panel.

There are three levels of distribution between the utility service entrance and the load (A, B and C), involving application of three levels of circuit protection. The entire facility is served by 1600 amp service equipment using a 1600 amp power frame breaker. Four 400 amp circuits are fed from the utility service, one 400 amp emergency circuit and three 400 amp non-emergency circuits, each of which is protected by 400 amp power frame or molded case breakers. The 400 amp emergency circuit feeds a utility emergency panel containing four 100 amp emergency load molded case breakers that connect to the utility side of four 100 amp transfer switches. The generator is connected to a generator emergency panel at the third level of distribution ©, the panel containing four 100 amp molded case breakers feeding the emergency side of the four 100 amp transfer switches.

The transfer switch must be selected to supply the required load current at the desired load voltage. In addition, the transfer switch must be capable of withstanding the available fault current at the point of interconnection. In this example, the transfer switch shown is a type that does not include integral overcurrent protection. Available fault currents at the different levels range from 65,000 RMS symmetrical amps at the utility service entrance to 25,000 at level B and 10,000 at level C. The transfer switches are required to have line side external overcurrent protection which is provided by the 100 amp molded case breakers. These breakers are required to have instantaneous trips for short circuits in order to provide proper protection for this type of listed transfer switch.

Optimally, in a coordinated system, the system should be designed in such a way that when a fault occurs on the load side of a transfer switch, the fault is cleared by the first upstream breaker, C, and breakers at levels B and A remain closed. For this example, the breakers have trip characteristics shown in **Figure 2**.

Electrical Interconnection Location (cont'd)

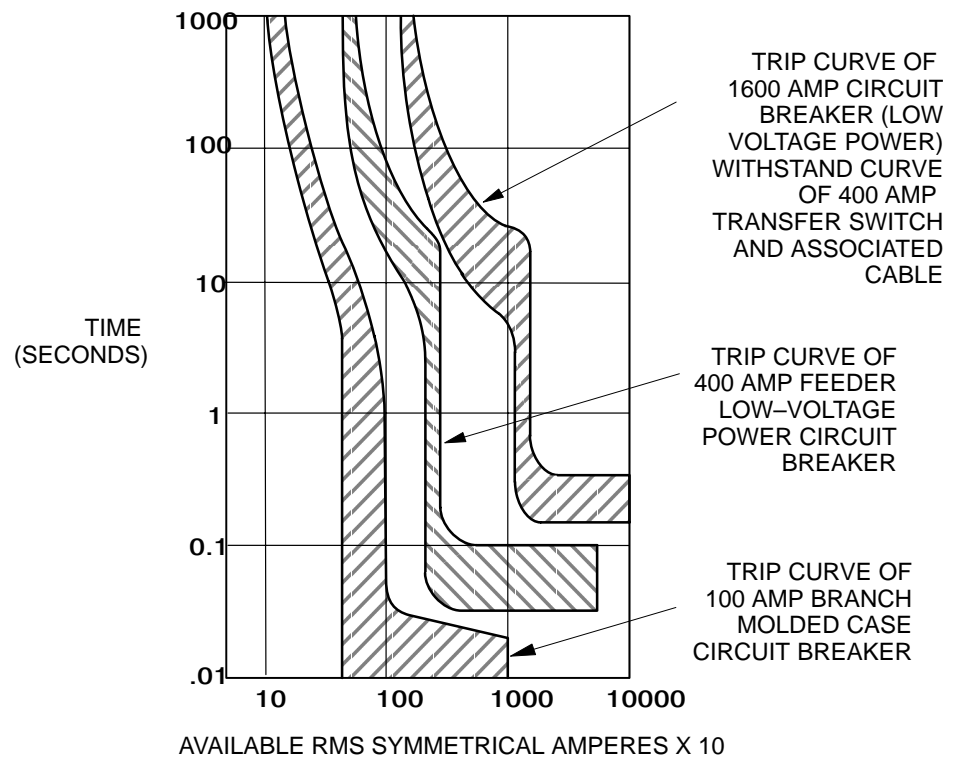


Figure 2. Selectively Coordinated Breakers.

The breakers at level C are molded case with instantaneous trips and have interrupting ratings suitable for the available fault current at that level (10,000 amps or greater). The breakers at levels A and B have no instantaneous trips. Rather, they include intentional time delays (short and long time) to prevent cascade tripping of the breakers at all levels. For any overcurrent condition up the the maximum available short circuit, only the breaker at level C of the faulted branch would trip, leaving all other circuits energized. If one of the emergency breakers is tripped (or, for that matter, merely opened by someone), an automatic transfer switch will detect power loss, signal the generator to start, and transfer the load when proper generator output power is detected. If the fault was temporary or the fault condition was cleared, power to the load will be restored. If the fault is still present (permanent), the generator side breaker will clear it, provided the generator supplies sufficient fault current. This is generally accomplished when the generator has sustained short circuit capability (separately excited PMG, for instance). Note that the generator may be equipped with a main output breaker. Care should be taken to be sure this breaker is coordinated with the branch breakers to avoid loss of power when all emergency loads are on generator and a fault occurs on one of the emergency load circuits. Optionally, generator controls are available that provide overcurrent protection for the generator that include intentional time delays to allow downstream breakers to trip. With these generators, the main output breaker is not required or recommended.

More often than not, the breakers at level B are also molded case with instantaneous trips, sacrificing some degree of coordination. This is shown in **Figure 3**. The degree of coordination achieved in this case is a function of the relative size

Electrical Interconnection Location (cont'd)

of the breakers at levels B and C, the breaker instantaneous trip settings and the fault current that can flow at each location. If the breakers sizes and settings are far enough apart, some degree of discrimination is achieved.

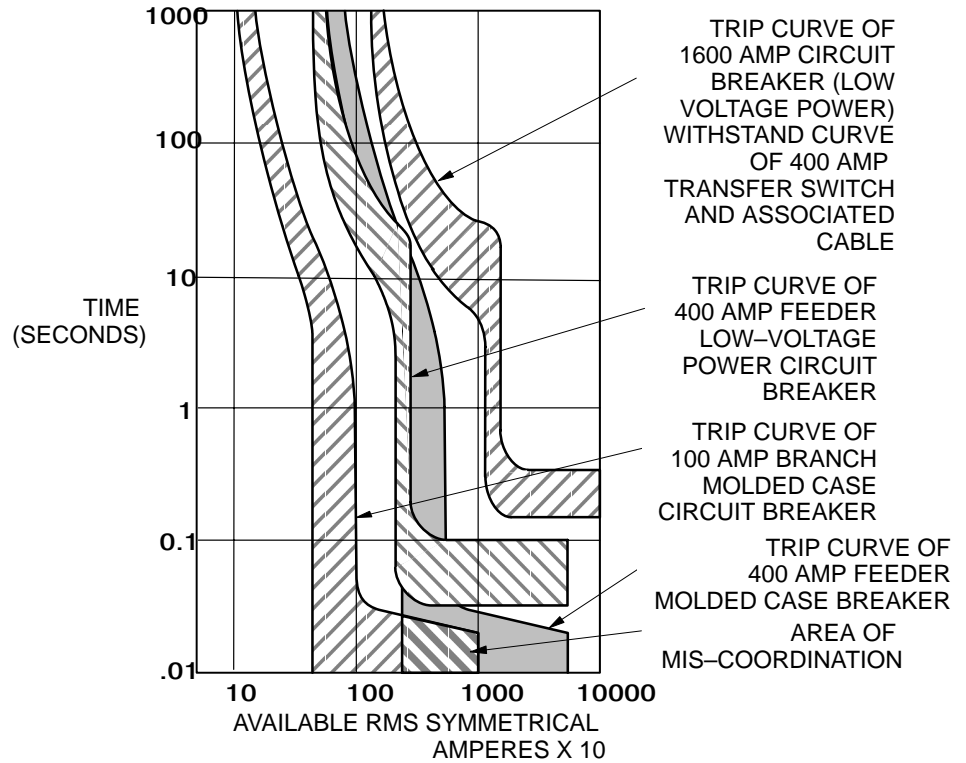


Figure 3. Mis-Coordinated Breakers.

In this example system, the next optional point of interconnection for the transfer switch is between level B and C as shown in **Figure 4**.

Electrical Interconnection Location (cont'd)

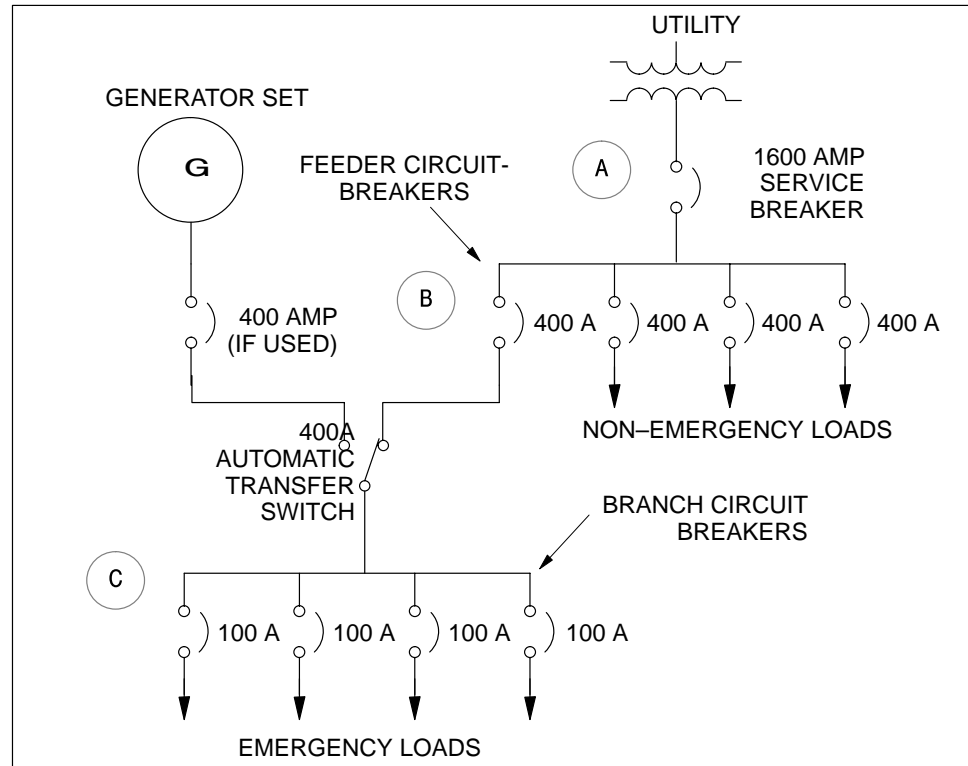


Figure 4. Transfer Switch Connected Ahead of Load Branch Breakers.

In this arrangement, a single larger 400 amp transfer switch is used to provide source sensing and load switching for all four 100 amp emergency load circuits. The transfer switch continuous current rating must be selected to satisfy the total connected load. This sacrifices some degree of power reliability to the emergency loads. For instance, if any one or more of the 100 amp branch breakers is turned off or trips due to overload, power is lost to those circuits, whether or not the disconnect is inadvertent. Another concern may be with lack of selective coordination between the circuit breakers at B and C. If faults on the load side of breakers at C cause a cascade operation of the breaker at B, and B breaker trips, there will be at least a momentary outage to all emergency circuits. Power will be lost until the power loss is detected, the generator is started and the switch transfers the remaining loads to the generator. It also goes without saying that if the switch malfunctions, power may be lost to all emergency load circuits.

The transfer switch must also have a fault withstand and closing rating suitable for use with the upstream overcurrent protection characteristics of devices at locations A and B especially when intentional delays are introduced to achieve coordination.

Finally, consider the arrangement shown in **Figure 5** where a single large transfer switch is installed at the service entrance level between A and B.

Electrical Interconnection Location (cont'd)

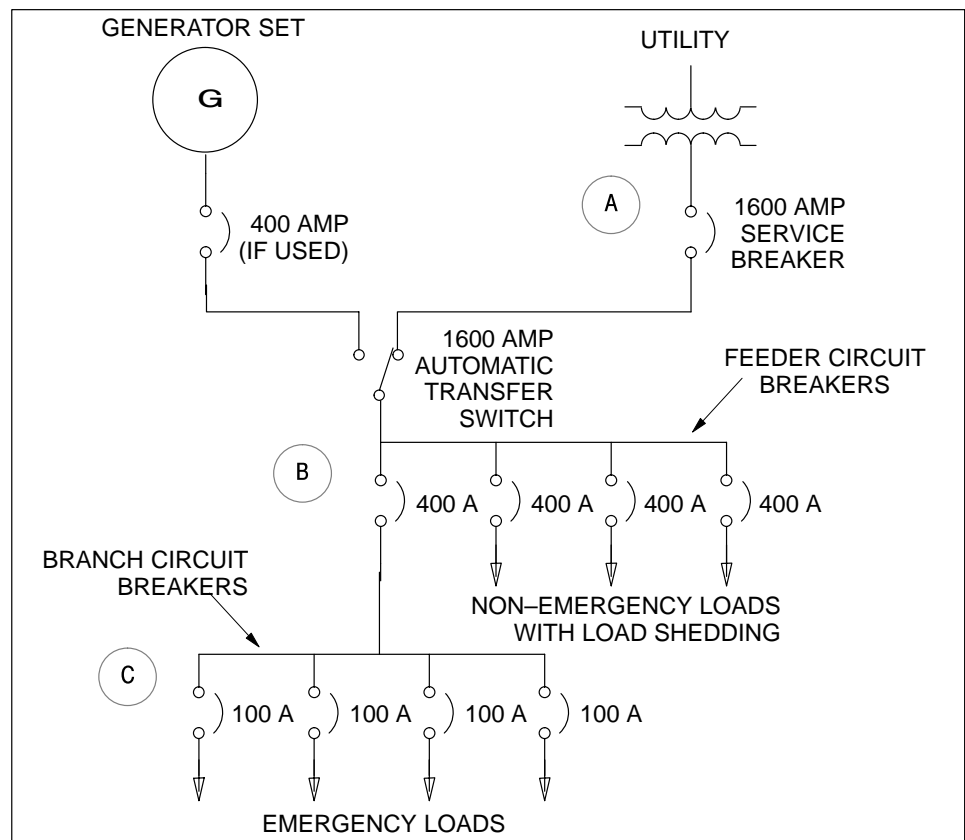


Figure 5. Transfer Switch Connected at Service Entrance.

In this arrangement, a single larger 1600 amp transfer switch is required. The switch must be sized not only for the connected emergency load of 400 amps, but for the normal utility load. Power reliability to the emergency loads suffers even more when the switch is located here. Operation of any of the transfer switch load side breakers results in loss of power to the connected loads and selective coordination becomes an even bigger concern. Unless the generator is also sized to handle all of the facility load, the non-emergency load circuits will need to include provisions for automatic load shedding if the operating load exceeds generator capacity. Some inspection authorities will not even allow this arrangement for some critical applications where life safety is paramount. If the generator is sized to handle all facility loads and only isolated loads remain in use following a utility outage, the generator may be left running too lightly loaded, damaging the engine.

In many applications, where the transfer switch is applied at the service entrance, service entrance rated switches are applied, commonly consisting of interlocked circuit breakers containing integral phase and ground fault overcurrent protection. Depending on the configuration of this type of equipment and the controls, it is possible that power is not restored to unfaulted circuits following a fault in only one.

Separation of Circuits – Certain critical applications, such as health care facilities or where electrically driven fire pumps serve the premises, require the emer-

Electrical Interconnection Location (cont'd)

gency loads to be separated from the non-emergency (non-essential) loads and served by dedicated transfer switches. In these applications, if the generator is going to be used to supply a mix of emergency and non-emergency loads, multiple switches will be required. Step loading is recommended for these applications, connecting the emergency loads first within any code mandated time limitations, typically within 10 seconds. Subsequent load steps should be limited to a capacity allowed by the generator capability to not disturb the connected emergency loads.

Step Loading – Generator sets are limited power sources, generally much lower capacity than the normal utility source serving critical loads. Abrupt transient load changes on the generator will likely result in larger voltage and frequency disturbances on the generator than on the utility source. When transferring load to the generator, either after a normal source failure or during system testing, the load steps must be controlled to limit the disturbance to levels that connected loads can tolerate. Although other building system controls may be used, this is easily accomplished by using multiple transfer switches using sequenced transfer time delays. A few seconds should be allowed between load steps to allow the generator voltage and frequency to stabilize. Some transfer switch controls have optional load sequencing provisions, typically a timed relay output module that can be used to connect designated loads to the load side of the transfer switch in an adjustable timed sequence following a transfer to either or both power sources.

Service Entrance – In some applications, such as a small pumping station, it is desirable or necessary to provide standby power to the entire facility. Although it is advisable to apply individual smaller transfer switches for multiple loads, particularly motor loads with high starting power requirements, it may be desirable to start all of the loads simultaneously. This requires careful consideration for both generator and switch sizing. If a single switch is available suitably sized for the entire connected load, it may be advisable to connect the switch at the service entrance, using a service entrance rated switch. This is particularly true for facilities that do not have an on-site, permanently installed generator which rely on a portable generator delivered to the facility during an outage.

Overcurrent Device Coordination – Connecting the transfer switch near the load equipment minimizes the number of overcurrent devices between the transfer switch and the load, perhaps even between the generator and the load. All transfer switch equipment that does not include integral overcurrent protection requires external upstream overcurrent protection of the switch. Most transfer switches are designed to be protected from short circuit by either molded case circuit breakers or current limiting fuses. They are not designed to withstand the high level, long duration short circuit currents allowed by circuit breakers incorporating intentional time delays that allow them to be coordinated with other downstream breakers. To some degree, this forces the transfer switch point of interconnection closer to the load in more complex installations.

Care should be taken to provide individual feeder branch circuit protection on the load side of transfer equipment feeding multiple loads. This is necessary to achieve coordination between the source and load breakers for load side faults. The system should be designed so that a fault in one load circuit will not cause interruption of the transfer switch line side breaker, removing power to all con-

**Electrical
Interconnection
Location
(cont'd)**

nected load. Even if this should occur, the transfer switch design should allow the switch to detect loss of power and transfer the remaining unfaulted load circuits to the generator. This may be difficult to achieve with transfer switches that incorporate integral overcurrent protection.

**Load Power
Interruption**

There are several possibilities for load power interruption. The interruption can be complete power loss or simply disturbances causing the power quality to be disruptive to the load. Most of the discussion will be around complete power loss or forced interruptions resulting from the operation of transfer equipment when transferring the load between power sources.

Utility Normal Source Power Disruptions – Utility power disruptions occur for a variety of reasons and last for varying durations. The usual concern is for complete interruptions of power but many different types of disturbances can be as disruptive or even damaging to load equipment. Transfer equipment is available to respond to many different power quality concerns including undervoltage, overvoltage, underfrequency, overfrequency, phase sequence, even overcurrent. Controls are even available to just disconnect certain loads from either power source until a suitable source is available. The transfer equipment can be very fast acting, particularly solid state devices, and may have practical application in utility to utility transfer schemes. However, note that transfers to a standby generator will require several seconds and may not be suitable for protecting the loads against some power quality conditions without the presence of some type of power conditioning device, even for very short duration disturbances.

Interruption of power to the load is always a concern, more so in critical life safety and many other applications where even short interruptions can be very costly. Even the short power interruption that can occur during the actual load transfer switching time (forced interruptions while switching between available power sources such as retransfer from generator to utility after an outage) can be disruptive and must be considered in power system design. For computer and other life safety and life support systems where it is impractical for load equipment manufacturers to incorporate ride through capability for short power interruptions, some type of power conditioning equipment may be required. This equipment is used to bridge the gap between load equipment susceptibilities and power–line disturbances. For overvoltages or electrical noise problems, isolation transformers or transient suppressors may be an effective deterrent when installed in the building power source. Required stored energy to ride–through low voltage and momentary interruptions may be obtained from a power buffering motor–generator set or, when the need for power continuity warrants, a UPS (battery system).

Transfer equipment is not designed to protect the load during these short disturbances of the normal supply. In fact, transfer switch equipment includes intentional delays to avoid starting the generator unless the disturbance exceeds several seconds, the kind of time interval required to start a generator and have it ready to load.

Forced Interruptions – All open transition type transfer equipment causes a forced interruption of power to the load when transferring the load between two available power sources. This condition would occur when transferring the loads on retransfer to the utility after a power failure or when transferring the load from utility to generator while testing the system. This interruption is typically 3 to 10

Load Power Interruption (cont'd)

cycles for mechanical switches (varies depending on size) and less than $\frac{1}{4}$ cycle for solid state switches. This can be disruptive to some loads, particularly on mechanical switches, where, the lights will certainly blink, if not extinguish and motor contactors can drop out in 10 cycles. This is an even greater issue when the transfer switch is equipped with controls that incorporate an intentional delay (from fractions of a second to several seconds) in the center off position to protect the load from damage or misoperation. This type of control is used to prevent large motors from being closed out of phase to the oncoming source or computer loads from losing data when not allowing an ordinary shut down. To minimize problems, these types of loads should be placed on separate transfer switches to allow fast transfer of other loads or place on an UPS if the load cannot tolerate the interruption.

A word of caution regarding the application of solid state switches. Although most loads will tolerate the short interruption, the load transfer may not be transparent. In fact, when transferring from a utility to a generator source, as the load being transferred approaches the capacity of the generator, significant voltage and frequency disturbances can result causing secondary load misoperation.

Some applications will require closed transition switching to minimize problems with forced interruption. However, these switches should be equipped with load ramping controls that limit the rate of load change when transferring from the utility to the generator to limit voltage and frequency disturbance. This requires longer duration utility parallel operation and all of the required protection.

Loss of Back-up Power Source – Whether the back-up power source is a utility or generator, loss of the back-up source will cause a power interruption if the load is not being supplied by a UPS or some other form of alternate power. Automatic transfer switch controls should detect this condition and transfer the load to the primary source as soon as it is available.

Load Sensitivity

Different loads have varying degrees of sensitivity to power source voltage and frequency disturbances, too numerous to cover in detail here. Although the utility is certainly prone to both voltage and frequency disturbances of the utility system, transferring load from a generator to the utility is not normally a major concern except in larger generator paralleling systems where installed capacity approaches rated utility capacity at the point of interconnection. These systems generally have complex load controls to limit these issues. The more common problems occur when transferring load to a generator. A generator will always produce a voltage and frequency disturbance on sudden application of load. These disturbances must be controlled by limiting the rate of load application on the generator to limit the disturbance to levels that don't impact the loads. Load equipment manufacturers specifications should be consulted to determine what the load can tolerate. Some typical considerations follow:

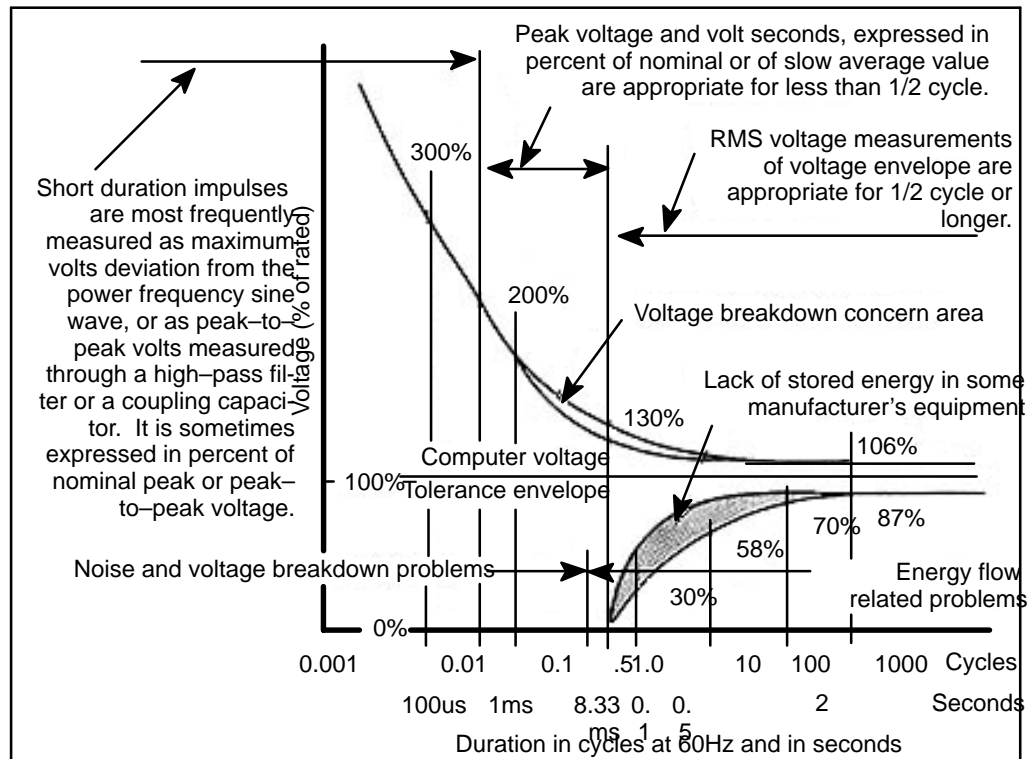
- **Lighting:** All types of lighting will dim and/or flicker with power below rated voltage and frequency. Of particular concern are the various forms of discharge lighting including florescent and HID. These lights will extinguish completely if the voltage falls below about 80% of rated for even a few cycles. HID lighting will require several seconds to restart after voltage returns to normal.
- **Motors:** Induction motors will run with voltage and frequency below rated provided adequate torque is available for the load. Speed may be reduced

Load Sensitivity (cont'd)

which could affect the load performance. Running at lower voltage will result in higher current which may cause overheating or overload shutdown. Transient voltage dips below about 65% of rated voltage may cause motor starting contactors to drop out, particularly if the voltage recovery time exceeds more than about 100 msec. Motor controls may also include protection against sustained over/under voltage and over/under frequency.

- **UPS:** UPS equipment can be susceptible to misoperation if power supply frequency changes at a rate greater than 1–2 Hz/sec. This rate of frequency change is referred to as slew rate. A static UPS typically is equipped with a solid state bypass switch to allow direct connection of the load to the source in the event of severe UPS overload or in internal failure. To accomplish this function, the UPS inverter output must remain synchronized with the UPS input power to allow the instantaneous switch to operate. Typically the UPS load cannot tolerate rapidly changing frequency so, if the source frequency is moving too fast, bypass must be disabled and alarmed until the frequency stabilizes. UPS equipment can also misoperate if the voltage distortion on the input becomes too high. This can occur if the UPS is inducing high levels of harmonic current on a generator source. One of the problems can be the presence of extra zero crossings in the input voltage waveform, zero crossings the UPS is monitoring to determine frequency and slew rate. Most UPS equipment is susceptible to damage if the input power is switched rapidly between unsynchronized sources.
- **VFD:** VFD equipment is subject to many of the same problems as motor and UPS loads during sustained operation off rated voltage and frequency and is equipped with automatic controls to protect the drive and the drive load. Most VFD equipment is susceptible to damage if the input power is switched rapidly between unsynchronized sources.
- **Computers:** Computer tolerance to off rated voltage conditions is shown in **Figure 6** (CBEMA Curve). Most computer disc drives are susceptible to damage if the frequency is out of specifications or changing rapidly. This is why most computers are placed on a UPS or have some other form of power conditioning. Most computers not protected by a UPS should not be switched rapidly between power sources. A computers require a definite off time to reset memory and preserve data. Data may be corrupted if a computer is switched open transition with no intentional off delay (such as programmed transition).

Load Sensitivity (cont'd)



The CBEMA Curve from FIPS No.94.

Figure 6. CBEMA Curve.

Electrical Code Requirements

Following is a discussion of many of the known electrical code requirements affecting product design, application of these switches and facility design and installation. Many of these code requirements are specific to North America where they are more prevalent and heavily enforced than in other parts of the world. Although many of these requirements are adopted uniformly by various inspection authorities, the local inspection authority (facility installation jurisdiction) must be satisfied and should be consulted if there are any questions or concerns.

Where Required – Transfer switch equipment is needed wherever loads are required to be switched between one or more available power sources. Where they are required and what sort of equipment meets the intent of the required equipment is usually defined by applicable local building codes or other ordinances. In North America, the NEC is the predominant reference for establishing what types of transfer switch are required or allowed in “Emergency” and “Legally Required Standby Systems”.

“Emergency” systems are those legally required and classed as emergency systems by municipal, state, federal or other codes, or by any governmental agency having jurisdiction. Emergency systems are intended to automatically supply illumination, power, or both, to designated areas and equipment in the event of failure of the normal supply intended to support, distribute, and control power and illumination essential for safety to human life.

Electrical Code Requirements (cont'd)

“Emergency” systems are generally installed in buildings likely to be occupied by large numbers of people where artificial illumination is required for safe exit and for panic control. These are generally buildings like hotels, sports complexes, health care facilities, and similar institutions. These systems commonly also supply ventilation, fire detection and alarm systems, elevators, fire pumps, public safety communication systems, industrial processes where interruption could cause life safety or health hazards.

All equipment in these Emergency systems must be approved for use in Emergency systems in the US. This typically means that transfer switches are listed and certified for use by some independent third party such as Underwriters Laboratories. The switches must be automatic, identified for emergency use and approved by the authority having jurisdiction. They must be electrically operated and mechanically held. The switches must also be dedicated to emergency loads (cannot simultaneously serve emergency and non-emergency loads). Fire pumps must also be served by dedicated transfer switches and approved for fire pump service. Typically, health care facilities are required to have separate switches serving emergency systems (critical and life safety branches) and equipment systems.

“Legally Required Standby Systems” are those legally required and classed as legally required standby systems by municipal, state, federal or other codes, or by any governmental agency having jurisdiction. These systems are intended to supply power to selected loads in the event of failure of the normal supply. The loads are typically heating and refrigeration systems, communications systems, ventilation and smoke removal systems, sewage disposal, lighting systems, and industrial processes that, when stopped, could create hazards or hamper rescue or fire fighting operations.

Transfer switch equipment may also be used for optional loads, those not specifically mandated by code to be on the emergency/standby system. Typically, optional loads must be served by their own transfer switch and are not allowed to be transferred to the generator if an overload would result.

Location – Typically transfer switch equipment can be located most anywhere in a facility, even outside the facility. However, the location should be chosen to minimize potential damage due to acts of nature (lightning, flooding, etc.), vandalism or fire. The normal and emergency electrical circuits should be kept separated to prevent damage in one circuit from damaging the other circuit conductors, with these circuits only coming into close proximity in the switch enclosure. Fire pump transfer switches are required to be located in the same room as the fire pump and must be enclosed in a water resistant enclosure.

Equipment Type



Figure 7. Typical Enclosed Automatic Transfer Switch.

Automatic

Figure 7. Automatic transfer switches include controls that continuously monitor the condition of both sources, comparing the quality of the two sources to the set-points for conditions including any or all of the following: voltage, frequency, phase rotation, phase loss. If any of the sensed conditions fall out of specifications within the time set for any intentional time delays, transfer is initiated to the alternate source if the alternate source conditions are within proper operating conditions. Thus, transfer is automatic and unaided by an operator. This type of transfer switch provides for the most reliable power and is imperative for unattended operation.



Figure 8. Enclosure Interior of Automatic Transfer Switch.

Figure 8 and Figure 9. Many automatic switches also include provisions for manual transfer. Some switches limit the manual transfer to no load and require

Automatic (cont'd)

the load be disconnected (or the transfer switch to be isolated) prior to load transfer. Some switches even require the switch be disconnected from all power sources for manual transfer operation.

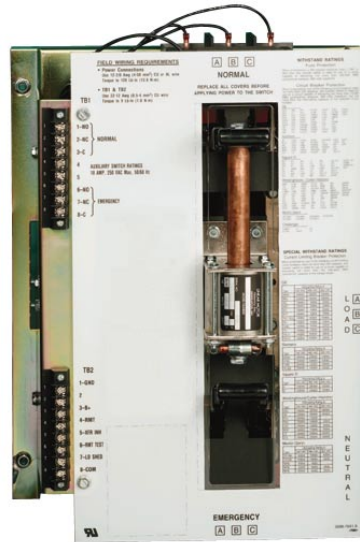


Figure 9. Power Switching Device in an Automatic Transfer Switch.

Nonautomatic

Nonautomatic switches must be actuated manually by an operator and are intended for applications where operators are present. They are also commonly applied to facilities that are not required to be on line by code in very short time periods and where the facility operation does not pose immediate life safety or health hazards upon loss of power. These are often applied in facilities that do not include a permanently installed generator, but rather, at facilities where a mobile generator is dispatched during extended utility outages.

These switches are available with either electric or manual operators. Electrically operated switches generally have operator pushbuttons mounted on the switch enclosure. However, the operator pushbutton controls can be located remotely such as in a facility monitoring station, convenient to personnel responsible for facility operations. Switches with manual operating handles require personnel to go to wherever the switch is located to transfer loads. Some manually operable switches may not be designed with load break capability. These require transfer at no load after the loads are disconnected by other means. To achieve full load manual operating capability, the switch must employ a fast acting switching mechanism that is spring loaded and operates at speeds independent of how fast the operator moves the manual operating handle.

Open Transition

Transfer switch equipment may be either open transition or closed transition. Open transition equipment transfers the connected load between power sources with a momentary interruption in power, when both sources are available, as the switch contacts open from one source and close to the other source. This momentary power interruption is called Contact Transfer Time; and without intentional delay during transition, has a duration of 6 cycles or less depending on the size of the equipment. A mechanical interlock is provided to prevent interconnection of the two power sources.

Closed Transition



Figure 10. Typical Closed Transition Transfer Switch.

Figure 10. With both sources available, closed transition transfer equipment parallels the power sources either momentarily or for an adjustable duration sufficient to ramp load onto and off of the generator set. Closed transition transfer equipment can either actively synchronize both power sources before paralleling them, or passively check for synchronism before allowing paralleling. Closed transition equipment operates in open transition when one of the sources has failed, and closed transition when both sources are present. Closed transition operation prevents the momentary interruption in power when both sources are present, such as exercise, test, and retransfer. Closed transition transfer equipment does not substitute for an uninterruptible power supply where one is required by the load equipment.

Bypass Isolation



Figure 11. Typical Bypass/Isolation Transfer Switch.

Figure 11. Bypass–Isolation automatic transfer switch equipment is configured with a manual bypass transfer switch in parallel with an automatic transfer switch.

Bypass Isolation (cont'd)

The parallel connections between the bypass switch and the transfer switch are made with isolating contacts such that the automatic transfer switch can be drawn out for testing, service and repair. While the transfer switch is isolated, 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. There is no power interruption to the load when the equipment operates to bypass. 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 a two–source bypass. The bypass switch can be operated to either source (if power is available). Also available from other manufacturers is single–source bypass where the bypass switch can be switched to only one source, typically the normal source.

Equipment Ratings

Continuous Current

Generally, the continuous current rating must be selected in accordance with the total connected load requirements, sized essentially in the same manner as the circuit conductors. Most transfer switches are capable of carrying 100% rated current at an ambient temperature of 40°C. However, transfer switches incorporating integral overcurrent protective devices may be limited to a continuous load current not to exceed 80% of the switch rating. The manufacturer's specification sheets indicate whether the device is 80% or 100% rated.

Most switches that incorporate a switched fourth neutral pole utilize a neutral pole rated the same as the phase poles but the manufacturers literature should be referenced to confirm. It is recommended that fully rated neutrals be used in applications containing nonlinear loads, where the load induced harmonics create substantial neutral current. The ampacity of the switch must meet or exceed that of the connected conductors. Certain applications may require the switch to be sized larger including:

- Situations where feeder conductors are oversized to limit voltage drop and the minimum rated switch cannot accept the larger cable. The field wiring lugs have a limited cable size range.
- Where heavy concentrations of nonlinear load are present, and the harmonics combined with single phase load unbalance are likely to cause high levels of neutral current, it may be desirable to have the neutral circuit sized larger than the phase circuits.
- Fire pump applications require any normal source overcurrent devices be sized to carry the fire pump locked rotor current indefinitely. This may require overcurrent devices larger than allowed for transfer switch upstream protection, forcing the switch to be oversized.
- Where available fault current exceeds the capability of the switch, a larger switch may be required to achieve the required withstand capability.

Most Cummins transfer switch continuous current ratings are Underwriter's Laboratories "Total System Transfer" ratings. The transfer switch is suitable for use with any combination of motors, electric discharge lamps, tungsten filament lamps, and electric heat equipment. This rating is intended for general use

Continuous Current (cont'd)

where the sum of full load ampere ratings does not exceed the rating of the transfer switch, and the tungsten lamp load does not exceed 30% of the total. Included in the "Total System Transfer" rating is test verification of the ability to switch, interrupt and close onto currents of six times the transfer switch rating at low power factor. Therefore, the rating permits use with a single squirrel-cage induction motor, with a full load current up to the rating of the transfer switch.

Voltage

Transfer switch equipment is available for a wide range of operating voltages at both 50 and 60 Hz. All types of switches are available for low voltage (600 VAC and below) applications. Transfer switch types required for higher voltages (medium and high voltage) are limited to those using mechanisms comprised of high voltage contactors and breakers.

The voltage chosen for the transfer switch will match the system voltage for the application, however, withstand and closing ratings for the switch may vary with its voltage rating. This rating difference can affect the type of protection equipment required upstream of the transfer switch.

Switching Duty

Transfer switches have unique load switching requirements from most other load switching equipment. Transfer switches must be capable of switching loads with many different electrical characteristics between two available power sources that can be operating at different frequency and at opposite polarity. When transferring loads between two energized power sources (when re-transferring to the preferred source or when testing the system), the switch must be capable of load break transfer when the two sources are up to 180 degrees out of phase. During load transfer, the load current must be interrupted by open transition type switches. During interruption, arcing occurs across the open contacts. This arc must be completely extinguished before the opposite source contacts are closed to prevent source-to-source faults. Of course the situation is most severe when the two sources are completely out-of-phase and twice rated voltage exists across open contacts.

The problem is further exaggerated due to the characteristics of the loads being transferred. Some loads like tungsten lights, motors and transformers draw many times rated current when initially connected to a power source. Inductive loads, like motors, maintain terminal voltage for some time after being disconnected from a power source. Transfer switching mechanisms must be designed to accommodate these conditions.

The basic contact structure may consist of both main current carrying contacts and separate arcing contacts, both contained within an arc chute assembly. The arcing contacts are configured to be the last contacts to open and the first to close during transfer in order to perform the arc extinguishing function during opening, preventing erosion of the main current carrying contacts. The arc chutes are designed to be a part of the arc current carrying path and serve to lengthen the path gradually during opening, cooling and extinguishing the arc prior to contacts closing to the opposite source.

Phase

Transfer switch equipment is generally available with three phase poles and a solid neutral connection block; or with four poles, three phase poles and a neutral pole. Four-pole transfer switch equipment is typically used in electrical distribution systems as required to assure accurate sensing of ground fault protection systems.

Short Circuit

Withstand and Closing Ratings – An important consideration in the application of transfer switch equipment is its ability to withstand and close into fault currents. This is an important factor in achieving the highest power reliability to the loads. Often times, faults are temporary in nature. These faults are initiated by wires touching, contaminants or debris falling into electrical gear, internal arcing faults in motor insulation systems, etc. Quite often, these temporary faults are arcing faults and, if the source of power is intentionally interrupted (by some overcurrent device), the faulted circuit can be successfully re-energized by re-applying power. In a properly designed distribution system, if a temporary fault occurs on the load side of a transfer switch, either a load side branch breaker will clear the fault and the remaining loads continue to operate or a breaker upstream of the switch operates and the source is lost. When the source is lost, the transfer switch should detect loss of power and initiate transfer to the alternate source in an attempt to restore power. If the fault was temporary and cleared during the initial fault (debris blown clear, for example), power may be reapplied to the load. If, however, the fault is permanent, the switch must be capable of closing into the fault and withstanding the fault current until a protective device on the alternate source interrupts the fault.

Two types of mechanical transfer switch equipment have been defined by the IEC Standard 947, and are recognized by National Electrical Code 110–9 and 110–10. Type PC (contactor type) transfer switch equipment is designed to withstand and close into short circuit current until an external upstream overcurrent protective device opens and clears the fault. Type CB (circuit breaker type) transfer switch equipment includes integral overcurrent devices that are intended to interrupt fault level current. All transfer switch equipment, both classes, have short circuit ratings that are Withstand and Closing Ratings (WCR), which are expressed in RMS symmetrical amperes at a maximum system voltage. The asymmetrical current capability is based on X/R ratios used for short circuit testing. See Short Circuit Protection and Application below. The WCR is established by testing only. Calculations of short circuit ratings have no validity for application.

Solid state switches typically have considerably lower fault current capability than mechanical switches, particularly when protected by circuit breakers. Solid state switches are generally equipped with fast acting current limiting fuses that interrupt the fault current before damaging the solid state elements of the switch.

The suitability of transfer switch equipment for application in circuits with high available fault current is tested to the requirements of UL Standard 1008. A contactor type transfer switch must be able to withstand the mechanical and thermal stresses caused by short circuit currents, remain closed until the upstream overcurrent device has cleared, and then be capable of transferring the load to the opposite source. (A short time delay is standard in the control to override the voltage drop caused by a fault and to allow the transfer switch contacts to remain closed.) A circuit breaker type transfer switch is allowed to open or interrupt the short circuit current, and then transfer the load to the opposite source.

If a fault occurs on the load side of the transfer switch and is cleared by an overcurrent protective device, the transfer switch will transfer to the opposite source, if and when available. It cannot be assumed that the fault condition will have cleared before the opposite source restores power. Therefore, UL1008 also re-

Short Circuit (cont'd)

quires demonstration by test that the transfer switch is capable of closing into a short circuit fault with the same available fault current as the withstand test. Thus the UL rating is a Withstand and Closing Rating, not a withstand rating only. Because arcing across the contacts as they close makes the closing test considerably more severe than the withstand test where contacts remain closed under pressure, the closing test capability usually determines the WCR. Some manufacturers publish a withstand rating only without including closing ability. These ratings should not be compared on an equal basis to a WCR as published by Cummins and as required by UL 1008.

Cummins transfer switches are tested and rated with specific upstream overcurrent protection devices. Short circuit tests using both current-limiting fuses and molded case circuit breakers as the upstream overcurrent protection establish the WCRs with specific overcurrent devices. Accordingly, Cummins transfer switch equipment has two sets of overcurrent device specific WCRs, one rating with molded case circuit breakers, and one rating with current limiting fuses. In compliance with UL 1008, the circuit breaker WCR lists the circuit breaker manufacturer's name(s) and type designation(s), and maximum circuit breaker rating. The fuse WCR specifies the UL fuse class and the maximum continuous current rating of the fuse. These ratings and the allowable overcurrent device information are required markings on the transfer switch equipment. Inspection authorities can easily verify that appropriate overcurrent devices are installed upstream of the transfer switch equipment.

UL 1008 also permits short circuit tests without specific upstream overcurrent devices where the test current is maintained for 3 or 1.5 cycles depending on the rating of the transfer switch. Using overcurrent devices marked specifically on the transfer switch equipment is not required when the transfer switch is applied within this WCR, usually referred to as the "3-cycle" rating. However, just the same as with specific device ratings, the upstream overcurrent device must be either a current-limiting fuse, or a molded case circuit breaker with an instantaneous response and without an adjustable short-time delay. Power frame breakers are not permissible, nor are circuit breakers with an adjustable short-time delay function, including molded case and insulated case breakers. A 3-cycle WCR will typically be lower than a specific overcurrent device WCR for the same transfer switch.

Cummins recommends application of the transfer switch equipment using one of the two specific overcurrent device WCRs, because the coordination between the specific overcurrent device and the transfer switch equipment has been verified by UL as a condition of the listing. The inspection authority need only check that the upstream overcurrent device is included in the marking on the transfer switch. If the transfer switch equipment is applied based on a 3-cycle WCR, the inspection authority can only verify that the WCR is adequate based on the installed upstream overcurrent device interrupting rating. It then becomes the responsibility of the system designer to select, specify, and verify the field installation of an overcurrent device that will clear the available fault current in less than 1.5 or 3 cycles; and that the device has no adjustable short time delay function included.

Short Time Withstand and Closing Rating – Some transfer switches also carry a long time WCR, typically lower than the short time WCR. These ratings are generally limited to circuit breaker type switches applied near the normal utility

**Short Circuit
(cont'd)**

point of supply. The long time withstand ratings are needed to allow the switch to remain connected during short circuits for sufficient time to allow downstream overcurrent devices closest to the fault to clear the fault.

Interrupting – Transfer switches have unique load switching requirements from most other load switching equipment. Transfer switches must be capable of switching loads with many different electrical characteristics between two available power sources that can be operating at different frequency and at opposite polarity.

Circuit breaker style transfer switches contain integral overcurrent protection. These switches also must carry an interrupting rating sufficiently high to allow them to safely interrupt load side faults at the required available fault current level.

Transfer Equipment Switching Means

Mechanical Switches

Contactor Type

Typical construction of the switching mechanism in a contactor type transfer switch is a pair of mechanically and electrically interlocked lighting or motor starting contactors as shown in **Figure 12**. Actuation is by individual solenoids included with each contactor. Contactors are electrically held, unless furnished with optional mechanical latches. If mechanically latched, a release mechanism is required for both electrical and manual operation. If electrically held, contactors may drop out if voltage dips, and contacts may chatter at lower than rated voltages and frequencies. Mechanical latching is required by NFPA standards for use in emergency systems. Lighting and motor starter contactors use contacts that are typically double break with spring tensioners, pulled closed by a constantly energized solenoid (electrically held). The contacts are not quick-break quick-make and are without an over-center mechanism.

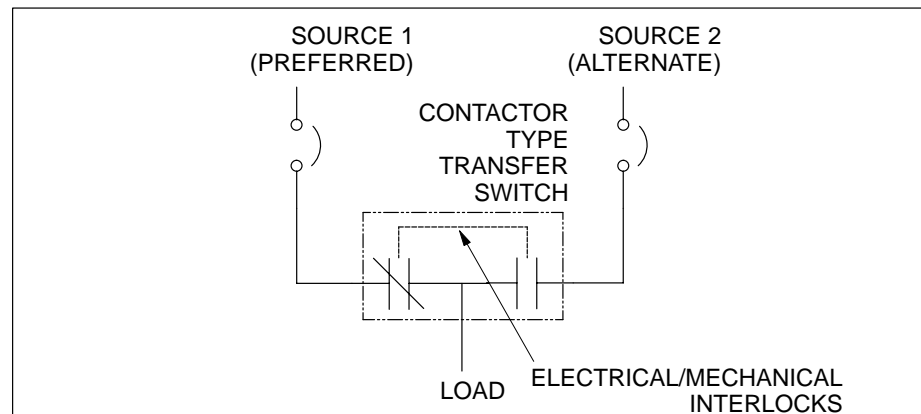


Figure 12. Contactor Style Transfer Switch.

High volume production of lighting and motor starting contactors result in an economical package for continuous current ratings below about 600 amps. To meet the temperature rise requirements of UL 1008, the continuous current rating of the contactors usually have to be substantially derated.

Because contactors are typically used in branch circuits in the lowest end of the distribution system, the short circuit ratings are relatively low. Contactor type transfer switches require external upstream overcurrent protection, and current-limiting fuses or special (high interrupting capacity or current limiting) circuit breakers are usually required to achieve higher withstand and closing ratings.

Circuit Breaker Type

Typical construction of the switching mechanism in a circuit breaker type transfer switch is a pair of electrically and mechanically interlocked molded case switches or circuit breakers as shown in **Figure 13**. Mechanical interlocking can be omitted for closed transition operation, which then requires reliable electrical con-

Circuit Breaker Type (cont'd)

controls to prevent out-of-phase paralleling. Individual motor operators with each switch or breaker actuate the switching mechanism.

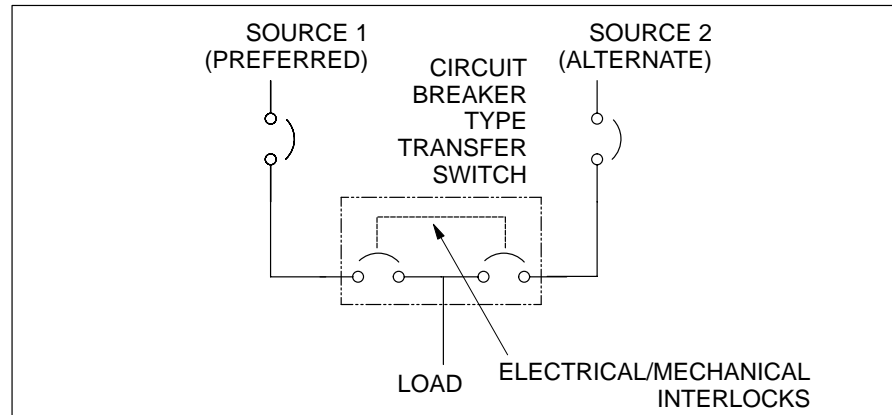


Figure 13. Breaker Type Transfer Switch.

Circuit breakers and molded case switches have quick-make quick break contacts and over-center mechanisms. Contact transfer time, the duration of source-to-source operation, of circuit breaker type transfer switches can be relatively slow, particularly in larger equipment.

If using molded case switches, an external upstream overcurrent device for short circuit protection is required.

If using circuit breakers with integral overcurrent protection, an external upstream overcurrent device is not required for transfer switch short circuit protection, which can allow use of the transfer switch as utility service entrance equipment, if rated and marked as suitable for use as service equipment. If applied with upstream overcurrent devices for cable protection, the integral overcurrent protection of the circuit breaker type transfer switch must be selected or set such that it will not operate without the upstream device also operating under short circuit conditions.

Depending on the type of circuit breaker used; molded case, insulated case, or power frame, the short circuit ratings range from high to very high because the circuit breaker design is intended to interrupt fault level current. Insulated case and power frame circuit breakers may have extended withstand ratings, up to 30 cycles.

Circuit breaker transfer switches with thermal-magnetic molded case and some solid-state molded case circuit breakers may require continuous current derating to 80% of the breaker frame rating.

Definite Purpose Type

The switching mechanism construction is designed specifically for switching between two power sources, which may be 180° out of phase with twice rated potential across the contacts. These mechanisms can be either single or double throw as shown in **Figure 14**. Single throw mechanisms are inherently interlocked to prevent source-to-source interconnection. Single throw mechanisms also provide fast open transition contact transfer time only. Double throw mechanisms can provide fast or slow contact transfer time, open or closed transition,

Definite Purpose Type (cont'd)

and load shed capability. A source-to-source mechanical interlock is required for double throw transfer switches designed for open transition only to prevent source-to-source short circuit. Double throw mechanisms have quick-make quick break contacts and over-center mechanisms.

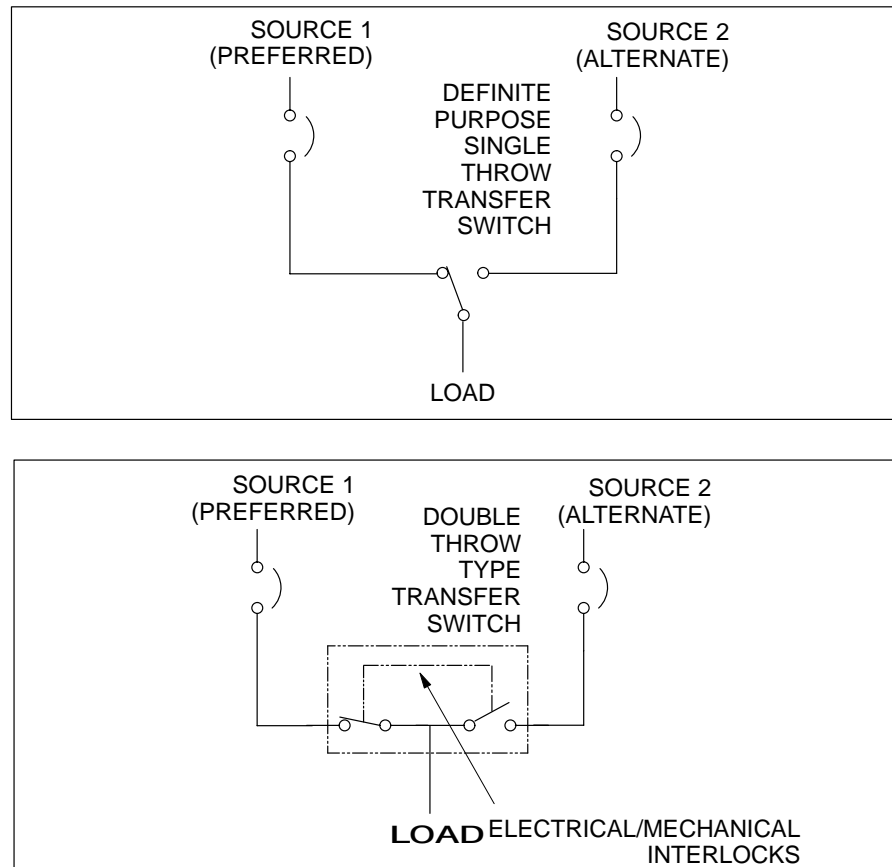


Figure 14. Single and Double Throw Definite Purpose Transfer Switches.

Integral overcurrent protection is not included in this type of transfer switch (IEC Type PC), and external upstream overcurrent protection is required. The dedicated purpose transfer switch contacts are designed to both remain closed during short circuits and close into fault level currents until an external upstream overcurrent device opens.

The contact transfer time, from one source to the other, of this type transfer switch can be fast, six cycles or less, depending on the size of the equipment.

Solid State

Solid state switches are available in several configurations and sizes and use SCRs or transistors as the switching means. A basic two source switch is shown in **Figure 15**. These switches have been used in solid state UPS equipment and are now available as dedicated and listed transfer switches. These devices are considerably more costly than equivalently sized mechanical switches (up to 4 times higher). These switches are typically used in an open transition mode with a total transfer time of 1/4 cycle or less. This is an attractive feature when used to

**Solid State
(cont'd)**

transfer between two available sources, such as during system testing and re-transfer. Most loads will not be impacted by this short disconnect time and loads like motors, VFD's and UPS subject to misoperation or damage during fast out-of phase transfer are not affected due to the essentially instantaneous transfer provided the two power sources are essentially synchronized when both are available.

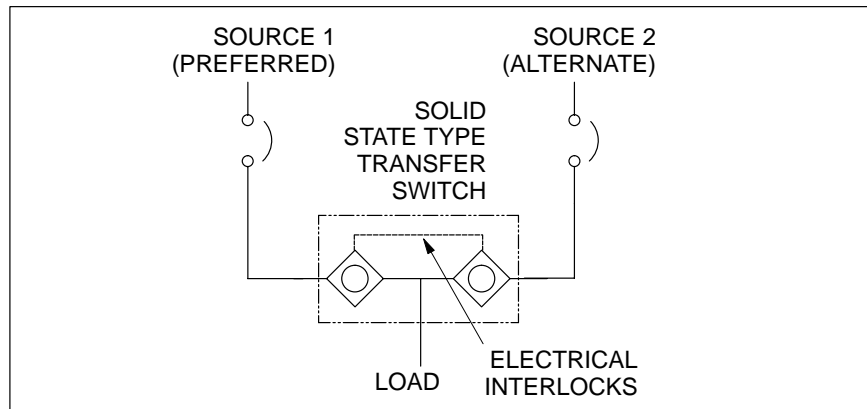


Figure 15. Solid State Transfer Switch.

Solid state switches can be damaged, however, when transferring between out-of-phase sources. These switches include a transfer inhibit function that requires the sources to be within some acceptable phase shift, around 15 degrees. Although this is of no consequence when these switches are used to transfer between synchronized utility sources, it can be an issue when transferring between a generator and a utility source. In this case, it is necessary to have at least a slight frequency difference between utility and generator in order for the sources to achieve momentary synchronism. The greater the frequency difference, the faster the sources will move in and out of phase. Problems are avoided if the frequency differential is maintained within limits since solid state switches complete the transfer very fast (less than $\frac{1}{4}$ cycle), not allowing the sources to drift out of phase. This is also beneficial for motor load transfer. The inductive motor load terminal voltage should lack adequate time to drift out of phase from the source in the short time it takes to transfer. Potential problems can still occur even with fast transfer, however, when transferring from a utility to a generator source. If the generator is hit with a very large sudden load change during the short transfer time, a sudden phase shift could result and the motor could be connected out of phase to the generator, resulting in a sudden inrush current.

Alternative Arrangements and Configurations

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 as shown in **Figure 16**, meaning there is no power interruption to the load when the equipment operates.

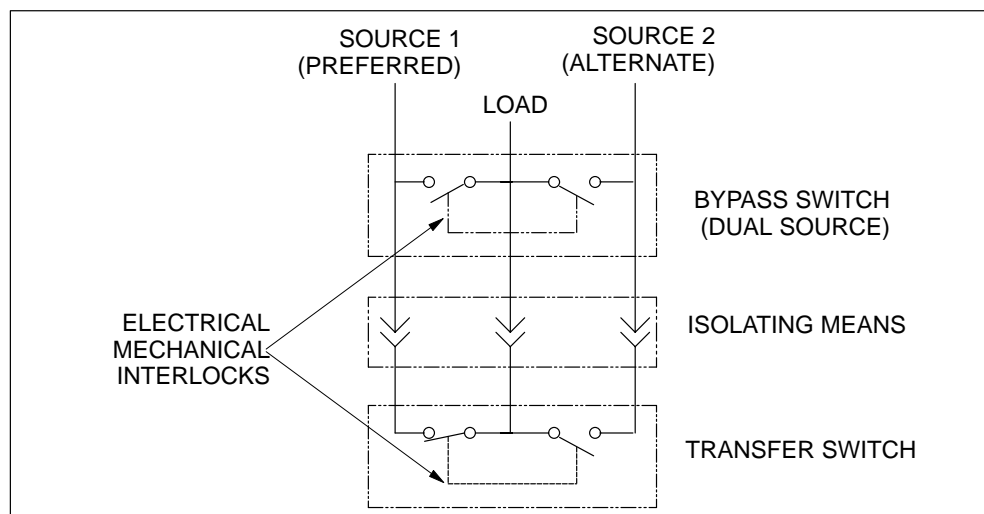


Figure 16. Non Load Break Bypass Isolation Transfer Switch.

Also available from other manufacturers is load break isolation–bypass equipment as shown in **Figure 17**, 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.

Bypass Isolation (cont'd)

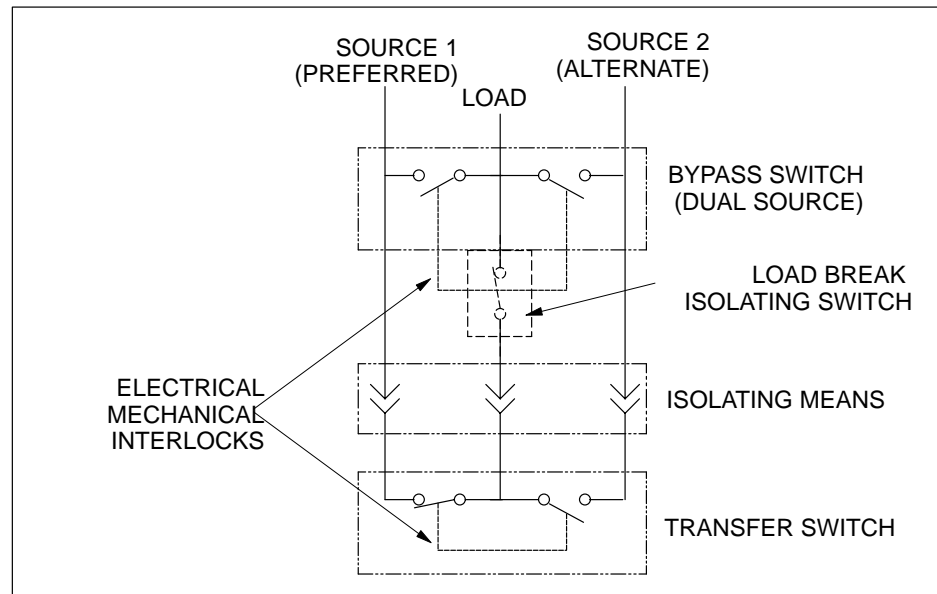


Figure 17. Load Break Bypass Isolation Transfer Switch.

Closed Transition

Mechanical transfer switch equipment may be configured for either open transition or closed transition operation. Open transition equipment transfers the connected load between power sources with a momentary interruption in power, when both sources are available, as the switch contacts open from one source and close to the other source. This momentary power interruption is called Contact Transfer Time; and without intentional delay during transition, has a duration of 6 cycles or less depending on the size of the equipment. A mechanical interlock is provided to prevent interconnection of the two power sources.

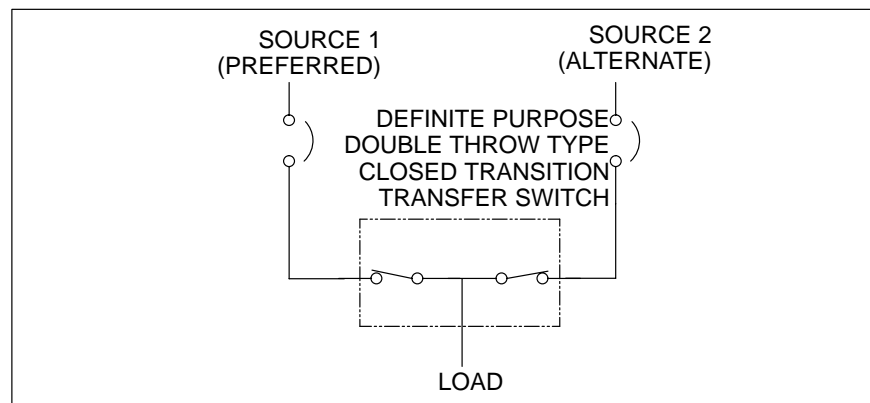


Figure 18. Closed Transition Transfer Switch.

With both sources available, closed transition transfer equipment parallels the power sources either momentarily or for an adjustable duration sufficient to ramp load onto and off of the generator set. Closed transition operation requires double throw type mechanical switches to allow either source to be closed independent of the other and does not include source-to-source mechanical interlocks as shown in **Figure 18**. Closed transition transfer equipment can either actively synchronize both power sources before paralleling them, or passively check for synchronism before allowing paralleling. Closed transition equipment

Closed Transition (cont'd) operates in open transition when one of the sources has failed, and closed transition when both sources are present. Closed transition operation prevents the momentary interruption in power when both sources are present, such as exercise, test, and retransfer. Closed transition transfer equipment does not substitute for an uninterruptible power supply where one is required by the load equipment.

Automatic Mains Failure This is an arrangement that is very popular outside of North America. Basically, the generator set and transfer equipment controls are integrated into a mains failure panel that typically also includes the transfer switch mechanism. This arrangement is generally used to provide total facility standby power and is interconnected at the main service entrance. In the event of a utility outage detected by the mains failure panel, the generator set is signaled to start and the mains panel transfers the entire facility connected load to the generator. Some form of automatic or manual controls may be required for those situations where the total connected load exceeds the generator capacity.

Transfer Equipment Controls

Control Types The type of control system for the transfer switch will vary depending on the type of switching equipment it is. A manual transfer switch for example, will have no electrical controls where a fully automatic switch may utilize a microprocessor with user programmable features. Most switches utilize a type of control based on either traditional relay functionality, solid-state circuits, or a microprocessor based system.

Earlier designs of control systems were relay based, with solid state controls becoming widespread in later designs. The most recent designs employ microprocessor systems¹. Any of these controls monitor voltage and frequency of each source and compare those signals to acceptable specification windows for the specific parameters. These specification windows are adjustable or programmable. This comparison is the basis for the control decision to initiate switching to the alternate source. Each type also can include optional functions for metering, display and remote annunciation. More sophisticated microprocessor based control systems can also include additional monitoring functions such as phase rotation detection, loss of phase detection, voltage imbalance, and more. Time delay functions for parameter evaluation, transfer and retransfer control are also often included. Frequently, clocks to time for automatic exercising of a generator set are additional equipment or, in the case of microprocessors, integrated into the control itself.

Transfer switch equipment may be designed with manual, nonautomatic, or automatic operation. The type of control system for the transfer switch will vary depending on the type of switching equipment it is.

Manual Transfer Switches Manual switches, as the name suggests, are manually controlled and require direct operation by a person to transfer the load. This operation is through a lever or handle; the switch does not have electrically actuated solenoids, contactors, or linear motors. The actual contact mechanisms are operated through the use of spring energy in order to achieve a “quick” make or break of the current carrying contacts. The handle operates the spring mechanism, in effect loading the springs with energy. These switches do not have monitoring capability for the power sources.

Nonautomatic Transfer Switches Nonautomatic switches, similar to manual switches, are controlled by an outside source which could be an automatic transfer switch. This type of design utilizes electrically operated transfer mechanisms. Transfer of the load with these switches is accomplished with an electrical signal from either an operator or from an external control. As with manual switches there is no source monitoring capability. Often these switches can also be operated manually.

Automatic Transfer Switches Automatic switches incorporate electrical controls which monitor both power sources and if the connected source becomes unacceptable, will transfer the load to an acceptable source (if available) without operator involvement. In the

¹ Contemporary controls available on transfer switches from Cummins Power Generation are solid state, Power Sentry, or microprocessor, “PowerCommand[®]”.

Automatic Transfer Switches (cont'd)

case of a backup generator system, the first action, if the primary source becomes unavailable, will be to send a signal to initiate automatic start of the generator set. When the primary source of power returns and is within acceptable parameters, the control will initiate switching back to that source and, in the case of a generator system, initiate the stop sequence of the generator set. Usually an automatic transfer switch can be set to operate in nonautomatic mode or operated manually.

Automatic Control Modes

Utility to Generator The most common application is where a utility (mains) is the normal of power and the generator set is the emergency standby source. In this application the normal power source is preferred, and the automatic control will always connect the load to the normal source when it is available and acceptable (after standard time delays).

The basic functions of an automatic utility-to-generator set control are the following:

1. Continuously monitors the Normal power source and senses unacceptable power. Acceptable power is defined by the settings of one or more sensors referenced to the nominal system voltage. All automatic controls include undervoltage sensing and optionally may include any or all of the following; overvoltage, over/under frequency, loss of single phase, and voltage imbalance/phase rotation. If power is outside any of the sensor(s) settings, power is unacceptable and the control begins the Start Time Delay.
2. Senses when power remains unacceptable for a predetermined amount of time. At the end of that Start Time Delay the control signals the generator set to start. The control monitors the voltage build up as the generator set accelerates. When the generator voltage reaches the pickup setting of the emergency side undervoltage sensor the Transfer Time Delay begins. The purpose of the Transfer Time Delay is to allow the engine governor to stabilize engine speed before applying load to the generator set. It may also be used in multiple transfer switch installations for step loading the generator set.
3. Transfers the load to the generator set when the Transfer Time Delay is complete. If required, an additional Programmed Transition Delay may be used. This delay may be used, when more than one transfer switch is connected to a generator set, to deliberately offset the timing of multiple load connections, thus reducing transient affects on the generator set.
4. Senses the return of acceptable utility (normal) power source voltage and begins the Retransfer Time Delay, which gives the utility source time to stabilize. Occasionally the return of the utility may be brief, followed by unacceptable conditions, before it returns and stabilizes. The Retransfer Time Delay also provides a minimum run time for the generator set once started. An immediate bypass of the retransfer time delay is automatic should the generator set stop inadvertently during this delay.
5. Retransfers the load to the Normal power source when the Retransfer Time Delay is complete and begins timing the Stop Time Delay. The retransfer function is always between two energized sources, and an additional control

Utility to Generator (cont'd)

function for reducing inrush currents may be required for motors, lightly loaded transformers, UPS and other electronic loads. This delay is a deliberate momentary delay in the neutral position of the switch (i.e. no power sources connected to the load side) for the purpose of allowing voltage decay of inductive loads to avoid transition issues.

6. Sends a stop signal to the generator set after the Stop Time Delay. This delay allows the generator set to cool down while running at no load before being shut down.

Generator to Generator

A generator set-to-generator set controller can control a two-generator configuration for either dual standby or prime power. One generator is designated the preferred source. The control automatically transfers the load to the backup genset if the preferred genset fails.

A separate changeover timer (typically used in prime power genset-to-genset applications) automatically transfers loads between the two generators. The changeover timer is set from the digital display or the PC service tool. The exerciser is not available in this configuration.

Preferred Source Selection – With both prime power and dual standby applications, either genset can be set up to be the preferred source. If the preferred source is changed while one of the gensets is running, the control starts the second genset and transfers the load to it when it becomes available.

The default preferred source is Source 1.

Prime Power (Plant to Plant) Operation – In prime power applications utility power is not available. The system includes one transfer switch and two gensets. One genset is always running and supplying power to the load while the other genset is the backup genset.

Under normal operation, one genset is designated as the preferred source and supplies power to the load. The second genset is the backup power source. If the preferred genset fails, the backup genset starts and the transfer switch transfers the load to the backup genset.

Automatic Changeover – The transfer switch can be set up to change the preferred source automatically by enabling the changeover timer.

The automatic changeover timer automatically changes the preferred source and transfers the load to the new preferred genset. After the transfer is complete, the control initiates a cool-down period on the old preferred genset before shutting it down. The old preferred genset is now the new backup genset. The changeover timer is now timing for the next changeover and the cycle continues as long as the changeover timer is enabled.

Dual Standby Operation – In dual stand-by applications (see Figure NO TAG), utility power is available. The system includes two transfer switches and two gensets. Utility power supplies power to the load and both gensets are backup gensets.

Under normal operation, the utility is supplying power to the load through the lead transfer switch. The lead transfer switch is a utility-to-genset switch.

The two gensets are connected to the genset-to-genset transfer switch. The load side of this switch is connected to the genset side of the lead transfer switch.

Generator to Generator (cont'd)

Upon loss of utility power to the lead transfer switch, a signal is sent to the genset-to-genset transfer switch to start the preferred genset. When the lead transfer switch senses generator voltage, it transfers the load to that genset. If the preferred genset fails to start, a signal is sent to the backup genset to start.

If the preferred genset becomes available while the backup genset is active, a retransfer is initiated and the load is retransferred back to the preferred genset. A time delay cool-down period is initiated before turning off the backup genset.

When the lead transfer switch senses the return of utility power, it initiates a retransfer sequence and transfers the load back to the utility. The lead switch sends a signal to the genset-to-genset switch to shut down the genset.

Alternating Preferred Source – In an attempt to keep the running time equally distributed between both gensets, the control can be set to alternate between the gensets when utility power fails. The selected preferred genset starts with the first power outage. The second power outage starts the backup genset, which now becomes the preferred genset. Upon subsequent outages, the preferred genset alternates.

Only utility outages and tests or exercises initiated at the lead transfer switch result in the gensets being alternated. The designated preferred genset will not change if it fails and the backup genset takes over the load.

Utility to Utility

Use of multiple utility service is economically feasible when the local utility can provide two or more service connections over separate lines and from separate supply points that are not apt to be jointly affected by system disturbances, storms, or other hazards. It has the advantage of relatively fast transfer in that there is no 5–15 second delay as there is when starting a standby engine-generator set. A separate utility supply for an emergency should not be relied upon unless total loss of power can be tolerated on rare occasions. The supplying utility will normally designate which source is for normal use and which is for emergency. If either supply is not able to carry the entire load, provisions must be made to drop noncritical loads before transfer takes place. A manual override of the interlock system should be considered so that a closed transition transfer can be made if the supplying utility wants to take either line out of service for maintenance or repair and a momentary tie is permitted. Otherwise, use of engine generator sets is recommended. Also, in some installations, such as hospitals, codes require on-site generators.

The utility-to-utility control automatically directs transfer of the load from one utility power source to another, providing power with only a brief interruption during contact transfer time when using open transition switches. The basic functions are similar to the other automatic controls, except there is no start/stop signal circuit, and as follows. A Source Selector Switch selects which source is preferred and which source is the backup. In the Source One position, the Normal power source supplies the load power. In the Source Two position, the Emergency power source supplies the load power. Regardless of the Source Selector Switch position, if the utility source to which the load is connected fails, the control will automatically transfer the load, provided the other source is acceptable as determined by the settings of the voltage sensors.

This is a potential application for closed transition equipment only if the utility will allow parallel operation of the two utility feeds. A “no load break” transfer can

Utility to Utility (cont'd)

then be used to transfer a facility between two available supplies at either the utility's or facility's desire. Perhaps even more frequently, solid state switches are used to accomplish a nearly seamless transfer in these applications.

Source Monitoring

Undervoltage

An automatic transfer switch uses undervoltage sensors to continuously monitor the normal power source and the emergency power source. Control logic is provided so that the normal source is the preferred source and therefore the normal switch position if acceptable to the source monitors. The automatic transfer switch control will not permit the load to be disconnected from both sources simultaneously when either or both are acceptable to the monitors.

NOTE: NFPA 110 has a source monitoring requirement to sense undervoltage on all ungrounded lines of the normal power source and at least one ungrounded line of the generator set source.

Single phase sensing is used on single-phase sources. On three-phase systems sensing may be 1) single-phase on normal and emergency, 2) three-phase on normal and single-phase on emergency, or 3) three-phase on both sources. Single-phase sensing on a three-phase system would only be recommended in applications where possible loss of a single phase would not cause problems with the connected load equipment. See also Loss of Single Phase Detection.

Undervoltage sensing uses two parameters for determination of condition and action, a pickup and dropout setting. The pickup setting determines the voltage that the control will consider acceptable for the transfer switch contacts to close on the source and connect the load. The dropout differential setting determines the voltage that the control will consider unacceptable and initiate a transfer operation towards the opposite source. The pickup and dropout settings may be fixed or adjustable depending on the control type. If fixed, typically the pickup setting will be 85% of the nominal system voltage and the dropout differential setting will be fixed at 75% of the pickup setting. If adjustable, the pickup setting range is typically 85 to 100% of nominal system voltage and the dropout range is 75 to 98% of the pickup setting.² See **Figure 19**.

The undervoltage sensors include a brief time delay before signaling the control to begin the Start Time Delay. This time delay allows the control to ignore very brief voltage dips that may result from short-circuit faults and re-closure operation, etc. Undervoltage sensing time delay can be either fixed, typically at 0.5 seconds or so, or adjustable, typically from 0.1 to 1.0 seconds.

² Setting on PowerCommand transfer switches from Cummins Power Generation are selectable within the ranges listed using the transfer switch digital display or the PC service tool.

**Undervoltage
(cont'd)**

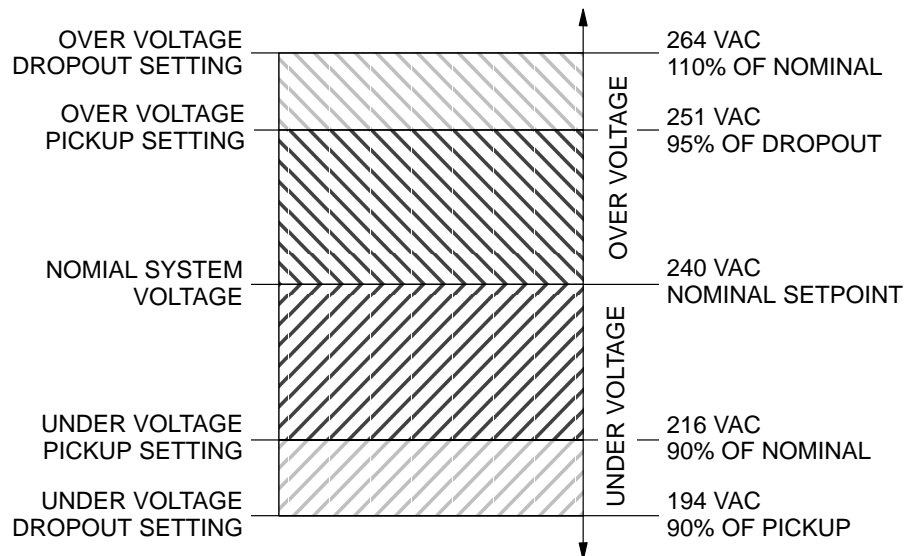


Figure 19. Over/Under Voltage Settings.

Figure 19 shows an example of undervoltage and overvoltage settings based on a 240–volt system with pickup and dropout percentages as noted. In this example a generator start would be initiated at 194 volts (90% of pickup) and transfer sequence completed if the voltage remains below 216 volts (90% of nominal). When the normal (or preferred) source voltage rises above 216 volts, the retransfer sequence would be initiated (and completed assuming the voltage remains within the undervoltage and overvoltage dropout settings). Similarly, if the system voltage reached 264 volts (110% of nominal) the start/transfer sequence would be initiated after time delay. When the system voltage returns to within 251 volts (95% of dropout) the retransfer sequence would begin.

The wide range in voltage between the pickup voltage setting and the minimum dropout voltage (75% of pickup) is used where line voltages are poorly regulated or not stable enough to stay within a close differential setting. This prevents repeated pickup and dropout and frequent starting and stopping of the generator set and transfer of the load.

Many applications require more precise voltages for reliable operation of the connected load equipment and require the use of tighter windows for these settings. In those applications, the utility line voltage should be stable enough under normal conditions to stay above the product of the pickup and dropout settings.

The end–user or consulting engineer should determine the optimum settings of the voltage sensors after analyzing both the normal source voltage characteristics and the voltage requirements of the load equipment. In general, the pickup voltage setting should be reasonably low, and the dropout setting reasonably high. Typical close voltage settings are 90 to 95% for both the pickup and dropout differential. These settings would result in a range of dropout voltage from 80 to 90% of nominal voltage. See **Table 1** for typical steady–state voltage tolerances of common load equipment.

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

Table 1. Typical Voltage and Frequency Tolerances

Overvoltage

An automatic transfer switch control may be provided with overvoltage sensors. Sensors continuously monitor line–to–line voltages, single–phase on single–phase systems and three–phase on three–phase systems of both sources.

As with undervoltage, two settings are used for overvoltage sensing, a pickup and dropout setting. The pickup setting determines the voltage that the control will consider acceptable for the transfer switch contacts to close on the source and connect the load. The dropout setting determines the voltage that the control will consider unacceptable and initiate a transfer operation towards the opposite source. The pickup and dropout settings are fixed or adjustable. When adjust-

Overvoltage (cont'd)

able, the dropout setting range is typically 105 to 135% of nominal system voltage and the pickup range is 95 to 100% of the dropout setting.

The overvoltage sensors include a time delay before signaling the control to begin the Start Time Delay. This time delay allows the control to ignore brief overvoltages that may result from switching surges, lightning induced surges, static discharges, etc. Typically this time delay is adjustable from 0.5 to 120 seconds².

Electrical systems are subject to disturbances of many types that unavoidably produce overvoltages, which may or may not be damaging to load equipment. Overvoltages have many different characteristics in terms of rate of voltage rise, voltage magnitudes, and duration. A means other than transfer to an alternate power source would be required for protection from transient overvoltages that result from lightning induced surges, switching surges, etc.

For the purpose of transfer switch selection and application, only repeated or prolonged overvoltages that could damage insulation and/or equipment are a concern. Most causes of prolonged overvoltages can be effectively addressed by grounding the system neutral. On ungrounded low voltage AC systems, repeated or prolonged overvoltages may be caused by:

- 1) Contact with a higher voltage system (primary–secondary shorted transformer),
- 2) Unintentional connection of inductive reactance to ground (motor winding short to ground),
- 3) An intermittent arcing ground fault,
- 4) Others.

Over/Under Frequency

An over/under frequency sensor may be used to monitor either or both the normal and emergency power sources. Frequency sensing is seldom used to monitor a commercial utility power source, but often used to monitor one ungrounded line of a generator set. Frequency sensing on one ungrounded line of an emergency generator set is required by codes such as NFPA 110. NFPA 110 requires that transfer to the generator set be inhibited until there is adequate voltage and frequency to serve the connected load equipment.

Over/under frequency sensors typically operate with an adjustable pickup bandwidth of $\pm 5\%$ to $\pm 20\%$ of nominal. In some switch control designs, the nominal frequency is selected as either 50 Hz or 60 Hz. In microprocessor controls this is typically selectable between 45 and 60 Hz. A dropout bandwidth is set wider than the pickup bandwidth. Depending on the automatic transfer switch equipment selected, the dropout bandwidth is either fixed or adjustable, typically in the range of 1 to 5%. An adjustable dropout time delay with a typical range of 0.1 to 15 seconds allows the control to ignore momentary dips or rises in frequency.

Loss of Phase

In applications where a large part of the connected load equipment is induction motors, the undervoltage sensors may not detect the loss of a single phase. If a single phase is open, voltage on that phase may be held up at a relatively high value due to generator action of connected motors. Depending on the pickup setting of the undervoltage sensor on the open phase and the regenerated voltage on that phase, the loss of the phase may not be detected and the motor(s) may operate to damage. Loss of single-phase detection addresses this problem by detecting a drop in the relative phase angle between the three-phases. Typically, balanced three-phase voltage sources have relative phase angles of $120^\circ \pm 2^\circ$.³

Voltage Unbalance

Voltage unbalance detects an unbalanced voltage on a three-phase voltage source. It is not available on single-phase systems. A voltage Imbalance Sensor can be set to monitor the sources individually. Unbalanced phase voltages commonly occur because of open delta transformer connections, or unequal single phase loading. If the utility source is not an open delta transformer connection, then the Voltage Imbalance Sensor may be set to monitor the generator source only, assuming the generator capacity is less than the utility source. In that case, a single phase loading problem severe enough to cause voltage unbalance on the utility would cause even greater unbalance on the generator source.

The percentage of voltage imbalance is defined by the equation:

$$\text{Percent Imbalance} = (\text{Maximum Voltage Deviation from } V_{AVE}) \div V_{AVE} \times 100\%$$

For example if the three line-to-line voltages are 245, 235, and 230 volts on a nominal 240 volt system, the average voltage is 237. The percent voltage imbalance is $8/237 \times 100\% = 3.4\%$.

A Voltage Imbalance Sensor has adjustable dropout settings typically from 2 to 10%. The pickup setting is usually fixed at 10% of the dropout value. For example with a 4% dropout setting, the pickup will be 3.6%. The dropout setting initiates the transfer sequence of operation and the pickup setting would initiate the return of the switch to that voltage source. There is usually an adjustable time delay on dropout of 2–20 seconds.

In 3-phase systems, a small percentage of voltage imbalance can cause large increases in temperature rise in motors. Current unbalance at full load is six to ten times as great as voltage unbalance. The percentage of overheating caused by unbalanced voltage will be equal to twice the square of the percentage unbalance (see **Figure 20**).

³ PowerCommand transfer switches from Cummins Power Generation are available with loss of phase sensing and if the relative phase angle between any line-to-line voltage drops below 90° the sensor detects that one of the phases has been lost and initiates the transfer sequence.

Voltage Unbalance (cont'd)

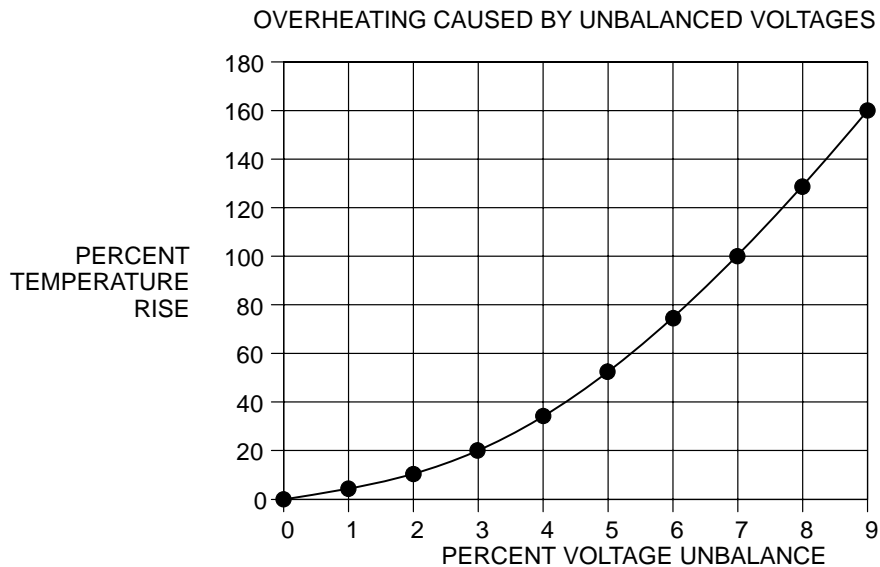


Figure 20. Motor Heating Versus Supply Voltage Unbalance.

Phase Rotation

Phase Rotation Sensing detects the phase rotation of both three-phase power sources. If the phase rotations are not the same the control considers the non-connected source unacceptable and will signal a warning.

While it is standard practice during installation to check phase rotation of both sources, this check may be mistaken or overlooked. The Phase Rotation Sensor would prevent the transfer switch from transferring to a source with opposite rotation, during installation acceptance testing or testing after system repairs.

NOTE: Phase Rotation Sensing is a transfer switch feature required by NFPA 20 for fire pump installations.

Time Delays

Time delays have been mentioned in previous sections in regard to various functions of a transfer switch but are outlined here individually.

Start

The purpose of the Start Time Delay is to avoid starting the generator or initiating a transfer sequence in the case of a short duration power outage or disturbance of the primary (normal) power source. Typically this delay is adjustable from 0 to 15 seconds or may have optional longer delay adjustability to as much as 120 seconds. Timing starts the moment the source monitors signal an unacceptable source. If the duration of the source interruption exceeds the delay time, the control signals the generator set to start.

Stop

This time delay allows the generator set to cool down at no load before being shut down. This delay is typically adjustable from 0 to 30 minutes. It begins timing when the load is retransferred to the Normal power source. At the end of the delay, the stop signal is sent to the generator set.

NOTE: The Start and Stop Time Delays are not provided on the Utility-to-Utility control.

Transfer

This brief time delay allows the generator set to stabilize before the load is applied. This delay begins when generator voltage and frequency (when used) reach acceptable limits determined by the settings of the control. After the delay,

Transfer (cont'd)	the transfer switch transfers the load to the Emergency power source. It typically has an adjustable range of 0 to 120 seconds.
Retransfer	This delay allows the Normal source to stabilize before retransfer, thus avoiding multiple transfer/retransfer cycles if the normal source is unstable. Also, this delay creates a minimum generator set operation time under load allowing for the generator set to warm up. This delay begins the moment Normal line voltage and frequency (when used) return. After the delay, the transfer switch will retransfer the load to the Normal source. In the event of generator set failure, the retransfer time delay is bypassed. Typical adjustment range is 0 to 30 minutes
Exercise and Test	<p>Automatic transfer switch equipment controls may include a programmable exerciser clock. Generally, only one automatic transfer switch per system would be required to include an exerciser clock. The clock will automatically start and run the generator set for a selected duration at a selected time and day. The automatic controls will immediately return the switch to the normal position if the generator voltage fails during the exercise period. Exerciser clocks are generally provided with integral battery backup so that the set time of day does not change due to brief power interruptions. The automatic controls include a “with or without load” selection that will cause the transfer switch to either transfer the load or not, depending on the setting.⁴ In multiple transfer switch applications, care must be taken in the system design to transfer sufficient load to the generator to meet minimum loading requirements, typically at least 30% of generator set nameplate kW.</p> <p>No clock would be required in automatic and nonautomatic transfer switches that are part of a multiple transfer switch system, where at least one transfer switch has a clock. Also, in some health care facilities an automatic exerciser clock would not be required where the facility has a regular testing schedule that follows a schedule in compliance with codes.</p> <p>Exerciser clock selections may include 1) no clock, 2) a programmable multi-day exerciser clock, or 3) a programmable calendar based exerciser clock. A programmable exercise clock may be selected to provide automatically repeated exercise periods at the same time on the same day of each week, month, etc. or at regular intervals. Typically stand-alone, multi-day clocks may have to be reset for daylight savings time and leap year. A microprocessor, calendar clock should take these events into account automatically.</p>
Operator Interface	The operator interface may include various combinations of indicators; metering, displays and controls mounted on the door of the enclosure to allow closed door operation of the automatic transfer equipment. The operator interface may range from basic to comprehensive with the addition of optional features.
Indicator Lamps	A basic feature is lamp indication of source availability and switch position, provided standard on automatic and nonautomatic transfer switch equipment. Typically four lamps are provided; Normal Available, Normal Connected; Emergency Available, and Emergency Connected.
Test Switch	A means to test the transfer equipment, either a keyed switch or a sealed-membrane pushbutton switch is provided on automatic utility-to-generator set trans-

⁴ The switch serving the emergency system should always be set to transfer load during exercise and test to comply with NFPA Standard 110.

Test Switch (cont'd)	fer switch equipment. This control will simulate a normal power failure, start the generator set, and will either transfer the connected load, or not, depending on selected preference. An indication that the transfer equipment is actively operating in test or exercise mode is included with microcontrollers.
Retransfer Override Switch	A means to manually initiate retransfer of the load during a test, either a keyed switch or a sealed-membrane pushbutton switch, is provided on automatic utility-to-generator set transfer switch equipment.
Not-In-Automatic Indication	An indicator that the transfer equipment is not ready to operate automatically. This helps avoid inadvertently leaving the switch in a mode other than normal operating mode due to a test or service operation.
Metering	Microprocessor controlled automatic transfer equipment is normally provided with a front panel security key that disables the operator panel to prevent unauthorized changes to settings and adjustments.
Security Key	Optional metering packages are often available allowing monitoring of load side power. Typically these include voltage, current, and frequency. Microprocessor controllers will usually offer additional monitoring options including AC power and power factor. Dial indications and bar graph displays are variations available on some equipment.
Fault Monitoring	Microprocessor based control systems will often monitor the switch and power sources for events related to the settings and operations mentioned previously. Recent event storage in memory is also often included to facilitate event or problem diagnostics.
Communication	With the emergence of microprocessor control systems comes the availability of network communications between transfer switch and operator or monitor, or between multiple transfer switches. This network communication capability can be used for monitoring a switch or series of switches, initializing test modes, tracking events, and sequencing transfer events between multiple switches.
Closed Transition Transfer Control	Closed transition transfer, as described in various places in this manual, involves momentarily connecting two power sources together. With this type of switching, connections of two live power sources can occur during an exercise cycle or during return from the generator to the restored normal source after an outage. This type of switching is accomplished by monitoring the two power sources, which operate independently, and when they are within phase, voltage and frequency windows, initiating the switching action, paralleling the power sources for a brief period. Specific control functions are required to do so successfully; monitoring and requiring tight windows of acceptance for frequency, voltage and phase angle. Also, if closed transfer is aborted for any reason, and open transfer initiated, programmed transition is needed for significantly large inductive load content. If the inductive load voltages are not allowed to decay, the closure to a new power source could result in large transient events that in turn could result in the load dropping off-line or damaged equipment.

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.

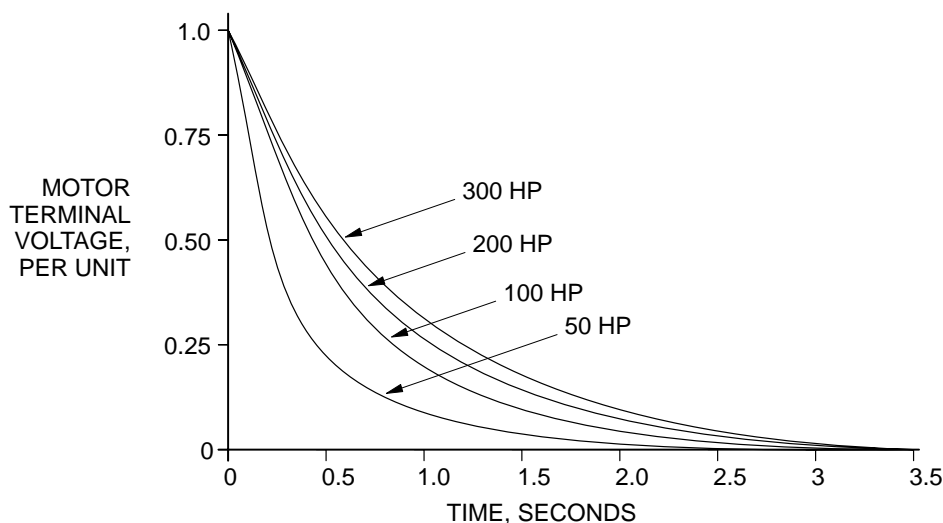


Figure 21. Induction Motor Open Circuit Voltage Decay

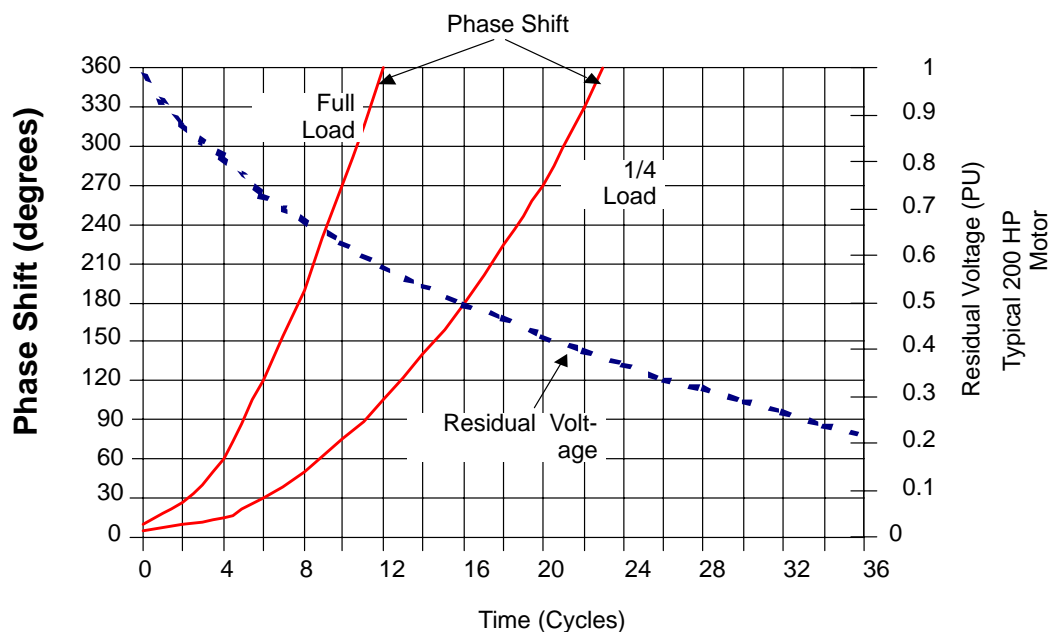
Reconnection of these inductive loads with an out-of-phase residual voltage present of more than .25 per unit can result in transient currents high enough to trip overcurrent devices and/or transient torque high enough to damage the load equipment. Several transfer switch control and construction considerations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

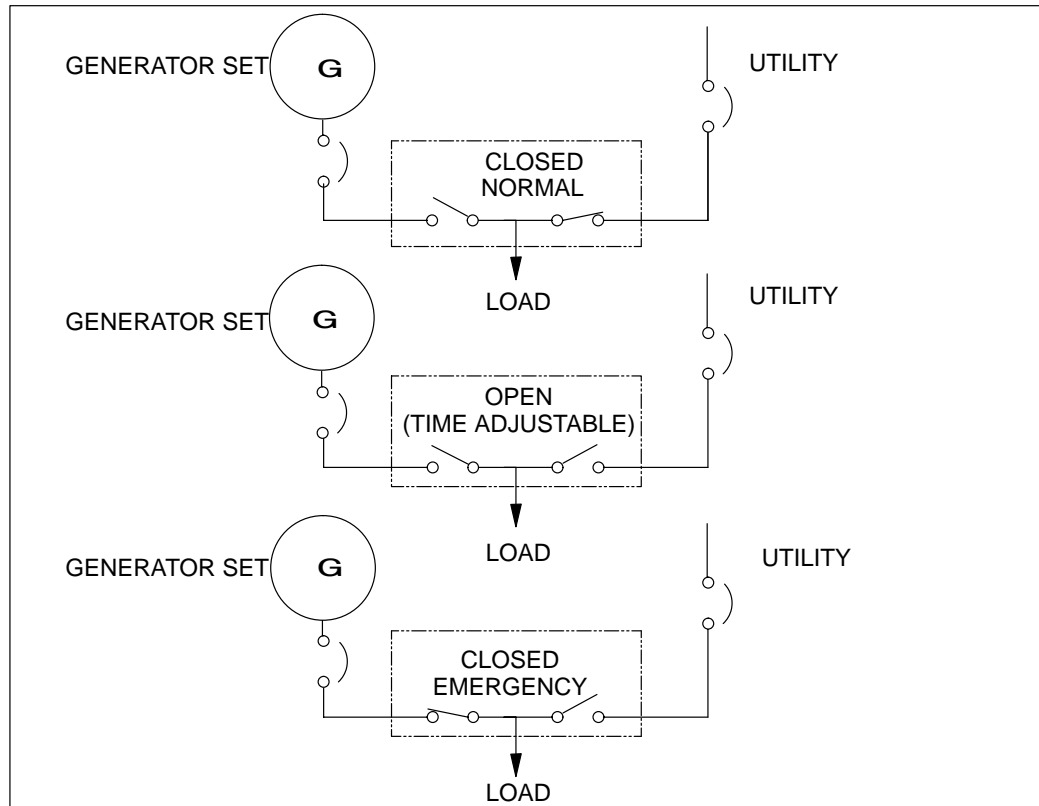


Figure 23. Programmed Transition Operation

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**.

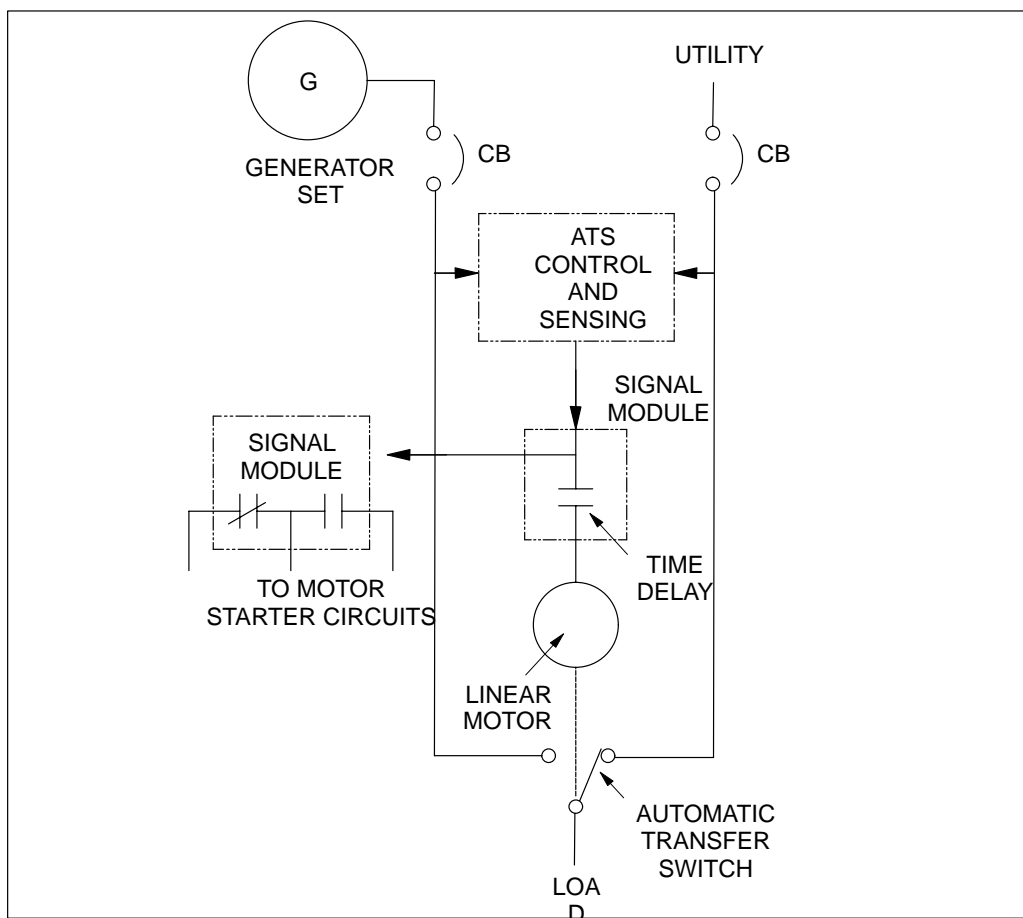


Figure 24. Motor Load Disconnect Circuit.

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 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 $\frac{1}{4}$ 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 shut-down, 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)

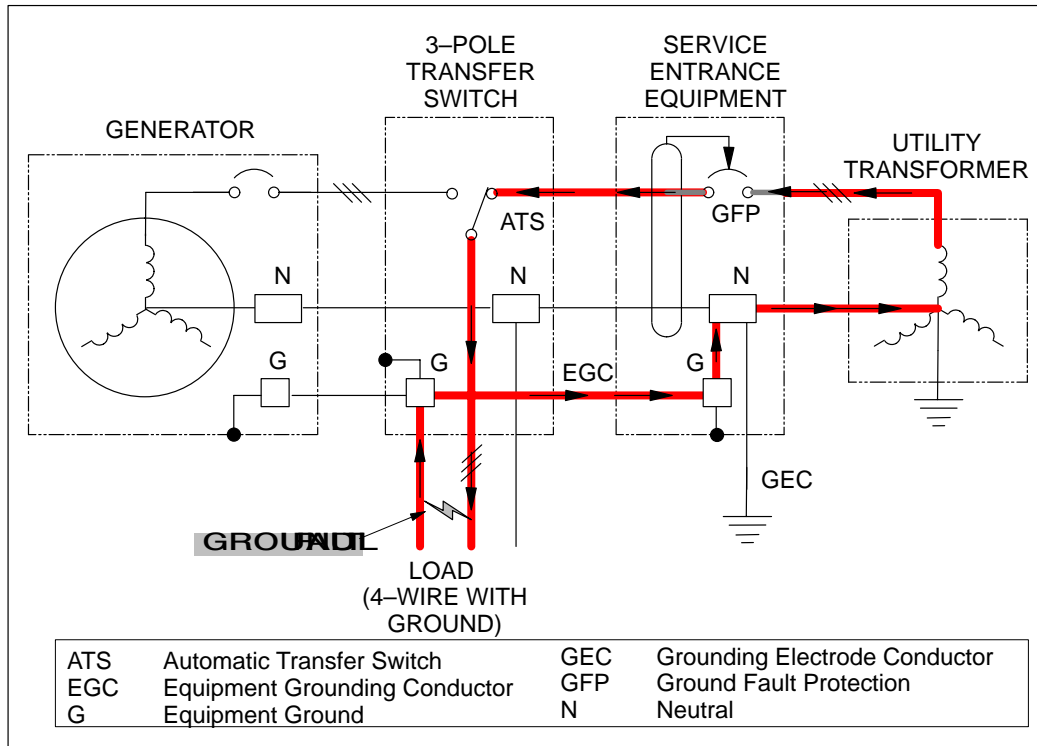


Figure 25. Single System Ground at Utility Service Entrance.

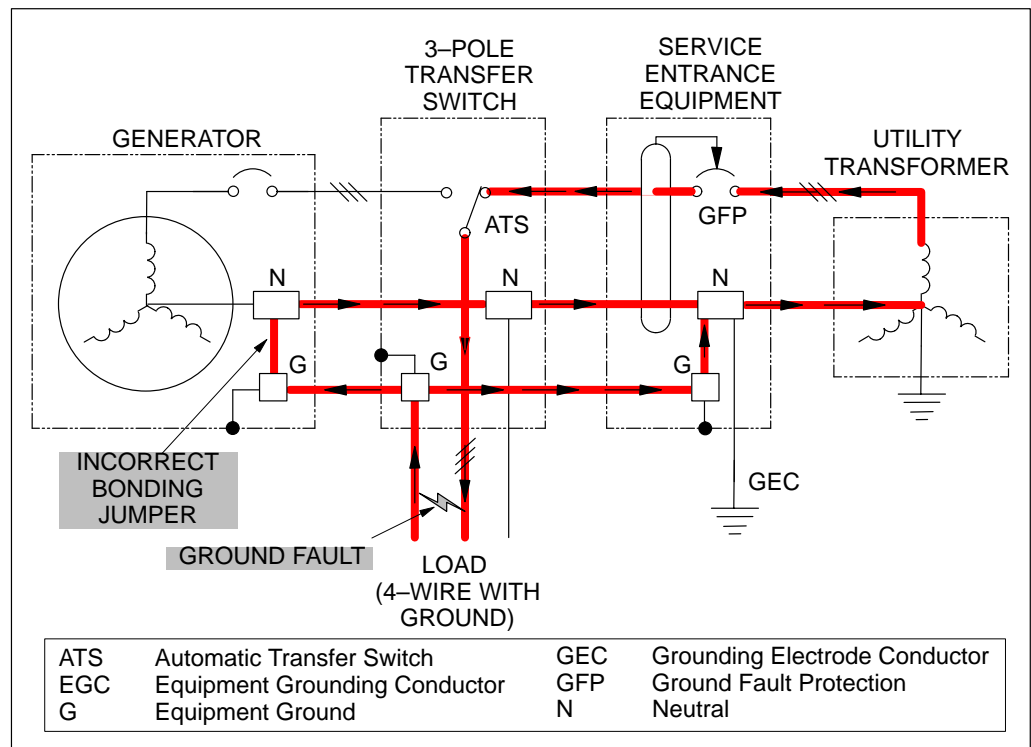


Figure 26. Multiple System Grounds (Neutral to Ground Bond Improperly Installed).

Grounding Methods (cont'd)

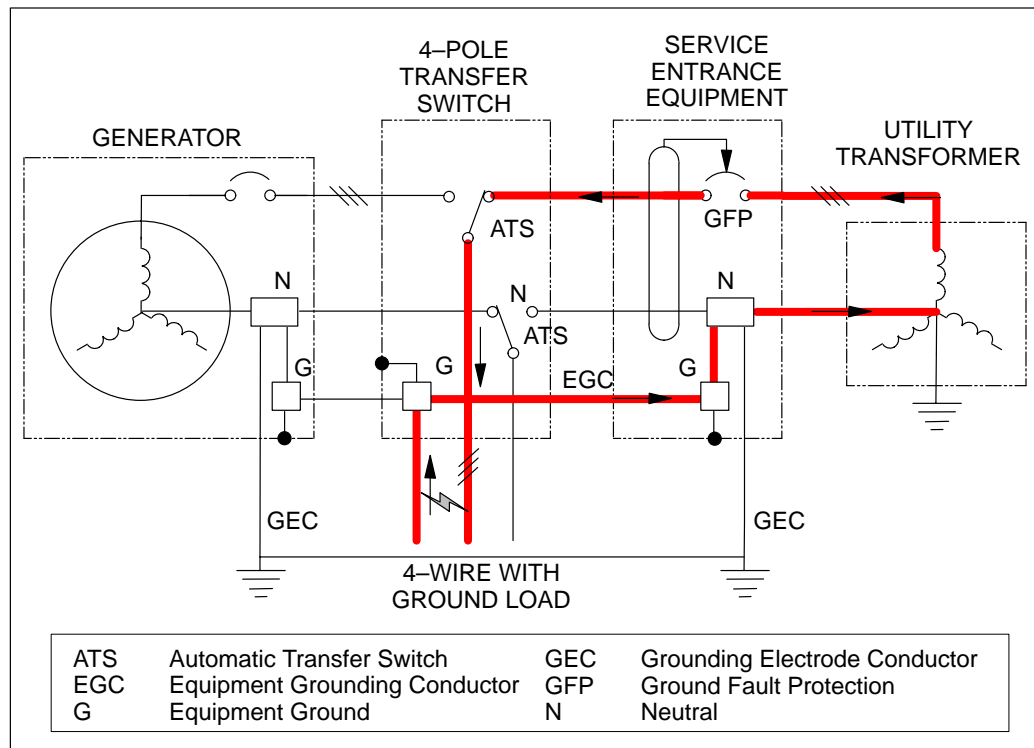


Figure 27. Separately Derived Generator with a Switched Neutral Transfer Switch.

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 parallel 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)

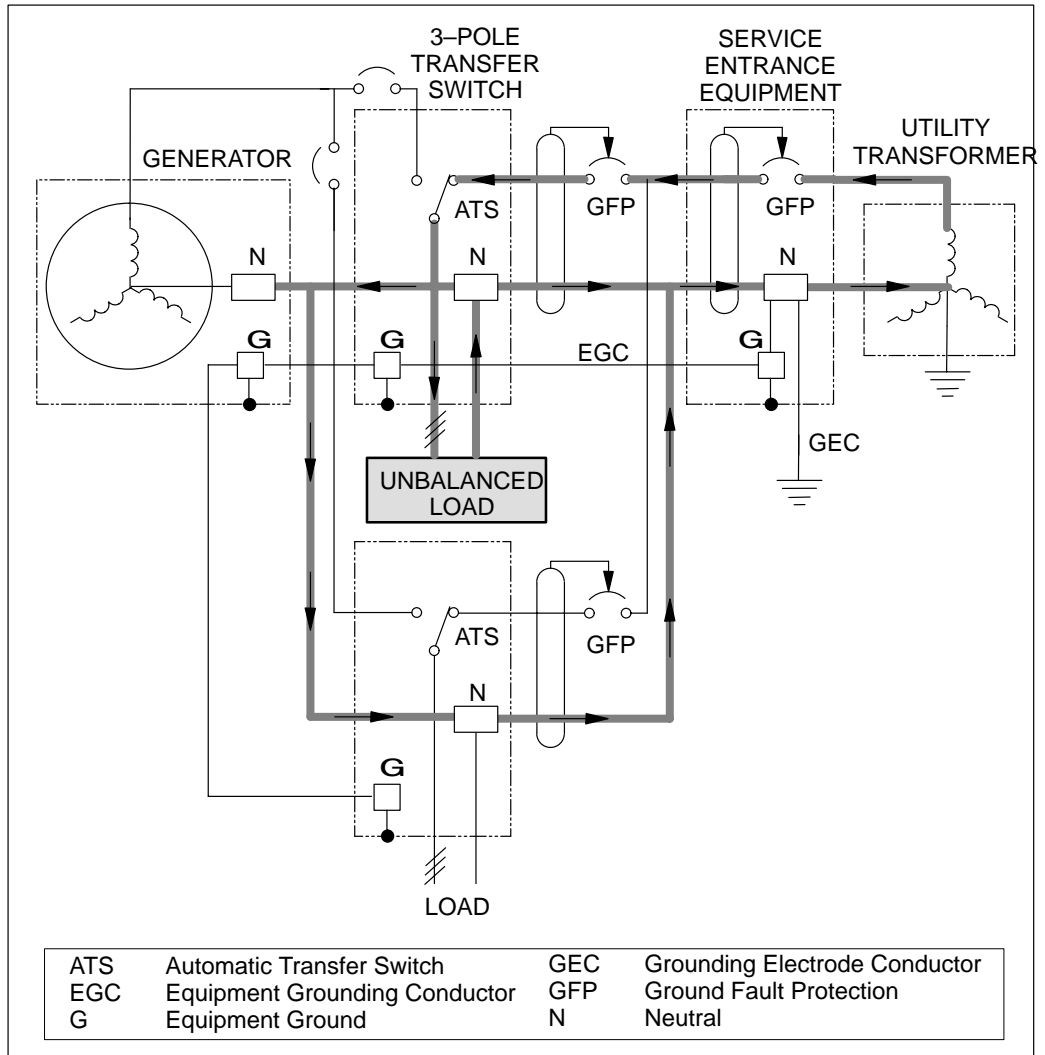


Figure 28. Unbalanced Neutral Current.

Grounding Methods (cont'd)

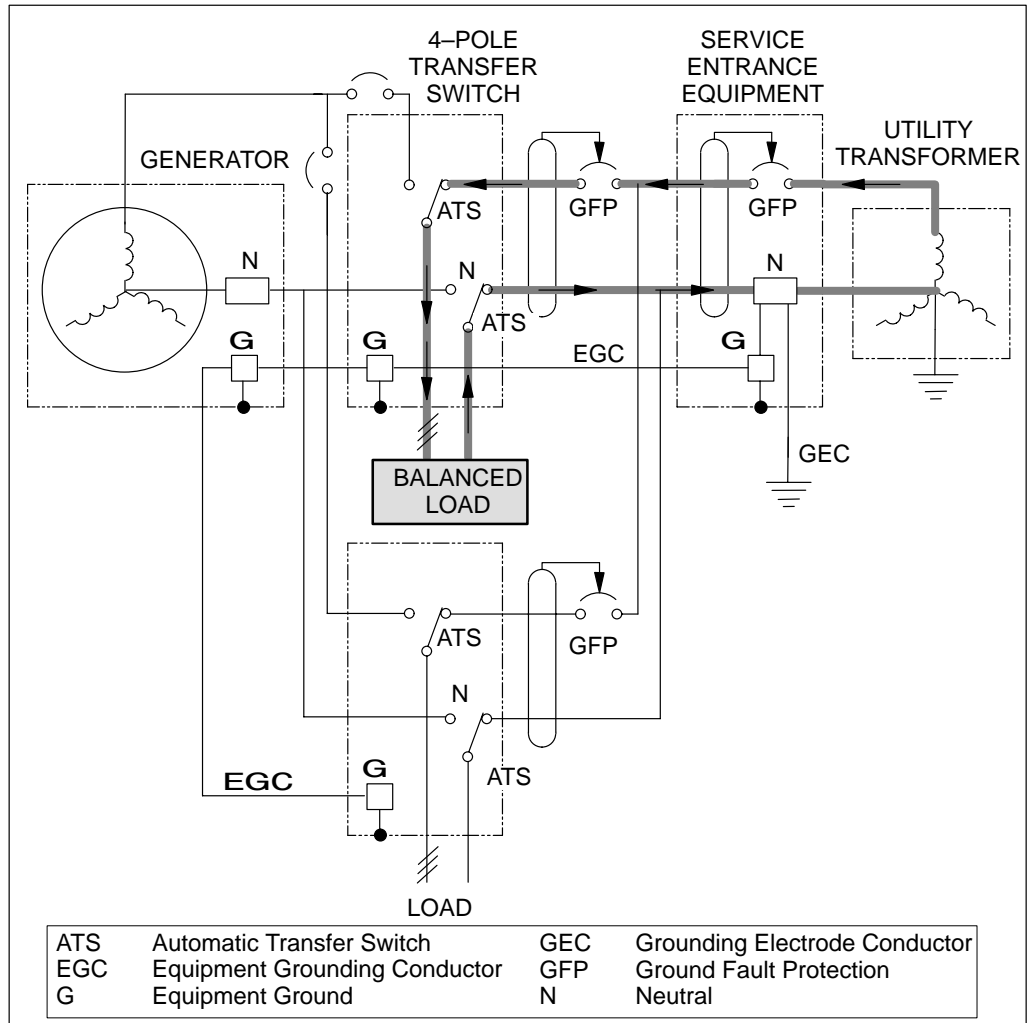


Figure 29. Neutral Pole Switches Applied in Multiple level GFP Systems.

Grounding Methods (cont'd)

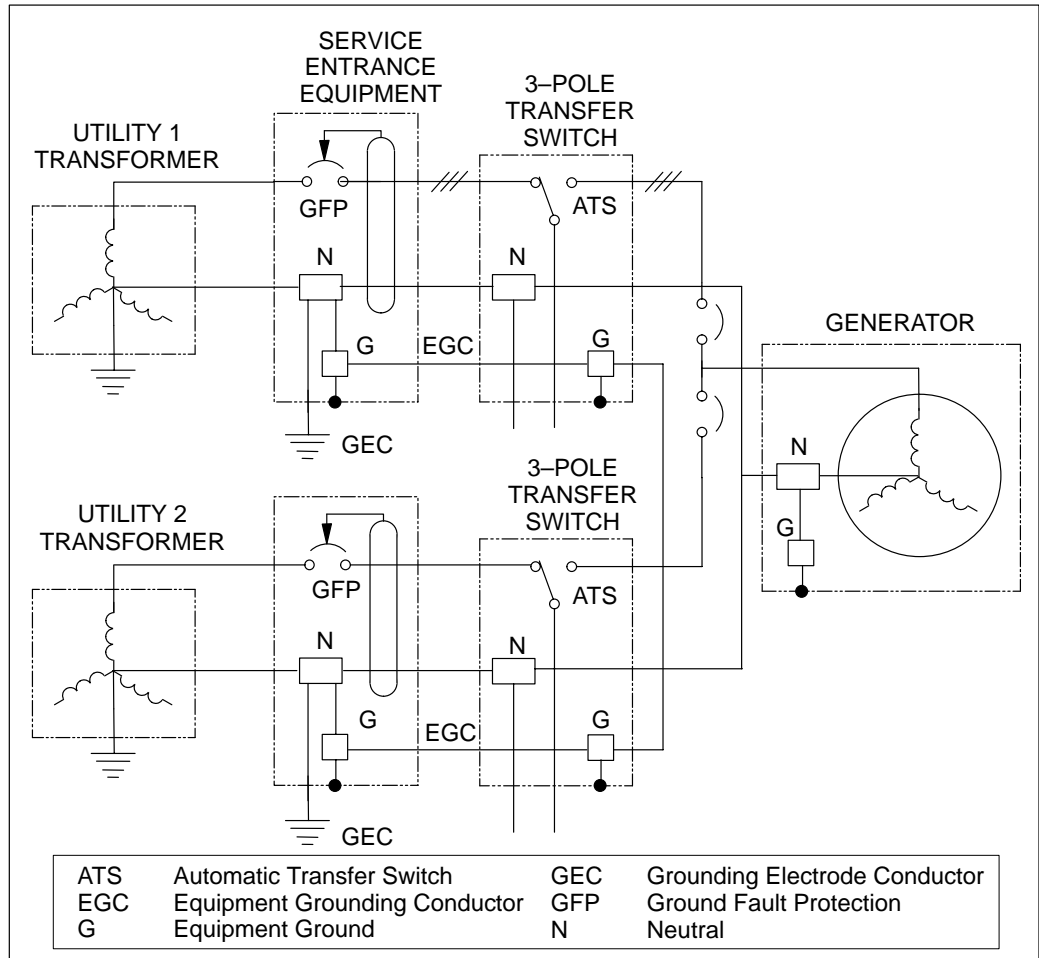


Figure 30. One Separately Derived Generator Serves Two Buildings with Three Pole Switches.

Grounding Methods (cont'd)

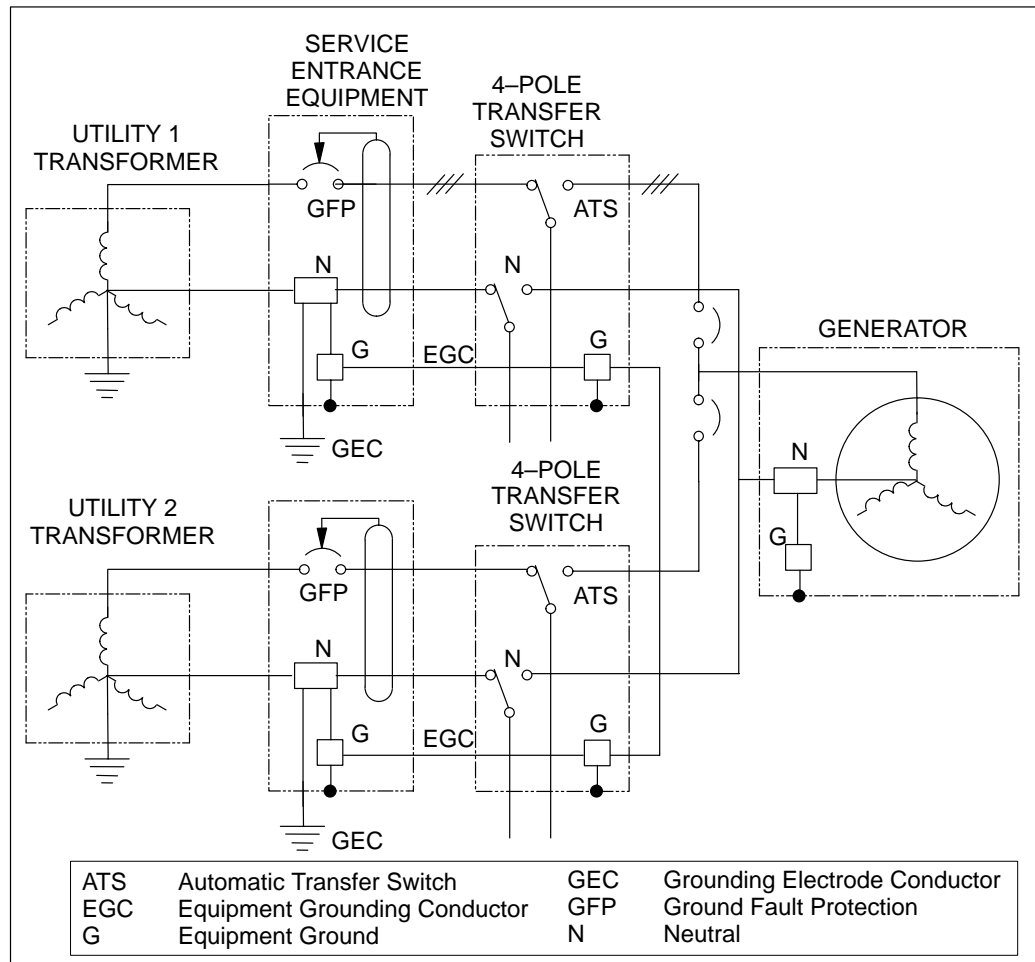


Figure 31. Single Separately Derived Generator Serving Two Buildings with Switched Neutral Switches.

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 from 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 be 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 Ratio
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 possibly 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 – Principles 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 various kinds of overvoltages.

Manual Operation

Some transfer switch equipment is available with optional manual external operators while most include provisions for manual operation internally, usually only after the switch has been isolated from all sources of supply. These switches may not be designed for operation under load since they are not equipped with quick make and break contact mechanisms. Some switches are designed with manual internal operating handles and contact mechanisms employing over-center stored energy quick make and break contacts suitable for load break operation. Even these type switches should be operated with extreme care when energized. Should a fault occur during manual operation, the operator could be subjected to hazardous conditions.

Installation Considerations

Physical Location

Transfer switches may be located either inside buildings or in exterior locations. They may be located in individual enclosures or unit mounted as part of an aggregate assembly such as switchboards, motor control centers, distribution switchboards or paralleling switchgear. Local codes may dictate location for some loads in some applications so be sure to check with authorities having jurisdiction for location requirements. Following are some considerations for determining switch location:

- Transfer switches must be mounted in enclosures acceptable for the intended duty and application.
- Switches should be placed in locations not likely to be adversely impacted by acts of nature or vandalism.
- NEC requires fire pump transfer switches to be located in the same room as the fire pump.
- Switches should be secured in locations accessible to only qualified personnel.
- Switches typically are not to be installed in the same room where the normal utility service equipment is installed.
- Electrical point of interconnection may dictate physical location in many instances. Care must be taken to maintain separation of the normal supply circuits and emergency circuits until they enter a transfer switch. This is done to prevent a catastrophic failure in the normal circuits from disabling the emergency circuits.

Enclosures

All Cummins transfer switch enclosures are UL Listed. The standard enclosure meets the requirements of the National Electrical Manufacturers Association (NEMA) and Underwriters Laboratories for a Type 1; a general-purpose, indoor enclosure that provides protection from accidental contact.

Optional enclosures available in the range of 40– to 1200–ampere transfer switches are: NEMA/UL Type 3R Rainproof and Dustproof, and NEMA/UL Type 4 Watertight enclosures. NEMA/UL Type 1 enclosures are standard on 1600– to 3000–ampere transfer switches. **Table 3** has more detailed information on enclosure application.

Enclosures (cont'd)

Type	Intended Use	Tests
1	Indoor use primarily to provide protection against contact with the enclosed equipment and against a limited amount of falling dirt.	Rod entry and rust resistance or corrosion protection.
3R	Outdoor use to provide a degree of protection against falling rain; undamaged by the formation of ice on the enclosure.	Icing, protection against corrosion, rain and rod entry.
4	Either indoor or outdoor use to provide a degree of protection against falling rain, splashing water, and hose-directed water; undamaged by the formation of ice on the enclosure.	Hosedown, icing, and protection against corrosion.

Source: UL Standard 1008.

Table 3. Enclosure Types and Tests.

Inspection, Testing and Maintenance

Transfer switch equipment generally requires limited maintenance, but some regular care and testing is required to be sure that the equipment will operate properly upon power failure; start the generator set, and transfer power reliably to the alternate power source. Emergency power systems testing is required on a regular basis, and the transfer switch is required to be tested at least once per month per NFPA 110.

Weekly Inspection

On a weekly basis an operator or maintenance technician should inspect the entire emergency power system, including the transfer switch. That inspection should verify that all of the indicating lamps are functional, the control switches are in the proper (automatic operation) position, and that there are no obvious indications of overheating or misoperation.

Monthly Testing

Once per month the emergency power system should be tested. The transfer switch, as a part of this system, should go through its exercise sequence to initiate the test. In a standard exercise sequence, the transfer switch should signal the generator set to start, monitor the generator set as it starts, and transfer load to the generator set. When the generator set test is completed, the transfer switch should transfer load back to the normal service, and shut down the generator set after a cool-down period. Test initiation can be done either by manual operation of a control switch on the transfer switch, or by an automatic time clock in the transfer switch or other building management system device.

This testing not only verifies that the generator set will start and carry load, but also verifies the ability of the transfer switch to detect a power failure, and mechanically connect to the alternate power source. Generator sets are required to be operated at 30% or more of rated load on a regular basis, in order to meet certain codes and standards.

Annual Maintenance and Testing

NFPA110 and NFPA 70B both require an annual inspection and maintenance of automatic transfer switches. These inspection and maintenance actions are intended to detect overheating contacts or connections which may result from overloads, wear in contact assemblies, or loose cable terminations. If these conditions remain uncorrected, the transfer switch can overheat and completely fail. This would result in total power loss to critical loads in a facility for extended periods of time because the transfer switch serves critical loads all the time. Because the transfer switch is always energized in the building's electrical system, replacement of the transfer switch is generally difficult if a catastrophic failure does occur.

Annual Maintenance

Keeping the switch clean will help to prevent dangerous or damaging ground fault conditions. The basic yearly work needed on the transfer switch starts with a thorough cleaning and inspection of the switch. Power to the transfer switch from both the utility source and the generator source is disconnected, and these sources are locked out and tagged for safety. The switch cabinet is then vacuumed and cleaned to remove all dirt and debris from the enclosure.

Exterior surfaces of the switch can be carefully cleaned as long as care is taken to prevent liquid from entering external switches or the interior of the cabinet.

Annual Maintenance (cont'd)

The transfer switch is then inspected for carbon tracking, cracks, corrosion, or any other type of deterioration. Covers over the contact mechanisms should be removed and the contacts themselves should be inspected for abnormal wear or degradation. Transfer switches are operated under load many more times than other distribution circuit devices, and some contact wear is normal. So, it's necessary to monitor transfer switch condition and make corrections and repairs when necessary. Most transfer switches require no lubrication, but if it is required, lubricate according to the manufacturer's instructions.

After the transfer switch is cleaned and reassembled, all the power and control connections should be checked for deterioration and re-torqued according to manufacturer's specifications. In particular, check for wear on wiring which goes across doors, and any wiring which is connected to a moving part.

Annual Testing

On completion of the annual maintenance, a full power failure test is recommended. In the monthly testing of the system, a power failure is typically simulated by manipulation of the control circuits in the transfer switch. In the yearly test, we recommend that the power supply to the facility be physically opened, so that the generator set and power transfer system must function exactly as in a real power failure condition. This verifies that all the critical support equipment is connected to generator power, and that the generator can start and run critical loads.

Thermography

A regular thermographic or infrared examination of transfer switches can be valuable in monitoring transfer switch condition and loading. A thermal evaluation will detect overheating due to not only failure or deterioration of components, but also overloading or the effects of nonlinear loads in the distribution system.

In general, thermographic evaluation is most useful when historical data is available for use in comparing current test data to samples of previous performance. Comparison of current performance to other contacts of identical or similar design with similar load levels, or between contacts of a single device will often highlight contacts that need further inspection or even repair.

If no historical data is available, then test data can be evaluated based on maximum allowable temperatures allowed by UL standards. For transfer switches rated 400 amps and smaller, the contact and lug assembly should be no more than 50C over ambient with full load on the switch.

For transfer switches larger than 400 amps, the maximum temperature allowed is 60C over ambient. Connecting straps and bus bar may operate at temperatures up to 60C over ambient at full load.

Note that thermographic evaluation does not take the place of the required yearly inspection and maintenance, but can highlight problems between service intervals, or indicate the certain need for repairs such as contact replacement which are not commonly required. The advance notice of the need to repair these components can prevent wasted time and unnecessary down time in the system for unplanned or additional shutdown periods.

Appendix A

Bibliography

The following were used as general references in developing the content of this Application Manual:

1. Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems, IEEE Buff Book, Standard 242–1975.
2. The New IEEE Standard Dictionary of Electrical and Electronics Terms, Fifth Edition, IEEE Standard 100–1992.
3. On–Site Power Generation: A Reference Book, Electrical Generating Systems Association, 1990.
4. Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications, IEEE Orange Book, ANSI/IEEE Standard 446–1980.
5. Recommended Practice for Electric Systems in Health Care Facilities, IEEE White Book, IEEE Standard 602–1986.
6. Beaman, D., Industrial Power Systems Handbook, McGraw Hill Book, First Edition, 1955.
7. Smeaton, Robert W., Switchgear and Control Handbook, McGraw Hill, 1977.
8. Ayraud, Stephen and Thumann, Albert, Introduction to Efficient Electrical Systems Design, Fairmont Press, 1985.
9. Standard for Safety, Transfer Switch Equipment, Underwriters Laboratories, Inc., Fifth Edition, 1996.
10. Motors and Generators, National Electrical Manufacturers Association, NEMA Standard MG 1–1998.

Appendix B

Alternative Power Generation System Arrangements

Basic Standby

Basic protection of the electrical service requires one generator set, one utility-to-generator set transfer switch, and two distribution panels as shown in **Figure 32**. One distribution panel feeds utility power to the nonessential loads and the other feeds power to the essential loads. In this application, the transfer switch connects standby generator set power to the essential loads only.

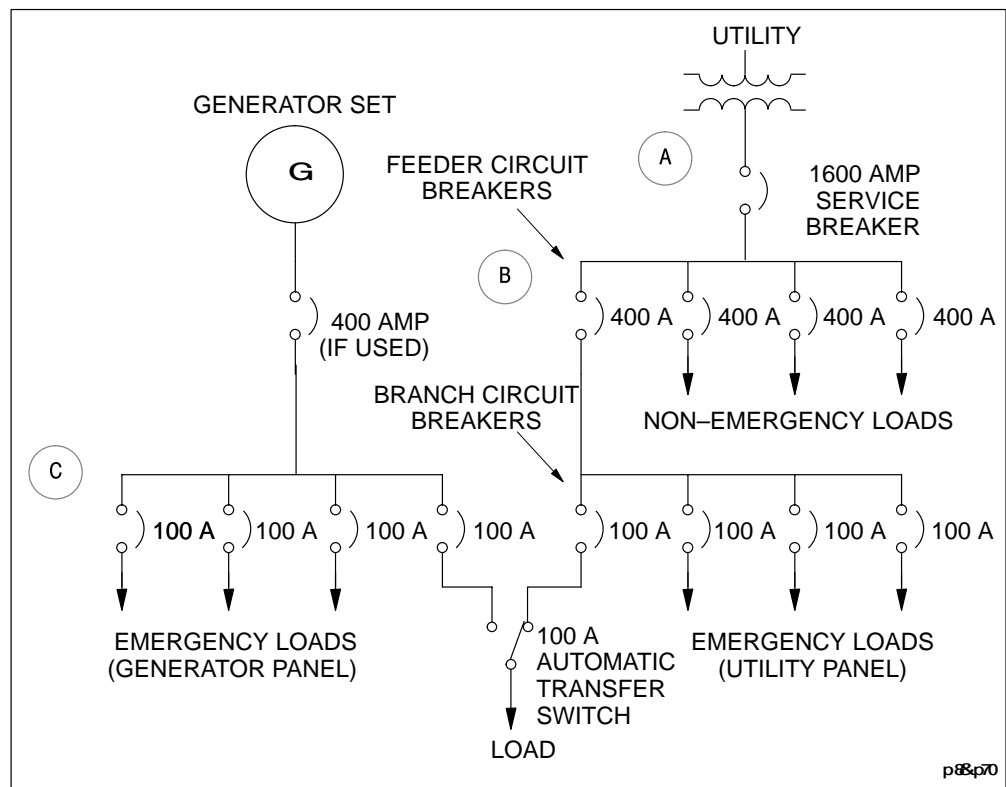


Figure 32. Basic Standby Protection.

Redundant Standby

In a redundant standby arrangement, shown in **Figure 33**, the utility line is backed up by a generator set, which is in turn, backed up by a second generator set. Under normal conditions, the load is supplied with power from the Normal source. If the Normal power source is interrupted, the load is transferred to the first generator set. If the first generator set fails to start or fails during operation, the load is transferred to the second generator set. When Normal power returns, the load is retransferred to the Normal power source.

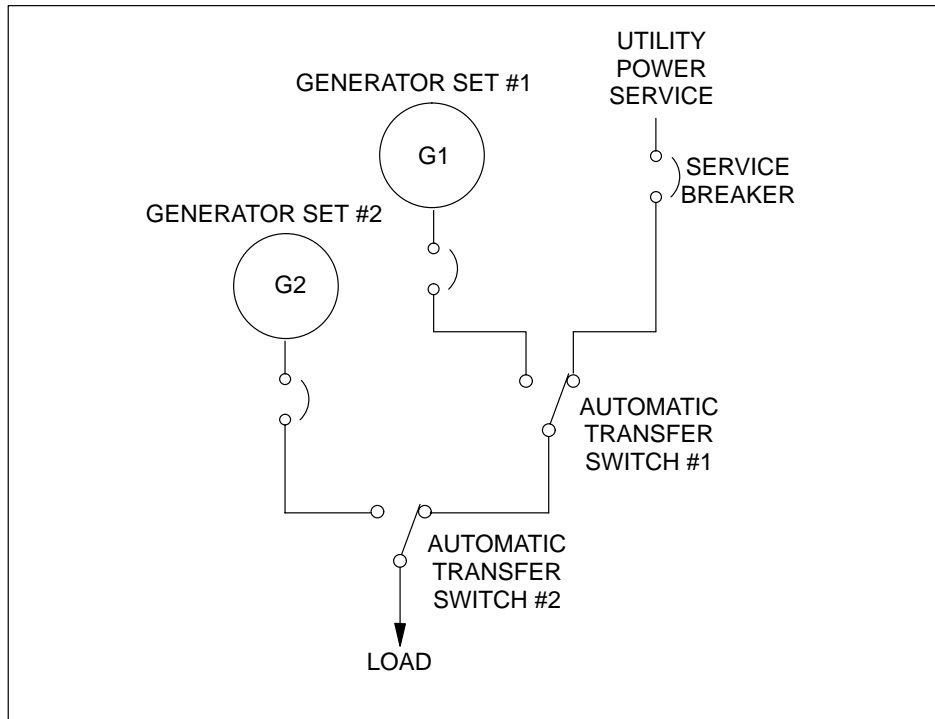


Figure 33. Redundant Standby.

Dual Standby Operation

In dual stand-by applications, shown in Figure NO TAG, utility power is available. The system includes two transfer switches and two gensets. Utility power supplies power to the load and both gensets are backup gensets.

Under normal operation, the utility is supplying power to the load through the lead transfer switch. The lead transfer switch is a utility-to-genset switch.

The two gensets are connected to the genset-to-genset transfer switch. The load side of this switch is connected to the genset side of the lead transfer switch.

Upon loss of utility power to the lead transfer switch, a signal is sent to the genset-to-genset transfer switch to start the preferred genset. When the lead transfer switch senses generator voltage, it transfers the load to that genset. If the preferred genset fails to start, a signal is sent to the backup genset to start.

If the preferred genset becomes available while the backup genset is active, a retransfer is initiated and the load is retransferred back to the preferred genset. A time delay cool-down period is initiated before turning off the backup genset.

When the lead transfer switch senses the return of utility power, it initiates a retransfer sequence and transfers the load back to the utility. The lead switch sends a signal to the genset-to-genset switch to shut down the genset.

Alternating Preferred Source – In an attempt to keep the running time equally distributed between both gensets, the control can be set to alternate between the gensets when utility power fails. The selected preferred genset starts with the first power outage. The second power outage starts the backup genset, which now becomes the preferred genset. Upon subsequent outages, the preferred genset alternates.

Only utility outages and tests or exercises initiated at the lead transfer switch result in the gensets being alternated. The designated preferred genset will not change if it fails and the backup genset takes over the load. Alternating preferred sources can only be enabled with the PC Service tool.

Automatic Priority Selection

The priority selection arrangement, shown in **Figure 34**, uses three transfer switches and two generator sets and allows either of two generator sets to be connected to the critical load during a power outage. Priority load 2 receives emergency power from generator set 2 only if load 1 is receiving power from the normal power source or from generator set 1. If generator set 1 fails during a power outage, automatic transfer switch 3 performs two primary functions. The first is to transfer generator set 2 power to the critical load. The second function is to send a load shed signal to transfer switch 2. Applied to transfer switch 2, the load shed function disconnects generator set 2 from the noncritical loads.

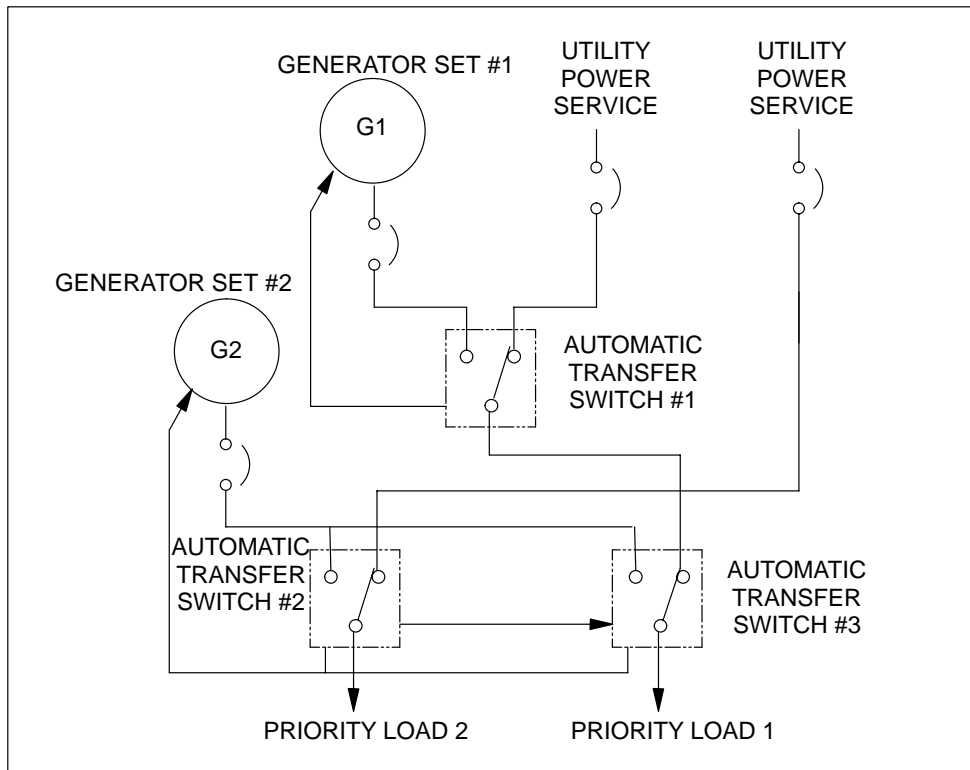


Figure 34. Automatic Priority Selection.

**Prime Power
(Plant to Plant)
Operation**

In prime power applications, shown in Figure 1, utility power is not available. The system includes one transfer switch and two gensets. One genset is always running and supplying power to the load while the other genset is the backup genset.

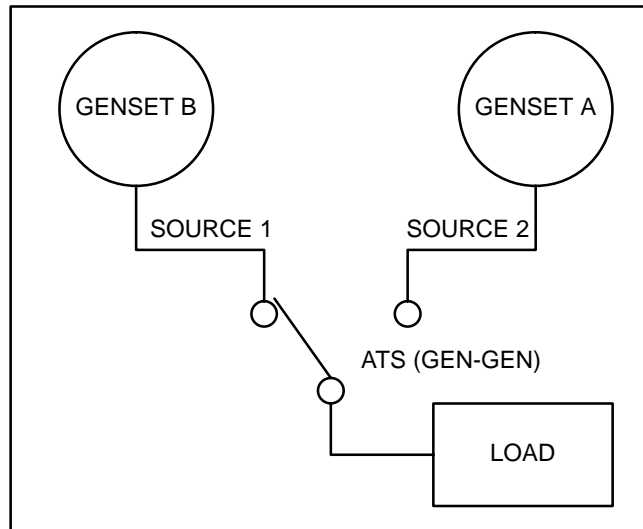


FIGURE 1. PRIME POWER OPERATION

Under normal operation, one genset is designated as the preferred source and supplies power to the load. The second genset is the backup power source. If the preferred genset fails, the backup genset starts and the transfer switch transfers the load to the backup genset.

Automatic Changeover – The transfer switch can be set up to change the preferred source automatically by enabling the changeover timer.

The automatic changeover timer automatically changes the preferred source and transfers the load to the new preferred genset. After the transfer is complete, the control initiates a cool-down period on the old preferred genset before shutting it down. The old preferred genset is now the new backup genset. The changeover timer is now timing for the next changeover and the cycle continues as long as the changeover timer is enabled.

Sequential Prime Power

The sequential prime power arrangement uses three generator sets, running at alternate times, to provide power to a load. This arrangement requires three generator sets and two automatic transfer switches, as shown in **Figure 35**. If generator set 1 fails to operate within a selected range of voltage and (optionally) frequency, transfer switch 1 automatically starts and connects generator set 2. If generator set 2 fails to operate within a selected range of voltage and (optionally) frequency, transfer switch 2 automatically starts and connects generator set 3.

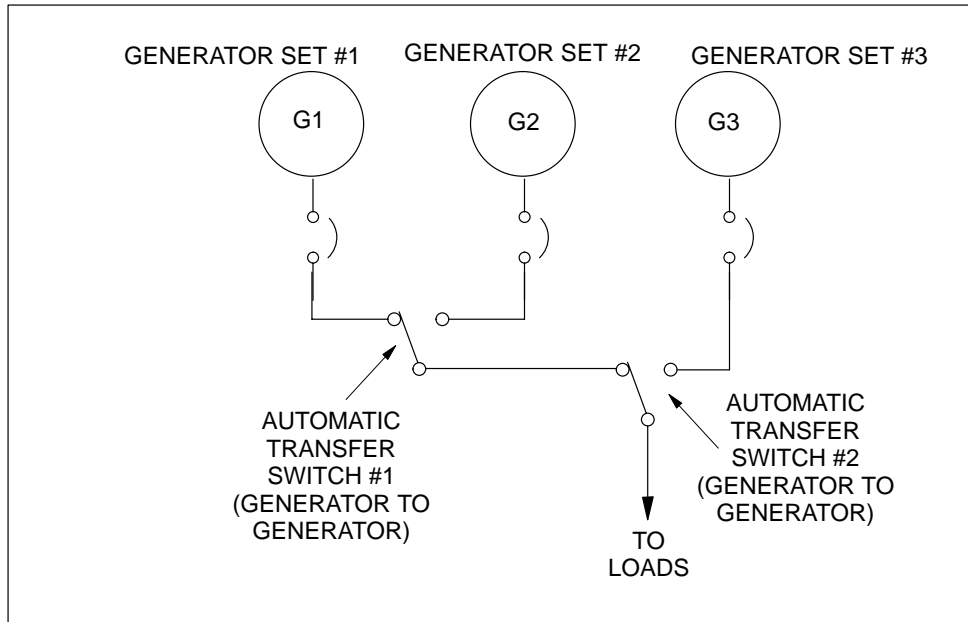


Figure 35. Sequential Prime Power.

Dual Utility With Standby Generator

In this arrangement, a utility-to-utility transfer switch automatically directs transfer of the load from one utility power source to another, providing nearly continuous power, as shown in **Figure 36**. In addition, the utility-to-generator set transfer switch and the generator set provide an additional level of standby power. If the utility 1 power source is interrupted, the load is transferred to the utility 2 power source. If both utility power sources are interrupted, the load is transferred to the generator set.

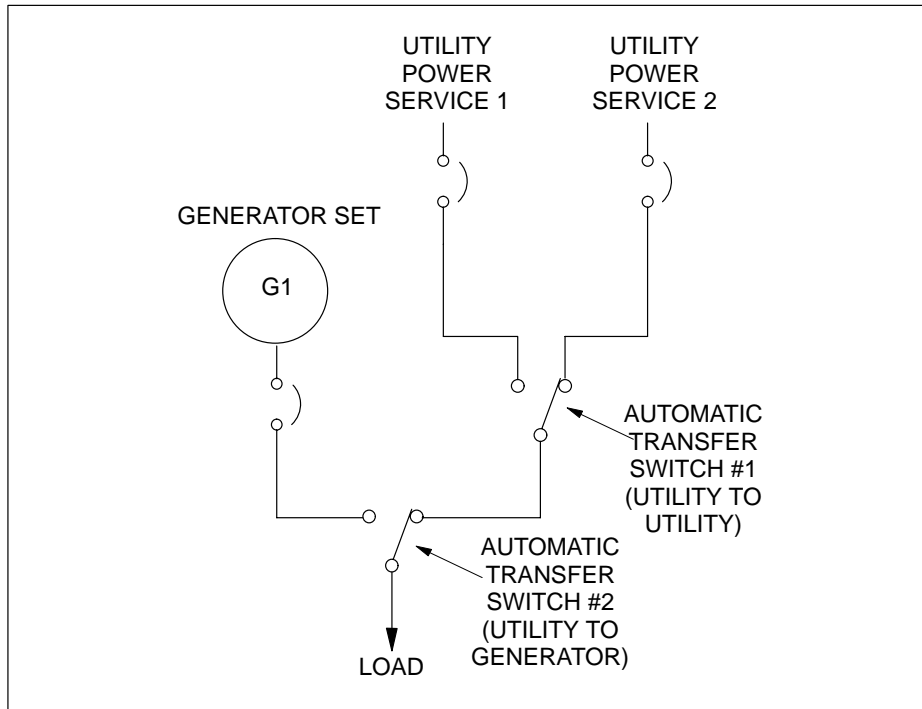


Figure 36. Automatic Dual Utility with Standby Generator Set.

Automatic Transfer Switch with Dual Remote Switches

In this arrangement, as shown in **Figure 37**, the automatic utility-to-generator set transfer switch provides the voltage sensing, generator set control signals, and the timing functions. The more economical remote/nonautomatic transfer switches respond to transfer/retransfer signals from the automatic transfer switch and provide power to their respective loads.

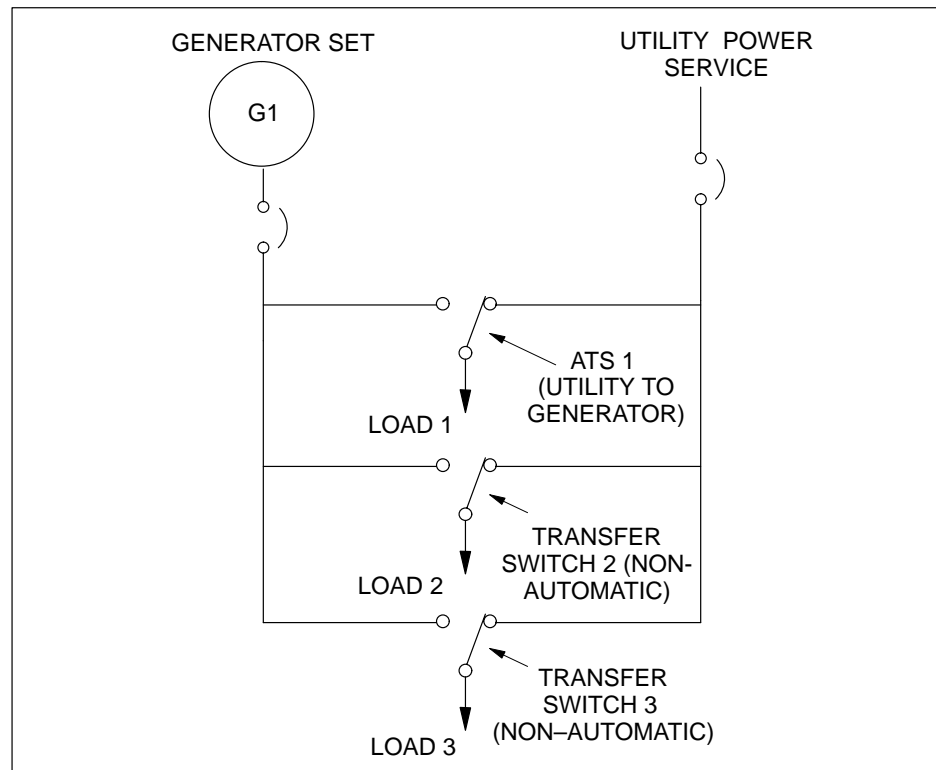


Figure 37. Automatic Transfer Switch with Dual Remote Switches.

Table Number Index

Table 1. Typical Voltage and Frequency Tolerances, **39**

Table 2. Standard Withstand and Closing Ratings and X/R Ratios., **64**

Table 3. Enclosure Types and Tests., **71**

Figure Number Index

Figure 1. Transfer Switch Connected Near the Load., **6**

Figure 2. Selectively Coordinated Breakers., **8**

Figure 3. Mis-Coordinated Breakers., **9**

Figure 4. Transfer Switch Connected Ahead of Load Branch Breakers., **10**

Figure 5. Transfer Switch Connected at Service Entrance., **11**

Figure 6. CBEMA Curve., **16**

Figure 7. Typical Enclosed Automatic Transfer Switch., **18**

Figure 8. Enclosure Interior of Automatic Transfer Switch., **18**

Figure 9. Power Switching Device in an Automatic Transfer Switch., **19**

Figure 10. Typical Closed Transition Transfer Switch., **20**

Figure 11. Typical Bypass/Isolation Transfer Switch., **20**

Figure 12. Contactor Style Transfer Switch., **26**

Figure 13. Breaker Type Transfer Switch., **27**

Figure 14. Single and Double Throw Definite Purpose Transfer Switches., **28**

Figure 15. Solid State Transfer Switch., **29**

Figure 16. Non Load Break Bypass Isolation Transfer Switch., **30**

Figure 17. Load Break Bypass Isolation Transfer Switch., **31**

Figure 18. Closed Transition Transfer Switch., **31**

Figure 19. Over/Under Voltage Settings., **38**

Figure 20. Motor Heating Versus Supply Voltage Unbalance., **42**

Figure 21. Induction Motor Open Circuit Voltage Decay, **45**

Figure 22. Motor Voltage and Phase Shift, **46**

Figure 23. Programmed Transition Operation, **48**

Figure 24. Motor Load Disconnect Circuit., **49**

Figure 25. Single System Ground at Utility Service Entrance., **52**

Figure 26. Multiple System Grounds (Neutral to Ground Bond Improperly Installed)., **52**

Figure 27. Separately Derived Generator with a Switched Neutral Transfer Switch., **53**

Figure 28. Unbalanced Neutral Current. , **55**

Figure 29. Neutral Pole Switches Applied in Multiple level GFP Systems., **56**

Figure 30. One Separately Derived Generator Serves Two Buildings with Three Pole Switches., **57**

Figure 31. Single Separately Derived Generator Serving Two Buildings with Switched Neutral Switches., **58**

Figure 32. Basic Standby Protection., **75**

Figure 33. Redundant Standby., **76**

Figure 34. Automatic Priority Selection., **78**

Figure 35. Sequential Prime Power., **80**

Figure 36. Automatic Dual Utility with Standby Generator Set., **81**

Figure 37. Automatic Transfer Switch with Dual Remote Switches., **82**

Word Index

Table 1. Typical Voltage and Frequency Tolerances, **43**

3-cycle rating, **24**

alternate source, **5**

Ampacity , **1, 3, 21, 60**

Annual Maintenance and Testing, **72**

Arc chute, **1, 22**

Arcing contacts , **1, 22**

Automatic Mains Failure, **32**

Automatic transfer switch, **1, 2, 8, 18, 19, 20, 21, 30, 33, 34, 37, 39, 40, 43, 60, 61, 65, 66, 67, 68, 72, 78, 80, 82**

Automatic Transfer Switches, **33**

available fault current, **6**

Branch circuit, **1, 2, 12, 26, 63**

Bypass isolation switch, **1, 61**

bypass isolation switch, **4**

cascade operation, **10**

CBEMA Curve, **15**

CEC, **4**

circuit breaker type transfer switch, **26**

Closed transition, **2, 4, 14, 19, 20, 26, 27, 31, 32, 36, 44, 50, 61, 62, 63**

Closing rating, **2, 10, 22, 23, 24, 26, 63, 64**

contactor type transfer switch, **26**

continuous current rating, **21**

CSA 282, **4**

current limiting breakers, **6**

current limiting fuses, **6**

Definite Purpose Type, **27**

Delayed Neutral, **47**

dropout setting, **37**

Emergency Systems, **16**

Equipment ground, **2, 52, 53, 55, 56, 57, 58**

Equipment grounding conductor , **2, 52, 53, 55, 56, 57, 58**

exerciser clock, **43**

Extended Parallel Operation, **62**

Fault Monitoring, **44**

Feeder circuit, **2, 6, 10, 11, 75**

Fire pump transfer switches, **17**

Fire Pumps, **59**

Forced Interruptions, **13**

Ground, **2, 3, 40, 51, 52**

ground, **53, 63**

Ground fault protection, **2, 3, 22, 51, 53, 58, 63**

Grounded conductor, **2**

Grounding conductor , **2, 51, 54**

Grounding Methods, **51**

I2t rating, **66**

IEC 947, **4**

In-phase monitor , **2, 49, 50, 62**

induction motor loads, **45**

Induction motors, **39**

Integral overcurrent protection, **28**

Interrupting Capability, **63**

Interrupting rating, **2, 4, 8, 24, 25, 63, 65, 66, 67, 68**

Isolating switch, **2**

isolating switch, **4, 31**

Legally Required Standby Systems, **16**

life safety, **11**

life safety branch, **17, 60**

Listed, **2, 7, 17, 28, 59, 70**

Load Disturbances, **62**

load power interruption, **13**

load power requirements, **5**

load utilization equipment, **5**

Maintenance, **72**

Manual Transfer Switches, **33**

mechanical interlock, **28**

Monthly Testing, **72**

Motor Starter Disconnect, **48**

Motor Starters, **39**

NEMA ICS10, **4**

Neutral conductor, **2, 51, 54**

Neutral ground, **3**

neutral pole, **22**

NFPA 110, **4**

NFPA 70, **4**

NFPA 99, **4**

Nonautomatic switch, **3, 19, 33**

Nonautomatic Transfer Switches, **33**

Nonlinear load, **3, 21, 60, 73**

Nonlinear Loads, **60**

normal source, **5**

Not-In-Automatic Indication, **44**

Word Index

- Open transition, **3, 13, 15, 19, 20, 22, 27, 28, 31, 32, 36, 47**
- out-of-phase sources, **29**
- Overlapping neutral pole, **3, 59**
- Overload, **3, 10, 15, 17, 72, 73**
- Paralleling Controls, **62**
- phase angle, **46**
- pickup setting, **37**
- Program transition, **3**
- Programmed Transition, **3, 15, 34, 44, 47, 48, 49**
- Residual magnetism, **47**
- residual voltage, **45**
- Retransfer Override Switch, **44**
- Separately Derived Generator, **53**
- Separately derived system, **3, 51, 53**
- Separation of Circuits, **11**
- Service Entrance, **12**
- Service entrance rating, **5**
- Service equipment, **3, 7, 27, 51, 70**
- Short Time Withstand Rating, **24**
- Simultaneously Switched Neutral, **58**
- Solid State Loads, **50**
- solid state switches, **14**
- source monitoring, **37**
- Start Time Delay, **42**
- Step Loading, **12**
- Stop Time Delay, **42**
- Surge Withstand Capability, **68**
- switched neutral pole, **4, 51, 53, 54**
- Switching Duty, **22**
- Synchronizing Controls, **62**
- three phase poles, **22**
- UL 1008, **4**
- uninterruptible power, **4**
- Utility Approval, **62**
- voltage rating, **22**
- Weekly Inspection, **72**
- Withstand rating, **4, 24, 25, 27, 65, 66, 67**
- Withstand ratings, **23**