



## Switching the Neutral Conductor

### Abstract

Automatic transfer and bypass switches are made in two, three and four pole versions. The two and three pole variety are generally understood as to usage and ampere/voltage rating of the load carrying contacts. The use of the fourth pole to switch the neutral is less commonly understood. Questions of when to switch the neutral or not in standby power systems must be answered in light of NEC 230-95 and NFPA 70-1996. These standards refer to ground fault protection requirements. The safety and advantages of GFP can only be realized if proper grounding and consideration of neutral switching is taken. When neutral switching is dictated, then the determination of fourth pole contact ratings, synchronization, reliability and integration with GFP must be taken into account. Since April 1989 UL has required more stringent test conformance of the neutral pole and this has a bearing on the designer's choices for standby power systems.

### Standby Power Systems

Modern utility systems are generally reliable but human error or the uncertainty of weather can and does call for emergency or standby power availability. These systems are found in a wide range of environments, including industrial, commercial, office, military, remote, medical, malls, public safety, academic or scientific sites. In all cases, safety as to personnel or destructive fires and outages must be designed in and accounted for. An important element of the standby power system is the transfer switch. These switches are made in two, three and four pole versions. The use of a transfer switch in traditional two or three pole applications, as pertains to automatic voltage sensing of normal source failure and the commands to start and cut over to a standby source, is straightforward. Typically these installations are two pole for single phase and three pole for three phase circuits. The neutral may or may not require switching which would dictate

an additional pole on the transfer switch. The neutral and its relation to grounding, in terms of safety to personnel and equipment for standby systems, must first be understood.

### Grounded vs. Ungrounded Neutrals

NEC differentiates between system and equipment grounding as follows:

*System Ground:* A system ground is a connection to ground from one of the current-carrying conductors of a distribution circuit or of an interior wiring scheme. *See Fig. 1.*

*Equipment Ground:* An equipment ground is a connection to ground from one or more of the non-current-carrying metal parts of the wiring system or of apparatus connected to the system. As used in this sense, the term equipment includes all such metal parts as metal conduits, metal raceway, metal armor of cables, outlet boxes, cabinets, switch boxes, motor frames and metal enclosures of motor controllers. *See Fig. 2.*

*System Neutral Ground:* A system neutral ground is a connection to ground from the neutral point or points of a circuit, transformer, rotating machine or system. The neutral point of a system is that point which has the same potential as the point of junction of a group of equal nonreactive resistances if connected at their free ends to the appropriate main terminals or lines of the system. *See Fig. 3.*

An ungrounded system features no intentional connection between the system conductors and ground. What is easily forgotten though is the capacitive coupling that always exists between system conductors and ground. *See Fig. 4.* Because of the danger to personnel and possible damage to equipment and property, should there be leakage to ground due to shorts or high impedance paths, the NEC decrees that certain grounding practices and detection of these faults be designed into systems.

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The utilities generally provide power to large users via three phase grounded wye distribution. The power transformer feeding the user will have its neutral grounded. For a system having a neutral conductor that is not grounded, the possibility of destructive transient voltages appearing from line to ground during switching of a circuit having a line to ground fault is very likely. *See Fig. 5.* In addition, an ungrounded neutral system developing a fault to ground may go unnoticed until a second ground fault causes a line to line fault which can be of major proportions. *See Fig. 6.* These ungrounded systems are designed into critical industrial processes that cannot afford tripping of protective devices should a ground fault develop. Such a condition could shut down operations or parts of process that could result in explosion or loss of product being processed.

A system featuring **neutral grounding** has many advantages over the ungrounded system. That is:

- Greater safety for personnel and equipment
- Increased service reliability
- Lower operating and maintenance expense
- Reduced magnitude transients
- Simplified ground-fault location

The NEC requires that **ground fault protection** must be used for all solidly grounded wye services. This requirement first appeared in the NEC in 1971 (230-95). It stated, "Ground fault protection of equipment shall be provided for solidly grounded wye electrical services of more than 150 volts to ground, but not exceeding 600 volts phase to phase for each service disconnecting means rated 1000 amperes or more." *See Fig. 7.*

The reason behind this requirement was an awareness that sustained arcing on grounded 480Y/277 volt systems could be very damaging. The selection of 1000 amperes or more for ground fault protection was made with the belief that smaller overcurrent devices with long trip times of 1000 amperes or less would probably clear an arcing ground fault in sufficient time to limit damage. A designer could under this rule, choose as many as six 800 amperes mains in a 480Y/277 volt switchboard (4800 amps of service) without having to install ground fault protection.

Ground fault protection equipment is designed to detect phase to ground faults ignoring over-

loads and phase to phase faults. Three methods of detection are employed:

- Zero Sequence, detects vector unbalance of current sum in each phase and the neutral. Outputs if not zero.
- Residual Connected, uses 3 or 4 CT's and 4 time relays. Any leakage to ground will output a signal.
- Source Ground, detects current flow through system grounding conductor which is connected between neutral and ground.

None of these methods are totally without problems. Proper operation requires that detection will monitor all fault currents to ground. Should there be multiple grounding of the neutral it is possible that proper operation of the GFP device will not monitor the total fault. *See Fig. 8.* Therefore, it is important to insure that grounding of the neutral not take place at multiple locations so as to create unintended paths and defeat the GFP sensor. The NEC further limits neutral grounding via the "separately derived system" rule. That is, a system source such as a transformer or a generator can have its neutral grounded at only one place. The correct place to ground the service neutral is at the main panelboard or switchboard. It is not permitted to be grounded at other points.

## **Standby Power Systems**

A correctly grounded standby generator system including the transfer switch is shown in *Fig. 9.* Note that a three pole transfer switch is used and the gen set does not have its neutral grounded at the generator although the housing is grounded. Should a fault develop to ground only one path exists and the GFP sensor would signal the unbalance. Since the neutral is common to both the normal and standby sources, the generator is not considered separately derived. Under this scheme the neutral is not grounded at the housing. *Fig 10* depicts the division of current that would occur in the event of a ground fault. Some portion would return outside the GFP sensor. Yet another problem with a generator neutral ground is shown in *Fig. 11.* In this case the neutral current can divide and return via the gen set ground path. This also will fool the GFP sensor into monitoring less fault current than may be flowing.

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In all the above cases the three pole transfer switch must have contact structures that are able to withstand the fault currents for the time that is taken before sensing and the protective devices clear the circuit. Transfer switches that are properly designed will have relatively high withstand and close into fault current values for this demanding work. Also in the above cases the neutral current carrying line was solidly connected and not switched. Should the designer want to ground the generator and still adhere to code and avoid the problems of split return paths and improper GFP sensing, the use of a four pole transfer switch is called for.

### ***Four Pole Transfer Switches***

Four pole switches are employed to insure that the generator can be grounded without compromising the NEC. That is, the gen set can be wired as a separately derived system by grounding the neutral at the gen set as long as the neutral is no longer solid through the transfer switch. This of course infers that neutral be switched at the same time as the phases. This scheme will also insure GFP operation as intended. *Fig. 12* shows a four pole transfer switch wired with a gen set having its neutral grounded at the housing. In this wiring the neutral return path is deliberately open for ground return currents by the transfer switch contacts. This will also avoid nuisance tripping in the case of an unbalanced load. In effect, the gen set is now completely isolated from the utility service and presents an effective and safe alternative to solid neutral lines.

A designer has the tools to now configure a standby system as either separately derived or not. If the system needs are for not grounding the gen set at its site then a three pole transfer switch with a solid neutral should be employed. If the gen set needs to be grounded at its site, then a four pole transfer switch must be designed into the system. This will insure that the neutral is switched isolating the normal or utility supply. Lastly, should the designer decide to switch the neutral, consideration to contact ratings and performance should be taken into account.

### ***Fourth Pole and UL Requirements***

As of April 1989, UL 1008 required that the fourth pole of a transfer switch be tested and proven to have ratings equal to its phase contacts [if not of the same construction. And that bus spacing is closer to line than its line to line spacing or it has a different means of support for its neutral bus. That means that the neutral contact must be capable of withstand and close into fault ratings at least equal to the phase contacts. The fact is, not all transfer switches employing

a fourth pole are constructed in like fashion.

There exist four pole switches that utilize contacts:

- of different amperage (lower) capacity than the phases
- that do not actuate by the same means as the phase contacts
- that have bus supports differing from the phase supports
- that have bus structures with closer spacing than phase to phase spacing
- that have synchronizing characteristics differing from phase contact make-break timing

Since all transfer switches must comply with and meet the requirements for UL 1008, a designer must examine the ratings and specifications of a four pole transfer switch should the system call for switching the neutral.

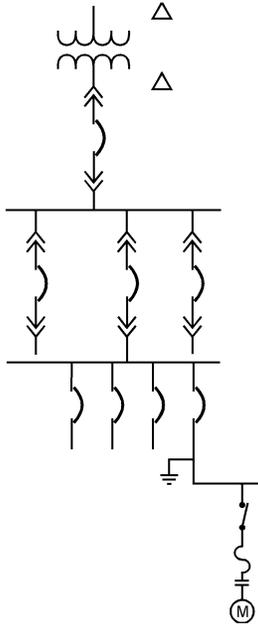
At a minimum the designer should insure that all four poles are equally rated as to carrying, withstand, close into fault currents and voltage. The designer should also ascertain that bus supports, spacings and actuating means are identical for all contacts. The aspect of actuating means can be critical.

If all contacts are actuated by a common shaft, there can be no question of a neutral never having been switched while the phases were. There are switches that have fourth pole contacts actuated by means other than the main phase contact shaft. Interesting results are obtained by transferring the phases to standby power and leaving the neutral connected to the normal power source. There exists some debate over synchronizing the timing of the fourth pole.

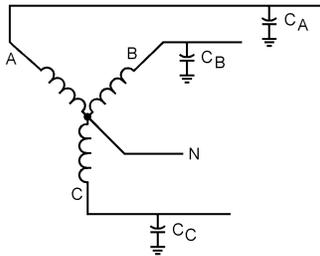
For those transfer switches having all contacts actuated by a common shaft, the neutral will swing in harmony with the phase contacts. In fact, if the neutral leads the phase contacts by an amount to insure make first, break last, then the possibility of transient voltages during switching is diminished or eliminated. For those switches employing a separate actuating means for the neutral, the possibility of timing differences are much greater. These switches employ the overlapping contact arrangement which adds to complexity. Four pole transfer switches with common shafts change position rapidly enough to minimize any currents due to transients.

Although the subject of another discussion, the more recent attention to third harmonic current appearing on the neutral and its attendant emphasis on having greater contact capability, the need for reliable fourth pole operation is even more pronounced.

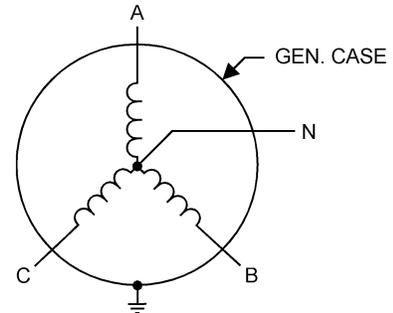
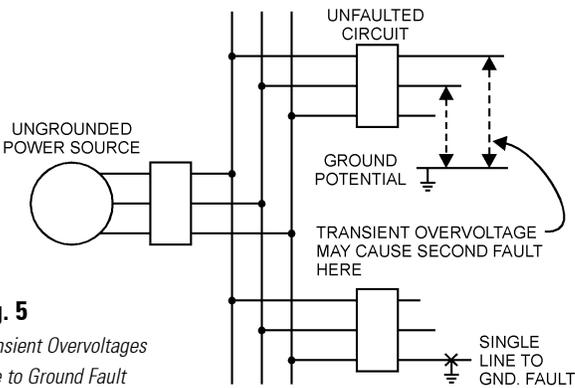
**Fig. 1**  
System Ground on an  
Ungrounded System



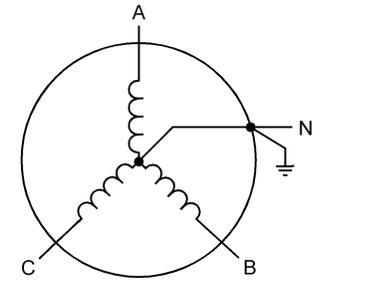
**Fig. 4**  
Ungrounded System  
Capacitively Coupled  
to Ground



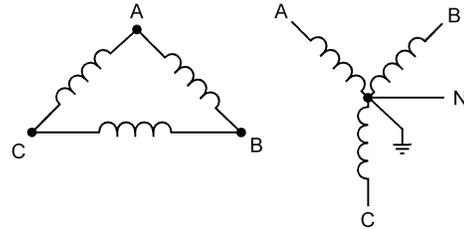
**Fig. 5**  
Transient Overvoltages  
Due to Ground Fault  
Interruption on  
Ungrounded System  
May Cause Other  
Faults to Occur  
on System



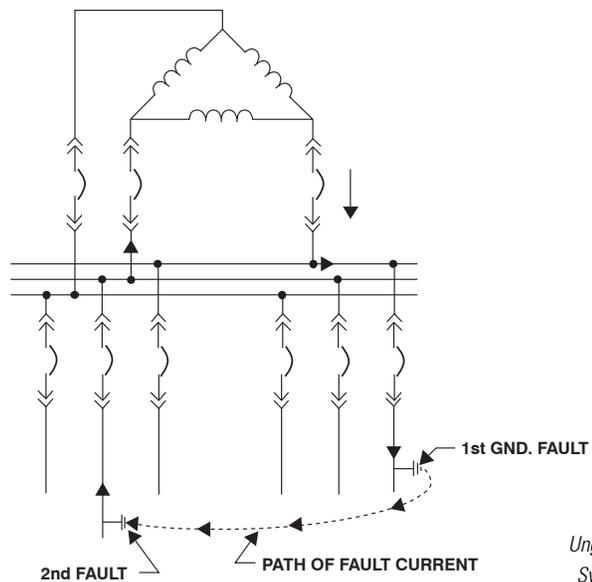
**Fig. 2**  
Equipment Ground  
Ungrounded Neutral



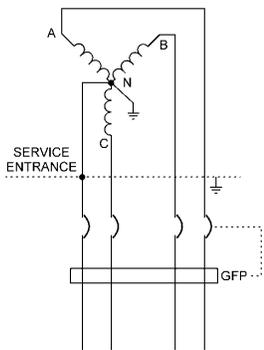
OR



**Fig. 3**  
System Neutral Ground

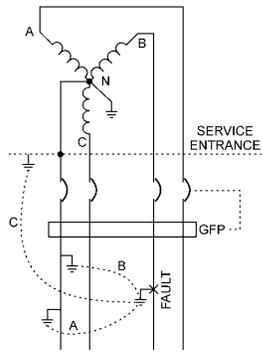


**Fig. 6**  
Ungrounded Neutral  
System Developing  
Second Fault to Ground



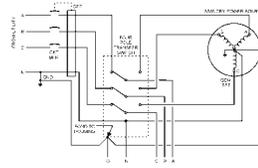
**Fig. 7**

Source Featuring Grounded Neutral at Transformer and Service Entrance with GFP Sensor



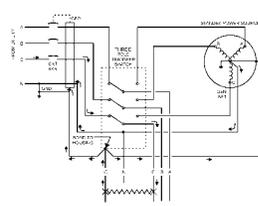
**Fig. 8**

Multiple Grounding of Neutral Allows Fault Current to Flow Back Through Neutral Via Paths A & B (Flow via is outside GFP Sensor)



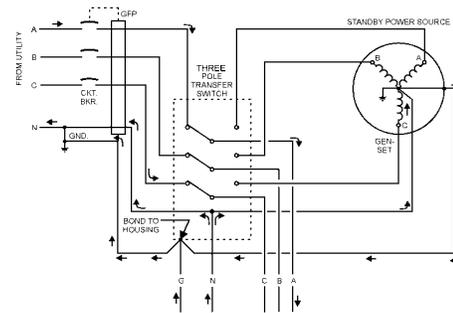
**Fig. 9**

Correctly Grounded Standby Power Source



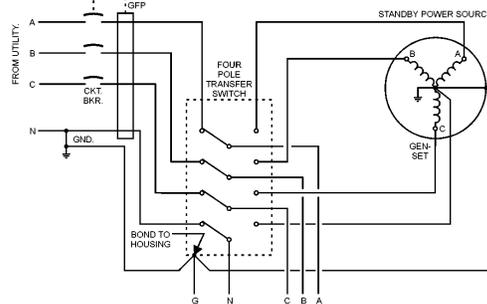
**Fig. 10**

Generator Set Grounded to Neutral at Housing Neutral Bus Isolated from Housing of Transfer Switch



**Fig. 11**

Neutral Current Returning on Ground (Partial Current Outside GFP)



**Fig. 12**

Use of 4 Pole Transfer Switch to Permit Grounding of Generator Set at Site

## Summary

While the system designer has the option of selecting two, three and four pole transfer switches for standby power systems, the choice of ground vs. ungrounded systems is one of safety and code. The NEC requires systems of particular capabilities to incorporate ground fault protection. If GFP is employed, then consideration of appropriate grounding and neutral switching is warranted. Complications and errors can be avoided in grounded systems employing GFP by utilizing four pole transfer switches. These switches must be selected on the basis of the fourth pole ratings, actuation and synchronization.

## References

*ANSI/NFPA 70 – 1996 National Electric Code*

*Nash, Hugh O. Jr, "Ground Fault Protection and the Problem of Nuisance Tripping of Critical Feeders" IEEE CH2581-7/88*

*D. Beeman, "Industrial Power Systems Handbook" McGraw-Hill, 1955*

*A. Freund, "Double the Neutral and Derate the Transformer - Or Else!" E C & M, Dec. 1988*

*UL 1008 now mandates that the four pole transfer switch will have its neutral pole contact meet testing identical to its phase contacts. Recent emphasis by designers is to insure fourth pole integrity by specifying an equal to current rating. Therefore three or four pole transfer switching is available to solve the problem at hand.*



**GE Zenith Controls**