Grounding of AC generators and switching the neutral in emergency and standby power systems

> White paper

By Lawrence A. Bey, Senior Sales Engineer
Jim Iverson, Senior Applications Engineer

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Cummins Power Generation

This is the second part of a two-part white paper on grounding AC generators and switching the neutral in Emergency/Standby systems. In the first part, several basic types of system grounding were covered. In this part the subjects of ground fault protection on the normal source, ground fault sensing and indication on the emergency source, and switching the neutral using 4-pole transfer switches are addressed.

Ground fault protection and switching the neutral

Whenever ground fault protection (GFP) for equipment is provided on the normal source distribution system, and the service has interconnected neutrals with an emergency/standby generator through transfer equipment, the electrical design should include consideration of the use of 4-pole transfer switches and grounding the generator as a separately derived system. Without the use of 4-pole transfer equipment, there may be sensing problems with the GFP and the possibility of nuisance trips. If GFP is not being installed initially, but may be added in the future the initial installation cost of 4-pole transfer equipment may be neglible given the cost of future retrofit. Perhaps increases in capacity for the service are planned or possible so that a GFP system would be desired or required by code. If ground fault indication (alarm) is provided on the generator, 4-pole transfer equipment will be necessary for proper sensing. Generally, whenever a core balance or zero sequence type sensing function for ground fault current is required on either source, or may be in the future, 4-pole transfer switches are recommended. Plans and specifications should include specifics about the number of poles switched by the transfer equipment and instructions on the selected method of generator grounding.

The National Electrical Code (NEC™ Article 230.95(B)) requires ground fault protection (GFP) for equipment installed on solidly grounded 277/480 volt electric services rated 1000 amps or more. At the system designer's option, ground fault protection for equipment may be installed on services less than 1000 amps. The NEC goes on to say,

> "Where ground fault protection is provided for the service disconnecting means and interconnection is made with another supply system by a transfer device, means or devices may be needed to assure proper ground fault sensing by the ground fault protection equipment."
>
> —NEC Article 230-95(C) Fine Print Note No. 3

The Fine Print Note calls attention to the need for a 4-pole transfer switch (a transfer switch with a switched neutral pole) or if 3-pole transfer switches are used that the generator neutral should not be grounded a second time at the generator on the load side of the normal service disconnecting means.

The potential sensing problems that may be experienced by the GFP does not always require 4-pole transfer equipment. A brief review of these GFP sensing problems should provide enough background for the designer to make this judgment for a given application. If it is determined that 4-pole transfer equipment will be installed, the next step may include a review for possible changes in the coordination of ground fault protection equipment settings, depending on the method used for switching the neutral in the transfer equipment. As will be explained later, a simple break-before-make operation of the neutral pole simultaneously with the phase poles will not interfere with GFP operation or settings. There may be the possibility of desensitizing GFP settings where the neutral is switched make-before-break (momentarily overlapping contacts).

SINGLE SYSTEM GROUND

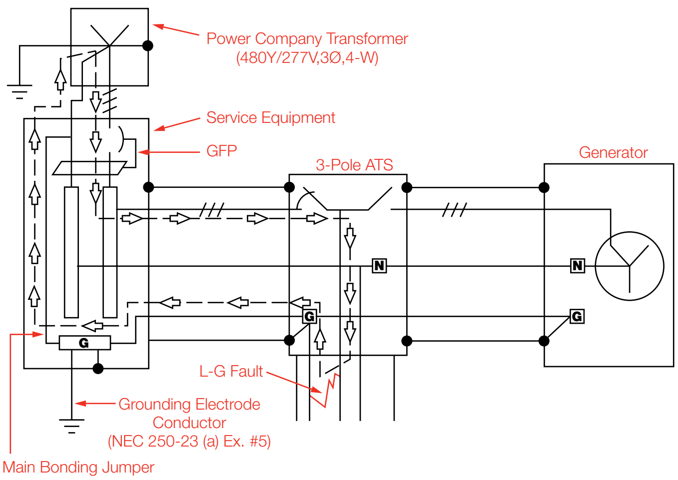


FIGURE 1

Where the normal service is solidly grounded, and the generator neutral is interconnected with the grounded circuit conductor (neutral) from the normal service at the neutral terminal block in 3-pole transfer equipment (FIGURE 1), the generator is considered effectively grounded. These systems are the most typical of those that are required to be solidly grounded by NEC 250.5: using 3-pole transfer switches that switch the ungrounded conductors only and have a terminal block for neutral connections from both the normal source and the generator. In this case, the generator would not be considered a separately derived system, and the generator neutral must NOT be bonded to the generator frame (equipment ground) or GFP sensing problems may result.

> "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."
>
> —NEC Article 250.20(D) Fine Print Note No. 1

In the system shown in FIGURE 1, the neutral conductor is grounded at a single point at the normal service equipment and is not grounded at the generator. The utility neutral and the generator neutrals are interconnected at the 3-pole transfer switch. The generator neutral is not separately grounded, because to do so would create multiple ground fault current paths; one of which would be through the sensor, the other outside the sensor. Ground fault protection for equipment (GFP) may be used on the normal service equipment and it will function as intended with a 3-pole transfer switch in the normal position since the only path for ground fault current is outside the GFP sensors. With a single level of GFP on the service as shown, more than one 3-pole transfer switch may be used without interfering with GFP operation. If additional levels of ground fault protection are used on normal source feeders and branches in the downstream distribution, the system design should not include more than one 3-pole transfer switch.

The problem with grounding the neutral both at the normal service and at the generator is shown in FIGURE 2. Multiple neutral grounds would not be recommended because ground fault current would split and (low in two parallel paths according to the impedance of each path. The NEC 250.24(A)(5) would prohibit a bonding jumper between the generator neutral and ground show in FIGURE 2. The ground fault current sensed by the GFP sensor will be the difference between the actual total of ground fault current and that part of the ground fault current returning through the sensor on the neutral. If the sensed ground fault current does not exceed the setting of the GFP, the GFP equipment will be rendered ineffective. The solutions are to not ground the neutral a second time at the generator, or ground the generator neutral and not connect the normal distribution and generator neutrals together, i.e., use 4-pole transfer switches.

MULTIPLE SYSTEM GROUNDS

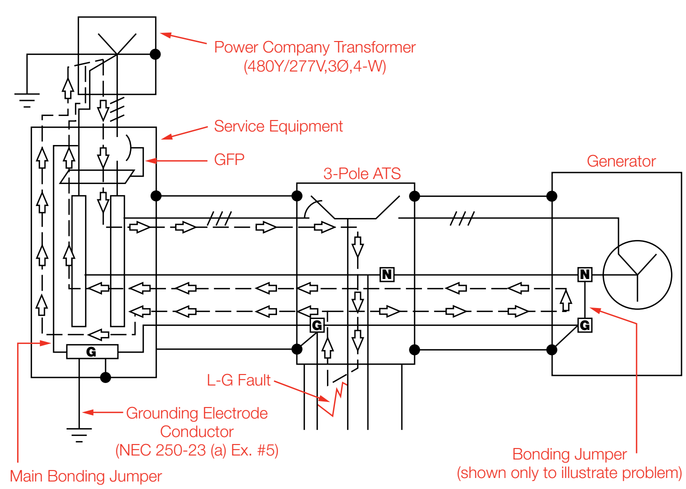


FIGURE 2

Four pole transfer switch (switched neutral pole)

A 4-pole transfer switch is used in applications where it is necessary or desired to ground the neutral of the on-site generator set as a separately derived system. Where the transfer equipment includes a switched neutral pole, there is not a solid interconnection with the service-supplied neutral, so the generator becomes a separately derived system and its neutral must be grounded in accordance with NEC 250.30. There are cases where it will be necessary to use 4-pole transfer switches and ground the neutral of an on-site generator set.

IMPROPER GROUND FAULT SENSING

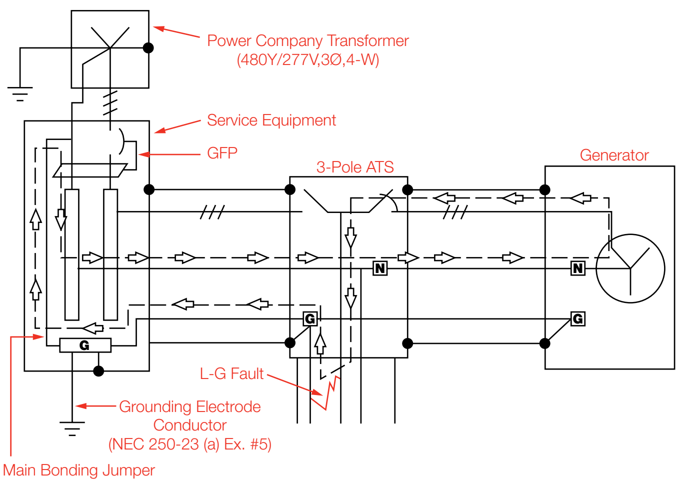


FIGURE 3

FIGURE 1 shows a 3-pole transfer switch with the load connected to the normal source. The operation of the GFP equipment must also be considered when normal power is available and the generator source connected to the load as it would be during tests and during time delays on retransfer as shown in FIGURE 3. Because the generator neutral is not grounded, the only path for ground fault current back to the source is through the equipment grounding conductor to the normal service equipment, through the GFP sensor and back to the generator on the neutral.

If a ground fault occurs while normal power is available and the generator is supplying power to the load, a potential exists for a trip of the GFP equipment at the utility service. If this possibility were to occur, the transfer switch control would not allow a retransfer operation to an open disconnect even though utility power was available on the line side. The limited circumstances under which this could occur and the extent to which this would become a problem warrants engineering judgment to determine whether to use 4-pole transfer switches and ground the generator as a separately-derived system.

Hospital essential electrical systems serve as a typical example of an application where 4-pole transfer equipment would likely be required. In hospitals, NEC Article 517.17 requires selectively coordinated two-level ground fault protection of equipment for feeders when the service has been provided with GFP. Hospitals with large (150 kVA or more) essential electrical systems are also required by the NEC to have a minimum of three transfer switches. If the normal service has GFP with additional levels of GFP also provided for feeders (two or more levels) and the system includes more than one transfer switch, then switched neutral transfer equipment and a grounded neutral generator are necessary so that the GFP system equipment will operate as intended.

FIGURE 4 illustrates one potential problem with the arrangement where the normal distribution has GFP on the service and on the feeders, and the neutral conductors are solidly interconnected in two or more 3-pole transfer switches. In this situation, two parallel paths exist for neutral current caused by unbalanced loading or non-linear loads, so that the neutral current may split according to the impedances of the parallel paths. The second level GFP sensor on the feeder may be bypassed such that there is a non-zero net difference of current sensed, which could result in a nuisance trip. Parallel paths for ground fault current may also be the result of multiple ground faults that could defeat the GFP sensors.

One solution to GFP sensing problems is shown in FIGURE 5. The basic arrangement is the same as in

MULTIPLE PATHS FOR NEUTRAL CURRENT

Some Detail Omitted

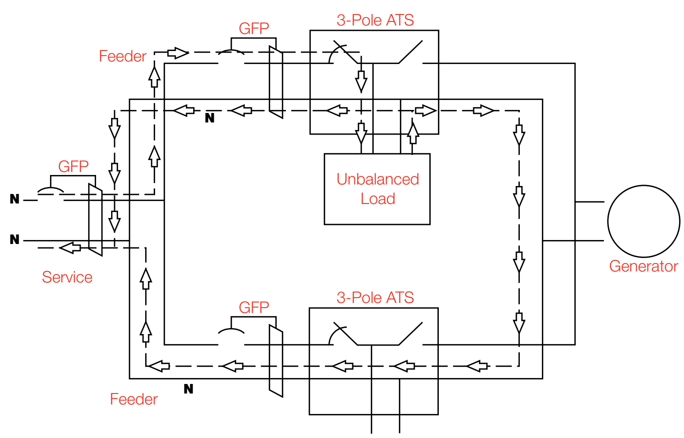


FIGURE 4

Power Generation

FIGURE 2 and 3, except that 4-pole transfer equipment with a switched neutral pole has replaced the 3-pole transfer switches with a solid neutral terminal block. The alternate paths for ground fault current described above and shown in FIGURE 2 and 3 have been eliminated by the open neutral pole in the transfer switch. Because there is no solid interconnection with the service-supplied neutral, the generator is considered a separately-derived system and its neutral must be grounded.

If the emergency generator set is rated 277/480 or 347/600 wye, and the generator main disconnecting means is rated 1000 amps or more, NEC Article 700.7 (D) will require a ground fault indication on the generator. Note that this requirement is for an indication (alarm) only, and circuit interruption is not required. The NEC does not require that sensing ground fault current cause a trip that would result in a loss of power to emergency systems involving life safety. While ground fault indication is required by NEC above 1000 amps, it can be and often is provided on smaller systems below 1000 amps as well.

Sometimes the NEC requirement of 230.95 for ground fault protection on high capacity services is interpreted to apply to emergency standby generators as well. However, the NEC states in 700.26 that ground fault protection of emergency services that would include a trip shall not be required. Providing ground fault protection that includes circuit interruption may be contrary to the intent of codes for essential electrical systems. The codes suggest that higher priority be given to continuity of service than to the protection of essential electrical system equipment, except where equipment protection is required to prevent a greater hazard than lack of essential electrical service. In general, Cummins Power Generation does not recommend using ground fault protection that includes tripping off critical emergency service or feeders.

SWITCHED NEUTRAL POLE

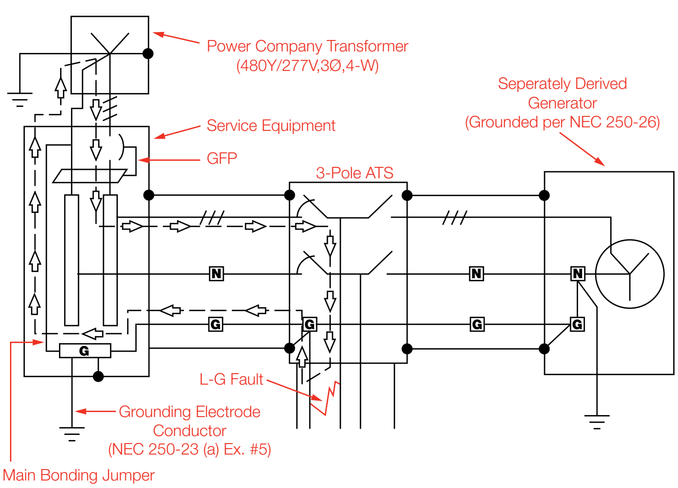


FIGURE 5

Neutral switching methods

All major manufacturers of transfer equipment have switched neutral transfer switch equipment available, using one or two methods. One manufacturer uses an overlapping (make-before-break) neutral contact switching method, while all the rest of the major manufacturers, including Cummins Power Generation, use a simultaneously switched (break-before-make) neutral pole.

Overlapping neutral contacts

With overlapping neutral contact switching, the neutral is momentarily closed to the grounded neutrals of both power sources in a make-before-break action. In a transfer operation from the normal power source to the generator source, one set of neutral contacts close to the generator side while the other neutral contacts remain closed to the normal source, then the phase poles transfer from normal to the generator, and then the neutral contacts to the normal power source open. Retransfer to the normal source from the generator reverses this operation. A temporary neutral connection is created with multiple grounds such that neutral current has two paths of return to the source during the overlapping make-before-break switching action.

Overlapping neutral switching requires a mechanism that is separate from the 3-pole phase conductor mechanism. Close tolerance adjustments control the critical timing between the phase poles and the make-before-break action of the neutral contacts, necessary for predictable and reliable performance.

When considering application of overlapping neutral contacts, a close analysis is strongly recommended to determine the effect of momentary multiple neutral grounds on the selective coordination of ground fault protection equipment. With unbalanced neutral current, a nuisance GFP trip could result when no ground fault exists. Such an analysis of the system design should include:

1) A calculation of the amount of neutral current based on the unbalance of linear phase currents with multiple neutral grounds (non-linear current represents a more difficult analysis), and

2) a determination of the precise duration of the multiple neutral grounds (overlap duration) for the specific size of transfer switch used.

With this information and based on the ratings and settings of the around fault protection equipment used, analyze the effect of the neutral current unbalance for the specific overlap duration on the sensitivity of GFP equipment to determine that a nuisance trip will not occur. FIGURE 6 shows the ground fault trip characteristics of one manufacturer's circuit breakers. From these characteristics, it can be seen that an overlapping neutral duration that exceeds 100 milliseconds may affect selective coordination of the GFP equipment. If a nuisance trip is possible, it may be necessary to decrease the sensitivity of the affected GFP equipment to avoid the nuisance trip. This would sacrifice the maximum protection the GFP can provide in minimizing the damage due to an actual ground fault. If the sensitivity of the affected GFP is decreased. It may also require the designer to re-examine the GFP selective coordination of upstream GFP equipment.

GROUND FAULT PICK UP SETTINGS

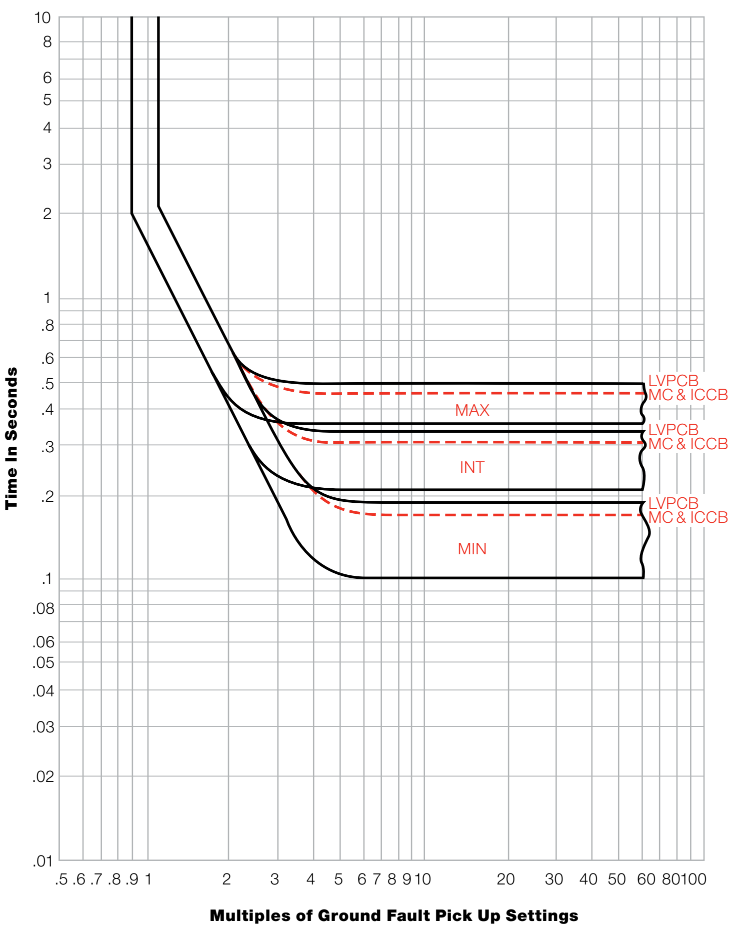


FIGURE 6

Increasing GFP current settings or extending time delays to avoid nuisance tripping, would reduce protection for single-phase ground faults. J. R. Dunkle-Jacobs, a leading authority on protection, has found that in bare bus switchboards, an arcing single phase ground fault can escalate into an arcing multi-phase fault within as little as 1 to 2 cycles.*

Once the escalation occurs, the fault current is again balanced or nearly balanced and will not be detectable by a GFP sensor once balanced. The arcing fault will have to be cleared by the relatively slower phase overcurrent devices, and more extensive damage can be expected.

Therefore GFP equipment should be set to initiate a trip as fast as possible to be most effective in limiting damage. Ground fault detection using instantaneous overcurrent relays (ANSI device #50) which can respond in $1\frac{1}{2}$ cycles (25 milliseconds) from onset of the fault condition would provide the most sensitive protection. These relay devices could not be used with an overlapping neutral pole, which may require the GFP delay to be extended beyond 100 milliseconds to avoid nuisance tripping, and would significantly reduce the protection afforded by the GFP.

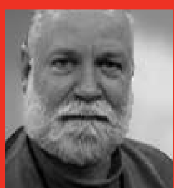
Simultaneous neutral switching

Simultaneous switching of neutral and phase conductors has the advantage of being simple and reliable, and not interfering with the selective coordination of GFP settings. With simultaneous switching, the neutral pole is mounted on a common crossbar with the phase poles, and is switched at the same time as the phase conductors in a break before make action. Use of a simultaneously switched neutral pole does not require GFP to be delayed because the grounded neutrals of the two power sources are never connected together, not even momentarily. Also, use of a common crossbar ensures simultaneous isolation of all phase conductors and the neutral, preventing any possibility of developing transient high voltages on the neutral as a result of isolating the neutral substantially sooner than the phase conductors.

The Cummins Power Generation switched neutral pole has a construction identical to the ungrounded poles which are designed to interrupt inductive load current; including main contacts made of heavy duty silver alloy with arcing surfaces, and multiple leaf arc chutes to cool and rapidly extinguish arcing. FIGURES 7a and 7b

* Reference. J. R. Dunkle-Jacobs *The Escalating Arcing Ground Fault Phenomenon*, IEEE. Transactions on Industry Applications a, VOL. 1A-22. No. 6. November/December 1986.

About the author



Lawrence A. Bey is a Senior Sales Engineer and a 1978 University of Minnesota graduate. Larry has been a Cummins Power Generation employee and a CPG Distributor Sales Engineer for a total of 29 years. Larry represents Cummins Power Generation on Technical Committees of the National Fire Protection Association for NFPA 110 Emergency and Standby Power Systems, NFPA 99 Essential Electrical Systems for Health Care Facilities, and CMP 20 of the National Electrical Code. Larry also represents Cummins Power Generation on the Canadian Standards Association for Emergency Power Supply Systems. Larry is active with the National Electrical Manufacturers Association (NEMA) on the Automatic Transfer Switch Subcommittee. He has written articles for industry publications on grounding of generators, overload protection of generators, as well as starting motors from generators.

are partially assembled Cummins Power Generation 3-pole and 4-pole transfer switches, respectively.

The figures show that the fourth pole is identical in construction and operates from the same common crossbar as the phase poles, without complex linkages. The Cummins Power Generation over center stored energy contact mechanism (used up to 1000 amps) controls the speed of contact opening and closure in a quick break quick make action, minimizing gassing caused by drawing an arc across the contacts. The design and construction of the contacts, and the controlled rapid speed of contact closure and opening, maintain the low impedance of the switched neutral pole. No maintenance is required or recommended.

FIGURE 7a – 3-pole transfer switch (partially assembled)

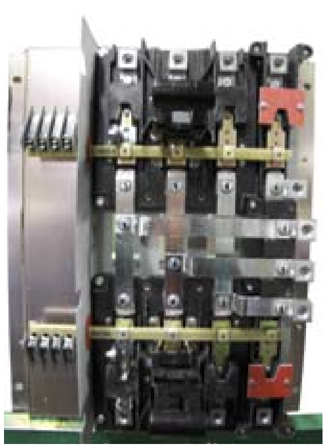


FIGURE 7b – 4-pole transfer switch (partially assembled)

Summary

Use 4-pole transfer switches where required to avoid GFP sensing problems, typically where the normal service has two or more levels of GFP installed and multiple transfer switches are used. 4-pole transfer switches are also required where indication of ground fault is provided on the emergency generator, so that the sensing will detect downstream faults rather than look backwards into the generator. Future consideration of the possible addition of GFP systems may favor the initial installation of 4-pole pole transfer switches.

If, and only if, 4-pole transfer switches are used the generator must be grounded as a separately derived system. The generator neutral should not be bonded to its equipment grounding electrode where the generator neutral is solidly interconnected with the grounded neutral of the normal supply, except where switched neutral transfer equipment is required.

Based on the premises that arcing ground faults can escalate to a balanced arcing fault in 2 cycles or less, and that overlapping contact neutral devices may require significant reductions in GFP sensitivity, simultaneously switched 4-pole switches are recommended where neutral switching is required.

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