

Avoiding Ground Fault Problems When Designing For Multiple Low Voltage Sources

By Mike Pintar, GE LV Switchgear/Switchboard Application Engineer

The need for more reliable electric power in commercial and industrial applications has caused the design of low voltage distribution equipment to migrate from simple, single-ended loadcenter unit substations to power systems with multiple utility sources, emergency and back-up generators, and uninterruptible power sources. The purpose of this article is to point out some of the problems associated with meeting the requirements of providing equipment ground fault protection on multiple-source low voltage distribution equipment, both switchgear and switchboards, and how to contend with them.

Grounded 3-Wire Systems With Multiple Power Sources

A grounded 3-wire system has the neutral of the source bonded to ground at the source and/or at the service entrance equipment, but the neutral conductor is not carried through the low voltage distribution system. Methods for properly applying equipment ground fault protection on 3-wire systems are well understood. Ground current is monitored at either the neutral bonding connection at each source (ground return) or at each service disconnect (ground-sensor or residual sensing). Ground return sensing will only work when the neutral is bonded in one location per source and the current sensor monitors that one location. Bonding the neutral at the source **AND** at the service entrance equipment will likely render the ground fault system inoperative since the ground current will have parallel return paths, of which only one will be monitored. Ground fault protection that is provided as an integral function of the circuit breaker trip unit uses a residual connection or summation of the phase overcurrent sensors to determine the presence of a ground fault. Ground fault systems with discrete components (sensors and relays) may use any of the three ground fault sensing methods – ground return with a single sensor around the neutral-to-ground bonding connection, ground-sensor with a single sensor encircling all three phase conductors, or residual using three individual sensors, one in each phase.

Operating non-parallel -- Multiple sources operating in a non-parallel configuration will have electrical or mechanical interlocking to allow only one source to be connected to a given feeder bus. These systems operate similarly to the single-ended (one source) configuration where all ground fault current will be sensed either at the main and feeder breakers supplying current to the ground fault or at the neutral-to-ground bonding connection for the source supplying current to the ground fault, as described above. Fig. 1 illustrates ground return sensing on the left side main and residual sensing on the tie and right side main.

Operating in parallel -- Ground fault protection for systems with multiple sources that can operate in parallel, either through a normally closed tie breaker or a single bus with two or more active sources, is the same as for systems operating in a non-parallel

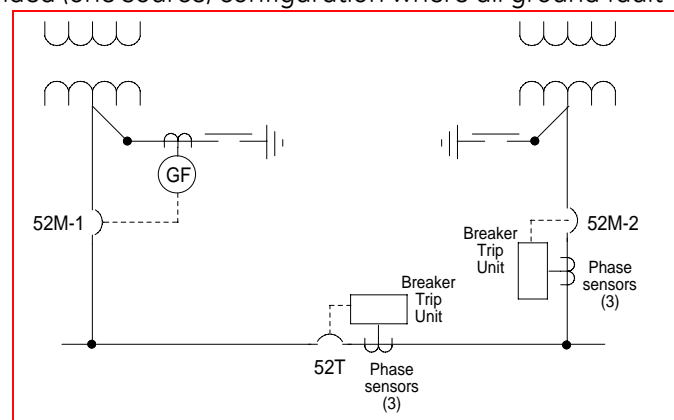


Fig 1 - Grounded 3-wire, multiple source system

mode. The only differences between the two are that the interlocking is removed from the source breakers and that the total ground fault current will not be sensed at a single point but a portion will be sensed at each source contributing ground fault current. A single-point ground system, similar to that shown in Fig 4, could also be used for multiple source 3-wire line-ups to trip the tie breaker(s) and isolate the feeder buses. After the buses are isolated, the source breaker feeding the faulted bus will be tripped (by time delayed setting) to clear the fault, leaving the balance of the low voltage line-up energized.

4-Wire Systems With Multiple Power Sources

Four-wire systems present a unique set of challenges for ground fault sensing because of the common neutral connection between the power sources. A “common neutral” means the wye point from all sources are connected together through the low voltage distribution system, typically via the neutral bus in the low voltage switchgear or switchboard. This common neutral connection between sources provides an alternate path, in addition to the normal ground grid, for ground fault current to flow. As a result, precise ground fault current sensing becomes more complex. The most common method of sensing ground fault current on multiple-source, 4-wire systems is a “modified differential scheme” where the ground fault sensors for each source (and tie) breaker are interconnected.

Modified differential schemes can be implemented via the trip units in each source and tie breaker with interconnections between each of their neutral sensors as shown in Fig 2. A similar scheme can also be executed with external current sensors and relays. The proper interconnection of these sensors can provide accurate detection of the ground fault current, determine which bus has the faulted circuit (if the system has more than one feeder bus), and selectively isolate the smallest portion of the power system to clear the ground fault. It is also able to distinguish between true neutral current and ground fault current.

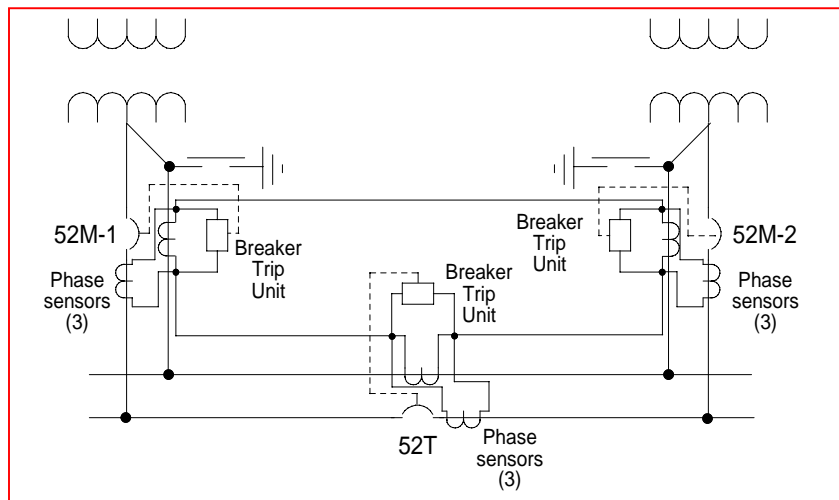


Fig 2 - 4-wire, modified differential, integral ground fault scheme

Operating non-parallel -- Multiple sources operating in a non-parallel 4-wire configuration are similar to the 3-wire scheme described above except that now ground fault current can take at least two paths back to the source – one being the actual ground path, the second being the system neutral. Using the modified differential scheme for ground fault sensing will cause only the breaker(s) supplying current to the fault to trip. If there is more than one breaker in series with the faulted circuit, the breaker closest to the fault can be made to trip first, providing a selective system. Selective tripping for breakers in series between the source and the fault is accomplished by time delay settings on the ground fault protective device (trip unit or component relay).

Operating in parallel -- Multiple sources operating in parallel through a normally closed tie breaker or on a common feeder bus add a further level of complexity to systems with a common neutral. It now

becomes more difficult to determine which breakers to trip and the proper sequence to quickly isolate the ground fault with minimum impact on the rest of the system.

- o Circuit breaker trip units with integral ground fault protection require their neutral sensors be connected to their corresponding trip units for proper operation (refer to Fig 2). This scheme also requires at least one of the source or tie circuit breakers to be open so that its neutral sensor can act as a current source for the loop made by all the interconnected neutral sensors. In a parallel operating mode, there is no open breaker and therefore no neutral sensor to drive current around the loop. Ground fault protection integral to the circuit breaker trip units should therefore not be specified for this mode of operation.

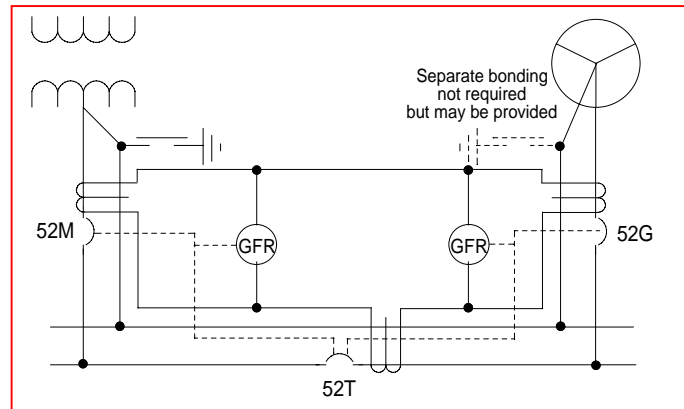


Fig 3 - Modified differential using component sensors and relays

- o The modified differential (or current summation) method, employing sensors and relays, as shown in Fig 3, can be used to provide selective tripping of the source and tie breakers supplying ground fault current to a faulted bus. This scheme will simultaneously trip source and tie circuit breakers supplying current to the faulted bus. Referring to Fig 3, circuit breakers 52M and 52T would trip for a fault on the left-hand bus and 52G and 52T would trip for a fault on the right-hand bus. Tripping the source and tie breakers only occurs if a branch circuit breaker fails to clear the ground fault or if the ground fault is in the distribution equipment bus.

- o Another alternative for ground fault protection on parallel systems is to provide a single point where the common neutral is connected to ground instead of grounding the neutral at each source or service entrance. This is called “single-point ground” or “T-connection” because the common neutral connection to ground looks like the letter “T”, shown in Fig 4. All ground fault current passes through

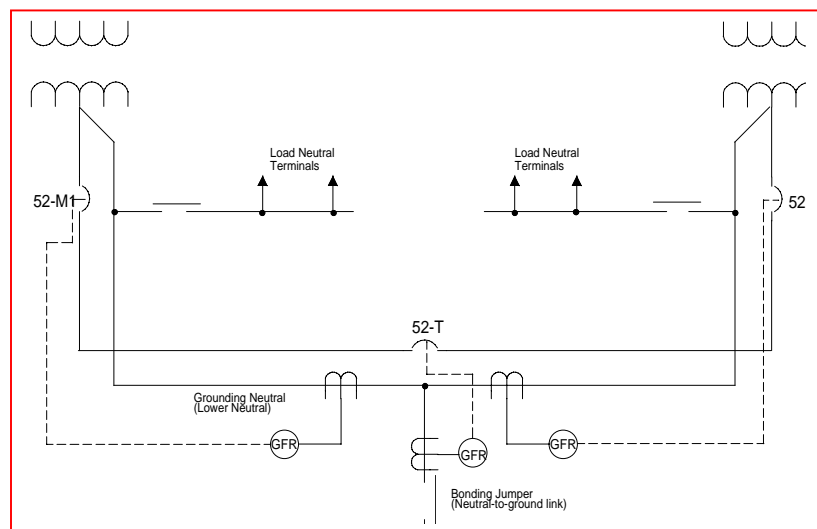


Fig 4 - Single-point ground or T-connection ground fault scheme

- the ground fault sensor at the neutral bonding connection. This current will cause all tie circuit breakers to trip and isolate the feeder busses. At this point, there is only one source feeding the faulted bus and a separate ground fault relay will trip the source breaker supplying ground fault current. In this scenario, clearing the ground fault is a 2-step process – open the tie breakers to

isolate the feeder busses and then open the source breaker.

The total time delay to clear the fault is the sum of the time delay settings of the ground fault relay that trips the tie breakers plus the time delay of the relay associated with the source providing the fault current.

Implementation of the single-point ground sensing scheme requires additional buswork in the switchgear or switchboard. For this scheme to work properly and to meet the requirements of UL, the neutral bus serving feeder loads must be separate from the neutral bus that is common to all of the sources. This typically involves two physical levels of neutral buswork in the low voltage distribution equipment and must be so specified.

General Guidance

Location of the ground sensors with respect to the neutral bonding point(s) -- Location of any ground sensing equipment is critical to proper operation. A general rule of thumb is to make sure that any neutral bonding to ground is carried out "ahead" of the ground fault sensors. Neutral bonding downstream of the ground fault sensor will render the system ineffective as ground fault current may be misinterpreted as normal phase-to-neutral load current and not cause the ground fault relay or breaker trip unit to operate.

Multiple neutral bonding points -- Using the modified differential scheme for ground fault sensing provides the user with the ability to have a neutral to ground bond at each source. This becomes important when the location of the low voltage distribution equipment may be remote from the source. In this case, the neutral may be bonded at the remote source and also in the low voltage service entrance equipment. Multiple neutral to ground bonds, though not desired, will not render the modified differential scheme ineffective provided all neutral-to-ground bonding takes place ahead (upstream) of the ground fault sensing equipment.

The sensitivity of ground fault systems -- The sensitivity of a residual sensing ground fault system is a function of the phase sensor primary rating and, in some cases, the ground fault sensing device. Lower primary current ratings on the phase sensors allow more sensitive ground fault settings. For example, if the minimum ground fault pick-up of the ground fault sensing device is 20% of the sensor rating, then an 800 amp sensor will detect a minimum ground fault current of 160 amps. A 4000 amp sensor used with the same ground sensing device will have a minimum pick-up of 800 amps.

Generators connected to utility systems

-- Generators used as emergency, back up, or parallel sources may or may not be grounded at the generator. Per the 2005 NEC, Article 250.20.(D), generators may be considered as "separately derived" systems which means the neutral of the generator is not connected to the utility source neutral. This occurs when 4-pole transfer switches are used between the sources and the load. Separately derived sources must have the neutral grounded at the source. Ground fault protection for a separately derived source is the same as for any single source in a non-parallel configuration.

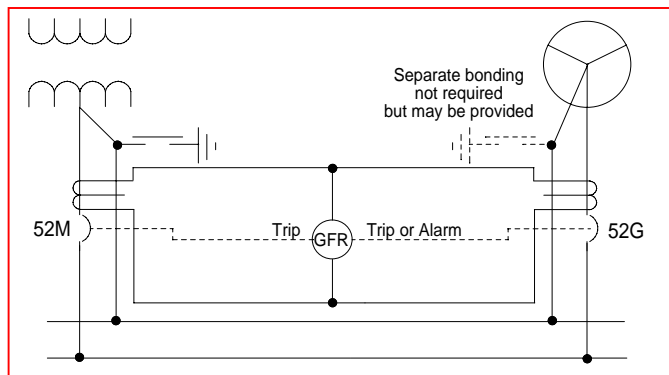


Fig 5 - Non-separately derived system

Generators that feed low voltage distribution equipment without the use of 4-pole transfer switches are not considered separately derived systems and therefore may utilize the ground on the utility source as the bond for the generator neutral. The correct ground fault protection scheme for this application is modified differential, shown in Fig 5. This scheme will work properly for generators grounded by the utility neutral or if the generator neutral is also grounded.

Ground fault alarm, ground fault tripping -- Ground fault alarm is recommended in some generator and emergency system applications (ref NEC Article 700.7.(D)). Ground fault protection utilizing external ground fault sensors and relays will allow the ground fault system to either trip or alarm any of the source and tie circuit breakers in the system. Such a ground fault scheme, for example, can be used, with appropriate control logic, to trip a main source breaker when the bus is fed from a utility and provide an alarm signal when the bus is fed from the emergency source.

Zone Selective Interlocking – When specifying zone selective interlocking, consideration should be given to the compatibility of the devices that are to be interlocked. In general, zone interlocked devices must be of the same type to assure proper communication between the zones.

Applications That Require Caution

Connecting a new line-up into an existing line-up, 4 wire -- Expanding an existing 4-wire power system by adding a new line-up of low voltage equipment with source and tie breakers can provide some engineering challenges when trying to provide a coordinated ground fault scheme for the entire power system configuration.

- **Identical manufacturers, compatible and non-compatible trip unit technology** -- Extending or expanding low voltage switchgear or switchboard line-ups may be very straightforward or it may require some modifications to the existing ground fault equipment. If the existing equipment has up-to-date trip units, then it is simply a matter of interfacing with the existing neutral sensor loop to expand the modified differential circuit. If the existing low voltage breakers have older generation trip units, upgrading the outdated trip units may be possible and, if so, will allow the engineer to design a modified differential scheme that will encompass both existing and new source and tie circuit breakers. Some wiring modifications may be required in the existing low voltage equipment. If the breaker trip units cannot be updated, separate sensors and relaying may need to be added as discussed below. If the existing equipment has ground fault protection using components, the new low voltage equipment must also use similar components. Integral ground fault provided by the circuit breaker trip units IS NOT usually compatible with discrete ground fault components (sensors and relays).
- **Mixing manufacturers** -- If new gear is to be interfaced to an existing system and a new manufacturer is to be introduced or new vintage gear is to be added which is not compatible with the old, one of the following options must be implemented:
 - A) Upgrade the existing circuit breakers with new trip unit conversion kits and create the appropriate modified differential integral ground fault scheme. This may require some modification to the existing equipment in order to accommodate new neutral sensors.
 - B) Provide component sensors and relays on all existing and new source and tie breakers and create a new modified differential scheme for the power system. This may require some modification of the existing equipment in order to accommodate new ground fault sensors and relays. The existing source and tie circuit breakers may have to be equipped with shunt

trip coils for ground fault tripping. AC or DC control power will be required if not already in place.

Two feeders connected to the same load, with or without an automatic transfer switch -- The best solution to this arrangement is to have a 4-pole transfer switch between the feeders and the load or provide a delta/wye transformer between the two feeders and the load. As long as the feeders are 3-wire or a 4-pole transfer switch is used there will be no issues with ground fault protection. When the neutrals of two power systems are tied together through a common load, the same conditions exist for multiple ground fault paths as discussed above in the multi-source arrangements using tie circuit breakers. In most of these cases it is not practical to provide the required interconnected ground fault sensors and relays or trip units. Therefore, the proper solution is a 4-pole transfer switch or a delta/wye isolation transformer.

Disabling ground fault – Because of obvious safety concerns, “defeatable” or “switchable” ground fault protection is not a UL-recognized protective function and therefore circuit breakers with this function may not carry the UL label. This non-UL recognized function affects the entire switchgear/switchboard UL label and listing. The end result, if such functions are specified, could be a low voltage distribution line-up with few or none of its sections UL labeled.

Momentary versus extended parallel operation through the tie circuit breaker -- As covered in the section describing 4-wire systems with sources operating in parallel for an extended period of time, the correct ground fault scheme is designed with component sensors and relays. For systems that have momentary paralleling of less than one second (bumpless transfer or make-before-break), modified differential ground fault protection using circuit breaker trip units can be implemented successfully.

A Checklist of DO's When Specifying This Equipment

- Specify ground fault on feeders so that there is selectivity between the main and feeder for a ground fault on a branch breaker. Service entrance requirements only apply to the Service Disconnect but without ground fault protection on the feeder circuit breakers, a ground fault on a branch can cause the main circuit breaker to trip and de-energize the entire low voltage system.
- Specify ground fault protection on the tie breaker of multiple-source line-ups so that the tie breaker can be interchangeable with the main breakers and there can be selectivity between the main and tie for ground faults fed through the tie breaker
- Properly describe the desired operation of main and tie breakers relative to parallel operation (extended or momentary)
- Consider 3 wire systems for complex power systems with parallel operation in order to simplify the ground fault protection scheme. Use small delta-wye lighting transformers or 4-pole transfer switches to feed 4-wire loads.
- Consider component ground fault sensors and relays in lieu of integral ground fault for sources operating in parallel or for breakers requiring ground fault alarm.
- Specify ground fault relays or trip units with memory functions that integrate intermittent low level ground fault currents over time to provide protection for arcing ground faults.
- Review GE publication GET-6533 – Ground-Fault Protection for Solidly Grounded Low-Voltage Systems for a thorough discussion of ground fault protection.

A Checklist of DON'Ts When Specifying This Equipment

- Don't assume ground fault systems are compatible between different manufacturers of equipment or between different vintages of equipment for the same manufacturer.
- Don't bond the neutral of downstream switchboards fed by low voltage service entrance equipment. Doing so may cause the ground fault protection scheme in the service entrance equipment to malfunction.
- Don't ground the neutral on an individual load. Also, don't use the ground for connecting a single-phase load. Both conditions may cause the upstream ground fault protection to mis-operate.