

240.85: CHANGES TO THE 2002 NEC® CLARIFY REQUIREMENTS FOR THE USE OF SLASH-RATED CIRCUIT BREAKERS AND APPLICATION OF INDIVIDUAL POLE INTERRUPTING CAPABILITIES FOR VARIOUS GROUNDING SCHEMES

Typical plant electrical systems use three-phase distribution schemes. As an industry practice, short-circuit calculations lead to the selection of overcurrent protective devices based on available three-phase fault currents. If the overcurrent devices have an adequate three-phase interrupting rating, engineers are generally satisfied that the system complies with NEC® 110.9.

How often, however, do three-phase faults occur? Commonly referred to as "three-phase bolted faults", these shorts require all three legs to be electrically connected. Though bolted faults do occur, far more common is the mishap of a slipped screwdriver, dropped wrench, or worn insulation that shorts one phase to ground, creating a single-pole short-circuit. These phase-to-ground faults affect the performance of circuit breakers in different ways, depending upon the grounding scheme. Two of these performance areas were addressed by changes to the 2002 NEC®. They are the proper usage of slash ratings and individual pole interrupting capabilities. The following paragraphs explain the reasons behind these 2002 Code changes.

SLASH RATINGS

A slash-rated circuit breaker is one with two voltage ratings separated by a slash, such as 208Y/120 volt. The smaller of the two ratings is for overcurrents at line-to-ground voltages, meant to be cleared by one pole of the device. The larger of the two ratings is for overcurrents at line-to-line voltages, meant to be cleared by two or three poles of the circuit breaker. Slash-rated circuit breakers are not intended to open phase-to-phase voltages across only one pole. Where it is possible for full phase-to-phase voltage to appear across only one pole, a fully rated circuit breaker must be utilized. A fully rated circuit breaker is one that has only one voltage rating, such as a 480 volt circuit breaker. For example, a 480 volt circuit breaker can open an overcurrent at 480 volts with only one pole, such as might occur when Phase A goes to ground on a 480 volt B-Phase grounded system.

240.85 of the 2002 NEC® was changed to read:

240.85 Applications. A circuit breaker with a slash rating, such as 120/240V or 480Y/277, shall be permitted to be applied in a solidly grounded circuit where the nominal voltage of any conductor to ground does not exceed the lower of the two values of the circuit breaker's voltage rating and the nominal voltage between any two conductors does not exceed the higher value of the circuit breaker's voltage rating..."

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The change was the addition of the words "solidly grounded"*. This was needed to emphasize that slash-rated devices were not appropriate on resistance-grounded and ungrounded systems. The following paragraphs explain why slash-rated devices cannot be utilized on these types of systems.

* Solidly grounded is defined in 230.95 of the NEC® as "Connection of the grounded conductor to ground without inserting any resistance or impedance devices."

SINGLE-POLE INTERRUPTING CAPABILITIES

The single-pole interrupting capability of a circuit breaker is its ability to open an overcurrent at a specified voltage utilizing only one pole of the circuit breaker. What are the single-pole interrupting capabilities for overcurrent devices? Per ANSI C37.13 and C37.16, an airframe/power circuit breaker has a single-pole interrupting rating of 87% of its three-pole rating. Listed three-pole molded case circuit breakers have minimum single-pole interrupting capabilities according to Table 7.1.7.2 of UL 489. Table 1 of this paper indicates the single-pole ratings of various three-pole molded-case circuit breakers taken from Table 7.1.7.2 of UL 489. A similar table is shown on page 54 of the IEEE “Blue Book”, Recommended Practice for Applying Low-Voltage Circuit Breakers Used in Industrial and Commercial Power Systems, (Std 1015-1997). Molded-case circuit breakers may or may not be able to safely interrupt single-pole faults above these values since they are typically not tested beyond these values. For current-limiting fuses, the marked interrupting rating is the tested single-pole interrupting rating.

If the ratings shown in Table 1 are too low for the application, the actual single-pole rating for the breaker must be ascertained to insure proper application.

As an example of single-pole interrupting capability in a typical installation, consider a common three-pole, 20 amp, 480 volt circuit breaker with a three-pole interrupting rating of 65,000 amperes. Referring to Table 1, this breaker has an 8,660 ampere single-pole interrupting capability for 480 volt faults across one pole. If the available line-to-ground fault current exceeds 8,660 amps at 480 volts, such as might occur on the secondary of a 1000 KVA, 480 volt, corner-grounded delta transformer, the circuit breaker may be misapplied. In this case, the breaker manufacturer must be consulted to verify interrupting ratings and proper application.

A Fine Print Note was added to 240.85 of the 2002 NEC[®] to alert users that circuit breakers have single-pole interrupting capabilities that must be considered for proper application.

240.85 FPN: Proper application of molded case circuit breakers on 3-phase systems, other than solidly grounded wye, particularly on corner grounded delta systems, considers the circuit breakers' individual pole interrupting capability.

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The following paragraphs will also explain why this FPN was added to the 2002 NEC[®].

CALCULATING GROUND FAULT CURRENTS

How much short-circuit current will flow in a ground fault condition? The answer is dependent upon the location of the fault with respect to the transformer secondary. Referring to Figure 2, the ground fault current flows through one coil of the wye transformer secondary and through the phase conductor

to the point of the fault. The return path is through the enclosure and conduit to the bonding jumper and back to the secondary through the grounded neutral. Unlike three-phase faults, the impedance of the return path must be used in determining the magnitude of ground fault current. This ground return impedance is usually difficult to calculate. If the ground return path is relatively short (i.e. close to the center tap of the transformer), the ground fault current will approach the three-phase short-circuit current.

TABLE 1

Single-Pole Interrupting Ratings for Three-Pole Molded Case
Circuit Breakers (ANY I.R.)

FRAME RATING	240V	480/277V	480V	600/347V	600V
100A Maximum 250V Maximum	4,330	--	--	--	--
100A Maximum 251-600V	--	10,000	8,660	10,000	8,660
101 – 800	8,660	10,000	8,660	10,000	8,660
801 – 1200	12,120	14,000	12,120	14,000	12,120
1201 – 2000	14,000	14,000	14,000	14,000	14,000
2001 – 2500	20,000	20,000	20,000	20,000	20,000
2501 – 3000	25,000	25,000	25,000	25,000	25,000
3001 – 4000	30,000	30,000	30,000	30,000	30,000
4001 – 5000	40,000	40,000	40,000	40,000	40,000
5001 – 6000	50,000	50,000	50,000	50,000	50,000

Theoretically, a bolted line-to-ground fault may be higher than a three-phase bolted fault since the zero-sequence impedance can be less than the positive sequence impedance. The ground fault location will determine the level of short-circuit current available. The prudent design engineer assumes that the ground fault current equals at least the available three-phase bolted fault current and makes sure that the overcurrent devices are rated accordingly.

SOLIDLY GROUNDED WYE SYSTEMS

The Solidly Grounded Wye system shown in Figure 1 is by far the most common type of electrical system. This system is typically delta connected on the primary and has an intentional solid connection between the ground and the center of the wye connected secondary (neutral). The grounded neutral conductor carries single-phase or unbalanced three-phase current. This system lends itself well to industrial applications where 480V(L-L-L) three-phase motor loads and 277V(L-N) lighting is required.

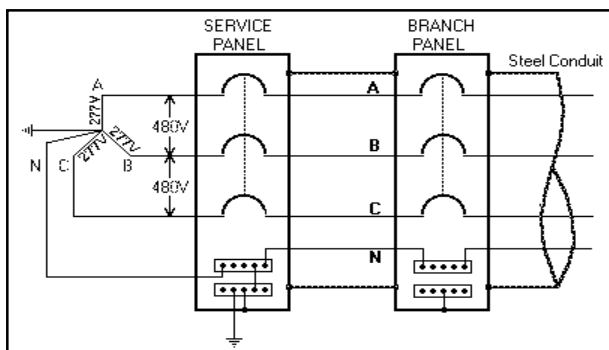


Figure 1 - Solidly Grounded WYE
System

If a fault occurs between any phase conductor and ground (Figure 2), the available short-circuit current is limited only by the combined impedance of the transformer winding, the phase conductor and the equipment ground path from the point of the fault back to the source. Some current (typically 5%) will flow in the parallel earth ground path. Since the earth impedance is typically much greater than the equipment ground path, current flow through earth ground is generally negligible.

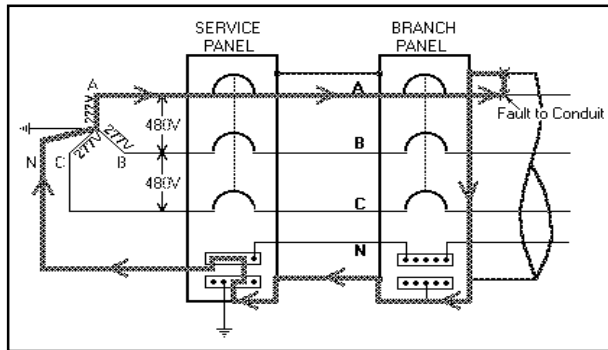


Figure 2 - Single-Pole Fault to Ground Solidly Grounded Wye System

In solidly grounded wye systems, the first low impedance fault to ground is generally sufficient to open the overcurrent device on the faulted leg. In Figure 2, this fault current causes the branch circuit overcurrent device to clear the 277 volt fault. Because the branch circuit device will clear the fault with only 277 volts across one pole, a slash-rated 480Y/277 volt circuit breaker is perfectly acceptable.

This system requires compliance with single-pole interrupting capability for 277 volt faults on one pole. If the overcurrent devices have a single-pole interrupting capability adequate for the available short-circuit current, then the system meets NEC® 110.9.

Although not as common as the solidly grounded wye connection, the following three systems are typically found in industrial installations where continuous operation is essential. Whenever these systems are encountered, it is absolutely essential that the proper application of slash ratings and single-pole interrupting capabilities be assured. This is due to the fact that full phase-to-phase voltage can appear across just one pole. Phase-to-phase voltage across one pole is much more difficult for an overcurrent device to clear than the line-to-neutral voltage associated with the solidly grounded wye systems.

CORNER-GROUNDED-DELTA SYSTEMS (SOLIDLY GROUNDED)

The system of Figure 3 has a delta-connected secondary and is solidly grounded on the B-phase. If the B-phase should short to ground, no fault current will flow because it is already solidly grounded.

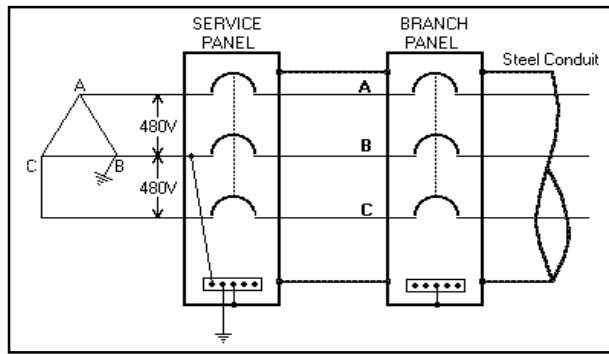


Figure 3 – Corner-Grounded Delta System (Solidly Grounded)

If either Phase A or C is shorted to ground, only one pole of the branch-circuit overcurrent device will see the 480V fault as shown in Figure 4. A slash rated 480Y/277 volt circuit breaker could not be utilized on this 480 volt corner-grounded delta circuit because the voltage to ground (480 volts), exceeds the lower of the two ratings (277 volts). This system also requires compliance with single-pole interrupting capabilities for 480 volt faults on one pole because the branch-circuit circuit breaker would be required to interrupt 480 volts with only one pole.

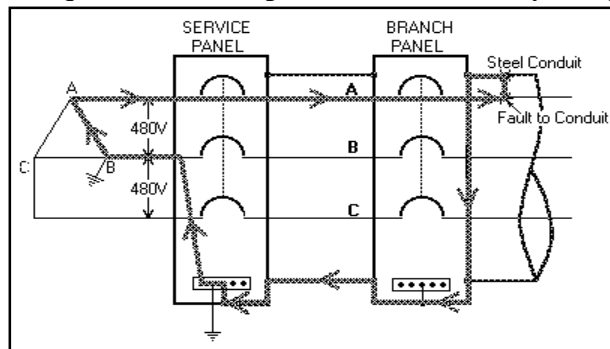


Figure 4 – Fault to Ground on a Corner-Grounded Delta System

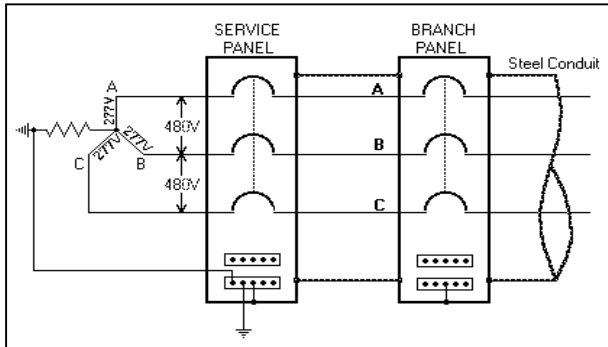
A disadvantage of Corner-Grounded Delta systems is the inability to readily supply voltage levels for fluorescent or HID lighting (277V). Installations with this system require a 480-120V transformer to supply 120V lighting. Another disadvantage, as given on page 33 of IEEE Std 142-1991, Section 1.5.1(4) (Green Book) is "the possibility of exceeding interrupting capabilities of marginally applied circuit breakers, because for a ground fault, the interrupting duty on the affected circuit breaker pole exceeds the three-phase fault duty."

RESISTANCE GROUNDED SYSTEM

"Low or High" resistance grounding schemes are found primarily in industrial installations. These systems are used to limit, to varying degrees, the amount of current that will flow in a phase to ground fault.

"Low" resistance grounding is used to limit ground fault current to values acceptable for relaying schemes. This type of grounding is used mainly in medium voltage systems and is not widely installed in low voltage applications (600V or below).

The "High" Resistance Grounded System offers the advantage that the first fault to ground will not draw enough current to cause the overcurrent device to open. This system will reduce the stresses, voltage dips, heating effects, etc. normally associated with high short-circuit current. Referring to Figure 5, High Resistance Grounded Systems have a resistor between the center tap of the wye transformer and ground.



With high resistance grounded systems, line-to-neutral loads are not permitted per National Electrical Code, 250.36(4).

Figure 5 - Resistance Grounded System

When the first fault occurs from phase to ground as shown in Figure 6, the current path is through the grounding resistor. Because of this inserted resistance, the fault current is not high enough to open protective devices. This allows the plant to continue "on line". NEC® 250.36(3) requires ground detectors to be installed on these systems, so that the first fault can be found and fixed before a second fault occurs on another phase.

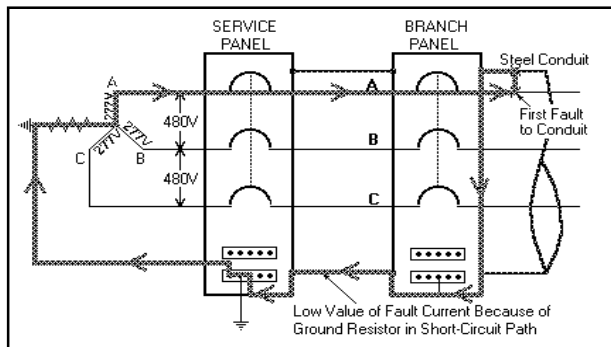


Figure 6 - First Fault in Resistance Grounded System

Even though the system is equipped with a ground alarm, the exact location of the ground fault may be difficult to determine. The first fault to ground **MUST** be removed before a second phase goes to ground, creating a 480 volt fault across only one pole of the affected branch circuit device. Figure 7 shows how the 480 volt fault can occur across one pole of the branch circuit device. It is exactly because of this possibility that a slash rated 480Y/277 volt device can not be used in this system. 480 volts would be impressed across one pole of the branch circuit device, even though it had been tested for only 277 volts.

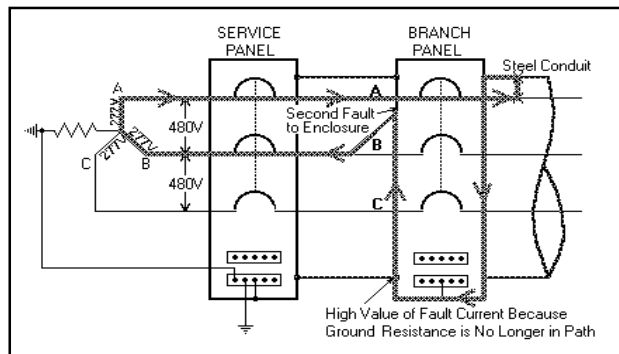


Figure 7 - Second fault in Resistance Grounded System

The magnitude of this fault current can approach 87% of the L-L-L short-circuit current. Because of the possibility that a second fault will occur, single-pole interrupting capability must be investigated. The IEEE “Red Book”, Std 141-1993, page 367, supports this requirement, “One final consideration for resistance-grounded systems is the necessity to apply overcurrent devices based upon their “single-pole” short-circuit interrupting rating, which can be equal to or in some cases less than their ‘normal rating’.”

UNGROUNDED SYSTEMS

The Ungrounded System of Figure 8 offers the same advantage for continuity of service that is characteristic of high resistance grounded systems.

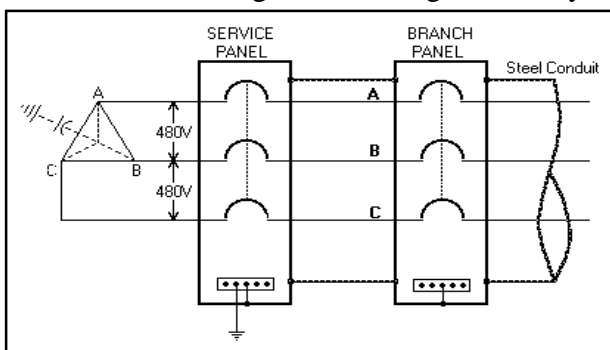


Figure 8 –Ungrounded System

Although not physically connected, the phase conductors are capacitively coupled to ground. The first fault to ground is limited by the large impedance through which the current has to flow (Figure 9). Since the fault current is reduced to such a low level, the overcurrent devices do not open and the plant continues to "run".

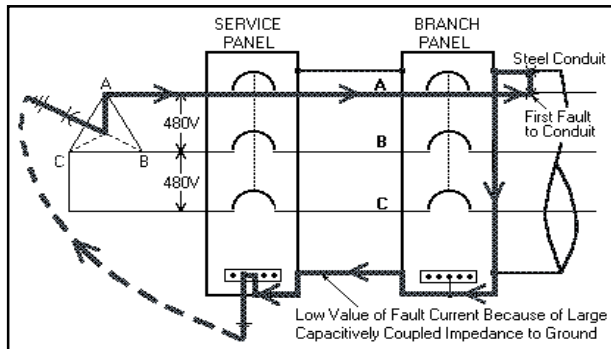


Figure 9 - First Fault to Conduit in Ungrounded System

As with High Resistance Grounded Systems, ground detectors should (but are not required by the 2002 NEC) be installed, to warn the maintenance crew to find and fix the fault before a second fault from another phase also goes to ground (Figure 10).

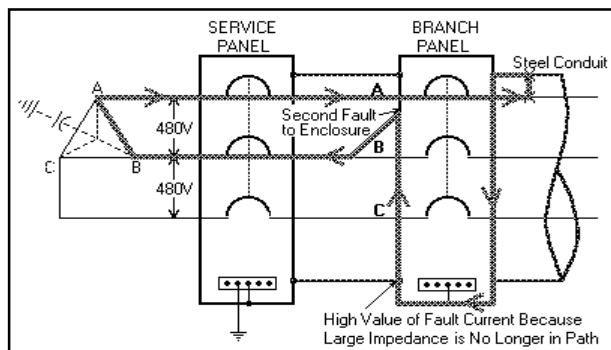


Figure 10 - Second Fault to Conduit in Ungrounded System

The second fault from Phase B to ground (in Figure 10) will create a 480 volt fault across only one pole at the branch circuit overcurrent device. It is because of this possibility that a slash-rated device cannot be used on this type of system. A pole that was tested for 277 volts might see an overcurrent and try to open 480 volts.

Again, the values from Table 1 must be used for molded case circuit breaker systems as the tradeoff for the increased continuity of service. The IEEE "Red Book", Std 141-1993, page 366, supports this requirement, "One final consideration for ungrounded systems is the necessity to apply overcurrent devices based upon their "single-pole" short-circuit interrupting rating, which can be equal to or in some cases less than their normal rating." In 250.4(B) Ungrounded Systems (4) Path for Fault Current of the 2002 NEC®, it is required that the impedance path through the equipment be low so that the fault current is high when a second fault occurs on an ungrounded system.

CONCLUSIONS

Two significant additions to NEC 240.85 were included in the 2002 NEC[®]. They cover voltage ratings of slash-rated circuit breakers and single-pole interrupting capabilities of circuit breakers. The proper application of both of these ratings is dependent upon the type of grounding scheme utilized.

Slash-rated devices must be utilized only on solidly grounded systems. This automatically eliminates their usage on resistance-grounded and ungrounded systems. They can be properly utilized on solidly grounded wye systems, where the voltage to ground does not exceed the smaller of the circuit breaker's two values and the voltage between any two conductors does not exceed the larger of the circuit breaker's two values. Slash-rated devices can not be used on corner-grounded delta systems whenever the voltage to ground exceeds the smaller of the two ratings. Where slash-rated devices will not meet these requirements, fully rated devices are required.

An overcurrent protective device must have an interrupting rating equal to or greater than the current available at its line terminals for both three-phase bolted faults and for one or more phase-to-ground faults. Although most electrical systems are designed with overcurrent devices having adequate three-phase interrupting ratings, the single-pole interrupting capabilities are easily overlooked.

Simple solutions exist to provide adequate interrupting ratings if molded case circuit breaker single-pole interrupting capabilities as shown in Table 1 are not sufficient. First, the manufacturer can be consulted to see if single-pole interrupting capabilities are in compliance. Second, air frame/power circuit breakers have tested single-pole interrupting ratings that are 87% of the published three-pole rating. And third, current-limiting fuses are available that have tested single-pole interrupting ratings of 200,000 and 300,000 amps.