

Applying Interrupting Rating: Circuit Breakers

Single-Pole Interrupting Capability

An overcurrent protective device must have an interrupting rating equal to or greater than the fault current available at its line terminals for both three-phase bolted faults and for one or more phase-to-ground faults (110.9). Although most electrical systems are designed with overcurrent devices having adequate three-phase interrupting ratings, the single-pole interrupting capabilities are easily overlooked. This section will examine single-pole interrupting capability (also referred to as individual pole interrupting capability).

This section will show how single-pole interrupting capabilities must be considered in some applications. It will also show there are simple solutions that exist to provide adequate interrupting ratings if molded case circuit breakers, self protected starters and other overcurrent protective devices are found to have insufficient single-pole interrupting capabilities.

A Fine Print Note was added to 430.52(C)(6) of the 2005 NEC® and 240.85 of the 2002 NEC®. These Fine Print Notes alert users that mechanical devices, such as self-protected combination controllers and circuit breakers, have single-pole interrupting capabilities that must be considered for proper application. They state:

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.

430.52(C)(6) FPN: Proper application of self protected combination controllers on 3-phase systems, other than solidly grounded wye, particularly on corner grounded delta systems, considers the circuit breakers' individual pole interrupting capability.

As will be shown, there are other overcurrent device types and other grounding system types where individual pole interrupting capability must be analyzed.

The single-pole interrupting capability of a circuit breaker, self protected starter and other similar mechanical overcurrent protective device is its ability to open an overcurrent at a specified voltage utilizing only one pole of the multi-pole device. Multi-pole mechanical overcurrent protective devices are typically marked with an interrupting rating. This marked interrupting rating applies to all three poles interrupting a three-phase fault for a three-pole device. The marked interrupting rating of a three-pole device does not apply to a single pole that must interrupt a fault current at rated voltage.

Single Pole Interrupting Capabilities

A circuit breaker's, self protected starter's, or other mechanical protective device's ability to open an overcurrent at a specified voltage utilizing only one pole of the device.



Single-Pole Interrupting Capabilities For Overcurrent Devices

Current-Limiting Fuses: the marked interrupting rating is the tested single-pole interrupting rating. So single-pole interrupting capability is not an issue with fuse applications.

Airframe/Power Circuit Breaker: per ANSI C37.13 and C37.16 the single-pole interrupting rating is 87% of its three-pole interrupting rating.

Molded Case Circuit Breakers: 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 on this page indicates the single-pole test value for 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).

Self Protected Starters: UL 508, Table 82A.3 specifies the short circuit test values on one pole as 4320A for 0 to 10Hp devices rated 200 to 250 volts and 8660A for 0 to 200Hp devices rated 600 volts maximum.

Molded case circuit breakers and self protected starters may not be able to safely interrupt single-pole faults above these respective values shown in previous paragraphs. Per 110.9, all overcurrent protective devices that are intended to interrupt fault currents must have single-pole interrupting capabilities for the maximum single-pole fault current that is available. And typically, engineers, contractors and inspectors (AHJs) rely on the applicable product standard testing and listing criteria to verify device ratings as being suitable for specific applications.

TABLE 1: "Standard" UL 489 Interrupting Tests For 3-Pole Molded Case Circuit Breakers

	"Standard" Single-Pole Interrupting Tests Values					"Standard" 3-Pole Interrupting Values
	240V	480/277V	480V	600/347V	600V	
FRAME RATING	240V	480/277V	480V	600/347V	600V	
100A Maximum 250V Maximum	4330	--	--	--	--	5000
100A Maximum 251-600V	--	10,000	8660	10,000	8660	10,000
101 – 800	8660	10,000	8660	10,000	8660	14,000
801 – 1200	12,120	14,000	12,120	14,000	12,120	20,000
1201 – 2000	14,000	14,000	14,000	14,000	14,000	25,000
2001 – 2500	20,000	20,000	20,000	20,000	20,000	30,000
2501 – 3000	25,000	25,000	25,000	25,000	25,000	35,000
3001 – 4000	30,000	30,000	30,000	30,000	30,000	45,000
4001 – 5000	40,000	40,000	40,000	40,000	40,000	60,000
5001 – 6000	50,000	50,000	50,000	50,000	50,000	70,000

Note: This data is from UL 489 Table 7.1.7.2.

Molded Case Circuit Breaker Testing - UL 489

Devices must be applied within the limitations of their listing. UL 489 is the standard for molded case circuit breakers. UL 489 has tests which it refers to as "standard" interrupting tests for molded case circuit breakers. A more appropriate term would be "base" or "lowest" interrupting level that any circuit breaker of a given rated voltage and amp rating must meet. There are circuit breakers on the market that just test to these "standard" or "base" interrupting tests. However, because these base interrupting ratings are rather modest values, some circuit breakers are listed with higher interrupting ratings than the standard or base levels; for these circuit breakers, there are additional procedures for higher level interrupting tests.

These "standard" or "base" interrupting tests for three-pole circuit breakers involve individual single-pole interrupting tests and multi-pole interrupting tests. Table 7.1.7.2 of UL 489 provides the single-pole (individual) and multi-pole interrupting current values for various voltage rating and amp rating circuit breakers. Table 1 shows the single-pole short-circuit current values (from Table 7.1.7.2 of UL 489) for which all three-pole circuit breakers are tested and evaluated under single-pole interrupting capabilities. The far right column of Table 1 shows the three-phase short-circuit current values (from Table 7.1.7.2 of UL 489) for which all three-pole circuit breakers are tested and evaluated. These "standard" circuit breakers would be marked with an Interrupting Rating (if above 5000A) corresponding to the three-phase short-circuit current value. The "standard" circuit breaker is not marked with a single-pole interrupting rating which would correspond to the single-pole interrupting test value.

Single-Pole Interrupting Capability

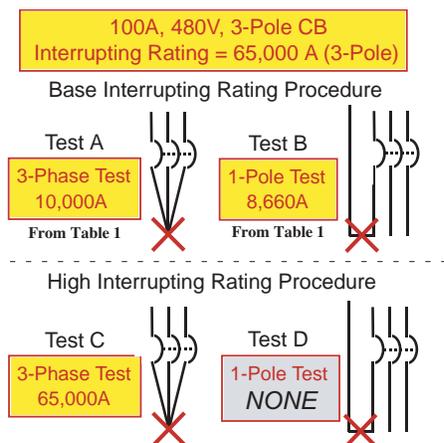
Circuit breakers with interrupting ratings higher than the “standard” interrupting values are needed in today’s systems, so additional provisions are in UL 489. Higher interrupting rated molded case circuit breakers are additionally tested and evaluated per 7.1.11 of UL 489 to a “High Short Circuit Test” procedure in order to be marked with a higher interrupting rating. This test procedure does not include a single-pole test of higher short-circuit current value than the “standard” test provisions. The three-pole test current value can be equal to any value listed in Table 8.1 of UL 489, from 7500A to 200,000A. This three-phase test value must be greater than the values in the far right column of Table 1. If a circuit breaker successfully tested to a higher three-pole interrupting value per the “High Short Circuit Tests,” the molded case circuit breaker is marked with this higher interrupting rating which corresponds to the three-pole “high short circuit” current test value.

As mentioned, a single-pole interrupting test at a higher value than shown in Table 1 is not required in these optional “High Short Circuit Test” procedures. Because of this, the marked three-pole interrupting rating can be much higher than the tested individual pole interrupting capability. In addition, the single-pole capability is not required to be marked on the molded case circuit breaker; it can only be determined by reviewing the UL 489 standard.

Actual Example

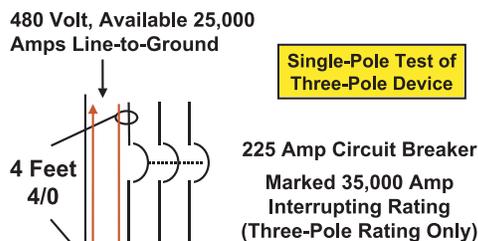
The diagram below illustrates the UL 489 test procedure for a 100A, 480V, three phase circuit breaker that gets listed for a high interrupting rating. Test A and B are the required standard or base interrupting tests. Test A is a three-pole interrupting test at 10,000A (Table 1, right column), which is a modest three-phase available short-circuit current, and Test B is a single-pole interrupting test at a modest single-phase available short-circuit current of 8660A (Table 1). Then, in addition, to be listed and marked with the higher 65,000A interrupting rating, the circuit breaker must pass the criteria for Test C. Test C is a three-pole interrupting test at 65,000A three-phase available short-circuit current. Test D is not conducted; it is not part of the UL 489 evaluation procedure. This higher three-phase interrupting rated circuit breaker does not have to undergo any test criteria at a corresponding higher single-pole short-circuit current.

Three-Pole Interrupting Rating & Single-Pole Interrupting Capabilities Test Procedures for Molded Case Circuit Breakers – UL 489

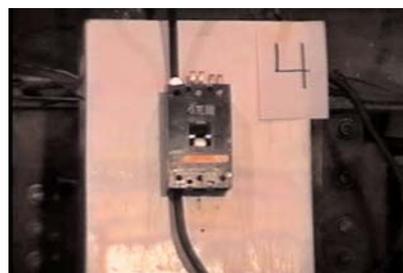


As an example of single-pole interrupting capability in a typical installation, consider this three-pole, 100A, 480V circuit breaker with a three-pole interrupting rating of 65,000A. Referring to Table 1, this breaker has an 8660A single-pole interrupting capability for 480V faults across one pole. If the available line-to-ground fault current exceeds 8660A at 480V, such as might occur on the secondary of a 1000kVA, 480V, corner-grounded, delta transformer, the circuit breaker may be misapplied.

Shown below are three still photos from a videotaping of a single-pole fault interruption test on a three-pole circuit breaker rated 480V. This circuit breaker is marked with a three-pole interrupting rating of 35,000A at 480V. This marked interrupting rating is per UL 489 test procedures. This circuit breaker is tested for individual single-pole interrupting capabilities in UL 489 at an available fault current of 8660A (Table 1 prior page). The test that is shown below is with an available fault current of 25,000A.



This device is tested for three-pole interruption with available fault of 35,000 amps and is tested for individual single-pole interruption with available fault of only 8,660 amps (UL 489)



Test set up prior to closure of test station switch.



Photo of 3-pole circuit breaker during test of individual single-pole interruption of a fault current beyond the value in Table 1. Magnetic forces of short-circuit current caused test board to move.



Photo (later in sequence) of 3-pole circuit breaker during test of individual single-pole interruption of a fault current beyond its single-pole interrupting capability - it violently exploded.

Single-Pole Interrupting Capability

Possible Fault Currents During A Ground Fault Condition

The magnitude of a ground fault current 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.

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. 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.

Type of Ground System Affect On Single-Pole Interruption

The method in which a system is grounded can be a significant factor in the performance of multi-pole, mechanical overcurrent protective devices used in three phase systems. To illustrate this, several different grounding systems with molded case circuit breakers will be analyzed.

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 commercial and industrial applications where 480V (L-L-L) three-phase motor loads and 277V (L-N) lighting is needed.

Solidly Grounded WYE System

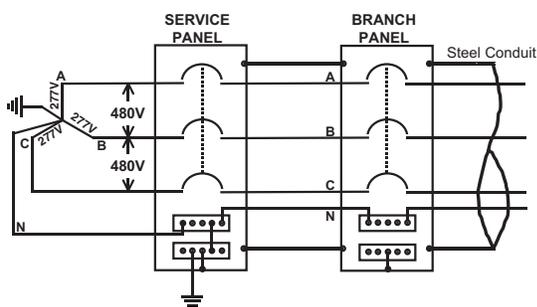


Figure 1. Solidly Grounded WYE System

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.

Solidly Grounded WYE System

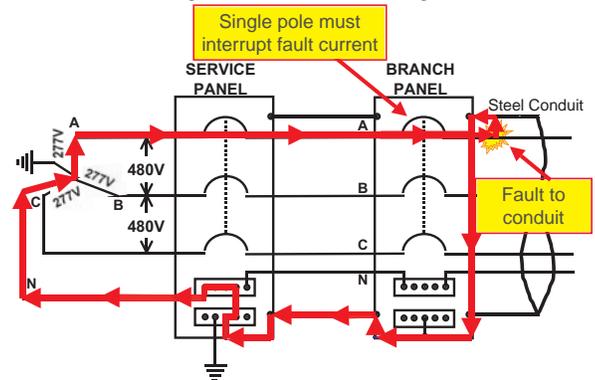


Figure 2. Single-Pole Fault to Ground in Solidly Grounded Wye System

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 277V fault. This system requires compliance with single-pole interrupting capability for 277V 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 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.

Corner Grounded Delta System

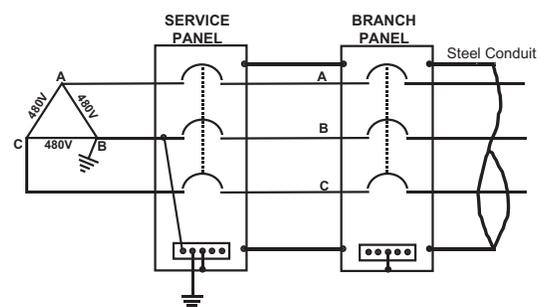


Figure 3. Corner-Grounded Delta System (Solidly Grounded)

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. This system requires compliance with single-pole interrupting capabilities for 480V faults on one pole because the branch-circuit circuit breaker would be required to interrupt 480V with only one pole.

Single-Pole Interrupting Capability

Corner Grounded Delta System

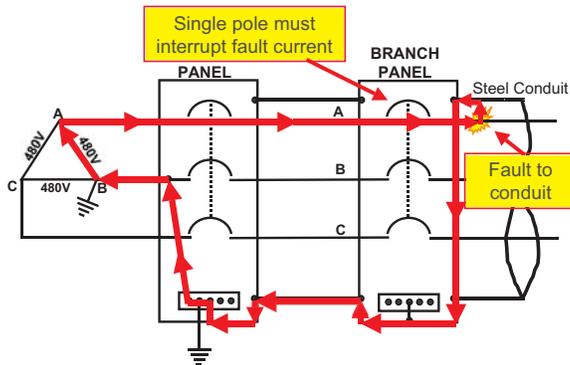


Figure 4. Fault to Ground on a Corner-Grounded Delta System

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.” A line-to-ground fault with this type grounding system is essentially a line-to-line fault where the one line is grounded. The maximum line-to-line bolted short-circuit current is 87% of the three phase bolted short-circuit current. Review the photo sequence testing (page 30) of the 225A, three phase circuit breaker with a 35,000A interrupting rating (three-pole rating). 87% of 35,000A is 30,450A. The single-pole test was run with an available of only 25,000A.

Impedance Grounded System

“Low or High” impedance 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” impedance 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” impedance 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 impedance grounded systems have a resistor between the center tap of the wye transformer and ground. High impedance grounding systems are used in low voltage systems (600V or less). With high impedance grounded systems, line-to-neutral loads are not permitted per National Electrical Code®, 250.36(4).

High Impedance Grounded System

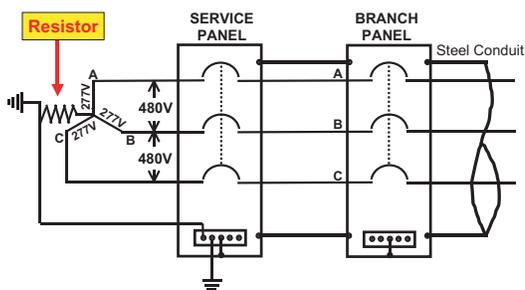


Figure 5. Impedance Grounded System

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.

High Impedance Grounded System

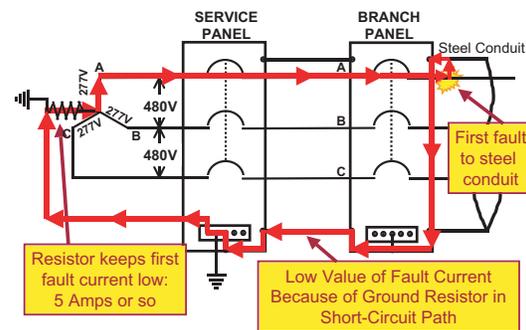


Figure 6. First Fault in Impedance Grounded System

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 480V fault across only one pole of the affected branch circuit device. Figure 7 shows how the 480V fault can occur across one pole of the branch circuit device. It is exactly because of this possibility that single-pole interrupting capabilities must be considered for mechanical overcurrent protective devices.

High Impedance Grounded System

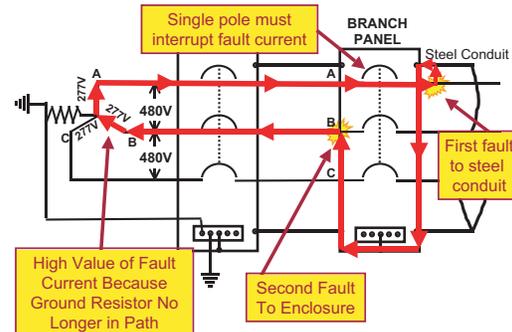


Figure 7. Second Fault in Impedance Grounded System

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 impedance-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’.”

Single-Pole Interrupting Capability

Ungrounded Systems

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

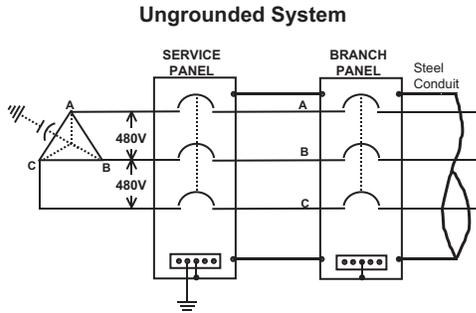


Figure 8. Ungrounded System

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.”

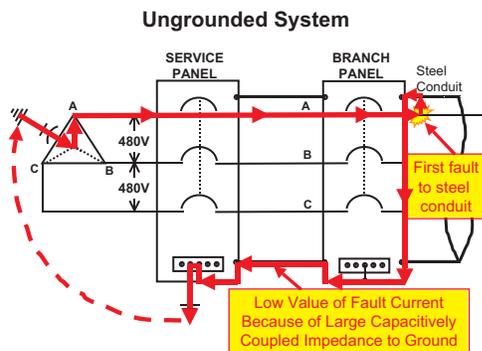


Figure 9. First Fault to Conduit in Ungrounded System

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

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. Again, the values from Table 1 for single pole interrupting capabilities 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.”

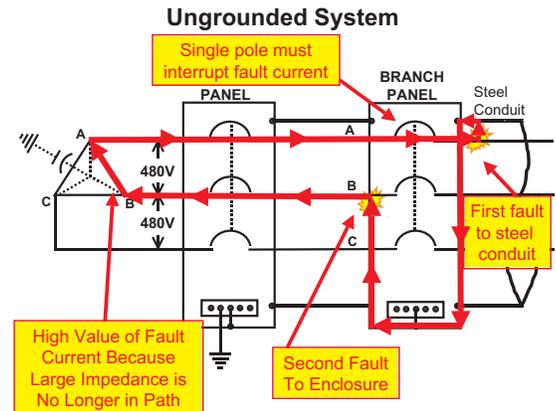


Figure 10. Second Fault to Conduit in Ungrounded System

In the NEC® 250.4(B) Ungrounded Systems (4) Path for Fault Current, 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.

What Are Single-Pole Interrupting Capabilities For Fuses?

By their inherent design a fuse’s marked interrupting rating is its single-pole interrupting rating. Per UL/CSA/ANCE 248 Fuse Standards, fuses are tested and evaluated as single-pole devices. Therefore, a fuse’s marked interrupting rating is its single-pole interrupting rating. So it is simple, fuses can be applied on single phase or three phase circuits without extra concern for single-pole interrupting capabilities. There is no need to perform any special calculations because of the grounding system utilized. Just be sure the fuses’ interrupting ratings are equal to or greater than the available short-circuit currents. Modern current-limiting fuses are available with tested and marked single-pole interrupting ratings of 200,000 or 300,000A. Low-Peak LPJ_SP, KRP-C_SP, LPS-RK_SP and LPN-RK_SP fuses all have UL Listed 300,000A single-pole interrupting ratings. This is a simple solution to assure adequate interrupting ratings for present and future systems no matter what the grounding scheme. Review the three drawings for a fusible, high impedance grounded system.

High Impedance Grounded System

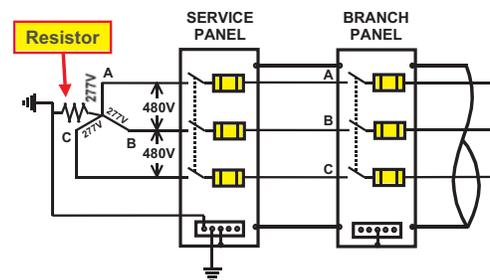


Figure 11. Fusible high impedance grounded system.

Single-Pole Interrupting Capability

High Impedance Grounded System

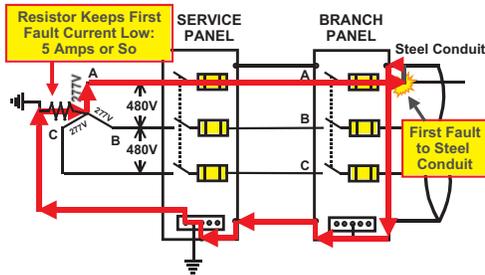


Figure 12. Upon first fault, the fault current is low due to resistor. As intended the fuse does not open.

High Impedance Grounded System

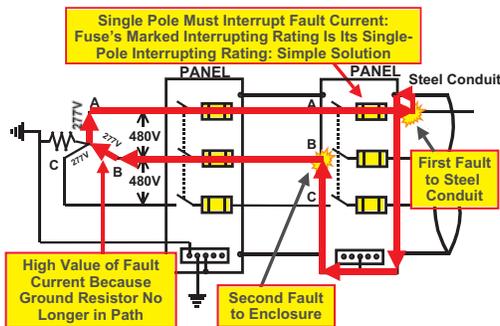


Figure 13. Upon the second fault, the fault is essentially a line-line fault with the impedance of the conductors and the ground path. The fuse must interrupt this fault. Since a fuse's interrupting rating is the same as its single-pole interrupting capability, modern fuses with 200,000A or 300,000A interrupting rating can be applied without further analysis for single pole interrupting capabilities.