DO YOU KNOW THE FACTS ABOUT SINGLE-POLE INTERRUPTING RATINGS?  
YOU MAY BE IN TROUBLE!

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 is safe and sound and complies with NEC® Section 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 may occur, far more common is the mishap of a slipped screwdriver or dropped wrench that shorts one phase to ground, creating a single-pole short-circuit. An area commonly overlooked is the single-pole interrupting rating of the overcurrent devices.

SINGLE-POLE INTERRUPTING RATINGS

What are the single-pole interrupting ratings for overcurrent devices? Modern current limiting fuses such as Class RK1, J and L have single-pole interrupting ratings of at least 200,000 amperes RMS symmetrical. For example, per UL/CSA 248-8, a 600 volt Class J fuse is tested at a minimum of 200,000 amperes at 600 volts across one pole. Bussmann® has recently introduced the above fuse types with 300,000 ampere single-pole interrupting ratings. Per ANSI C37.13 and C37.16, an airframe/power circuit breaker has a single-pole rating of 87% of its three-pole rating. Listed three-pole molded case circuit breakers have minimum single-pole interrupting ratings according to Table 7.1.7.2 of U.L. 489. Table 1 (page 2) indicates the single-pole ratings of various three-pole molded-case circuit breakers taken from Table 7.1.7.2 of U.L. 489. A similar table is shown on page 54 of the IEEE “Blue Book” (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.

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. Or, modern current limiting fuses or airframe/power circuit breakers can be utilized.

As an example of single-pole interrupting ratings 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 rating for faults across one pole. If the available line-to-ground fault current exceeds 8660 amps, the MCCB may be misapplied. In this case, the breaker manufacturer must be consulted to verify interrupting ratings and proper application.
**TABLE 1**

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

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

**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 Figures 3 and 4, 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 available. However, to insure a safe system, the prudent design engineer should assume that the ground fault current equals at least the three-phase current and should assure that the overcurrent devices are rated accordingly.
SOLIDLY GROUNDED WYE SYSTEMS

The Solidly Grounded Wye system shown in Figures 1 and 2 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.

If a fault occurs between any phase conductor and ground (Figures 3 and 4), 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.]

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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 Figures 3 and 4, this fault current causes the branch circuit overcurrent device to clear the 277 volt fault. This system requires compliance with single-pole interrupting ratings for 277 volt faults on one pole. If the overcurrent devices have a single-pole interrupting rating adequate for the available short-circuit current, then the system meets Section 110-9 of the National Electrical Code®.

Although not as common as the solidly grounded wye connection, the following systems are typically found in industrial installations where continuous operation is essential. Whenever these systems are encountered, it is absolutely essential that the single-pole ratings of overcurrent devices be investigated. 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.

**B-PHASE CORNER-GROUNDED DELTA SYSTEMS (SOLIDLY GROUNDED)**

The systems of Figures 5 and 6 have a delta-connected secondary and are 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.

If either Phase A or C is shorted to ground, only one pole of the overcurrent device will see the 480V fault as shown in Figures 7 and 8. This system requires compliance with single-pole interrupting ratings for 480 volt faults on one pole.

**Figure 5 - B-Phase Grounded (Solidly)**
System - Circuit Breakers

**Figure 6 - B-Phase Grounded (Solidly)**
System – Fuses
A disadvantage of B-phase solidly grounded 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 Figures 9 and 10, 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 the (1999) National Electrical Code, Section 250-36(4).
When the first fault occurs from phase to ground as shown in Figures 11 and 12, 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.

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. Figures 13 and 14 show how the 480 volt fault can occur across the branch circuit device.
The magnitude of this fault current can approach 87% of the L-L-L short-circuit current (3). Because of the possibility that a second fault will occur, single-pole ratings 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 Systems of Figures 15 and 16 offer the same advantage for continuity of service that are characteristic of high resistance grounded systems.

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 (Figures 17 and 18). Since the fault current is reduced to such a low level, the overcurrent devices do not open and the plant continues to "run".

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As with High Resistance Grounded Systems, ground detectors should warn the maintenance crew to find and fix the fault before a second fault from another phase also goes to ground (Figures 19 and 20).

The second fault from Phase B to ground (in Figures 19 and 20) will create a 480 volt fault across only one pole at the branch circuit overcurrent device. Again, the values from Table 1 must be used for molded case circuit breaker systems as the tradeoff for the increased continuity of service. Or, properly rated current limiting fuses and air frame/power circuit breakers can be utilized to meet the interrupting rating requirements. 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.”
CONCLUSIONS

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 single-pole ground faults. Although most electrical systems are designed with overcurrent devices having adequate three-phase interrupting ratings, the single-pole interrupting ratings are easily overlooked. When applying molded case circuit breakers, the manufacturer must be consulted to verify single-pole interrupting ratings are in compliance with NEC Section 110-9.

A simple solution exists to insure adequate interrupting ratings both in present installations and in future upgrades. Modern current-limiting fuses are available that have tested single-pole interrupting ratings of 300,000 amps. Air frame/power circuit breakers are also available that have tested single-pole interrupting ratings that are 87% of the published three-pole rating.