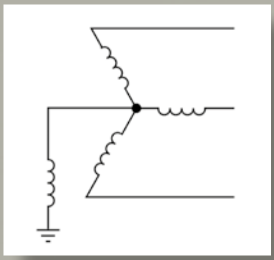
FEATURE

System Grounding

in the Americas, Australia, South Africa and Other Regions

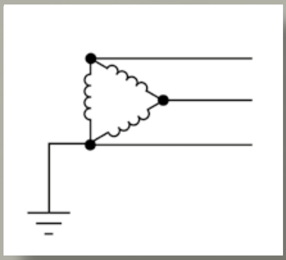
Industrial power-system grounding in the Americas, Australia, South Africa and other regions, in different industries and applications, has evolved over time. Typically, low voltage systems (those below 600 V) employ one of the three most common grounding methods: solidly grounded, resistance grounded and ungrounded. There have been trials and applications that have tried reactance grounding and corner- or center-grounded delta but those are extremely rare. In many areas, a preference for resistance grounding has been growing. There are benefits with resistance grounding, but there should be an understanding of the hazards and potential faults on such systems to best prepare the design engineer not just for code compliance and minimum design requirements, but also for proper system performance and protection.

Figure 1:

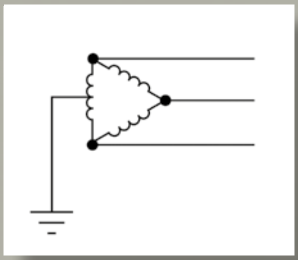


Reactance Grounding

Figure 2:

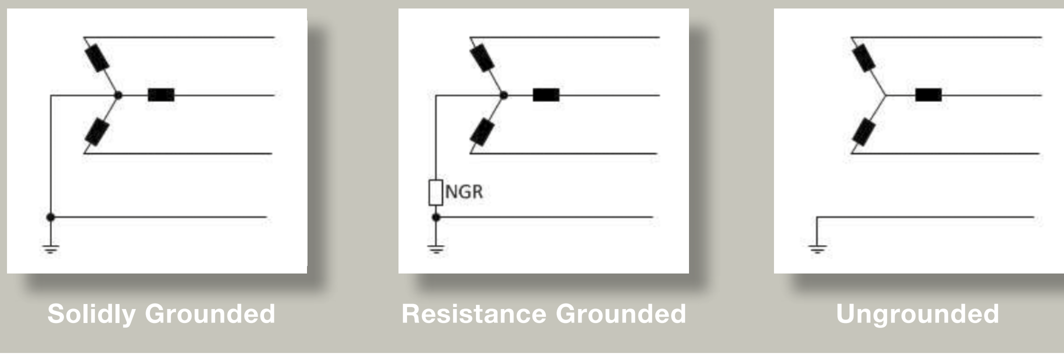


Corner-grounded delta



Center-grounded delta

Figure 3: Graphic of three common grounding methods



The use of resistance grounding started in the 1950's in many of the regions mentioned. Resistance grounding was first used to replace ungrounded systems that had experienced transient overvoltages and the resulting phase-to-phase faults. The transient overvoltages that were caused by intermittent or arcing faults building up charge on systems with distributed capacitance to ground. Distributed capacitance to ground is a common property and well documented especially for cables used in electrical distribution. The more cable in a system, the higher the charging current or leakage to ground. While transient overvoltages are rare, they can and do occur. The resistance grounded system designer must be aware that this can be a problem when resistor current is lower than the charging current of the power system. Modern systems may employ more advanced voltage protection devices than were used previously. Lightning arrestors or Metal Oxide Varistors (MOV's) for example can help prevent the dangerous escalation of transient overvoltages (rated for L-L Voltage).

Resistance grounding is used because it shares the benefits, but not the drawbacks, of both solidly grounded and ungrounded systems. High-resistance grounding and ungrounded systems have many similarities and shared benefits. Unless directly required by local regulations to trip, low-voltage systems can be configured two ways to respond to a ground fault; either 1) trip, or 2) alarm/annunciate the fault and continue to operate.[1] Modern electrical protection systems can use quick fault clearing to help prevent the possibility of transient overvoltages on both high resistance grounded and ungrounded systems. Tripping is often overlooked as a method of protection when production is seen as critical, even though not all loads are critical to the operation. A power system with one phase faulted to ground has a heightened probability of a second-phase ground fault. The increased downtime that may be caused by a phase-to-ground-to-phase fault should not be overlooked. A system that is set to alarm should at a minimum have a defined time limit to allow operation before de-energizing the system; otherwise it is too easy for production to continue to run indefinitely, increasing the probability of additional failure.

Low-voltage transformers, those rated below 600 V, can be wye or delta connected. The neutral of a wye connection can be solidly grounded or resistance grounded. The grounding resistance can be anywhere in the range of very little (or solidly grounded) to very high (or ungrounded). Typically, ground-fault current is limited to 5 Amps, but many other values can be used. For power-system voltage stability, the system neutral voltage must not be allowed to deviate far from ground potential (to avoid a transient overvoltage condition). To ensure the power system cannot support a transient overvoltage, minimum resistor current rating is equal to system charging current. Charging current is directly related to distributed system capacitance, hence to system size.

In many cases where system stability is paramount, such as power transmission, the power system is solidly grounded. In low-voltage distribution applications in industrial facilities a solid connection to earth has negative effects during a phase-to-ground fault. The energy available to a ground fault is similar to that of a phase-to-phase fault. The solid connection to ground does not limit the current during a ground fault and there is potential for release of a large amount of energy during every ground fault. Different references mention that 80-90 % of the faults that occur in a facility start out as a single-phase-to-ground fault. Ground faults are often the result of insulation breakdown resulting in an energized conductor contacting a metallic enclosure or frame that is at ground potential. Solid grounding increases the risk of arc-flash exposure to workers, as compared to other grounding methods. The increased awareness of arc-flash hazards, and newer standards such as National Fire Protection Association NFPA 70E Standard for Electrical Safety in the workplace, have done a great deal to help protect workers from one of the hazards of electrical work. These are not the only hazards present in an electrical system although they seem to have taken the spotlight away from contact forms of danger such as shock and electrocution. Additional risk is present in a system that is allowed to operate continuously with a fault on the system.

Markets using Resistance Grounding and Why?

The Institute of Electrical and Electronic Engineers (IEEE) Std 142 [3] stated the purposes of grounding as:

1. Controlling the voltage-to-ground (within predictable limits) to limit the voltage stress on the insulation of conductors. The control of voltage also allows reduction of shock hazard to persons who might come in contact with live conductors.

2. Providing for a flow of current to allow detection of an unwanted connection of conductor(s) to ground. Such detection may then initiate operation of automatic devices to remove the source of voltage from these conductors.

Industries in many countries have used resistance grounding, including: mining, refining, chemical plants, manufacturing, pipelines, datacenters, shore-to-ship power, and pulp, paper and forestry. It is used primarily for safety and in many cases for continuity of service.

Some North American companies may have adopted resistance grounding due to a lack of awareness that ground-fault location systems (IFLS: insulation fault location system) are available for ungrounded systems. The capability of allowing continued operation on ungrounded and high resistance grounded systems is a major advantage over solidly grounded systems and low resistance grounded systems. The ability to automatically locate the ground fault is another advantage that customers value. Preventing downtime is not the only purpose of a ground-fault relay. Ground-fault devices such as insulation monitors and CT-based ground-fault relays are there to detect abnormal conditions. With the correct selection of sensors on individual feeders and the use of hand-held fault locaters they can be used to rapidly determine the ground-fault location. Maintenance personnel can't fix the problem until they know where it is. The savings in person hours is a major benefit of quick fault detection and location. The ground-fault equipment can also automatically trip a circuit to help prevent fire, equipment damage, and arc flashes but the cost of protection can be unscheduled downtime.

Moveable and mobile equipment used in mining and other industries is often required by code to be powered by a resistance-grounded system, and be required to trip on the occurrence of a ground fault. CSA M421 Use of Electricity in Mines, AZ/NZ 2081 Electrical Protection Devices for Mines and Quarries Standards Australia, National Fire Protection Association National Electrical Code (NEC) 2017 Article 250.188 are some of the standards for such portable or mobile power requirements. There are differences, but most are similar in that they require ground conductor monitoring of the cable feeding power to the portable equipment. It is obviously not possible to ground a mining vehicle or rubber-tired vehicle the same way that a facility can be grounded. The cable feeding power to the equipment contains the conductor used to bond the equipment to the supply ground. It is important for anyone that comes into contact with such equipment that the voltage of the frame does not become energized, to prevent touch potential hazards.

Mining codes often require a grounding location for substation neutral grounding resistors that is isolated from chassis ground of the substation. This isolation is to help prevent touch potential elevation at the substation resulting from substation-high-side ground faults and the dangerous transfer of this potential to portable loads, as illustrated by Fault A in CSA M421-16 Appendix A below.

What is the difference

between high-resistance grounding and low-resistance grounding? Why are both still being used?

High-resistance grounding is not well defined in standards, but uses resistors with high ohmic values resulting in low ground-fault

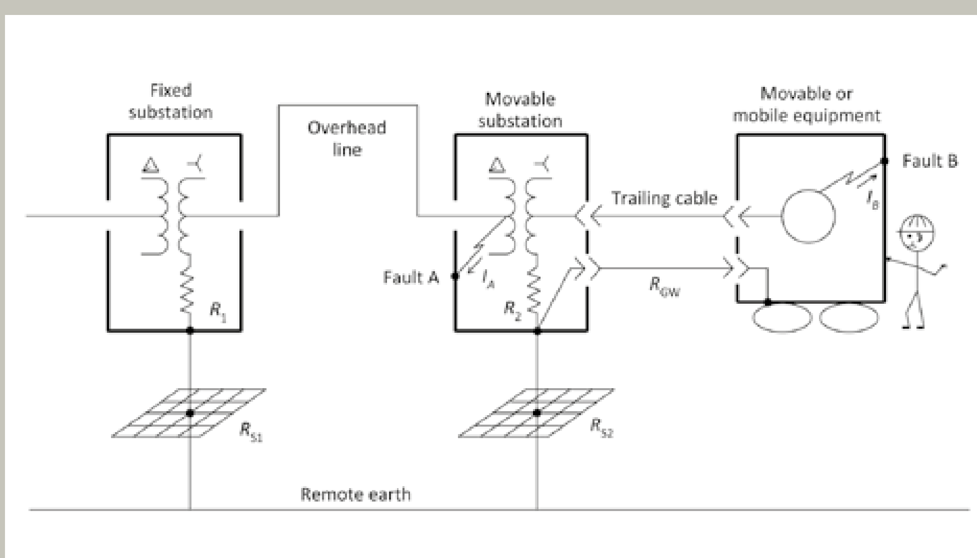
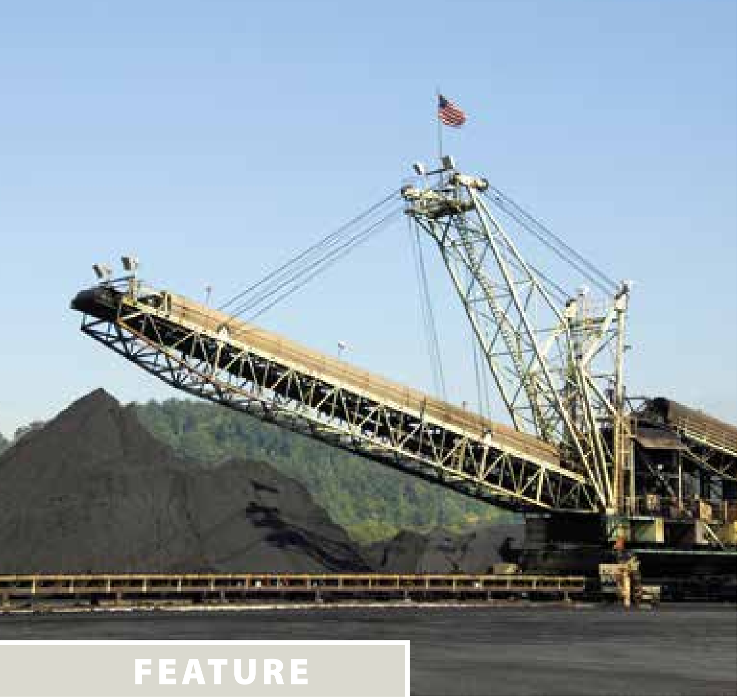


Figure 4: Drawing from Figure A.1, CSA M421-16 – Use of electricity in mines.
© 2016 Canadian Standards Association*

*) "With the permission of Canadian Standards Association, (operating as "CSA Group"), 178 Rexdale Blvd., Toronto, ON, M9W 1R3, material is reproduced from CSA Group's standard CSA M421-16 – Use of electricity in mines. This material is not the complete and official position of CSA Group on the referenced subject, which is represented solely by the Standard in its entirety. While use of the material has been authorized, CSA Group is not responsible for the manner in which the data is presented, nor for any representations and interpretations. No further reproduction is permitted. For more information or to purchase standard(s) from CSA Group, please visit store.csagroup.org or call 1-800-463-6727."



current levels. Due to the low current levels during phase-to-ground faults, alarming (instead of tripping) can be selected and facility operation is not interrupted. On the other hand, low resistance grounding has the opposite characteristics. In Canada, the Canadian Electrical Code defines clear limits that make design work simpler. In most cases outside of mining, an electrical power distribution system is not required to deenergize due to a ground fault if system voltage is 5 kV or lower and the ground-fault current is limited to 10 A. [3] While the U.S. NEC does not clearly define this level, another American standard, NFPA 70E-2015 Informational Annex O [4] acknowledges high resistance grounding as one incident energy reduction method.

Low voltage systems normally enjoy the benefits of high resistance grounding. Medium and high voltage systems sometimes default to low resistance grounding but they can certainly be high-resistance grounded. Tripping is more common in medium- and high-voltage applications. There is often fewer feeders and loads at 4160 V and higher voltages. Medium voltage conductors may be given more respect than low-voltage cables. Loads such as transformers are less prone to ground faults than low-voltage motors and heaters.

Generators are a unique application that are often required to be resistance grounded. High resistance can be employed in generator applications to help control fault damage and in some cases control faults to make the system alarm only. Addition of downstream sensitive earth-fault detection is an advantage but it may not be necessary to add single function ground-fault detection devices. Modern devices such as feeder and motor protection relays, adjustable speed drives and some breakers have sensitive ground-fault pickup levels – although they have their own limitations for frequency response and pickup that may make selection of individual ground-fault devices advantageous.

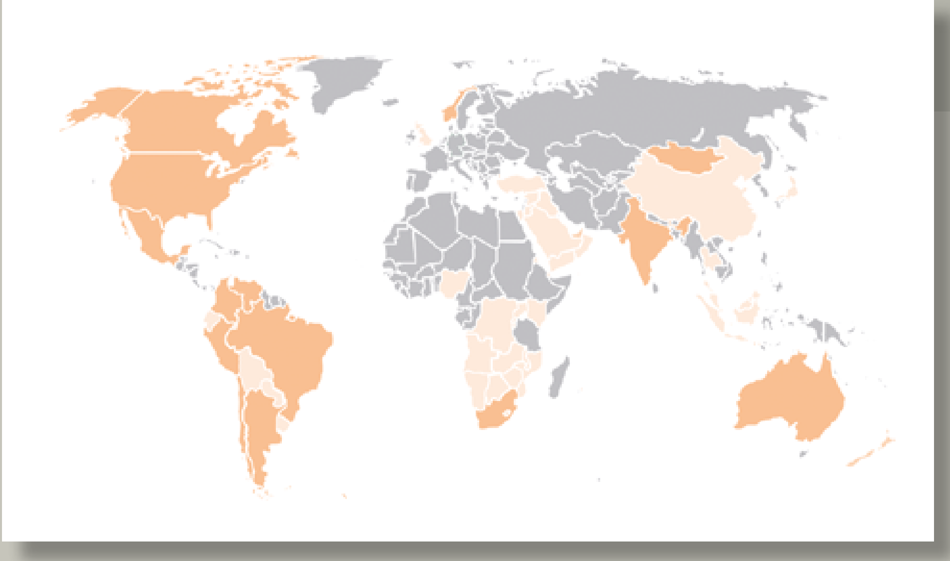
Neutral grounding resistor current flow that is not at the standard power frequency is another abnormality that should be monitored. A disadvantage that can be present on generator systems is the potential for non-fundamental frequency (50/60 Hz) current flow. There have been cases where harmonics such as the 3rd have flowed between generators' neutrals when they have been tied to a common bus [6]. This condition and any other faults caused by harmonics or dc currents when detected early can be remedied before they have had a chance to heat the grounding resistor and cause premature failure. In many European countries the requirement to use a ground-fault device with a wide frequency response range that includes dc, such as the European-defined Type B ground-fault protection device, gives enhanced awareness to abnormal situations and should be considered in all applications where non-linear loads are used.

Customer requirements and the understanding of root causes of ground faults advances with time. There is a definite and serious gap in protection if a neutral-grounding resistor fails open. Current transformer (CT) based ground-fault protection cannot function. Such monitoring has been required in many jurisdictions for years while others use the technology because it is a best practice. Code changes in a few jurisdictions have added requirements for detection of open and shorted grounding resistors (see reference [3] section 10-302) for any impedance grounded system. The US Mine Safety and Health Administration has added special requirements on adjustable speed drives to provide ground-fault protection response that works across the entire output frequency range of the drive. There may be many older systems that are blind to faults that are not at fundamental i.e. 50/60 Hz. The next generation of resistance grounding monitors are available to not only meet such requirements but go beyond the minimum and greatly enhance the protection and performance of a system. Awareness of global standards can lead to product enhancements.

CONCLUSION

No matter how the designer chooses to ground a system there is more than adequate protection available. Bender has advanced solutions to detect insulation failures, with Global experience in applications, codes and standards. ■

Jeff Glenney, P.Eng , Bender Inc. USA
Torsten Epkes, B.Eng.,
BU Industrial Solutions, Product Management



Focus Market   Enhanced Market   Known application (rarely)

REFERENCES

[1] System Grounding and Ground-Fault Protection in the Petrochemical Industry: A Need for a Better Understanding – John P. Nelson
[2] IEEE Std 142 - 1991
[3] C22.1-18 Canadian Electrical Code, Part I Safety Standard for Electrical Installations
[4] National Fire Protection Association NFPA 70E-2015
[5] Low Zero-Sequence Impedances on Generators – Michael Simpson and John Merrell, August 30, 2000
[6] 3rd Harmonic Current in a Generator Neutral Earthing Resistor Connected to a Large Cable Network – Jason Mayer and Ryan Turner (2017-PSEC-0804)