

New Approaches for Maintenance Grounding in Medium-Voltage Switchgear

by Joe Richard and David Mabius

Executive summary

Maintenance grounding has traditionally been performed by maintenance personnel working in close proximity to open switchgear. However, to decrease risk of personal injury, workers should stay away from open energized switchgear panels prior to proper equipment grounding. Modern grounding switches now allow personnel to achieve grounding with the switchgear completely enclosed. This paper reviews how this engineered safety solution works.

Introduction

Performing maintenance on medium-voltage electrical distribution switchgear involves inherent risk to the maintenance personnel in and around the switchgear. U.S. Occupational Safety and Health Administration (OSHA) 1910.269 is the standard which governs safety practices that must be undertaken, equipment that must be provided and training that must be given by employers for maintenance work in the electrical power industry. The National Fire Protection Association (NFPA) 70E is a consensus standard that lays out specific steps that shall be followed in order to create “an electrically safe work condition” during electrical switchgear maintenance.

First, those performing the work must understand all the possible sources of electrical energy supplied to the switchgear being maintained. This includes, but is not limited to, reviewing the most current electrical drawings and sources of energy to the switchgear. Second, all the sources of electrical energy found must be properly disconnected. Third, the isolation of these sources should be visibly verified. This can be done via switch viewing windows or by withdrawing a circuit breaker from its cell. Fourth, lockout/ tagout devices should be applied according to an established policy developed by the owner or organization performing the maintenance. Fifth, the absence of electrical energy needs to be verified. This can be done with an appropriately rated voltage detection device used to test voltage differences between phase-to-phase and phase-to ground. Before and after each test, the voltage detector should be tested to determine correct operation. Lastly, the conductors in the area of switchgear being maintained should be properly grounded with devices rated for the available fault current in order to create an “equi-potential zone,” as described in OSHA 1910.269(n)(3), in which maintenance personnel may work.¹

If bus bars and feeder cables could be grounded without removing switchgear panels or covers, the risk to maintenance personnel would be significantly reduced.

Maintenance grounding is a traditional and proven method for protecting electrical workers during medium-voltage switchgear maintenance. When properly applied, it eliminates dangerous differences in electric potential, and can redirect harmful current during events such as unforeseen induced voltage from motors and generators, accidental bus contact with adjacent live parts, or human error that causes equipment to be re-energized. However, the process for grounding switchgear when beginning maintenance can be potentially perilous. Any time panels are removed and energized components are exposed, the chance for arc flash or electrocution increases. According to OSHA 1910.269 and NFPA 70E, unless the bus is grounded and tested, it must be considered energized.

If bus bars and feeder cables could be grounded without removing switchgear panels or covers, the risk to maintenance personnel would be significantly reduced. This paper will discuss integral grounding switches – a new engineered safety solution that makes this possible.

The hazards of switchgear maintenance

The purpose of grounding before routine inspection or switchgear maintenance is to reduce the risk of arc flash or electrocution for maintenance personnel during maintenance processes. By placing current-carrying switchgear parts at ground potential, incident current can be redirected to ground instead of through maintenance personnel. Incident current can result from a variety of sources and occurrences, which may affect the application of grounding protection. This paper will explore a few of the situations that can result in incident current while performing maintenance.

A common source of risk during maintenance is human error. While lockout/tagout (LOTO) procedures that follow the OSHA 1910.269(d) standard can help ensure switchgear is properly de-energized and help prevent it from being re-energized during maintenance, there

¹ NFPA 70E®: Standard for Electrical Safety in the Workplace, 2012 Edition, Technical Committee on Electrical Safety in the Workplace, Quincy, Mass., Copyright © 2011 National Fire Protection Association® and U.S. Occupational Safety and Health Administration Standard 1910.269: Special Industries, U.S. Department of Labor, 59 FR 40672, 9 August 1994; 59 FR 51672, 12 October 1994, www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9868.

is anecdotal evidence in the industry of lockout/tagout procedures being bypassed or causing electrocution or arc flash incidents. Improperly locked and tagged switches, failing to lock and tag all sources of incoming energy to switchgear, and locks and tags being improperly removed or even cut during work can put maintenance personnel in danger of working in switchgear that can be energized. Proper grounding applications, in addition to proper lockout/tagout procedures and education, can help prevent workplace incidents during switchgear inspection or maintenance.

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Another source of risk during maintenance is electromagnetic energy storage in equipment connected to the power system. The promotion of renewable power sources, uninterruptable power supplies (UPS) and power quality devices have increased the number of sources of energy on modern electrical distribution systems. Renewable energy, generators and battery systems complicate distribution systems, and can make securing all sources of energy difficult. Microturbine and UPS systems, which are becoming more prominent in critical power applications, can transfer unexpected energy onto the system while switchgear is under maintenance. Power factor correction capacitor banks that have not been properly discharged can pose a danger in switchgear being maintained. Automated generator systems or power transfer switches can energize switchgear in unforeseen power loss scenarios. Lengthy, medium-voltage cable runs will hold capacitive energy that can be suddenly released to de-energized switchgear during maintenance or mechanical testing procedures.

These sources, plus more common incidents such as dropped tools, initial construction errors or misread electrical drawings, illustrate that the possibility of incidental energization of switchgear while under maintenance is quite possible. This is by no means a comprehensive list of all the possible situations that could occur during electrical switchgear maintenance. The central reason for grounding equipment before testing is to reduce the threat of unexpected energy in order to create a zone of protection in which maintenance personnel can work. If all possible failure scenarios could be predicted and prevented, grounding would be unnecessary. Therefore, in order to better protect maintenance personnel from incident energy, one must give that energy a low impedance conduit of escape other than through maintenance personnel.

Maintenance grounding applications

According to article 120.3 (A) of NFPA 70E: Handbook for Electrical Safety in the Workplace, 2012 Edition, “temporary protective grounds shall be placed at such locations and arranged in such a manner as to prevent each employee from being exposed to hazardous differences in electric potential.”² However, this loose description leaves room for interpretation as to the actual application. When applying maintenance grounds, several factors must be considered and the placement of the ground can affect what areas will be safeguarded during maintenance. Three techniques most often used to ground switchgear will be discussed here: bus bar grounding, load side grounding and main grounding.

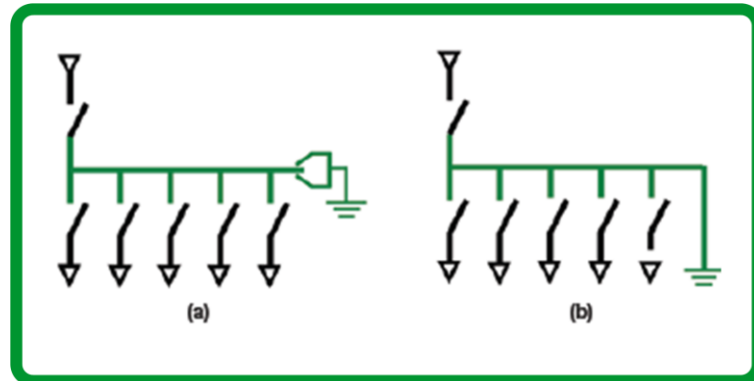
The most common placements of a ground are directly on the bus bars or on the load side of a switch/ circuit breaker (**Figure 1**). Bus bar grounding can be achieved by one of two methods: grounding clamps applied to bus bars or a separate switchgear section with a switching mechanism dedicated to ground. The benefit of direct bus bar grounding is that the bus bars are grounded in the majority of situations. Maintenance personnel working in the bus compartment of metal-clad switchgear or in the interior of metal-enclosed switchgear are better protected from inadvertent voltage application to the bus bars. It usually means the grounding application will be present at the site where maintenance is taking place. This helps protect against human error by allowing the maintenance personnel to physically and visually see the ground, and secure it from other people who may accidentally disconnect it. However, any cable sections behind an open switch relative to the bus bars become

² NFPA 70E®: Standard for Electrical Safety in the Workplace, 2012 Edition, Technical Committee on Electrical Safety in the Workplace, Quincy, Mass., Copyright © 2011 National Fire Protection Association®

ungrounded. In main-tie-main (M-T-M) switchgear, bus isolation becomes an issue requiring multiple grounding applications. This problem is common for grounding in all M-T-M applications. If a switch in a separate compartment is used for grounding, this can add to the footprint of the switchgear.

Figure 1

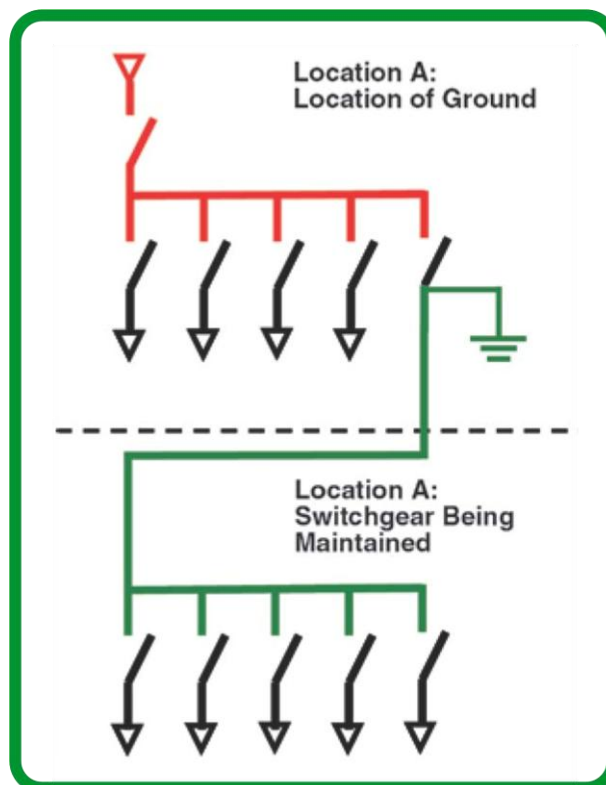
Bus bar grounding with a ground clamp and with a grounding switch section



A load-side grounding application is grounding of the load side of a feeder to protect downstream equipment or prevent back feeding from downstream equipment, such as large motors. This method is usually accomplished with a grounding truck or ground and test (G&T) device. The benefit of this method is the ground is placed close to the source of the energy should a fault occur. In this scenario, the ground is applied to the de-energized, load-side cables of switchgear upstream from the switchgear undergoing maintenance. If the main of the switchgear under maintenance is closed, the bussing of that switch gear will also be kept at ground. The downside to this method is that the ground placement is usually at a separate location from the switchgear being maintained (**Figure 2**). This can make maintenance personnel feel uneasy since the grounding is not visible and is vulnerable to being tampered with by other plant personnel unaware of the ongoing maintenance.

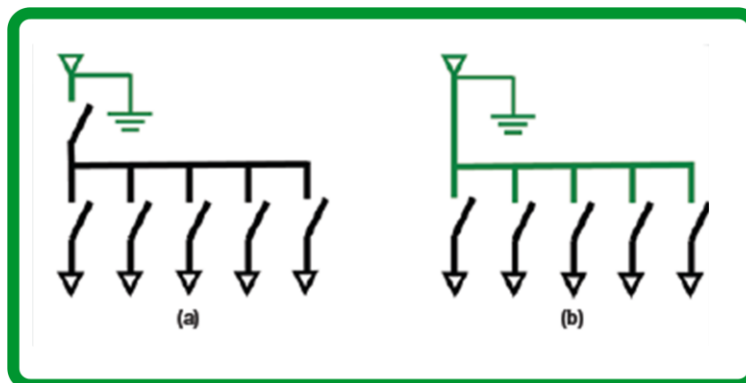
Figure 2

Cable feeder grounding



A third practice used is main grounding. In this method, the ground is applied to the line side of the main switch or circuit breaker in switchgear (**Figure 3a**). The benefits of this method are that the ground is applied close to the source of potential fault, but is also physically close to the rest of the switchgear undergoing maintenance, and therefore, usually visible by the maintenance personnel it is protecting. When the main is closed, the bussing is also grounded (**Figure 3b**). This method is particularly useful in the case of upstream automated generator systems or in switchgear with long cable lengths upstream of the main.

Figure 3
Main grounding



While all of these methods provide a certain amount of protection on their own, they each leave areas of vulnerability. As with many problems, the best solution is a combination of these applications. Depending on the maintenance task being performed, different levels of grounding protection are required. The best grounding application decision will be made when all potential sources of energy are considered in tandem with the maintenance tasks being performed.

Grounding methods

There are two traditional methods of maintenance grounding. The majority of maintenance grounding is still applied manually inside open switchgear wearing the appropriate personal protective equipment (PPE) as defined by NFPA 70E. This usually involves clamps, grounding cables, and a connection to the system ground (**Figure 4**). The other traditional method is the use of a ground and test device. Most metal-clad switchgear manufacturers offer G&T devices or grounding trucks that can be inserted in place of a circuit breaker to ground either the cable side or the bus side of switchgear (**Figure 5**). A new, safer, robust engineered design option is an integral grounding switch built into the switchgear. This method allows for grounding before the removal of panels or covers, and helps prevent exposure to energized parts. These three methods will be further discussed in the following paragraphs.

Figure 4
Applied grounding clamps



Figure 5*Ground and test device*

When performing maintenance on performing maintenance on medium-voltage switchgear, precautions must be taken per OSHA 1910.269. Assessing the potential risk is accomplished by studying the most current drawings to be aware of all possible sources of energy. Additionally, if an arc flash study or short circuit coordination study sticker is on the switchgear, it should be noted for indication of the available fault current. An arc flash study sticker will give the additional information of personal protective equipment (PPE) classification and safe work distances. The PPE required is most commonly between category levels 2 and 4, and the working distance is commonly between 18 and 36 inches from energized parts. A qualified assistant shall also always be present to help with the work and to provide assistance in case of an incident. Assistants shall be equipped with shepherd's hooks or ropes in case an emergency rescue is required. They must also be provided with a means to call for help. Qualified persons shall be trained in CPR and basic first aid, in accordance with OSHA 1910.269(b)(1).³

While ground clamps are a proven method of grounding switchgear during maintenance, they pose the distinct hazard of putting workers in front of what must be considered energized bus bars until the ground has been successfully made and tested. There are a number of styles of clamping used in the industry. A common type is flat bus bar clamps. Flat bus bar clamps are simple and intuitive to use; however, they are prone to slipping and sliding from position.

Ball-and-socket design clamps work in tandem with grounding ball studs installed in switchgear. The grounding ball, installed in cable compartments of switchgear, is coupled to a socket-shaped clamp fitted with a ground conductor connected to the switchgear ground bus. The clamp is fitted over the ball and tightened with a screw retainer.

While this method is quicker and more secure than the bus bar clamp method, fitting the ball and socket together can be a cumbersome task in category 4 PPE gear, especially since a live-line tool (such as a hot stick) must be used to create more distance between workers and the open switchgear per OSHA 1910.269(n)(6). The ball is usually only about an inch in diameter. The combination of wielding six to eight feet of hot stick, looking through an arc flash suit mask and wearing thick gloves that limit hand coordination can make connecting the grounding ball with the small socket clamp a time-consuming and difficult task.

In addition, the clamp apparatus is a danger to nearby workers. During a fault event, great physical stress is transmitted through the switchgear system. This force is projected into the grounding cables connected to the grounding clamps. At best, the cables flail wildly with the

³ U.S. Occupational Safety and Health Administration Standard 1910.269: Special Industries, U.S. Department of Labor, 59 FR 40672, 9 August 1994; 59 FR 51672, 12 October 1994, www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9868.

potential of striking nearby workers or bumping into loose panels or other equipment that can then be projected onto nearby workers. At worst, the cables can fly loose, striking workers like a whip and causing serious injury. In this type of event, the current carrying portions of the switchgear that were protected are now energized and present the danger of arc flash or electrocution.

Ground and test devices (**Figure 5**) are sold by most metal-clad switchgear manufacturers. They can be inserted into breaker compartments and allow grounding of either the cables or bus bar, depending on their configuration and versatility. Two general types of G&T devices are offered: manual and electrical. Simple, manual G&T devices consist of one or two terminal sets with a means of connection to the switchgear grounding system. Cables or bussing are usual. Simple, electrical G&T devices consist of a terminal set with a power-operated, ground-making switch that connects the terminal set to the switchgear ground system. A complex, electrical G&T device is similar to the simple, electrical G&T device, but adds a second terminal set and a manually operated switch with key interlocks to select which terminals are being used. Electric devices are commonly supplied with voltage test ports.⁴

G&T devices work well for feeder cable grounding when working on downstream switchgear or bus bar grounding when working in a compartment separate from the G&T device. G&T devices are required by Institute of Electrical and Electronics Engineers (IEEE) standards to have an interlocking system to prevent their use in systems of voltage beyond the tested capacity. They should also have impulse and short circuit current ratings equal to or greater than the switchgear in which they are used. G&T devices must be properly maintained just like medium-voltage breakers, including periodic inspection and cleaning.

A large problem reported by maintenance service teams is that the G&T devices are not maintained and many customers never learn to use them after purchase. As with most safety equipment in the industry, educated use can save time, property and lives. Improper use can result in serious consequences, including loss of switchgear and injury to personnel.

Integral grounding switches

A newer option gaining attention in the American National Standards Institute (ANSI) market is the use of integral grounding switches. When operated, these switches connect current-carrying parts of the switchgear to ground. This allows maintenance personnel to ensure the removal of electric energy from the potentially energized parts of switchgear during maintenance. These switches have long been used in the International Electrotechnical Commission (IEC) market, where they are usually referred to as “earthing switches.” They are a tried and tested method of grounding switchgear, cables and transformers. Grounding switches offer the benefits of being simple to operate, easy to secure during lockout/tagout procedures, and, most importantly, give the added protection of grounding the switchgear without exposing maintenance personnel to exposed energized parts. Personnel that operate switchgear with grounding switches have a higher degree of confidence in applying ground without having to open switchgear compartments first. By installing switchgear with internal grounding switches, that is, by specifying equipment to the highest standards, owners send a message to their maintenance service teams that they are serious about personnel safety and equipment protection.

Proper grounding switches will meet the following requirements to be used safely during maintenance or routine inspection. First, a grounding switch must be tested and approved for the available fault current of the distribution system. An undersized switch may not adequately reduce the risk to personnel. Second, an effective bonding and grounding mechanism must be constructed to bond the switch to the ground bus of the switchgear.

⁴ IEEE Standard for 4.76kV to 38kV Rated Grounding and Testing Devices Used in Enclosures, IEEE Std C37.20.6-1997(R2003), ©1997 Institute of Electrical and Electronics Engineers Inc., ISBN 1-55937-910-3.

Third, the switch must be of robust construction so as to withstand the mechanical forces experienced during a fault.

Fourth, there should be a source of voltage indication on the bus or cables being grounded. Live line indicators (LLIs) are an excellent example of how to meet this requirement (**Figure 6**). LLIs typically use three, single-phase capacitive voltage dividers to monitor the presence of line-to-line and line-to-ground voltage in switchgear.⁵ A panel-mounted interface indicates the presence or absence of voltage at the point of monitoring. LLIs are commonly used in conjunction with mimic bus in order to better illustrate to workers which side of the switch is being monitored. LLIs can be used to check for the absence of voltage before closing a grounding switch. Maintenance personnel still must follow the guidelines of OSHA 1910.269(d) or (m) before the switch-gear can be considered de-energized for maintenance.

Figure 6
Live line indicator

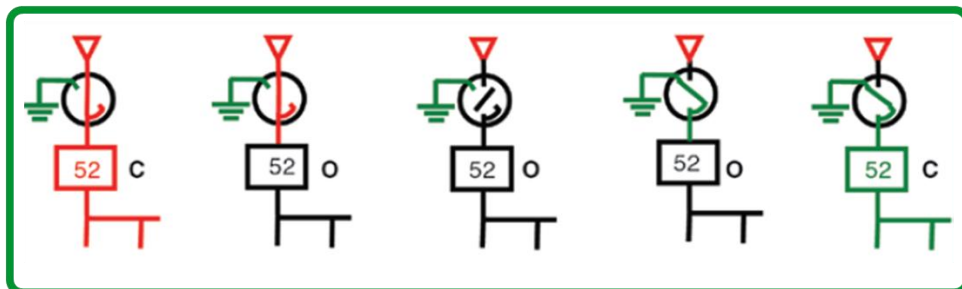


Finally, an effective interlocking scheme should be implemented to prevent closing the grounding switch while the switchgear is under normal operation and voltage is present. This scheme should be intuitive and should not allow for circumvention in any circumstances.

The implementation of internal grounding switches allows for more robust protective interlocking schemes. In combination with standard door interlocks and the previously mentioned use of voltage indicators, an interlock scheme can be developed that would prevent switchgear panel doors from being opened until the bussing has been properly grounded. This additional safety step would go a long way toward reducing the risk of exposing maintenance personnel to energized bussing or cables in switchgear.

Due to the safety designs engineered into grounding switches, the likelihood that mistakes will be made that can damage switchgear or endanger personnel should be reduced. One of the problems of traditional grounding methods is that they leave too much potential for human error during many steps of the process. With a proper grounding switch, personnel need only follow the interlock scheme, which will help prevent grounding with voltage present (**Figure 7**). Live line indicators can indicate voltage on the system before the grounding switches are closed, adding another layer of information and acknowledgment to workers. This process reduces the amount of training needed and the probability of human error.

Figure 7
Five stages of closing a grounding switch to ground the main bus

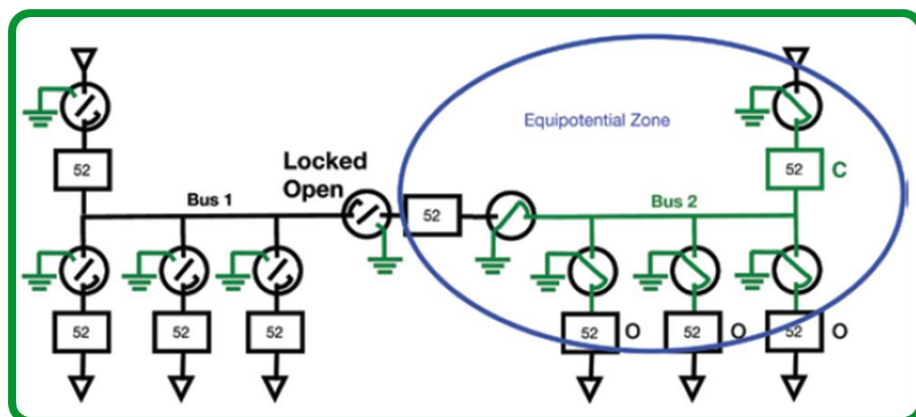


⁵ "HVL/cc™ Medium-Voltage, Metal-Enclosed Switchgear Catalog 2004, Class 6045," (document No. 6045CT98D1R3/04), p. 26, HVL/cc™ Grounding Switch Application, © Schneider Electric 1999-2004.

Applications with grounding switches

By adding grounding switches to the grounding application designs discussed earlier, further benefits can be realized. Bus bar grounding can be accomplished by connecting the load side of a dedicated switch to ground. However, as mentioned before, this requires the extra space of an additional switch section in metal-enclosed switchgear, and at least an extra circuit breaker compartment in metal-clad switchgear. With an integral dedicated grounding switch, grounding can be accomplished within existing sections without adding to the equipment footprint. In addition, when grounding switches are integral to the switchgear, it is easier to make design considerations that protect M-T-M switchgear line-ups in multiple configurations. With the appropriate application, as shown in **Figure 8**, it even allows for the testing and switching of main and tie breakers while keeping the bus at a protected ground potential. Because the grounding process is shortened with the use of grounding switches, this versatility is accomplished in less time and in a safer manner compared with traditional clamp methods.

Figure 8
Live line indicator



Main switch grounding and feeder cable grounding become inherent if grounding switches are installed in each switchgear section. The interlocking scheme will be dependent on the grounding switch placement compared to the switch or circuit breaker. For instance, if the grounding switch is positioned on the source side of the main breaker, the main breaker will need to be opened, the grounding switch closed, and then the breaker closed in order to ground the main bus bars (**Figure 7**). As stated before, voltage indicators at the incoming line would be important to make sure the grounding switch is not closing into live voltage. This would isolate the main bus and ground the breaker from voltage without removing the switchgear panels and exposing personnel to energized bussing or cables. In addition, when grounding switches are installed in each section of the switchgear (as shown in **Figure 8**), robust, redundant grounding can be accomplished. Because both the main for bus 2 and the bus 2 side of the tie breaker have complementary grounding switches, there are two sources of ground for the established equi-potential zone.

Grounding feeder cables to protect downstream equipment is also easier with grounding switches installed. Again, switchgear panels do not have to be removed from the upstream switchgear with an internal grounding switch. Once the grounding switch is engaged, it is more easily secured by lockout/ tagout of the grounding switch mechanism, and only the downstream gear being maintained needs to be opened to check for voltage. This not only reduces the risk of human error at the point of grounding, but gives maintenance personnel more control and a stronger sense of security over a clamp method.

Grounding switches can be very useful in the application of substation primaries. When working on transformers, traditionally the substation primary must be opened and grounded before work can begin. With a grounding switch, the primary switch or circuit breaker can be isolated and grounded before removing switchgear panels. Once the primary is grounded, the transformer can be opened for testing and maintenance. This further helps to protect workers

by securing the ground before any switchgear is opened and maintenance personnel are exposed.

An important distinction that should be noted is the difference between operating an internal grounding switch and the required steps for grounding for maintenance. The purpose of an internal grounding switch is to provide a process to ground medium-voltage switchgear before removing panel covers and exposing personnel to potentially energized equipment. However, this process does not eliminate the duty of maintenance personnel to properly follow lockout/tagout procedures as established by OSHA 1910.269(d) and/or maintenance grounding procedures as established by OSHA 1910.269(m) before maintenance is performed on the gear.

Conclusion

Due to the hazards of electrocution and arc flash during electrical switchgear maintenance, workers have rightly taken to the safety practice of grounding the switchgear on which they are working in order to eliminate the possibility of dangerous voltages which could destroy the equipment or cause severe injury. A variety of methods have been traditionally used, including grounding clamps and grounding trucks. However, these methods involve many risks; the worst of which is the exposure of personnel to potentially energized, current-carrying switchgear parts. The potential for human error is too great, and the time consumed with the traditional methods is lost money in uptime.

Implementation of grounding switches at the switchgear design phase can assuage many of these concerns. Safety enhancements decrease the risk to workers. Interlock schemes help protect workers from grounding into live parts, and live line indicators act as a visual safety indication. The intuitive design of integral grounding switches decreases the likelihood of human error by eliminating additional dangerous steps during the manual grounding process. The largest benefit is removing the need to expose personnel to energized equipment by grounding current carrying elements before panels or covers are removed. The risks to workers are significantly reduced. Implementing switchgear with integral grounding switches shows a dedication to safety and high-quality switchgear maintenance.



About the authors

Joe Richard is a Senior Marketing Specialist for Schneider Electric. He graduated with a BSEE from the Georgia Institute of Technology in 2007. He has worked for Schneider Electric for six years, specializing in medium-voltage switchgear and applications.

David Mablus is an Engineering Manager for Schneider Electric. He has over 25 years of project management experience focusing on expansion and improvement of manufacturing equipment, processes, control systems, and power consumption. His experience includes design through implementation, achieving results within schedule and budget. He works closely with internal/external development and design teams overseeing and coordinating project priorities, scope, resources, and schedules.