Session No. 640

Personal Protective Grounding for Electrical Workers: "If It Isn't Grounded, It Isn't Dead"

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Personal Protective Grounding /Bonding (PPGB) is one of the most important yet often misunderstood topics in High Voltage (>600 volts) electrical work (author's opinion). PPGB refers to techniques used to provide shock protection for electrical workers by connecting de-energized equipment on which work is to be performed to the earth. PPGB is a paradox in that, if it is done correctly, it is by far the most effective means of protecting electrical workers from electrical shock. However, if PPGB is done incorrectly, it can precipitate arc-flash events of unimaginable magnitude. This technical paper will explain the purpose of PPGB and proper methods for installing PPGB on typical industrial equipment. Although every effort has been made to put this topic into layman's terms, PPGB is a very technical topic and it will be best understood by readers who possess a good understanding of basic electrical concepts such as Ohm's law and Series and Parallel circuitry.

Why PPGB Is Necessary

The techniques of PPGB were developed because High Voltage (HV) workers were being killed on lines and equipment that either were mistakenly thought to be de-energized or accidentally became energized through some external means[1]. The "external means" could include the following:

- *Switching Errors*- where equipment was energized remotely from the work location or a relay caused a switch to close after the circuit had been tested for voltage.

- *Induction*- HV circuits can "induce" voltage (measured in volts) and current (measured in Amperes) on conductive surfaces even several yards away from the energized conductors. The author has personally tested brand-new HV 13,200 volt switches that had been opened but not "racked-out" (physically separated from the energized bus bars to which they are connected) and a voltage of several hundred volts was present. This is the reason that HV switches must be racked-out AND grounded before workers touch them with any part of their bodies.

- *Equipment Failure*- Insulators within HV switchgear can either break allowing conductors to come into contact with each other or insulators contaminated with conductive residue can begin to "track" allowing voltage to flow over them.

- Backfeed- The proliferation of customer-owned generators provides an alternate feed for electricity that can present shock hazards to anyone working on the circuits to which the generators are connected.

Definitions

(Italicized text from National Electrical Code. Other text is author's commentary)

There are a number of definitions that must be understood by the reader in order to properly digest the information included in this paper. These definitions include:

- *Bonding- Connected to establish electrical continuity and conductivity*. The main purpose of bonding is to equalize any differences in potential (voltage) that might exist between conductive surfaces.

- *Dead-Front Equipment- Without live parts exposed to a person on the operating side of the equipment*. A common circuit breaker panel found in any home is an example of dead-front equipment. Opening the door of the panel reveals only a grounded metal panel cover and non-conductive circuit breakers. This is "dead-front".

- *Equipotential Grounding/Bonding-* A technique used in PPGB where the worker places his/her body at the same potential as the system on which work is being performed. Should the equipment become energized, the equipment AND the worker are both energized to the same voltage. Because the worker does not have a "difference of potential" (voltage) across their body, they do not experience an electrical shock. A bird standing on an energized wire on a power pole is an example of this phenomenon. The bird's body is indeed energized to thousands of volts but the animal is not injured because there is no "difference of potential" across its body.

- *Fault Current or Short-Circuit Current (SCC)-* The amount of electrical current (amperes) that can possibly be supplied to any point in the electrical system should the system accidentally be faulted such that Current flows in unwanted paths.

- *Grounding- Connecting to ground (the earth) or to a conductive body that extends the ground connection*.

- *Grounding Electrode- A conducting object through which a connection to the earth is established.*

- *Ground Fault-* An unwanted path for current to flow from an electrical system to the earth.

- *Live-Front Equipment-* Electrical equipment that has exposed parts energized to 50 volts or more on the operating side of the equipment. Live-front equipment is the opposite of "dead-front" equipment that has NO exposed parts on the operating side of the equipment.

- *Metal Enclosed Power Switchgear (MEPS)-* A switchgear assembly completely enclosed on all sides by sheet metal except for ventilating openings and inspection windows and containing primary power circuit switching, interrupting devices, or both.

The Basics of PPGB

The basic procedure for PPGB is as follows:

1. De-energize the electrical equipment by isolating ALL possible electrical sources to the equipment.

2. For HV systems, it is a requirement to get a "visual open" in the circuit[2] such that the worker can visualize an air-gap in the switches used to isolate the circuit. The can be achieved either by opening a solid-blade switch that can be visualized, "racking-out" a circuit breaker by removing it from contact with an electrical bus or any other means that positively separates the electrical contacts in an Energy Isolating Device.

3. Follow normal Lockout/Tagout (LOTO) procedures per 29 CFR 1910.147 and 29 CFR 1910.269 (D &N)

4. It is required to perform a <u>3-point test</u> with a sensitive voltage testing devices to verify a Zero Energy State[3]. A 3-point test consists of testing the voltage tester on a known energized source to verify it is working properly (test #1). Then test the circuit on which work is to be performed (test #2). Then test the voltage tester on the same energized source as was used in Test #1 to verify the tester is still working properly (test #3).

   Examples of "sensitive voltage testing devices" include "glow-sticks" (light pens), "Tic-Tracers" (the make a sound when near energized parts) or direct-reading voltmeters.

5. Install grounding cables following the procedure listed below:

As is the case with most of electrical work, grounding cables must be installed and removed in a specific order.

1. ALWAYS connect the grounded-end of the grounding cables first.

2. Connections to the phase conductors are made next.

3. The grounding jumpers must be removed in the <u>reverse order.</u> There have been fatalities when workers attempted to move or remove the ground connections while the jumpers were still connected to the phase conductors.

Further, the cables must be placed only at proper points in the electrical system to ensure they perform as expected should the equipment become energized. Many arc-flash accidents have occurred when workers improperly applied grounding cables and the systems became energized. Figure 1 below illustrates a case where workers incorrectly tried to ground the low voltage side of a transformer. In this case, the ensuing arc-flash was hot-enough to actually burn-through the steel walls of the transformer enclosure.

Figure 1

Photo by J. Kolak

The techniques for grounding also vary by the types of systems on which work is being performed. For example, the procedure for installing grounds in a substation with exposed overhead conductors is quite different from installing grounds in a MEPS (enclosed in a metal enclosure) switchgear in an industrial facility. We will explain how to perform PPGB on overhead conductors and MEPS equipment in this paper. However, the reader must understand that the techniques to properly ground the systems in their specific facility may vary due to the configuration of their equipment. They should consult with a fully-Qualified Worker regarding proper grounding techniques in these cases.

How PPGB Works

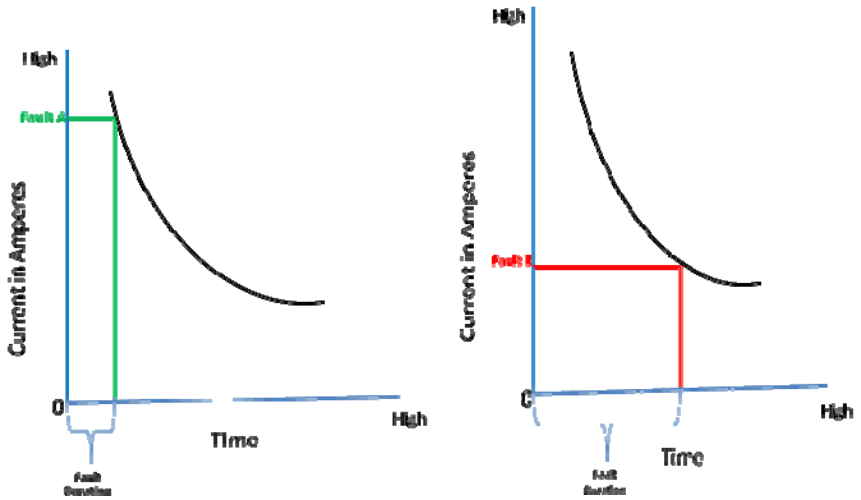
The main purpose of PPGB is to cause the maximum amount of SCC to flow in an electrical circuit by bonding the phase conductors and the neutral or grounding conductors together with specialized equipment. While this may seem like insanity at first, the reason for doing this is two-fold. The first reason is to maintain the voltage at the work location to a safe level until such time as the Overcurrent Protective Devices (fuses, circuit breakers) that protect the circuit and trip the equipment off-line. The second purpose is to reduce the duration of the fault. The reason for this is best illustrated by a common example that often occurs in the home:

> *Nearly everyone has been in a home when an appliance with a motor (refrigerator, table saw) starts-up and the lights in the home dim momentarily and then they return to their normal brightness. The reason the lights dimmed momentarily was because it takes substantially more current to start the device than it does to keep it running. This is known as "inrush current" meaning that the system must "rush-in" current to the load lest the voltage in the system sags to the point where it causes problems for voltage-sensitive devices. When the motor first started, it required more current than the electrical system could provide and the voltage in the house "sagged" momentarily and the lights dimmed. However, the electrical system eventually "catches up" with the demand for Current and the voltage returns to normal as does the brightness of the lights.*

PPGB works much the same way. When a circuit has been properly grounded for the protection of workers, and it accidentally becomes energized, the grounding cables installed on the circuit create a very low-Impedance connection to each other and to the earth. The electrical system reacts to this as if there is an extremely large "load" that requires maximum amounts of Current. If the grounding cables are properly sized and installed, the "load" is too great for the electrical system and the voltage "sags" to near-zero. However, the grounding cables cannot carry these massive amounts of current for more than a fraction of a second so the lives of the workers depend upon the Overcurrent Protective Devices (OCPD) that protect the circuit to de-energize the circuit BEFORE the grounding cables melt-open and voltage levels return to unsafe levels.

Figure 2 below illustrates the relationship between SCC and the time it takes for OCPD to shut-down a faulted circuit (knows as “Clearing” time):

Figure 2



Here we can see that there is an <u>inverse</u> relationship between SCC and clearing time, meaning that as the Fault Current increases, the Clearing time decreases. For Fault A, the high SCC causes the OCPD to open more quickly and the resultant duration of the fault event is much shorter. For Fault B, the OCPD are set to allow this level of current to flow for a longer period of time and the resultant fault duration is <u>much</u> longer. It is important for the reader to understand that the difference in the fault duration between Fault A and Fault B be might only be 1 second. However, with SCC levels of this magnitude, faults lasting only a fraction of a second longer than needed can be fatal.

<u>Parallel Grounding versus Equipotential Grounding</u>

The traditional methods for grounding overhead circuits are illustrated in Figure 3. We will initially use an overhead line to illustrate grounding techniques because it is easier to visualize what is happening. Later, we’ll cover how to properly ground MEPS circuitry such as what occurs most frequently in industrial facilities:

Figure 3.

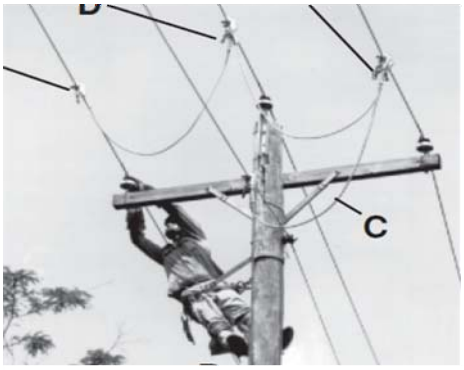


Illustration by A.B. Chance Co.

The worker in Figure 3 first made the connection from the neutral conductor (the conductor just above his pole strap) to the phase opposite him on the pole. He then made connections from that phase to the middle phase. The last connection was made between the middle phase and the phase on which he is working. The reason this paper has both “Bonding” and” Grounding” in the title is that one can see that the phase conductors are actually “bonded” together and the only connection to Ground is from the opposite phase to the neutral conductor. Therefore, the phase wires are bonded and the “system” of bonding jumpers is grounded.

Should this line become energized, most of the current will flow between the phase conductors and the connection to the neutral conductor is there mostly to “hold” the voltage in the system to near-zero. The hope is that the fuses or circuit breakers that feed this line will trip off-line quickly enough to avoid having a voltage redevelop on the line and injuring the Lineman touching the conductor.

From about the 1930’s to the 1970’s, this method of grounding was used by Lineman and other HV workers[4]. Unfortunately, many workers died while working on lines and equipment that had been grounded in this manner. The reason this occurred is explained in the next paragraph.

Figure 3 depicts a method of grounding called “parallel grounding”. If the line in Figure 3 were to become energized, the grounding cables (designated with the letter “C”) represent a <u>parallel</u> path for Current to flow because the Current could flow through the cables OR through the worker to the pole on which he is standing (the pole is conductive and is buried in the earth, therefore, it is grounded). In truth, the Current will probably flow through the worker AND the grounding cables but the problem is that a difference of potential (voltage) can develop across the worker and he could receive a shock as a result.

The reason this could occur relates to the properties of parallel circuitry. Figures 4 & 5 below illustrate this concept:

Figure 4

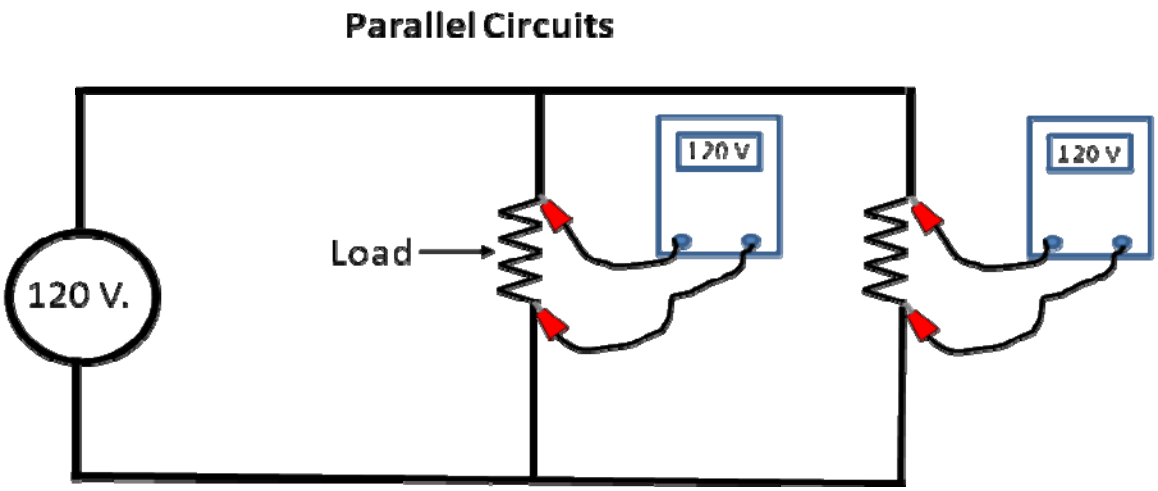
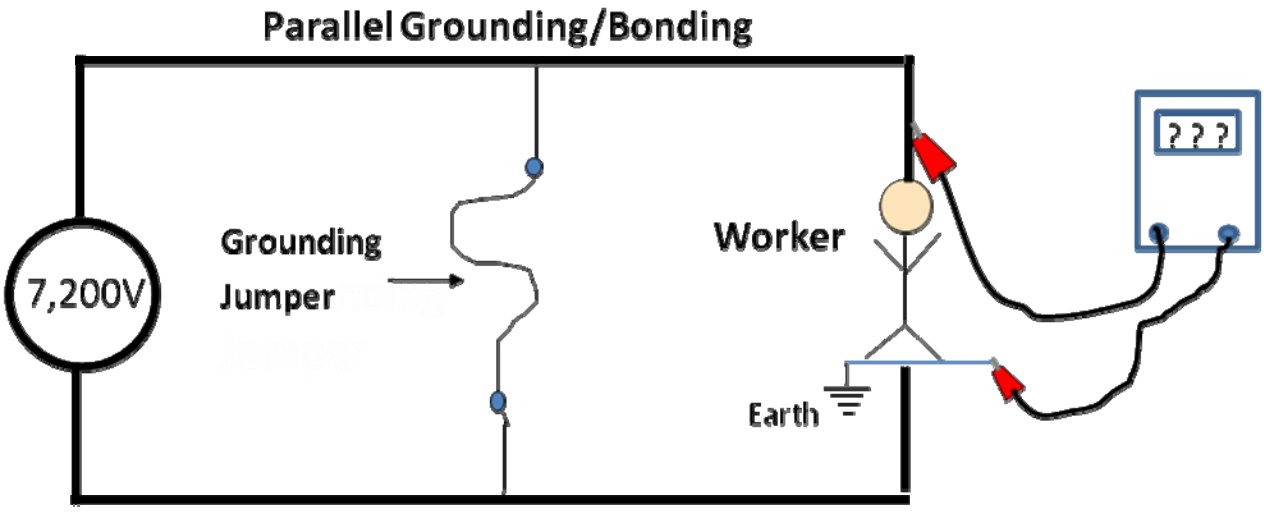


Figure 5



Parallel circuits have the property that ALL loads connected in parallel have the same voltage across them as the source voltage. Figure 4 shows this in that the voltmeters read the same (as the 120 volt source) across all the resistors in parallel.

Figure 5 illustrates that if a worker becomes one of those “parallel resistors” it is quite possible that a voltage will be impressed across the worker’s body and they will receive a shock. The reason parallel grounding sometimes doesn’t protect workers is that holding the system voltage near-zero requires exceptional quality connections between the grounding cables, the phase conductors and the earth. Even a small amount of oxidation that wasn’t properly wire-brushed off the conductors could provide enough additional Resistance (measured in Ohms) to allow a hazardous voltage to develop should the system become energized. It was because of this challenge that EPGB was developed. Using this method, even if a voltage does develop on the phase conductors, it won’t shock the worker because there is no “difference of potential”

across the worker's body. The regulations refer to this as "limiting voltage across the workman."[5]

Figure 6 depicts EPGB and it simply involves making one additional connection from a Cluster bracket (designated with the letter "B") beneath the worker's feet to the neutral conductor which was originally connected in the parallel grounding example.

Figure 6

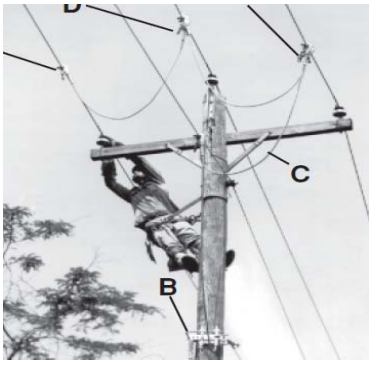


Illustration by A.B. Chance Co.

Making this connection effectively creates an "equipotential plane" from the cluster bracket to the top of the pole. This places the worker and everything he can reach or touch at the same voltage potential. This is so because, if a voltage develops on any conductor on the pole, the pole would become energized to the same voltage as the line. So, if there is some difference of potential that develops when the circuit becomes energized, the worker is effectively a "bird on a wire" and he will not experience a shock because there is no "difference of potential" across his body. This is the essence of EPGB.

MEPS Installations

For MEPS installations, it is necessary to use a "grounding mat" to create an 'equipotential plane". A grounding mat is especially constructed to be conductive rather than an insulator such as a rubber mat. All the electrical concepts just explained in the overhead line example apply to the MEPS installation except that the grounding cluster is replaced with a grounding mat. Figure 7 depicts a grounding mat used in conjunction with a boom truck:

Figure 7.

Picture by A.B. Chance Co.

If the boom on the truck were to contact an overhead line, the worker and the truck chassis would both be energized to the same voltage. Once again, because there is no difference of potential across the worker's body, he will not receive an electrical shock. This technique works with all metal clad enclosures, such as pad mounted transformers, Motor Control Centers or any electrical apparatus that is contained within a metal enclosure.

The construction of the mat is discussed later in this paper but it is important to recognize that use of the grounding mat protects the worker standing on that mat but it represents a potential hazard to anyone stepping on or off of the mat. Should the system to which the grounding mat is connected become energized, a difference of potential (voltage) will likely exist between the mat and the earth in the vicinity of the mat. Although the probability of the system becoming energized while a worker has one foot is on the mat and one foot is on the earth is quite remote, it nonetheless warrants mention here because it is a legitimate hazard. Suffice it to say that care should be taken not work on the grounded equipment unless the worker is standing completely on the grounding mat.

The worker's body position is also important and care should be taken to assume a position where the door of the enclosure shields the worker from an arc-blast should one occur while installing grounds. If the door opens to the left, the worker should install the first ground on the left-most conductor then ground the center conductor and finally the right-most conductor. Obviously, the process is reversed if the door to the cabinet opens to the right. Figure 8 illustrates a worker assuming a safe body position when installing protective grounds on MEPS equipment:

Figure 8

Photo by J. Kolak

There are a few important practical points to understand at this point.

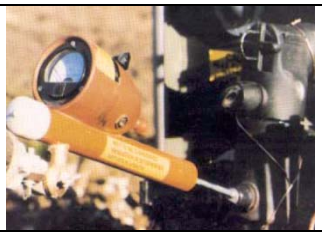
1. The system is not safe to touch until ALL three phase conductors are effectively bonded and grounded.
2. The grounding cables should be laid-out on the floor such that the worker can pick them up with the loop stick (discussed later) without touching the conductors (if possible).
3. The connection to the neutral or grounding conductor must NEVER be removed until the grounding jumpers have been removed from all three phase conductors/nodes.

Proper PPG Equipment

PPGB is actually a "system" of connections, in that there are a number of points where the various components of the grounding cables must connect to the system to be grounded and to each other. It is vitally important to recognize that the grounding system is only as good as the weakest connection. In other words, having high-quality grounding cables but under-sized grounding heads will render the system ineffective in protecting workers. Table 1 below

provides pictures of “typical” equipment needed to properly ground overhead lines and MEPS equipment:

Table 1

Grounding Equipment	Overhead Lines	MEPS
Grounding Heads (Many variations)		
Grounding Electrodes (Many variations)		
Wire Brushes (Many variations)		
Voltage Testers (Many variations)		
“Shotgun” Sticks		
Grounding Clusters/Mats		

Grounding Cables ***(Many variations)***		

All pictures by A.B. Chance Co.

There are a number of key concepts to remember when selecting PPGB equipment and they include:

- ***Grounding Heads***- The grounding head is the only connection between the grounding system and the electrical circuit on which work is to be performed. Like grounding cables, the grounding heads must be rated to "withstand" the maximum available Fault Current on the system on which they will be installed. Table 2 identifies the Withstand ratings of their grounding products.

- ***Grounding Electrodes:*** The grounding electrodes are the "other end" of the grounding system in that the electrode provides the physical contact with the earth. There are many different ways to connect to the earth and only two are shown in the table above. On overhead circuits it is common to use a "screw-in ground rod" which is manually "screwed-in" to the earth with handles. The grounding cables are then connected to the screw-in ground rod and then connected to the system to be grounded. NOTE: Screw-in ground rods are not very good grounding electrodes because the earth around the ground rod has been disturbed during the installation. It is preferable to use a grounding electrode where the earth has not been disturbed such as a ground grid, etc.

  On MEPS equipment the connection to the earth is usually through a "grounding bus" which is a metal bar that is in turn connected to another grounding electrode. Care must be taken to ensure the grounding bus is in fact "effectively" connected to the earth via an effective grounding electrode.

- ***Wire Brushes***- One of the most important steps in the grounding process is to <u>properly clean the conductors before connecting to them</u>. This task is performed using a wire brush that is *connected to an insulated stick*. Wire brushes come in many different styles to accommodate the many different types of equipment that must be grounded. The main point to remember is that <u>all oxidation on both the phase conductors and the grounding electrodes must be removed</u> before attaching grounding cables to them.

- Voltage Testers: As previously discussed, it is a requirement that a 3-point test is performed on any circuit to be grounded prior to installing protective grounds. There are several different types of voltage detectors that can be used for this task, namely:

  - ***Glow Sticks***- Glow sticks are devices that energize a light on the meter ("glow") when they sense the presence of voltage. Glow sticks must be set to the proper voltage range for the circuit to be tested. The main limitation of

Glow Sticks is that they don't indicate the voltage levels present. They only indicate the voltage IS present. If it is important to know the voltage levels present (and it often is important) then the Qualified Worker must switch to a direct-reading voltmeter.

- ***Tic-Tracers-*** Like Glow Sticks, Tic-Tracers are voltage "indicators" and not direct-reading meters. The difference is that Tic-Tracers make a sound rather than illuminating a light when they sense voltage. Tic-tracers have the same limitations as Glow Sticks as described above. Some testers, such as the one depicted in the "Overhead Lines" side of the Table 1, are combination devices that incorporate a Glow Stick and a Tic Tracer.

- ***Direct-reading Voltmeters***- As the name implies, Direct-Reading Voltmeters are devices that provide digital readouts of voltage levels. The main drawback to using direct-reading meters is that it often requires that the meter be connected between the phase conductors or between the phase conductors to ground in order to read voltage and this task (when done improperly) has resulted in numerous arc-flash and arc-blast events that have resulted in fatalities.

Regardless of the type of tester used the main point to remember is that the meters **must be properly rated for the voltage and Fault Current** of the systems on which they will be used.

- ***Grounding Clusters/Grounding Mats-*** Grounding Clusters and Grounding Mats are used in EPGB to place the worker at the same potential (voltage) as the equipment on which they are working. The Grounding Cluster is just a chain that is wrapped-around the pole and tightened into place with a wheel binder. The cluster should be placed just below the worker's feet and it is then attached to the grounding conductor.

  The Grounding Mat is essentially a tarp with aluminum strands braided into it in a cross-hatched pattern. The aluminum is connected to a "node" on the edge of the mat that allows for a connection that is then connected to the grounding conductors of the system on which work is to be performed. The aluminum is only installed on one side of the mat so that side must (obviously) be facing "up" so the worker is standing on the aluminum grid.

- Grounding Cables- The grounding cables are responsible for providing a low-impedance path for Fault Current to flow on a properly grounded circuit. The conductors must be made of multi-stranded copper and can be no smaller than #2 American Wire Gauge (AWG). The primary considerations when selecting grounding cables is their Withstand rating for Fault Current and their length. The table below lists the Withstand ratings of typical sizes of grounding cables:

Table 1

Cable Size	Withstand Rating (1/4-second)	Withstand Rating (1/2-second)
#2	14,500 Amps	10,000 Amps
1/0	21,000 Amps	15,000 Amps
2/0	27,000 Amps	20,000 Amps

4/0	43,000 Amps	30,000 Amps

Data taken from W. H. Salsbury Co.

The designations "1/0, 2/0, etc." are pronounced "one aught" meaning "one zero." So, a 2/0 conductor is actually size "00" and a 4/0 conductor is "0000". It is one of idiosyncrasies of electrical work that wire sizes increase as their size designations decrease. In other words, a #2 wire can carry more Amperes than can a #4 wire. A 1/0 wires is the next size larger size than a #2 wire.

An important point to note in the Table 2 is that the Withstand ratings are a function of fault duration. Note that the longest duration listed is ½ second. As previously discussed, the energy released in an electrical fault is so intense that the electrical system can only withstand it for a fraction of a second. Therefore, anything that is done to the Overcurrent Protective Devices that would cause them to retard fault clearing should be avoided if possible. For example, some workers will install slightly larger fuses when troubleshooting a faulted circuit when they suspect that the reason for the service interruption was overload. However, by "up-sizing" the fuse they actually increased the amount of Current that will flow should the circuit be faulted again and the duration of the fault will also increase. The combination of increased Current flows with increased duration may well exceed the Withstand ratings of the grounding cables and they will melt leaving the workers exposed to shock hazards on the circuit.

The final thing to remember about selecting grounding cables is to keep the length of the cables as short as possible. When any circuit conducts high Current flows very strong magnetic fields develop that cause the cables to try to "whip" violently in response to the attractive or repulsive magnetic fields between the phase conductors. This whipping motion can cause the grounding cables may move back and forth several times in one second and could result in severe physical trauma to anyone in the vicinity of the cables.

Hazards Associated with Grounding

Aside from the shock hazards that have been grounded have already been discussed, the most significant hazard associated with grounding is the potential for generating an arc-blast when attempting to install the grounding cables. This usually occurs in conjunction with a human error because, if proper procedures are followed for testing the circuits, the probability of the circuit becoming energized while the grounds are being installed is remote. However, many workers have mistakenly installed grounds on energized circuitry as the following case study from an actual accident illustrates:

A High Voltage Electrician was tasked with performing maintenance on a 7200/12,470 volt circuit in an industrial sewage plant. The plant was fed by MEPS switchgear that includes 6 separate switches configured as in Figure 9:

Figure 9

Front of HV Circuit Breaker (Photo by J. Kolak *)*

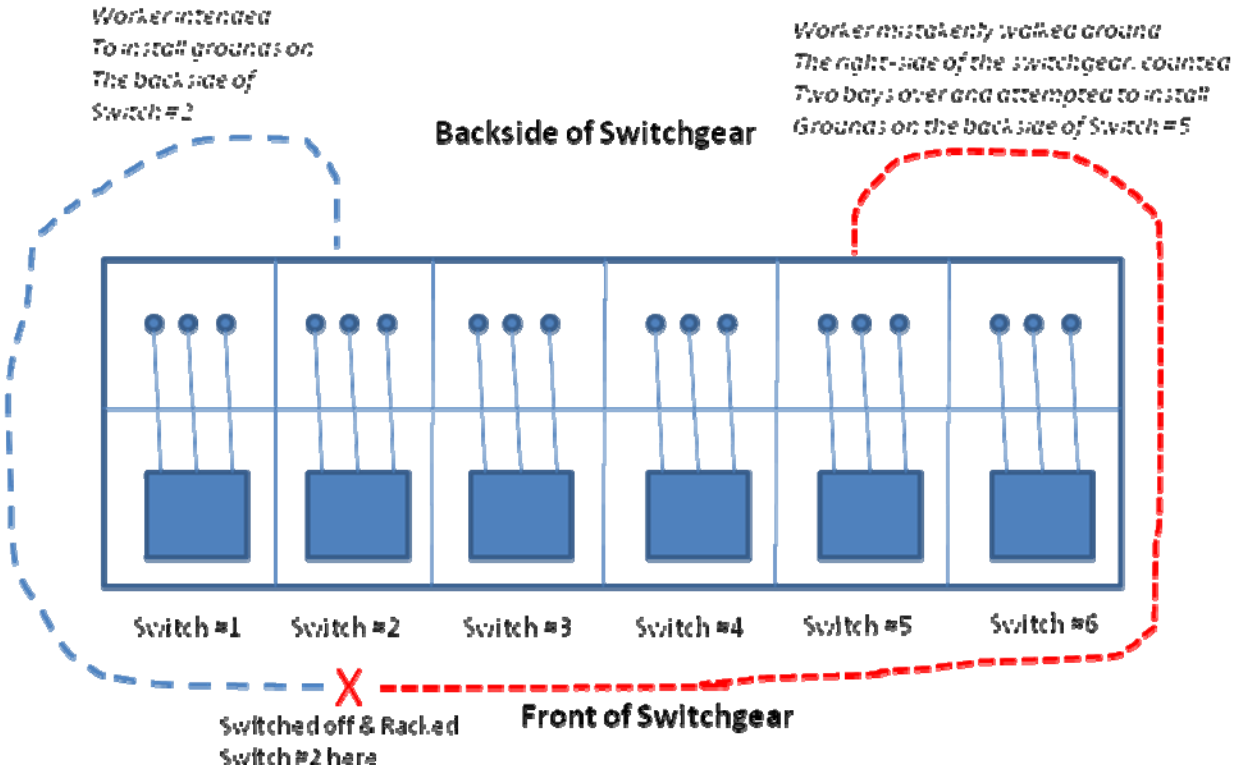
Back-side of the same HV Circuit Breaker
Photo by J. Kolak

The Electrician was to switch-out and ground Switch #2 for the work at hand. He correctly identified Switch #2, opened it and racked it out. He then installed his personal Lock and Tag and closed the front door to the switch. His next task was to go around the backside of the switchgear to install the grounds because the conductors connected to HV switches were located on the backside of the switchgear.

His first mistake was that he walked around the right-side of the gear and counted two bays-in from the end, which he thought was correct because Switch #2 was two bays-in from the end of the gear (but on the opposite end). He opened the gear and, without making the required 3-point voltage test (his fatal mistake) he attempted to install grounding jumpers on the energized conductors. The ensuing arc-blast was so severe that the heat released actually melted his hardhat. His burns were exacerbated because the HV switchgear was fed by a oil circuit "recloser" which is a device intended to automatically reset itself (i.e. "re-close") two more times. So, the worker actually suffered THREE arc-blasts as the circuit repeatedly re-energized itself.

The accident scene was horrific. The flash associated with the fault was so intense that the outline of the Electrician's body was burned into the wall some 6 feet behind where he was standing. He received 3rd and 4th degree burns to the majority of his body and died 3 weeks later in the hospital. Figure 10 depicts the accident scenario.

Figure 10



This sort of accident is surprisingly common in industry. It does illustrate one of the rather unique issues associated with HV work, namely, that HV switches sometimes have the actuating mechanism some distance away from the place where grounds would be installed. This increased the possibility of circuit misidentification. This is commonly found in substations or locations where switches may be controlled with SCADA (Supervisory Control and Data Acquisition) systems.

The other common accident associated with grounding is that workers sometimes forget to remove grounding cables that they personally have installed. While this may seem like an incredibly stupid mistake, it happens with much greater frequency than might be expected.

Recommendations

After reviewing an accident like the one just discussed, it may seem like the "safest" thing to do is to NOT install protective grounds on an electrical circuit but that would be a serious mistake. As was discussed in the opening paragraph of this paper, PPGB is a paradox, in that HV circuitry can NEVER be touched with any part of the body until such time as it has been effectively grounded and bonded. This is why one of the Cardinal rules of HV work is: "***If it isn't grounded, it isn't dead.***" HV workers must be trained to know that there are only two options for working on HV circuitry: Either the circuits are properly Locked-out, Tested AND Grounded or the equipment must be treated as though it were energized, complete with Energized Work Permits.

Therefore, here are some recommendations to help ensure that PPGB can be safely performed at any facility:

1. ***Ensure Only Qualified Electrical Workers Install Grounds***: If this paper achieved nothing else, it hopefully illustrated that PPGB is a highly-technical topic and only well-qualified workers should be allowed to install grounds. Normally, Electrical Workers must acquire significant experience under Qualified supervision before allowed to install grounds. Workers should demonstrate proficiency in both technical knowledge and proper grounding techniques before they are allowed to act as the Lead person on a job requiring PPGB.

2. ***Consult Arc Flash Hazard Analysis (AFHA) Studies Prior to Grounding Equipment***: The Electrical Engineering study known as AFHA has two critical pieces of information that are useful for HV workers. Namely, AFHA includes the available SCC calculations and the Incident Energy (heat) calculations at the proposed work location. The SCC calculations will help the workers insure their grounding cables are adequately-sized for the job at hand and the Incident Energy calculations ensure they will be wearing the proper Flame Resistant clothing as well.

3. ***Use Written Checklists For HV Switching/Grounding***: Use of a step-by-step checksheet will help to ensure that the proper switching sequences are followed and will keep a log of grounding cables installed to prevent workers accidentally re-energizing previously grounded circuits.

4. ***Disable Reclosing Relays on Circuits to be Grounded***: Any circuit that includes a reclosing relay must have that relay disabled before any switching or grounding occurs on that equipment. The reclosing relays may be physically disabled on the switch itself (mostly in overhead or substation installations) or the relay may reside inside the substation relay house along with the other relays for the sub.

5. ***Exceed Minimum Safety Standards When Needed***: There may be times, especially when parallel grounding or any other time when the integrity of the grounding system is in question, when it may be prudent to wear HV rubber gloves or take additional precautions even after protective grounds have been installed.

6. ***Adopt a "think twice, act once" Methodology***- The case study illustrated how omitting a single step (failing to take a voltage reading) in the grounding procedure resulted in a fatality. Clearly, HV work exerts a severe penalty on anyone who fails to completely follow safe work procedures.

7. ***Use a "Buddy System" When Grounding Equipment***- Similar to #6, it is a prudent work practice to assign a team of TWO Qualified Electrical Workers to perform PPGB. The "second pair of eyes" may well catch a missed step in the process and that person may well serve as a rescuer if something unforeseen occurs. The second person should also assume a position outside the Arc Flash Protection Boundary so that they will not be injured in the event of an arc-flash.

Conclusion

The use of EPGB techniques for HV work is by far the most effective means of protecting Electrical Workers from shock hazards on the job. When properly installed, workers can feel secure that they will be protected even if the circuitry on which their working should become energized for any reason. However, the very real danger of precipitating an arc-blast also comes with PPGB so only highly-skilled Electrical Workers should be allowed to install grounds.

This paper only covered the fundamentals of PPGB and anyone performing grounding must continue their study of the topic until they become fluent with these concepts and can effectively apply them at their work location. Further, this paper did not cover every type of installation where PPGB would be needed. For example, we did not discuss proper grounding techniques on dead-front installations or HV motor circuits. Suffice it to say that extreme care must be exercised to ensure that the functionality of the systems to be grounded is well-understood and the grounding equipment and techniques being used are appropriate for the job at hand.

Finally, HV workers would do well to maintain high levels of professionalism and strict adherence to safe work procedures. Truly "professional" electrical workers thoughtfully and deliberately perform their work and do not take shortcuts. While HV work is clearly a hazardous endeavor, HV workers can also take pride in being part of an elite group of professionals who possess the ability to safely work on electrical systems of any voltage.

References

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