Applications and Considerations

Section 11

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Applications and Considerations

The preceding sections reviewed the topic of providing worker protection beginning with some history, various notable current levels, equipment characteristics and ending with a general description of various protection schemes and installation methods.

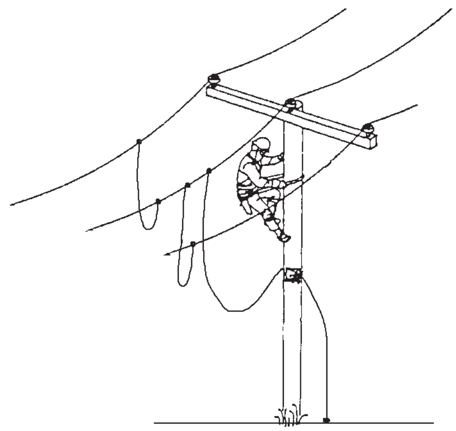
The following methods present a general approach. They attempt to present some of the benefits and drawbacks of the various practices. They should be considered in conjunction with the work practices of the worker's utility. The discussions that follow represent workers doing maintenance at conductor level (aloft) on either wood or steel structures, a ground support person, truck grounding, substation work, maintenance and protection while doing underground maintenance.

Only special cases of working between grounds formed by Bracket Grounding are included due to the possibility of a misapplication that could lead to a hazardous situation.

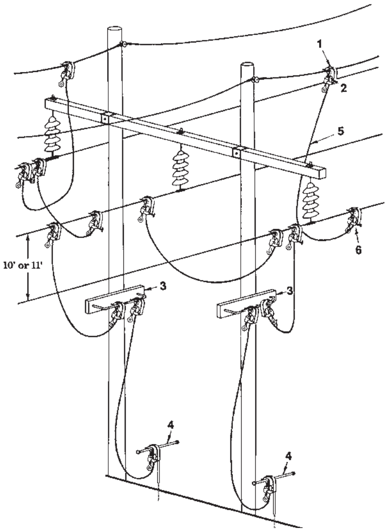
Equipotential or Single-Point Grounding at the Worksite

The Equipotential Method is the recommended method whenever it can be used. It consists of a complete set of ground sets bonding the phases, the neutral and Earth together to form an equipotential zone for the worker, as discussed in Section 9. The ground sets are placed on the same structure as the required maintenance. Both neutral and Earth connections are used if both are available, the neutral as primary fault current return path and the Earth as a backup path. The connections are made as described in the installation section. The ground sets bonding the phases and neutral to the cluster bar must be of a gauge no smaller than the maximum value calculated in Section 9 and to prevent cable fusing during a fault condition.

On a wood pole, a cluster bar is used as a tie point for the several ground sets used. The cable from cluster bar to the Earth must be large enough to avoid fusing, but may be expected to have a higher resistance due to the longer required length.

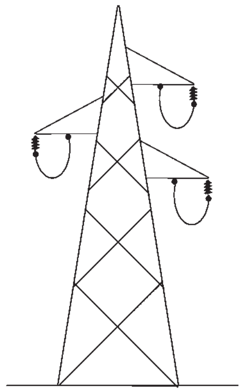


Equipotential Method on a Wood Pole
Figure 11-1



Equipotential Method on an H-Frame Structure
Figure 11-2

On a steel tower, the cluster bar is not used. A cable from each conductor to the tower below the worker's feet is recommended for each conductor that the worker may contact. Ground sets to additional phases may not be required if spacing is so great that the worker cannot reach another phase. Although, there may be other reasons for adding additional ground sets.

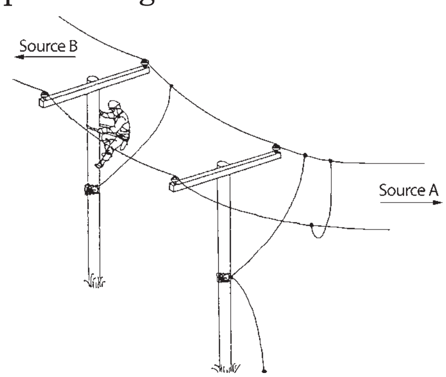


Equipotential Method on a Steel Tower
Figure 11-3

This method offers protection for the worker within the equipotential zone. Other workers on the same tower may or may not be affected during a fault. While the tower will experience a rise in voltage, if the workers are not in a path of current flow, their bodies may not bridge a difference of potential. Or, a worker located between the ground set contact point and the Earth may notice an electrical shock depending upon the resistance of the steel, the amount of corrosion of the various joints, the voltage present and the resistance in the series path.

Worksite Remote from Grounds (Limited Distance)

In some circumstances, working at a distance from the pole or structure with the full set of installed grounds is required. To provide safety to the worker, working away from the grounds a personal ground set is required, consisting of a cluster bar and single grounding jumper. Note that this method requires the installation of both the full set described as Equipotential (or single-point protection) plus the personal ground set.



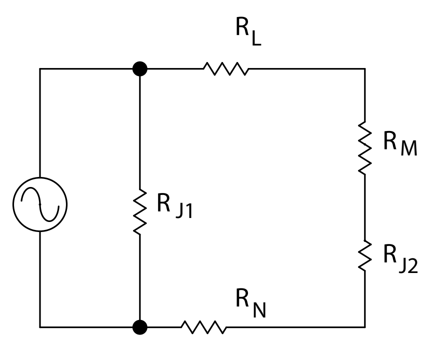
Personal Jumper, Away From Worksite
Figure 11-4

On a wood pole, the cluster bar is installed below the worker's feet and the ground set connects the cluster bar to the neutral. In this case, the low resistance path in parallel with the worker is some distance away. The worker's path consists of the length of conductor and neutral wire between the installed personal protective ground set and the worker's remote worksite plus the jumper.

In this case, it is important to know the value of available fault current and the size of the conductor and neutral. Using techniques described earlier, it can be determined if the division of fault current will result in a worker voltage that exceeds the maximum selected level. The direction of the current source must also be considered. The circuit shown in Figure 11-4 illustrates this. A calculation is made for both the jumpers installed between the worker and the source and again for the case of the ground sets installed downstream from the worker and the source. There is a significant difference in the current values through the 1,000-Ohm man in these cases.

I_{SOURCE} = 10,000 Amp.
R_L = 1 span conductor or 300 ft. of 2/0 ACSR = 0.024 ohm
R_N = 1 span Neutral or 300 ft. of 2/0 ACSR = 0.024 ohm
R_{J1} = Jumper Resistance = 0.001 ohm
R_{J2} = Jumper Resistance = 0.001 ohm
R_M = Worker Resistance = 1,000 ohm

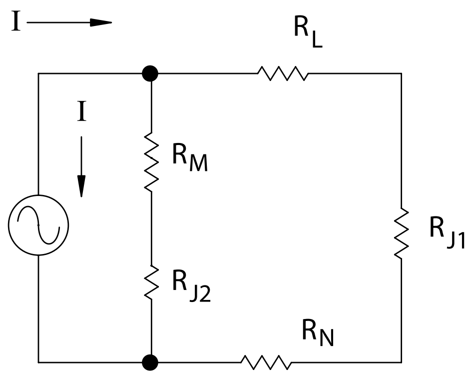
Personal protective jumpers between the worksite and Source A:



$$I_M = I_{SOURCE} \times [R_{J1} / (R_{J1} + R_L + R_M + R_{J2} + R_N)]$$
$$= 10{,}000 \times [(0.001/(0.001 + 0.024 + 1{,}000 + 0.001 + 0.024)]$$
$$= 10 \text{ milliampere}$$

or 10 volts impressed across the worker.

Personal protective jumpers opposite from the worksite and Source B: **This is a situation to avoid.**



$$I_M = I_{SOURCE} \times (R_L + R_{J1} + R_N) / (R_L + R_{J1} + R_N + R_M + R_{J2})$$
$$= 10{,}000 \times (0.024 + 0.001 + 0.024) / (0.024 + 0.001 + 0.024 + 1{,}000 + .001)$$
$$= 490 \text{ milliampere}$$

Or 490 volts impressed across the worker.

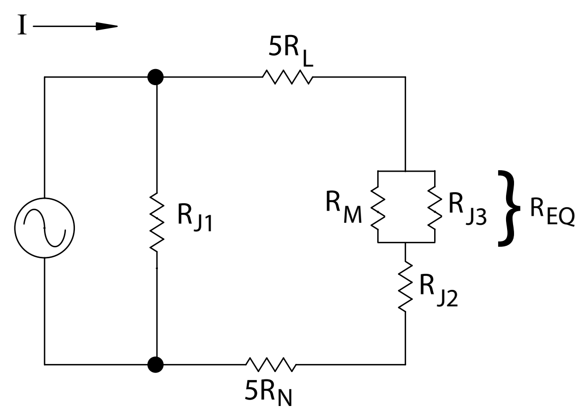
Utilities vary on the allowable distance from the installed set, that is, the number of allowed spans. The calculation is based upon their available fault current, selected maximum worker voltage, conductor resistance (length and resistance/unit length) and direction to source. This method requires both field judgments by the maintenance workers and the review of the safety and engineering departments of each utility. It will be necessary to adjust both R_L and R_N in the above example.

Modified Worksite Remote from Grounds by Adding a Personal Jumper

In some situations, working away from grounds is required to complete the task. As explained earlier, this can be a hazardous situation. Use of the personal ground mentioned above in the Worksite Remote from Grounds (Limited Distance) section can be modified by adding a protective jumper from the cluster bar to the conductor, as here contact is expected, in parallel with the worker to provide protection to the worker aloft. Again, the distance from the fully installed set must be considered. In this case, there always will be a full set of protective ground sets present and a low resistance ground set in parallel with the worker, assuring lower current through the worker and rapid removal of the line voltage.

Additional distance away from the full set is achieved by adding the jumper to the personal jumper described earlier. Placing the ground sets from the cluster bar to the neutral and from the cluster bar to the phase being worked ensures the worker always will be in parallel with a low resistance ground set.

Assume the worksite is now five spans from the installed personal protective ground set on the side away from the source. R_L and R_N are now (5 X 0.024) = 0.120 Ohms each.



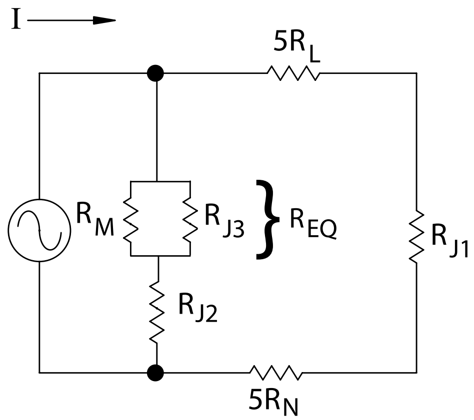
$$R_{EQ} = (R_M \times R_{J3}) / (R_M + R_{J3})$$

$$I_{EQ} = I_{SOURCE} \times [R_{J1}/(R_{J1} + R_L + R_{EQ} + R_{J2} + R_N)] = 41.2 \text{ Amp}$$

$$I_{MAN} = I_{EQ} \times [R_{J3} / (R_{J3} + R_{MAN})] = 41.2 \text{ microamp}$$

Or a body voltage of 41 millivolts

Now assume the worksite is five spans from the installed personal protective ground sets on the side toward the source. R_L and R_N remains = 0.120 Ohms each.



The parallel combination formed by the worker and R_{J3} remains 0.001 Ohm

$$I_{EQ} = [(R_L + R_{J1} + R_N) / (R_{J2} + R_{EQ} + R_L + R_{J1} + R_N)]$$
$$= 9{,}918 \text{ Amp.}$$

Now calculate the current through the worker using Equation 5.

$$I_M \cong 10{,}000 \text{ X } (R_{J3} / (R_{J3} + R_M)) = 10 \text{ milliampere}$$

Or a body voltage of 10 Volts

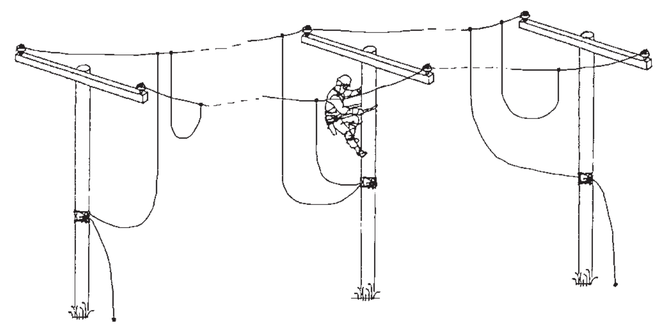
This is a significant improvement over the 490 Volts previously present when the worksite was only one span removed from the fully installed set of personal protective ground sets.

Working between Grounds Installed on Remote Structures

An improvement to the previously described worksite with the additional personal jumper can be made that eliminates the problem of the source direction. The installation of a second full grounding assembly, but away from the worksite on the side opposite the initial set eliminates the increase in worker current if the fault comes from the other direction. Figure 11-6 illustrates this configuration. This provides a low resistance current path closer to the source than the worksite regardless of the source direction that activates the protective equipment in the minimum time. The low reistance path placed closely in parallel with the worker provides the worker protection.

Working between Grounds Installed at the Worksite

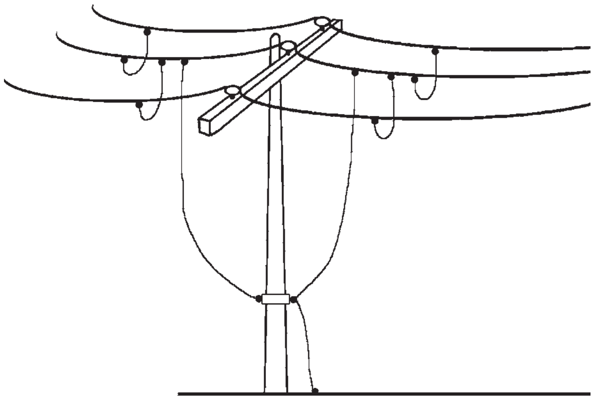
Using two sets of personal protective ground sets was also an earlier method of working between grounds. In this case, the worksite is at the conductor level, on a single pole. One ground set is installed on the source side of the worksite, the other on the load side. This method does not present the hazard of Bracket Grounding between ground sets installed on remote structures because the worker is in a close equipotential zone, see Figure 11-7.



Bracket Grounding of Multiple Spans with Personal Jumper, at Worksite
Figure 11-6

There is benefit to this scheme. Remember that some current will flow through every current path. This means the fault current will divide between the two low resistance ground sets on the contacted phase and the worker. The division of the fault current means less current in any one ground set, allowing smaller sized personal protective jumper sets. This is one method of providing protection for very large values of available fault rather than increasing the size of the cable and clamps to accommodate the larger current.

While this was referred to as "working between grounds," it is really an example of creating an equipotential zone using parallel jumpers for increased current carrying capability.



Bracket Grounding at Single Structure
Figure 11-7

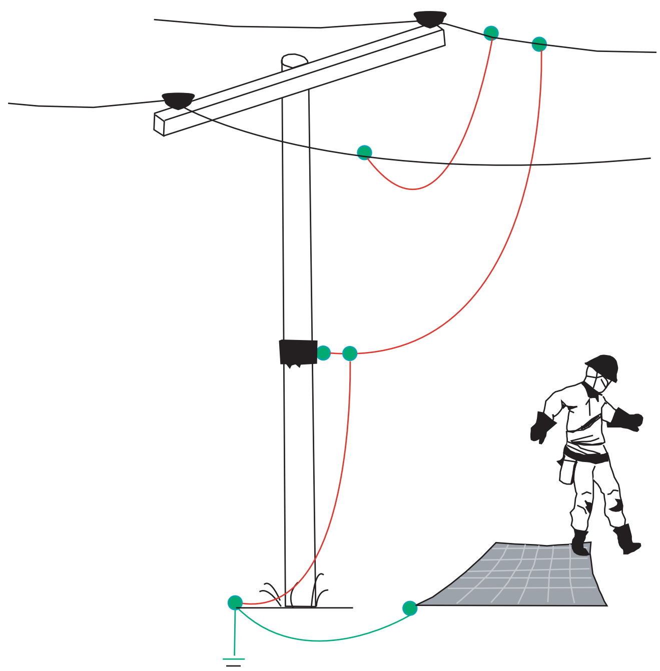
Ground Support Workers

Methods are available to protect the worker aloft. It is more difficult to protect the ground worker from a twofold problem of the step or touch potential hazards. The methods of protection remain the same: Insulate, isolate or use equipotential zoning. Rubber insulating mats or boots could be used. However, the mat would have to be large and maintaining the dielectric integrity of either mats or boots could be difficult. Walking on rough surfaces could partially or completely puncture the insulation, eliminating the protection. Inspection would not be as easily done as for rubber gloves.

Barricading is often used to maintain isolation between the worker and any contact with an energized item. After the pole top worker is set and has the tools and components needed, the work pole could be barricaded. By maintaining a safe work distance from anything that may become energized, the ground worker could avoid injury. Caution must be used whenever necessary to lower the barricade to send up additional tools or line components.

The technique of equipotential zoning could be used. This involves placing a conductive mat or conductive grill under the worker's feet that is bonded to the touch point that may become energized. This method eliminates the step or touch voltage because the conductive mat rises uniformly to nearly the same voltage as the voltage to which it is connected. This minimizes the voltage developed on the worker's body using the same low resistance parallel path as discussed earlier.

A hidden hazard of this method is that the maximum step voltage is transferred from the Earth contact point to the edge of the conductive mat. The worker must remain on the mat during a fault condition. If he steps off, he bridges the same 3 feet of voltage drop as discussed earlier. Figure 11-8 illustrates this technique. Therefore, the worker must take proper precautions such as using insulated steps or hopping onto or off the conductive mat.



Step Potential
Figure 11-8

As an example of touch potential, overhead switch handles are often connected to grills placed where the operator must stand to operate the switch.

Working with or around Trucks and Equipment

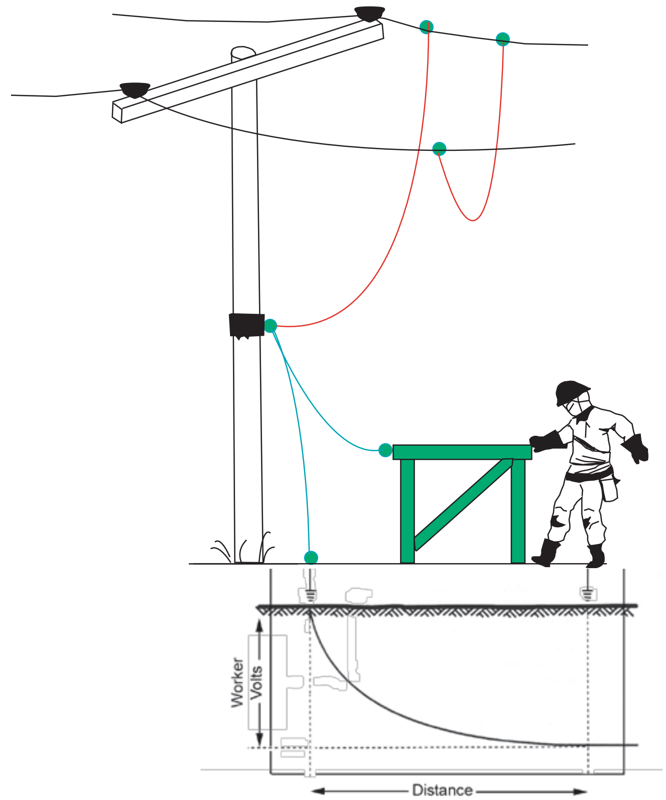
An equipotential zone of protection is needed when performing maintenance from a bucket. If the boom is metal, the worker will be a primary path to Earth if a conductor becomes accidentally energized while the worker is in contact. Connecting the boom tip to the conductor provides the low resistance parallel path.

This is not the hazard if the truck has an insulated boom. The boom insulation isolates the worker as a current path to Earth. However, the close spacing of distribution lines and some transmission lines may present a different hazard. The worker may lean into a phase while working on another phase. Or he may come in contact with the pole, crossarm or down wire while working on a phase. Any of these inadvertent contacts may put the worker in danger. By using a full personal protective ground set as described earlier, the worker can remain in parallel with low-resistance ground sets while working.

A major step and touch hazard is presented to ground support personnel working around trucks or other equipment. For example, if the lower elbow of an insulated boom swings into an energized phase, the truck body becomes energized and the ground worker may not be aware of it. There is no path back to the source through the insulated boom. The worker in the bucket probably would also be unaware of the problem. There may be sufficient resistance through the truck parts, tires, outriggers and Earth to hold the current flow to a level below that considered fault current. In this case, the system protection devices (breakers, reclosers, etc.) do not operate. Energizing the truck body is a common scenario of accidents around trucks and other installation equipment.

Consider for a moment that a truck has become energized, the outriggers and tires touching the Earth. Also assume less than fault current flows and the breakers or fuses do not operate. Anyone who walks up to the truck and touches any metal part essentially is touching the line voltage. Remember: For protection, a worker must be insulated, isolated or in parallel with a low resistance path.

Tests have indicated that the voltage across the body of a person standing immediately beside an outrigger is lowered. Because the outrigger is steel, and while there is higher resistance, it is conductive. The outrigger functions as a path of lower resistance, lowering the voltage across the person by raising the voltage at the Earth contact point to near that of the truck body. This is not to be construed as a safe work area. The resistance of outriggers varies with construction and location (on concrete, on dry wood blocks, on asphalt or bare Earth).



Touch Potential
Figure 11-9

However, if the person makes contact at some other part of the truck, the voltage across the body is increased because of the workers location. Remember that the voltage nearly halves with each 3-foot distance from the energized connection point. If contact is made near the rear of the vehicle, the potential at the Earth surface there is near zero. The full line voltage would then be developed across the person. If the outriggers are placed on dry wood blocks, there may not be a good Earth contact and any contact with the vehicle could be fatal. This is an excellent but deadly example of the "touch potential" hazard, illustrated in Figure 11-9.

Grounding the truck body does not change anything. It only protects the system. Grounding to a driven rod helps ensure the system will recognize a fault current and the breakers or fuses will operate, but does not offer any protection to the person in contact with the truck while standing on the Earth. The truck already has multiple contact points with the Earth formed by the tires and outriggers. Each of those contacts transfers the voltage from the truck body to the Earth at that point. Adding another contact point only provides a redistribution of the available current into the available paths. Tests have verified these scenarios. See Table 11-1.

Table 11-1

Truck energized to 7.2 kV (5 tests)		
	Volts across worker	Current thru worker
Ungrounded truck, tires & outriggers only	5,397 to 5,856	5.8 to 6.3 amp.
Grounded truck, driven rod 30 ft. from truck	5,304 to 5,601	5.8 to 6.0 amp.

To ensure protection to persons around a truck, needed tools, the drinking water container, etc. should be removed from the truck before elevating the boom. Then, a system of barricades should be established so the truck cannot be touched during the work. After this, the boom can be elevated and work begun. The barricade should not be removed until the boom has been lowered again into a definite position of non-contact with a phase.

Portable ground mats could be placed and connected around the truck. This develops an equipotential zone for the worker. However, he must remain on the mat during the entire time the boom is elevated and until it is lowered before it is safe to step off.

Underground

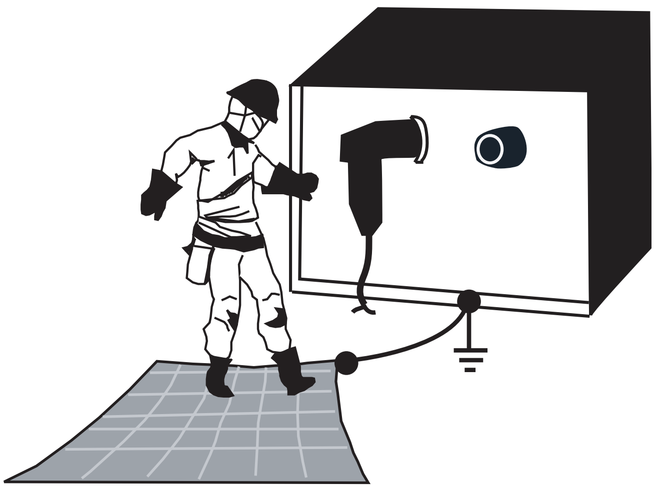
Protection for workers on underground systems is much more difficult because of the compactness of the equipment, the location of the work and the difficulty defining safe work procedures in this environment. However, the same methods of protection apply: insulation, isolation or equipotential zone. They can be more difficult to implement. In the close confines of enclosed equipment, an additional hazard to be aware of is flash burns from a high current arc that may occur during a fault current flow.

Maintenance on the above-ground equipment typically requires the cables coming up from below grade to be de-energized. This usually means placing both end elbows of the same cable on a grounded parking stand, a feed-thru bushing with a fault-current-rated grounding elbow, or other equivalent method as allowed by the utility work rules. This bonds the center conductors, concentric neutrals and the Earth together at those points. Similar requirements apply to work in vaults.

Insulation methods use rubber gloves and insulating mats at connection points, such as switches or transformers. The compactness of the enclosed equipment often makes rubber glove or hot stick work difficult, if not impossible. Because of this difficulty, workers may resist this method. Insulation is not a practical method to use for working on buried cables between connection points. Rubber gloves make cable stripping and splice assembly nearly impossible.

Isolation is the method of keeping the worker away from any situation that would allow contact with any possible source voltage. The alternative is to totally isolate equipment from any power source. This may not be practical for maintenance of existing installed equipment because every connection must be removed and isolated. This method also is plagued with the difficulty of work problems similar to that of insulation.

The Equipotential Method is better suited for use at connection points, switches, transformers, etc. Because a worker is standing on the Earth and handling parts that may become energized, a protection zone should be established. It can be established by bonding a conductive mat to the normally energized part to be contacted (after it is de-energized). Note: The elbow is parked on a grounded parking stand. This connection and the mat under the worker establish the zone. As long as the worker remains on the mat, the voltage developed across the body is limited to the drop across this parallel connection. This is illustrated in Figure 11-10. The size of the mat can be extended to include a second worker or tool placement by bonding additional mats to the first. The mats must remain bonded together during the work and the hand-to-foot resistance of the total path in parallel with the contacting worker must remain low.



Use of a Conductive Mat to Develop an Equipotential Zone
Figure 11-10

The Equipotential Method also is suitable for some tasks that occur between connection points, but is not suitable for others. Adding a switch or transformer between existing switches or transformers requires digging, cutting and the installation of equipment. The cables are first de-energized and then exposed by digging. If the end connections have been grounded on each end, the cable is both isolated and grounded. Line spikers are often used to verify that no voltage remains on the conductor about to be cut. A spiker is similar to a clamp but with a moveable spike mounted on the eyescrew. The spiker is placed around the cable using a Gripall Clampstick or hydraulics to maintain a safe distance and tightened to penetrate and connect the jacket, concentric neutral and the center conductor. If the conductor is energized, an arc is established to the neutral. This is a crude but effective means of ensuring the correct line has been de-energized.

After this determination, work can begin. Extra care must be exercised during the actual cutting to ensure the cable remains de-energized as there is no protection until the conductor is exposed and bonded. Remote-operated hydraulic cutters often are used for this task. A temporary connection should be made between the concentric neutrals of the two open ends to maintain continuity as it functions as part of a system neutral. A conductive ground mat to work from can then be bonded to the concentric neutral. The two center conductors cannot be included in the bonding until they are exposed. During the stripping, a hazard will exist if the line becomes accidentally energized. When the connections are complete, see Figure 11-11A, the mat develops an equipotential zone for the worker if the cable is accidentally re-energized by a fault from either direction.

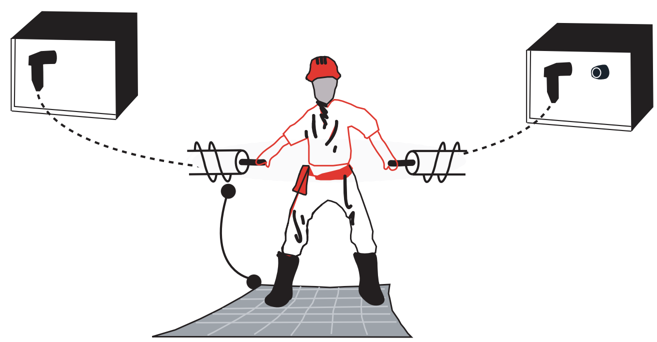


Figure 11-11A

NO protection is available to a worker splicing a conductor "mid-span" if it becomes accidentally energized until both URD cable ends are properly parked and protective jumpers are installed. Unfortunately, there is no convenient way to put a clamp on the conductor at the splice location without removing the conductor jacket and insulation. Figure 11-11A does not provide any protection at the work site if the cable becomes accidentally energized from either end. If such an event occurs, the worker is in the primary current path through the grounded mat.

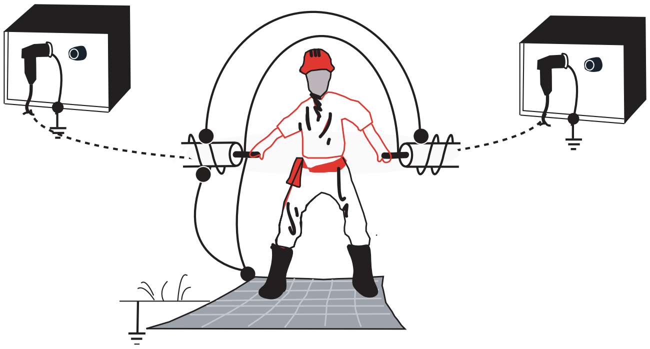


Figure 11-11B

Figure 11-11B demonstrates a method of developing an equipotential zone with neither the worker nor the portable ground mat as part of the primary current path. This configuration requires making a grounding connection to the primary conductor on each side of the open point, which requires the removal of the protective jacket and cable insulation in order to make the protective connections. During this initial work, rubber gloves may be required unless it has been determined that there is a complete absence of voltage on the cable and neutral. Proper care also will be required to repair each clamping location during the completion of the installation of a repair or T-splice. Rubber gloves again may be required during this closing phase. With an equipotential work zone in place at the work location, if the conductor becomes accidentally energized before the splice is in place, the voltage of the center conductors, the concentric neutral and the portable mat will all elevate to nearly the same level, offering worker protection.

If jumpers are removed to install a splice, protection will be lost. If an equipotential work zone is not fully made at the location of the splice and the previously grounded conductor becomes accidentally energized after the splice is in place, the grounded ends will experience the fault. If the worker is in contact with the conductor and Earth, there is a potential for electrical shock because he becomes a separate current path. A worker in contact with the Earth, and a bare conductor at the splice location would have a voltage drop across his body that exceed safe levels. This is why the worker must wear rubber gloves of the appropriate class.

Communication is an important factor to ensure worker safety. The grounded connections at each end of the cable should be properly tagged and not removed until it is absolutely certain the worker is clear from any energized sections of the cable. The cable should be tested to ensure it has been properly spliced before being re-energized.

In any situation where it is not feasible to use a protective jumper to make connections across the open points and to include a temporary ground, the use of a portable ground mat is not recommended. Without the bypass jumpers in place, an equipotential zone cannot be established. The worker must use other protective means.

If the conductor becomes re-energized due to another worker replacing the previously grounded elbow on an energized bushing, and the splice is in place, the opposite grounded end will assure the system will see a fault because the grounded parking stand connects the center conductor to the neutral and earth. The earth resistance will keep the voltage at the connection point at some elevated level until the system fault protection equipment clears the fault. During this time the concentric neutral and the center conductor will have the same voltage. With temporary ground sets connecting the neutrals, and a conductive mat beneath the worker connected to the neutral, the worker is in an equipotential zone of higher resistance, see Figure 11-12.

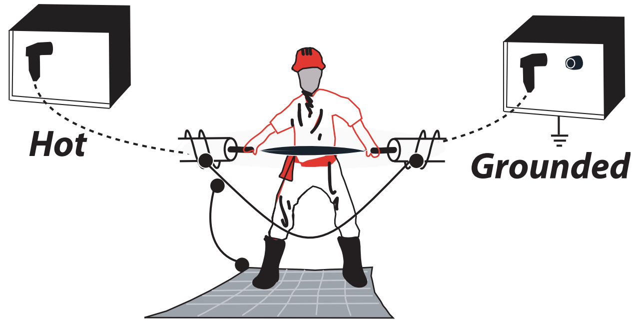


Figure 11-12

Without temporary grounds connecting the neutrals across the cut, the work zone safety depends upon the location of the conductive mat's connection during the time the conductor is being separated and prepared. For example, if the mat connection is to only the source side neutral, but an accident causes the line to become energized on the opposite side, there is no protection if worker contact is made. The source center conductor and neutral are both at ground potential by way of the source grounded parking stand and worker contact with the load side places the full fault voltage across the worker. But, if the accident causes the line to become externally energized somehow on the source side, an equipotential zone is present. See Figure 11-13. Rubber gloves are required in these situations until the full equipotential zone is established.

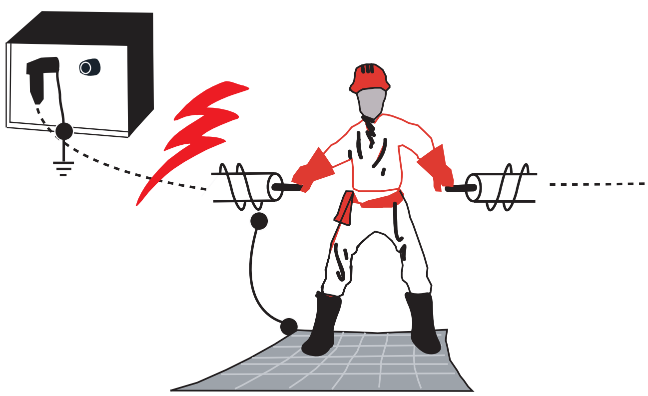


Figure 11-13

In all of the previous cases it is assumed that the concentric neutral for which so much depends is present and continuous to the source. This is often difficult to verify in the field as these URD cables are buried and not readily visible. Utilities should regularly review their work procedures on underground systems to identify methods that might be able to improve worker safety. Underground systems remain the most difficult situations for providing worker protection.

Substations

Use of personal protective grounds inside substations is both easier and, at the same time, more difficult. It is easier because more suitable connections for current return points are available. It is more difficult because available fault currents are likely to be significantly greater, requiring larger and heavier ground sets and clamps. Also, because of the wide variety of installed equipment that require different considerations, equipment connection styles and placement, the underlying grid helps keep step potential at a minimum, but the potential for transfer voltage, or touch potential is increased. Each task must be considered individually and no universal rules can be developed.

Induced voltages and currents are very common in substation work because maintenance is done on one or a few items while the rest of the station remains energized. A grounding set reduces the effect of capacitivity coupled voltage but multiple jumpers will allow induced current flow through the loop formed. This is the same phenomenon as that discussed for parallel transmission lines.

The substation normally supplies several circuits. This means the available fault current is greater than at a single remote worksite.

An alternative to the use of increasingly large size jumper equipment is to use multiple sets placed in parallel. Refer to Section 7 (Theory of Personal Protective Grounding) for a discussion of paralleling personal protective jumper equipment. Another means of grounding very large fault currents is the use of grounding switches. These devices are permanently mounted and are left open until the need to maintain a ground connection during maintenance arises. They provide a convenient method for grounding a de-energized bus or attached line but they may form an induced current loop. They are widely used in large substations.

Because of the size, length and weight of the protective equipment, assistance with the installation is sometimes required. A tool that is very helpful in lifting a large bus clamp with one or two AWG 4/0 cables attached is the Chance Lift Hook Assembly (Shepherd's Hook). This is a long, insulated handle with a large hook on one end. Near the hook is a rope pulley. The hook is placed over the bus and the rope is connected to the clamp to be landed on the bus. A second worker guides and tightens the clamp using an equally long Gripall Clamp Stick (commonly called a "shotgun" stick). The rope must be clean and dry to be considered insulating.

Other specialty items available for use in substation personal protective jumpering are various lugs, stirrups and studs. These devices are all designed to provide permanent connection points for the protective equipment necessary for working safely. Figure 11-14 illustrates some of these devices.

Specialty Connection Devices
Figure 11-14

Special attention must be given when working on equipment installed in substations. For example, transformers have the capability to step low voltages up to lethal levels. Even test equipment connected to the low voltage windings can raise the output to a high voltage. Capacitor banks must be discharged before handling. The terminals must remain shorted to prevent charge from migrating from the dielectric material to the terminals and re-establishing a hazard. Large power cables and their terminations can retain a charge. They should be grounded and remain grounded before handling or cutting.

Personal protective jumpering methods in substations are similar to the methods used at remote work sites. The underlying principle of maintaining a low-resistance path closely in parallel with the worker remains the same. One difference is that a grounding jumper some distance away from the actual worksite can be added to the protection in a substation that has a buried grid. While the multiple connections aid in increasing the overall current carrying capability, it poses other problems. The greater the separation, the larger the loop formed by the jumpers, the worker and the grid. As this loop increases, the voltage across the worker will increase. A hazard if applying or removing the personal jumper by hand.

Remember that at remote towers when jumpers were placed on adjacent structures and there was no connection to the base at the worksite between them, the full voltage was developed across the worker because the Earth potential remained near zero at that point. If a fault in a substation occurs, the entire grid rises to the line voltage and limits both the voltage that can be developed across the worker and the step potential.

The same principles for placement, sizing and paralleling of jumpers apply as at other worksites.

The presence of transformers presents a large inductance on circuits in the substation. This combination presents the special problem of asymmetrical current. A discussion of asymmetrical current and the associated problems is presented below and in Appendix B. The mechanical force associated with an asymmetrical current peak could be significantly greater because the magnetic force increases as the square of the current. That is, twice the current produces four times the force. Additional heating of the conductor from the offset current coupled with the increased force may cause the assemblies to prematurely separate. Table B-1[6] (in Appendix B) is used to size equipment for applications where asymmetrical currents are cause of concern.

The issue of asymmetrical current must be considered when selecting personal protective grounding equipment for use in substations. This is a current that begins upon the sudden re-energization of a line previously de-energized for maintenance work. The current at the beginning of flow becomes significantly offset from the zero axis as compared to that of a normal symmetrical current. The cause is the large amount of inductance present from reactors and transformers normally present in substations compared to the small amount of resistance in the buses. The greater the ratio of inductance to resistance, the more pronounced will be the initial offset. The peak current of the first loop may be nearly 2.7 times the normal RMS current value at an X/R ratio of 30:1. Such an offset waveform is shown in Figure 11-15. Depending upon the X/R ratio, the offset portion decays to a normal symmetrical current some cycles after current initiation.

The mechanical force associated with current flow varies as the square of the current. The resulting mechanical force may be nearly four times the normal level at the 90% asymmetry ratio shown above. Aluminum welded bus grounding connection points may break off from the bus under these forces or the clamps themselves may break, removing any protection provided by the grounds. Additional heating also occurs due to the offset current, further softening the copper and allowing a mechanical failure that occurs prior to rated cable melting. Special equipment should be provided that can withstand these forces yet carry the current.

These conditions have been known for many years, but often did not present a problem. The equipment used performed satisfactorily because the current levels were smaller and the forces were less. It has become more important with the increased demand for electricity and the increased size of substations needed to supply this increased demand in many areas. It is recommended that utilities work with their equipment supplier to ensure the selected grounding items are fully rated for these conditions.

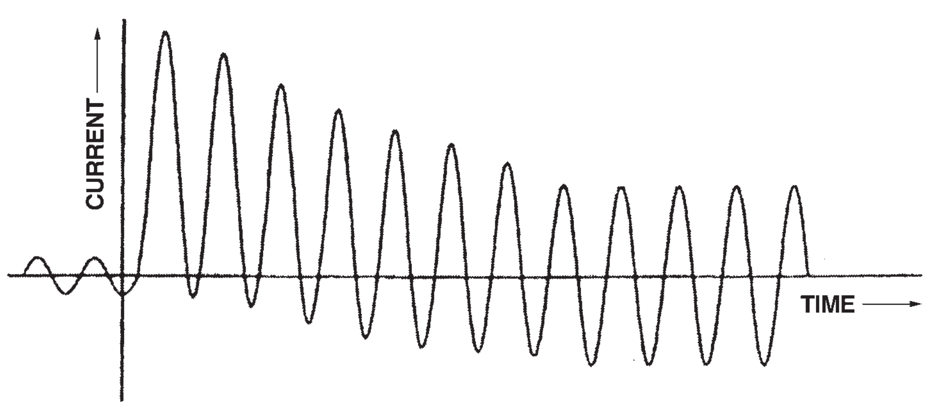


Figure 11-15