SECTION 9

Basic Protection Methods

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PERSONAL PROTECTIVE JUMPERING METHODS

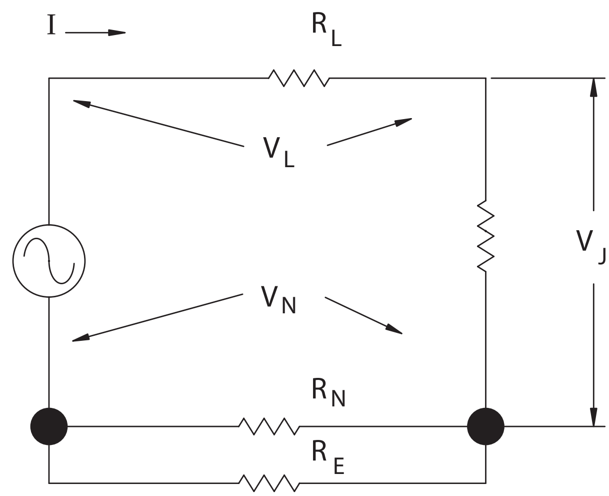
Methods using isolation and insulation are not always adaptable at elevated worksites so other methods were developed. Worksite, bracket, worksite bracket and combined grounding are used today. "Equipotential" or "Single Point" and the older "Bracket Grounding" scheme were the most common and are discussed in this section. Today, "Equipotential" or "Single Point" (as it is sometimes called) is the recommended method, used wherever it can be applied.

It must be remembered that many variables enter into the evaluation of a suitable protective grounding method. Some of the key variables typically unknown to the worker at a worksite are the source impedance, the neutral ground resistance or soil resistivity and the resistance of a wooden pole. Some of the variables that are known or can be estimated are available fault current, the distance from the source, the presence of a neutral, the size of conductor or neutral, the presence of a pole down wire and the pole spacing between down wires.

A term used frequently in this section is potential rise. It is the rise in voltage in the vicinity of the worksite and is a function of the resistance values of the various circuit elements included. These combine to create an almost infinite number of worksite scenarios. However, an understanding of the basic principles, estimates of the unknowns and common sense will allow the development of a method that is suitable for multiple locations. For example, if a neutral is present the voltage rise during a single phase (the worst case) fault may reach 50% or more of the line voltage.

V_L = Voltage drop along source conductor
V_N = Voltage drop along neutral
V_L = V_N if size and length are equal
V_J = Voltage drop of personal protective jumper ≅ 0 (near 0)

The actual value will depend very little upon the earth return resistance value since it is in parallel with the low resistance neutral. Review the discussion related to Figure 5-7 for the explanation. If the neutral conductor size is less than that of



Protective Circuit with Neutral Included
Figure 9-1

the source conductor, the worksite voltage will be greater than 50% of the source because the voltage division is a function of the neutrals resistance fraction of the total circuit resistance. Again, see Section 5 for this discussion.

To ensure maximum safety is achieved, voltage must be reduced to a level below that of the onset of heart fibrillation, as discussed in Section 2, the section on medical theory. It is not enough to reduce the body voltage from a high level, which causes injury or serious burns to a level that may result in heart fibrillation, which is often fatal.

Worksite or Single-Point or Equipotential Grounding

The key to a successful equipotential protection method is to place the worker in a parallel path with a conductor of sufficiently low resistance to shunt the dangerous levels of current around the body and limiting the maximum voltage across the worker to an acceptable level. Remember that some current will flow in every possible path, but it divides in inverse proportion to the path's resistance. The use of a low resistance jumper is the major factor. The second key factor is to have the line protective equipment provide fast fault removal.

This method is commonly referred to as "Single-Point", "worksite" or "Equipotential Grounding."

The OSHA 29 CFR 1910.269 document requires grounding wherever it can be used. It uses multiple jumpers at the worksite to offer both worker protection and fast operation by the system protective equipment.

The term "Equipotential" technically means equal potential, or objects that are at the same voltage (or equal potential). Potential is another name for voltage. As used in personal protective grounding, it refers to the voltage developed across a worker during the time of fault current flow. The voltage cannot be exactly the same because current flow through anything with resistance creates a voltage drop (refer to Equation 2 in Section 1). The drop can be very small compared to the typical utility line voltage. The voltage across the worker will be the same as that of the jumper because it forms a parallel circuit with the worker. The maximum voltage on the worker then becomes a function of the fault current through the personal protective jumper. This is an application of one form of Equation 2:

$$V_{MAN} = R_{JUMPER} \times I_{JUMPER}$$

$I_{JUMPER} = I_{FAULT}$ for all practical purposes because of the extremely low jumper resistance. This voltage must be limited to the maximum selected safe value.

This method requires additional protective grounding jumpers, beyond the minimum one in parallel as described in the previous paragraphs. All phases, the neutral and an Earth connection would be bonded together at the worksite. The low resistance ground set in parallel with the worker provides the worker protection. The bonding of the phases to the neutral and Earth ensure the maximum speed in fault clearance. This meets the two requirements of a safe worksite: a low resistance parallel path to the worker and the shortest time energized as possible. The multiple connection of neutral and Earth represent a dual return path to ensure a fast clearance. This could be a critical feature if an undersized neutral is present and has insufficient current-carrying capability to avoid fusing during the fault current flow. The worksite potential rise remains a function of the Earth return resistance and conductor and neutral resistances. In many cases, the maximum level achieved will be around 50% of the line voltage at the time the line becomes accidentally re-energized.
The actual connections recommended for a wooden structure are:

- Attach a cluster bar to the pole ensuring that it is making conductive contact with a metal spike or nail that penetrates the wood at least as far as the climber's gaffs (OSHA 1910.269 Appendix C)
- A ground set from an Earth connection point to a cluster bar mounted below the worker's feet
- A ground set from the cluster bar to the neutral
- A ground set from the cluster bar to the nearest phase conductor
- A ground set from the nearest phase conductor to the next phase conductor
- Finally, a ground set to the last phase conductor

A ground set may be used to connect to a static wire overhead. The static wire normally should not be used as the only return path. It often is steel wire, which has a higher resistance. It does not always provide a continuous return path to the source because it may be intentionally broken at periodic lengths. But, it may provide a connection to multiple Earth return paths to help divide any fault current present.

It is the resistance of the protective ground set(s) that is in parallel with the worker that must be kept below the maximum calculated value because this is the jumper providing protection to the worker. Its resistance must be based upon the utility's selected maximum body current and/or voltage. This can be achieved by selecting an appropriate conductor size and length, keeping in mind that resistance increases with length and decreases as the cross sectional area increases. The remaining ground sets must be sized to ensure they do not fuse during the flow of fault current. These ground sets are to maximize the fault current so the system protective devices operate as quickly as possible. An example will be used to illustrate the procedure for calculating this maximum resistance value. The values used in the example were selected only for the example. First, we request the available fault current and maximum breaker operation time at the site from the engineering department. Next, the company safety department provides the maximum allowed voltage across the worker, the current through the worker, or both.

Assume: Maximum worksite available fault current = 12,000 amp.
The maximum breaker interrupt time is 20 cycles (0.333 sec.)
The accepted level of safety:
Voltage across the worker,
$V_{WORKER, MAX}$ = 100 volts OR
Current through the worker,
$I_{WORKER, MAX}$ = 1/3 the heart fibrillation level
The average worker's weight = 155 lb.
Average man resistance = 1,000 Ohms

$$I_{FIBRILLATION} = I = k/\sqrt{t}$$

where k = 157 for 155 lbs.
and t = .333 seconds

$$I_{FIBRILLATION} = 272 \text{ milliampere}$$

$$I_{WORKER,} MAX = 1/3 \times I_{FIBRILLATION} = 1/3 \times 272 = 91 \text{ milliampere}$$

$$I_{MAN} = \frac{(R_{JUMPER}) \times I_{AVAILABLE}}{(R_{MAN} + R_{JUMPER})}$$

Rearranging this equation to solve for R_{JUMPER}:

$$R_{JUMPER} = R_{MAN} \times [I_{MAN} / (I_{FAULT} - I_{MAN})]$$

$$R_{JUMPER} = 1{,}000 \text{ Ohms} \times [0.091\text{amp} / (12{,}000 \text{ amp} - 0.091 \text{ amp})] = 0.0076 \text{ ohm or } 7.6 \text{ milliohm}$$

Therefore:

$$V_{MAN} = I_{JUMPER} \times R_{JUMPER} = (12{,}000 \text{ amp} - .091 \text{ amp}) \times .0076 \text{ ohm} = 91.2 \text{ volts}$$

Which meets the requirement.

This will meet the two specified requirements. Now it is necessary to select the components for each jumper assembly.

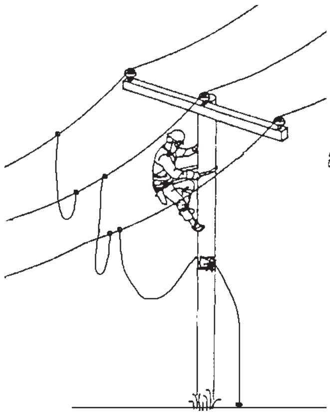
Note that this is the maximum resistance permitted for the complete assembled jumper(s) in parallel with the worker. As the worker reaches from one phase to another, the number of jumpers in parallel with the body may change, depending upon the installation. The maximum number that can be in parallel must be considered. On a 3-phase system, the worker may place his body in parallel with up to three series jumpers without thoughtful placement, see Figures 9-2 and 9-3.

The cable is chosen from Table 8-1. The available 12,000 amp for 20 cycles exceeds the AWG #2 rating so AWG 1/0 is selected. Wiring tables for copper AWG 1/0 grounding cables show it has 0.098 milliohm/ft. Assume each cable/ferrule/clamp combination resistance is 0.5 milliohm. This provides three 10 ft. jumpers equal to 1.98 milliohm each or 5.94 milliohm total.

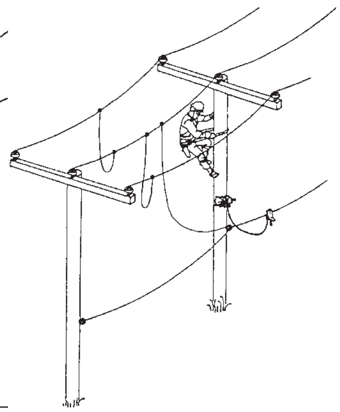
By careful placement of jumpers at the worksite, we ensure the worker never has more than two series ground sets in parallel with his body. This will meet the safety specifications.

Corrosion on the line may add sufficient resistance at the connection points in the parallel path to exceed the selected safe level of body current selected by the workers utility.

If it is necessary to use longer jumpers, a larger cable size should be considered as a means of maintaining the needed low resistance. The resistance of the protective ground set making the Earth and neutral connections should be sized to prevent fusing under the available fault current. They increase the worksite safety by providing a return path, but are not in parallel with the worker, so their voltage drop does not add to the voltage across the worker.



Parallel with up to Three
Series Jumpers
Figure 9-2



Parallel with up to Two
Series Jumpers
Figure 9-3

Paralleling Grounds

Any ground assembly not paralleled must be fully rated for the total available fault current. In some instances, it may be necessary to parallel grounds to adequately carry the available fault current. This is also used as a convenience for the workers when the size of the equipment becomes so large or heavy that it is difficult to install. To obtain equal current flow through each paralleled set, the sets should be identical to ensure the resistance of each path is equal. The clamps should be installed as close together as possible. Because higher fault currents are expected, cables should be tied to the structure to minimize whipping or mechanical damage to the clamps. When using this method and tying the cables together, each paralleled ground set must have its current carrying capability de-rated by 10%. Do not wind the cables around the structure as this increases the coupling between the cables and the structure and increases any induced current or voltage in the structure.

For example:

Assume the available fault current is 40,000 Amperes and it can be expected to flow for 15 cycles. The available personal protective jumpers are formed from ASTM Grade 5 clamps and AWG 2/0 cable. Each set carries an individual rating of 27,000 Amperes for 15 cycles.

The choices are to increase the cable size to AWG 4/0 cable or to parallel two sets. Reference to Table 8-1 (Section 8) shows the withstand rating of AWG 4/0 cable is 43,000 Amperes for 15 cycles. For parallel cables, the de-rated current withstand carrying capability of the original 2/0 set is 24,300 Amperes each. Paralleling two sets gives a current carrying capacity of 48,600 Amperes. This meets the current carrying requirement and the installation may be more acceptable. Keep in mind that there is no protection until the parallel set is fully installed because the current exceeds the rating of a single set during installation.

Double-Point or Bracket Grounding

For many years it was a common practice to place the protective equipment on structures on either side of the worksite, one toward the source, the other toward the load. It is called “working between grounds” and considered to be quite safe. An often-heard comment was that if the current comes from the right, the current will return through the ground sets on the right. If the current comes from the left, the current will return through the ground sets on the left. This is inaccurate. Some current will flow through every possible path. In one form, the two sets of ground were placed on separate structures on either side of the worker. A thoughtful evaluation of this method shows that this is not always safe. In some cases, it is the most hazardous.

First consider a 3-phase line with 3-phase jumpers connected between the phase conductors and the neutral, or earth. Several variables will affect this protective scheme. Among them will be the relative balance between the phases, the requirement for the fault to be a 3-phase fault for the worker to be safe, and the location of the worksite with respect to the center of the bracketing jumpers.

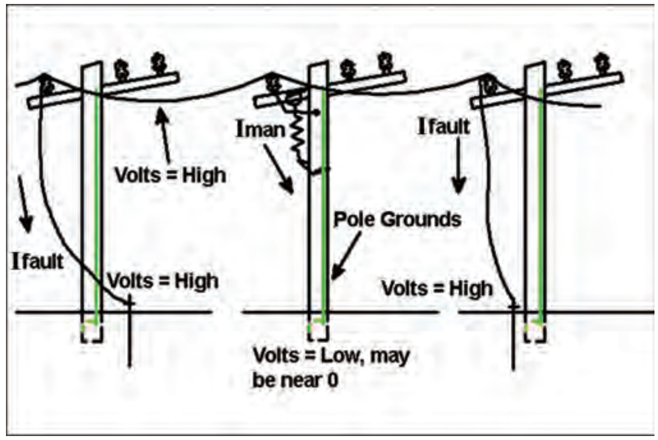
The fault current resulting from a 3-phase fault on a balanced system flows back to the source on the source conductors. Only the current resulting from the unbalance of the system flows through the jumper connection to the neutral or earth. But the worker has no way of knowing how well the system is balanced, and typically it is not well balanced.

Next consider a single phase fault, which is more common than a 3-phase fault. Commonly the two bracket sets are placed on adjacent or even more remote structures on either side of the worksite. If a de-energized line becomes accidentally re-energized, the conductor voltage rises to the voltage level that the system can support before the fault sensing equipment operates and clears the voltage from the line. The protective ground sets have very low resistances, so the elevated line voltage is transferred from the ground set connection point to the neutral and/or Earth connection point at the nearby structures. The tower bases at the ground connection then rise to equal nearly that of the voltage on the line. But with the worksite between the installed protective ground sets, without a connection between the conductor and earth, there is no elevation of voltage of the Earth or tower base below the worksite. The voltage level of the Earth or tower base will remain near zero. If the structure is conductive (steel) or a pole down wire on a wood pole is present and near the worker, the potential near the feet stays near zero. If the worker is in contact with the conductor at the time the line becomes energized, the full-elevated voltage of the line may be across the body. Remember, the larger the value of resistance, the larger the voltage drop developed across the resistance. Review Figure 5.7 and the associated text if necessary. In this portion of the series circuit, the worker resistance (assumed to be 1,000 Ohms) is by far the largest in most cases. Assuming an Earth resistance of 25 Ohms means nearly the full voltage drop is across the worker by the fraction of V_{source} x [1000/(1000+25)].

Figure 9-4 illustrates this scenario. This situation can cause injury or death at utility voltage levels because there is no direct low resistance path shunting the current around the worker's body. The worker becomes a path from the line through his body then through the Earth return path.

If the worker is on a wood pole that has no pole down wire, the pole and worker become part of the series circuit between the conductor and the Earth. The fraction of voltage across the worker then depends upon both his resistance and that of the pole. In some cases, this increases worker protection. In others, it may not.

Remember, voltage divides in a circuit in the same proportion as each element's part of the total circuit resistance. What is the resistance of the pole? Values of pole resistance have been measured that range from a few thousand Ohms to several megohms. So a wide variation of voltage on the worker could occur unless other precautions are taken. If on a steel tower, a similar situation occurs. What is the resistance of the tower, how does the voltage divide? Notice the lack of a system neutral in this discussion. That leaves the worker as a direct connection to Earth. Other systems may have a neutral present. Ground sets connected between



Bracket Grounding, Adjacent Structures
Figure 9-4

conductors and the neutral provide a low resistance return path for the current to its source. This forms a low resistance path in parallel with the higher resistance path through the Earth. If the worker is still in a separate current return path (for example, when the neutral is mounted on an insulator) the neutral resistance usually is so low that most of the current returns by way of the neutral, reducing the current available through the worker. In some cases, this may provide a measure of protection to the worker, through luck rather than planning.

Often the bracketing jumpers are placed a great distance apart, allowing the worker to relocate the worksite within this span. As the worksite approaches the source, within the span, the workers body current increases. Conversely, as the worksite transfers toward the remote end of the bracketed span the worker body current is reduced. Moving the worksite toward the source removes some line resistance between the source side bracketing jumper and the worker, allowing body current to increase. When moving in the opposite direction line resistance is added, reducing the worker current. Review the parallel circuit shown in Fig. 5-6. Changing the resistance of either parallel path changes the division of current within the parallel circuit.

Here, good judgment by the worker must be exercised to evaluate the site, the variables and conditions present. Because so many situations possible in Bracket Grounding would require a judgment decision by the worker at each site, it is recommended to develop a suitable work method to avoid such field judgments.

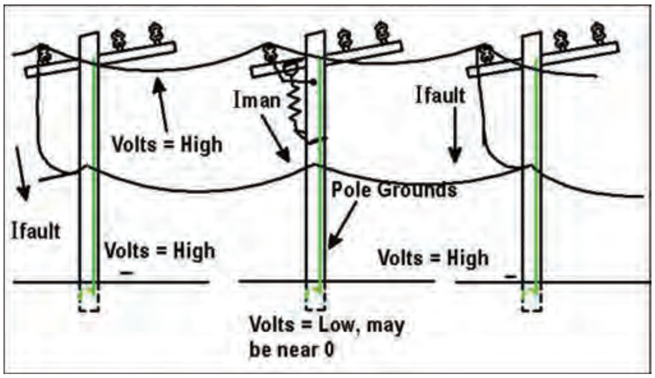
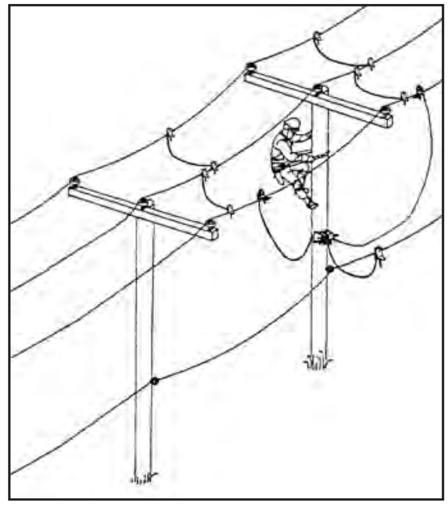


Figure 9-5

Now consider the situation where two personal protective ground sets are both installed on the same structure, one on each side of the worker. This form is an adaptation of both the Bracket Method mentioned above and the Equipotential Method. In Figure 9-6, conductors have been connected together and to a cluster bar beneath the worker's feet. Protection results from the low resistance ground sets directly in parallel with the worker, not because there is a set on either side. There is a benefit to using this technique. If very large fault currents are available, the jumper cables themselves can be of a smaller size as the current is now divided between the two sets. This may make installation easier and receive more acceptance from the line worker because the equipment is lighter weight. Attention must be paid to the sizing of any single connection in this scheme that must carry the full current. That is, if smaller size cable can be used to bond the phases to a cluster bar on each side of the worker, a single connection to the Earth or to the neutral must be larger to carry the full current.

Storm damage often requires Bracket Grounding. It is used if a conductor has broken and is on the ground. Then it becomes necessary to ground at the structures on either side of the break. But if the



Bracket Grounding, Same Structure
Figure 9-6

line becomes energized and the worker is standing on the Earth, he is also a return path. In this case, it would be necessary to bond a conductive mat to the two conductor ends for him to stand on while making repairs, to maintain the same voltage from the hands to the feet.

There are other maintenance situations that do not lend themselves to Single-Point (or equi-potential worksite) grounding. In most of those situations Bracket Grounding can be a usable method if thought is given to worker protection in combination with bracketing (see Combination Grounding below).

Single Bypass Ground Set - Minimum Requirement for Worker Protection

In this configuration, only a single jumper used with a cluster bar would be used. It would connect from the one conductor being maintained to the cluster bar below the worker's feet. The jumper maintains the required low resistance path in parallel with the body. As in all parallel situations, all current available divides between the jumper and the worker if the worker is in contact at the time of current flow.

Whether sufficient current bypasses the body to maintain a safe environment is a function of the equipment and body resistances present. To use this method, some information or estimates must initially be acquired. Needed are the worksite available fault current, the assumed value of worker resistance and required jumper length and the resistance of the remaining path to Earth (pole or tower), because that would be the return path. With these data, calculations can be made for sizing the protective jumper. Equation 7 is a repeat of Equation 5a and can be used to make this calculation.

$$I_{MAN} = I_{AVAILABLE} \times \frac{(R_{JUMPER})}{(R_{MAN} + R_{JUMPER})} \qquad \text{Eq. 7}$$

Again using parallel circuit theory, the maximum ground set resistance can be determined which would maintain the body current level below the selected value. Even if there is only a very small current due to high pole and earth resistance in the overall circuit, the percentage division between the paths remains the same as the calculated ratios. Obviously, the higher the current, the lower the protective ground set resistance must be to keep the body current below the safe level.

If the worker is on a wood pole with only one protective ground set in place, the pole resistance and return Earth path become the current-limiting resistances. The ground set would protect the worker, but the current magnitude may be so low the line protection equipment fails to recognize that a fault has occurred, leaving the line energized for an extended time.

This is an incomplete solution because the system protective equipment may not see that a fault exists, or because the estimates may be completely wrong. Therefore, this is not a recommended method. By expanding upon this method, a usable method can be obtained.

Combination Grounding

An acceptable form of single bypass ground set method is the use of a Single bypass ground set AND the Bracket Method. The bracket grounds provide the system fault information to the protection equipment. The single bypass ground set, called a personal ground set, connects between the cluster bar and the conductor to be contacted. It provides the low resistance parallel path without requiring the installation of a full set of ground sets at the worksite on all phases, neutrals, etc. This combination method provides a means of worker safety when the worksite moves from pole to pole, within the area between the two ground sets that make up the bracket grounds span.

It is important that the worker not touch any conductor except the one connected to the single bypass ground set. For example, if contact is made to phase B while the ground set is connected to phase A, the current shunt path is now phase B conductor length from the worksite to the bracket set and back to the worksite on phase A, then to the cluster bar. The added resistance of the added conductor lengths may be fatal, depending upon the resistance of the conductors.