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MORENCI OPERATIONS

BEST
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Revision - 2

Personal Protective Grounding Policy

1. POLICY

The policy is to install protective grounding in order to prevent accidental death or injury to personnel by:

- Limiting voltage differences across personnel to a safe level in the event that the circuits (hereafter referred to as circuit) being worked on are accidentally energized from any source.
- Protecting against induced voltages from adjacent parallel energized circuit, lines or foreign power crossings.
- Ensuring protective devices (breakers, circuit switches, or fuses) operate and disconnect any unexpected energizing source.

2. PROTECTIVE GROUNDING PROCEDURES

Electrical safety guidelines dictate the need to develop and implement protective grounding procedures that provide a safe work environment. These procedures must limit worksite voltage differences across personnel, and the resulting currents, to safe levels if the circuits being worked on are inadvertently energized by an electrical source or by voltages induced by other proximate energized circuits or lines.

This grounding requirement is designed to apply to exposed, non-insulated, ungrounded conductors. It is recognized that there are conditions that this may not be a safe application. In this situation, a detailed hazard analysis must be performed and an SOP must be developed to eliminate the use of the personal protective ground.

The key elements in providing effective protective grounding are:

- Obtaining a Clearance (BEST Policy 98-004)
- De-energizing & Lock Out Tag Out (BEST Policy 98-005)
- Test the Circuit (BEST Policy 98-008)
- Protective Grounds (BEST Policy 98-010)
- Hot Line Procedures (BEST Policy 98-014)

In order to test the circuit that is to be grounded, the voltage detection equipment shall be tested on a known source of equal voltage, and then the circuit checked for voltage and finally retest the voltage detection equipment on the same known source of voltage (Test – Check – Re-test). The individual performing such testing shall keep every part of the body at the required distance with the use of insulated tools and equipment. If voltage is not present the grounding may be completed. Before grounding any circuit, the individual shall first connect one end of the grounding device to an effective ground. Grounding switches may be employed to connect the circuits being grounded to the actual ground connections. The grounding device may then be brought into contact with the circuit using insulated tools and equipment to securely clamp onto the circuit.

Until the circuits are grounded they should be considered energized and personnel should not come into contact with them.

Record the placement of each grounding jumper by placing a green grounding jumper placement tag on the point of energy isolation.

When removing grounding equipment, the procedure should be reversed by first removing the secured clamp from the circuit. The last step is to remove the grounding device from the effective ground.

When a conductor is to be cut or opened, the conductor must be grounded on both sides of the separation or grounded on one side of the separation and bridged with a jumper cable across the point of separation.

3. RESPONSIBILITY

All electrical personnel must be adequately trained and responsible for being knowledgeable of protective grounding procedures, and for following these procedures when working on de-energized circuits. Supervisors and workers are responsible for developing a Safe Operating Procedure (SOP) that includes the implementation of safe protective grounding procedures and for ensuring compliance with these procedures.

4. GROUNDING JUMPER REQUIREMENTS

Personnel protective grounding jumpers must:

- Minimum conductor size of 2/0 AWG flex stranded copper conductor is required. Aluminum conductors have demonstrated unacceptable fatigue characteristics under repeated flexing conditions.
- Ferrule type connectors to attach grounding cables to grounding clamps. The ferrule shall be either unshrouded or stepped-bore type.
- Bronze or aluminum grounding clamps with continuous current ratings of 400 amperes RMS (minimum) and fault current ratings of approximately 27,000 amperes for 30 cycles. Aluminum clamps must be used with aluminum ferrules and bronze clamps with copper ferrules.
- Cable jacket materials that are made of clear, orange or yellow ultra violet inhibited polyvinyl chloride.
- Limit the length and keep to a minimum. Exceptions would include midspan work and work on ungrounded wood pole structures where the leads to driven grounds may be as long as necessary and when grounding mobile equipment.
- Each grounding jumper should be numbered, or otherwise identified, by means of a permanently attached tag or an identification number stamped on the clamps.
- In addition to before-use inspection, annual testing of grounding jumpers and clamps should be performed. A record of the annual test for each grounding jumper should be maintained for as long as that jumper remains in service.

5. SOURCES OF HAZARDOUS VOLTAGES / CURRENTS ON DE-ENERGIZED CIRCUIT, LINES OR EQUIPMENT

Potential sources of voltages / currents on de-energized lines are:

- Re-energization – Voltages that can produce lethal currents will occur on de-energized circuits if the devices used to de-energize the circuits are accidentally closed or if an energized circuit or line falls into or across the de-energized circuit. If the de-energized circuit has been properly grounded, protective devices should interrupt the voltage source in 30 cycles or less.

- Lightning – When lightning strikes an overhead line, structure, pole, overhead ground wire or phase conductor or is discharged to the earth by lightning arresters the voltage surges travel along all circuit or line conductors in all directions from the point of strike. These surges dissipate as they travel along the circuit or line. Factors that determine the voltage level of these surges are line voltage classes, structure or pole footing resistance, and the level of the lightning strike.

  Protective grounds will normally provide protection against lightning induced voltage surges, if the lightning strike is some distance away. However, the exact distance is difficult to predict due to the many variables involved. As such, protective grounds cannot be relied upon to provide complete protection from a nearby direct strike. Circuit or line work should, therefore, not be performed if there is lightning in the immediate area.

- Sources of Induced Voltages and Currents on De-energized Circuits

  - Static – A direct current (DC) charge or voltage can build up on a de-energized line, circuit or equipment due to wind, dry conditions, dust, etc. This dc potential adds to any alternating current (ac) potential that may exist. A single connection to ground will drain off the charge and reduce the potential to a safe level.

  - Capacitive Coupling – Whenever two or more conductive surfaces are separated by insulation, and one or more of the surfaces is energized from an ac source, an ac voltage will be induced in each of the remaining conductive surfaces. A steady state charging current will flow as a result of this capacitive effect. These currents are normally not large enough to operate protective equipment, but they may be large enough to be potentially hazardous to personnel.

    If de-energized circuits are insulated from ground but located near energized circuits, they will become charged to a level above ground potential. When protective grounds are installed, the potential, at the point of ground application, drops to ground potential. The discharge current that flows when the ground is applied may reach several amperes for long circuit or lines. After the initial charge is dissipated, the circuit or line takes on a smaller charge that increases as the distance from the grounded point increases. The grounded circuit will draw a capacitive charging current, which flows, from the earth to the circuit through the protective ground. If all grounds are removed the circuit will instantly become charged to a potential above ground.

In general, the capacitive charging currents encountered by personnel working on de-energized circuits that are in near proximity to other energized circuits are very small.

- Electromagnetic Coupling – Electromagnetic coupled voltages also exist in de-energized circuits or lines that closely parallel energized circuit or lines. The energized circuits or lines act as the primary winding of a transformer, the de-energized circuits or lines as the secondary winding and the air between as the insulation. In other words, the circuits or lines form a transformer with a 1:1 ratio and a low value of mutual inductance. A voltage is induced in the de-energized circuits or lines that is determined by circuit/line lengths, separation distances and the magnitude of the current.

6. GROUNDING / JUMPERING THEORY

Proper grounding and jumpering are the keys to working safely on de-energized circuits. For this discussion, "Grounding" is defined as a physical connection to earth and "Jumpering" is the use of low resistance grounding jumpers to bypass workers and/or the worksite. Both grounding and jumpering are applicable to de-energized circuits, lines and fixed or mobile equipment.

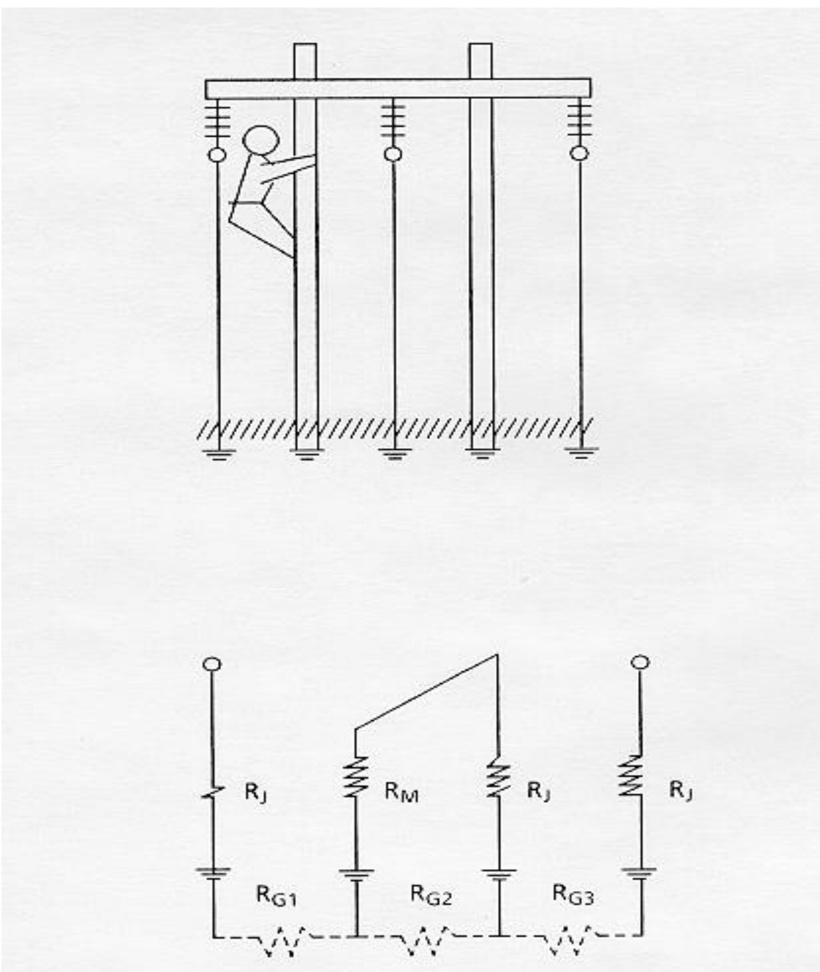

Figure 1

Unsafe Procedure

Electrical Equivalent

At first glance, the worker shown on this overhead pole or structure may seem safe. However, this is not the case, as the following analysis clearly shows.

The electrical equivalent of the structure is shown at the bottom of Figure 1.

R_J = Resistance of the ground jumpers

R_M = Resistance of the worker

R_G = Resistance of the ground

The key point of this equivalent circuit is that RJ and RG2 are in series and this combination of resistance's is in parallel with RM. The equivalent value of RJ and RG2 in series will vary considerably from one worksite to another. For purposes of this discussion, let's consider a very low combined value of 1 ohm. Suppose this grounded de-energized circuit suddenly became energized from some source and that about 1,000 amperes of fault current is flowing through the system and through each ground jumper. The voltage drops across RJ and RG2 in series will be approximately equal to the product (1,000 amperes x 1 ohm, = 1,000 volts). If the worker has his hands on the conductor and his feet on or near the ground wire of the metal structure or pole, the 1,000 volts is impressed across RM, the worker. The resulting current flow through the workers body (1,000 volts divided by 500 ohms = 2 amperes). As was calculated earlier, maximum safe body currents are 150 mA to 200 mA. The worker is in serious trouble even on this grounded and supposedly de-energized system. The largest contributor to this problem is the excessive voltage drop across the ground resistance RG2.

A natural step to seemingly improve the grounding scheme shown in Figure 1 would be to connect all three grounding cables to a common driven ground rod as shown in Figure 2.

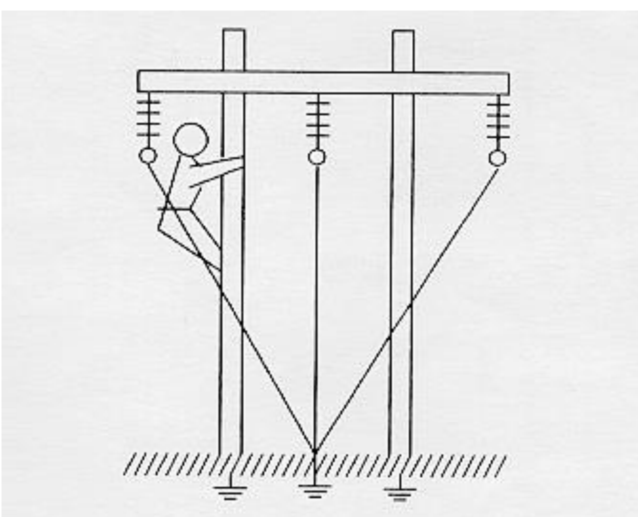

Figure 2

Unsafe Procedure

This would reduce the ground resistance. It would also result in faster system protection reaction to clear the faulted line. Unfortunately, there is still a ground resistance in parallel with the work area. The voltage across the worker is minimally reduced.

Another approach would be jumper the three phases and connect one of the phases to a driven ground as shown in Figure 3.

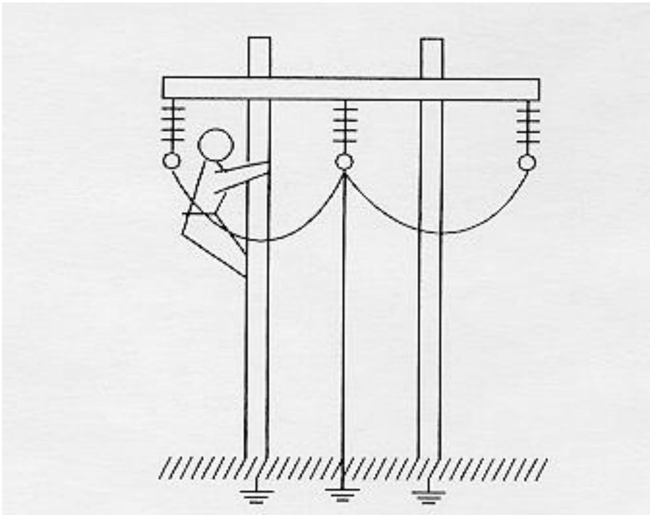

Figure 3

Unsafe Procedure

This reduces lead lengths and achieves a minimum resistance between phases for rapid clearing of protective devices. The method still uses a single lead from one phase to a driven ground and still leaves a high potential for a high voltage drop across the work area.

Figure 4 shows the required equi-potential grounding procedure and its electrical equivalent. This grounding is not only recommended while climbing it should be used in bucket truck applications.

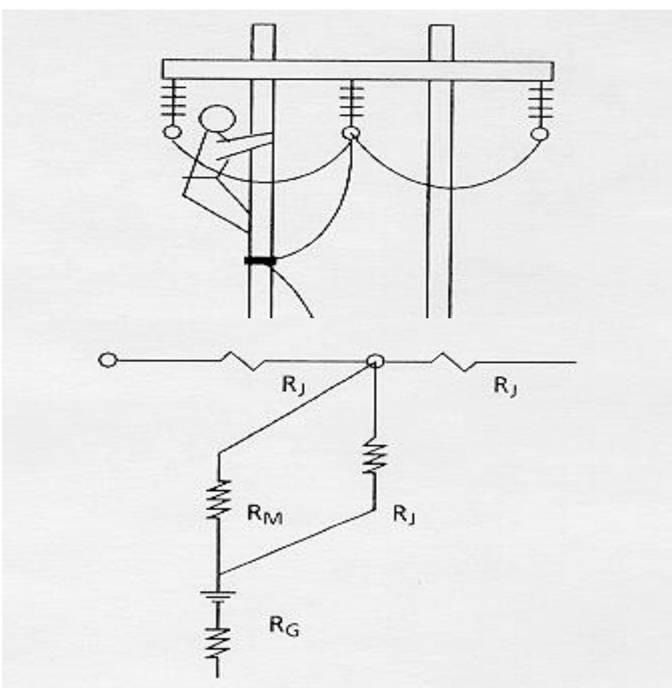

Figure 4

Required Procedure

Ungrounded Structure

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Electrical Equivalent

The procedure results in short jumper lengths between phases and, most importantly, places the worker in parallel with the voltage drop across only the ground jumper resistance, including all connection impedances. This resistance may be of the order of milliohms rather than 1 ohm. The resultant voltage drop across the worker is reduced by a factor of 1,000, or from 1,000 volts to 1 volt.

The resultant current is also reduced by a factor of 1,000, from 2 amperes to 2 milliamperes. The lower voltage drop also reduces the likelihood of skin puncture in the event of energization.

Note, however, that a potential hazard exists for personnel, workers or the public, who are on the ground if they were to touch the structure or the structure grounding system while it is carrying fault current due to energization.

7. PROTECTIVE GROUND JUMPER RESISTANCE

The required protective grounding procedure places the worker in parallel with the voltage drop across the ground jumper resistance. As such, minimizing this resistance increases the level of protection to the worker. This jumper resistance is the sum of several resistances in series:

- Contact resistance – clamp to conductor, ground grid, ground rod, and ground wire
- Clamp resistance
- Contact resistance – cable to ferrule or bolted clamp
- Cable resistance

Cleaning conductors, buss, equipment terminals, etc. will reduce clamp to conductor, ground rod, and ground wire resistances. Visual inspection shall be performed prior to each use. Cable resistance is a function of length and conductor size and material type.

Grounding jumpers shall not exceed 30 feet in length.

8. STEP AND TOUCH POTENTIALS

Currents resulting from accidental energization of a circuit or line with protective grounds installed will flow down the steel structure or pole, and / or the protective ground cable to ground rods, structure or pole grounds. It then spreads out at the ground surface around the tower legs, ground grid, ground rod or structure or pole ground before going deeper into the earth. This results in two related phenomenon, step potential and touch potential.

- Step potential is caused by the flow of fault current through the earth. This current flow causes a voltage drop at the earth's surface. A person standing with feet apart bridges a portion of this drop. This places a potential difference from foot to foot. Test programs have been conducted to define the characteristics of this voltage drop. The tests indicate that the voltage distribution decreases with distance, but in a nonlinear manner. A plot of this nonlinear relationship is shown in Figure 5.

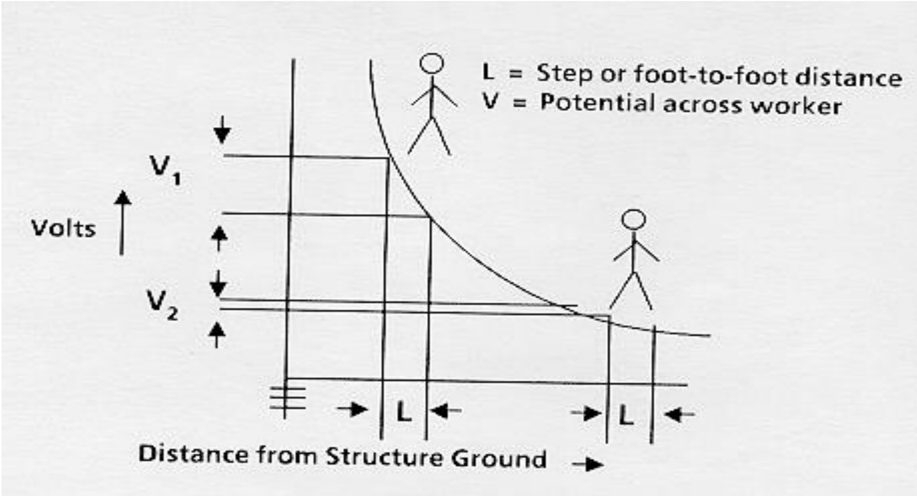


Figure 5

Variation of Step Potential With Distance

Relative to the step potential problem, this nonlinear relationship means a person standing near the point where the current enters the earth may have a large potential difference (V1) from foot to foot. It may also mean the potential difference over the same foot-to-foot span will be less and less as the span moves away from the fault current entry point.

- Touch potential is a problem similar to step potential. It involves a fault current flow in the earth establishing a potential difference between an earth contact point and hardware or equipment such as a tower, as shown in Figure 6.

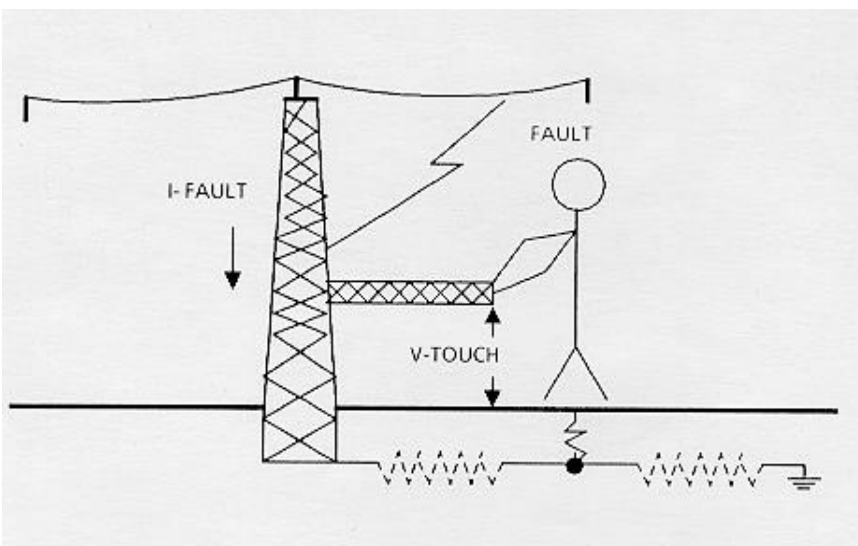


Figure 6

Touch Potential

The use of a switching platform will provide step and touch potential protection for workers. The switching platform may be either insulating, to isolate the person and interrupt the circuit path, or conducting which maintains the worksite walk area at a constant potential. The use of a switching platform moves the problem area to the switching platform's edge. As such, a worker must remain on the switching platform to stay in a safe zone.

9. SUBSTATION TECHNICAL CONSIDERATIONS

Ground fault conditions in a substation produce current flow to earth and voltage gradients within and around the substation. Unless proper design precautions are taken, the gradients along the earth's surface in the substation may be so great (under very adverse conditions) as to endanger a worker walking there. Dangerous potential differences may also be present (under very severe conditions) between equipment and structures which are "grounded" to nearby earth. The actual ground potential rise at any point within the substation is a function of the ground grid design, the resistance of the ground grid to remote earth and the division of the fault current flow through the grid to earth.

The effect of the portion of the fault current, which enters earth within the station, requires careful analysis. If the geometry, location of ground electrodes, local soil characteristics, and other factors contribute to an excessive earth gradient, the grounding system must be improved.

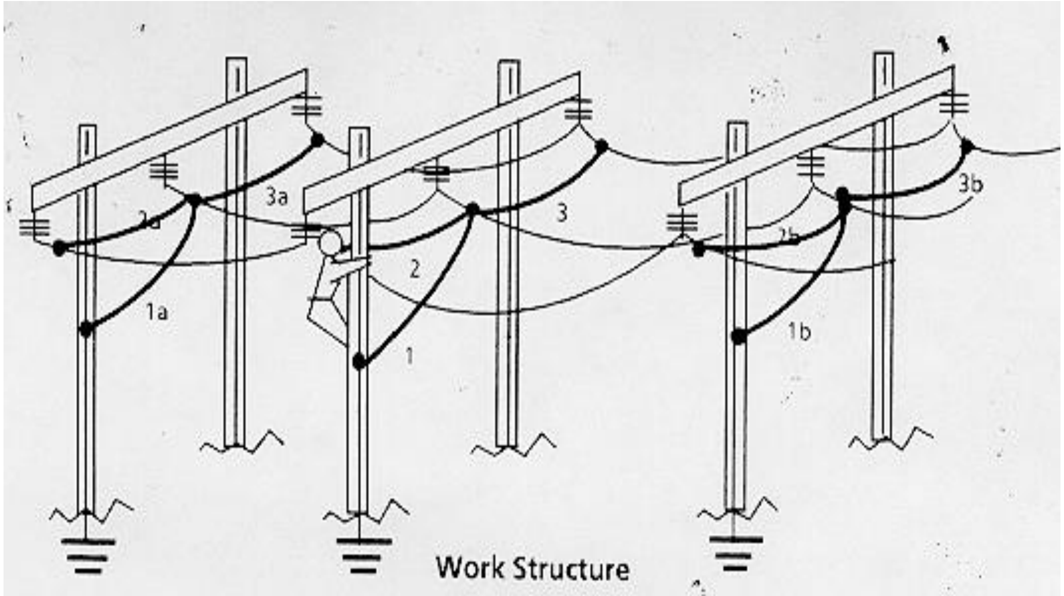
The goal of substation protective grounding is to keep all points in the work area, as near as practical, at the same potential, this is accomplished by jumpering all possible sources of electrical energy and conducting components with low resistance grounding jumpers. All jumpers are connected to a common point and to the substation ground grid. The frames of all equipment are permanently connected to the ground grid.

10. SINGLE-POINT VERSUS MULTI-POINT PROTECTIVE GROUNDING

Single-point protective grounding (equi-potential grounding) is the placement of grounding jumpers on the work structure only. Multi-point protective grounding is the placement of grounding jumpers within 1000' and on the structures adjacent to the work structure and equi-potential grounding applied at the work structure.

If equi-potential grounding were not installed at the work structure, there would be no step-potential hazard at the worksite due to not having a current flow into the earth to create the hazard. The high-voltage gradients associated with the current flow are present at the two adjacent structures only. However, with multi-point grounding and no grounding jumpers installed at the worksite, a person on the work structure and in contact with the energized hardware is in the worst possible position. The work structure is at zero volts and with the circuit, line or equipment energized, the full voltage is across the person. The use of a third grounding jumper at the work structure to create an equi-potential zone eliminates this hazard.

The use of grounding jumper sets on the adjacent structures or poles provide little additional protection above the use of a single set properly placed at the worksite. If adequate safety can be maintained with a single grounding jumper set at the worksite, then the use of one versus three sets becomes a matter of economics, not safety.



<u>Figure 7</u>

Single-Point versus Multi-Point Grounding

1, 2, 3 Single-point protective grounds at work structure.

1a, 2a, 3a Multi-point protection grounds on the
1b, 2b, 3b Structure on either side of the work structure.

11. UNDERGROUND CIRCUIT PROTECTIVE GROUNDING

The purpose of underground circuit protective grounding is the same as indicated in the preceding section. There are considerations unique to underground systems.

Maps, drawings, tags, etc. must be relied on for identification of de-energized cables that are to be worked on. The risk of misidentification increases when cables have been direct buried or are within direct buried conduit, concrete encased conduits, enclosures limit visual identification, multiple cables exist, etc.

12. GROUNDING JUMPER TESTING

Protective grounds are applied to circuits to prevent accidental death or injury to operations and maintenance personnel. As such, it is imperative that these grounds be inspected before each use to detect visible defects. Typical visible defects include broken strands, physical damage to conductor or clamps, loose connections between cables, ferrules, grounding clamps and worn serrated jaws.

Protective grounds should also be electrically tested with the appropriate test equipment annually to detect non-visible defects.

Each protective ground cable shall be assigned an identification number. This number shall be permanently marked on the cable and referenced in test documentation.

13. REFERENCES

NFPA 70E 2000 Edition & 70B 1998 Edition
ASTM F855
NESC - 1997
John Cadick's Electrical Safety Handbook - 2^{nd} Edition
OSHA 1910.331-335
MSHA 30CFR 56.12020