

GROUND RESISTANCE TESTING IN THE MINING INDUSTRY

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ABSTRACT

Ground beds provide safety grounding of mine electrical equipment. The lower the resistance of the ground bed, the better protection it provides. While ground beds may have a low resistance when first installed, corrosion of ground rods, breaks in interconnecting wires, and water table changes can all increase the resistance of the safety ground bed. For this reason it is important that the resistance of the ground bed be measured not only when first installed, but also periodically to ensure that it remains low in value. For many contractors the testing and recording of these measurements has not been completely understood.

The purpose of this paper is to describe a preferred method for measuring ground bed resistance that can give confidence in the value of the resistance obtained. Methods are also presented for lowering the resistance value in high resistivity areas.

INTRODUCTION

A reliable equipment grounding system that connects all the metallic frames of electrical equipment together must be kept at a safe reference potential. Since earth ground is considered to be at zero potential, making an electrical connection to earth is a logical choice. The earth grounding electrode should provide the lowest impedance connection possible to earth and maintain this reference at a low value. The objective is that in the event of a fault to ground, sufficient current will flow through the ground path to allow the protective equipment to operate and isolate the circuit.

In the real world, however, the ground system does have resistance. All ground beds, even the very largest, have some measurable amount of resistance. "Earth resistance" means the resistance of the

earth to the passage of electric current. In comparison with metal conductors, soil is not a good conductor of electricity. Resistances in the two to five ohm range are generally found suitable for industrial plant substations, buildings and large commercial installations.

The National Electrical Code requires that made electrodes shall have resistance to ground not to exceed 25 ohms and that where the resistance is not as low as 25 ohms, two or more electrodes connected in parallel shall be used. They should not be less than six feet apart.

“The 25 ohms value noted in the National Electrical Code applies to the maximum resistance for a single electrode. There is no implication that 25 ohms per se’ is a satisfactory level for a grounding system.”[2]

The Institute of Electrical and Electronics Engineers Standard 142, Recommended Practice for Grounding of Industrial and Commercial Power Systems states:

“The most elaborate grounding system that can be designed may prove to be inadequate unless the connection of the system to the earth is adequate and has a low resistance. It follows, therefore, that the earth connection is one of the most important parts of the whole grounding system. It is also the most difficult part to design and to obtain... For small substations and industrial plants in general, a resistance of less than 5 ohms should be obtained if practicable.”

However, from a practical standpoint, no grounding electrode no matter how low its resistance can be depended upon to clear a ground fault. If equipment is effectively grounded as pointed out in the National Electrical Code under 250-51, a path of low impedance (not through the grounding electrode) must be provided to facilitate the operation of the overcurrent devices in the circuit. While the lowest practical resistance of a grounding electrode is desirable and will better limit the potential of equipment frames above ground, it is more important to provide a low-impedance path to clear a fault promptly to ensure safety. To obtain the lowest practical impedance, the equipment grounding circuit must be connected to the grounded conductor within the service equipment.

For maximum safety, one grounding electrode system should be used with everything connected to that grounding system. If multiple grounding electrodes comprise the system, they must be bonded together to form a common grounding electrode.

One topic which needs to be stressed is that the resistance of a ground bed, as shown in figure 1, cannot be accurately measured unless it is isolated from other parallel ground paths. The current generated by a test instrument will be split among all the paths. Therefore, the meter reading on a test instrument will not represent the ground bed resistance accurately. Also, the “effective ground bed” will include the mine, the mill, and the pole line as well as the substation to be tested. The auxiliary current and potential electrodes would have to be miles away to make an accurate measurement on such a large ground bed.

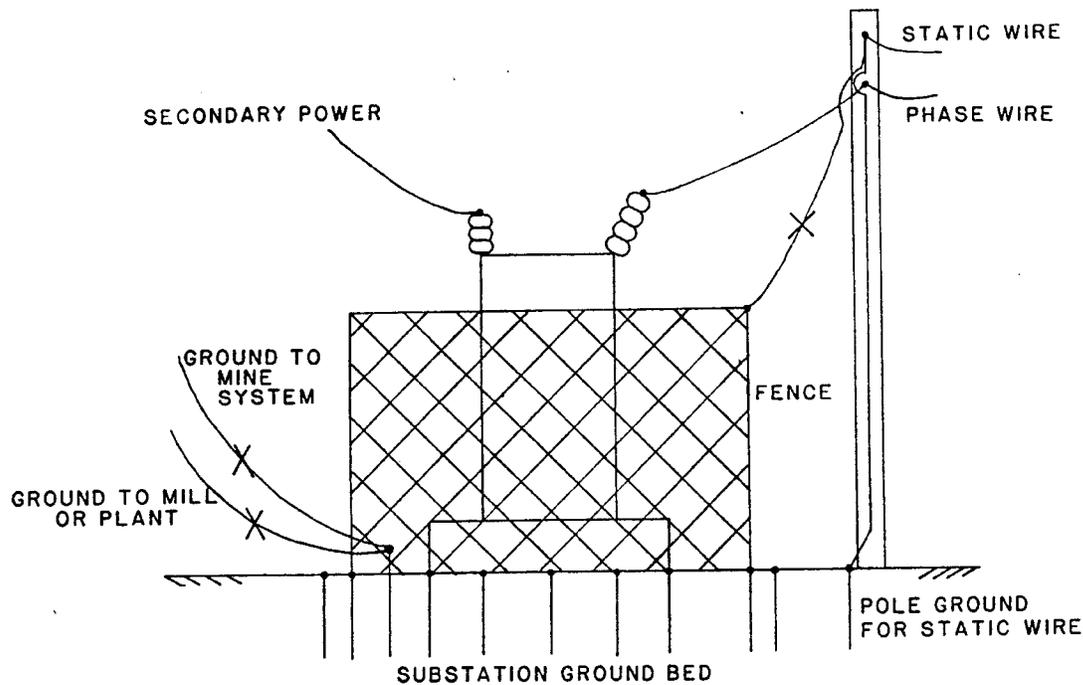


Figure 1. Substation with Substation Ground Bed and Three Parallel Ground Paths

MEASUREMENT OF EARTH RESISTANCE

Since many variable factors contribute to the earth electrode resistance, it is not practical to expect a precise or repeatable measurement over different seasons. Such factor as moisture content, soil temperature and dissolved salts may vary considerably from summer to winter. When the moisture content of dry soil is increased by 15% the resistivity can decrease by a factor of 50,000.[3] When water in the soil freezes, the earth resistivity will increase since ice is not a good conductor. They type and grain size of each soil also contributes to the resistance value.[4]

Through research conducted by the U.S. Department of Interior, Bureau of Mines[5], the most reliable and accurate method for determine the earth electrode resistance was identified as the “fall-of-potential” method.

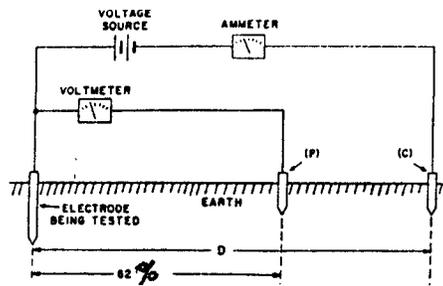


Figure 2. "Fall-of-Potential" Method

This method involves passing a current into the electrode to be measured and measuring the voltage between the ground electrode under test and a test potential electrode (P). A test current electrode (C) is driven into the earth to permit passing a current into the electrode to be tested. Potentials are measured with respect to the ground electrode under test which is assumed to be at zero potential.

A graph is then made of the resistance measured with the instrument as a function of potential electrode distances (X). The potential electrode is moved roughly on a straight line from the electrode under test in enough steps to plot a smooth curve. The value in ohms at which this plotted curve appears to flatten out is taken as the resistance value of the earth ground bed under test. This value is usually about 62% of the distance (D) from the electrode under test to the current probe.

The current probe (C) should be far enough away from the electrode under test to be out of the "sphere of influence" of the earth electrode. Usually a distance of five times the rod length is adequate.

There are special instruments which are designed to make earth-resistance measurements simple and straightforward. Most of these instruments adjust a potentiometer until no current exists in the potential electrode at balance and the resistance of the potential electrode and the connecting wiring does not affect the measurement value.

Other common features of these instruments are:

1. The use of low-frequency (usually less than 100 Hz) alternating current drive.
2. The combination of a current generator and a device for measuring potential built into a single portable unit.
3. Well-identified current and potential terminals.
4. Battery or hand-cranked operation of the equipment.
5. Direct reading in ohms or ohms multiplied by 2B.

The following is a listing of the minimum equipment that is required to make earth resistivity measurements:

- Tester (and instructions)
- Leads (500 feet minimum each)

Probes (2 minimum)
Cloth or plastic tape measure, 250 feet minimum
(metal tape may short circuit the earth or the probe)
Hammer
Spare batteries (if battery-operated)
Test resistor; 5 ohms, 10 watts (for meter calibration)
Notebook
Carrying case
Position markers
Walkie-talkies (if long runs are anticipated)
High voltage gloves

The following guidelines should be used to insure a safe testing procedure.

1. Wearing proper safety equipment, determine the location and full extent of the grounding electrode for the electrical system to be checked.

CAUTION--Multiple power systems may have a common grounding electrode.

2. De-energize all power systems which use the grounding electrode to be tested. Open visible disconnects.

CAUTION--Do not test with system energized. Lock it out or provide other no less effective means.

3. Check thoroughly for voltage on the system and take steps to eliminate the hazard.

CAUTION--Make certain you check for loop feeds and capacitors. Allow five minutes for charge to bleed off the capacitors.

4. With the system de-energized, ground all power (phase) conductors to the existing grounding electrode using safe procedures.

CAUTION--There must be no voltage on the power conductors prior to grounding them.

5. Disconnect the ground bed from the ground system. Measurements made on a connected system do not yield correct results. They always show the bed resistance to be lower than it really is because of the connected equipment; this may allow a dangerously high bed resistance to go undetected.

6. Test for voltage or current between the grounding conductor(s) and the grounding electrode once the connection has been broken. More than a few volts could identify a hazard to test personnel or test equipment.

7. Set up the earth resistance tester in preparation for performing the tests. Be certain that the meter is tightly connected to the ground bed by short leads. If the meter provides the option of making separate current and voltage connections to the bed (a four-terminal meter), make these connections independently rather than using a jumper at the meter.
8. Estimate the dimension of the ground bed under consideration. This is defined as the longest straight-line measurement within the volume of the bed. It is the length of any single rod, the diagonal of a rectangular grid, the diameter of a circular bed, etc.
9. Establish a straight line extending from the estimated center of the bed for a distance equal to five times the dimension of the bed or 50 feet, whichever is larger. This line should lie on fairly uniform earth wherever possible and stay far away from any buried metallic objects such as water pipes or other ground beds. Drive one of the stakes a few inches into the earth at this point to form the auxiliary current electrode.
10. Mark off points along the line at 20%, 40%, 50%, 60%, 70%, and 80% of the distance from the center of the ground bed to the auxiliary electrode.
11. Perform the necessary grounding electrode resistance tests following specific instructions provided with the earth resistance tester being used (a fall-of-potential test method is recommended). Earth resistance testers are available from several manufacturers. Test equipment not especially designed for earth resistance testing should not be used.
12. Plot the data, graphing resistance versus distance. This should form an S-shaped curve with a relatively flat portion at its center. If it does, then the true resistance of the ground will be found at the point the curve crosses a line 62 percent of the distance to the auxiliary current electrode. If the resistance value at 60 percent differs from the value at 50 percent by more than 10 percent, or if the curve is not relatively smooth, it suggests that the measurement is not satisfactory and should be done again along a new line.

Figure 3 indicates some typical data curves and the conditions that produce them. Curve A is the correct curve as described above.

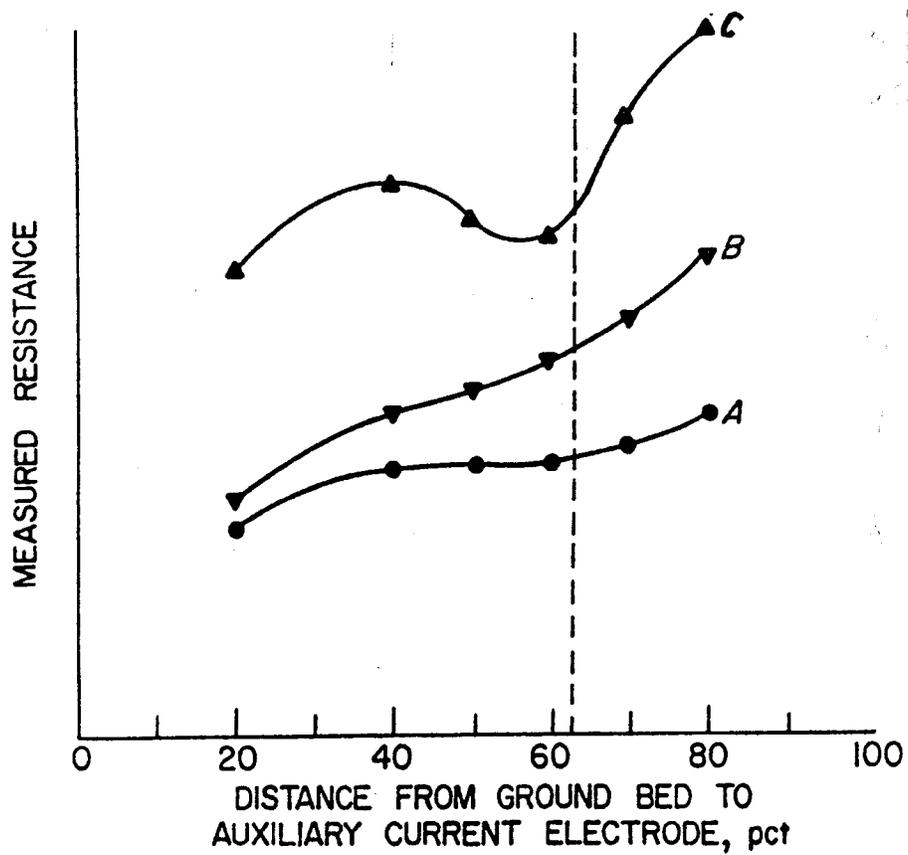


Figure 3. Fall-of-Potential Resistance Curves

If the current electrode is placed too close to the electrode under test then curve B will result. The measured resistance is increased steadily as the potential electrode is moved along the line joining the earth electrode to the current electrode, as shown in figure 4.

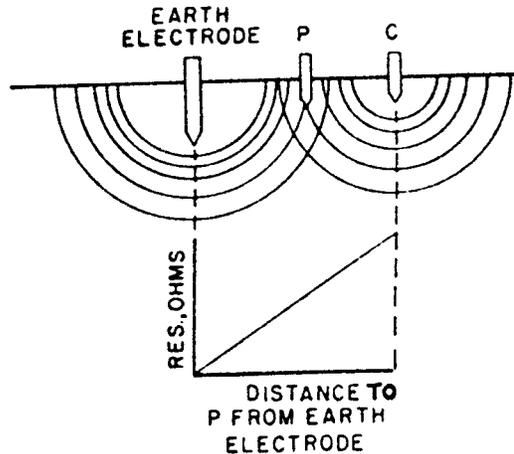


Figure 4. Auxiliary Current Probe Within Sphere of Influence of Earth Electrode

Conditions shown in B and C (figure 3) can usually be remedied by repeating the measurement with a longer or different base line.

14. Record test results for comparison with future tests. Tests should be conducted annually.
15. Reconnect all grounding conductor(s) to grounding electrode using line-man's gloves.
16. Disconnect phase conductor grounds.

The importance of de-energizing the power system before conducting grounding system tests is clearly illustrated in the following non-fatal accident.

An electrician sustained severe burns to his left forearm when he disconnected the neutral ground from an energized 4160 volt capacitor bank in a substation. The accident is illustrated in figure 5.

The electrician was in the process of isolating the system from all external power sources and power company grounds. He was doing this in order to make a check of the grounding system.

The power was not turned off since it was assumed that the grounding electrode conductor could be removed from the grounding rod on the capacitor bank without any hazard involved. When he removed the grounding conductor from the ground rod an arcing action developed at his arm and hands causing serious burns to both hands and left arm.

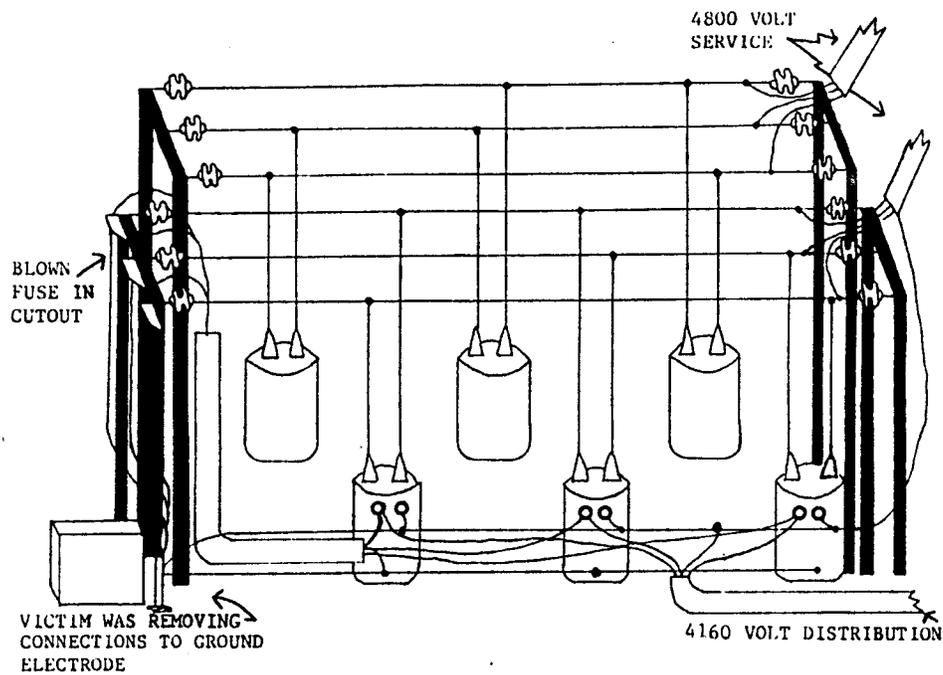


Figure 5. Grounding Electrode Accident

Power at the mining operation was reduced from 4800 volts to 4160 volts through two banks of three single phase transformers. Both banks were connected delta-wye with the neutral connected to the system ground. One transformer bank was connected on the 4160 volt wye secondary through fused cutouts to a capacitor bank. The capacitors were connected to the system ground.

The investigation revealed that the voltage potential between the grounding conductor and the ground rod had been 1200 volts. This condition was brought about by a blown fuse in one of the capacitor bank cutouts.

As previously mentioned, it has been established that the resistance of mine ground beds should be designed as low as practical with a 5 ohm value a design goal. If space is limited or the terrain does not lend itself to a driven-rod bed design, then a borehole or composite bed can be utilized. U.S. Department of Interior publication IC9049, Earth Grounding Beds Design and Evaluation, [8] describes how to design a borehole and composite ground bed.

CONCLUSION

The proper grounding of electrical mine power systems is extremely important at mine sites. There have been many fatalities involving power systems at mine sites that were not properly grounded. Since a ground is not required for equipment operation, it can become deteriorated to an unsafe value and can remain that way for some time without detection. To be relied on, it must be tested periodically.

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