SAFE MEASUREMENT OF GROUND RESISTANCE

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ABSTRACT

The mining industry uses a large amount of electric power. Their equipment is subject to extreme environmental conditions and mechanical shock. A significant number of electrical accidents are a result of improperly grounded electrical equipment.

Federal regulations require the safety ground bed resistance to be measured once a year or after modifications for the Metal/Nonmetal Mining Industry. Coal mine regulations require connection to a low resistance ground medium. A ground resistance measurement can be accepted as evidence of compliance with these regulations. Most commercially available instruments used to measure the ground bed resistance require the ground conductor to be disconnected and the power system disconnected for safety reasons. The “fall of potential” method requires auxiliary ground rods and approximately two hours to complete the test. Although a new instrument was initially thought to measure the ground bed resistance immediately without isolating the ground bed, field tests have shown this method is not accurate.

In some cases, a continuous measurement of the ground resistance is desired. A monitor has been developed and is presently being evaluated at several mines. These installations will be discussed.

INTRODUCTION

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. It is, therefore, 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.

A reliable equipment ground system that connects all the metal 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 largest, have some measurable amount of resistance. "Earth resistance" is defined as 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 "man 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."[2]

However, from a practical standpoint, a grounding electrode, no matter how low its resistance, can not 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.

GROUND BED RESISTANCE MEASUREMENT

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. 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.

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 factors 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. The 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 determining the earth electrode resistance was identified as the "fall-of-potential" method.

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

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. A test current electrode 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 from the electrode under test to the current probe.

The current probe 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.

The graph obtained from plotting the resistance versus distance should form an S-shaped curve with a relatively flat portion at its center. The ground bed resistance is that value where the flat portion of the curve would intersect with the resistance values.

Although the instruments which are specifically designed to measure ground bed resistance do not clearly state that the power should be turned off, the Mine Safety and Health Administration recommends this practice due to the potential dangers involved.

EVALUATION OF SPECIFIC INSTRUMENTS

The AEMC Corporation[1] has developed an instrument which they claim can be used without isolating the ground conductor or turning off the power. The clamp-on ground resistor tester model 3700 clamps around the grounding conductor and displays a resistance value. A 5 ohm loop resistance is used to check the instruments calibration before each use.

This instrument operates on the following principle. Current is fed to a special transformer via a power amplifier from a 4.5 kHz constant voltage oscillator. This current is detected by a detection CT. Only the 4.5 kHz signal frequency is amplified and used for the display. The filter amplifier is sued to cut off earth current at commercial frequencies and high frequency interference. Voltage is detected by coils wound around the injection CT and then amplified and rectified to be compared by a level comparater.

If the clamp is not closed properly, the LCD's least significant digit flashes. The manufacturer precautions not to use the instrument on live conductors or ground conductors with more than 2 amperes AC flowing in the conductor.

Figure 2 shows an example of how the model 3700 is proposed to be used. A high resistance reading indicates:

(a) poor ground rod
(b) open ground conductor
(c) high resistance bonds

The operating instructions for model 3700 require that the measurement be made on a conductor with only one return path to neutral. This can be a problem especially where there are multiple parallel paths to the system neutral.

Figure 2. Measurement Location for Ground Resistance Meter

In order to determine whether the instrument was obtaining accurate readings, several mining installations were evaluated. In each case the "fall-of-potential" method was compared to readings obtained using the model 3700. Since the readings obtained were significantly different, the AEMC instrument company representative was asked to explain these differences.

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[1]Use of a manufacturers' name is for identification purposes only and does not imply endorsement by the Mine Safety and Health Administration.

In a letter from AEMC Corporation to MSHA,[12] it is explained that the readings obtained with the model 3700 are actually series resistance measurements of the ground bed under test and the total system impedance combined.

In the case of two deeply driven ground rods, as shown in Figure 3, an attempt to use the model 3700 would be thwarted by the limited number of rods and the colliding spheres of influence of the ground conductors.

Figure 3. Mine Safety Ground Bed

Therefore, it appears that the applications for this instrument are limited to large multiple grounding systems which are separated from the system ground by a large ratio. The AEMC corporation concludes that "the fall-of-potential testing for the mining configurations is the only way to achieve accurate test results."[12]

It is concluded therefore, that this device will not provide accurate results in order to comply with the Mine Safety and Health Administration's requirement to maintain a low resistance ground bed. (See AEMC Letter)

Another new instrument which has been developed is a continuous ground bed monitor. Model GBM-100 developed by American Mine Research[2] was designed to provide a continuous digital readout of the ground bed resistance. This unit utilizes the fall-of-potential method to continuously monitor the resistance of a ground bed to earth.

In accordance with this method, two auxiliary electrodes are driven into the earth in a straight line from the ground field to be measured as shown in Figure 4. The auxiliary current electrode is placed far enough away to insure that it is not within the ground fields sphere of influence. This is usually between 5 and 10 times the maximum distance across the area of the field. A constant current source is used to provide current between the ground field and the auxiliary current electrode. Using the fall-of-potential measurement technique, the resistance value is determined and the potential probe is permanently installed at the distance which, corresponds to that resistance value.

Figure 4. Operation of Continuous
Ground Bed Monitor

When properly installed, the ground bed monitor will accurately display the resistance of the ground system to earth.

A trip level can be programmed into the unit to alert the operator when the ground bed is out of tolerance. An analog output of the ground field resistance is also available to allow the operator to chart the resistance over a given time period.

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The continuous monitoring of a site that has several different grounds brought together at one point can produce problems for this installation. If the multiple grounds cannot be separated the ground bed monitor will not accurately display the resistance of the ground bed being tested.

A blocking inductor can be added as shown in Figure 5 if a utility ground is connected to the safety ground bed. The inductor saturates at voltages above 30 volts and would act as a dead short and provide a path to ground in the event of a fault current. During normal operations with the inductor installed, the current from the GBM Model 100 would circulate only from the auxiliary probe to the safety ground bed. This use of a blocking inductor should be installed after consulting the engineering department at American Mine Research Company. This unit has been installed successfully at several mining installations.

Figure 5. Location of Ground Bed Monitor and Blocking Inductor

CONCLUSIONS

Since the mining applications of the AEMC Model 3700 clamp-on ground bed resistance meter would be very limited, it is concluded by the manufacturer and the Mine Safety and Health Administration that the device will not be useful in order to comply with the requirement of maintaining a low resistance ground bed.

The continuous ground bed monitor has been shown to be effective in several mining applications when it is advisable to carefully monitor possible changes to the safety ground bed. (See AEMC Letter)

REFERENCES

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[10] Instruction Sheet, Model 3700, AEMC Corporation.

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[12] Letter to Jerry Collier, Mine Safety and Health Administration from Dan Wiswell, Manager, AEMC Corporation, August 10, 1991.