MSHA METAL/NONMETAL ELECTRICAL GROUNDING REQUIREMENTS

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ABSTRACT

Several MSHA Regulations have been written that directly deal with grounding of electrical equipment at plants and quarries. These regulations, as written, are of a general nature.

Since proper grounding of electrical equipment is vital to maintain a safe work environment for miners, regulations concerning grounding must be strictly adhered to.

This paper will discuss several of these standards and the methods that MSHA prefers to use in complying with these standards. The grounding electrode, grounding electrode conductor and equipment grounding conductor will be discussed along with methods for testing these components.

INTRODUCTION

Proper grounding of electrical equipment at Metal/Nonmetal plants and mines is necessary in order to insure electrical safety to mine personnel. Several regulations in the Metal/Nonmetal mine safety law relate to electrical grounding. These regulations are found in CFR 30 Parts 55, 56 and 57, 12-25, 12-26, 12-27 and 12-28.

In Parts 55, 56 and 57, section 12-25 requires frame grounding of all electrical equipment. Section 12-26 requires grounding of substation enclosures. Frame grounding of portable equipment is required by 12-27 and 12-28 requires testing of all the grounding components at a mine. It is the intent of this paper to discuss these regulations and to detail what is needed to comply with these regulations.

Power systems at metal/nonmetal mines are of various designs such as solid grounded, ungrounded, resistance grounded, and reactance grounded and can generally be classified as either grounded or ungrounded. The classification of grounded or ungrounded should not be construed to mean that in a grounded system a safety ground conductor is needed and likewise with an ungrounded system it

is not needed. Whether the system is grounded or ungrounded, a safety grounding system is required. This safety grounding system in a mine must meet the requirement that it normally does not carry any electrical currents. It is therefore a noncurrent carrying conductor or metallic path back to the electrical service equipment.

When a ground fault occurs on a mine power system, the safety grounding system carries ground fault currents. This condition must be corrected in order to eliminate shock and burn hazards which could result while operating a faulted system.

It is therefore recommended that ground fault protection be provided on mine electrical power systems. This protection can be of several acceptable forms that are readily found in engineering publications and will not be discussed in this paper.

FRAME GROUNDING

Parts 55, 56 and 57, 12-25, 12-26 and 12-27 deal with frame grounding of electrical equipment. In simpler terms, these regulations require the noncurrent carrying metallic parts of equipment being supplied electrical power to be grounded. There are three separate cases to be considered when complying with this regulation. The first case is the metallic noncurrent carrying parts of permanently mounted electrical equipment. The second case is the metallic noncurrent carrying parts of portable electrical equipment, and the third case is the metallic noncurrent carrying parts of electric equipment classified as double insulated. The two objectives of frame grounding are:

1. To insure freedom from dangerous electric-shock voltage to persons that may contact the equipment.

2. To provide current carrying capability both in magnitude and duration, adequate to accept the ground fault current permitted by the overcurrent protection without creating a fire or burning hazard to persons in the area of the equipment.

Accident statistics compiled by MSHA's Health Safety Analysis Center indicate that approximately 14% of all electrical fatalities occur from improper or inadequate grounding.

STATIONARY EQUIPMENT GROUNDING

The frame grounding of stationary equipment is covered under two separate standards 55, 56, 57, 12-25 and 12-26. Both of these regulation essentially require the same thing; that all metallic items enclosing electrical circuits be grounded. To comply with these regulations, every item that is supplied electrical power will have the metallic conduits, boxes, and frames, that the electrical cable passes through, grounded back to the system grounding medium. The grounding circuit should preferably be a conductor that is continuous and of an ampacity to safely cause the protective equipment to operate under fault conditions. This conductor should also be located in the same cable or conduit as the power conductors. If this is not possible, then a metallic path that offers the lowest

impedance path back to the circuit protective devices should be used. The use of gas, airlines, and other pipelines should be avoided since these items are subject to repairs and modifications. It would be during the repair of the pipe system that a phase to ground fault would occur and a person working on the pipe system would be subjected to hazardous voltages. Although, it is desirable to have these pipelines electrically grounded, they should not be used to carry ground fault current.

Another item that should not be used to carry ground fault currents is the metallic portions of buildings. It is desirable to have the building's metallic framework grounded, but again this is not considered to be a reliable and low impedance path to be used to operate protective devices.

The following accident clearly illustrates the importance of grounding the metallic portions of buildings. The operator of a front end loader walked from the end of the crushing and screening plant to the front side and started to climb up the metal ladder on the side of the plant. The plant with the approximate location of the victim are illustrated in Figure 1.

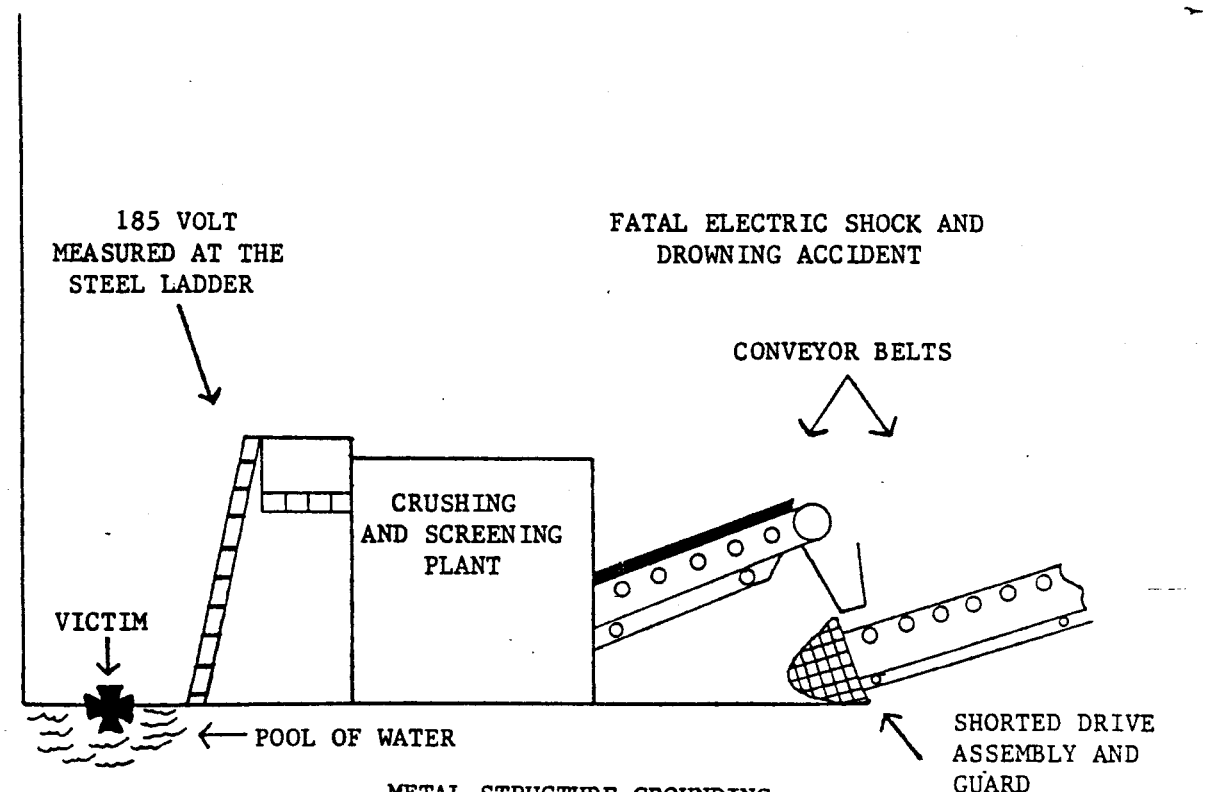

Figure 1. Metal Structure Grounding

The loader operator received an electrical shock on touching the ladder. A foreman who was near the main power switch disconnected the power from the plant. When the foreman and the plant operator went to look for the loader operator they found him submerged in a pool of water at the base of the ladder.

The investigation revealed that a 1-1/2 hp motor on a conveyor of the crushing plant was short-circuited through a piece of wire mesh which was being used as a chain drive guard. The guard, which was not rigidly fixed, had worn a hole in the insulation of the powerline. The motor was not frame grounded and the resulting short delivered approximately 180 volts to the frame of the crushing and screening plant. The voltage from the guard to ground measured 285 volts. When the guard was removed from the motor, the voltage on the ladder disappeared.

Grounding is a general term that is often used loosely to refer to safety grounding electrical system grounding and earth grounding. Operators of mines have often misinterpreted grounding to mean that anything in contact with the earth is considered to be grounded.

According to accident reports, operators have tried to use earth as their safety grounding system. When this has been done, fatalities have normally been the end result. The following accident report details the hazards of using earth as a safety grounding system.

Electric power for the crushing plant and several adjacent installations was purchased from the utility at 480 volts. It was fed from a single pole mounted transformer bank by separate conductors to the electrical control van for the crushing-screening plant, the paint shop, and to the water pump station. The transformer bank was connected ungrounded delta. All system grounding was through local ground rods and unit to unit bonding.

The loader operator at the mine was fatally injured when he contacted an energized, defective, electrical junction box on a portable jaw-crusher. The junction box to which a pressure switch and gauge were attached contained a defective electric circuit which caused the electrocution. This junction box was suspended alongside the jaw-crusher with rubber-covered portable electrical cable. It was connected to the crusher lube oil pressure system through copper tubing and a rubber hose.

The primary cause of this accident was improper installation and/or maintenance of the low pressure oil gauge switch box. Contributing to the cause of the accident were the following:

1. The lack of frame grounding for the junction box.

2. The existence of phase to ground faults elsewhere in the system.

3. The practice of grounding the equipment through local grounds or “peg grounds”.

The use of earth as the safety grounding system has often been referred to as “peg grounding”. This term comes about from the practice of grounding each individual piece of equipment on a property with a separate ground rod, driven into the earth. “Peg grounding” therefore, relies upon the earth to conduct ground fault current. The resistivity of earth varies dramatically from location to location as can be seen from test data and published data and does not come close to the resistivity of copper or steel. This system of safety grounding permits multiple faults to occur and persist on electrical equipment that is in close proximity to one another. When this condition occurs, the only other ingredient for a fatality is a person to come in contact with the equipment that has the faults. When a system is being supplied power from a grounded power system and “peg grounding” is employed,

a single ground fault is all that is necessary to initiate a potentially fatal situation. As can be seen from this discussion, "peg grounding" should be avoided at all cost.

The best method of safety grounding system is to use a conductor of the same electrical characteristics as the power conductor. This conductor should be in the same cable or conduit as the power conductor and be continuous with as few amount of connections as possible. This method provides the lowest impedance path back to the circuit interrupting devices and insures positive operation of the protective devices.

PORTABLE EQUIPMENT GROUNDING

Frame grounding of portable electric equipment is covered under mandatory standards 55, 56, 57, 12-27. This standard states that frame grounding or equivalent protection shall be provided for mobile equipment powered through trailing cables. A noncurrent carrying metallic conductor becomes an essential part of the electrical system supplying mobile equipment from a safety standpoint. This conductor is used to tie the frame of the machine to earth ground and thus prevent hazardous voltage from occurring under fault conditions. Therefore, it is important that this conductor be continuous and have a low impedance value. Due to constant flexing and pressures that a trailing cable is subjected to, the ground conductor becomes quite vulnerable to wear. Therefore, it is likely that the wire could become broken within the cable. Since this is the only connection the machine has to earth ground, periodic checking of the integrity of this conductor is important. Testing of this conductor will be described in another section of this paper.

Since trailing cables are subject to wear and are an expensive component of the electrical power system, they periodically require repairing. Repairs of trailing cables are covered under Mandatory Standard 55, 56, 57, 12-13 which states: "Permanent splices and repairs made in power cables, including the ground conductor where provided shall be: (a) Mechanically strong with electrical conductivity as near as possible to that of the original; (b) Insulated to a degree at least equal to that of the original and sealed to exclude moisture, and (c) Provided with damage protection as near as possible to that of the original, including good bonding to the outer jacket." It is important that extra care be taken when splicing the ground wire since the continuity of this wire is not vital to operate the portable piece of equipment that it serves. It is, however, vital from a safety standpoint. Connections made in the ground wire should be mechanically strong to prevent loss of continuity. The following accident clearly demonstrates the consequences of not having a continuous ground wire in a trailing cable.

The operator of a sand and gravel operation died as a result of an electric shock and/or drowning. After receiving an electric shock from the intake pipe of a floating water pump unit, the operator fell into approximately 25 feet of water. The floating water pump unit where the accident occurred had been recently installed. During the installation of the unit, it was found that the 4 - wire electric cable from the controls in the plant was not long enough. A splice was made using a 3 - wire electric power cable which did not provide a continuous ground back to the control panel. The power cable had been run through an eyebolt on the pump motor and connected to the pump motor leads. At the point where the cable ran through the eyebolt, the outer insulation of the cable had been removed and

the insulation on one of the phases of the power cable had been worn through. The phase wire was in direct contact with the eyebolt.

The pumping unit and approximate locations of the victim are shown in figure 2. The centrifugal pump was powered by a 440 volt motor through a direct drive coupling. An aluminum rowboat was used to gain access to the unit.

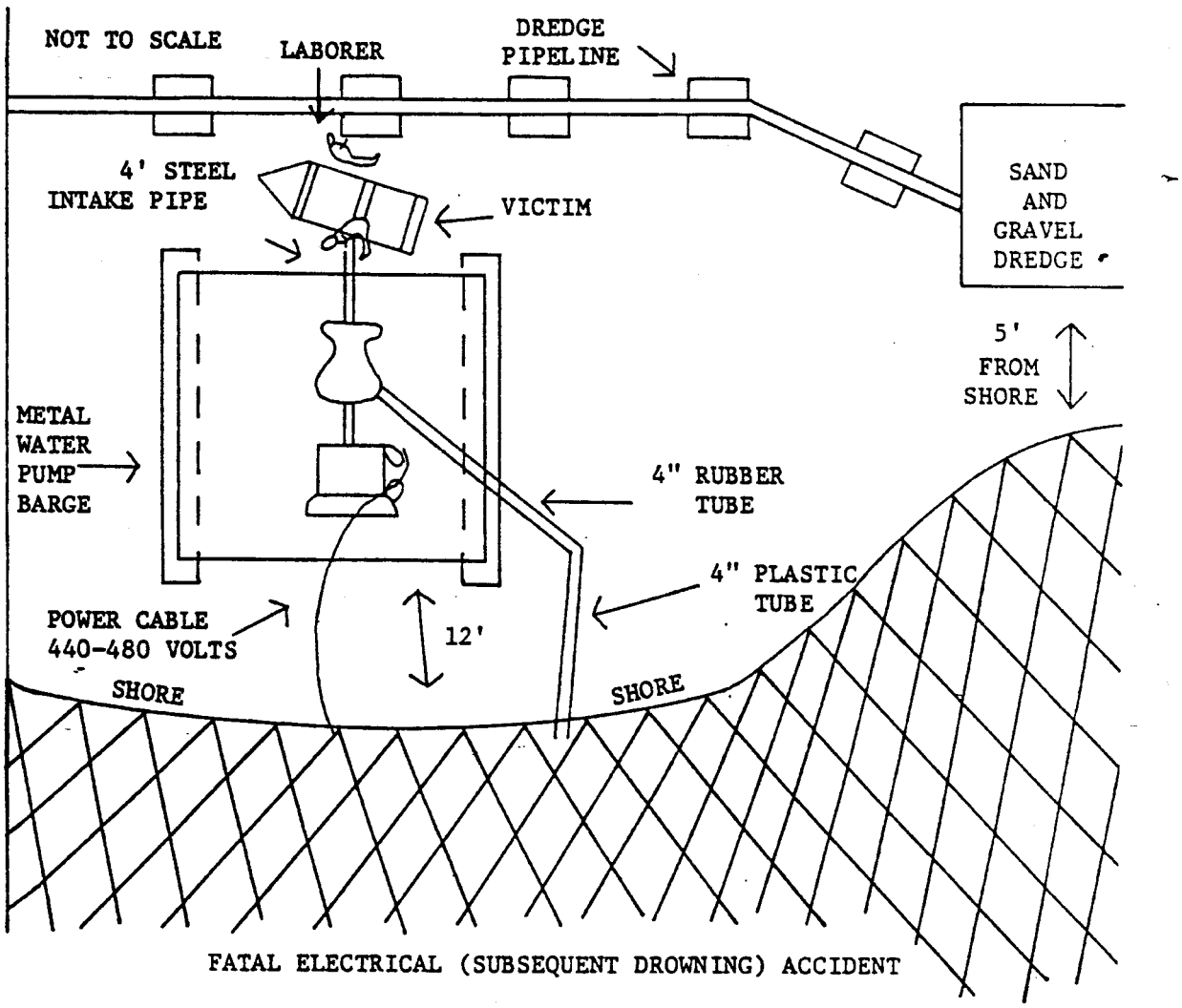

Figure 2.

Upon reaching the pump barge in the aluminum boat, the victim was in the center of the boat with the laborer in the front of the boat. When the victim put one hand on the 4-inch intake water pump, he received an electric shock. This caused the victim to fall into the water which was 25 feet deep.

The direct cause of the accident was the failure to ground the pump drive motor to the power control panel in the plant. A contributing cause was the failure to properly secure the power cable to the water pump unit: this undoubtedly caused the insulation to wear, thereby exposing the bare wire.

EARTH GROUNDING

Once a reliable system ground has been established that connects all the metallic frames of electrical equipment together, then the grounding system must be placed at some 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 have the lowest resistance value possible, preferably 5 ohms or less. There are several safety related reasons for making a low resistance connection to earth ground. The following is just a brief list.

1. Limits the potential of the electrical system to earth. Thus limiting the stresses placed on such electrical components such as switches, insulators and transformers.

2. Reduces the effects of static charges on the electrical system.

3. Protects against lightning strokes.

4. Protects against lightning induced voltages.

5. Minimizes the effects of transient overvoltages.

The most effective method to connect to earth ground is by constructing a ground bed. There are numerous methods of constructing a low resistance ground bed. The Bureau of Mines IR 8767, Guide for the Construction of Driven-Rod Ground Beds, details several methods of constructing a ground bed of 5 ohms or less in various soil conditions.

Another factor to be considered when connecting to earth ground is the separation of the substation ground from the safety ground. The substation ground is the ground to which the incoming power and transformation equipment is connected. It is also where the mine's primary protection is located. From a safety standpoint, it is advisable that the safety ground bed and the substation ground bed be separated by 25 feet or twice the largest dimension of the safety ground bed, whichever is larger. In cases where there is no substation ground bed and the utility supplies a ground or static conductor, no connection of the safety ground bed should be made to the utility ground conductor. Additionally, the lightning arrester protection incoming to the mine should be tied to the utility ground or substation ground. This in effect isolates the utility power system from the mine power system. Therefore, any faults that occur in the utilities power system will not be transmitted into the mine's power system.

If utility faults were permitted to be transmitted into the mine power system, this could eliminate the frames of mining equipment to hazardous potential limits.

TESTING OF EARTHS GROUND RESISTANCE

Through research conducted by the Bureau of Mines, the most reliable and accurate methods of measuring earth ground resistance is the fall of potential method. This method of measurement is detailed in the Bureau of Mines Publications IR 8835, Guide to Substation Grounding and Bonding for Mine Power Systems. The fall of potential method is also covered in many other publications that are readily available and is part of the instructions contained with earth resistance measurement equipment. The following is a safety test procedure which should be followed when testing safety ground systems of mines.

GROUND BED TEST PROCEDURES

1. Determine the location and full extent of the ground electrode for the electrical system to be checked.

   CAUTION--Different power systems can have a common grounding electrode.

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

   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.

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. Set up the earth resistance tester in preparation for performing the tests.

6. Disconnect the previously mentioned power conductors and all grounding conductor(s) from the grounding electrode using lineman's gloves.

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

8. Perform the necessary grounding electrode resistance tests following the 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 cannot be used.

9. Record test results.

10. Reconnect all grounding conductor(s) to grounding electrode using lineman's gloves.

11. Check the grounding electrode conductor(s) for continuity from the grounding electrode (including the connection) to the service. If the service is remote from the grounding electrode, check for continuity to a point where the grounding electrode conductor is physically protected as well as the power conductors.

12. Record continuity test results.

The importance of deenergizing the power system before conducting grounding system tests is clearly illustrated in the following nonfatal 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 3.

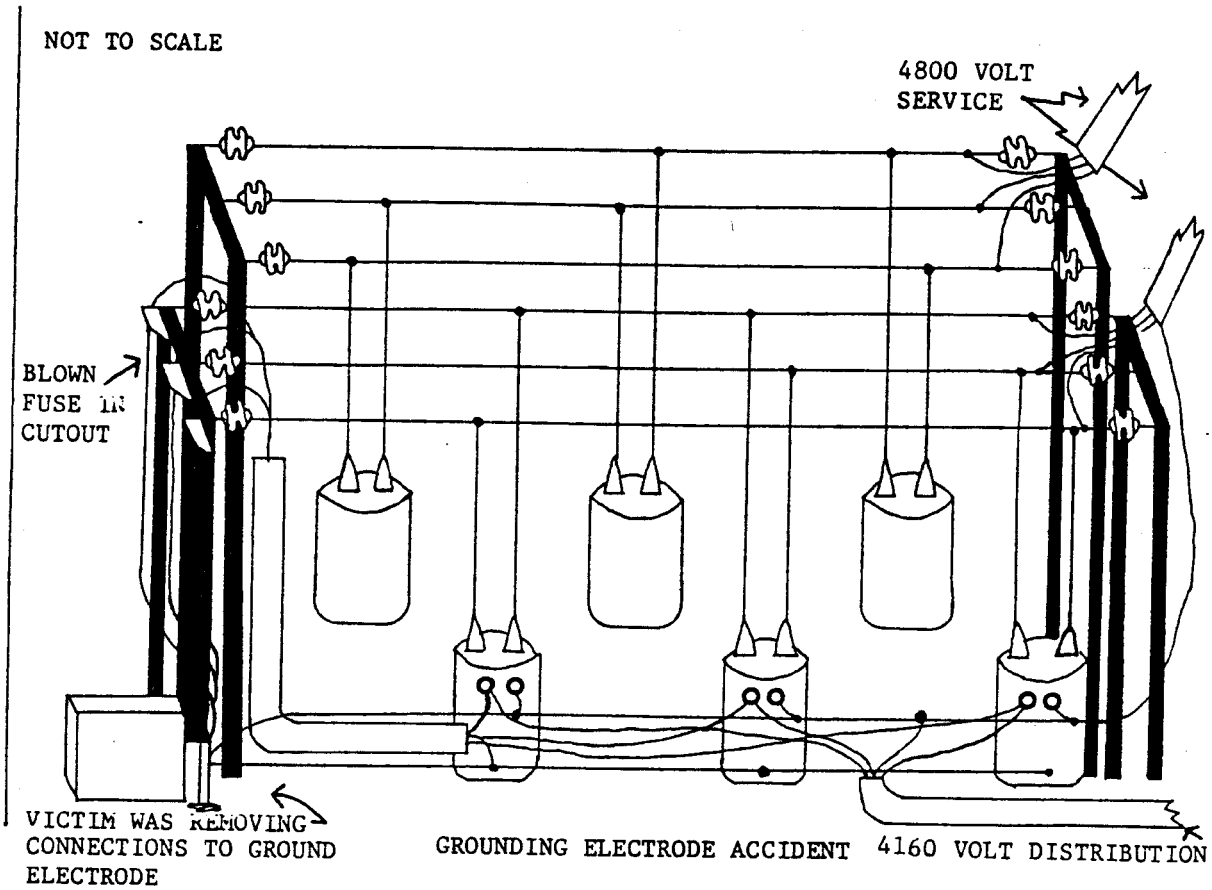

FIGURE 3.

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 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 arms and hands causing serious burns to both hands and left arm.

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.

Testing of Frame Grounding - Stationary Electrical Equipment

Improper frame grounding is the cause of many electrical accidents in metal/nonmetal mines. It is therefore important that the frame grounding system be periodically tested to determine if the grounding conductor is continuous throughout the mine power system. Ground loop impedance testing is not only required by MSHA in 55, 56 & 57.12-28, but is recommended by the National Fire Protection Association in their Publication 70B Electrical Equipment Maintenance 1977.

Ground loop impedance testing is used to determine the total alternating current resistance of the circuit that would be involved under fault conditions. Since the ground bed resistance testing was covered previously, the last two components to be tested according to 12-28 are the grounding electrode conductor and the frame grounding conductor. The grounding electrode conductor is the conductor that connects the ground bed to the service disconnect equipment serving the mine property. The continuity of this conductor must be checked annually. The frame grounding conductors are the conductors that go from the service disconnect to the frames of all electrical equipment. These conductors shall be checked once and then anytime repair or modification is made to the circuit. (Policy requires the frame grounding to be checked.)
See **http://www.msha.gov/REGS/COMPLIAN/PPM/PMVOL4D.HTM#53.**

This test can be conducted in several methods. One method employs a ground loop impedance tester. This tester places a limited fault current (approximately 20 amperes) on the circuit under test for a limited time (approximately 20 milliseconds) by measuring the voltage drop across a reference resistor the tester indicates the ohm's value of the fault loop.

Ground loop impedance tests should be used to identify circuits with high resistance. The high resistance may denote poor connections or excessive conductor lengths. Low ohm's values while a good indication do not assure that all elements of the circuit have sufficient capacity to handle large

ground faults. Good workmanship and careful visual inspection are essential in establishing the systems integrity.

TESTING PORTABLE ELECTRICAL EQUIPMENT FRAME GROUNDING

Grounding conductors in trailing cables, power cables, and cords, which supply power to portable electrical equipment require testing more frequently than the annual testing required of grounding conductors which are exposed or subjected to vibration, flexing, corrosive environments or frequent lightning hazards. The testing procedures and methods used to test this grounding conductor can be the same method used for testing stationary electrical equipment grounding conductors. However, this method of testing is time consuming when considering the frequency that the tests should be made in order to comply with the regulation. There are devices available and in use in coal mines that continuously monitor the continuity of the grounding conductor. These devices, called ground check monitors, are required by coal mine electrical regulations to continuously monitor trailing cable ground wire continuity. When a ground wire is broken, the monitor trips the circuit breaker feeding the trailing cable thus deenergizing the machine and preventing the machine frame from becoming energized. These monitors are of a fail-safe design and have been in use in mines for several years.

Although ground wire monitors are not required by the metal/nonmetal regulations, they can be used to comply with 55, 56 and 57, 12-28 requirements. They should primarily be used to monitor the trailing cable ground wire connected to portable mining machinery. Application of these monitors to portable hand held power tools is not practical due to the complexity and size of the ground wire monitoring equipment. However, the use of GFI's on portable hand held power tools would be practical and is preferred.

CONCLUSION

The proper grounding of electrical mine power systems is extremely important at mine sites. There have been many fatalities involving power systems that were not properly grounded. As one can see from this paper, a grounding system is like a mountain climbers life line. If the climber does not have the life line, he runs the risk of falling when he looses his footing. In addition, if the life line is not tested periodically, it cannot be completely relied upon. This is why the grounding system at the mine is required to be tested periodically.