Grounding of Mobile Equipment in Subarctic Surface Mines

Memorial University of Newfoundland

Prepared By: Colin Power

Date: April 19th, 2013

Summary:

Grounding is a commonly misunderstood, yet fundamental, aspect of electrical safety. The practices used for grounding in the Canadian mining industry are based on CSA M421-11 *Use of Electricity in mines* and the Canadian Electrical Code. Mobile equipment such as drills and shovels are directly feed by the system with trailing cables. Due to the dynamic subarctic terrain in the mine, grounding systems require special considerations to ensure flexibility in mobile equipment locations.

The key aspect of grounding is limiting the overall resistance of grounding installations such as electrode rods in soil to reduce the dangerous step and touch voltages induced when a fault current exists. The diameter, length, and material of the electrode have a substantial influence on the resistance of the ground and the economic cost of installation. Moreover, environmental variables such as climate, salt content, moisture, and type of soil all affect the difficulty of reaching the desired resistance.

Multiple configurations of grounding circuits exist. An electrical system can be considered ungrounded, solidly grounded, and high or low resistance grounded. Each setup has its own strengths and weaknesses, but high resistance grounds are generally more suitable for the high voltage mining environment where safety and productivity is of great importance.

TABLE OF CONTENTS **PAGE**

TABLE OF FIGURES PAGE

APPENDICES

1. Introduction:

In the Canadian mining industry, strict adherence to CSA M421-11 *Use of Electricity in mines* (M421-11) and the Canadian Electrical Code (CEC) is critical for ensuring safe sustaining operations. Provincial government safety inspectors regularly visit work sites to evaluate compliance and find deficiencies in electrical safety practices and equipment. Non-compliance issues can result in the lockout of equipment and thus reduced productivity. Power distribution equipment such as mobile substations, generators, overhead lines, and power packs each have individual grounding needs.

However, it is important to note that M421-11 is an evolving standard based upon the CEC. It serves as a series of best practices in the Canadian mining industry and is not absolute law. Older preexisting equipment in non-compliance with modern codes may be grandfathered in. Exceptions, known as variances, to the code may also be required due to lack of practicality or feasibility in the implementation of changes.

The Iron Ore Company of Canada (IOC) utilizes 46kV transmission lines to bring power into their open pit operation where it is then stepped down to 4160V. The power originates from the hydro-electrical dam in Churchill Falls and is disturbed to the mine through the Wabush Terminal Substation (WTS) at 230kV. High-voltage mobile equipment such as shovels and drills (see appendix B) are directly feed by the 4160V system with insulated and shielded trailing cables. Dewatering pumps utilize 4160V and 600V in their operation. Due to the constantly changing landscape in the mine, mobile substations are required so that equipment locations can remain flexible.

2. Basics of Grounding:

2.1 What is Grounding?

Grounding, also known as earthing, is the mechanism in which an electrical system is designed to enable fault currents to flow into the soil of the earth in order to protect the electrical system. The earth acts as a gigantic carrier for fault currents, effectively soaking them up. Grounding reduces the risk to personnel in the event of a system fault and the stray currents are led into the earth where the energy can be more safely dissipated with less risk of contact. Paul Simonds (2000) states that:

> "…poor grounding is second only to improper wiring as the leading cause of equipment malfunction. Standards for equipment performance mandate the installation and maintenance of a reliable, low-resistance earth ground." In addition, damage to mine equipment and lose of operationally is very costly to the business and reduces productivity." (p. 19)

Grounding systems come in many different forms. Conductive electrode(s) buried in the soil, large plates of conductive metals such as copper or steel, or connected grids, known as mats, are all used as grounds. Preexisting materials such as concrete rebar or underground water piping can also be used as grounds in circumstances where they are not a possible safety risk (E&S Grounding Solutions, 2010a, p.4). In buildings, grounds divert the voltages imparted by lightning strikes into the earth and therefore mitigate damage from voltage surges. Often, a bare copper wire runs throughout the building and into the basement where it connects to an appropriate ground.

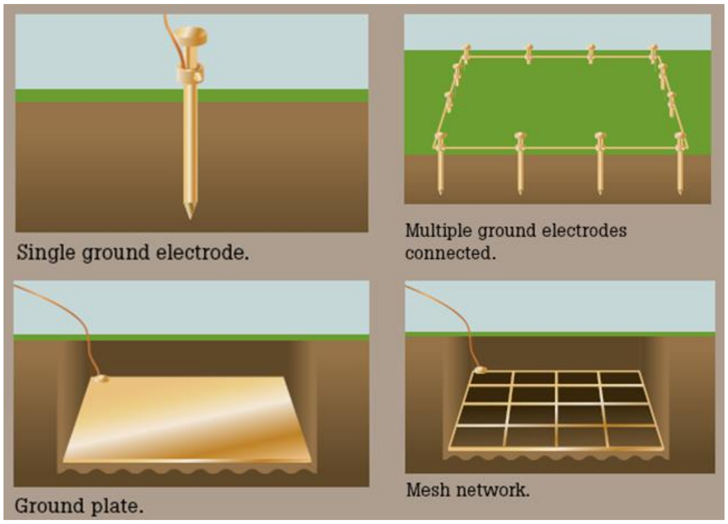

Figure 2.1.1:

There are many different ways to implement conductors for grounding purposes. Cost restraints and resistance requirements must be considered when determining the most appropriate installation. (Courtesy of Deschênes)

IOC typically drills 5/8" copper ground rods into the soil underneath the mine mobile substations. Next, IOC bonds the rods together and to the substation with #4/0 bare cooper conductor. The grounding rods are buried at least 10ft underground to ensure the company mandated resistance of 4Ω and to limit the ground potential rise (GPR) to 100V as required by M421-11 (Desjardins, 2005, p.7).

Due to the soil conditions in the mine pit, it is not economically feasible to use low resistance ground mats. To comply with the electrical codes an ordinary grid mat would have to around 400000m^2, which is prohibitively large when considering the number of mobile substations required and the terrain of the mine. Instead, IOC achieves a low grounding resistance by using diamond drills to create 100ft to 500ft holes where extremely long grounding electrodes are placed. This method bypasses the need for large surface areas in exchange for very deep holes. A mine substation may require up to 20 grounding electrodes before it has a sufficiently low resistance to meet the needs of the code. (Chen, 2004, p.1)

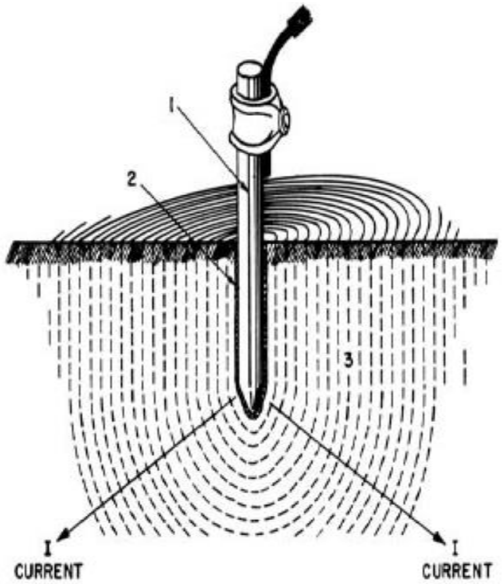

Figure 2.1.2: Current flows out from the buried electrode into the earth in all directions. The current flow can be visualized as an imaginary series of concentric spheres tapering in magnitude as the distance from the electrode increases (Megger, 2005, p.12).

2.2 Differences between Grounding and Bonding:

The IOC C2 Grounding Standard (2013) defines bonding as, "a low-impedance path that is obtained by permanently joining all non-current carrying metal parts to ensure electrical continuity and has the capacity to conduct safely any current likely to be imposed on it" (p.2). What differentiates grounding and bonding is an often misunderstood principle. An electrical system can have both grounding and bonding, neither, or just one. Bonding is simply connecting the metal conductors that do not carry current under normal circumstances together.

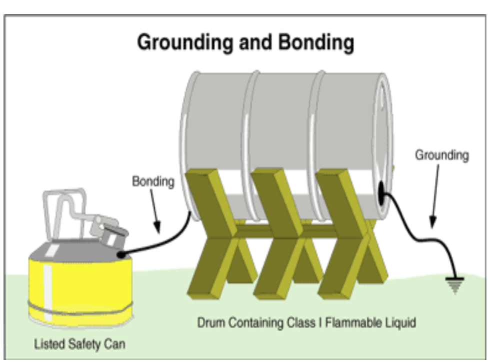

Figure 2.2.1: The drum filled with flammable liquid is bonded to the safety can and grounded to the earth. If a fault current touches the safety can it will flow through the drum and then to ground. Because the two objects are conductors and are connected as a circuit no electric potential will exist between them thus reducing the hazard of shocks or sparks igniting the drum's contents. (Figure from http://www.workplacegroup.net)

Bonding can be used to connect all these conductors so that in the case of a fault current on any part of the system, the fault current can be diverted into a connected ground. Moreover, bonding ensures equipotential voltages between the bonded elements so that voltage rises are prevented across the bonded conductors. It is also important to recognize that conductors on a system can be bonded to each other but not connected to a ground and vice versa. The optimal design for a grounded substation is to bond the grounding electrodes in a manner that evenly distributes the fault current across the earth. Doing so decreases the size of dangerous step and touch voltages that can exist during fault situations (Jinliang et al., 2005, p. 107).

3.1 Step and Touch Potentials:

In a fault current situation of a grounded system, the fault current will travel into the soil and induce a voltage gradient. Electrical potential will exist in a sphere around the ground with the voltage decreasing relative to the electrode as the sphere's radius increases. A step voltage is observed when a person or animal has their individual feet separated by adequate distance from each other and at some distance away from the active ground. The difference in potentials between the feet creates the step voltage. Section 36-002 of the CEC defines the distance for step voltage measurements as 1m. In contrast, a touch potential occurs when a person has their feet on the ground and makes contact with the electrical system using their hands. The difference between their hand and their feet causes a dangerous voltage to exist throughout their body.

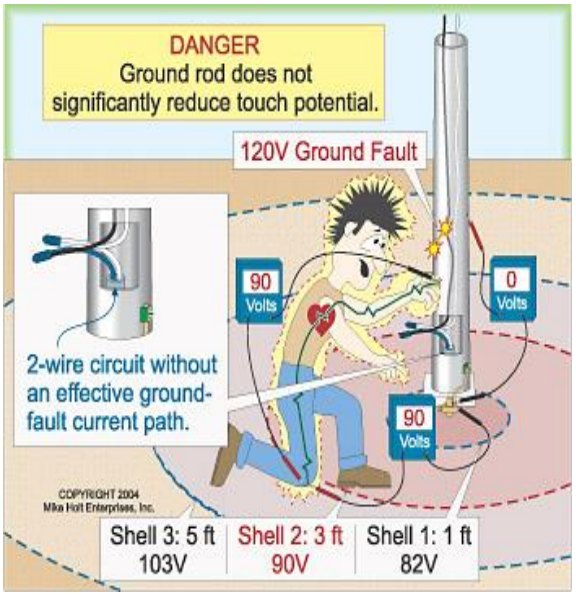

Figure 3.1.1: If the man had one leg placed on shell 3 and the other on shell 2, he would feel a potential step difference of 13V. Whereas, if he touched the ground rod with his hands while standing at shell 1 he would be subjected to a touch potential of 38V. (Figure courtesy of http://ecmweb.com/)

Interesting to note, is that a 4-legged animal such as a cow is more susceptible to step voltages than a human due to its physicality. When a potential difference is observed between the front legs and hind legs of a cow the voltage travels directly through the entire body and heart of the animal. In contrast, for humans the voltage will travel up one leg and down to the other, effectively bypassing the heart (Nelson, 2006, p.57). Thus there is a lower risk of ventricle fibrillation for bipedal animals when subjected to step voltages.

The allowable voltages of step and touch potentials are reflected by the following formulas:

$$\mathbf{V_{step} = (1000 + 6\rho_S) \times 0.157(t_S)^{-1/2}\ V}$$

$$\mathbf{V_{touch} = (1000 + 1.5\rho_S) \times 0.157(t_S)^{-1/2}\ V}$$

Where: $\boldsymbol{\rho_S}$ = surface resistivity in ohms-m and $\mathbf{t_S}$ = duration of shock current in seconds. ($\mathbf{V_{step}}$ and $\mathbf{V_{touch}}$ are for a 70-kg person. For a 50kg person, the constant 0.157 should be changed to 0.116 to account for the lighter weight person.

Observing the coefficients of $\boldsymbol{\rho_s}$, it is obvious from comparing the different values, 6 and 1.5, for $\mathbf{V_{step}}$ and $\mathbf{V_{touch}}$ respectively that a dangerous touch voltage will occur before a step potential (Nelson, 2006, p.57). In meeting the safety requirements for touch voltages, a system will consequently meet the requirements for step voltages.

Because the resistance of soil is never completely zero, and since there is always some stray current flowing into it, this means that stray voltages always exist in the earth (Nelson, 2006, p.57). The OH&S act requires that stray voltages be minimized to less than 50mA in blasting operations using electronic detonators (OHS Sec 417).

	Resistivity	Fault duration 0.5 s		Fault duration 1.0 s	
Type of ground	Ω•m	Step voltage, V	Touch voltage, V	Step voltage, V	Touch voltage, V
Wet organic soil	10	174	166	123	118
Moist soil	100	263	188	186	133
Dry soil	1 000	1 154	405	816	286
150 mm crushed stone	3 000	3 143	885	2 216	626
Bedrock	10 000	10 065	2 569	7 116	1 816

Figure 3.1.2: Different types of soil have different levels of resistance. This table shows the various tolerable step and touch voltages. The longer a person is exposed to a step or touch voltage during a fault the more likely they will be harmed. (Table courtesy of CEC)

3.2 Voltage Drops in Mine Mobile Equipment:

Trailing cable lengths affect equipment-to-equipment voltage drops and reduce the efficiency of the power distribution. Ohm's law, V=IR, is simply applied to the resistance of non-ideal conductors such as trailing cables to determine the voltage drop. As a cable gets longer the resistance increases and so does the magnitude of the voltage drops. Because the power needed by the mobile equipment must remain constant, more current will be drawn as the voltage drops become greater. This is seen by P=VI, the lower the voltage, the more current necessary to satisfy a specific power rating. This problem occurs when a vacuum cleaner with a long extension cord trips a fuse in a house.

Furthermore, before the current reaches a piece of mobile equipment such as a shovel, the internal resistance of the trailing cable may have caused the voltage to drop by as large as 10%. IOC is currently preparing to change the operating voltages of equipment from 4160V to 7200V to reduce the overall current through its equipment and increase their operational ranges.

M421-11 mandates that the GPR of any mine mobile equipment be limited to 100V as a safety precaution. This is achieved through grounding systems that limit the intensity of fault currents. Lower voltage drops would result in lower fault currents and therefore decrease the likeliness of a 100V GPR from occurring.

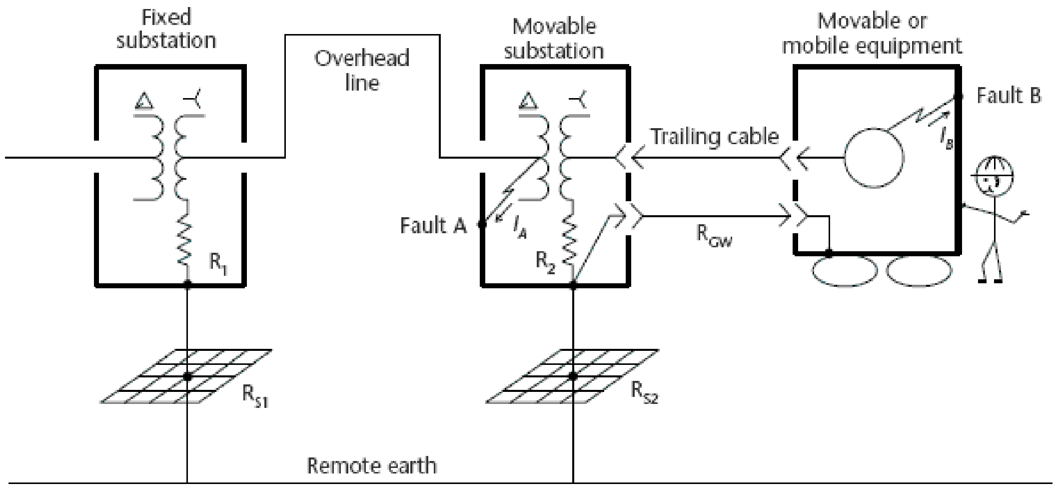

Figure 3.2.1: Ground potential rise is calculated by multiplying I_A and R_{S2} and this voltage is transferred from the movable substation via the trailing cable to the mobile equipment. This dangerous situation occurs during the Fault A situation. (Courtesy of CSA)

4. Grounding Systems:

4.1 Ungrounded Systems:

Ungrounded systems are ones in which the electrical lines are consciously not connected to any fault clearing grounds. Electrical systems made in the 1940s and 50s were typically ungrounded but this type of system has generally fallen out of favor. Despite this, ungrounded systems still have their own relative strengths and weaknesses with respect to grounded systems. In a fault situation the systems can still be operated with an ungrounded setup and the line-to-line fault current is restrained to a low value (Woodham, 2003). This comes at a cost however. During a fault, the line-to-line voltage will increase by 1.73x the nominal system voltage placing additional stress on the wiring and equipment. Failures on old motors and transformers are also often caused by destruction of the wiring insulation during a fault (Post Glover Resistors [IPC], 2006, p.4). Furthermore, the system is not well shielded against transient overvoltages and it is much harder to troubleshoot a line-to-ground (accounts for 98% of all faults) fault on an ungrounded system. Extra labour is required to find and clear the fault when an ungrounded system is used (Woodham, 2003).

4.2 Solidly Grounded Systems:

Solidly grounded systems are connected to ground without an added amount of resistance or impedance. This setup allows for some reduction in risk of transient overvoltages but in the event of extremely large fault currents it can result in equipment damage due to arcing of the fault current. Solidly grounded systems are superior in safety to ungrounded ones but are lackluster in comparison to resistance grounded ones (IPC, 2006, p.5).

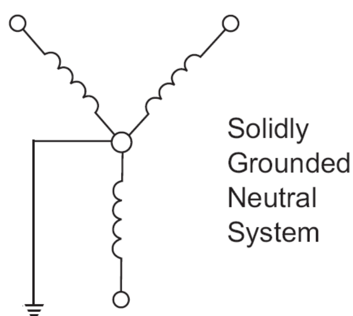

Figure 4.2.1: Circuit diagram of a solidly grounded system. Note the lack of any resistor connected to the ground. (Courtesy of IPC)

4.3 Resistance Grounded Systems:

Use a neutral grounding resistor (NGR) to alter the fault current characteristic before it reaches the grounding electrode. This limits the amount of fault current and the magnitude of transient overvoltages thus mitigating damage to equipment. The resistor can have either high or low ohmic resistance, with each setup possessing different functional attributes. Lastly, the limit of fault current is determined by using I=V/R where V represents the line-to-neutral voltage of the electrical system and R the resistance of the grounding resistor (IPC, 2006, p.5).

4.4 High Resistance Grounding:

Systems use NGRs with adequate resistance so that they limit ground fault currents to low levels. Even during a fault condition a power system can still function when using high resistance grounding. Properly installed and rated NGRs will disallow transient overvoltages and consequently protect the system from damages (IPC, 2006, p.6).

IPC resistors (2006) states that:

> “In mining applications, high resistance neutral grounding combined with sensitive ground fault relays and isolating devices can quickly detect and shut down the faulted circuit. This provides operating personnel with the added safety that's essential in this hostile environment.” (p. 6)

IOC uses Startco SE300 NGR monitors that detect excessive levels of fault current passing through the high resistance ground and then reacts by tripping the system to stop the flow of electricity. To adhere to M421-11, the monitoring relay must trip 4160V circuits during a fault situation in less than one second.

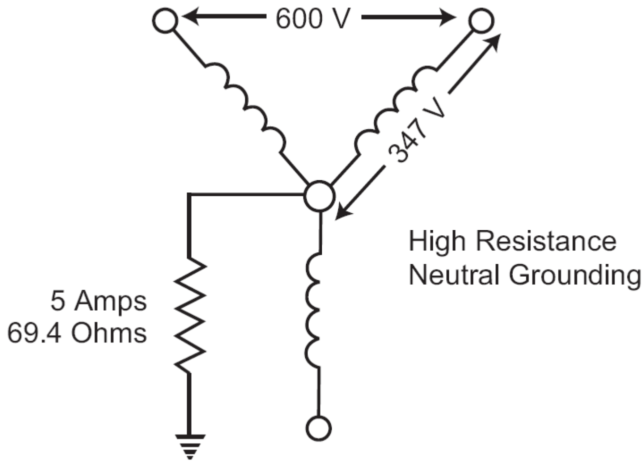

Figure 4.4.1: A high resistance ground circuit diagram. (Courtesy of IPC)

One of the biggest appeals of a high resistance ground is that old ungrounded systems can be cheaply retrofitted. Expensive equipment such as relays and breakers do not need to be installed alongside a high resistance ground (IPC, 2006, p.6). Nevertheless, relays can still be installed to improve safety and reliability.

According to IEEE (1986):

> "Ungrounded systems offer no advantage over high-resistance grounded systems in terms of continuity of service, and have the disadvantages of transient overvoltages, locating the first ground fault, and burndowns from a second ground fault. For these reasons, they are being used less frequently today than high-resistance grounded systems, and existing ungrounded systems are often converted to high-resistance grounded systems by resistance-grounding the neutral…". (p. 209)

4.5 Low Resistance Grounding:

When a low resistance NGR is used in grounding system ground fault currents are limited to a higher level than in the case of high resistance grounding. The consequence of this is that protective fault relays will have to quickly detect and clear the faults. This process occurs rapidly within a matter of seconds. A quick response time has the benefits of localizing the fault in the system, limiting the damage to equipment, and improving the safety of personnel. Also, because the fault current is limited to a short interval of time there is less chance for circuit elements to be damaged or stressed from overheating (IPC, 2006, p.6).

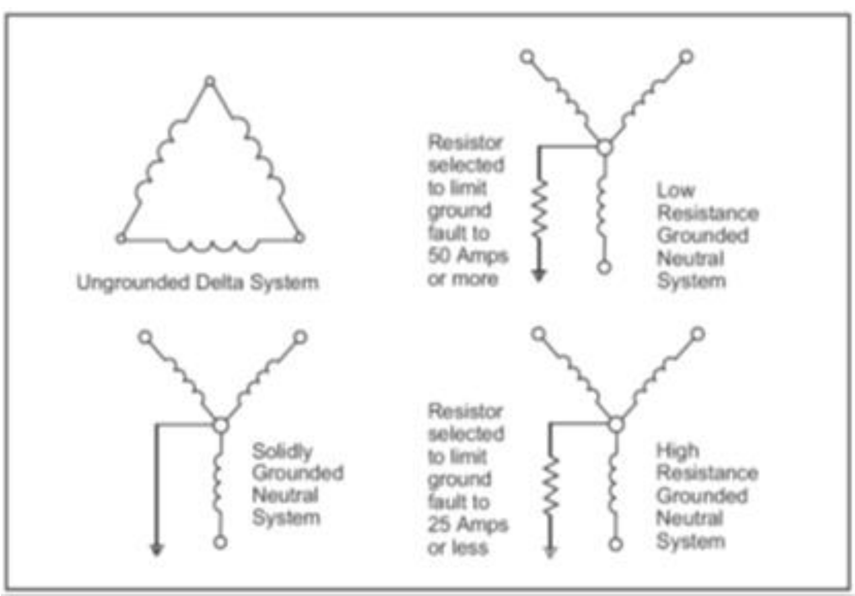

Figure 4.5.1: A quick look at the circuit diagrams for the previously described grounding systems. (Courtesy of IPC)

5. Factors Determining an Electrode's Resistance:

5.1 Moisture and Seasonal Conditions:

The effects that soil conditions have on the resistivity of the grounds are substantial. Factors such as frost, moisture, and salt content greatly influence the effectiveness and safety of the grounding. Soil normally possesses a low conductivity rating. The resistance of soil can be increased by up to 10X rating just by the presence of frost (Jinliang et al., 2005, p.107). Since conditions in soil vary throughout the year, grounds must be installed considering the worst-case weather for a location. What is adequate grounding in the summer may not be sufficient for winter. The resistance during the seasons can be observed below.

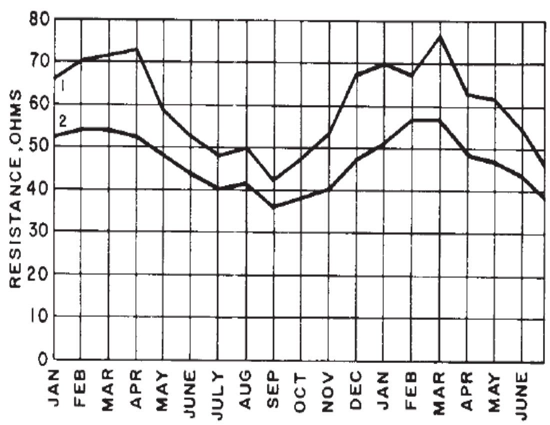

Figure 5.1.1: Seasonal soil resistance of a 3/4" electrode pipe in stony clay soil. Electrode depth is 3ft for curve 1 and 10ft for curve 2. (Megger, 2005. p.39)

The moisture content in the earth rapidly changes the conductivity of the system. Dry soil is far more resistive than when it is very moist. Since current travels through soil primarily by electrolytic properties, the presence of water is a major factor. This means that current weather, the local climate, and water table levels must all be accounted for (Megger, 2005, p.36). At IOC, special concern must be given to rain, melting snow in the winter to spring transition, and the usage of dewatering equipment. These all have the ability to alter the water levels in the soil and thus the resistivity of any grounding system in the mining pit.

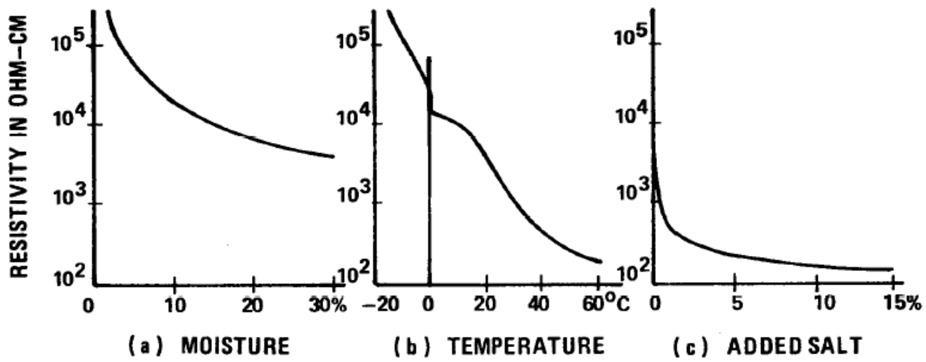

Figure 5.1.2: The effects of moisture, temperature, and salt on soil resistivity. (Courtesy of U.S. Department of Defense [DOD], 1987, p.2-9).

The ampacity and potential fault current must be considered in the design of a ground. During a fault, if the grounding conductor carries too much current it can transfer enough heat into the soil that the groundwater will boil and increase the resistance of the grounding system making the surroundings more dangerous (DOD, 1987, p.2-57).

In addition, retention of water and salts is important for a stable grounding resistance. Too much rain or flooding can wash away ground salts and increase the resistance. Plants such as legumes can be planted to prevent runoff and add salt back into the ground while nearby drainage channels should be dug away from the grounding system (DOD, 1987, p.2-60).

5.2 Chemical Treatment of the Soil:

It is possible to alter the electrolytic characteristic of soil using additive chemical treatment. According to Megger (2005), chemicals such as magnesium sulfate, copper sulfate, sodium chloride, and potassium nitrate are able to decrease resistance by altering the electrolytic interaction of soil near a grounded electrode. The more porous the soil the greater the affect chemical treatment can have because the chemical spread out more easily. The added chemical can also reduce seasonal variance by lowering the freezing point of the soil (DOD, 1986, p.2-60 –2-61).

However, chemical treatment also has several drawbacks. Many of the useable chemicals can corrode the electrode, and sulphates can damage nearby concrete. As well, chemical treatment is not permanent and it must be reapplied as the chemicals are washed away over time. Environmental regulations may also forbid the usage of certain chemicals within the soil (Megger, 2005, p.31). Because of these weaknesses, specifically the temporariness of the chemicals, IOC does not normally use chemical treatments in the mine. IOC has used coke breeze in the past as a fill around the electrode before it is fully buried. This helps to make the electrode more conductive by creating a complete conductive seal around the electrode.

5.3: Electrode-Earth Contact Resistance:

There exists a minor component of the grounding resistance caused by the physical interaction between the electrode rod and the soil. The resistance from physical contact is negligible when the soil is packed well and the electrode is left unpainted. Rust has little impact on the contact resistance because of the moisture. Nevertheless, if an entire electrode segment rusts through, it will isolate the bottom half of the rod and effectively render the deeper proportion of the rod useless (Megger, 2005. p.12).

5.4 Physical Factors Affecting Electrode Rod Resistance:

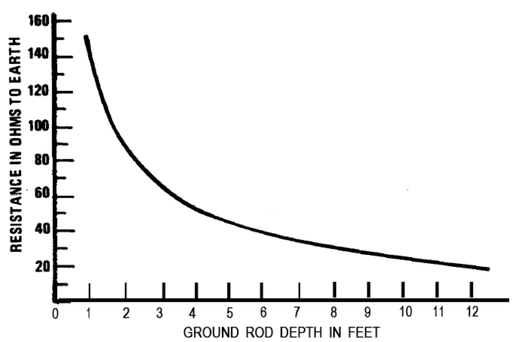

Figure 5.4.1: The effect of electrode depth on resistance. (Courtesy of DOD, 1987, p. 2-18)

Increasing the length of a grounding rod and therefore its buried depth will decrease the resistance but only to a certain extent. The rule of thumb is that doubling the rod length will decrease resistance by approximately 40% (Megger, 2005, p.27-28). This means that decreasing the resistance through length will get progressively more expensive. Getting a 40% reduction in resistance at 10ft will require 10ft more of conductor and subsequently 20ft will require 20ft more of conductor. Additionally, greater depths will require more elaborate drilling and installation procedures; going deeper will increase the likeliness of encountering hard rock that is more expensive to drill.

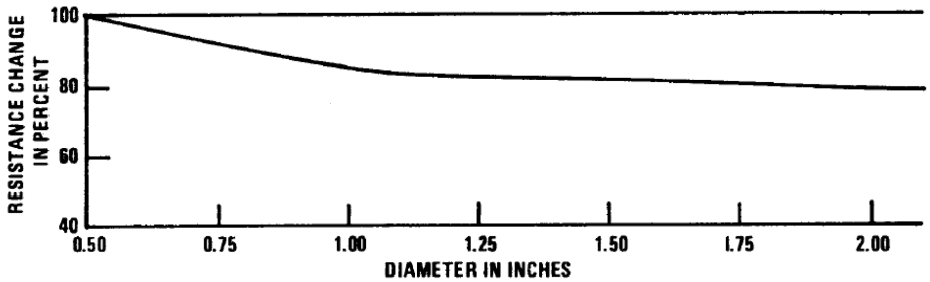

Figure 5.4.2: Effect of diameter on electrode resistance. (Courtesy of DOD, 1987, p. 2-18)

Increasing an electrode's diameter reduces resistance only by a small amount. Holding depth constant, increasing the diameter by a factor of 2 reduces resistance by about 10%. This option is only attractive when it is impractical to just drill deeper and lengthen the electrode (Megger, 2005, p.28).

Assuming the electrode is a perfect cylinder shape, the volume can be modeled by the formula: **Volume = $\pi \cdot r^2 \cdot h$**

This means that increasing the radius by a factor 2 will increase the volume by 4 times. On the other hand, doubling the height will also double the volume. Changing the radius requires much more conductive material than changing the length thus making it a generally a much more expensive method to achieve a specific grounding resistance.

References

Breton, Banville & Associates. (April 2005). *Mine Substation Grounding Prefeasibility Study.* Labrador City: Desjardins, D.

Deschênes, N. (January 31, 2013). Grounding and Bonding [.ppt]. Roche Consulting Engineers.

E&S Grounding Solutions. (2010). Grounding electrodes explained. *Grounding and Electrical Engineering Services.* Hermosa Beach, CA.

Getting Down to Earth. (2005). Dallas, TX: Megger.

IEEE recommended practice for protection and coordination of industrial and commercial power systems (1986). doi: 10.1109/IEEESTD.1986.81071

IOC-S-E-WP Grounding And Bonding. (2013). Labrador City, NL: Iron Ore Company of Canada.

Iron Ore Company of Canada. (December 2004). *Mine Grounding Pre-feasibility Report*. Labrador City, NL: Chen, A.

Jinliang He, Yanqing Gao, Rong Zeng, Weimin Sun, Jun Zou, & Zhicheng Guan. (2005). Optimal design of grounding system considering the influence of seasonal frozen soil layer. *Power Delivery, IEEE Transactions on, 20*(1), 107-115. doi: 10.1109/TPWRD.2004.835434

Military Handbook Grounding, Bonding, And Shielding For Electronic Equipments and Facilities Volume I of 2 Volumes Basic Theory. (1987). Philadelphia, PA: United States Department of Defense.

Nelson, J. P. (2006). Grounding power systems above 600 V. *Industry Applications Magazine, IEEE, 12*(1), 50-58. doi: 10.1109/MIA.2006.1578565

Neutral Grounding Resistors Technical Information. (2006). Erlanger, KY: Post Glover Resistors.

Simonds, P. (2000). Designing and testing low-resistance grounding systems. *Power Engineering Review, IEEE, 20*(10), 19-21. doi: 10.1109/39.876880

Woodham, J. (2003, May 1). The Basics of Grounding Systems. Retrieved from http://ecmweb.com/content/basics-grounding-systems

Bibliography

Bennett, R. B. (1953). Review of grounding practices on 480-volt portable distribution systems in strip mines. *American Institute of Electrical Engineers, Part II: Applications and Industry, Transactions of the, 72*(5), 300-304. doi: 10.1109/TAI.1953.6371350

E&S Grounding Solutions. (Sept 2010c). Ground potential rise explained. *Grounding Safety and Electrical Engineering Services.* Hermosa Beach, CA.

E&S Grounding Solutions. (2010b). The seven deadly sins of electrical grounding design. *Grounding Safety and Electrical Engineering Services.* Hermosa Beach, CA.

Gill, H. W. (1974). Design problems for an electric power system in an arctic region. *Industry Applications, IEEE Transactions on, IA-10*(2), 325-333. doi: 10.1109/TIA.1974.349172

Appendix A

Definitions from M421-11:

Fixed equipment - equipment that is not designed to be moved.

Hand-held equipment - equipment that has been designed to be held in the hand while operating.

Mobile electrical equipment - equipment that is designed to be energized while moving.

Movable electrical equipment - electrical equipment that does not have its own grounding network and is designed to be moved only when de-energized.

Ground potential rise (GPR) - the maximum voltage that a station-grounding grid can attain relative to a distant grounding point assumed to be at the potential of remote earth. The GPR is equal to the maximum grid current times the grid resistance.

Neutral-grounding device - an impedance device used to connect the neutral of an electrical system to ground for the purpose of controlling ground current and voltage-to-ground.

Step voltage - the potential difference between two points on the earth's surface separated by a distance of one pace, assumed to be 1 m in the direction of maximum voltage gradient.

Touch voltage - the potential difference between a grounded metal structure and a point on the earth's surface separated by a distance equal to normal maximum horizontal reach.

Prospective ground-fault current of a system - the ground-fault current that flows from a phase to a ground fault of zero impedance at rated system voltage under steady state conditions.

Definitions from CEC:

Ampacity - the current-carrying capacity of electric conductors expressed in amperes.

Bonding - a low impedance path obtained by permanently joining all non-current-carrying metal parts to ensure electrical continuity and having the capacity to conduct safely any current likely to be imposed on it.

Bonding conductor - a conductor that connects the non-current-carrying parts of electrical equipment, raceways, or enclosures to the service equipment or system grounding conductor.

Ground - a connection to earth obtained by a grounding electrode.

Ground fault - an unintentional electrical path between a part operating normally at some potential to ground, and ground.

Grounded - connected effectively with the general mass of the earth through a grounding path of sufficiently low impedance and having an ampacity sufficient at all times, under the most severe conditions liable to arise in practice, to prevent any current in the grounding conductor from causing a harmful voltage to exist

(a) between the grounding conductors and neighbouring exposed conducting surfaces that are in good
contact with the earth; or

(b) between the grounding conductors and neighbouring surfaces of the earth itself.

Grounding - a permanent and continuous conductive path to the earth with sufficient ampacity to carry any fault current liable to be imposed on it, and of a sufficiently low impedance to limit the voltage rise above ground and to facilitate the operation of the protective devices in the circuit.

Grounding conductor - the conductor used to connect the service equipment or system to the grounding electrode.

Grounding electrode - a buried metal water-piping system or metal object or device buried in, or driven into, the ground to which a grounding conductor is electrically and mechanically connected.

Appendix B

Drill

Shovel

Mobile Substation

Mobile Substation