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Mine Safety and Health Administration
Office of Technical Support
Approval and Certification Center
Electrical Safety Division

Technical Paper

On

Ground Wire Monitors

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Purpose

The purpose of this report is to introduce MSHA Inspectors to the basics of the development of ground wire monitors, descriptions of the types of ground wire monitors, and how ground wire monitors operate to insure that grounding conductors are continuous and provide low resistance paths for ground fault current.

Background

The Mine Act of 1969 required the use of ground wire monitors in underground coal mines. A problem surfaced almost immediately however, when it was discovered that the available monitors would monitor no more than the plugs and receptacles located at the power center bulkhead. Several deaths occurred before technologically capable monitors were developed and put into use in 1975.

If we look through 30CFR we will find that there are several sections which discuss ground wire monitors. Those sections are:

18.47(d)(2) Permissible AC equipment 661 thru 4160 Volts; A continuously monitored, failsafe grounding system is provided that will maintain the frame of the equipment and all accessory equipment at ground potential.

75.803 Fail safe ground check circuits on high-voltage resistance grounded systems; On and after September 30, 1970, high-voltage, resistance grounded systems shall include a fail safe ground check circuit to monitor continuously the grounding circuit to assure continuity and the fail safe ground check circuit shall cause the circuit breaker to open when either the ground or pilot check wire is broken, or other no less effective device approved by the Secretary or his authorized representative to assure such continuity, except that an extension of time, not in excess of 12 months, may be permitted by the Secretary on a mine-by-mine basis if he determines that such equipment is not available.

75.803-2; Ground check systems not employing pilot check wires, approval by the Secretary; Ground check systems not employing pilot check wires; approval by the Secretary. Ground check systems not employing pilot check wires will be approved only if it is determined that the system includes a fail safe design causing the circuit breaker to open when ground continuity is broken.

75.902 Low- and medium-voltage ground check monitor circuits; On or before September 30, 1970, low- and medium-voltage resistance grounded systems shall include a fail-safe ground check circuit to monitor continuously the grounding circuit to assure continuity which ground check circuit shall cause the circuit breaker to open when either the ground or pilot check wire is broken, or other no less effective device approved by the Secretary or his authorized representative to assure such continuity, except that an extension of time, not in excess of 12 months, may be permitted by the Secretary on a mine-by-mine basis if he determines that such equipment is not available. Cable couplers shall be constructed so that the ground check continuity conductor shall be broken first and the ground conductors shall be broken last when the coupler is being uncoupled.

75.902-2 Approved ground check systems not employing pilot check wires; Ground check systems not employing pilot check wires will be approved only if it is determined that the system includes a fail safe design causing the circuit breaker to open when ground continuity is broken.

If we also look in the Policy Manual, we will find that each of these sections have further clarification and or information concerning the use of ground wire monitors. That information is as follows:

75.803 Fail Safe Ground Check Circuits on High-Voltage; Resistance Grounded Systems Ground check circuits are required to be designed so as to ensure a safe dependable path for fault current by causing the circuit breaker to open when either of the following occurs:

1. The ground check wire is broken at any point; or
2. The grounding conductor is broken at any point.

If low-resistance parallel paths are present that prevent the ground check circuit from actuating the ground check relay when the grounding conductor is broken, the ground check circuit shall be acceptable as compliance with this Section if the ground check circuit is designed to cause the circuit breaker to open when the impedance of the grounding circuit increases beyond the amount necessary to cause a 100-volt drop external to the grounding resistor during fault conditions.

The following method may be approved by electrical inspection personnel as an alternate method for ensuring continuity of a safe, dependable path

for fault current for resistance-ground circuits extending to permanently installed, stationary equipment located on the surface:

1. Grounding circuit shall originate at the grounded side of the grounding resistor and shall extend along with the power conductors and shall serve as a grounding conductor for the frames of all equipment receiving power from the circuit.
2. Second grounding circuit shall connect the frames of the stationary equipment to a low resistance ground field located near the utilization location.
3. The resistance of the grounding resistor and the resistance of the ground field shall be maintained in such a manner that not more than 100 volts will appear between the equipment frame and earth under fault conditions in the event that the grounding conductor should be severed.

75.803-2 Ground Check Systems not Employing Pilot Check Wires; Approval by the Secretary; Wireless ground check circuits shall not be approved unless such circuits are tested and evaluated by Technical Support.

75.902 Low- and Medium-Voltage Ground Check Monitor Circuits; The following criteria shall be used for determining compliance of ground check circuits in low- and medium-voltage systems supplying power only to stationary equipment.

1. If a ground check conductor is used, the ground check circuit will trip the circuit breaker when the ground check conductor is broken.
2. The ground check circuit will trip the circuit breaker if the ground wire is broken at any point in the grounding circuit. If low resistance parallel paths for fault current and monitoring current are present, the ground check circuit will be acceptable if it is designed to trip the circuit breaker when the impedance of the grounding circuit increases beyond the amount necessary to cause a 40-volt drop in the grounding circuit external to the grounding resistor under fault conditions.
3. Current flow in the ground check circuit will cause pickup of the ground check relay.

Ground check circuits meeting the above performance criteria are considered to be a no less effective device to assure continuity of the

grounding conductor in circuits extending to properly installed stationary equipment only.

The following criteria shall be used for determining compliance of ground check circuits in low- and medium-voltage systems supplying power to self-propelled equipment:

1. If a ground check conductor is used, the ground check circuit will trip the circuit breaker when the ground check conductor is broken.
2. The ground check circuit will trip the circuit breaker if the ground wire is broken at any point in the grounding circuit. If low resistance parallel paths for fault current and monitoring current are present, the ground check circuit will be acceptable if it is designed to open the circuit breaker when the impedance of the grounding circuit increases beyond the amount necessary to cause a 40-volt drop in the grounding circuit external to the grounding resistor under fault conditions.
3. The ground check device shall be of failsafe design. "Failsafe" is interpreted to mean that the failure of any component, other than relay contacts, shall not prevent the ground check circuit from opening the circuit breaker when the conditions described in criteria 1 and 2 occur, unless the ground check circuit is designed to open the circuit breaker when such failure occurs.

Ground check circuits that have been accepted by Technical Support are assigned an MSHA acceptance number. Ground check devices that do not bear an MSHA acceptance number will be temporarily accepted if the first two criteria are satisfied. MSHA will obtain a similar device and will evaluate it for "failsafe" design.

When an arc suppression device is installed in a power center, the ground check circuit should be connected on the machine side of the device. Monitoring through an arc suppression device preloads the device and reduces its effectiveness in suppressing intermachine arcing and may also cause false tripping of the ground check circuit.

Any device inserted in a grounding conductor (including an arc suppression device and a parallel-path suppression device) shall have a short-circuit capacity that is not less than that of the grounding conductor in which it is installed. MSHA Technical Support tests such devices to determine their short-circuit capacity.

When an arc suppression or parallel path suppression device for a circuit is installed in a power center or distribution box and the receptacle for the circuit is not insulated from the metal frame of the power center or the distribution box, the circuit grounding conductor must be insulated through the receptacle and the associated plug. This is necessary to prevent shorting out the arc suppression or parallel path suppression device.

Nevertheless, the metal casings of both the plug and receptacle must be grounded. Normally, the receptacle is grounded by bolting it directly to the metal frame of the power center or distribution box. However, the plug must be grounded to the metal frame of the power center of the distribution box by an external grounding shunt or separate internal grounding conductor in the receptacle and plug. The grounding shunt or grounding conductor shall be sized in accordance with Section 75.701-4. In some cases, receptacles are insulated from the metal frames of power centers to prevent shorting out arc suppression or parallel path suppression devices. In such cases, both the receptacles and the associated plugs shall be grounded to the grounding conductors in the cables. In all cases, the metal casings of both halves of in-line cable couplers shall be grounded to the grounding conductors in the cables.

When wireless ground check circuits are used, an interlock circuit shall be provided for all cable couplers (including in-line cable couplers) to ensure that the power circuit will be deenergized before the power conductors are broken when the coupler is uncoupled. Typically, the pilot pins are connected together in the cable couplers to provide an interlock to trip the circuit breaker.

The wiring methods used on power center receptacles and cable couplers shall not result in the ground check circuits becoming ineffective. The pilot pins of the cable couplers shall not be connected together when one of the two pilot pins is connected to the system ground.

The following may be approved by the District Manager as a no less effective method for ensuring the continuity of grounding circuits of permanently installed stationary equipment.

1. A second grounding conductor sized in accordance with 30 CFR 75.701-4 and visible for its entire length when practicable shall extend from the power source at the grounded side of the grounding resistor to the frame of the stationary equipment.

2. The cable supplying power to the stationary equipment is shielded or steel armored and the shielding or armor is grounded at both ends.

Resistance grounded circuits extending to stationary low- or medium-voltage three-phase equipment located on the surface are not required to be equipped with ground check circuits.

75.902-2 Approved Ground Check Systems Not Employing Pilot Check Wire; This Section requires MSHA approval of all wireless ground check circuits; therefore, only wireless ground check devices bearing an MSHA acceptance number will be acceptable.

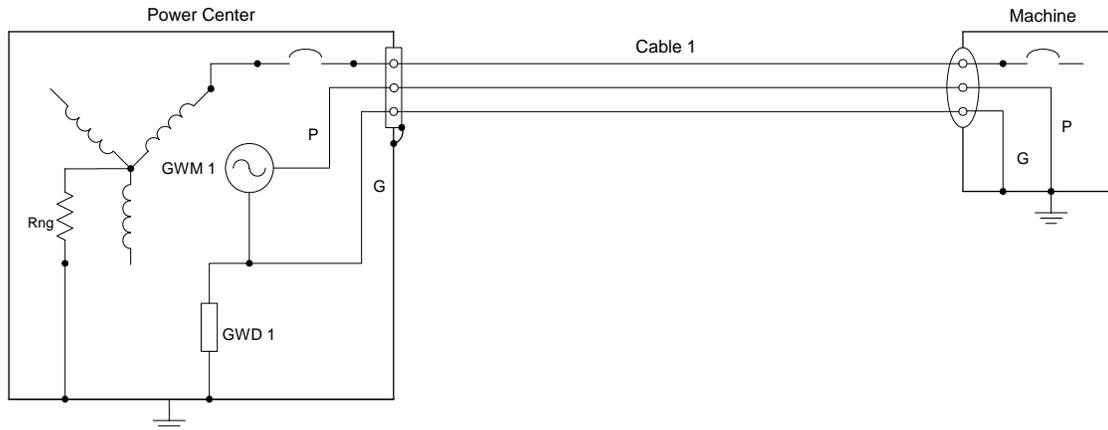
One additional section, 75.524 on inter-machine arcing, must also be considered when installing ground wire monitors. Inter-machine arcing can be created by the signal of the monitor or it might be enhanced because of components which are connected into the ground wire as a part of the monitor circuit. For this reason only components that are approved for use with a monitor should be connected into the monitor circuit.

Discussion

There are about 5 pages of information reflected in the background about regulations and policies for ground wire monitors. Sections 18.47(d)(2), 75.803, 75.803-2, 75.902, and 75.902-2 all call for a continuity type ground wire monitor. Sections 18.50(b), 75.803-1, and 75.902-1 were used to define “or other no less effective device approved by the Secretary” for meeting the regulatory requirements. As a result, two (2) types of ground wire monitors were developed and are employed to monitor the grounding conductor. Those types are continuity and impedance.

A continuity monitor operates to detect the continuity of the grounding conductor regardless of the presence of any other low resistance signal path. The impedance monitor is more a resistance monitor and operates to detect an increase in resistance of the pilot-ground wire system. That increase in resistance must not produce a voltage which exceeds 40 volts on the frame of the equipment being monitored when a ground fault occurs on the system.

The following figure can be used to represent both types of ground wire monitors for which MSHA has issued acceptances.



**GWM Installation
Figure No. 1**

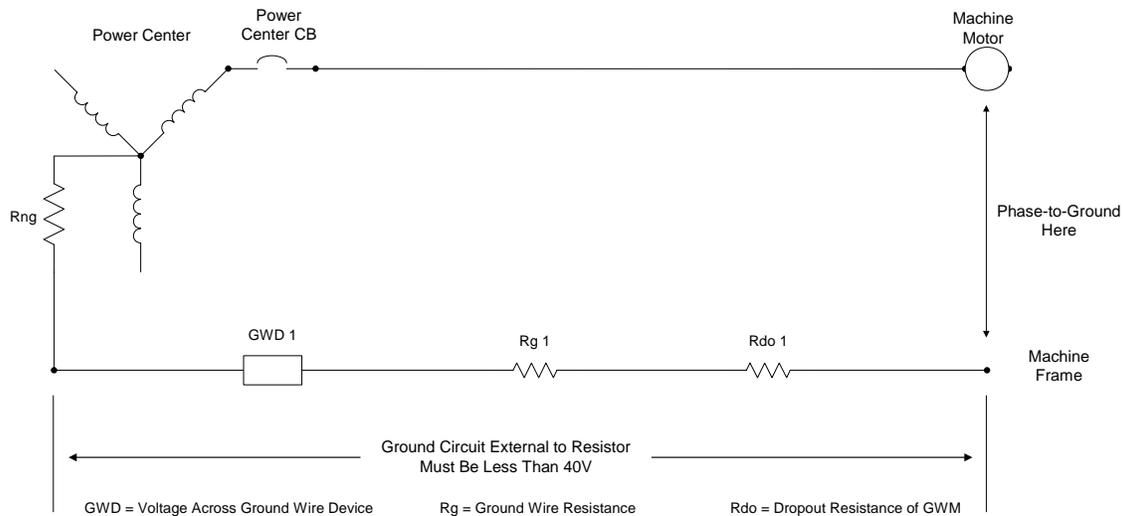
Note the location and number of items present. There is a power center where the section transformer, neutral grounding resistor, circuit breakers, ground wire monitor, and any ground wire devices are located. Next there is the machine which functions in the mining of the coal or ore. Between the two is a trailing cable. Both impedance and continuity were originally designed to operate with this type of equipment arrangement. They were not intended to have any components installed in the trailing cable between the power center and the machine. If not correctly treated, components installed between the power center and the machine can defeat the purpose of the monitor.

Impedance Ground Wire Monitors

The first type of monitor for discussion is the impedance or resistance monitor. To date all MSHA accepted impedance ground wire monitors must be installed on circuit which use ground check (pilot wire) conductors. As discussed earlier, the impedance monitor was accepted by the Secretary as a "no less effective device" in 1975. The interpretation was accepted because when properly installed and maintained, the monitor would eliminate frame voltage potentials which exceed 40 volts. Forty-volts had been established as an acceptable exposure value which would not cause electrocution. The impedance monitor uses basic impedance matching techniques to measure the resistance of the pilot-ground wire circuit. When this resistance, called dropout resistance, reaches a pre-determined value, the monitor relay de-energizes. The relay contacts, which are connected into a circuit breaker release, then trip the circuit breaker and power is removed from the circuit. An important consideration for application of the impedance monitor is the pre-determined value of dropout resistance required for tripping. These values are almost always based on the system maximum ground fault current. If the impedance monitor is not correctly

applied to the system based on the pre-determined value of dropout resistance, a hazardous voltage potential could be created during ground fault conditions.

To demonstrate this, the circuit in Figure No. 1 is analyzed with respect to a phase-to-ground fault on-board the machine. The circuit in Figure No. 2 is produced. From this circuit the amount of frame potential produced as a result of a ground fault on-board the machine can be calculated.



**Ground Fault Scenario
Figure No. 2**

Calculations:

Descriptively the frame voltage that a miner can potentially be exposed to is the voltage measured between the frame of the power center and the frame of the machine. This is technically the sum of the voltage drops across the grounding conductor (R_{g1}), the dropout resistance of ground wire monitor (R_{do1}), plus the saturation voltage of any ground wire devices (V_{sat1}) installed.

Writing an equation for the circuit yields

$$V_{frame} = V_{\phi - n} \left(\frac{R_{g1} + R_{do1}}{R_{ng} + R_{g1} + R_{do1}} \right) + V_{sat1}, \quad \text{Volts.}$$

The typical resistance, R_{g1} , of a grounding conductor can be estimated at approximately 0.5 ohms.

The dropout resistance, R_{do1} , of an impedance ground wire monitor designed for a 10 ampere grounding system is 4 ohms.

The resistance of a neutral grounding resistor, R_{ngr} , on a 480 volt, 10 ampere grounded system is 28 ohms.

The saturation voltage, V_{sat1} , of a National Mine Service Company (Femco) GM1004 ground wire device at 10 ampere is 10 volts.

Substituting these values into our equation, we have

$$V_{frame} = 277((0.5 + 4 \div (28 + 0.5 + 4)) + 10 \text{ volts})$$

$$V_{frame} = 48 \text{ volts.}$$

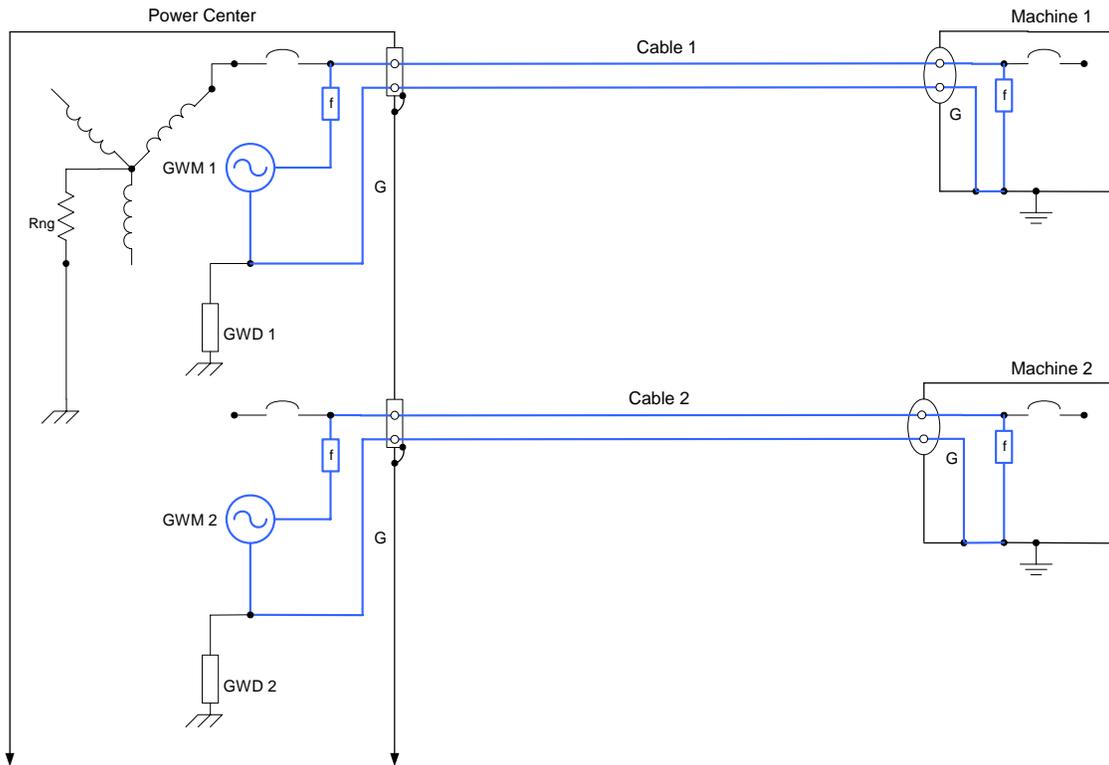
Since this number exceeds the established 40 volts limit (also see 30CFR 18.50(b)), this circuit does not meet the requirements of the ground wire monitor program; a violation of 30CFR 75.902 because it is low voltage. Modifications to the circuit are required so that the frame voltage does not exceed 40 volts. In this particular case one problem is the high saturation voltage, 10 volts, of the ground wire device. A device with a smaller saturation voltage will correct the situation.

Continuity Ground Wire Monitors

Next we will discuss the continuity type ground wire monitor. A continuity monitor may be installed with or without a pilot wire. When installed without a pilot wire, the circuit is completed through connections to the phase conductors through phase coupler filters. The strictest interpretation of the regulation requires a continuity type ground wire monitor. The major difference between a continuity monitor and an impedance monitor is that the continuity monitor will detect an open grounding conductor regardless of the presence of a low resistance parallel path. Figure No 3 which follows will be used to describe how this is accomplished.

Note the circuit portion that is highlighted in blue. This portion of the circuit is the intended path for the monitor signal. Note also that each monitor utilizes a ground wire device connected into the grounding conductor. This device is a required part of this particular monitor and each monitor of this acceptance number is required to have it installed as shown. All continuity monitors use some device which must be either connected into the grounding conductor or encircle the grounding conductor to ensure that the major portion of the monitor signal stays on the intended path. When a ground wire device is used, the impedance of that particular part of the path (called parallel path) is increased by the resistance of the device. That resistance is based on the frequency of the monitor signal and is generally very large compared to the resistance of the

grounding conductor. When the monitor signal is returned to the monitor only through that resistance, it is attenuated by such an amount that the monitor interprets the signal path as being an open circuit and trips the circuit breaker. The continuity monitor makes the same interpretation even if the signal is returned on other equipment's grounding conductors.



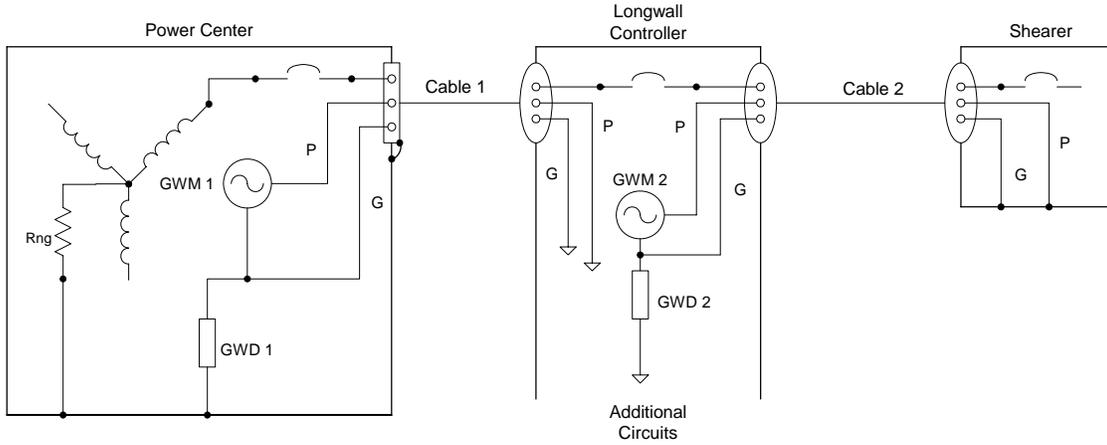
Continuity Ground Wire Monitors
Figure No. 3

There are no calculations to conduct for continuity monitors that are installed according to the accepted installation instructions. There are calculations which apply to Monitor and Power System (MAPS) installations.

MAPS Ground Wire Monitors

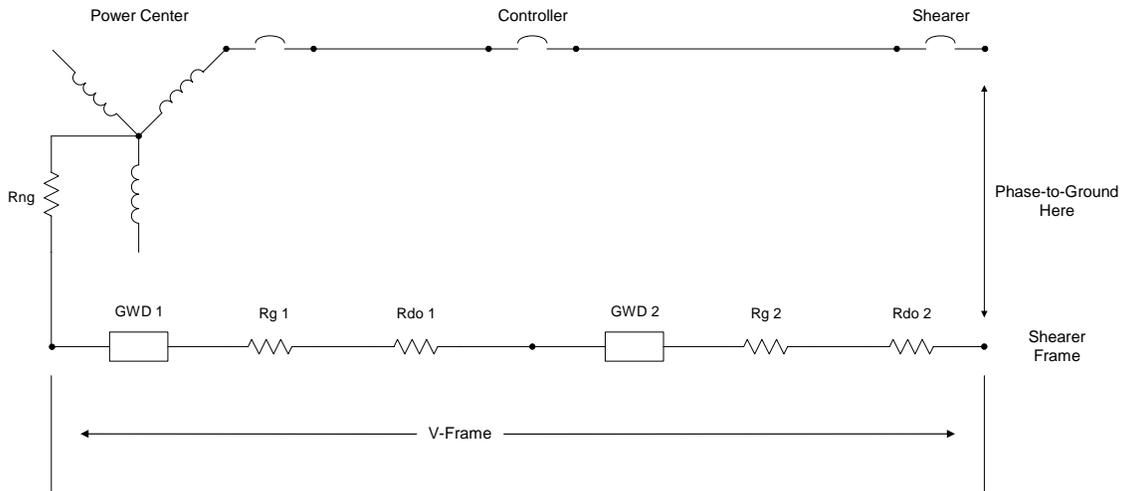
MAPS ground wire monitors are monitors which have been previously accepted by MSHA, but are installed in a manner which was not expected in the original application process. While this can apply to low voltage monitors use on high voltage circuits, extended distribution circuits, etc., it mostly applies to continuity monitors that have been installed to operate like impedance monitors. One of the major benefits of a continuity monitor operating like an impedance monitor is that the continuity monitor maintains its most beneficial attribute. That of recognized that the grounding conductor is open even in the presence of a low resistance parallel return path.

The continuity monitor operates like an impedance monitor by the use of high resistance neutral grounding resistors, sensitive ground fault detection systems, etc. The most common use is on longwall mining systems because those items can be controlled on longwall installations. One installation is shown in Figure No. 4.



Longwall/Shearer Circuit
Figure No. 4

When the circuit in Figure No. 4 is analyzed with respect to a phase-to-ground fault on-board the shearer, the circuit in Figure No. 5 is produced.



Longwall Shearer Circuit Frame Voltage Schematic
Figure No. 5

Descriptively the frame voltage that a miner can potentially be exposed is the sum of the voltage drops across the resistance of grounding conductor No. 1 (R_{g1}), the dropout resistance of ground wire monitor No. 1 (R_{do1}), the resistance

of grounding conductor No. 2 (R_{g2}), and the dropout resistance of ground wire monitor No. 2 (R_{do2}), plus the saturation voltage of ground wire devices No. 1 (V_{sat1}) and No. 2 (V_{sat2}).

Calculations:

Writing an equation for the circuit yields

$$V_{\text{frame}} = V_{\phi - n} ((R_{g1} + R_{do1} + R_{g2} + R_{do2}) \div (R_{ngr} + R_{g1} + R_{do1} + R_{g2} + R_{do2})) + V_{\text{sat1}} + V_{\text{sat2}}$$

The typical resistance of a grounding conductor in a longwall power cable is approximately 0.5 ohms. The dropout resistance of a continuity ground wire monitor is 50 ohms. The resistance of a neutral grounding resistor on a 4160 volt, 2 ampere grounded system is 4800 ohms. The saturation voltage of a National Mine Service Company (Femco) GM1004 ground wire device at 2 ampere is 0.3 volts. So

$$R_{g1} = R_{g2} = 0.5 \Omega,$$

$$R_{do1} = R_{do2} = 50 \Omega, \text{ and}$$

$$V_{\text{sat1}} = V_{\text{sat2}} = 0.3 \text{ volts.}$$

If we substitute these values into our equation, we have

$$V_{\text{frame}} = 2400((0.5 + 50 + 0.5 + 50) \div (4800 + 0.5 + 50 + 0.5 + 50)) + 0.3 + 0.3 \text{ volts}$$

$$V_{\text{frame}} = 50 \text{ volts.}$$

Since this value exceeds the established 40 volt limit, see 30CFR 18.50(b), this circuit does not meet the requirements of the MAPS program. Modifications to the circuit are required so that the frame voltage does not exceed 40 volts.

The open circuit voltage of welding machines, which is approximately 80 volts, is known to have caused electrocutions. It is not known for certain that 50 volts will not cause an electrocution under the right circumstances. There are readily available measures for limiting the potential frame voltage to less than 40 volts. It is therefore very important that ground wire monitors be carefully inspected and shown to be safely installed according to accepted installation instructions on file at MSHA.

Recommendations

Mining personnel can be exposed to potentially harmful frame voltages when ground wire monitors are not properly applied and installed according the accepted installation instructions on file at MSHA. It is therefore recommended

that ground wire monitor installations be closely scrutinized during inspections to insure they are properly applied and installed.