

ACCEPTANCE OF INNOVATIVE GROUND WIRE MONITOR INSTALLATION SCHEMES FOR MINING OPERATIONS

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ABSTRACT

The expanded use of longwall mining systems has led, in particular, to different installation arrangements and combinations of ground wire monitors and ground wire devices for the purpose of monitoring the grounding circuit. These installation arrangements and combinations of ground wire monitors and ground wire devices were not evaluated at the time MSHA originally tested and accepted the ground wire monitor. Although these installation schemes differ from the accepted scheme, they can provide equivalent protection when their operation is coordinated with other electrical power system components. For this reason MSHA's Approval and Certification Center developed an application procedure to evaluate these installation arrangements. To differentiate the procedure from the standard ground wire monitor or ground wire device application procedure, MSHA has identified this application procedure as the Monitor and Power System (MAPS) Program. This program includes tests and analyses to evaluate and assess various arrangements and combinations of proposed ground wire monitor and ground wire device installations.

INTRODUCTION

To determine compliance with the mandatory safety standards on ground check circuits which became effective for underground coal mines and surface coal mines in the early 1970's, ground wire monitor (GWM) designs were evaluated and tested by MSHA at in-mine locations. The Electrical Testing Laboratory at Beckley, WV., later began to evaluate and test ground wire monitors in the laboratory.

The acceptance tests and criteria developed for these monitors were based upon the early field evaluations and operation in a fail-safe mode, and were patterned after continuous mining systems. The continuous mining systems were comprised of individual mining machines such as roof bolters, shuttle cars and continuous miners, which received power through trailing cables. The trailing cable was a continuous cable which did not include in-line cable couplers

or connection boxes. Thus, the acceptance tests contained no provisions for grounded metallic in-line cable coupler(s) or connection box(es) such as those used in today's longwall mining Systems.

The expansion of longwall mining has fostered arrangements and combinations of ground wire monitors and ground wire devices that differ from the conventional arrangements used to test and evaluate monitoring systems. Consequently, a framework for evaluating unique or unconventional arrangements and combinations has been developed by MSHA.

SAFETY STANDARDS

Requirements concerning resistance grounding of high voltage three phase circuits extending underground are located in Title 30 Code of Federal Regulations (30 CFR) 75.802. Requirements regarding resistance grounding of low/medium voltage three phase circuits used in underground coal mines are located in 30 CFR 75.901. As specified in 30 CFR 75.701, "Metallic frames, casings, and other enclosures of electric equipment that can become "alive" through failure of insulation or by contact with energized parts shall be grounded by methods approved by an authorized representative of the Secretary". The machine frames are grounded by a grounding conductor that extends from the machine frame through cables to the power center and is connected to the grounded side of the grounding resistor. One purpose of grounding is to provide a low resistance path for fault current and thereby prevent dangerous electrical potentials on the metallic frames of equipment in the event of a phase-to-ground fault. A means of detecting a severed or disconnected ground wire, or other no less effective means of assuring ground circuit continuity is required. When the ground wire in the cable is severed and a parallel path of high resistance is present, the occurrence of a ground fault could elevate the voltage on the equipment frame. Therefore, it is essential that the ground monitoring circuit detect this condition and reenergize the equipment

Safety standards requiring ground wire monitors are specified in 30 CFR Part 18, section 47(d)(2), Part 75, Sections 803, and 902, and Part 77, Sections 803 and 902, for underground and surface coal mines, respectively. The standards require resistance grounded systems to include a fail-safe ground check circuit, or other no less effective device to monitor continuously the grounding circuit and to assure such continuity. The ground check shall cause the circuit breaker to open when either the ground or pilot check wire is broken. These regulations apply to both high voltage and low-medium voltage 'AC systems.

GROUND WIRE MONITORING IN UNCONVENTIONAL INSTALLATIONS

All equipment used in coal mines that receives power from a resistance grounded AC system is required to have a failsafe ground monitor circuit (ground wire monitor) to assure the integrity of the grounding circuit. All MSHA accepted ground wire monitors function in a manner consistent with the original acceptance tests and criteria when installed as accepted. The conventional monitor installations are limited in use to installations where the monitored ground wires are only connected at two locations (the GWM location and the equipment frame). In addition the only ground wire devices (GWD-a device connected in series with the grounding conductor to suppress intermachine arcing or isolate parallel paths) permitted to be used are those that have been tested and accepted with the specific monitor. In such situations, a severed ground wire or discontinuous grounding

circuit is readily detected and power is removed from the affected circuit. Longwall mining systems consisting of multiple cables with grounded in-line cable couplers or connection boxes attached to separate or interconnected equipment frames, create ground wire monitoring problems. The presence of one or more grounded metallic couplers or connection boxes lying on the mine floor or longwall structure (not insulated from earth or frames of equipment) introduces additional conductive parallel paths into the grounding circuit. A parallel path of low resistance between the equipment frame and a grounded metallic coupler may shunt the monitoring signal around a severed ground wire preventing all types of ground wire monitors from detecting the open ground wire. If a ground fault occurs at this instance, the current flowing through the parallel path would elevate the equipment frame potential to a magnitude based upon the resistance of the parallel path (see Figure 1).

Longwall installations use either impedance or continuity type ground wire monitors to monitor grounding circuits. The use of multiple ground wire monitors to monitor the grounding circuit to numerous motors and other electric equipment presents varied problems. Continuity-type monitors are designed to exclusively monitor the ground wire, but may monitor the resistance of the parallel path through the earth or longwall structure when a grounded cable coupler or connection box is part of the circuit. Impedance-type monitors are designed to monitor the grounding circuit resistance, but can interfere with one another and may not monitor the resistance of the grounding circuit.

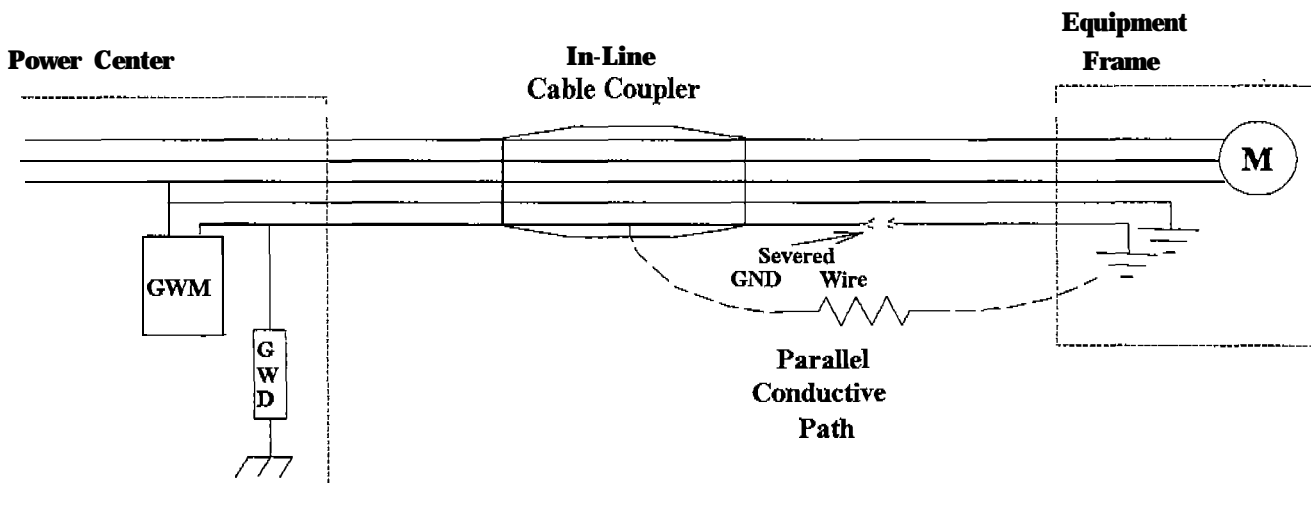


Figure 1. Low resistance parallel path shunting a severed ground wire between equipment frame and grounded metallic cable coupler.

**GROUND WIRE MONITORS
AND GROUND WIRE DEVICE COMBINATIONS**

A number of ground wire monitors (GWMs) and ground wire devices (GWDs) have been accepted by MSHA. Some GWMs are accepted for use with specific GWDs. Not all combinations of accepted monitors and devices will perform ground circuit monitoring consistent with the original acceptance test and criteria, when used in installations different from the accepted combination

The inherent characteristics of some GWM/GWD installations and the electrical system may produce undesirable conditions during phase-to-ground faults. These conditions are described as follows:

1. A ground fault may remain undetected by the system's grounded phase protection device, because the ground fault current is limited by the circuit resistance to levels below the current sensitivity setting of the ground fault relay. (See Figure 2 and Table 1).

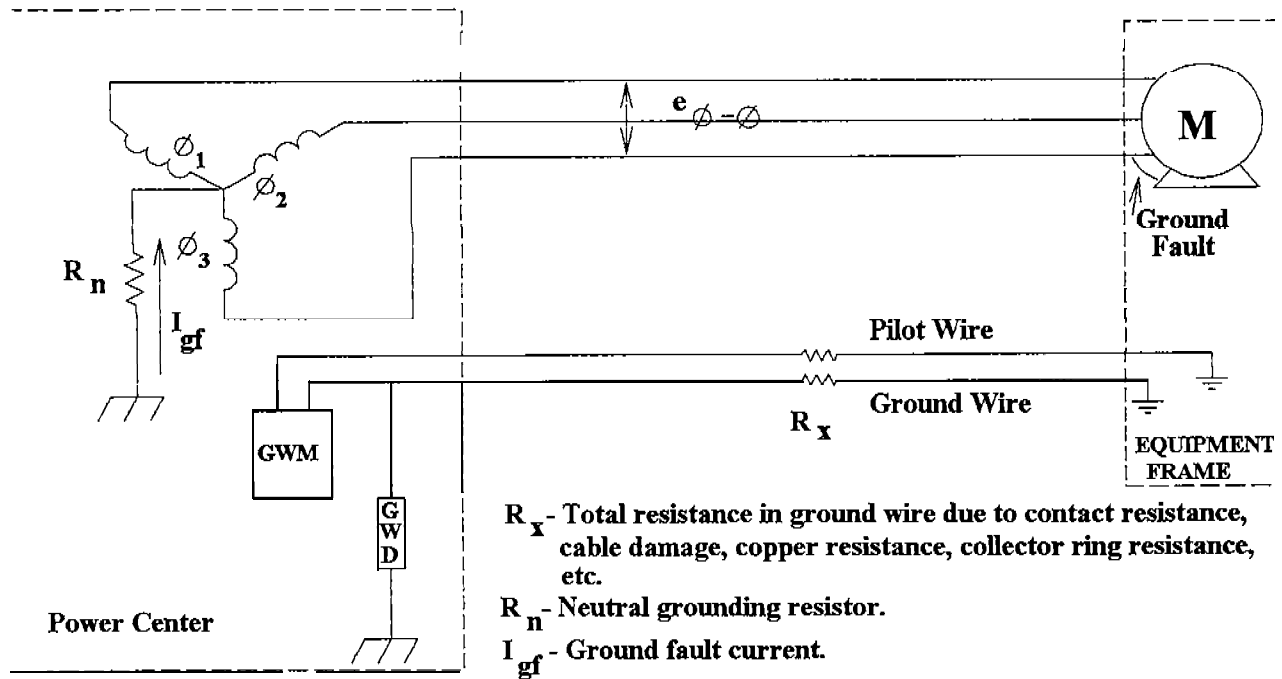


Figure 2. Typical electrical system depicting grounding circuit resistance and ground fault current during a ground fault condition.

TABLE 1

**ACTUAL GROUND FAULT CURRENT FOR VARIOUS ELECTRICAL SYSTEMS
WHEN THE GROUNDING CIRCUIT RESISTANCE EQUALS 50 OHMS
(THE MAXIMUM ALLOWABLE GROUND WIRE MONITOR DROPOUT RESISTANCE)**

$e \phi - \phi$	I_{gf} Available	R_n	R_x	I_{gf} Actual
480	25	11.1	50	4.5
	15	18.5	50	4.1
	5	55.6	50	2.6
600	25	13.8	50	5.4
	15	23.1	50	4.7
	5	69.2	50	2.9
1000	25	23.1	50	7.9
	15	38.5	50	6.5
	5	115.4	50	3.5

2. The resistance of the grounding circuit and ground wire devices in series may produce unacceptable equipment frame potentials during ground fault conditions. (See Figure 3 and Table 2)

3. The grounding circuit may not be effectively monitored when certain GWM/GWD installation configurations are used. (See Figure 4)

These conditions are dependent on the operating characteristics of the GWM/GMD installation and the electrical power system components. Coordination of the electrical system components with the operating characteristics of the ground wire monitors and devices is the focus of MSHA'S new acceptance program.

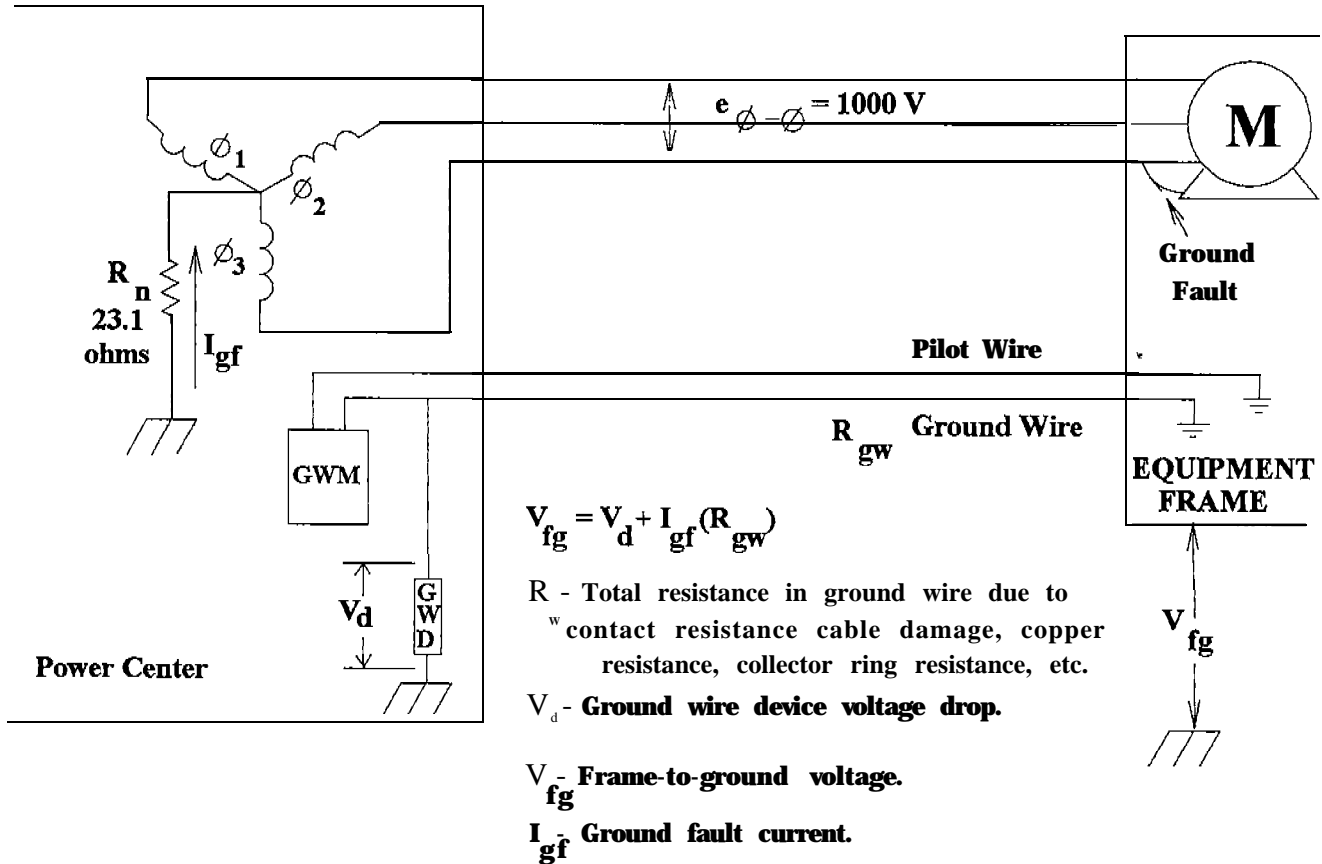


Figure 3. Equipment frame voltage during ground fault conditions on a typical 1000v, 25 amp ground fault current electrical system

TABLE 2

ACTUAL EQUIPMENT FRAME VOLTAGE DURING GROUND FAULT CONDITIONS ON A TYPICAL 1000v, 25 amp NEUTRAL GROUNDING RESISTOR ELECTRICAL SYSTEM AT VARIOUS GROUND WIRE RESISTANCES

$R_w = 0.0898$ ohms, (DC resistance of two -850 feet- 4# AWG ground wires),
 $R_{gw} = 1.6898$ ohms, (grounding circuit resistance when impedance type monitor trips circuit breakers),
 $R_{gw} = 50$ ohms, (maximum allowable ground wire resistance for a continuity type ground wire monitor).

R_{gw}	I_{gf}	V_d	V_{fg}
0.0898	24.9A	12.0V	14.2V
1.6898	23.3A	12.0V	51.3V
50.0000	7.9A	11.0V	406.0V

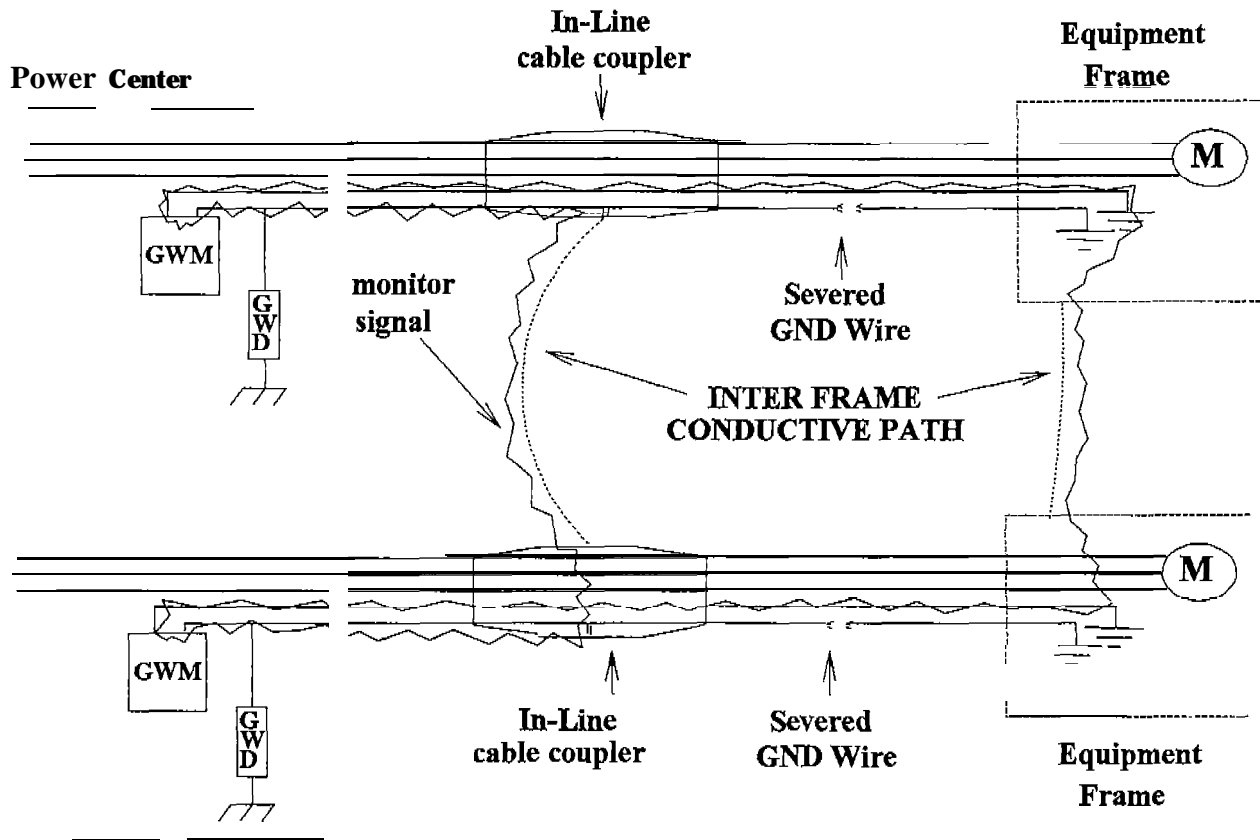


Figure 4. The ground wire monitor's control relays may remain energized when ground continuity is lost because some multiple sectionalized cable GWM/GWD configurations create complete monitoring loops. These loops do not include the ground wires or parallel paths which make up the grounding circuits.

MAPS ACCEPTANCE PROGRAM

The Monitor and Power System (MAPS) Program was developed by MSHA's Approval and Certification Center to determine the possibility of undetected ground faults and excessive equipment frame voltage conditions. The program also evaluates the effectiveness of multiple GWM/GWD installation configurations in monitoring the grounding circuit- The MAPS acceptance criteria increases safety as well as providing latitude and flexibility in equipment selection which can create more cost effective alternatives for the mining industry.

The MAPS application procedure may be used by operators, ground wire monitor manufacturers, or power center manufacturers, to determine the monitoring capabilities of an equipment installation. The applicant provides the required information and MSHA evaluates that information and, when applicable, authorizes the use of a label identifying those systems meeting the requirements of the MAPS Program.

Specifically, the MAPS Program addresses the following:

1. The use of directly grounded in-line cable couplers or connection boxes in a specific installation by reevaluating the use of continuity monitors in an impedance operating ride.
2. The evaluation of the interference of monitors with one another when used with sectionalized cables. A sectionalized cable is defined as cable interconnected by in-line cable couplers or connection boxes which are not electrically insulated from earth or equipment frames.
3. The possible equipment frame voltage during ground fault conditions.
4. The use of a specific ground wire device with a specific ground wire monitor whose use together has not previously been accepted.

5. The use of high voltage ground wire monitors and devices in low and medium voltage installations.
6. The use of low and medium voltage ground wire monitors and devices in high voltage installations.
7. The use of ground wire devices with cables that are larger in size than covered under the device acceptance.
8. The evaluation of specific system ground fault current and the ability to detect and trip at these levels.

A significant advantage for the mine operator is that prior to the installation of the ground wire monitor and devices in the power center or system, the installation can be evaluated and accepted. This will reduce the necessity of changing equipment already in operation. An additional advantage provided by the MAPS program to the mine operator is the ability to use in-line cable couplers or connection boxes which are not insulated from earth or equipment frames. This will eliminate the need to maintain isolation or insulation techniques for these enclosures. Another advantage is that manufacturers can offer systems accepted under the MAPS Program to mine operators, eliminating the need for MSHA to make an individual evaluation at the mine.

A Monitor and Power System (MAPS) acceptance applies to the mine power system and the GWM/GWD installation configurations which may be installed in the power center's electrical circuits. The acceptance of a GWM/GWD installation under the MAPS Program is based on (1) whether sectionalized or non-sectionalized cables are used in the installation, (2) an analysis of the available system ground fault current determined by the neutral grounding resistor (NGR), (3) the GWD voltage drop at the system's available ground fault current and (4) the GWM's maximum dropout resistance.

The MAPS Program makes it possible to evaluate the GWD voltage drop at the power system's available ground fault current based on the neutral grounding resistor (NGR) rating. The GWD's voltage drop is a function of the current generally increasing with current increases. For instance, when a NGR limits the ground fault current to 10 amperes, the acceptable number of GWDs in series with the ground wire is dependent on the GWDs voltage drop at 10 amperes. If a certain GWD drops 11 volts at 10 amperes, then three GWDs of this type installed in series with the ground wire would drop approximately 33 volts. If the same GWD is installed in a grounding circuit with a NGR that limits the ground fault current to 1 ampere, and the GWD drops 6 volts at 1 ampere, then six of these devices installed in series with the ground wire would drop approximately 36 volts. MSHA will make the determination of total GWD voltage drop by

an analysis included in the MAPS Program for grounding circuits which include both sectionalized and non-sectionalized cables. MSHA will also perform a voltage drop analysis for sectionalized cables which will account for increases in grounding circuit resistance. This voltage drop analysis is necessary because some GWMs intended to exclusively monitor the ground wire, may monitor parallel conductive paths when sectionalized cables are used.

The voltage drop analyses for both sectionalized and non-sectionalized cables are omitted under the MAPS Program if the ground fault current is limited to 1/2 ampere or less. Limiting the available ground fault current to this magnitude will provide equipment selection flexibility. In addition, the use of a 1/2 ampere NGR grounding circuit will not result in current levels below the sensitivity settings of the ground fault relay. Although not all power systems can utilize a 1/2 ampere NGR grounding circuit, equally safe systems can be realized with available ground fault currents greater than 1/2 ampere. Electrical systems using a neutral grounding resistor that limits the available current to quantities greater than 1/2 ampere will be analyzed by MSHA for grounding circuit voltage drops and by the applicant for undetectable ground fault currents. A ground fault current analysis will assure that the ground fault current is at least equal to or greater than the current sensitivity setting of the grounded phase protection device.

Grounding circuit installations with sectionalized cable will also require a GWM/GWD installation test to verify effective monitoring of the grounding circuit. This GWM/GWD installation test will determine how many of this type of installation can be connected to a common ground and be effectively monitored. The results of this test will not affect the original MSHA acceptance of the GWMs or GWDS used in the installation.

An additional analysis can be conducted by MSHA under the MAPS Program. This analysis is to verify the acceptability of a GWD used in a specific electrical installation which may not match the voltage and/or cable size rating of the GWD. The analysis will determine if the GWD can withstand the power center transformer's short circuit current for a time equivalent to the maximum clearing time of the short circuit protective device. The transformer's maximum short circuit current calculations can include the impedances of the entire electrical system up to the power center's receptacle or use an infinite buss approach.

Although changes in system components, such as the NGR, GWM, GWD, and ground fault relay are rarely made after initial installations changes such as cable coupler or connection box additions, may be commonplace. Each system change may require an analysis or tests by the user, manufacturer or installer, to confirm the installation's acceptability. Therefore, the MAPS acceptance process has been designed to facilitate testing (approximately 15 minutes for each test) and simplify the method of application.

The MAPS Program acceptance application is a single page application. The applicant supplies MSHA with the necessary information via the MAPS application and MSHA conducts the analyses. The MAPS application is included in an application procedure document, in addition to the method of MAPS ground fault current analysis and the GWM/GWD installation test procedure. Upon receipt of a MAPS application, MSHA will review the information and, if necessary, perform the grounding circuit voltage analyses. If the application information meets the criteria for the MAPS Program, a MAPS acceptance will be issued. An applicant who is issued a MAPS acceptance will receive a copy of the application form stamped with an MSHA acceptance. The applicant is required to affix a MAPS acceptance label to the power center or appropriate equipment- The acceptance label will contain the MSHA logo, the MAPS acceptance number, and the identification of the electrical circuits which can be used to supply power to sectionalized cables.

SUMMARY

Modern longwall mining systems present new challenges in the use of installation arrangements and combination of monitors to effectively monitor grounding circuits. These arrangements must be evaluated to ensure that effective monitoring of the grounding circuit is being accomplished as required by MSHA regulations. MSHA has developed a MAPS Program to address the potential problems inherent with these installations. Also, the MAPS Program will provide a means to evaluate the effectiveness of various GWMs when in-line cable couplers or connection boxes are used. Ground wire monitor and ground wire device installation arrangements and combinations accepted under the MAPS Program will provide equipment flexibility and improved safety.

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