ARC FLASH HAZARD ASSESSMENT IN THE MINING INDUSTRY

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Abstract - When it comes to electrical safety in the workplace, arc flash has become the most prominent topic over the past decade. The Occupational Safety and Health Administration (OSHA, including state chapters) is the only government body that recognizes NFPA-70E, *Standard for Electrical Safety in the Workplace*. However, OSHA does not have jurisdiction in mining operations. Electrical safety for the metal and nonmetal surface mining industry is covered by the Code of Federal Regulations (CFR) Title 30, Part 56, Subpart K (Electricity). The Mine Safety and Health Administration (MSHA) is responsible for enforcing electrical safety in mining operations. CFR Title 30 does not reference personal protective equipment (PPE) to protect electrical workers against arc flash hazards. This paper provides maintenance and safety personnel in surface Metal/Nonmetal mining operations with a step by step guide to implementing an electrical safety program that meets the requirements of MSHA, CFR Title 30 and NFPA-70E.

Index Terms — Arc Flash, MSHA, OSHA, NFPA 70E

I. INTRODUCTION

This paper is a case study of an electrical safety assessment for a large Metal/Nonmetal surface mine and the obstacles encountered. The primary intent of this particular assessment was to quantify the incident energy at locations where an employee might work on energized electrical equipment where an electric arc flash could occur. The incident energy was then used to determine the NFPA-70E Hazard Risk Category and appropriate PPE to protect the qualified worker. Installations traditionally not found outside the mining industry such as mobile sub-stations, drills and excavators with tail cables, and specialized grounding techniques posed challenges for both the analysis engineers and the mine electrical employees. Work tasks associated with these types of installations are not referenced in NFPA-70E and differ from those found in non-mining industrial facilities. As a result, this project forced the mine to reassess their overall electrical safety program.

II. CASE HISTORY

Since the onset of NFPA 70E, arc flash studies have taken place primarily in industrial facilities to comply with OSHA. The nature of the industrial facility process requires generous amounts of power and the means to deliver that power to individual loads. This requires electrical equipment such as switchgear, switchboards, panelboards, protective devices, transformers, conductors, etc. This equipment requires periodic maintenance which could be daily or every 5 years. In order to protect electrical workers who might interact with energized electrical equipment, employers are required to follow NFPA 70E whose purpose "is to provide a practical safe working area for employees relative to the hazards arising from the use of electricity." [1] OSHA recognizes NFPA 70E as an industry standard and has the ability to fine employers who do not provide a safe work environment. Avoiding levies imposed by OSHA is one incentive for employers to comply with NFPA 70E. However, per the Federal Mine Safety and Health Act of 1977, OSHA does not have jurisdiction in the mining industry where the accident rate is 3- to 7-times greater. [2] All mining regulations, including electrical safe work practices, are covered by MSHA. Title 30 CFR 56.12017 – *Work on power circuits* states, "Power circuits shall be deenergized before work is done on such circuits unless hot-line tools are used." [3] The intent is to protect the worker from electrical hazards (shock) yet makes no mention of the use of personal protective equipment (PPE) to protect against flash hazards.

When a new electrical manager of the mine site in question took office, he wanted to reduce the high rate of injuries related to electrical work, specifically arc flash injuries. Being a third generation industrial electrician, he endured several co-workers and friends being involved in arc flash accidents, some resulting in death. In his new position he felt it was the right time to conduct an arc flash hazard assessment at his mine site. One of the first obstacles he encountered was the fact that the authority having jurisdiction does not mandate this type of study. There is no regulation that identifies the requirements for arc flash protection. Conducting an arc flash hazard assessment when not required, in addition to changing the mindset of seasoned electrical workers was not going to be easy. The first step was to educate the senior and executive management of the company. None of the management in the company, including those in the electrical department had heard of arc flash, much less understood it. He took his case to upper management and molded his idea around the existing company safety manual. Once he had support from upper management, he contracted an engineering services firm experienced in arc flash hazard assessment.

III. ARC FLASH STEP BY STEP PROCEDURE

IEEE Std 1584-2002 [4] lists the steps to performing an arc flash hazard analysis:

1. Collect the system and installation data
2. Determine the system modes of operation
3. Determine the bolted fault currents
4. Determine the arc fault currents
5. Find the protective device characteristics and duration of the arc
6. Document the system voltages and classes of equipment
7. Select the working distances
8. Determine the incident energy for all equipment
9. Determine the flash-protection boundary for all equipment

These can be more generally grouped into three main categories: Data Collection, System Modeling, and Analysis.

A. Data Collection

The first phase of an arc flash hazard analysis is to perform data collection to obtain the necessary system information such as cable data, motor data, transformer sizes and impedances and protective device data such as manufacturer, style and adjustable settings, if any. One of the critical path items during the data collection phase is obtaining accurate utility fault current contribution data for use in the arc flash calculations. Because the magnitude of arcing fault current available at each bus is calculated based on the utility's available fault current, an infinite bus calculation while yielding the maximum arcing fault current does not necessarily produce the worst-case incident energy, as the arc duration maybe shorter for higher current magnitudes depending on the protective device's specific time current curve (TCC) characteristics [5].

The data collection phase presents significant additional challenges and considerations for mining sites. One of these challenges is the often rugged terrain encountered, which can significantly increase the time required to access electrical equipment. Adding to this is the distributed nature of electrical equipment throughout a geographic area that can exceed several square miles. Remote substations powering electric shovels, pumps, motors and other mining loads must be documented and modeled accurately for a successful arc flash hazard analysis. These remote substations may be supplied via pole-mounted overhead electrical distribution feeders throughout the mine site. The end user and the consultant performing the arc flash study must be aware of actual site conditions such as these when planning the data collection.

An ongoing consideration for maintaining an accurate system model is the portable nature of some mining equipment such as mobile substations for electric shovels. These mobile substations are not fixed in location relative to the electrical distribution system and will be relocated over time as the shovel is utilized in different areas of the mine. It is critical that an up-to-date record of the current system configuration be maintained, and in fact, this is a requirement of article 130.3 of NFPA 70E 2009 [1]. Each time mobile equipment is relocated, the corresponding fault current and arc flash hazard should be updated.

B. System Modeling

Once all pertinent data has been collected, it must be entered into the system model. Typically this is fairly straightforward, such as assigning the transformer ratings and impedances, but some systems components may require further consideration. Pole-mounted distribution feeders are used to supply power at medium voltage to remotely located loads, and these feeders must be accurately modeled for impedance, configuration and length, often requiring a custom conductor model to be created. These feeders are often bare conductors, either copper or ACSR. To determine the impedance of these feeder conductors, data such as size, length and conductor configuration need to be documented, and the diameter, Geometric Mean Radius (GMR) and resistance (usually in ohms/1000 ft) obtained from the manufacturer.

Another unique system component found in mining electrical systems is the portable shovel trailing cable. These cables are shielded, insulated and typically contain three (3) phase conductors, two (2) grounding conductors and one (1) ground-check conductor. The ground-check conductor is used in conjunction with a continuity ground check monitor to ensure that a continuous ground path is maintained during operation. Like the overhead distribution feeder, these trailing cables often require a custom conductor model to accurately represent the specific impedances in the system model.

C. Analysis

After fully modeling the system in the specified software, arc flash incident energy and the arc flash boundary can be calculated for each bus throughout the system. When performing the analysis it is important to keep in mind the type of equipment and possible ways that qualified personnel may interact with the equipment while it is energized. In Article 100 of NFPA 70E 2009 [1], it is stated that an arc flash hazard may exist even when energized conductors are not exposed, provided that a person is interacting with the equipment in a manner that could cause an arc.

The portable trailing cables described in the system model outlined above provide a unique example of interacting with energized equipment. In one particular mine, these trailing cables are occasionally moved or repositioned while energized. The qualified personnel interact with the cable at some distance along its length using a 3' hot-stick to manipulate the cable. The arc flash hazard should be evaluated at the typical working distance, in this case 3', to determine the required PPE for the task of moving these cables when energized. An additional complication is the fact that this interaction with the cable can occur along the entirety of its length, which can be up to 5000'. This necessitates the calculation of the incident energy and arc flash boundary at various points along the length of the conductor, as the worst-case arc flash hazard may not correspond to the highest fault currents. In this particular case, evaluation of the arc flash hazard was performed at three (3) distances from the line side connection of the portable cable to the upstream feeder breaker:

1) 5', with maximum and minimum utility contribution
2) 3000', with maximum and minimum utility contribution
3) 5000', with maximum and minimum utility contribution

The results of these six scenarios were compared and the worst-case arc flash incident energy identified for the task of moving these cables at any point along their length. In this specific case, the incident energy decreased as the length of cable increased. This indicates that the increased cable length does not reduce the fault current below the upstream relay's instantaneous trip setting. If this were the case, it would be expected that the incident energy would increase if the available fault current does not cause the relay to operate using its instantaneous response, resulting in increased arc duration (time). The following equation from IEEE Std 1584-2002 [4] for incident energy illustrates the relationship between the arcing duration and the resulting incident energy:

$$E = C_f E_n \left(\frac{t}{0.2} \right) \left(\frac{610^x}{D^x} \right) \qquad (1)$$

Where:

- E is incident energy (cal/cm^2)
- C_f is a calculation factor
  - 1.0 for voltages above 1kV, and
  - 1.5 for voltages at or below 1kV
- E_n is incident energy normalized
- t is arcing time (seconds)
- D is distance from the possible arc point to the person (mm)
- X is the distance exponent

It is apparent that the incident energy is directly proportional to the arcing time, or the length of time it takes the upstream protective device to operate.

IV. ARC FLASH MITIGATION & SYSTEM UPGRADES

While the primary purpose of an arc flash analysis is to determine the arc flash hazard category at each pertinent piece of electrical equipment, it also has the additional benefit of revealing other system issues or opportunities for improvement. For example, at the mine in question, implementation of the arc flash hazard labeling led to increased awareness and revisions to the planned maintenance of the electrical equipment, as the 2009 version of NFPA 70E 2009 [1] requires overcurrent protective device maintenance in accordance with the manufacturer's instructions or industry standards. Typical items that may be flagged during the study can include over-dutied equipment, overloaded cables or transformers, improperly rated over current devices, and other system considerations such as improved TCC coordination via trip unit upgrades. The data collection phase is a prime opportunity to take note of any existing system deficiencies.

Areas in the system identified as having unacceptable hazard risk categories that require maintenance or adjustment should be evaluated to see if the hazard can be reduced. For example, the easiest way to drop one or more risk categories is by reducing the operating time of the over current device. This can be done permanently or temporarily. In either case, this adjustment should be performed by an engineer experienced in arc flash mitigation. Several other methods can be employed to reduce arc flash hazards and should be considered on a case by case method.

Key to the continued success of any arc flash analysis is follow-through on the part of the qualified personnel to read, interpret and follow the arc flash labeling. Doing so requires the correct use of PPE as described in NFPA 70E [1]. It is not acceptable to hand an employee PPE and expect him to know how to properly apply the PPE. Formal training on the use and care of PPE should take place when it's first issued in accordance with NFPA 70E 2009 [1]. An alternative approach, chosen by the mine in question, is to use the simplified two-category clothing system outlined in Annex H of NFPA 70E. This method combined with additional PPE required for specific tasks meets the minimum requirements of Table 130.7(C)(9) and Table 130.7(C)(10) [1].

Additionally, regularly scheduled maintenance will help increase the probability that the overcurrent devices will function as intended if an arc flash event occurs. Periodic updating of the arc flash hazard analysis, whenever a major system change takes place or every 5 years [1] will ensure that the arc flash hazard analysis remains accurate and provides the necessary information to allow qualified personnel to select the appropriate PPE.

V. CONCLUSIONS

Mining operations under the jurisdiction of MSHA are not required to conduct arc flash hazard assessments. This could potentially leave electrical workers exposed to additional hazards beyond shock. Electrical workers have the right to a safe work environment. Creating an electrical safety program that includes the hazards associated with arc flash raises awareness. To implement such a program, consider the following steps:

1. Obtain necessary support from management and safety personnel
2. Select a company proficient in arc flash to perform the analysis
3. Collect system data
4. Build system model
5. Perform analysis
6. Mitigate when possible
7. Implement PPE and LOTO program
8. Perform testing on over current devices
9. Update model when system changes or every five years

If asked, "Why should we do it if it's not required?" The answer is simple, "because it's the right thing to do." Following the law isn't the only reason to provide an electrical safe work environment. Ensuring workers go home safe is just as important.

VI. ACKNOWLEDGEMENTS

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VII. REFERENCES

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VIII. VITA

Matthew Hopper received a Bachelor of Science degree in Electrical Engineering from Fresno State University in 2001. Upon graduating, he began his engineering career with Power Systems Testing Co. as a power systems studies and field engineer. In 2006 Mr. Hopper accepted a position with Eaton Corporation as a Power Systems Engineer. Primary duties included performing arc flash studies, power quality investigations, advanced power system studies, and training. In 2008 he accepted the Team Leader position within Eaton for the Southwest Zone. Mr. Hopper is a member of IEEE and a registered professional engineer in the state of California.

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