ARC FLASH HAZARDS RELATED TO OILFIELD ELECTRICAL SYSTEMS

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ABSTRACT

The danger of arc flash hazards is present at plants, facilities, beam pump and electrical submersible pump installations. Over the last decade, recognition of the effects of electrical arc flash hazards (severe burn injuries, hearing loss and death) has created industry and OSHA requirements to minimize arc flash exposure hazards to workers. Compliance with NFPA 70E is the bare minimum, however this standard must be applied correctly or it can be overkill or even inadequate, especially when dealing with oilfield electrical systems. The first step in evaluating the scope of arc flash hazards is developing a power system model with arc flash software (based on IEEE 1584) which calculates the levels of arc flash levels.

Oil field distribution systems are unique in many ways and especially regarding arc flash. These typically weak radial systems present unusual challenges to developing solutions. Sometimes, the PPE requirements exceed existing personal protective equipment technology. This paper will explain the hazards associated with arc flash and present several simple engineering solutions, which reduce the PPE requirements.

THE ARC FLASH HAZARD

Historically, most industries have been aware of electric shock or electrocution hazards and they have developed programs to protect workers. However, a second electrical hazard has remained unrecognized until recently. Arc flash hazard is this second electrical hazard. The National Fire Protection Association, Inc. (NFPA) reports that the majority of hospital admissions that are due to electrical accidents are from arc flash hazard, not from shocks. The awareness of this hazard has been growing since Ralph H. Lee published a theoretical model estimating the injury to people in 1982. Today, the devastating effects of arc flash hazards are better understood due, in part to research, testing, and new safety standards that specifically address this issue. In 2002, the National Electrical Code (NEC) added a requirement for owners to install warning labels that warn workers of potential arc hazards.

Arc flash events are fast occurring events that typically last less than .5 seconds in duration. These rapid releases of energy are due to an arcing fault between two-phase conductors or between phase conductors and ground. Arc flash usually occurs at voltages 208 or greater. Most oilfield equipment such as motors operates at 480 volts or greater. Although the source of these events normally burns away during the initial flash, the arc is sustained by highly conductive plasma. The massive energy vaporizes the copper, which causes an explosive volumetric increase thousands of times its original size. There are many causes of arc fault events including workers making accidental mistakes with conductive tools, dropped tools, improper procedures, failure of equipment, tools forgotten from previous repairs, dirt or water contamination and even animals. Almost anything conductive that can cause a short circuit condition can be the reason for an arc flash event.

These short duration events happen faster than the unaided human eye can even perceive. Often, we are not aware of events that are so quick in duration. The inability to see these high-speed events may be one of the reasons that workers may not be aware of this hazard. High-speed photography has helped to capture and document the distinctiveness of these events. Tests have confirmed that arc flash events are extremely hot; generating temperatures of up to 35,000 degrees F due to copper expanding at up to 67,000 times. Workers in proximity to an arc flash may be exposed to clothing temperatures of greater than 225 degrees F, sound waves of greater than 140db, pressures of greater than 2000 pounds per square ft and flying shrapnel traveling up to 700 mph! These hazards are great enough to severely burn, cause hearing damage and collapse lungs. Injuries can damage sight, hearing and internal organs, which may require years of skin grafts and medical attention. In some cases, arc flash accidents result in death. Sometimes, other indirect injuries are caused by a fall (when in an elevated position such as on a ladder) or trying to move away from the arc. In short, arc flash events devastate everything in their path.

The severity or extent of the energy released is dependent upon the duration of the clearing time of upstream overcurrent protective devices and the available fault current. Higher fault current and longer clearing times mean greater arc magnitude. The severity to workers depends upon the magnitude of the energy, distance to the arc, and level of PPE. One of the serious consequences of an arc flash exposure is the ignition of a worker's clothing and the continued burning of conventional or non-PPE clothing, which increases both burn depth and burn area. The incident or thermal energy produced by the effect of an arc flash striking the worker is measured in calories per centimeter squared (cal/cm2). PPE designed to reduce burn injury and minimize clothing ignition are rated according to the incident energy measured in cal/cm2. These levels are divided into hazard/risk categories described in NFPA 70E Table 130.7(C) (11). Hazard risk category zero (less than 4 cal/cm2) is essentially long sleeve cotton shirts and cotton jeans while hazard risk category four (up to 40 cal/cm2) is a multilayer flash suit and hood more affectionately know as the "bee suit".

NFPA 70E HISTORY

A NFPA committee was formed in 1976 to assist the Occupational, Safety and Health Administration (OSHA) with developing electrical safety standards. Due to OSHA's own rule making procedures, the complexity of the National Electrical Code, OSHA decided that it needed a new standard that addressed electrical worker safety. The standard would be compatible with the OSHA requirements for safety and would consist of four major parts: Installation Safety Requirements; Safety-Related Work Practices; Safety-Related Maintenance Requirements; and Safety Requirements for Special Equipment. The new standard, NFPA 70E, Standard for Electrical Safety Requirements for Employee Workplaces, was first published in 1979. The stated purpose of the standard was to create practices and procedures that are intended to provide for employee safety relative to electrical hazards at the workplace.

The fifth edition, published in 1995, updated the document to the 1993 NEC, introduced the "limits boundaries concept," and established a "flash protection boundary." Five years later, in 2000, the sixth edition updated NFPA 70E to the 1999 NEC and expanded flash protection boundary information and the use of personal protective equipment (PPE). This edition introduced the charts for determining appropriate PPE for common tasks. In 2004, it was updated to the 2002 NEC with significant reformatting and some new concepts introduced. The reformatting emphasized working on live parts as a last alternative and outlined the use of energized electrical work permits. Presently, OSHA is in the process of including NFPA70E into OSHA section 1910.

NFPA 70E, CHAPTER 1

Chapter 1 is a vital section to understand because it directly addresses safety related work practices. Article 110 of this section lays out training requirements, outlines the mandated employer electrical safety program, job briefings, use of test equipment, and sets forth the requirement for shock and flash hazard analysis. Every topic in this article is of great importance to understand and implement. It is important to remember that these training requirements and implementation of the electrical safety program are the backbone to provide structure and effective compliance with NFPA 70E. The goal is to safeguard workers through safe electrical work practices.

Section 110.8(B) (1) (b) of Chapter 1 stipulates that an arc flash analysis is required. This analysis must determine the arc flash boundary distance and PPE necessary for workers to wear when working inside the boundary. Section 130.3(B) allows employers to utilize Table 130.7(C) (9) (a) in lieu of performing an arc flash analysis. This table lists equipment type (panelboards, MCCs, switchgear, motor starters, etc.), activity (working on energized parts such as voltage testing, etc.) and gives the hazard risk categories (category 1, 2, etc.) associated with the equipment type and task. The hazard risk category defines the type of PPE required. Definitions of PPE requirements are listed as a matrix in Table 130.7(C) (10).

This is a very straightforward approach and where it applies, it is a very simple solution for determining arc flash PPE. However, proper use of this table is predicated on the user's detailed knowledge of the electrical system and the characteristics of the protective devices (fuses, circuit breakers, etc.). This means that in most cases, the user will need a detailed electrical model of the system. With this information provided by the model, it can be determined whether table 130.7 can be used or if an arc flash analysis must be performed. In general, the table works for some industrial businesses and plants that are typically served by a local substation and where detailed electrical information is readily available. However, the table is not always a good fit for oilfield electrical distribution systems and plants.

The basis of Table 130.7 is on relatively high available short circuit current and fast clearing times relative to oilfield distribution systems. In general, oilfield distribution systems are unique in that they are comprised of long radial distribution power lines, have smaller conductor sizes installed at the more distant line sections, and consist of mostly motor loads. Even more troublesome are systems with 480-volt distribution and long 480-volt underground services or feeders. A characteristic of oilfield high voltage distribution (15 kV) and low voltage (480 volt) distribution systems is that they often have lower available fault current than assumed by Table 130.7. Lower available fault current and typical long radial lines can result in longer clearing times for fuses and. Smaller sized conductors often installed to reduce costs can compound the problem. These characteristics translate into higher arc flash energies that are sometimes beyond the capabilities of existing PPE. Because of lower available fault current and slower clearing times, Table 130.7 will frequently not apply well to oilfield systems.

Even in situations where Table 130.7 is determined to be appropriate for the electrical system, it should be noted that when performing voltage testing at typical oilfield voltage levels (480 volts or greater), the clothing class is a 2* per the table. This means that the worker must wear a double-layer switching hood and hearing protection while performing the task. A double-layer switching hood, often referred to as a "bee-suit" is a protective clothing hood with a small face shield. Even during the winter, this hood is extremely uncomfortable and provides the user with limited visibility. Outdoors, during the summer, in places like West Texas where outdoor temperatures reach 100 degrees Fahrenheit, this hood would be very uncomfortable and awkward to use.

IEEE 1584

Where it is determined that the tables in NFPA 70E are not applicable to an oilfield situation, the Institute of Electrical and Electronic Engineers Inc. (IEEE) 1584, Guide for Performing Arc Flash Hazard Calculations provides and excellent guideline for performing an arc flash analysis. This document is based on extensive testing with actual equipment and provides better models based on statistical analysis and curve fitting of the test data. IEEE 1584 allows the user to model their specific installations and provides techniques to determine the arc flash hazard distance and incident energy. This standard includes several useful spreadsheets for making calculations. Additionally, several companies offer arc flash calculation programs that allow more graphical representation of the data and analysis. Once modeled, the user can then proceed to specific engineering solutions.

GENERAL METHODS OF MITIGATION

One of the most effective and perhaps under utilized methods of mitigating arc flash hazards is de-energizing the circuit with an upstream device. If the equipment is completely de-energized, then no arc flash hazard can exist. This means that a disconnecting switch or breaker must be opened upstream of the device being worked on such as a motor controller at a beam pump. Whenever this is practical, it should be the method implemented. Remember that this activity will necessitate verification of the circuit being de-energized and this will require the appropriate PPE to determine that the circuit is de-energized.

When live troubleshooting is required, this option is not available. If it is not practical to open an upstream device, then workers must wear the proper PPE to mitigate the risk. The upstream breaker or fuse is what limits the incident energy and determines the hazard/risk category of clothing. Where breakers serve as upstream protective devices, regular testing and maintenance is recommended to ensure that they operate as intended. In field locations where insects may build their homes in these devices or wind blown sand and dirt are a factor, the operating time of a circuit breaker may be affected, which may reduce the breaker operating time or even prevent the breaker from opening. It is worth noting that PPE and protection of workers is dependent on the upstream breaker functioning properly. If breakers are not tested and maintained then there is reduced confidence that the PPE selected will provide the expected protection.

The intent of wearing the proper arc flash PPE is to minimize burn injuries, but it does not necessarily guarantee injury free protection. Arc flash PPE diminishes burn injuries so that they are curable, but may not provide adequate protection against flying debris. In all cases, it is important to provide the proper signage (per the requirement of the NEC) to warn workers that the arc flash hazard is present and to ensure that all workers who are exposed to energized equipment have the proper documented training (OSHA and NFPA 70E requirements).

BEAM PUMP AND ESP METHODS OF MITIGATION

Beam pump and electrical submersible pump installations pose unique challenges to mitigating the arc flash hazards. These systems may receive power from owner-operated distribution systems or they may be connected to individual meters on rural-type distribution systems. Much of the oilfield distribution systems grew because of the need to electrify wells and not necessarily through planning. As wells were converted from flowing to artificial lift, electrification was necessary and occurred somewhat as an evolutionary process. This type of growth is further complicated because often the installation type changes over time (beam pump converted to an ESP and vice versa). Additionally, horsepower requirements vary as strategies evolve to produce the oil.

The result of this evolutionary process shows up as long power-lines with minimum sized conductors. While these lines may be adequately sized for ampacity, they are often minimum size such as #4 ASCR. The small size of these conductors combined with their long lengths that extend miles, can create very low available fault currents. Lower fault currents mean longer protective device clearing times, which creates higher incident energies and higher hazard/risk categories for PPE. The very worst-case scenarios are those where long 480-volt distribution systems extend beyond this system for thousands of feet with multiple connected motors. These systems can result in available fault current that is not measured in thousands of amps but instead in the hundreds of amps. These systems can get down to as low as a few hundred amps! These legacy systems provide a challenge to mitigate.

Beam pump and electrical submersible pump motors dominate the load on these systems and provide an additional motor contribution of fault current to the system when they are running. When working on energized motor panels, the incident energy level can usually be reduced by turning the motor off. By eliminating the motor's fault contribution, the incident energy level is reduced. While it is not prudent to calculate the incident energy levels with the motor contribution left out, it will always be a good practice to turn the motor off while troubleshooting. This should be remembered when working with any motor and especially for those motors that are served by individual transformer banks.

BEAM PUMPS ON HIGH VOLTAGE DISTRIBUTION SYSTEMS

There are at least two available options for mitigating arc flash hazards at beam pumps. Some beam pump installations consist of a transformer bank, main disconnecting means and motor controller. Installations with the upstream disconnect can benefit from the installation of current limiting fuses installed at the main disconnect. These fuses may result in lower incident energy levels and clothing class levels of zero so that no additional PPE is required at the motor controller (where most troubleshooting occurs).

Other installations may not have a main disconnecting means. These installations consist of a motor controller, which serves as both the main disconnecting means and as the controller. Systems with beam pumps that do not have a main disconnecting means upstream of the motor controller can prove to be troublesome with larger horsepower motors. However, lower horsepower motors may be able to be reduce the incident energy levels by downsizing the primary transformer fuses. Designers should consider lower amp rating of type "X" or type "KS" fuses as potential alternatives to other type of transformer fusing with these lower horsepower beam pumps.

BEAM PUMPS ON LOW VOLTAGE DISTRIBUTION SYSTEMS

Similar solutions may be applied in 480-volt distribution systems that do not extend beyond a thousand feet and especially where not serving multiple motors. It is possible that downsizing the primary size transformer fuses combined with adding a secondary-side disconnect with current limiting can reduce the incident energy levels. However, on longer lengths, this may not be an effective strategy. System modeling may reveal that the losses and voltage drop in these systems is so severe that it may be economic to replace parts of the system with high voltage distribution and individual transformer banks at each motor. Multiple beam pumps connected to a single transformer is arguably the most challenging design to mitigate. Conversely, multiple beam pump low voltage distribution systems hold the most opportunity to improve not only the arc flash hazard but reduce energy usage and improve reliability.

ELECTRICAL SUBMERSIBLE PUMPS

Because most electrical submersible pumps do not have a separate main disconnecting means in series with the controller, ESPs can benefit the most from downsizing the primary transformer fuse sizes. In many cases, this is all that is necessary to achieve a clothing class two or one. Additionally, ESP installations hold promise for installing modern microprocessor relays with more advanced algorithms and higher interrupting contactors.

FACILITIES

Water stations, compressor stations, and satellites present a unique challenge but offer more versatile solutions for mitigating arc flash. Some of these facilities have captive transformer designs (each motor has its own transformer) and some utilize a "main-tie-main" configuration (two transformers connected with a main breaker to increase reliability). Although these facilities may have higher fault current levels, they may still fall below the NFPA table assumptions. Each of these facilities should be considered separately. This usually means modeling individual sites to determine mitigation methods. Some typical solutions include current limiting fuses, special microprocessor relaying schemes, installing differential protection, changing bus designs, adding more CTs for additional zone protection, replacing air contactors with vacuum contactors, retrofitting transformers with high impedance grounding and installing high side interruption devices. One low cost solution for main-tie-main designs is to keep the main tiebreaker in the open position, which can greatly reduce the available current.

CONCLUSIONS

Worker injuries due to arc flash can be serious and which potentially may require the need for skin grafting and rehabilitation. Additionally, the cost of treatment for arc flash injuries can exceed more than one million dollars per case (not including litigation fees, insurance increases, downtime, equipment damage, etc.). Electrical safety programs, required by NFPA 70E, provide information to mitigate the hazard with PPE. Due to the severity of these types of injuries and the uniqueness of oilfield electrical systems, workers and companies may want to consider taking a more proactive approach to arc flash mitigation that is not solely limited to PPE. A proactive approach might include creating arc flash computer models for electrical systems, re-evaluating when "hot work" is required, installing current limiting fuses or microprocessor relays, modifying existing system designs and making arc flash mitigation part of new electrical design processes.