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Electrical Safety Breakdown: An Investigative Method for Electrical Events that Will Save Lives

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Introduction

Each day we are faced with the fact that our employees take risks and a large number of these decisions result in injuries to employees and/or interruptions to business. On multiple occasions these everyday actions taken by employees involve electricity and result in an electrical shock, arc fault, blast, fire or some combination of all. Between 2005 and 2006, the Occupational Safety and Health Administration (OSHA) cited employers in the "Construction" industry for more than $288,000 dollars and "General Industry" for greater than $960,000 dollars for failure to meet the minimum requirements for wiring design and protection and for wiring methods being utilized.

> It was a beautiful Wednesday morning and I had great plans for the weekend. I was about to begin work on an assignment given to me the day before; to install a three phase, 480 volt circuit breaker. I had been a master electrician for almost 30 years and had outlasted all the young electrical engineers. On the way to the job site, a new engineer, who had only been out of school for nine months, stopped me and tried to tell me how to do my job safely, as if I wasn't aware of how to conduct myself. He wanted me to wear some special clothes and special gloves. I told him in no uncertain terms that I had been doing this job for more years than he had been alive and I did not need his opinion on how to install a breaker. I collected my tools and stopped by the supply room to pick up the breaker. I had gotten a jump on the job earlier in the morning and had already removed the cover on the breaker. Everything had been going fine. I knew it would take a little while to install the breaker and land the wires, so I decided to go to break early for food. I had a large breakfast, you know, a three egg omelet, loaded with bacon, sausage, peppers, mushrooms, onions and cheese. After finishing, I headed back to the job site and from there I don't remember too much except someone asking if I was OK. I could not hear what they were saying but saw their lips moving. I could not see out of one eye and did not know why. My body felt like it was on fire and there was an odor overwhelming me. When I looked down, my shirt was gone except for the shirt tail and my jeans were burned. What happened? This is a critical question.

Objectives

In an attempt to answer this question this paper will discuss the components of an electrical event, identify one method of preparing for an electrical event investigation, basic electrical components and ways to detect potential problems with electrical installation in a preventative manner, and finally, a case study review.

Components of an Electrical Event

Electrical accidents can be devastating to family members of a worker as well as their workgroup. When electrical events occur there are three basic external components which can cause injury to the worker: electrical shock, arc flash or blast. To better understand the results of a shock it is critical to have knowledge of the path in which the current enters and exits the body. The body is made up of approximately 75% intracellular fluid and 25% extracellular fluid (Bledsoe, 1994) and when the skin is moist due to perspiration or external conditions the resistance of the skin is greatly reduced allowing for a better conductor which in turn will provide for a better path for electrical current to flow. Men and women have different sensitivities due to the resistivity differences in their bodies. Men typically have more body mass and their hands are more calloused therefore, the amount of resistance created by this dry dead skin and their increase in mass will result in an increase resistance to an electrical shock. To demonstrate the effects of electricity on a human body, Table 1 (Geddes, L., & Roeder, R., 2006) will identify an average body's reaction to an electrical current flowing through it.

Effect of Electrical Current flowing through the Body	**Men**	**Women**
Slight tingling sensation felt	0.4 ma	0.3 ma
Threshold of perception	1.1 ma	0.7 ma
Painful but able to release from electrical source	9.0 ma	6.0 ma
Painful and unable to release from electrical source	16.0 ma	10.5 ma
Severe pain and difficulty breathing	23.0 ma	15.0 ma
Possible heart fibrillation after 3 seconds	100.0 ma	100.0 ma

Table 1.

In addition to the body's ability to provide resistance to current, the body also varies the amount of resistance based on the path in which the current enters and exits the body. The average person will have a resistance of 500 ohms from hand to hand contact. If the individual was making two handed contact with an energized conductor and was leaned against an object at the shoulder level the individual would reduce their resistance to approximately 400 ohms (Geddes & Roeder, 2006). There are many different resistance values that an individual could possess based on the location for which they are being shocked and their body condition. As with any shock the path in which the current travels through the body, the duration of exposure and the amount of current will affect survival potential.

One of the most common examples of an arc flash can be demonstrated by identifying a welder who strikes a plasma (arc), which is an ionized gas at very high temperatures (~54,000°F). The plasma is generated by sending a jet of gas through an electric arc. Plasma welding is only done on automatic machines (Torben & Lenau, 2006). This high intensity electrical arc created when the end of the electrode makes contact with the metal allows for a much focused intense heat source. When an electrical event resulting in an arc flash occurs, the focus is no longer in a controlled location as would be with plasma welding, it will expand until the space is filled and continue to expand until the fault clears and the gas has been vaporized. The arc flash from this event can reach a temperature up to 35,000°F which is three to three and one half times hotter than the sun. Although the temperature is unlikely to reach the 35,000°F, it is likely to reach the 16,000°F to 20,000°F (Jones & Jones, 2008).

The skin provides the body with a layer of protection that can withstand the elements at normal temperature and pressure however; when skin is exposed to heat for an extended period of time, this exposure can result in a burn. To better illustrate the results of exposure to heat, Table 2 (Jones, R. & Jones J., 2000) identifies the results of exposure of the skin to heat over time.

Skin Temperature	Time to Reach Temperature	Damaged Caused
110°F	6.0 hours	Cell breakdown begins
158°F	1.0 seconds	Total cell destruction
176°F	0.1 seconds	Second-degree burn
200°F	0.1 seconds	Third-degree burn

Table 2. Effects of temperature on human skin.

Consider copper, which is a common metal used in the electrical arena due to its conductivity properties. Copper will begin to melt at 2000°F and will boil at 4703°F, and when an arc flash event occurs where temperature can climb up to 35000°F, the results are copper melting, boiling and finally vaporizing and expanding due to the temperatures of the event. During the aforementioned event, worker(s) in the associated area experience a dramatic increase in temperature from the event. The dramatic change in temperature will induce a pressure change and create a blast effect. Copper vapor expands to 67,000 times the volume of solid copper (water expands ~1700 times). For example, 16.39 cm^3 (1 $inch^3$) of copper vaporizes into 1.098m^3 (1.44 yd^3) of vapor. The air in the arc stream expands in heating up from ambient to that of the arc vaporization of metal and heating of the surrounding air results in a very rapid blast due to the high pressure (Lee, 1987). This sudden unexpected release of temperature and energy is what creates an incident requiring the initiation of an investigation.

Electrical Systems and Early Warning Signs

To better understand how injuries and fatalities occur, a basic understanding of electrical systems is beneficial. Electrical systems are composed of many different components including conductors (wire), conduits, distribution systems, switches and transformers. Typically, electricity is delivered from the power company to your facility through electrical transmission lines (conductors). Once electrical power reaches your facility the power is stepped down to a desired

voltage through a transformer where then the distribution of electricity can occurs. Once the voltage has been reduced to the desired amount, a distribution system is utilized to deliver the power to equipment. The distribution of electricity can be achieved, through the use of an electrical panel or combination of control centers and panels. During the transmission and distribution of electricity multiple opportunities exist for failure.

During the installation or maintenance of these electrical systems there are two categories in which failure can occur resulting in an electrical event. These failures types are equipment-related or human- related. Equipment-related failures include: a) failure of a transmission system or a distribution system(s) which can be caused by trees falling over power lines, wind, rain, ice or automotive accidents involving the transmission system; b) frayed or defective conductors created by age, small animals, or the environment in which it travels; c) poor wiring methods include: failure to tighten a conductor to a connector device leading to overheating, failure to create a positive connection between the equipment and the power distribution; d) overloading of electrical circuits, which can include installing to much load for the circuit breaker or panel to safely accommodate or overfilling the conduits during installation; e) loose or defective connection points; and f) physical equipment failure which can cause a short or fault in the electrical system are examples of equipment failure means. This type of equipment failure may be reduced or prevented with the implementation of a quality control system or as simple as a checks and balances process to verify the accuracy of the design and installation process. Human-related failures include: a) incomplete understanding of a system to be serviced; b) poor work technique; c) wrong tool for task involving electricity; d) improper or inadequate training; e) lack of job planning prior to beginning task involving electricity; and f) system modifications which result in the creation of an unsafe condition. These failures no matter the cause, human or equipment, can lead to catastrophic results.

All electrical events despite the cause have one possible commonality, electricity can kill. To prevent the electrical event or reduce the severity of the event, companies should evaluate their electrical installations and safety programs as well as their employee electrical training programs. There are many techniques for your total system evaluation of electrical safety however; the one goal should be to provide a safer work environment through the understanding of electricity and how to prevent electrical events from occurring. An electrical evaluation program should include: a) acknowledgement of the dangers of arc flash; b) definition of specific and measurable goals; c) analysis of electrical systems and incident energy calculations, PPE requirements, flash hazard boundaries, shock hazard and limited restricted boundaries; d) placement of labels on electrical systems to identify hazards present; e) insurance of appropriate PPE availability for hazards within a facility; f) creation/implementation of hot work permit process to document safe work practices; g) review of current safety program for insurance of compliance with all safety standards; h) insurance of safety program effectiveness and implementation; i) insurance of a method to maintain change, and; j) evaluation of economic benefits for management buy-in (ESA, Inc, 2005).

Investigation Method

Several considerations should be made to prepare in advance for an electrical event. The first consideration should be to determine what your potential flash hazards and shock hazards might be. An extensive study of your facility should be conducted to ensure that the hazards of your

facility are understood and appropriate measures are taken, when possible, to reduce the hazards. Secondly, it should be determined how an event will be investigated. When establishing incident investigation teams remember to identify the key players who will assist in the examination of the scene and identification of witnesses, prepare a method to collect relevant information about the incident and prepare an incident investigation report (Geddes & Roeder, 2006). The investigation report should contain only facts and no opinions. Incident reports should include scene security, chain of custody of relevant physical evidence, photos and videos of the scene initially as well as during the investigation, documented statement from all witnesses, building and area drawings of the affected area and equipment, information about investigator assignments during the investigation and other relevant documentation that supports the incident investigation. During preplanning for incident investigations, an incident investigation committee is established to assist with incident investigation as well as a list of available contacts to assist, in the event that the incident is outside the field of initial expertise.

When an electrical incident does occur, there are many concerns to be addressed immediately. The initial concern with considerable immediacy is rescue of the employee(s) without exposing others to the hazard(s) and seeking medical treatment for the injured. Other focuses are: isolation of the area in which the event occurred until it can be confirmed that the area is safety to enter; beginning of the fact finding mission which will involve identifying and gathering of employees who may be witness to the event; providing grief consolation for those individuals who may have witnessed the event and gathering of the facts which led up to the event and any additional information associated with the event. This might include: scope of work, bid documentation, work permits, list of employees assigned to the job and a list of individuals overseeing the job.

Prior to anyone making contact with victims of an electrical event, it is critical to ensure all electrical components that the victim(s) had come in contact with, are off and in a safe state (lockout tagout if possible) so that additional electrical events do not occur for rescue personnel. If the victim(s) is transported, the next step to the investigation is a dual process. Part one of the process is interviewing witnesses and gathering witness statements and part two is beginning the investigation of the physical area associated with the event. If the victim(s) is not removed from the site, isolation of the area including covering of the person(s) should be done to protect the individual's privacy and protect the scene for investigation purposes. If an electrocution occurs, OSHA should be notified within eight hours of the incident.

In establishing a witness interviewing process it is important to set interviewing ground rules. For example, the interview process is to determine: a) what happened, not to establish blame; b) how and why it happened, and; c) establish a timeline that led up to the event and post event, what happened up until the emergency responders arrived. As you begin to gather information from the witnesses there are several critical data points to gather from witnesses. These points include: a) where were you when the event occurred; b) what did you see; c) what actions did you take when you witnessed/heard the event; d) did you assist the victim; e) what assistance did you provide; f) what was your job assignment for the day; g) how far along had you gotten on your assignments before this event occurred; h) ask if there is any additional information that might assist with investigation i) when you left the area, did you leave any unsafe conditions that need to be addressed immediately, j) what was the victim(s) assignment and; k) contact information for all witnesses, by-standers, and co-workers working on the job. Contact information should include name, employee number, home address and phone number and their email address.

While a team of ESH professionals are gathering witness statements, a second team should be establishing a safe work environment and investigating the physical evidence. Their investigation should include ensuring the site is in a safe state, that all the needed equipment experts are present and able to assist. A list should be created containing the names of all employees assisting with the investigation. It may seem unusual to gather names of employees however legal exports reviewing the incident later could call of you to recall who the experts were at the event and how they assisted in gathering information at the event scene. Once you have established a team to assist with the physical event site assessment, a process should be established to document everything associated with the event. This gathering of information should include photos and videos of everything in there current state and a progression of photos to help understand how things at the event presented and how you concluded with the event's root cause. An incident investigation document should include all make, model and serial numbers from event related equipment. It should also include the location of the equipment prior to the event and if it was displaced due to the blast, the location of the final resting place should be documented; including measurements from the origin to the destination, size of equipment (or pieces) and mass if possible. This information will help to establish the amount of force that was exerted from the event.

Case Study

Below is small portion of an investigation to allow for you to begin evaluating your response and who could assist should your facility have an electrical incident. The following is a summary of an event taken from a report published by the National Institute of Occupational Safety and Health (2001)

> At approximately 13:00, the fire department received a call stating that for smoke was coming from an electrical room inside the local department store. The fire department dispatched several units including the battalion chief to assist with the potential fire situation at a local department store. Upon arrival there was no lighting in the building, including emergency lighting. The responders met with the store manager and determine there was no additional smoke found and all customers and employees had been safely evacuated from the building. The store manager notified the fire department that he had contacted an electrician, the Assistant Building engineer and the Loss Prevention Engineer and they were in route to the facility. The Battalion chief cleared all units to return to services and requested assistance from the Assistant Chief with the Fire Prevention Bureau. Three individuals, the electrician, the Assistant Chief and the Assistant Building Engineer arrived at the store location and began to investigate the lighting problem. The electrician accompanied by the Assistant Chief and the Assistant Building engineer began investigating the problem with the emergency generator to evaluate why the generator had not started. Borrowing an inexpensive analog multimeter from the department store maintenance team the electrician tested the transfer switch and all appeared normal. The electrician then proceeded to the emergency breaker compartment where the utility power entered the store, removing the protective cover to expose the breaker lugs noting at that time there was a melted screw head in the compartment. Upon the initial evaluation of the incoming power, 480 volts 200 amp breaker, all phases, A, B, C, tested normal. The electrician was puzzled by his readings and observation of the melted screw head and stated "that is not right"

so he began to test the phases in the reverse order. He tested C phase and then B, when he touched the B phase an arc flash occurred.

The emergency responders were dispatched back to the store this time to assist with a medical emergency involving one of there own. The electrician, the Assistant Chief and the Assistant Building Engineer were transported to a local hospital with severe burns. The electrician, who was standing in from of the panel received 3rd degree on 98% of his body, the Assistant Chief, who was standing just to the left of the panel received 3rd degree burns on 96% of his body. Both men died from this event, the electrician died the next day and the Assistant Chief lost his battle 10 days later. The Assistant Building Engineer, who was standing behind the electrician received critical burns but survived the event.

When an electrical event like the one above occurs you should already know who your contacts will be and begin requesting assistance to ensure the area is safe and gathering all the witnesses to begin the investigation. As soon as possible a gathering of written statements documenting everything the employee(s) witnessed will need to be initiated and collected to help provide information on who, what, when, where, why and how the incident occurred. The second team of investigators will be summoned to evaluate the current state of the electrical equipment and ensure the area is safe prior to anyone entering the effected area to begin evaluating the physical evidence.

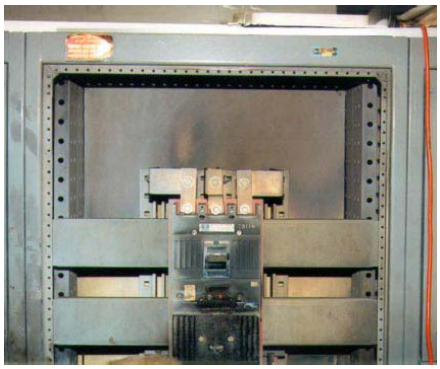

Exhibit 1. Emergency Power Breaker in Cabinet.

Exhibit 1 indicates the emergency power breaker, noticed the discoloration on the back portion of the breaker box.

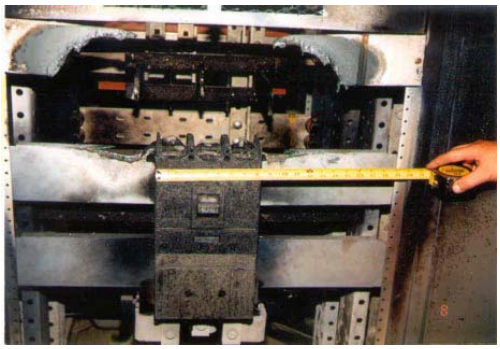

Exhibit 2. Remains of Panel and Breaker.

Exhibit 2 indicates the remains of the panel and breaker after the arc flash occurred. Notice the bus missing from the panel.

In conducting an investigation that involves electricity finding the root cause is only a portion of the investigation. You should always assume that an event involving people could lead to legal action by the injured party or the family of the injured party. It is critical to perform a thorough investigation which includes arc current calculations, incident energy calculations, and flash protection boundaries from the event. Lee (1982) conducted significant research on arc flash hazards in open-air. He identified curable burns by establishing a threshold for the human body as 1.2 cal/cm^2. To help understand how much energy 1.2 cal/cm^2 an example that is commonly used to describe a 1.2 cal/cm^2 burn is: take a butane lighter, light it and hold your hand over the blue portion of the flame for 1 second, this will produce a 2nd degree burn.

Doughty, Neal, Dear and Bingham (1997) provided us with a better understanding of how PPE protects the employee and how different levels of PPE can provide the needed protection based on arc flash hazard analysis. In addition, Doughty, Floyd and Neal (2000) established a means to calculate the potential arc hazard and this incident energy calculation is used in the NFPA 70E standard. Ammerman, Sen and Nelson (2007) conducted extensive comparisons to determine which formula should be used when performing the aforementioned calculations and the results indicated that although the formulas identified by IEEE 1584 are very inclusive, the formulas in the NFPA70E provide a conservative estimate with a drawback of possibly providing a higher level of protection than what might be needed. During an incident investigation it would be to your advantage to conduct calculations using both methods and to document the results as to which formulas were used. In addition to the calculations, the investigation of the event might uncover that your Hot Work Permit was not followed or implemented as a part of the current job you are investigating.

Conclusion

In summary, the ultimate goal is to stop electrical events from occurring at your facility. This paper discussed ways to achieve this goal. Achieving this goal starts with identifying the three basic external components which can cause injuries to workers and implementation of a risk assessment to mitigate risks or hazards which will reduce the number of electrical events from

occurring at your facility. Second, an extensive risk assessment of your facility should be conducted to ensure that the hazards of your facility are understood and appropriate measures are taken to reduce those hazards. Your risk assessment should include the evaluation of your existing electrical programs and processes and evaluation of your company's electrical training programs for all aspects of electrical safety. Third, when establishing incident investigation teams remember to identify the key players who will assist in the examination of the scene and identification of witnesses, prepare a method to collect relevant information about the incident and prepare an incident investigation report (Geddes & Roeder, 2006). Only facts of the event should be reported and documented. Speculation can lead to miscommunication and false information sharing. Fourth, preparation is critical in the event of an electrical incident. Preparation will assist your team in gathering pertinent information from the event and will assist you in identifying the root cause of the event.

Communicating the company's commitment to everyone understanding the hazards of electrical events and how to reduce or prevent the occurrence of electrical events makes good business sense. Unfortunately electrical events will continue to happen. Your response to electrical events at your facility is critical to ensuring the safety and well being of all your employees.

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