Electrical Safety in Motor Maintenance and Testing

By Dennis K. Neitzel, CPE

Introduction

Electrical safety in motor maintenance and testing carries the same requirements as any other work that involves working on or near exposed energized and deenergize parts of electrical equipment operating at 50 volts to ground or more. OSHA 29 CFR 1910.331-.335, "Electrical Safety-Related Work Practices" as well as NFPA 70E-2004, "Standard for Electrical Safety in the Workplace" provide the most up-to-date requirements for working safely with this type of equipment.

NFPA 70E-2004, Article 205, "General Maintenance Requirements", Section 205.1, "Qualified Persons" states: "Employees who perform maintenance on electrical equipment and installations shall be qualified persons as required in Chapter 1 and shall be trained in, and familiar with, the specific maintenance procedures and tests required."

Article 100 defines a qualified person as: "One who has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training on the hazards involved."

One of the key issues related to being a qualified person is to be trained in the hazards involved. This paper will address the hazards associated with working on or near electrical circuits and equipment, as well as the personal protective equipment (PPE) and safe work practices that must be used to protect workers from the hazards.

Electrical Hazards

We must first understand the hazards of electricity. All of the studies reviewed have revealed three major hazards of electricity, which are: 1) electrical shock, 2) electrical arc-flash and 3) electrical arc-blast. Each of these hazards will be addressed as to the physiological effect on the human body and the analysis needed to determine the extent of the hazard.

Electrical shock

It takes a very low value of current, flowing through the human body, to cause death or serious physical harm. Many studies have been performed in this area with different values of current that causes each effect. The following chart shows average values of current and the effects as taken from the published studies:

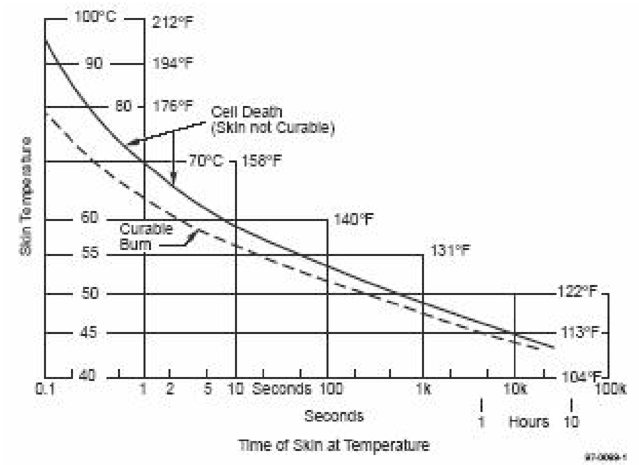
Current	*Effect*
1 mA	**Barely perceptible**
1-3 mA	**Perception threshold (most cases)**
3-9 mA	**Painful sensations**
9-25 mA	**Muscular contractions (can't let go)**
25-60 mA	**Respiratory paralysis (may be fatal)**
60 mA or more	**Ventricular fibrillation (probably fatal)**
4 A or more	**Heart paralysis (fatal)**
5 A or more	**Tissue burning (fatal if vital organ)**

Physiological Effects of AC Current on the Body

OSHA 29 CFR 1910.333, as well as NFPA 70E, Chapter 1 requires employees, who are exposed to the electrical shock hazard, to be qualified and that the circuits or equipment be deenergized and properly locked and tagged. However, if they must work the circuits or equipment energized then they must use safe work practices and procedures, and the appropriate personal protective equipment and insulated hand tools.

Electrical arc-flash

There are two different issues with this hazard, the arc temperature and the incident energy. The main concern with the arc temperature is the flash flame and ignition of clothing. At approximately 203^{0}F (96^{0}C) for one-tenth of a second (6 cycles), the skin is rendered incurable or in other words a third-degree burn. With only 1.2 cal/cm^2 of incident energy, we have the onset of a second-degree burn. It does not take a very high temperature or very much energy to cause extreme pain and discomfort to the worker.



Electrical arc-blast

The pressures developed by an electrical arc can be extremely high. One study noted that copper, when vaporized, expands at a factor of 67,000 times, which one expert estimated was the same expansion as that produced by dynamite. Doors or covers must be securely latched before operating a switch or circuit breaker. Technicians or operators must place their body in the safest position possible before operating the equipment.

Electrical Hazards Analysis

Recent changes in consensus standards, along with a better general understanding of the seriousness of electrical hazards have resulted in a renewal of interest in the subject of hazard analysis. The NFPA 70E-2004 addresses the requirements for conducting an “Electrical Hazard Analysis” with emphasis on the “Shock Hazard Analysis” and the “Flash Hazard Analysis”. NFPA 70E also tells us that if circuits operating at 50 volts or more are not deenergized (placed in an electrically safe work condition) then other electrical safety-related work practices must be used. These work practices must protect the employee for arc-flash as well as inadvertent contact with the live parts. These analyses must be performed before an employee approaches exposed live parts within the Limited Approach Boundary.

This paper will provide an overview of the principle types of electrical hazard analysis, along with a discussion of the relevant standards and regulations pertaining to the subject.

Shock Hazard Analysis

Each year several hundred workers are killed due to inadvertent contact with energized conductors. Because of this, the 2004 edition of NFPA 70E established a new requirement for conducting a “Shock Hazard Analysis” in order to determine the voltage that a person would be exposed to, establish shock protection boundaries, and determine the proper personal protective equipment.

Recent investigations into the causes of these fatalities point to three principle factors:

- Failure to properly or completely de-energize systems prior to maintenance or repair work;
- Intentionally working on energized equipment; and
- Improper or inadequate grounding of electrical system components.

These three factors form the basis for hazard analysis of the electrical shock hazard.

To appropriately assess the electrical shock hazard associated with any type of maintenance or repair work, it is necessary to evaluate the procedures or work practices that will be involved. These practices should be evaluated against regulations and consensus standards requirements as well as recognized good practice within the industry. These principles are summarized below.

OSHA Regulatory Requirements

- All equipment must be placed in a deenergized state prior to any maintenance or repair work. (Limited exceptions exist).
- The deenergized state must be verified prior to any work.
- The deenergized state must be maintained through the consistent use of locks and tags, and in some cases, grounding.

- When energized work is performed, it must be performed in accordance with written procedures.

NFPA 70E-2004 Standard Requirements

- The Shock Hazard Analysis must establish the:
  1. Limited Approach Boundary
  2. Restricted Approach Boundary
  3. Prohibited Approach Boundary
- This applies to all exposed live parts operating at 50 volts or more
- Only qualified persons are permitted within these boundaries.
- Unqualified persons may not enter these boundaries unless the conductors and equipment have been placed in an electrically safe work condition.

Industry Recognized Good Practices

- Plan every job.
- Anticipate unexpected results and the required action for these results.
- Use procedures as tools.
- Identify the hazards. Keep unqualified workers away from these hazards.
- Assess employee's abilities. Remember, there is a difference between ten years of experience, and one year of experience repeated ten times.

In addition to the assessment of work practices, the shock hazard analysis must include an assessment of the physical condition of the electrical system. The assessment must also identify the proper PPE for shock protection, which would include, but not be limited to, rubber insulating gloves with leather protectors, rubber blankets and mats, insulated hand tools, and properly rated test equipment.

Insulated Tools and Rubber Insulating Gloves

Of equal importance is to insure that equipment covers and guards are in place; that access to exposed conductors is limited to electrically qualified personnel; and overcurrent protective devices are operable and of appropriate interrupting rating. Even the safest procedures, when performed on poorly constructed or maintained equipment represent a risk to employees.

Flash Hazard Analysis

An estimated 75% to 80% of all serious electrical injures are related to electrical arcs created during short circuits and switching procedures. In recognition of this fact, standards organizations such as the National Fire Protection Association (NFPA) have provided the industry with better techniques to evaluate both the magnitude of the electrical arc hazard and appropriate protective clothing and equipment.

An electrical arc is basically an electrical current passing through ionized air. This current flow releases a tremendous amount of energy as both radiated light and convected heat. The amount of liberated energy is obviously dependent upon the system configuration, but the principle factors used in the determination of the hazard to personnel are as follows:

1. Available short circuit current at the arc location.
2. Duration of the electrical arc (protective device clearing time).
3. Distance from the arc to personnel.
4. The arc gap.
5. Environmental conditions and surroundings at the arc location.

To accurately assess the arc hazard, and make appropriate decisions regarding personal protective clothing, it is necessary to fully understand the operation of the system under fault conditions. This requires both a short circuit analysis, in all likelihood down to the panel board level, and a protective devices coordination study. It is a common misconception that arc hazards are an effect of only high voltage. The actual arc hazard is based on available energy, not available voltage. In certain conditions, a low voltage arc's duration is longer than a high voltage arc. With this information available, the magnitude of the arc hazard at each work location can be assessed using several techniques. These techniques include:

- NFPA 70E-2004 Equations and Tables.
- IEEE Std. 1584-2002.
- SKM, E-Tap, EDSA, EasyPower, and other similar engineering software.

Each of these techniques requires an understanding of anticipated fault conditions, and the limitation of the calculation method, both of which are beyond the scope of this paper.

The results of the arc hazard assessment are most useful when they are expressed in terms of the incident energy received by exposed personnel. Incident energy is commonly expressed in terms of calories per cm^2 (cal/cm^2). Arc protective clothing is rated in terms of its Average Thermal Performance Value (ATPV), also expressed in terms of cal/cm^2.

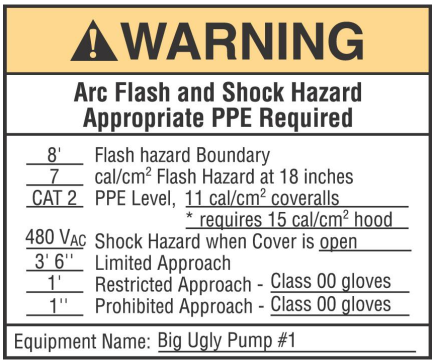
In addition to flame-resistant (FR) clothing and PPE, there are some safe work practices that can be adopted to minimize or eliminate the hazards. These practices include clothing, body positioning, insulated tools, and other factors that must be carefully scrutinized to insure that the risk to employees is minimized. The first choice should be to minimize or eliminate the hazard; however when this is not possible FR rated clothing and PPE must be utilized.

Workers wearing FR protection

The 2005 NEC Section 110.16 states, “Switchboards, panel-boards, industrial control panels, and motor control centers that are in other than dwelling occupancies and are likely to require examination, adjustment, servicing, or maintenance while energized shall be field-marked to warn qualified persons of potential electrical arc-flash hazards. The marking shall be clearly visible to qualified persons before examination, adjustment, servicing or maintenance of the equipment.”

Section 80.9(B) sets forth the provision for the Authority Having Jurisdiction to require all existing equipment to be marked if it is determined that non-conformity would present an eminent danger condition to occupants or qualified workers. Because of the NEC 2002 requirements, we can conclude the following:

1. The 2002 NEC requires equipment to be field-marked to warn of potential flash hazards.
2. The energy level will have to be determined from Short Circuit and Protective Device Coordination Studies.
3. The Authority Having Jurisdiction may require all facilities to be marked.



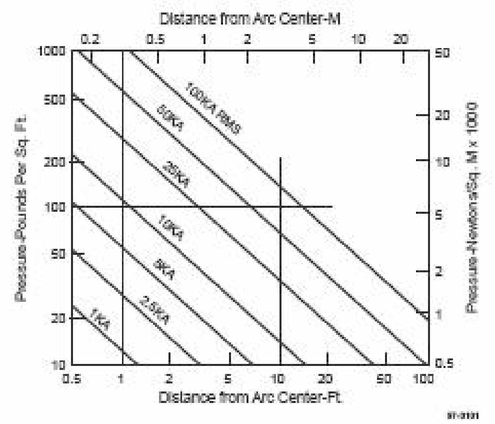
Recommended Warning Label

As with the electrical shock hazard, the easiest and most effective way to mitigate the arc hazard is to completely de-energize the system for any type of maintenance activity.

Blast Hazard Analysis

An electrical blast, or explosion, as it is often termed, is the result of the heating effects of electrical current and the ensuing arc. This phenomenon occurs in nature as the thunder that accompanies lightning, a natural form of an electrical arc.

During an electrical arc, both the conducting material and the surrounding air are heated to extremely high temperatures. The resulting expansion of the air and vaporized conductive material creates a concussive wave surrounding the arc. The pressures in this wave may reach several hundred lbs/ft^2, destroying equipment enclosures and throwing debris great distances. Pressures as low as 50 lbs/ft^2 have knocked down cinderblock walls several feet away. The pressure created during an electrical explosion is directly proportional to the available short circuit at the arc location. With an up-to-date short circuit study available, the anticipated blast pressure can be estimated from tables or charts.



Unfortunately, little can be done to mitigate the blast hazard, at least in terms of personal protective clothing or equipment. Blast pressure calculations can be used to determine whether enclosures will withstand an internal fault if sufficient manufacturer's data is available. Again, it may be more important to merely recognize the magnitude of the hazard so that appropriate safety practices, such as correct body positioning can be incorporated into work procedures. If the blast hazard is high, or if it is in a limited space, the blast can severely injure or kill a person. If these conditions are present, serious consideration should be given to not allowing personnel in the area during specific equipment operations.

Selection of Electrical Protective Equipment

Most employers, operators, and electricians are knowledgeable in the selection and inspection requirements for electrical PPE used for the prevention of electrical shock hazards, as well as head, eye, hand, and foot protective equipment. These requirements are readily found in OSHA 29CFR1910, Subpart I, "Personal Protective Equipment" with 1910.137 covering "Electrical Protective Equipment" which also provides requirements for the in-service care and use of electrical protective equipment. Unfortunately, most have limited knowledge or experience with the arc and blast hazards that may be associated with the maintenance, testing, and operation of energized electrical equipment and the necessary protective clothing and equipment that would be required.

The OSHA requirements for the hazard analysis and selection of protective clothing are found in 29CFR1910.132, "General Requirements for Personal Protective Equipment", paragraph (d) states "The employer shall assess the workplace to determine if hazards are present, or are likely to be present, which necessitates the use of Personal Protective Equipment (PPE). If such hazards are present, or likely to be present, the employer shall: "Select, and have each employee use, the type of PPE that will protect the affected employee from the hazards identified in the hazard assessment."

1910.132 (f) – Training (1) states: "The employer shall provide training to each employee who is required by this section to use PPE. Each such employee shall be trained to know at least the following:"

- When PPE is necessary;
- What PPE is necessary;
- How to properly don, doff, adjust, and wear PPE;
- The limitations of the PPE; and
- The proper care, maintenance, useful life, and disposal of PPE.

Included in this hazard assessment should be the three electrical hazards; shock, arc, and blast. 1910.137 identifies the selection, inspection, and use requirements for electrical PPE. OSHA does not identify specific clothing that should be worn to protect the employee from the arc-flash hazards but OSHA does specify what type of clothing is prohibited. OSHA states "Clothing made from the following types of fabrics, either alone or in blends, is prohibited…, unless the employer can demonstrate that the fabric has been treated to withstand the conditions that may be encountered or that the clothing is worn in such a manner as to eliminate the hazard involved: acetate, nylon, polyester, rayon."

OSHA also requires protection from the hazards of electricity in 1910.335(a)(2)(ii) which states: "Protective shields, protective barriers, or insulating materials shall be used to protect each employee from shock, burns, or other electrically related injuries while that employee is working near exposed energized parts which might be accidentally contacted or where dangerous electric heating or arcing might occur."

If, during the operation, insertion, or removal of a circuit breaker, a fault occurs, the worker may be exposed to an electric arc with temperatures up to 35,000ºF. Unprotected workers exposed to an increase in skin temperature of 203ºF for 0.1 second or 1.2 cal/cm^2 of energy may suffer second or third degree burns and ignition of clothing. Protective clothing, including a complete multi-layered flash suit with hood and face shield, may be required for these activities.

Once it has been determined that protective clothing and/or equipment is necessary to perform the specific task, it must be purchased and the employees trained to wear it properly. Having the properly sized and rated clothing will provide protection of the employee when performing the task. The required PPE may be uncomfortable to wear, especially in hot climates but it is better to suffer ten minutes in an uncomfortable environment then ten months, or longer, in a burn center.

Summary

In analyzing and resolving the issues of electrical hazards in the industry, we must follow a path that will lead to a comprehensive analysis of the problems that exist and provide a quantified value to ensure the selection of appropriate personal protective equipment. An analysis of all three hazards; shock, arc, and blast must be completed and steps taken to prevent injuries. The following are steps that could be taken to ensure adequacy of the electrical safe work practices program and training of "qualified" electrical personnel:

1. Conduct a comprehensive Job Task Analysis.
2. Complete a Task Hazard Assessment including:
   a. Shock hazard.
   b. Arc-flash hazard (using current Short Circuit and Coordination Studies).
   c. Blast hazard.
   d. Other hazards (Slip, fall, struck-by, environmental, etc.).
3. Analyze task for the Personal Protective Equipment needed.
4. Conduct Training Needs Assessment for Qualified and non-qualified electrical workers.
5. Revise, update, or publish a complete Electrical Safe Work Practices Program.

Regulatory agencies and standards organizations have long recognized the need to analyze the hazards of electrical work and plan accordingly to mitigate the hazards. Unfortunately, many in the electrical industry have chosen to "take their chances", largely because nothing bad has yet to happen. As more information becomes available on the economic and human costs of electrical accidents, it is hoped that more in the industry will recognize the need for systematic hazard analysis, and an electrical safe work program that emphasizes hazard identification and abatement.

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