Electrical Hazards Analysis

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Abstract The subject of electrical hazards analysis has been recognized by a small segment of the electrical industry for many years. The petrochemical industry and many government institutions have performed research on this subject for over twenty years. For the most part however, the electrical industry, at least at the user level, has largely ignored the subject, essentially reacting to catastrophic accidents, rather than proactively trying to predict and prevent them. 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.

As the awareness of electrical hazards increase many are puzzled by phrases like; "Limited", "Restricted", and "Prohibited Approach Boundary", and "Flash Protection Boundary". Understanding these terms is important to understanding shock and arc-flash hazard protection.

NFPA 70E-2004, Standard for Electrical Safety in the Workplace requires that an electrical hazards analysis be performed prior to working on or near exposed energized electrical conductors and circuit part operating at 50-volts or more. This is especially critical if the circuits have not been placed in an electrically safe work condition.

This paper will address the requirements to perform the "Shock Hazard Analysis" and the "Flash Hazard Analysis" required by NFPA 70E-2004, Section 110.8(B)(1), "Electrical Hazard Analysis" as well as the "Blast Hazard Analysis" and personal protective equipment requirements.

I. INTRODUCTION

Below are the definitions of these terms as found in NFPA 70E-2004, Article 100: [1]

Limited Approach Boundary- "An approach limit at a distance from an exposed live part within which a shock hazard exists." NOTE: Limited Approach Boundary may be more or less than Flash Protection Boundary as illustrated in Figure 1.

Restricted Approach Boundary- "An approach limit at a distance from an exposed live part within which there is an increased risk of shock, due to electrical arc over combined with inadvertent movement, for personnel working in close proximity to the live part."

Prohibited Approach Boundary- "An approach limit at a distance from an exposed live part within which work is considered the same as making contact with the live part."

Flash Protection Boundary- "An approach limit at a distance from exposed live parts within which a person could receive a second degree burn if an electrical arc flash were to occur."

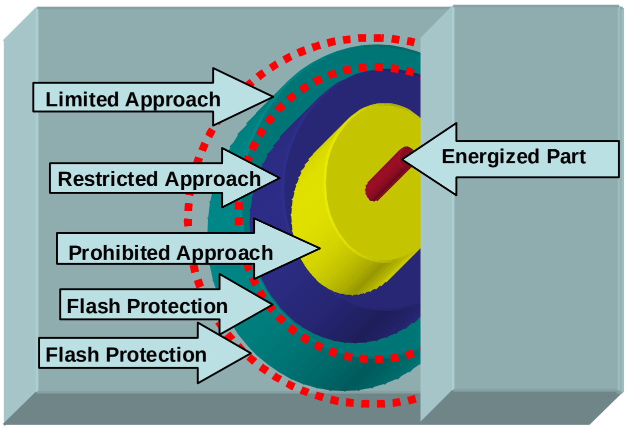

Figure 1
Illustration of Boundaries

The NFPA 70E-2004, "Standard for Electrical Safety in the Workplace", addresses the requirements for conducting an "Electrical Hazard Analysis" with emphasis on the "Shock Hazard Analysis" and the "Flash Hazard Analysis". NFPA 70E-2004 states 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 from an arc flash, as well as inadvertent contact with live parts operating at 50 volts or more. Each analysis must be performed before an employee approaches exposed live parts, within the Limited Approach Boundary. NFPA 70E-2004, paragraph 130.2(B) FPN provides a reminder that the Flash Protection Boundary may be a greater distance from the exposed live parts than the Limited Approach Boundary, in some instances.

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

II. Shock Hazard Analysis

Each year several hundred workers are injured or killed due to inadvertent contact with energized conductors. Surprisingly, over half of those killed are not in traditional electrical fields (i.e. linemen, electricians, technicians, etc.), but are from related fields such as painters, laborers, and drivers. [Detailed surveillance data and investigative reports of fatal incidents involving workers who contacted energized electrical conductors or equipment are derived from the National Traumatic Occupational Fatalities (NTOF) surveillance system maintained by the National Institute for Occupational Safety and Health (NIOSH)]. NFPA 70E-2004 established a requirement for conducting the “Flash Hazard Analysis” to assist in reducing these injuries and fatalities.

This analysis will: determine the voltage that a person would be exposed to, establish the shock protection boundaries, and identify the personal protective equipment requirements.

Investigations into the causes of injuries and fatalities point to several contributing factors [2]:

- Contacting overhead power lines;
- Faulty insulation;
- Improper grounding;
- Loose connections;
- Defective parts;
- Ground faults in equipment;
- Unguarded live parts;
- Failure to deenergize electrical equipment when it is being repaired or inspected;
- Intentional use of obviously defective and unsafe tools; or
- Use of tools or equipment too close to energized parts.

These factors form the basis for a shock hazard analysis.

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 both regulatory 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).[3][4]
- The deenergized state must be verified by a qualified person prior to beginning any work.[3]
- The deenergized state must be maintained through the consistent use of locks and tags, and in some cases, grounding.[3][4][5]
- When energized work is performed, it must be performed in accordance with written procedures.[3][6]

NFPA 70E-2004 Standard Requirements [1]

- The Shock Hazard Analysis [110.8(B)(1)] 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 [110.8(A)(2)]. NOTE: A qualified person shall be trained and knowledgeable of the construction and operation of equipment or a specific work method, and be trained to recognize and avoid the electrical hazards that might be present with respect to that equipment or work method.
- Paragraph 110.8 (B)(3) states that unqualified person may not enter these boundaries unless the conductors and equipment have been placed in an electrically safe work condition. However, paragraph 130.2(D)(2) allows unqualified persons to enter the Limited Approach Boundary only, but a qualified person must advise them of the hazards and continuously escort the them while they are inside the boundary. NOTE: An employee, who is undergoing on-the-job training and who, in the course of such training, has demonstrated an ability to perform duties safely at his or her level of training and who is under the direct supervision of a qualified person shall be considered to be a qualified person for the performance of those duties.

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. An OSHA premise is that electrical equipment installed safely per a nationally recognized code is safe until deterioration occurs, unsafe acts are performed or carelessness take place. The assessment must also identify the proper personal protective equipment (PPE) for shock protection, which could include, but not be limited to, rubber insulating gloves with leather protectors, rubber blankets and mats, and insulated hand tools.(see Fig. 2 for examples of PPE)

Figure 2
Insulated Tools and Rubber Insulating Gloves

Another consideration is the continuity and low resistance of the equipment grounding system, which is a major concern. Of equal importance is to ensure 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

Two industrial electricians began work in the basement electrical room one day. They wanted to take some physical measurements and knew the switchgear was energized but were in a hurry to get started. As they were taking measurements on the bus with a wooden ruler the metal tip of the ruler made contact with the bus and caused a massive electric arc. The arc-flash only lasted a fraction of a second. Although no one was electrocuted, one man died instantly from the arc-flash and the other man was badly burned. The man that died was within 24 inches of the bus while the other man was about ten feet away.

A large number of serious electrical injures are related to electrical arcs created during short-circuits and switching procedures. In recognition of this, standards organizations such as the National Fire Protection Association (NFPA) and the Institute of Electrical and Electronics Engineers (IEEE) have provided the industry with better techniques to evaluate both the magnitude of the electrical arc hazard and appropriate protective clothing and equipment.

Human errors and equipment malfunctions contribute to the initiation of an electrical arc. Engineering design and construction of arc resistant equipment as well as requirements for safe work practices are continuing to target the risk of electrical arc-flash hazards. 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 along with radiant 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.
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 (PPC) and equipment, it is necessary to fully understand the operation of the system under fault conditions. The assessment must also include matching the appropriate PPC for arc flash hazard, which would include, but not be limited to, flame resistant (FR) clothing, face shield, flash suit with hood. (See Fig. 3 for example of PPC). This requires both a short-circuit analysis, in all likelihood down to the panel board level, and a protective device 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, Standard for Electrical Safety in the Workplace, 2004 Edition
- IEEE Std. 1584-2002, IEEE Standard for Performing Arc-Flash Hazard Calculations

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-flash hazard analysis 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-flash protective clothing is rated in terms of its Arc Thermal Performance Value (ATPV), also expressed in terms of cal/cm^2.

In addition to flame-resistant (FR) PPC and PPE, there are some safe work practices that can be adopted to minimize or eliminate the hazards. These practices include lockout/tagout along with temporary grounding, body positioning, clothing, 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 PPC and PPE must be utilized.

Figure 3
Worker wearing an FR Rated Flash Suit

National Electrical Code 2005 Flash Protection Requirements

The 2005 NEC Section 110.16 states, “Switchboards, panelboards, industrial control panels, meter socket enclosures, 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 electric arc flash hazards. The marking shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment.” Section 110.16 also has a FPN No. 1 that refers to NFPA 70E-2004 for “assistance in determining severity of potential exposure, planning safe work practices, and selecting personal protective equipment.”

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.

III. 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. The pressure created during an electrical explosion is directly proportional to the available short-circuit at the arc location. With a current short-circuit study available, the anticipated blast pressure can be estimated from tables or charts. [7]

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.

IV. 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 PPC used for head, eyes and face, hands, and foot protection. All of these requirements are readily found in OSHA 1910, Subpart I, Personal Protective Equipment. Although not addressed in OSHA 1910, Subpart I, body protection would also be required as addressed in NFPA 70E-2004. OSHA 1910.137, Electrical Protective Equipment, provides the requirements for the in-service care and use of electrical protective equipment. Unfortunately, most employers, operators, electricians, and engineers have limited knowledge or experience with regard to arc and blast hazards that may be associated with the maintenance and operation of energized electrical equipment and the necessary PPE/PPC that is required.

The OSHA requirements for the hazard analysis and selection of protective clothing must first be defined.

OSHA 1910.132, 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.”

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

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

Included in this hazard assessment should be the three electrical hazards; shock, arc, and blast. OSHA 1910.137 identifies the selection, inspection, and use requirements for electrical PPE/PPC. 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.

1910.269(l)(6)(ii) requires that "The employer shall train each employee who is exposed to the hazards of flames or electric arcs in the hazards involved." Additionally, 1910.269(l)(6)(iii) states "The employer shall ensure that each employee who is exposed to the hazards of flames or electric arcs does not wear clothing that, when exposed to flames or electric arcs, could increase the extent of injury that would be sustained by the employee."

"**Note:** Clothing made from the following types of fabrics, either alone or in blends, is prohibited by this paragraph, 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 does, however, require 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 as well as high levels of incident energy. 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.

The consensus standard for determining the necessary clothing and training is NFPA 70E-2004, "Standard for Electrical Safety in the Workplace". In order to properly select rated PPE/PPC to provide this protection, the employer has but two options. The employer must calculate the incident energy (in cal/cm^2) available at the work site, and the protective clothing required for the specific task, or as an alternative, use NFPA 70E Table 130.7(C)(9)(a) "Hazard/Risk Category Classifications" to identify the clothing required for the hazards associated with the specific task the employee is to accomplish. **Caution** must be used if applying Table 130.7(C)(9)(a) because the short-circuit current and protective device clearing time must be known as stated in the notes at the end of the table.

Note: The employer must also determine the "Flash Protection Boundary" in accordance with paragraph 130.3(A) for all energized work. The "Flash Protection Boundary" establishes the approach limit to exposed live parts where a person could receive a second degree burn.

Once it has been determined that protective clothing is necessary to perform the specific task, the necessary protective clothing must be procured and the employees trained to wear it properly.

Summary

In resolving the issues of analyzing electrical hazards in an 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 protection. An analysis of all three hazards, shock, arc, and blast must be completed and steps taken to prevent injuries. The following steps 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 up-to-date Short-Circuit Current and Protective Device Coordination Studies, plus arc-flash hazard calculations).
    c. Blast hazard
    d. Other hazards (Slip, fall, struck-by, environmental, etc.)
3. Analyze task for the Personal Protective Equipment /Personal Protective Clothing 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".
6. Conduct training in the "Electrical Safe Work Practices"

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 a systematic hazard analysis, and an electrical safe work program that emphasizes hazard identification and abatement.

REFERENCES

[1] NFPA 70E-2004, Standard for Electrical Safety in the Workplace

[2] OSHA 29 CFR 1910, Electrical Standards, Federal Register Vol. 46, No. 11, Friday, January 16, 1981, Supplementary Information, I. Background, *(3) Nature of Electrical Accidents, (a) Basic Contributory Factors.*

[3] OSHA 29 CFR 1910.331-.335, Electrical Safety-Related Work Practices, August 6, 1990

[4] OSHA 29 CFR 1910.147, Control of Hazardous Energy Source (Lockout/Tagout), September 1, 1989

[5] OSHA 29 CFR 1910.269, Electric Power Generation, Transmission, and Distribution, January 31, 1994

[6] OSHA Instruction STD 1-16.7, Directorate of Compliance Programs, July 1, 1991

[7] Ralph H. Lee, "Pressures Developed by Arcs", IEEE Transactions on Industry Applications, Vol. IA-23, No. 4, p. 760, July/Aug. 1987.

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