2006-491: THE IMPORTANCE OF ELECTRICAL SAFETY TRAINING IN UNDERGRADUATE POWER ENGINEERING EDUCATION

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The Importance of Electrical Safety Training in Undergraduate Power Engineering Education

Abstract

At Colorado School of Mines (CSM) there is a unique opportunity to educate the future electrical engineers about the vital topic of electrical safety. All electrical specialty undergraduate students are required to take a three-week (3-credits) Field Session course during the summer months between their junior and senior years. This paper discusses the outline and the theoretical framework of the electrical safety training and education program currently being developed and implemented in the CSM undergraduate degree curriculum.

Introduction

Arguably one of the most significant engineering accomplishments of the 20th century was the electrification of our modern world. The widespread availability of electricity forever changed our lives, providing a convenient source of energy for our homes and businesses. Even though electricity plays such a critical role, it is frequently misunderstood and often times is not treated with respect and caution based on the inherent hazards. According to the National Institute for Occupational Safety and Health (NIOSH) [1], an average of one worker is electrocuted on the job every day in the United States. Statistics indicate that additional injuries and deaths occur because of arc flash events. Within the U.S., arc flash explosions occur at the rate of five to ten per day.[2]

Tremendous progress in the broad area of electrical safety has occurred during the past three decades, advancing the overall understanding of how to recognize electrical hazards and take the appropriate precautions (developing Codes and Regulations) to ensure that the exposure to hazards does not result in injury or death and to minimize the equipment damage and loss of production. Not surprisingly, most of this work has been conducted and accomplished outside of academia. For example, at the 2006 IEEE IAS Electrical Safety Workshop held in Philadelphia, PA, less than 1% of the participants represented academic institutions.[3]

At CSM, in the undergraduate curriculum currently offered for the B.S. in Engineering (Electrical Specialty), there is a unique opportunity to instruct the future electrical engineers about the importance of electrical safety. All undergraduate students are required to take a three-week (3-credits) Field Session course. This opportunity doesn't normally exist in traditional engineering programs. To address the vulnerability of young technical personnel and engineers to electrical incidents, a week-long module on electrical safety education is now a permanent part of the (Electrical Specialty) Engineering Field Session curriculum at CSM. The primary objective of the module is to equip the students with the necessary skill set to be able to recognize and avoid or control the hazards posed by electrical work. The different types of electrical hazards, the health effects of electrical incidents, methods of limiting the exposure, and the pertinent safety standards are described. This course was designed to provide the students with a thorough overview of the essential topic of electrical safety in an active learning environment.

A common criticism from industry representatives is that their new hires have very little understanding of how to conduct themselves safely in the work environment. Universities have largely overlooked this important aspect of a student's training and development. In collaboration with the National Renewable Energy Laboratory (NREL), a national laboratory of the U.S. Department of Energy, CSM is working to address this deficiency. NREL recognizes and embraces as a core value, the elements of electrical safety. Regular workers, subcontractors and students alike must have the required skill set to conduct work safely. Guidance provided by NREL safety engineers has been instrumental in helping CSM to develop a level of student training that has far reaching benefits.

Why We Teach Electrical Safety?

The IEEE Standard 902-1998, Guide for Maintenance, Operation, and Safety of Industrial and Commercial Power Systems[4], emphasizes "*We should work safely ourselves, look out for the safety of those around us, and help educate as many people as we can about electrical safety.*"

IEEE Std 902-1998 identifies the following reasons for practicing electrical safety:

- <u>Human Factor:</u> Injury, death, and emotional trauma are common adverse affects of electrical incidents. As the term incident implies, most injuries or fatalities caused by electrical hazards are predictable and as a result avoidable.
- <u>Business Considerations:</u> Electrical incidents resulting in injury, death, loss of production or property damage are very costly to businesses.
- <u>Regulatory Reasons:</u> Laws dictating requirements for electrical safety must be followed. Failure to comply can result in fines to a business or imprisonment of the individuals responsible for seeing that the laws are followed.

The NFPA 70E Handbook[5] identifies the fact that unsafe equipment and facilities (design issues) account for 33% of all electrical incidents and injuries. The remaining 67% are attributed to unsafe acts. It is important that students understand their professional responsibilities as engineers. The electrical safety training they receive in the early stages of their education emphasizes that engineers are required to design safe products, systems, homes, and workplaces. Engineers are also required to safely perform or supervise work on electrical systems. Therefore, an engineer is required to understand the hazards inherent to an electrical environment and adhere to the applicable engineering standards necessary to protect personnel and property.

Teaching Electrical Safety: Theoretical Framework

A recent NIOSH publication, which focuses on mine safety training, emphasizes the importance of developing educational materials that provide the motivation to learn. Many important lessons about safety training can be learned from the mining industry, because since 1977 extensive safety training has been mandated for all mine workers. "*Their most memorable learning came from personal experiences, from working within groups of other adult learners, and from mentoring they received from someone they perceived to be both knowledgeable and wise.*"[6] The authors of the report then observe; "*In spite of this preference for real-world training, over 70% of current training in organizations was still the talking-head variety, with a* *trainer in front of a classroom and the trainees sitting and listening passively. It's no wonder that trainees are impatient with this type of training.*"[6]

During the Field Session class, students are required to attend 40 hours of training each week. Students are completely immersed in the topic of electrical safety for an entire week. Our experience developing the training material shows that electrical safety training does not have to be boring. Students are not taking other courses during their field session training so they are able to devote their complete attention to the subject matter. This intensive focus helps to emphasize the importance of electrical safety. The approach would have to be modified if the same material were to be presented over a 15 week semester. The distinctive character of our summer field session course provides an ideal opportunity for us to employ a number of innovative approaches for instruction which are described below.

(1) Active Learning: Much has been written about the importance of actively engaging students in the learning process. A meta-analysis performed by Springer et al. concludes "*that various forms of small-group learning are more effective in promoting greater academic achievement, more favorable attitudes toward learning, and the increased persistence in Science, Mathematics, Engineering, and Technology courses and programs.*"[7] Educational research reveals that the more students work in cooperative learning groups the more they will learn. The electrical safety course module features many cooperative learning techniques. All the work assignments designed for the electrical safety training module are to be completed by student teams.

(2) Social Learning Theory: Social learning theory advances the concept that people learn by observing others. The important work of Bandura focused on the cognitive processes that occur when we observe others. He maintains that "*Virtually all learning phenomena resulting from direct experiences can occur on a vicarious basis through observation of other peoples' behavior and its consequences for the observer.*"[8] This learning theory is extremely relevant to electrical safety training because it suggests an effective way to create meaningful lessons. The reason we provide training is to try and change people's behavior in some fashion. Social learning theory is commonly adopted because of its applicability to changing the behaviors and beliefs of individuals toward adopting healthier and safer choices. Adult learners may learn best by experience, but in the case of electrical incidents, adults can learn by reflecting on the experiences of others. Much of the curriculum we developed for use in the Field Session features the use of electrical incident case studies. These real life stories generally have tragic outcomes. The case studies are compelling, providing a graphic reminder about the consequences of not following fundamental safety practices. Students can learn many valuable lessons about how to conduct themselves safely in an electrical environment by listening to these visceral stories. In addition, this is a practical way to have students observe a number of varied electrical incidents during a one-week course module. While there are many resources available for obtaining electrical incident case studies, we have chosen to use examples that are posted on the NIOSH Electrocution Fatality Investigation Reports Web site.[9]

(3) Mentoring: Another important aspect of the social learning theory is mentoring. "*Explanations of learning may need to focus on more than overt behavior*."[10] It is important to provide appropriate role models when teaching electrical safety. A number of guest lecturers are

brought in during the week to help deliver the electrical safety information to the class. A senior industrial safety engineer from NREL, a safety officer from CSM's Environmental Health and Safety Department, electricians and engineers from CSM's Plant Facilities, a NFPA code authority, and engineers from a large power plant all assist in delivering the safety message. The students, recognizing the credibility of the safety experts, and the relevance of the information being conveyed, are usually very attentive and rate this part of the experience very high.

(4) Addressing Students' Misconceptions: At CSM we have been involved in research that provides evidence that the mental models used by students can often be faulty even after advanced coursework has been completed. The study shows that undergraduates with advanced training in physics and electrical engineering may still view electrical processes like voltage and current as substances.[11] [12] A substance-based view of electrical phenomenon may not adversely impact students' ability to perform circuit calculations, but it can significantly affect their ability to work safely in an electrical environment. Consequently, the misconceptions regarding voltage and current can have dire consequences. Our research provides evidence that safety training involving a discussion of step potentials, touch potentials, and the importance of grounding electrical systems may be an effective way to help students address their misconceptions regarding electrical processes.

Collaboration with the National Renewable Energy Laboratory

At CSM we are fortunate to be located near the National Renewable Energy Laboratory (NREL), a national laboratory of the U.S. Department of Energy. NREL is a leader in industrial safety education and practice. The challenges and risks faced by a national laboratory when conducting research are formidable and dynamic. The nature of the work embodies change. To address this environment of continuous change, NREL has established a formal process for identifying and evaluating the hazards presented by research activities so that appropriate controls can be implemented to maintain an acceptable level of risk. This process begins during the conceptual development of the research activity. The researcher, working with their Environment, Safety, and Health (ES&H) Office Point of Contact, begins this process by conducting a safety assessment. This assessment identifies the hazards and maps out the risk assessment techniques that will be applied to assure that an appropriate set of controls are established and implemented, and that they will evolve to keep pace as the work changes. Many organizations view "management of change" as a separate safety mechanism. At NREL it is integrated into a continuous and effective risk assessment process. NREL's concept of risk and hazard assessment applies to all aspects of work.

At CSM one of our goals is to train students to evaluate the risks associated with energized electrical work environments. The hazards must be identified and evaluated so that the necessary set of controls (e.g. selecting the proper Personal Protective Equipment (PPE) compliment and defining the approach boundaries) can be implemented to assure an individual's safety. With guidance from a senior industrial safety engineer from NREL, we have been given the opportunity to develop a similar proven risk assessment program at the university level. Instructors developing the CSM Electrical Safety Module have attended Electrical Safety Training sessions at NREL. In addition, NREL has provided copies of their Laboratory-Level Electrical Safety Procedures Manual and Safety Hazard Identification and Control Program.

NREL also supports our safety program by providing guest lecturers and training material. We believe that our partnership with NREL allows us to provide a level of electrical safety training for our students that is unprecedented.

Electrical Safety Course Curriculum

Energy Systems, Machines and Power Electronics represent one of the major electrical focus areas at CSM. A more detailed description of CSM's Power Engineering Curriculum is provided in another paper accepted for publication at the 2006 Annual Conference of the American Society for Engineering Education.[13] The Electrical Safety Training Module that is included as part of the Electrical Specialty Field Session is described below. In the required Field Session course, students must participate in a minimum of 40 hours of training each week. This opportunity doesn't normally exist in traditional engineering programs. This gives CSM a unique opportunity to educate the future engineers about the important topic of electrical safety. The course curriculum we developed for the Field Session Electrical Safety Module focuses on the following topics:

(1) Exposure to Electrical Hazards: NFPA 70E, Standard for Electrical Safety in the Workplace, defines an electrical hazard as: "*a dangerous condition such that contact or equipment failure can result in electric shock, arc flash burn, thermal burn, or blast.*"[5] In general, there are three major categories of injury that may result while working on or near electrical equipment.

- Electrical Shock: Electric shock is caused by the release of energy when a person contacts a live circuit. The primary factors affecting the severity of the shock depends on the current magnitude flowing in the person's body, the path that the current takes, and the time duration. The effects of electric shock vary dramatically ranging from a barely perceptible tingle to death.
- Burns: Another common shock-related injury is a burn. Burns are the most common result of a nonfatal electric shock, which may cause very serious injuries, requiring specialized medical treatment.
- Impacts from Blasts: An arc-blast is defined as the explosive release of molten material from equipment caused by high-amperage arcs. Arc-blasts occur when high currents arc through the air because of equipment failure.

(2) Managing Electrical Hazards: Over the past century, from experience and detailed scientific and engineering analyses, engineers have developed methods to significantly reduce specific electrical hazards. For example, the ground fault circuit interrupter (GFCI) is credited for a 50% reduction in residential electrocutions since its development nearly forty years ago.[14] Some of the most common methods used to protect people from the hazards related to the exposure to electrical installations are presented to the students:

- Insulation: Contact with bare energized conductors can be significantly reduced through the use of insulation, e.g. the use of nonconductive gloves and shoes. Hotsticks are another example of how workers can be insulated from bare energized conductors.

- Interlocks: Electrical interlocks automatically de-energize equipment whenever a protective enclosure is opened.
- Warning Signs: Warning signs are often posted at points of access to hazardous electrical systems.
- Isolation: Barriers are used to isolate untrained personnel from electrical hazards. Unauthorized personnel must be prevented from exposure to a potentially dangerous situation.
- Ground Fault Circuit Interrupters (GFCI): A GFCI monitors a system and interrupts the circuit for ground faults by sensing the current flow in a system.
- Grounding and Bonding: Grounding provides an alternative low resistance path to ground, thereby protecting people from receiving a current due to a fault. Bonding is a form of grounding in which all major parts of a system are linked with an effective conductor to provide a continuous path to ground. Bonding is a physical connection between separate parts of a system.
- Double Insulation: Double insulating involves enclosing the electrical components of equipment in a layer of insulation, and then enclosing that within a case made of nonconductive material.
- Arc Fault Circuit Interrupters: An arc fault circuit interrupter is designed to monitor and protect systems for arcing faults.
- Arc Resistant Switchgear: The energy from an arc flash and blast is directed away from personnel.
- Proper Applications and Better Coordination of Protective Devices

(3) Codes, Regulations and Standards: There are many codes, regulations and standards written that pertain to electrical safety which must be strictly followed. Laws, standards, and recommended practices relating to electrical safety include:

a. Occupational Safety and Health Administration (OSHA): OSHA's mission is "*to assure the safety and health of America's workers by setting and enforcing standards.*" The OSHA standards are federal law that must be followed.
   Title 29 of the Code of Federal Regulations (29 CFR)[15] deals with:
   - Part 1910: General Industry; safety standards for electrical systems and safety-related work practices.
   - Part 1926: Construction Industry; general electrical practices and standards for power transmission and distribution.

b. National Fire Protection Administration (NFPA): The NFPA has acted as the sponsor of the National Electrical Code since 1911. The NFPA publishes a number of standards covering recommended practices for electrical equipment and safety in the workplace. This includes:
   - NFPA 70E-2004: *Standard for Electrical Safety in the Workplace*[5]
   - NFPA 70B-2002: *Recommended Practice for Electrical Equipment Maintenance*[16]

c. The National Electrical Code (NEC-2005): The original NEC document was developed in 1897. The NEC covers the installation of electrical equipment in public and private premises. This is also referred to as NFPA 70.[17]

d. Numerous IEEE/ANSI Standards including:
  - IEEE Std. 1584-2002, Guide for Performing Arc-Flash Hazard Calculations[18]
  - ANSI C2. National Electrical Safety Code (NESC)[19]
  - IEEE Color Book Series: This series developed by the Institute of Electrical and Electronics Engineers provides recommended practices that go beyond the minimal requirements of the NFPA, NEMA, and UL standards.

Electrical Safety Training Course Objectives

CSM's electrical safety training program has established the following objectives.

(1) Hazard Awareness: From NFPA 70E-2004 Edition, Article 110-6, Training Requirements: "*Such employees shall be trained to understand the specific hazards associated with electrical energy. They shall be trained in safety-related work practices and procedural requirements as necessary to provide protection from the electrical hazards associated with their respective job or task assignments. Employees shall be trained to identify and understand the relationship between electrical hazards and possible injury.*"[5] The purpose of our safety training program is to raise the awareness of the students, so that they conduct themselves safely in an electrical environment. After completing the course the students should be more cognizant of the rules, responsibilities, and procedures regarding electrical safety.

(2) Engineering Solutions to Mitigate Electrical Hazards: An objective of the training module is to make the students aware of the role engineering has played in developing technology to significantly reduce electrical hazards.

(3) Compliance with Federal Law: Another goal of the training module is to make the students aware of the applicable laws governing electrical safety.

(4) Electrical Incidents Safety Investigations: As practicing engineers many of the students will be asked to serve on safety investigation committees. Accurately documenting electrical incidents is an important part of any electrical safety program and students are expected to understand the requirements of an electrical incident safety investigation.

Electrical Safety Training Course Schedule and Grading

Formal Lectures:
- Introduction to Electrical Safety:
- Electrical Code Seminar: Featuring NFPA 70, NFPA 70E, and IEEE 1584
- Electric Power Generation Systems and Electrical Safety
- Misconceptions Regarding Electrical Processes

Guest Lectures, Videos and Demonstrations:
- Safety Presentation: Defibrillators
- Safety Presentation: NREL
- Video: Electrical Safety

- Video: Arc Flash Hazards
- Video: Electrical Case Histories

Field Trips:
- Tour of CSM's Electric Power Distribution System
- Tour of an Xcel Energy Generating Station

In-Class Projects and Presentations:
- Risk Assessment (Arc-Flash Comparative Study): NFPA 70E and IEEE 1584
- Safety Investigation Group Presentations

Grading:

- Group Assignments: 50%
- Miscellaneous Homework (Field Trip Reports, Assignments, etc.): 20%
- Final Exam: 10%
- Attendance and Participation: 20%

Electrical Safety Training Course Assessment

Extensive assessment data is not yet available because this paper has been written early in the course development process. At this time it is impractical to determine if the course objectives have been met. Nevertheless, the electrical safety module course curriculum appears to be well received by the students, as they rated their learning experience very high during the pilot program that was offered during 2005. The overall sentiment of the class can be summarized by the comment made by one student: "*Because of the electrical safety presentation in field session, I have a much greater respect for electricity. As an engineering student, I used to think of electricity only in terms of equations and analysis techniques.*" A more thorough evaluation of the safety module is planned for the 2006 Field Session. It is our intention to present a more detailed assessment after the electrical safety course becomes well established and sufficient data is available.

Conclusions

While it is premature to determine if the course objectives have been met, or to suggest improvements for future classes based on the available assessment data, some conclusions about the Electrical Safety Module can still be drawn. The module addresses the concern expressed by many in industry that young engineers have very little understanding of what is required to manage the risks in electrically hazardous environments. As a result, CSM views electrical safety training as a vital part of an electrical engineer's education. It is imperative that they are made aware of the potential dangers and understand how to conduct themselves safely. We have worked closely with industrial representatives to develop relevant safety training materials for our students. Because the industry sees a tangible benefit from our approach they are willing to support our electrical safety program. Through this cooperative effort we have integrated proven methods for risk and hazard assessment into our curriculum. The course is designed to advance the electrical safety culture through education at the university level.

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Appendix A: Electrical Incident Safety Investigation, A Case Study

An electrical incident investigation is one of the major assignments given during the one-week safety training module. Student groups of three are required to prepare a thorough engineering report and make a formal presentation of their findings to a faculty panel on the last day of class following the electrical incident case history format suggested in an article titled: "Making the Case for Safety" appearing in a recent edition of the IEEE Industry Applications Magazine. [20] The report is divided into four major categories:

- Description of the electrical incident.
- Detailed description of the injuries that resulted from the incident.
- Background information revealing why the electrical incident occurred.
- Description of the lessons learned from the incident and recommendations how to avoid such incidents in the future.

While there are many resources available for obtaining electrical incident case studies, we have chosen to use examples that are posted on the NIOSH Electrocution Fatality Investigation Reports Web site: NIOSH Fatal Accident Circumstances and Epidemiology (FACE) Study.[9] Two electrical incidents that the students were asked to investigate during the pilot program (Summer of 2005) are given below.

Example 1: Case Number FACE 84-17, Electrocution in a Fast Food Restaurant: On June 30, 1984 at approximately 1:05 a.m., an 18-year-old employee with 15 months of experience at a fast food restaurant was electrocuted while plugging a portable electric toaster into a 110 volt/20 amp receptacle.

Example 2: Case Number FACE 85-32, 20-Year-Old Construction Worker Electrocuted when Backhoe Contacts 7200 Volt Power Line at Construction Site in Kentucky: On July 8, 1985, the owner of a construction company was driving a crawler backhoe through a partially developed residential subdivision. The raised boom of the backhoe struck the bottom three lines (cable TV, phone, and neutral) of a four-wire utility line (approximately 26 feet above the road), breaking a 40 foot utility pole located approximately 70 feet from the point of contact (east of the road). The top line (a 7200 volt single-phase primary distribution line) fell to the ground after striking the rear of the backhoe. A 20-year-old construction worker was approaching the backhoe from the rear and was electrocuted when the 7200 volt line fell a few feet away from him.

During the initial offering of the safety training course we had fourteen student groups. This is a practical way to have students observe a number of varied electrical incidents during a one-week course module. Because of this exposure to a number of different case studies the students have an increased awareness of the possible electrical hazards they may face during their lifetime.