Principles of Electrical Safety

Peter E. Sutherland

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Table of Contents

List of Illustrations

List of Tables

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To all the victims

Preface

From the beginning of my career in electric power engineering, safety has been an important topic. The first training provided by my new employer, after we had completed the paperwork and received an introduction to the company and its many products and services, was a series of safety training talks and films. The graphic nature of this material can cause some discomfort, but it was looked on as the only way to communicate the severity of the problem.

When arc flash protection became the law in the United States, instituted in a peculiar fashion by OSHA, which meant that industry had to follow the private industry consensus standard NFPA 70E, all of this changed. Soon I found myself toting two large duffel bags of safety gear to the arc flash hazard and electrical safety classes I was teaching to electricians, engineers, and managers in industry. The most telling moments of the course were in the showing of a video, "The Mark Standifer Story" (Standifer, 2004), which was a somber moment in the proceedings, after which I had to pause and let people reflect on what they had just witnessed. This was the story of a man who was going to work on energized high voltage electrical equipment, when he was injured by a severe arc flash, receiving second- and third-degree burns over 40% of his body. After months of excruciating treatment and rehabilitation in a burn center, he recovered fully, and was able to tell his story. Mark Standifer is now an electrical safety speaker and trainer, spreading the message of electrical safety. After that video, the course covered many aspects of electrical safety, shock hazards, and arc flash protection. Teaching the course was the beginning of my interest in the field, which led to this book.

There was, in fact, an incident where I worked which bore many similarities to the Mark Standifer story, and I visited one of my colleagues in a burn unit, where he was swathed in bandages, lying in a hospital bed, and unable to speak. He also, has since recovered and returned to his electrical career. But many are not so lucky, and the number of fatalities is still unacceptably high.

Another episode, of which I was aware, was when an engineer went to measure the voltage and current of energized electrical equipment. Here, one attaches voltage leads to the “hot” conductors, for example, putting an alligator clip around the end of a bolt and clamp-on current probes around a conductor. The current probes had an iron core, and when they were opened, the conductive iron was exposed, and an arc occurred to an energized conductor, causing severe burns, and sending the engineer to the hospital.

A third example was the case of the motor control centers (MCCs). Here, an experienced engineer and a newly hired engineer were doing troubleshooting of some low voltage, 480 V, MCCs. This work involved taking measurements with a digital voltmeter (DVM) of the voltages on the equipment. The lead engineer had to step out for a minute to answer a phone call, and the younger engineer continued working, taking more measurements. When the first engineer returned to the room, he found the other engineer knocked down on the floor, and severely burned. This was because the next MCC was a 4160 V high voltage unit. This tragedy should never have happened. The first mistake was inadequate preparation and planning. The tasks should have been clearly laid out, the equipment to be worked on identified, and safety procedures put in place. All personnel who work on specific equipment are required to be trained in that equipment in addition to their general safety training. This training did not occur for the high voltage MCC, because it was not part of the work scope. When the first engineer left the room, all work should have stopped. The rule is never to work alone on electrical equipment. No measurements should be taken on any equipment unless the expected voltage level is known, and the appropriate test equipment is used. In this case, VOMs should never be used on high voltage circuits.

Electrical accidents have been relatively common in the industry. Incidents such as these are readily preventable, but it takes knowledge and organization to provide effective protection. With the advent of more comprehensive safety programs, safer equipment, greater awareness, and improved arc flash protection, they are fortunately becoming rarer.

Electrical safety is an often-neglected area of electrical engineering. There has been a wide-ranging and pervasive set of changes taking place in attitudes toward electrical safety. Beginning with the Institute of Electrical and Electronics Engineers (IEEE) annual Electrical Safety Workshops, and with new and updated safety standards, the process of changing the electrical safety culture has been changing the world. The earlier attitude toward electrical safety was that industrial production took priority and that if it was necessary to take risks by working on live equipment, this went with the job. This was compounded by a lack of safe work procedures, inadequate safety equipment, and unawareness or indifference to the terrible human cost of industrial accidents. It has become clear now that electrical injuries are not acceptable. People's lives and health should not be sacrificed for the sake of production. An occupational health and safety policy (AIHA, 2012) should commit the organization to “protection and continual improvement of employee health and safety.” The ultimate goal of electrical safety is “prevention by design,” which is designing or redesigning equipment and systems such that they are safe to work with in the first place.

The word electricity is derived from the Greek “elektron,” for amber. This substance, a fossil tree resin, produces static electricity when rubbed on cloth or fur. Everybody is familiar with the “tingle” of electricity when touching a household conductor, 120 V or higher. Children have been electrocuted while playing with electrical outlets and sticking objects into the openings. Electricity has been the cause of innumerable fires, in homes and elsewhere, which are surely also electrical accidents.

Electricity is a hazardous substance, just as arsenic is hazardous, or any of hundreds of other materials which cause injury on exposure, contact, or ingestion. This has not always been considered to be the case, because electricity is invisible, odorless, and colorless. Electricity travels through solid materials, as well as through gas and liquids, and even vacuum. Furthermore, electricity consists of two parts, a physical flow of charged particles and a nonphysical flow of energy in force fields. So the entire concept of electricity as a substance is nebulous. But it is a substance which has its own precise definition, its characteristics, and its very definite hazards. Exposure to electricity can cause injury and death just as surely as exposure to more conventional hazardous substances. The same methodology of hazard analysis and risk assessment, preventive and protective measures should be followed with electricity as with other dangerous materials (Mitolo, 2009a). The complexity and ubiquitous nature of electromagnetic phenomena, however, put them in a different category than other hazards, and warrant their special treatment.

Electricity has always been known to be hazardous and to have significant biological effects. The early experiments of Volta with frog's legs are known to all. The muscular contractions caused by the flow of electricity through living tissue are a significant cause of injury and death. The reaction from somebody touching an energized conductor can cause them to jerk their arm and be bruised or cut or throw them across the room. Internal muscular contractions can cause invisible injuries which only show up much later or they can cause cessation of breathing or of the heartbeat, resulting in immediate death. Protection against contact with energized electrical conductors is an essential safety practice.

The well-known experiments of Franklin showed that lightning is the flow of electricity in the air, and the electrical energy can be collected for scientific analysis and human use. Lightning has been the major source of electrical injury and death throughout all of human history. Lightning has first of all and most dramatically caused death by direct strike to the person. A direct strike will first of all kill by the flow of a large current, often thousands of amperes, through the body. At this level of current, muscular contractions are not an issue. The flow of current causes heating, as it does in any conductor, causing severe burns, both internal and external. While there have been many stories of miraculous escapes, lightning can, and does, do to people what it does to trees. Who has not seen the burned and charred remnants of a direct stroke on a tree, usually damaging only part of it, causing the trunk to split and branches to fall off? The tree may live, with partial remnants of living tissue giving continuing life to some branches. What is more rarely seen is the death and destruction of a tree. The tree is totally burned, inside and out, leaving a forlorn and blackened stick. This can and does happen to people as well as trees. Fires caused by