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Case Report

Analysis of Two Electrocution Accidents in Greece that Occurred due to Unexpected Re-energization of Power Lines

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ABSTRACT

Investigation and analysis of accidents are critical elements of safety management. The over-riding purpose of an organization in carrying out an accident investigation is to prevent similar accidents, as well as seek a general improvement in the management of health and safety. Hundreds of workers have suffered injuries while installing, maintaining, or servicing machinery and equipment due to sudden re-energization of power lines. This study presents and analyzes two electrical accidents (1 fatal injury and 1 serious injury) that occurred because the power supply was reconnected inadvertently or by mistake.

1. Introduction

Nothing can kill or injure a human being more rapidly than electricity or charged equipment. There is no time to react after an error is made. Working with electricity requires thorough planning and extreme care. Unintended energization or operation of equipment during the service, installation, or maintenance may result in serious injury or death. The electrician must ensure that the power is off and remains off. In the United States, 152 hazardous energy-related fatalities were documented in a program conducted between 1982 and 1997. Among these cases, 82% were due to failure to remove hazardous energy, 11% were due to failure to prevent re-energization, and 7% were due to failure to verify de-energization [1]. In Greece, according to a survey conducted by the Ministry of Labour, 429 lethal injuries occurred from 2007 to 2012, 62 of which were due to electric shocks, fires, or explosions [2–4] (Table 1).

According to another survey conducted in Quebec by Pineault et al [5], 63 fatalities were recorded between 1981 and 1988. Investigation reports were available for 57 cases (90.5%). They all occurred in males, 70.2% of whom were <35 years; 49.1% were performing tasks related to the construction sector. Of the fatalities, 90.2% are classified into two categories: victims assigned to electrical tasks indoors and those assigned to nonelectrical tasks outdoors. Victims of the first group (56.5% of the cases) were electrocuted by direct contact with a voltage of <10 kV, and victims of the second group by the intermediary of a vector with a voltage of >10 kV. Identification of these two patterns of electrocution provided an additional argument for shifting recommendations for prevention—from educating the workers to reducing the electrical hazards at the source.

The purposes of this publication are to promote awareness of unexpected energization of power lines, describe and analyze two electrical accidents that occurred in Greece, and present their fault tree diagram. The investigation report was created based on the direct observations of the investigator (the author of this study), witness accounts, and deductive or speculative information.

1.1. Background

Casini [6] described electrocution in terms of five hazard patterns, which are based on three types of electrical sources (i.e., power lines, energized equipment, and damaged or improperly

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Table 1
Lethal injuries in Greece from 2007 to 2012 [2–4]

	Lethal injuries					
Category	2007	2008	2009	2010	2011	2012
Fall	38	39	20	20	7	9
Electric shock, fire, explosion	14	15	14	4	10	5
Construction machines, various tools	7	4	6	9	9	10
Other	35	46	44	30	13	21
Total	94	104	84	63	39	45

installed equipment) and two major possible methods of electrocution (i.e., direct contact or through an intermediary object and indirect contact, which was further divided into indirect contact through a boomed vehicle and indirect contact through a conductive material).

Chi et al [7] added two new hazard patterns, indirect contact through energized equipment and that through damaged equipment, to improve the analysis and prevention measures for these types of accidents.

Furthermore, in the survey of Pineault et al [5], a flow diagram was proposed to show possible paths between the electrical source and the victim in terms of vectors. The idea is to block the flow of electricity from the electricity source to the victim to prevent electrocution. However, Chi et al [7] modified this flow diagram by replacing vectors with the source of injury (i.e., the object that conducts electricity to the victim from the electrical source) because the victims were not always working with an electrical source or performing electrical tasks.

2. Case reports

Two electrocutions that took place in Greece due to unexpected energization of power lines (operation errors) are reported below.

2.1. Case 1

An electrical contractor, 58 years old, was installing a lighting system for a small athletic stadium. The distribution board was connected by four subsidiary circuits, four pillars, and four lighting poles with underground cables, as well as by a low-voltage network. The electrician was working in a pillar without wearing any personal protective equipment when the circuit was suddenly energized. He was killed immediately. This event occurred in the morning in an outdoor area in Greece in daylight. There were no labels or barriers of any type on the distribution board to prevent the switch from being accidentally turned on. The stadium entrance was open to the public. The electrician had the necessary qualifications and adequate experience. He was working alone.

2.2. Case 2

Three electricians were replacing a damaged, de-energized underground cable in an urban area. Two of them were inside the trench and had cut the damaged cable using a portable grinder when they remembered that the conductor was not grounded. The substation was far away, and the third electrician had left to ground the conductor. By mistake, instead of grounding, he energized it with a voltage of 20 kV. The two workers were still in the pit and were injured by the arc. The resulting spark set fire to their clothes and caused severe burns to their lower limbs. They required emergency treatment. All three employees were electricians and had adequate experience. The operator was 51 years old and had been facing family problems. The victims were aged 42 years and 48 years. This event occurred in the morning in an outdoor area in Greece. The recloser, which was connected to the distribution network, worsened the workers' injuries.

3. Discussion

3.1. Accident analysis and corrective actions

Pineault et al [5] proposed a flow diagram to show possible paths between the electrical source and the victim in terms of vectors. The idea is to block electricity flow from the electricity source to the victim so as to prevent electrocution. In their study, Chi et al [7] used a flow diagram to show the possible paths of electricity traveling from the electrical source to the victim. Each path identified one source of injury (denoted by a circle) that occurred, caused when an object or equipment delivered an electric current from the source to the victim. The causes of accidents were incorporated into the flow diagram by rectangles. Each block has been placed between the electrical source and the victim in the flow diagram, to denote one cause of accident that has contributed to the accidental electrocution. In other words, each cause block created a potential path connecting the victim and the electrical source for the electrocution to take place. Thus, each cause block also corresponds to a feasible prevention measure. Generally, there are two main types of connections, i.e., series and parallel connections, between two or more cause blocks. In case of parallel paths being redundant, i.e., many alternative paths connecting the source and the victim, at least one of the parallel paths must fail for the entire network to fail. On the contrary, in case of series paths, it is necessary that all paths in the series must fail for the network to fail, i.e., for an accident to take place. The arrow indicates an electric current flowing from the electrical source and passing through the victim. The electrical "ground" symbols below the electrical source and the victim represent the "closed loop" leading to an electrocution [7].

The described electrocutions occurred because of unexpected activation of power lines. When a person receives an electric shock, electricity flows between parts of the body or through the whole body to the ground or the earth. The victim is electrocuted due to direct contact with energized equipment such as distribution box circuit, switches, fuses, or energized wire. The failure to de-energize was the only cause of these accidents (see Fig. 1). The second parallel series of cause blocks indicate that poor working practice (no work instructions, inadequate safeguards, lack of communication, etc.) touched a live part that could electrocute the body parts that are not currently covered by personal protective equipment

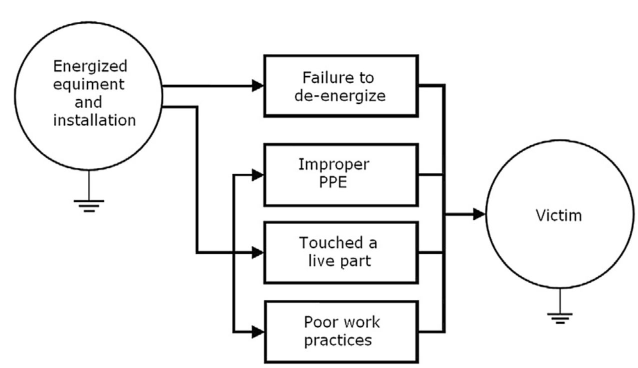

Fig. 1. Flow diagram for accidents [5]. PPE, personal protective equipment. *Note.* From "Flow diagram analysis of electrical fatalities in the construction industry," by C.-F. Chi, Y.Y. Lin, and M. Ikhwan, 2012, *Saf Sci*, *50*, p. 1205–14. *Copyright 20XX, Name of Copyright Holder.* Reprinted with permission.

(e.g., safety gloves and safety boots). The victim was also in touch with the ground and did not wear proper personal equipment when he touched the bare conductors. Therefore preventing injuries is extremely difficult in the absence of an understanding of the factors which are likely to favour the occurrence of accidents. By studying such factors, the root causes of accidents can be isolated and necessary steps can be taken to prevent the recurrence of the accidents.

3.2. Accident investigation process in Greece

All accidents that occur should be recorded in an accident book, which should be easily accessible. According to Greek laws, employers have a responsibility to investigate accidents. Root-cause analysis helps find out how and why an accident occurred. The process involves data collection, cause charting, root-cause identification, and generation and implementation of recommendations. Depending on the size and complexity of the accident, as well as the number of workers, a team may include a safety engineer and an occupational physician. Companies should also seek external specialist assistance if such expertise is lacking within the organization.

In addition, the employer should inform, within 24 hours, the Greek Ministry of Labour and the police when a worker has been injured. The accident conditions should be left unaltered until the accident has been investigated by technical inspectors of the Greek Ministry of Labour. Each investigation is followed by a report analysis, which may include photos of the accident conditions, a detailed description of the injured worker or an eyewitness, and the investigation results of the safety engineers and occupational physicians. The report analyzes the root causes of the accident and suggests protective measures that should be taken by the company to avoid such accidents in the future. This report would be sent to the police for prosecution when the working conditions are found to be illegal.

3.3. Conclusion

The present study focuses on two accidents that occurred due to unexpected energization of power lines. The flow diagram used in the current study was developed based on that proposed by Chi et al [7]. The flow diagram can be directly linked with feasible prevention strategies by cutting the flow of electricity. The flow diagram can be very effective in prevention of accidents among construction workers and general public.

Accidents due to unexpected energization of power lines have some particularities. Even in research papers, victims are often accused of working with live electrical circuits. As little information is available concerning the chain of events leading to an injury, the victim of an injury is often accused. In most cases, the person who re-energizes the network leaves immediately after the event and does not take responsibility for his actions. Witnesses are the primary source of evidence, and, when witnesses are found, justice can be obtained. In all other cases, because the investigation must be completed and a cause (or someone to blame) must be found as soon as possible, the electrician is accused. To eliminate these phenomena, companies should focus on taking measures to reduce the frequency and severity of accidents due to unexpected re-energization of power lines. Injury prevention policies are traditionally based on lessons learned from injuries. By investigating each event, the safety engineer learns about the causes and can take actions toward mitigating or removing those causes. By studying the factors that are likely to favor the occurrence of accidents, the root causes of these injuries can be isolated, and the necessary steps can be taken to prevent recurrences in the future.

Conflicts of interest

No potential conflict of interest relevant to this article was reported.

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