Safety and Health at Work 14 (2023) 124–130

Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.net

Case Report

The Role of Forensic Engineering in the Diagnosis of Electrocution Fatalities: Two Case Reports

Mohammad Alqassim*, Raneem Ewiss, Hamdah Al Ali

Specialty Forensic Evidence Department, General Department of Forensic Science and Criminology, Dubai Police GHQ, Dubai, United Arab Emirates

A R T I C L E I N F O

Article history:
Received 25 August 2022
Received in revised form
4 November 2022
Accepted 14 November 2022
Available online 21 November 2022

Keywords:
Electrocution accidents diagnosis
Forensic electrical engineering
Forensic medico-legal examination
Foresic tools
Trace evidence analysis

A B S T R A C T

The increase in the number of fatal electric accidents over the years has escalated the demand for specialized forensic engineers to determine their relevant technical causes. Likewise, the complexities associated with identifying the causes of electrocution accidents have prompted the General Department of Forensic Science and Criminology at Dubai Police to adopt a new methodology to diagnose electrocution accidents, consisting of an approach that involves medico-legal examination, electrical diagnosis of the evidence, and trace evidence analysis. This paper will discuss the application of the adopted method in further detail by unfolding two case reports. The first report outlines a case in which a worker got electrocuted at a construction site while attempting to turn on a lamp. The second case report involves the death of a technician in a workshop after trying to disconnect a washing machine from its plug. The methodology was utilized during the investigation of both cases, which were attended by the appointed forensic engineers and showed promising results.

1. Introduction

The number of electrical devices has risen drastically in recent years to the point that it has become one of the fundamental aspects of our lives. However, with everything in life, a drawback is inevitable. One disadvantage of electrical devices is the catastrophic consequences, such as death and injuries, due to the misuse of electricity.

Forensic engineers are usually employed as subject matter experts during the investigation of electrical failures. Their main role is to determine whether the cause of the incident was due to equipment design and installation, human error, or a mixture of both [1]. When the human body becomes exposed to an applied voltage, the current will be able to flow due to the resistance of the body, causing an electric shock. The flow of the current is made possible by the presence of two electrical contact points at different voltages, as explained in Fig. 1. Electric shock could lead to skin lesions, organ trauma, and in some unfortunate cases, death. Electrocution is when death occurs due to electric shock [2]. The electric shock severity depends on the current type, current strength, duration of exposure, body resistance, and the pathway the current takes through the body [3]. The longer the current flows through the body and the higher the current value, the greater the chance of an electrocution event [4].

This study will present the methodology adopted by the General Department of Forensic Science and Criminology (GDFSC) to diagnose electrocution incidents. Dubai has seen a rise in the electrocution incidents between 2019 and 2021, with 13 fatalities and 8 acute injuries reported to the GDFSC [5]. In 2019, Dubai had a 5.12% increase in the population over a one-year period, reaching to 3.35 million [6]. The following years had a population of 3.41 and 3.47 million in 2020 and 2021, respectively [6]. Out of the 17 electrocution cases investigated by the GDFSC, two case reports are included in this paper to demonstrate the applicability of the developed forensic tools during a forensic electrical engineering investigation.

2. Methods

Electrocution is a frequent cause of workplace death and domestic accidents [7]. The GDFSC has adopted several forensic tools to assist in

Mohammad Alqassim: https://orcid.org/0000-0001-9273-2505; Raneem Ewiss: https://orcid.org/0000-0002-0387-6820; Hamdah Al Ali: https://orcid.org/0000-0001-6289-8360

* Corresponding author. Specialty Forensic Evidence Department, General Department of Forensic Science and Criminology, Dubai Police GHQ, Dubai, United Arab Emirates
E-mail address: mam.qasim@dubaipolice.gov.ae (M. Alqassim).

2093-7911/$ – see front matter
https://doi.org/10.1016/j.shaw.2022.11.002

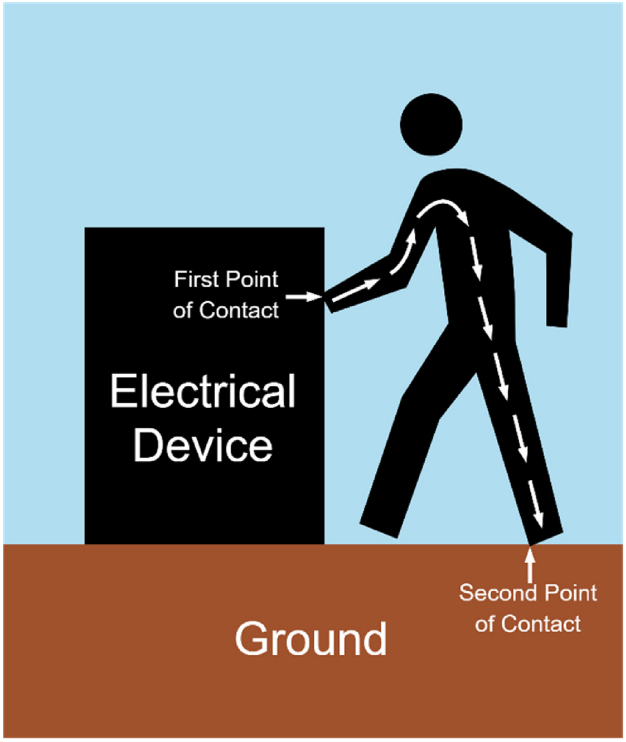

Fig. 1. Demonstration of how electrocution occurs.

the diagnosis of electrocution accidents. The first element for the diagnosis of electrocution deaths involves identifying the presence of markings in the skin through morphological findings [8]. In the event of electrocution, the electric current enters the body at one point and exits at a different point, leaving behind an entry and an exit mark [9,10]. The electric current heats the epidermis and dermis layers of the skin and causes a burned trace on the body that takes up the general shape of the conductor that caused the electrocution [11]. The most common entry marking location is the hand and the head, while the most frequent exit marking is the foot [9]. The role of the forensic medico-legal examination is to conduct an autopsy on the body to find skin lesions or any other indication of electrocution in the body. However, in some instances, the skin lesion may not be present or is exceedingly difficult to find or differentiate from other marking on the body [8,12]. In those cases, the investigation extended into the next step of the methodology.

The second element of the methodology is the electrical engineering diagnosis, which is a crucial aspect of the diagnosis of the electrocution incidents. The forensic engineer inspects the site of the accident and gathers any relevant evidence to the case for examination. [7]. The evidence gathered is tested remotely to evaluate whether it could have been a part of causing the electrocution or not. If further testing is necessary for the evidence gathered, it is collected and transferred to the lab for additional in-depth electrical troubleshooting.

The final aspect of the methodology is the trace evidence analysis, which is used to identify further indications of electrocution. Trace evidence is the term given to microscopic evidence that transfers between any two surfaces [13]. During electrocution case investigations, the trace evidence analysis is performed on the evidence collected. To conduct the trace evidence analysis, usually, a microscope is used. However, if further examination of the evidence is necessary, a scanning electron microscope can be used. Once all the evidence is tested and examined during the equipment diagnosis and trace evidence analysis steps, the information obtained helps in determining whether electrocution was the cause of the accident.

3. Case reports

3.1. Case report 1

The first case took place in September 2021 within a construction site. At around 6PM on the day of the incident, a worker got electrocuted when they attempted to connect two cables to illuminate the lamp as it was getting dark. The investigation commenced with the forensic medico-legal examination of the deceased body, revealing a burned trace on the right index finger on both hands, as shown in Fig. 2, indicating that electrocution is a possible cause of death. Further investigation was required to ensure the validity of this finding. The forensic electrical engineering investigation started with a visual inspection of the site and its surroundings to identify several pieces of evidence (Fig. 3), which included:

- A lamp fixed on a wooden base with an open-ended black cable (Fig. 3a)
- Two sockets installed on the ground (Fig. 3b)
- A white electric cable with two exposed ends (Fig. 3c)
- A generator connected to the socket outside the residential complex (Fig. 3d)

Technical examination of the evidence was required to determine the cause of the accident. The black cable of the lamp was found to have a missing earth wire. The current leakage test on the body of the lamp revealed that it did not leak excess current. The cables found near the body were then tested, and the earth wire in the white cable was found to be severed. The current on the wire was measured when it was connected to one of the sockets, which had a voltage of 240 V. The value of the current flowing through the cable was found to be 32.3 A.

The next phase of the investigation included the examination of the two sockets found on the ground. Both of these were double sockets, meaning that a total of four socket inlets were available. Three socket inlets were in the ON position, while the last one was in the OFF position. Each socket inlet supplied a voltage equivalent to 240 V. After examining the sockets, it was revealed that the sockets' cable did not have any earth wire. The sockets' cable was traced back to find the cable on the ground, next to the main distribution panel. The distribution panel was next to the generator outside of the residential complex. The cable was not connected to

Fig. 2. Burn trace found in the victim's right index finger during forensic medical examination of Case 1.

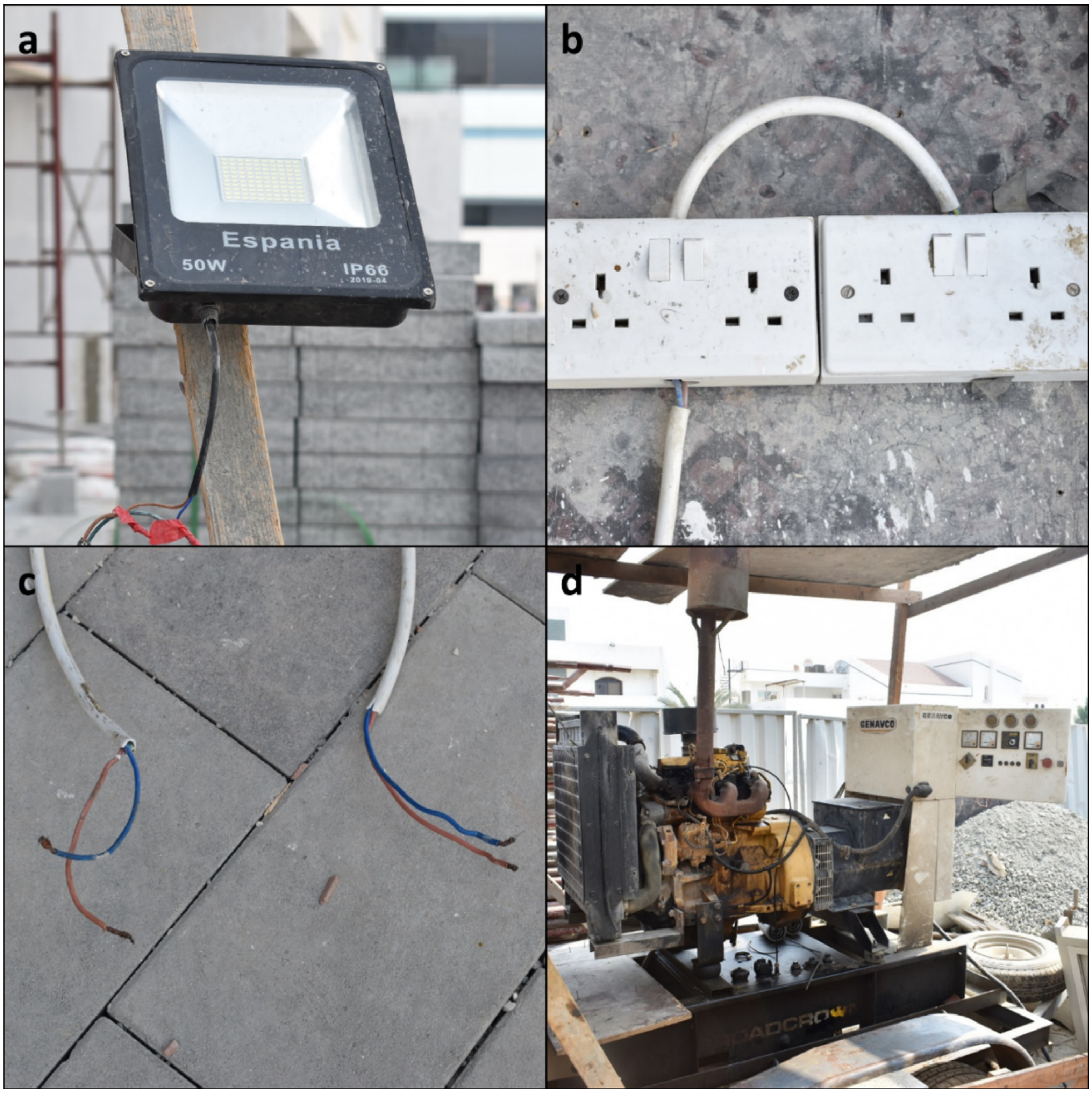

Fig. 3. Evidences found during the forensic investigation of Case 1 at the site of incident which include (**a**) lamp, (**b**) sockets, (**c**) cables, and (**d**) generator.

the main distribution panel as it was supposed to, therefore invalidating the working of the main distribution panel in disabling the current flow in the event of a fault.

The generator was the last evidence examined at the site of the accident. The generator was directly connected to the socket. The generator produced a total power of 28 kV, with a voltage of 380 V. The overall current produced by the generator was 80 A. The technical examinations of the lamp, the socket, the main distribution panel, and the generator were concluded on the site. However, both the black and white cables required further examination. The trace evidence analysis was conducted on the collected cables in the lab. The microscopic image of the cable is shown in Fig. 4.

3.2. Case report 2

The second case occurred in June 2020 in a repair workshop, where the victim was found lying on the ground next to the bathroom after having used the laundry washing machine. It was revealed through an autopsy of the deceased body that electrocution is a possible cause of death due to the burn traces found in the left thumb, as shown in Fig. 5. Further investigation was required by a Forensic Engineer to ensure the validity of the results. The electrical diagnosis commenced with the visual inspection of the site along with its surrounding. Several pieces of evidence were identified (Fig. 6), including:

- A washing machine, which had adjustments made to its wiring, which included the removal of a part of the body of the washing machine to add a socket and the replacement of the original wires (Fig. 6a).
- A white electric cable with a plug on either side (Fig. 6b).
- A socket on the wall of the bathroom (Fig. 6c).
- A distribution panel that is connected to the socket on the bathroom's wall (Fig. 6d).

After identifying the evidence through visual inspection, an in-depth technical examination of the evidence was conducted to determine the cause of the accident. This procedure started with examining the washing machine. In particular, the built-in socket area was inspected to identify all the alterations conducted in that

Fig. 4. Microscopic examination of copper wires in the cable for Case 1.

area and their purpose. It was concluded that the modifications were to enable the washing machine to operate using one special cable, which is the one found in the ground with a plug on either end of it. One end of the plug was inserted into the socket on the bathroom wall, while the other end was inserted into the built-in socket in the washing machine. The leakage current test was conducted using a multi-meter to ensure that the washing machine was not leaking excess current. The body of the washing machine was found to lack any defect that can cause it to leak excess current. The socket found on the bathroom wall, along with the distribution panel, was also inspected. All circuit breaker switches in the distribution panel were in the ON position, indicating they were operating during the incident. During this part of the investigation, two tests were conducted in each of the sockets and the circuit breakers in the distribution panel. The socket in the bathroom was tested using a socket tester to identify if any wiring issues were present in the socket. For the circuit breaker test, the troubleshooting kit was used to test the working of each switching system, along with the programming of the entire tripping structure of the circuit breaker. These tests concluded that the socket and the circuit breaker are functioning as expected.

Fig. 5. Burn trace found in the victim's left thumb during forensic medical examination of Case 2.

The last phase of the investigation was on the cable with a plug on either end. The cable itself was of type British Standard (BS) 6500 with a cross-section of 3×2.5 mm^2 and can withstand voltages up to 300–500 V. The current flow through the cable was calculated to be $\sim$229 mA. This current is lethal if it flows through the human body because it exceeds the maximum current that the body can withstand without experiencing an electric shock. After conducting tests on the washing machine, the socket, and the distribution panel, it was found that they had no defects. However, the cable was collected for further examination in the lab. After the thorough inspection of the cable, the two main hypotheses that were concluded for the investigation are the absence of the earth wire and the bypassed fuse in the cable.

In the lab, dismantling both plugs in the cable revealed the wiring inside. It was found that the earth wire was connected to neither of the plugs. Moreover, the fuse in one of the plugs, the one that was connected to the washing machine, was altered to become a bypassed fuse. Aside from the earth wire, the fuse is also an essential safety component in the plug. The fuse is designed to protect electric circuits by creating an open circuit in the event of an overcurrent [14].

In the context of electricity, bypass is defined as connecting wires or components in parallel to the circuit to provide an alternative path for the current [15]. A fuse is bypassed by adding low-resistance conductors parallel to the fuse to create two or more different paths for the current to flow through. Fuse bypassing

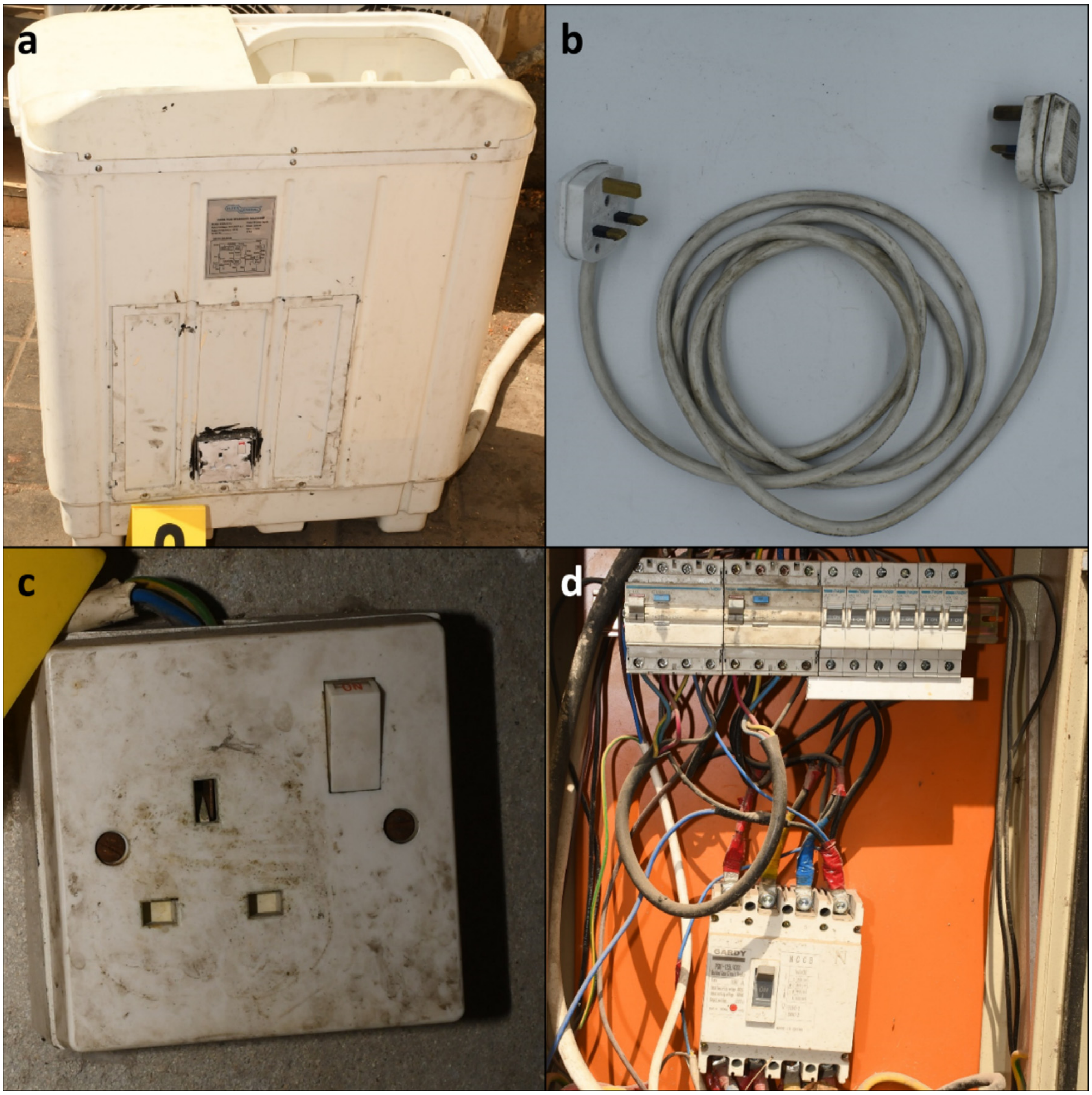

Fig. 6. Evidences found during the forensic investigation of Case 2 at the site of incident which include (**a**) washing machine, (**b**) cable, (**c**) socket, and (**d**) distribution panel.

dismisses the function of the fuse and allows the overcurrent to continue to flow through the circuit even after the fuse is blown, leading to potential electrical and fire hazards.

4. Discussion

The wirings inside electrical devices consist of three main parts; the live wire, the neutral wire, and the earth wire. The live wire delivers the high potential supplied by the power supply to the device, while the neutral wire sends back the current received from the power supply to complete the circuit. The earth wire's role is protection [15]. It is crucial to differentiate between the wires for safety purposes. Therefore, each of the three wires has a specific colored insulator. The live wire is insulated using a brown plastic covering, the neutral wire is insulated using a blue plastic covering, and the earth wire is insulated using a green and yellow striped plastic covering [16].

Although safety measures are taken into consideration when designing electrical devices, faults can still occur due to a failure in installation or an insulation bridging [16]. If the earth wire is missing in the event of a fault, the current will take an alternate path to the ground. If the body makes contact with the wire, the current can enter and exit the body, leading to electrocution if the current is high enough [4,10]. Hence, this is why the presence of the earth wire is crucial. Fig. 7 demonstrates the path of the current when the earth wire is present or absent. The electrical device indicates the device that contains the fault. In the figure, the white arrows indicate the current path in the absence of a fault, while the red arrows indicate the current path during a fault. The color codes introduced previously for the live, neutral, and earth wires are applied here.

Fig. 7a indicates the flow of the current when all three wires are present in the cable. The current path is from the power company to the distribution panel and then to the electrical device. The current is subsequently returned to the power company through the neutral wire. In the event of a fault, the earth wire will carry the fault current through the electrical device and ground it. If a person is in contact with a faulty electrical device, they will not be affected as the fault current takes the lowest resistance path through the earth wire rather than the high resistance path through the human

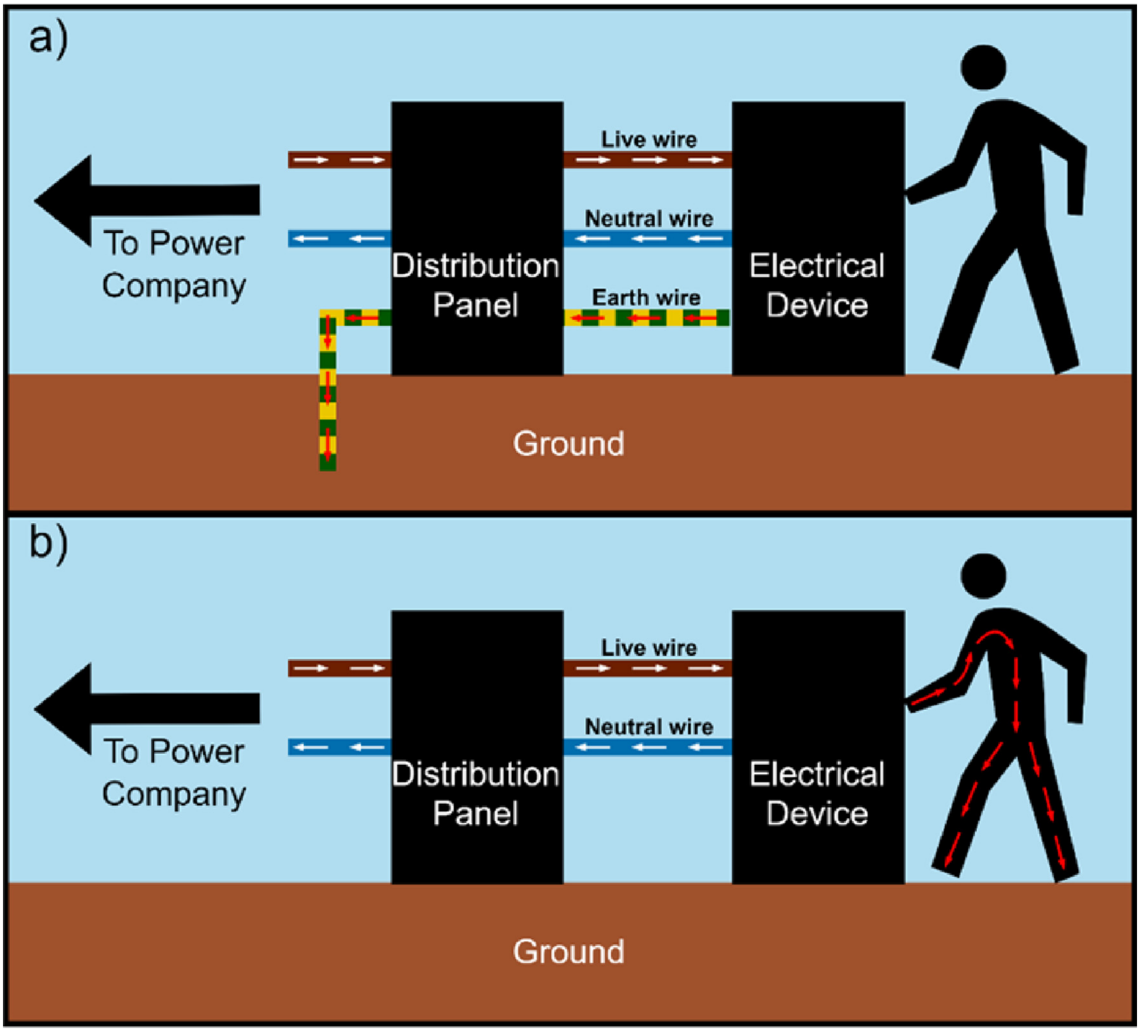

Fig. 7. Diagram demonstrating electric current path during a fault when (**a**) earth wire is present and (**b**) earth wire is absent.

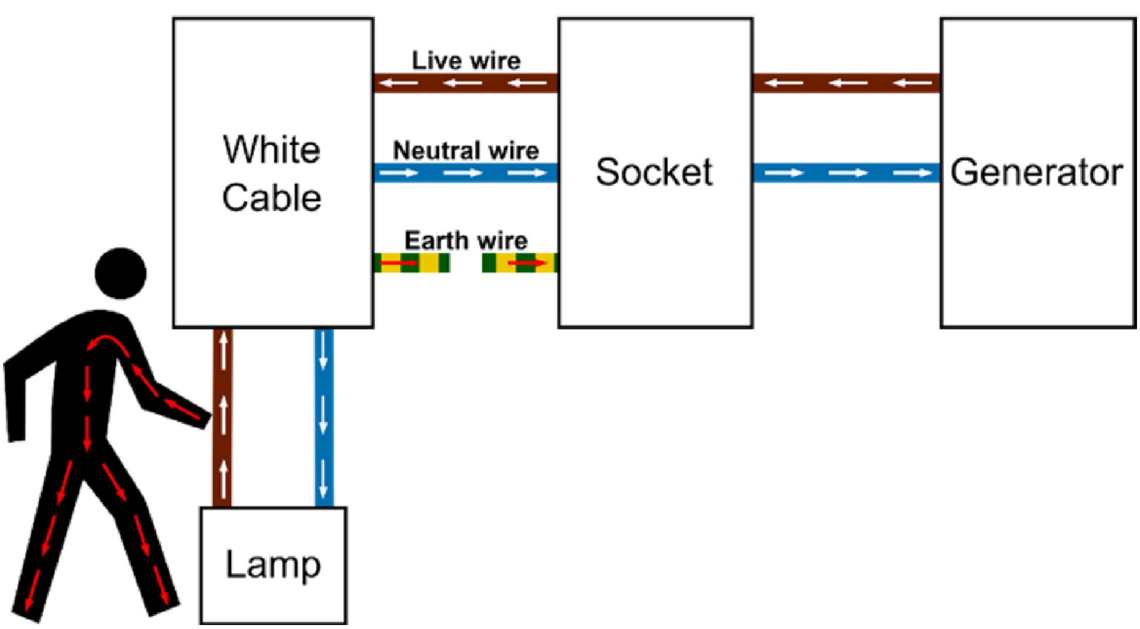

Fig. 8. Demonstration of how the accident in Case 1 took place.

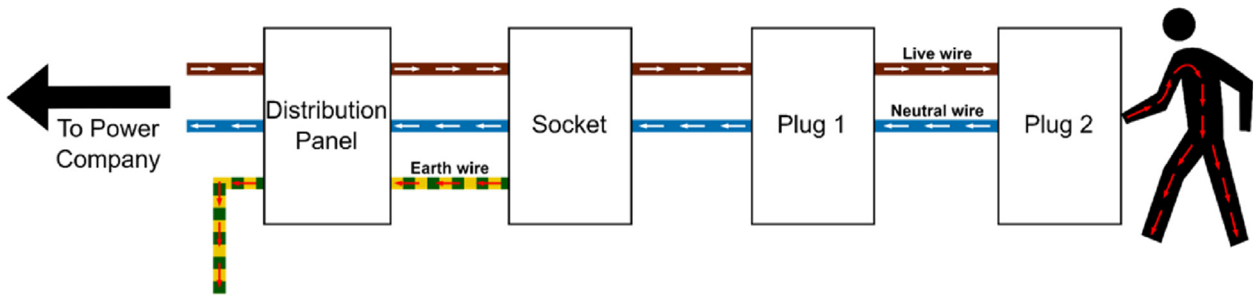

Fig. 9. Demonstration of how the accident in Case 2 took place.

body. In Fig. 7b, the earth wire is absent, which leads the current to flow through the body of the person making contact with the electrical device to the ground during the fault instead of its usual route through the earth wire. This current path can lead to electrocution if the amount of the current exceeds the maximum amount of current that the human body can tolerate.

In the first case, the victim was attempting to turn on the lamp when they got electrocuted as the current passed through them instead of its usual path through the earth wire. This incident occurred due to making contact with the white cable supplying live current while connected to one of the sockets in the ON position. The main contributors to the accident were the absent earth wire and the socket not being connected to the distribution panel, which would have stopped the current from flowing into the worker. Moreover, the worker was not wearing the required safety personal protective equipment, which could have prevented the electrocution. Fig. 8 demonstrates how the accident took place. In the second case, the victim had unplugged the side of the cable connected to the washing machine without initially turning off the switch on the socket on the bathroom wall. As evident from the burn traces found on the thumb of the deceased person, the cable was still supplying voltage at 230 V and 50 Hz when they removed the plug and had accidentally touched the conducting part of the live and neutral pins in the plug, which resulted in electrocution. The deceased person had been the one who made the adjustments to the washing machine and the plug. When modifying the plug, the deceased did not connect the earth wire to the earth terminal in the plug, an action that could have prevented the electrocution. Furthermore, the fuse was also tweaked to become a bypass fuse, which made it unable to discontinue the current flow during the electrocution. Fig. 9 demonstrates how the accident took place.

5. Conclusion

The diagnosis of electrocution deaths can sometimes be challenging. Adopting a scientific method to diagnose these accidents is necessary to make the process more reliable. The methodology introduced in this paper included forensic medico-legal examination, trace evidence analysis, and forensic electrical engineering investigation. Together, these three provide an ideal approach for identifying the cause leading to electrocutions.

The two case reports presented showcased the applicability of this methodology in practice. In both cases, the primary cause was the absence of the earth wire, which is an important safety feature found in electrical devices to prevent electrocution in the event of a fault. The cases showed a perfect demonstration of the applicability of forensic tools in the diagnosis of electrocutions and had proven the tools to be reliable and can help investigators in providing effective and efficient results for the causes of such incidents.

Conflicts of interest

All authors certify that they have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue. The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript.

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