ARE WE SAFE FROM LIGHTNING INSIDE BUILDINGS? - A STUDY OF LIGHTNING FATALITIES INSIDE BUILDINGS USING SMARTPHONES

Copyright Material IEEE
Paper No. ESW2024-19

Danilo Ferreira de Souza
Student Member, IEEE
Research at IEE/USP
Av. Prof. Luciano Gualberto, 1.289
São Paulo, SP 05508-010
Brazil
danilo.ferreira.souza@hotmail.com

Milton Shigihara PhD.
-
Research at IEE/USP
Av. Prof. Luciano Gualberto, 1.289
São Paulo, SP 05508-010
Brazil
mshigi@iee.usp.br

Hélio Eiji Sueta PhD.
-
Research at IEE/USP
Av. Prof. Luciano Gualberto, 1.289
São Paulo, SP 05508-010
Brazil
sueta@iee.usp.br

Abstract – Deaths caused by lightning are infrequent compared to other accidents of electrical origin (fires and electric shocks at industrial frequencies of 50/60 Hz). Deaths from lightning strikes inside buildings are even more challenging to occur. However, in Brazil, which has been the global leader in the number of lightning strikes, there has been a substantial increase in cases of electric shock caused by lightning, particularly involving victims using electronic devices, most notably smartphones. This study, therefore, presents an analysis of five cases of death caused by lightning, with victims using a smartphone connected to the mains at the time of the accident. Subsequently, a simulation is presented, built on the analysis of the five reported fatalities. The victim is subjected to a typical lightning current (directly striking an electricity distribution line). The victim was using a recharging smartphone directly connected to the socket. A high-frequency human body model was used in the simulations using the Electromagnetic Transients Program (EMTP) software. Based on the results of this study, there is an indication that damage to internal tissues can occur due to the circulation of an intense electric current, which can cause the death of victims.

Index Terms — Lightning fatalities; Smartphone accidents, Electric shock, Lightning, Modeling, Simulations.

I. INTRODUCTION

Lightning is one of the leading causes of climate-related deaths worldwide. In recent decades, there has been a considerable increase in lightning due to worsening global warming [1], [2].

Lightning damages buildings and disrupts economic and social activities. The sectors affected include hospitals, forestry, electricity generation, transmission and distribution, agriculture, telecommunications, transportation, tourism, and leisure [3], [4]. One of the most significant economic losses as far as industry is concerned is downtime. A few hours of downtime from regular operation or the loss of some crucial data stored in digital information systems can cause economic losses of several million dollars [5].

Lightning also causes loss of life directly and indirectly, as it can start fires that can destroy a building and injure the people living or sheltering inside [6]. In some cases, deaths are caused indirectly by lightning, as in the case of forest fires [7].

Brazil is the country with the highest number of lightning in the world. It is the largest country in the tropics, straddling the equator and the Tropic of Capricorn [8]. The Brazilian Association for Raising Awareness of the Dangers of Electricity (ABRACOPEL) publishes the annual Statistical Yearbook of Electrical Accidents, organized by collecting data from newspaper reports. According to ABRACOPEL, 273 victims of lightning strikes were recorded in Brazil between 2013 and 2020 [9]–[11].

De Souza et al. (2022) [12] analyzed deaths from lightning in Brazil between 2010 and 2020, using data issued by the Department of Informatics of the Unified Health System (DATA-SUS). In the period analyzed, 781 cases of deaths caused directly by lightning were observed. This study found that approximately 37% of lightning deaths occur in open places. A further 37.2% of deaths occurred in places not specified on the death certificates.

There are at least five mechanisms of direct damage caused by lightning. One of these is touch voltage: lightning energizes a metallic element or breaks the non-metallic insulation and affects someone in direct contact with this piece of equipment (for example, a metal lamppost). It is estimated that injuries due to touch voltage account for approximately 15% to 25% of deaths [13], [14].

Nowadays, people spend between one and three hours daily on smartphones [15]. In many cases, they use the device when recharging their internal batteries. This situation can become particularly dangerous when it rains and lightning strikes. Thus, two questions motivate this study: i) Are there any cases of people being killed by lightning while using a smartphone connected to the mains in Brazil? ii) What electric current can circulate through the victim in this case?

II. METHODOLOGY

This study presents collected, processed, and analyzed data related to electrical accidents caused by lightning in cases where the victim was using a smartphone. The data was obtained from news reports in 2022, which can answer the question (*i*). A simulation of a model of person in high frequency subjected to a typical lightning strike while using a smartphone and charging it in the socket is then presented to answer the question (*ii*).

The stages in the construction of this research are represented in the methodological flowchart as shown in Fig. 1.

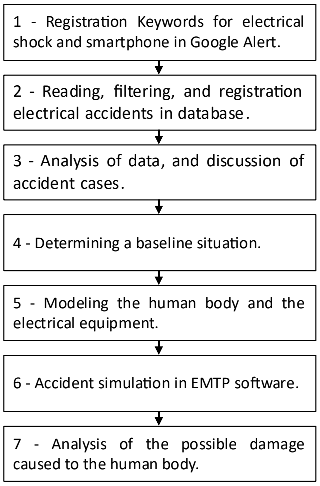

Fig. 1 Flowchart of the methodological steps used in the study.

The second stage of the research, shown in Fig. 1, is characterized by reading, filtering, and recording in the database. Many alerts were excluded for the following reasons:

a) They were received in duplicate.
b) They deal with subjects that are not related to electrical accidents.
c) They had no information about the accidents.

The third stage of the research consisted of processing and analyzing the data collected assessing the completeness and veracity of the information. In some cases, the victim's family was contacted; in others, the public health service was contacted.

The fourth stage consisted of establishing a base case, considered the most typical for this type of accident, involving electric shock when using a smartphone connected to the mains, the cause of which is lightning current.

The fifth stage consisted of modeling a human body for high-frequency electric currents. There are different ways of modeling the human body for electric shock studies. Several authors have already presented their proposals for this purpose, and each proposal has a specific methodology using discrete components (resistances, inductances, and capacitances). In studies of electric shock caused by lightning currents, choosing a model that represents a human body subjected to high-frequency electric currents is necessary because these currents have a strong dispersion effect (skin effect) on the human body [16]. For this purpose, IEC TS 60479-1 - Effects of current on human beings and livestock [17], [18] was considered. Subsequently, models of equipment commonly present in distribution lines up to the end consumer were presented in terms of high frequency, such as medium and low voltage networks, transformers, lightning rods, and cell phone chargers.

In the sixth stage, the complete circuit involving the lightning, the power line, the step-down transformer, the converter, the smartphone, and the coupling were modeled to simulate them in the Electromagnetic Transients Program (EMTP) software [19].

The seventh stage discussed the possible effects of the electric current circulating in the human body and the damage that the current of a lightning can cause.

III. RESULTS AND DISCUSSIONS

A. Accident data

In 2022, at least five people died in Brazil while using a smartphone plugged into the socket when lightning hit the power grid.

The first case involved two victims: two brothers, one 17 and the other 18, were electrocuted on the afternoon of January 4, 2022, in the city of Itapajé, in Ceará State. One of the brothers was holding a smartphone plugged in when lightning struck near the house. The other brother was nearby and also fell victim to the lightning current. The brothers were taken to hospital alive but could not resist their injuries and died the same day [20].

The second case occurred on the night of January 22, 2022, in the town of Santa Isabel, located in the state of Pará in the Brazilian Amazon region. The victim was a 65-year-old woman using a smartphone plugged into the socket during the accident. The lightning strike hit the house directly and damaged part of the roof [21].

The victim in the third case was 38 years old and was using his smartphone plugged in during a rainstorm on January 24, 2022, on a farm in Campo Verde, in Mato Grosso State. The victim had burns on his thumb and index finger [22].

The fourth case occurred on the afternoon of March 16, 2022, in Pernambuco's rural region of Santa Terezinha. The victim was a 16-year-old teenager who, during a rainstorm, was using her smartphone plugged into the socket. The victim was rescued and taken to the regional hospital, where she was hospitalized for two days and discharged [23].

The victim of the fifth case was a 43-year-old man who died with his smartphone in his hand while it was plugged in to charge the battery. The accident occurred on May 8, 2022, in the rural area of Palmares, in the city of Tailândia, in Pará State. The victim was taken to the hospital alive but could not resist due to his injuries and died [24].

Thus, in this period alone, in 2022, a series of five fatal accidents were observed in Brazil, where the victims were using smartphones plugged into sockets and being subjected to electrical currents from lightning. These incidents were distributed between Ceará, Pará, Mato Grosso, and Pernambuco States. The accidents were concentrated over five months, starting in January, and ending in May 2022.

In addition to the fact that the victims were often holding a smartphone plugged in at the time of the lightning strike, it was also observed that most of the strikes occurred in rural areas. It was also observed that the lightning strike occurred near the victim, as witnesses reported hearing the strike loudly. A summary scene of the general situation of the five reported accidents can be seen in Fig. 2.

B. Modeling the systems involved

The human body comprises various fluids and tissues, all with complex electrical properties. The human body is dynamic, distributed, anisotropic, and non-linear as a complete unit. Therefore, representing the body using circuit theory is a complex problem [25]. Applicable models can be built for specific analysis ranges with limitations and inaccuracies.

A common approach to studying electric shocks in the human body is to use equivalent models, where resistances, capacitances, and, in some cases, inductances represent different body parts (skin, muscle, internal organs, etc.). The most common case of electric shock is alternating current (50 or 60 Hz), medium or low voltage (100 V - 10 kV) [26]–[29]. For this reason, several research groups have already developed human body models for simulation using the classic conditions mentioned above [30], [31].

Fig. 2 Typical representation of an accident involving smartphones and lightning currents.

The human body behaves differently when subjected to low-frequency and high-frequency electrical currents [32]. When studying electric shock from lightning currents, choosing a model that represents a human body subjected to high-frequency electric currents is necessary since high-frequency currents have a strong dispersion effect (skin effect) on the human body [16].

In the human body model proposed by M. Rock, C. Drebenstedt, (2022) [32], for high frequencies, the human skin (head, hand, feet, and shoulder) was represented as a capacitance. In the model proposed by W. A. Chisholm, D. Nguyen, (2021) [33], the human body was modeled in more detail, with the heart as the source of a 2.5 mA impulse current, feeding a network of 13 resistors.

This study used the high-frequency response human body model described by IEC TR 60479-4:2020 - Effects of current on human beings and livestock - Part 4: Effects of lightning strokes [36] as shown in Fig. 3.

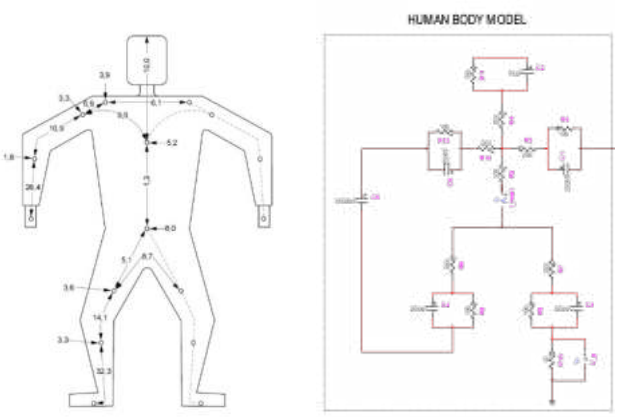

Fig. 3 Human body model according to IEC TR 60479-4.

Based on the description of accidents carried out in section A, a (1) typical lightning was modeled, hitting the (2) medium-voltage power line (MV). Subsequently, a portion of the lightning current circulates through the (3) electrical transformer, reaching the (4) low voltage power line (LV), where it encounters a (5) smartphone charger. The current then circulates the victim, transferring energy via a (6) coupling between the smartphone and the victim's hand. Finally, a portion of the lightning current circulates through the victim (7) and reaches the ground, where the final dissipation occurs. Figure 4 shows the items modeled in high frequency for the simulation.

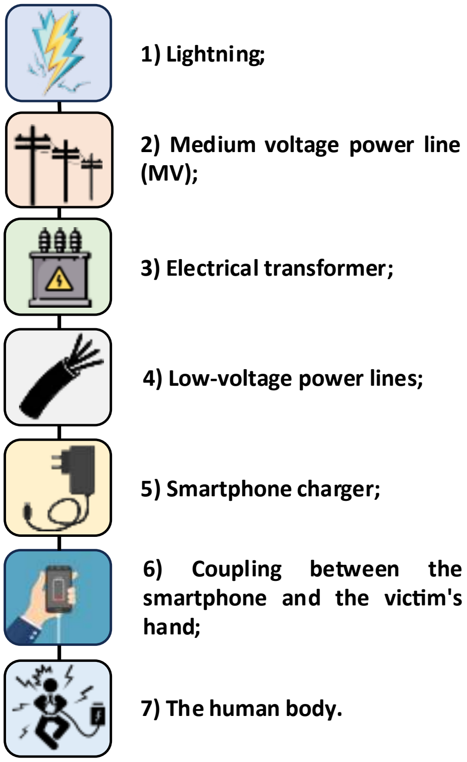

Fig. 4 Components modeled at high frequency to perform the simulation.

All the components of the items mentioned (from 1 to 7) were modeled in EMTP, using typical values and arrangements traditionally used in Brazil. To model the smartphone charger and the coupling between the victim's hand and the smartphone, tests were carried out at the Reduced Model Laboratory of the Institute of Energy and Environment at the University of São Paulo.

A frequency response sweep test was carried out to evaluate the high-frequency behavior (frequency response) of a smartphone charger and the coupling between the victim's hand and the smartphone. This test makes it possible to identify the response of the situation/equipment as a function of frequency. This makes it possible to represent the situation/equipment in an equivalent electrical circuit (resistors, capacitors, or inductors) that is a model capable of simulating high-frequency behavior. Fig. 5 shows the connections between the frequency response meter and smartphone charger terminals.

Fig. 5 Frequency response measurement of the charger's input plug.

As shown in Fig. 6, the victim's hand was represented by an aluminum plate mold with the size and shape of a "typical hand." The mold surrounds (holds) the smartphone to simulate coupling. The measurement was made between the "hand" and the conductor of one of the charger's output polarities (positive pole).

Fig. 6 Measuring the frequency response of the coupling between the victim's hand and the smartphone.

For both cases (modeling the charger and the coupling), measurements were made using a Sweep Frequency Response Analyzer (SFRA), model SFRA45, with a frequency sweep from 5Hz to 45MHz, by applying a sinusoidal voltage of up to 10 Volts peak [34]. The SFRA is typically applied to measure on inductive equipment, such as electric motors, transformers, reactors, etc. However, in the present situation, the validation tests showed promising results for this case of capacitive tendency, such as the situation shown in Fig. 5 and Fig. 6.

The smartphone charger was measured from its input, i.e., the two pins of the plugin Phase-Phase or Phase-Neutral configuration, as shown in Fig. 5. The measurement was made to obtain its frequency response. In addition, the equivalent model was obtained from the frequency response, i.e., a parallel RC (resistor-capacitor) circuit, with R = 1.1 MΩ and C = 1 nF, as shown in Fig. 7.

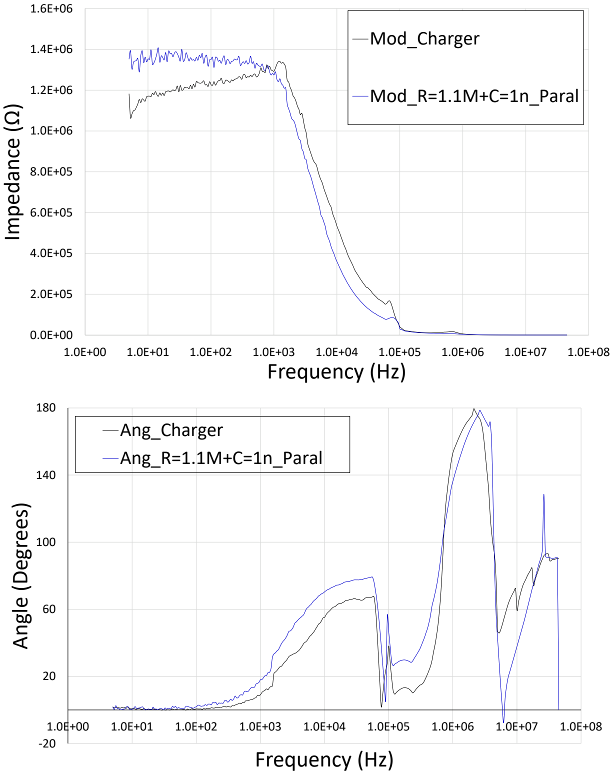

Fig. 7 Frequency response of the tested charger.

Based on the charger's behavior shown in Fig. 7, the closest model was an RC circuit. The R and C values were adjusted according to the charger's modulus and angle curves, thus obtaining an RC circuit with a close response to the chargers. Fig. 7 shows that the curves agree regarding trend as a function of frequency, both in terms of modulus and angle.

Figure 8 shows the frequency response of the coupling between the victim's hand and the smartphone. In this case, a capacitor of approximately 80 pF was the most suitable for building the model. The value of 80 pF coincides with that proposed in IEC 60479 [18] for couplings in situations similar to the one proposed in this study, which is 88 pF.

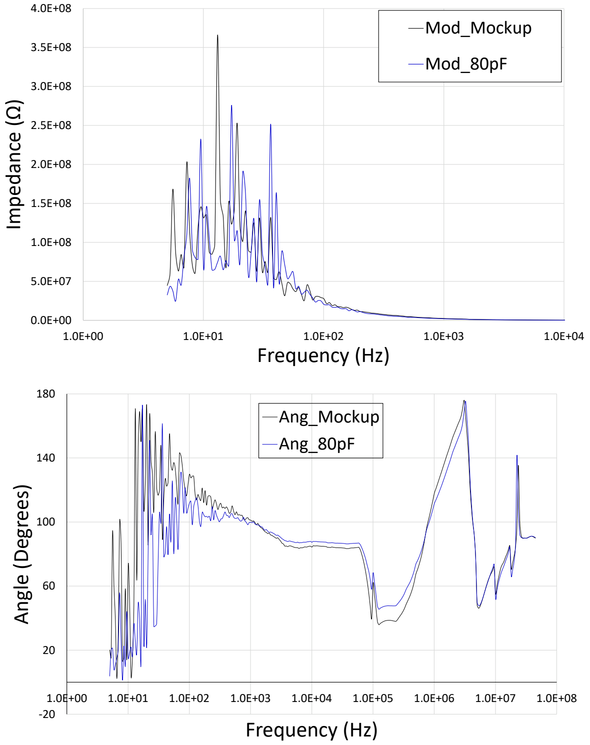

Fig. 8 Frequency response of the coupling between the victim's hand and the smartphone.

Figure 8 also shows good coupling between the victim's hand and the smartphone via an 80 pF capacitor.

Thus, for high frequencies (range up to a few tens of MHz), the circuit that best represents the (5) charger and the (6) coupling between the victim's hand and the smartphone is shown in Fig. 9.

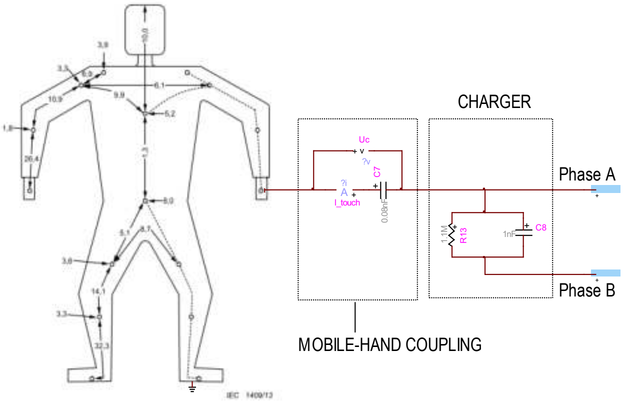

Fig. 9 Equivalent circuit of the smartphone charger and the coupling between the victim's hand and the smartphone.

In Fig. 9, the numbers indicated on the victim refer to the percentage impedance of the human body, considering the hand-to-foot path. This value can be estimated at around 1 kΩ [18].

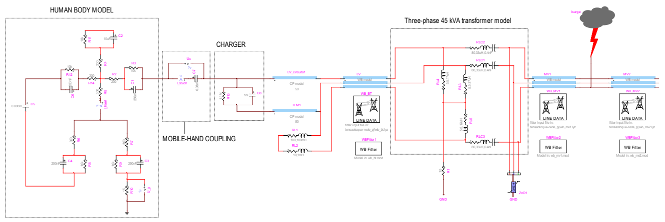

Fig. 10 Complete circuit modeled in EMTP.

To assemble the complete circuit, a low-voltage network was inserted (partial transmission line in wideband model [35], [36] and distributed parameters [36], [37]); the high-frequency transformer model (three-phase 45 kVA with typical parameters); and the medium-voltage network (wideband model). Further modeling details can be found in Siqueira, J. C. G. and Bonatto, B. D. (2021) [38]. Figure 10 shows the circuit model simulated in EMTP.

The lightning current was modeled with typical parameters: Ip = 30 kA; tf = 5.5 µs; th = 75µs and Zch = 1 kΩ, typical values indicated in the CIGRE technical brochure on lightning parameters for engineering applications (2013) [39].

The MV and LV lines were modeled in typical spacing and height configurations in the wideband model. The part of the final stretch on the LV side was modeled as a constant parameter with the following characteristics: VLV = 290 m/µs and ZLV = 500 Ω.

A high-frequency model was used to correctly configure the transformer in the electrical circuit [40], [41], with a three-phase 45 kVA transformer with a lightning arrester on the MV side.

C. Simulation results

Figure 11 shows the electrical current waveform of the lightning strike used in the simulation. Figure 12 shows the values and waveform of the voltage the victim was subjected to between the smartphone and the ground. Figure 13 shows the current circulating between the smartphone and the victim's hand.

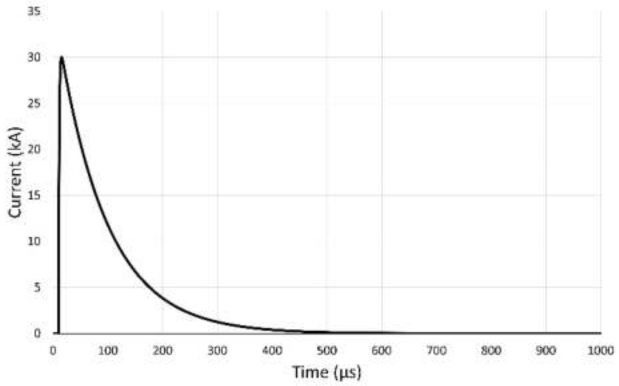

Fig. 11 Lightning current injected into the MV side, phase C.

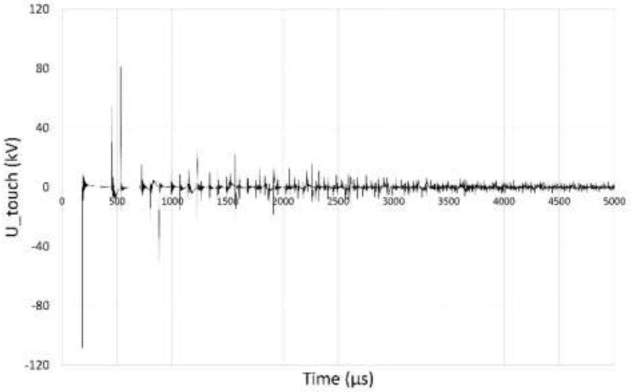

Fig. 12 Electrical voltage to which the victim is subjected.

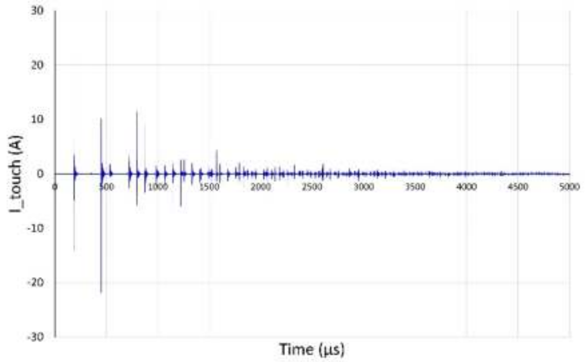

Fig. 13 Current circulating between the smartphone and the victim's hand.

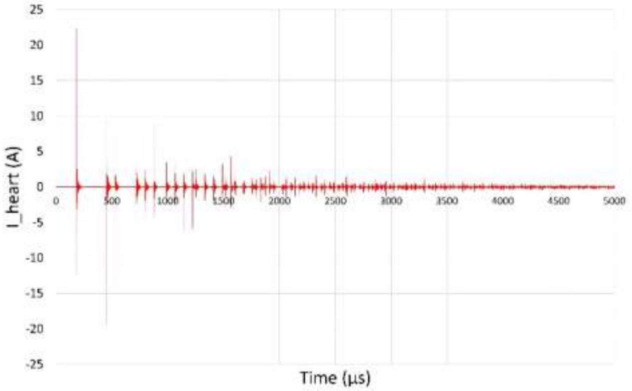

Fig. 14 Current circulating in the victim's heart (300 Ω resistor).

Figure 14 shows the magnitude and waveform of the current circulating in the victim's heart. It can be seen that the current reaches a peak value of 23 Amperes. In this case, the charger was connected between phases A and B, and the lightning was the phase C cable on the MV side. In addition, there is only lightning protection upstream of the transformer, with no surge protection devices upstream of the charger. The current values can cause severe damage to the victim and cardiac arrest, indicating that using a smartphone charging from the socket in a rainy situation with lightning is hazardous for users.

IV. CONCLUSIONS

The study sought to analyze and elucidate incidents related to electrical accidents involving lightning strikes and the use of smartphones plugged into sockets. The data collection indicated a worrying series of fatal accidents in Brazil, all concentrated in five months. The recurrence of these accidents in rural regions and the intense sound of the discharge reported by witnesses indicate the proximity and intensity of the lightning during the accidents.

On a technical level, it is clear that the human body has complexities and variability in its electrical properties. Representing the human body in electric shock scenarios, especially under the effects of high frequencies such as those originating from lightning, requires a suitable model. Using pre-established and standardized models associated with the characteristics of the devices and couplings, it was possible to create a relevant simulation that represents the real scenario of exposure to electrical currents from lightning.

The accuracy with which the charger and coupling models were validated, representing the real scenario, highlights the need to consider these variables when analyzing accidents. The frequency response, as well as the equivalent model for the charger and the coupling of the victim's hand with the smartphone, show an accurate correlation with literature data, reinforcing the validity of the simulation.

In recent years, the Association of Professionals for Protection and Alert Against Lightning (APPAR), the Brazilian Association for Awareness of the Dangers of Electricity (ABRACOPEL), and the National Institute for Space Research (INPE) have been working to disseminate information about these risks, with ongoing participation in television programs, conducting scientific dissemination, and alerting the public about the dangers. Additionally, the International Lightning Safety Day (ILSD) is held annually at the Institute of Energy and Environment (IEE) of the University of São Paulo (USP), where lectures are given on the risks associated with lightning.

Consequently, the following recommendations can be made to prevent the accidents highlighted in this study:

a) Avoid touching electronic devices connected to the electrical grid during periods of rain.

b) Install surge protection devices in electrical networks and periodically verify their operational status.

c) Immediately remove the cell phone charger from the socket when you notice the onset of lightning storms.

d) Ensure that the electrical grounding system in residences is in good working condition.

In summary, this study highlights the urgent need to raise awareness of the risks associated with using electronic devices during storms, especially in rural areas and places prone to lightning strikes. The combination of real data with the simulations presented provides a solid basis for promoting safer practices and developing possible technological solutions that minimize risks. It is hoped that this work can serve as a warning and guide for preventive measures to avoid future fatalities related to this scenario.

V. ACKNOWLEDGEMENTS

We extend our sincere thanks to Luisa Shigihara for the skill and dedication she showed in manually drawing Fig. 2 of our study, significantly enriching our study.

VI. REFERENCES

[1] C. Price and D. Rind, “Possible implications of global climate change on global lightning distributions and frequencies,” *J. Geophys. Res. Atmos.*, vol. 99, no. D5, pp. 10823–10831, May 1994, doi: 10.1029/94JD00019.

[2] D. M. Romps, J. T. Seeley, D. Vollaro, and J. Molinari, “Projected increase in lightning strikes in the united states due to global warming,” *Science (80-.).*, vol. 346, no. 6211, pp. 851–854, Nov. 2014, doi: 10.1126/science.1259100.

[3] B. Mills, D. Unrau, L. Pentelow, and K. Spring, “Assessment of lightning-related damage and disruption in Canada,” *Nat. Hazards*, vol. 52, no. 2, pp. 481–499, Jan. 2010, doi: 10.1007/S11069-009-9391-2/TABLES/7.

[4] M. A. Cooper and R. L. Holle, “Economic Damages of Lightning,” pp. 51–62, 2019, doi: 10.1007/978-3-319-77563-0_5.

[5] E. Renni, E. Krausmann, and V. Cozzani, “Industrial accidents triggered by lightning,” *J. Hazard. Mater.*, vol. 184, no. 1–3, pp. 42–48, Dec. 2010, doi: 10.1016/J.JHAZMAT.2010.07.118.

[6] M. Z. A. A. Kadir, M. A. Cooper, and C. Gomes, “An overview of the global statistics on lightning fatalities,” in *2010 30th International Conference on Lightning Protection, ICLP 2010*, 2017, pp. 1–4, doi: 10.1109/ICLP.2010.7845882.

[7] W. J. Koshak *et al.*, “Variability of CONUS Lightning in 2003–12 and Associated Impacts,” *J. Appl. Meteorol. Climatol.*, vol. 54, no. 1, pp. 15–41, Jan. 2015, doi: 10.1175/JAMC-D-14-0072.1.

[8] I. R. C. A. Pinto, O. Pinto, R. M. L. Rocha, J. H. Diniz, A. M. Carvalho, and A. Cazetta Filho, “Cloud-to-ground lightning in southeastern Brazil in 1993: 2. Time variations and flash characteristics,” *J. Geophys. Res. Atmos.*, vol. 104, no. D24, pp. 31381–31387, Dec. 1999, doi: 10.1029/1999JD900799.

[9] M. B. Martinho, E. Martinho, and D. F. de Souza, “ANUÁRIO ESTATÍSTICO DE ACIDENTES DE ORIGEM ELÉTRICA 2022 - Ano base 2021,” *ABRACOPEL*, vol. 1, p. 108, Mar. 2022, doi: 10.29327/560614.

[10] E. Martinho, S. R. Santos, and D. F. de Souza, “Accidents of Electrical Origin, a Detailed Analysis of Statistics. Brazil Compared to Other Countries,” 2022, pp. 1–7, doi: 10.1109/esw49146.2022.9925021.

[11] D. F. De Souza, W. A. Martins, E. Martinho, and S. R. Santos, “An Analysis of Accidents of Electrical Origin in Brazil between 2016 and 2021,” *IEEE Trans. Ind. Appl.*, vol. 59, no. 3, pp. 3151–3160, May 2023, doi: 10.1109/TIA.2023.3241138.

[12] D. F. De Souza, H. E. Sueta, H. Tatizawa, W. A. Martins Júnior, and E. Martinho, “An analysis of lightning deaths in Brazil 2010-2020,” *ICLP 2022 - 36th Int. Conf. Light. Prot.*, pp. 643–647, 2022, doi: 10.1109/ICLP56858.2022.9942657.

[13] C. J. Andrews, “Telephone-related lightning injury,” *Med. J. Aust.*, vol. 157, no. 11, pp. 823–826, Dec. 1992, doi: 10.5694/J.1326-5377.1992.TB141300.X.

[14] A. C. Koumbourlis, “Electrical injuries,” *Crit. Care Med.*, vol. 30, no. 11 SUPPL., Nov. 2002, doi: 10.1097/00003246-200211001-00007.

[15] M. A. Rasmussen, J. O. Frydendahl, E. D. Mekler, and K. Hornbæk, “Is Time on Smartphones Well Spent?,” *Interact. Comput.*, vol. 33, no. 5, pp. 522–536, 2021, doi: 10.1093/iwc/iwac003.

[16] C. M. Dowse and C. E. Iredell, “The Effective Resistance of the Human Body to High-Frequency Current,” *https://doi.org/10.1259/are.1920.0008*, vol. 25, no. 2, pp. 33–46, Mar. 2014, doi: 10.1259/ARE.1920.0008.

[17] L. Copy, R. Mil, S. Jisc, and U. Copy, “Effects of current on human beings and livestock —,” *Int. Electrotech. Com.*, vol. 1, no. September, p. 479, 2004.

[18] International Electrotechnical Commission (IEC), “IEC 60479 - Effects of current on human beings and livestock - Part 1: General aspects.” pp. 1–72, 2018.

[19] E. Haginomori, T. Koshiduka, J. Arai, and H. Ikeda, *Power system transient analysis: Theory and practice using simulation programs (AT P-EMTP)*, 1st editio. Hoboken, Nova Jersey, EUA: Wiley, 2016.

[20] Umirim Newsroom, “Two brothers die from electric shock in the district of São Miguel in Itapajé (In Portuguese),” *Umirim News*, 2022. [Online]. Available: https://www.umirimnoticias.com.br/noticia/2754/dois-irmaos-morrem-vitimas-de-descarga-eletrica-no-distrito-de-sao-miguel-em-itapaje. [Accessed: 30-Mar-2023].

[21] Acontece na Bahia, “Lightning strikes woman inside house and relatives say she was playing with her cell phone (In Portuguese),” 2022. [Online]. Available: https://acontecenabahia.com.br/raio-atinge-mulher-dentro-de-casa-e-parentes-afirmam-que-ela-estava-mexendo-no-celular/. [Accessed: 30-Apr-2023].

[22] “Woman dies after being shocked by charging cell phone in MT (In Portuguese),” *Folhamax*, 2022. [Online]. Available: https://tvcentrooeste.com.br/artigo/mulher-morre-ao-levar-choque-de-celular-que-estava-carregando-em-mt. [Accessed: 30-Apr-2023].

[23] J. Oliveira, “Teenager using cell phone is hit by strong shock when lightning strikes in Santa Terezinha (In Portuguese),” *Portal Santa Teresinha*, 2022. [Online]. Available: http://www.folhapatoense.com/2022/03/17/adolescente-que-utilizava-o-celular-e-atingida-por-forte-choque-no-momento-da-queda-de-um-raio-em-santa-terezinha/. [Accessed: 12-May-2023].

[24] “Public servant from Thailand dies after being hit by electric shock while using cell phone in Moju (In Portuguese),” *TN BRASIL TV*. [Online]. Available: https://tnbrasiltv.com.br/servidor-publico-de-tailandia-morre-apos-ser-atingido-por-descarga-eletrica-enquanto-usava-o-celular-em-moju/. [Accessed: 21-Mar-2023].

[25] C. L. Li, S. H. Du, and Y. Xia, “Study on equivalent circuit of the human body and its transient response against electric shock,” in *APAP 2011 - Proceedings: 2011*

International Conference on Advanced Power System Automation and Protection, 2011, vol. 1, pp. 590–594, doi: 10.1109/APAP.2011.6180469.

[26] N. Ichikawa and S. Sakaue, “Epidemiology of rate of fatality due to electric shock, 2015-2017: Copyright Material IEEE Paper No. ESW2021-31,” *IEEE IAS Electr. Saf. Work.*, vol. 2021-March, Mar. 2021, doi: 10.1109/ESW45993.2021.9461488.

[27] N. Ichikawa, “Electrical Injury Rate and Epidemiology in Japan, 2013-2015,” *IEEE Trans. Ind. Appl.*, vol. 56, no. 4, pp. 4319–4323, Jul. 2020, doi: 10.1109/TIA.2020.2982855.

[28] R. Blumenthal, “A retrospective descriptive study of electrocution deaths in Gauteng, South Africa: 2001–2004,” *Burns*, vol. 35, no. 6, pp. 888–894, Sep. 2009, doi: 10.1016/J.BURNS.2009.01.009.

[29] T. D. Bracken, G. G. Sias, C. Kim, R. S. Senior, and R. M. Patterson, “Survey of electrical utility worker body impedance,” *IEEE Trans. Power Deliv.*, vol. 23, no. 2, pp. 1251–1259, Apr. 2008, doi: 10.1109/TPWRD.2008.915838.

[30] D. Roberts, “50-v shock hazard threshold,” *IEEE Trans. Ind. Appl.*, vol. 46, no. 1, pp. 102–107, Jan. 2010, doi: 10.1109/TIA.2009.2036541.

[31] L. B. Gordon, B. K. Appelt, and J. W. Mitchell, “Complex dielectric nature of the human body,” *Conf. Electr. Insul. Dielectr. Phenom. (CEIDP), Annu. Rep.*, vol. 2, pp. 577–580, 1998, doi: 10.1109/CEIDP.1998.732963.

[32] M. Rock and C. Drebenstedt, “Lightning Impact on Human Modeled by Network with Lumped Elements,” *ICLP 2022 - 36th Int. Conf. Light. Prot.*, pp. 614–619, 2022, doi: 10.1109/ICLP56858.2022.9942467.

[33] W. A. Chisholm and D. H. Nguyen, “Coordinating the Einthoven Body Impedance Model for ECG Signals with IEC 60479-1:2018 Electrocution Heart Current Factors: Invited Lecture - Extended Summary,” in *2021 35th International Conference on Lightning Protection, ICLP 2021 and 16th International Symposium on Lightning Protection, SIPDA 2021*, 2021, doi: 10.1109/ICLPandSIPDA54065.2021.9627369.

[34] N4L, “Sweep Frequency Response Analyzer (SFRA) - SFRA45 - User Manual Version 2.10.” p. 87, 2018.

[35] A. Morched, B. Gustavsen, and M. Tartibi, “A universal model for accurate calculation of electromagnetic transients on overhead lines and underground cables,” *IEEE Trans. Power Deliv.*, vol. 14, no. 3, pp. 1032–1038, 1999, doi: 10.1109/61.772350.

[36] “Electromagnetic Transients Program (EMTP) - User Manual - Help - Constant Parameter Transmission line and Wideband line/cable,” Québec, 2019.

[37] H. W. Dommel, “Digital Computer Solution of Electromagnetic Transients in Single-and Multiphase Networks,” *IEEE Trans. Power Appar. Syst.*, vol. PAS-88, no. 4, pp. 388–399, 1969, doi: 10.1109/TPAS.1969.292459.

[38] J. C. G. de Siqueira and B. D. Bonatto, *Introduction to Transients in Electrical Circuits - Analytical and Digital Solution Using an EMTP-based Software*. Berlin - Germany, 2021.

[39] V. A. Rakov *et al.*, “CIGRE technical brochure on lightning parameters for engineering applications,” in *2013 International Symposium on Lightning Protection, SIPDA 2013*, 2013, pp. 373–377, doi: 10.1109/SIPDA.2013.6729246.

[40] A. Piantini and C. V. S. Malagodi, “Voltage surges transferred to the secondary of distribution transformers,” *IEE Conf. Publ.*, vol. 1, no. 467, 1999, doi: 10.1049/CP:19990582.

[41] A. Piantini and A. G. Kanashiro, “A distribution transformer model for calculating transferred voltages,” in *International Conference on Lightning Protection - ICLP*, 2002.

VII. VITA

Danilo Ferreira de Souza is an Electrical Engineer and Safety engineer. He is also a 'master's in energy and a PhD Student at the Institute of Energy and Environment - IEE of the University of Sao Paulo - USP. He is an Assistant Professor at the Federal University of Mato Grosso since 2011, where he teaches the disciplines of electrical installations, energy and safety engineering. Danilo has experience in Electrical Engineering, working on electrical installation projects, lightning protection, energy efficiency, energy and society. He is a member of the Performance and Safety Group for Electrical Equipment and Materials at USP – Brazil and is a member of the Interdisciplinary Center for Studies in Energy Planning - NIEPE/UFMT.

Milton Shigihara holds a degree in Electrical Engineering - Emphasis in Energy and Automation from the Polytechnic School of the University of São Paulo (2001), a master's degree in Energy from the Interunits Graduate Program in Energy at USP (2005) and a PhD in Sciences from the Graduate Program in Energy at USP (2015). He is currently an electrical engineer and researcher at the High Voltage Laboratory of USP's Energy and Environment Institute. He has experience in electrical engineering, with an emphasis on the protection of electrical power systems, working mainly on the following subjects: lightning, short-circuit, atmospheric overvoltages and protection.

Hélio Eiji Sueta, PhD - More than 30 years of field experience in Lightning Protection of Structures and High Currents tests. Deputy Head of the Planning, Analysis and Energy Development Scientific Division of the Energy and Environment Institute (IEE-USP) of the University of Sao Paulo. Lightning Protection: Participant of the Brazilian Electricity Committee in the study group that prepares and reviews the lightning protection standard, acting as coordinator and secretary of the commission (from 2009 to today). Brazilian representative at IEC TC 81: Lightning Protection. Coordinator of GT1 (COBEI-ABNT) on Safety Procedures to reduce risk outside structures. Participant of GT2 (COBEI-ABNT) on the development of a Brazilian standard corresponding to IEC 62793. Participant and coordinator of GT3 that reviews the Brazilian standard NBR 5419. Participant of GT5 who studied common points between NBR 5419 and NBR 5410. In GT6 we studied common grounding definitions. In GT7, which studies general lightning protection demands by COBEI and coordinator of GT9, which studies non-conventional rods. Lightning protection training course.