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Electrocutions and Downed Powerlines: a Forensic Electrical Engineering Analysis of Causes, Reasons, and Effects

By Helmut G. Brosz, PEng (NAFE 1029C)

Abstract

In October of 1999, four individuals were walking a dog after a storm. The group of three males and one female came upon a large puddle, which covered most of a T intersection on their intended route. The female walked around the puddle as her two sons entered the puddle barefoot. Two of the male individuals were electrocuted. The surviving male entered the puddle to help and was immediately electrocuted. The dog followed them into the pool and was electrocuted. The female turned around to see her two sons and friend lying face down in the puddle. She entered the puddle to help them and ultimately was electrocuted by the same 480VAC downed and energized streetlight powerline in the pool. The facts discussed in this paper include vegetation management, short-circuit electrical protection, the conductivity of water and soil, human response to electrical current, sag, and tension of power lines.

Keywords

Electrocution, downed power lines, vegetation management, electrical protection, conductor damage, forensic electrical engineering

Introduction

In October of 1999, after a storm reportedly produced winds of approximately 70 mph, a mother took her two sons, their friend, and the family dog out for a walk in the dark. The individuals approached a giant puddle covering the T intersection on the road. The two brothers decided to walk through the pool barefoot, their mother went around the puddle with shoes on, and their friend entered the puddle after taking off his running shoes (followed by the dog). Upon noticing the brothers, the friend, and the dog lying in the puddle unconscious, the mother turned around and entered the puddle as well. All were electrocuted by an energized 480-Volt (V) downed streetlight conductor found lying in approximately 4 inches of water. The heads of the three deceased males were located about 1 foot from the underwater streetlight conductor. The female's feet and head were approximately 25 feet from the other side of the conductor (**Figure 1**).

No witnesses observed the electrocutions. The electric utility responded to a phone call, and took down two pieces of 265 feet #4 AWG (American Wire Gauge) AAAC (All Aluminum Alloy Conductor) 480VAC (Volts Alternating Current) streetlight circuit between two poles. One-piece that remained energized in the water was a 126-foot length from the west pole where the conductor was broken. A second 139-foot piece from the east pole was de-energized. The entire 480V streetlight circuit, consisting of 52 streetlights, was supplied by a single-phase 25kVA (Kilovolt Ampere) rated pole-top oil-filled transformer from a 3-phase 13,200/7,600VAC overhead distribution circuit running east-west along the

Figure 1
Location of victims observed in the puddle of water after electrocution.

Helmut G. Brosz, PEng, Forensic Sciences International Group, 64 Bullock Dr. Markham, ON, L3P3P2, (844) 554.4666, hbrosz@forensicsig.org
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north side of the street. A neutral conductor (3/0AWG AAAC) was underbuilt. The #4 AWG AAAC streetlight conductor was mounted 1 foot below the neutral at each concrete pole (**Figure 2**).

The pole-mounted transformer was located only two spans to the west of the electrocution location. The streetlighting transformer 7,600VAC primary was protected with a 4K current-rated fuse after the fact. With this information, it was established in deposition to have been a 6K fuse, never operating during any time of the electrocution event. The electric utility de-energized the transformer, took down the streetlight control box, and stored it. The original 6K transformer fuse was not presented as evidence as it could not be located.

The 265-foot neutral and streetlight span, which crossed the intersection from west to east, was found to be in contact with a Ficus tree, among other trees and bushes displayed in **Figure 3**.

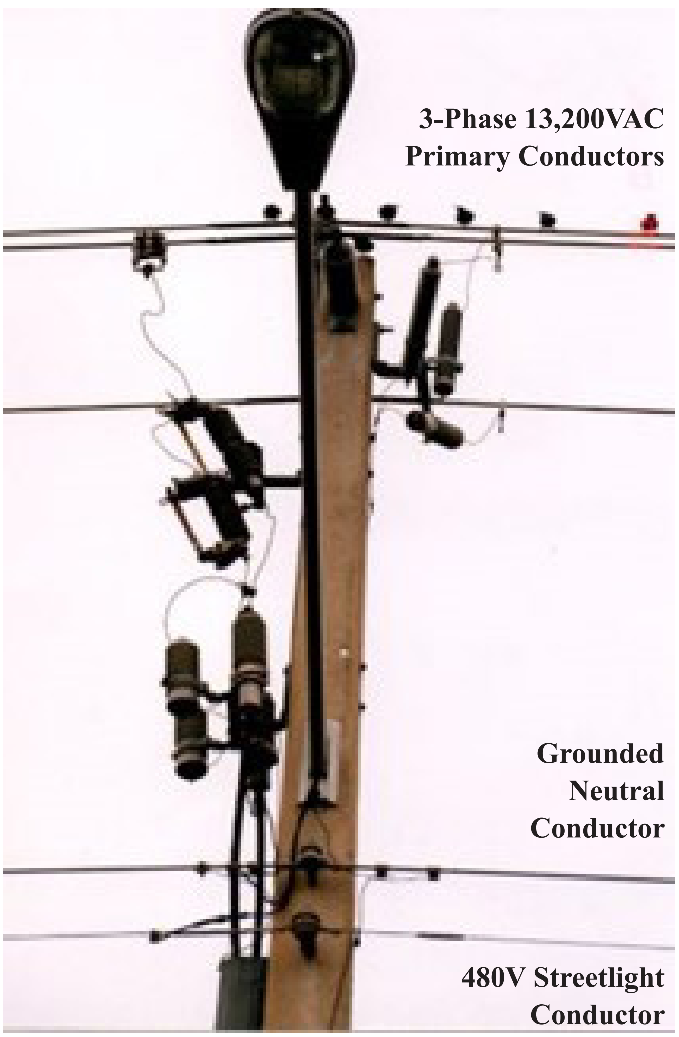


Figure 2
Streetlight conductor configuration.

Figure 3
Neutral conductor in the Ficus tree after the incident.

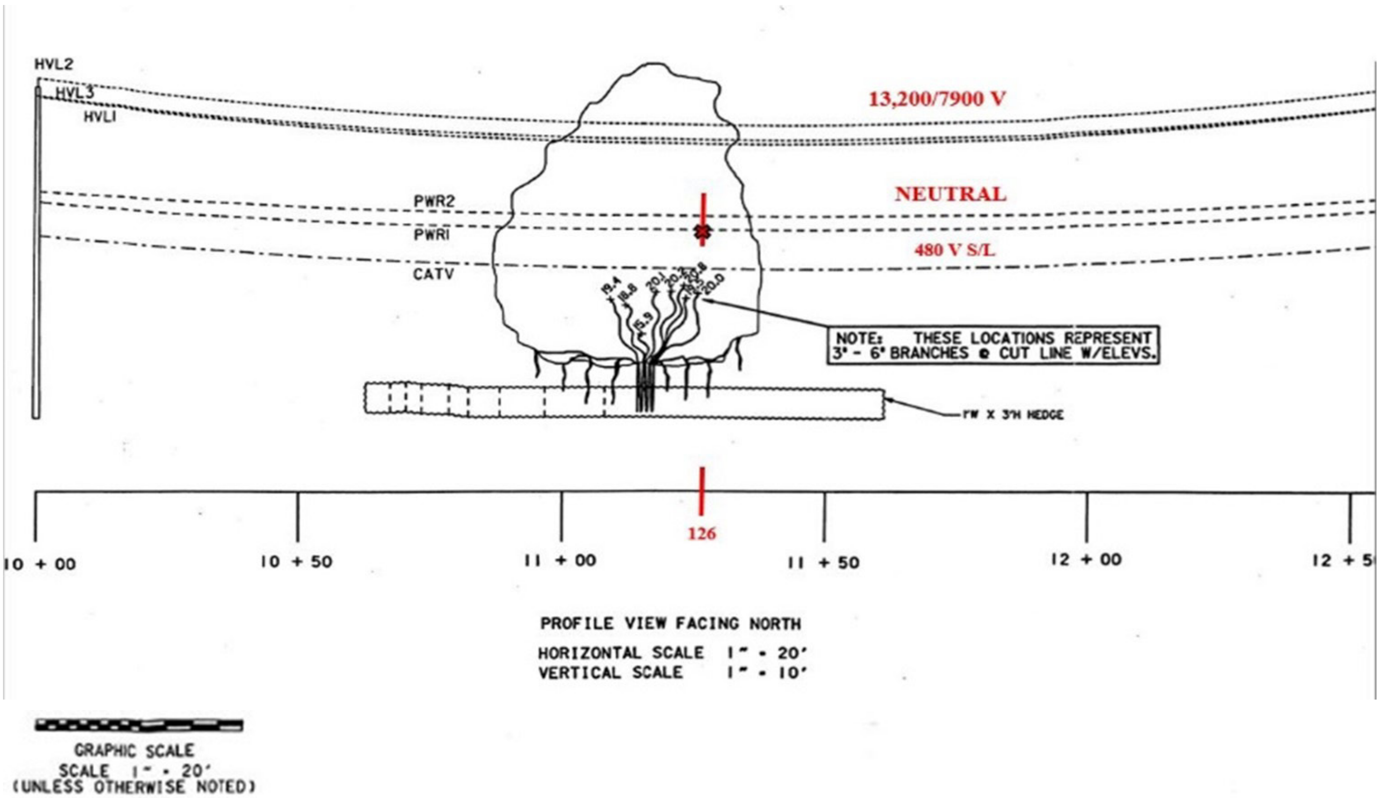
The utility trimmed the Ficus tree after the incident occurred. The cut marks were later marked on a survey drawing (**Figure 4** and **5**). The #4 AWG AAAC was found severed from its attachment point at the west pole 126 feet and 139 feet from its attachment point on the east pole. The 126-foot energized section of the conductor hung from its 22-foot vertical attachment point on the west pole, laying in the puddle spanning the entire width of the road. The 139-foot de-energized section of the conductor was suspended in the air by vegetation. The scope of work included reporting the causes, reasons, and effects of the streetlight conductor falling.

The cause of death of the victims was determined to be electrocution. No electrical burn marks were identified; this is consistent with electrocutions conducted in water.

Preliminary examination identified that — from ground level — there was an anomaly or damage to the still in-service neutral conductor at the 126-foot location six years after the incident occurred (**Figure 6**). Furthermore, two tape marks were observed wrapped around the neutral conductor on either side of the anomaly (**Figure 7**).

The evidence requested for analysis and documentation included:

1. The neutral conductor was examined while connected in place between the two concrete poles



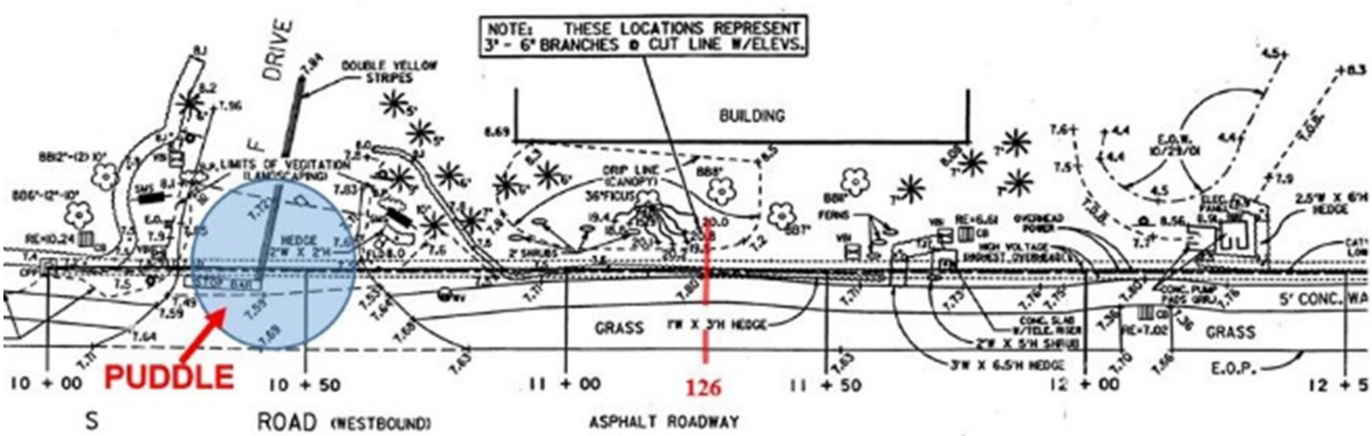


Figure 4 and **Figure 5**
Survey of scene.

Figure 6
Neutral conductor defect.

Figure 7
Two pieces of tape on 3/0 neutral conductor.

Figure 8
Forensic Engineer and Professor Helmut Brosz at the bucket truck to inspect the conductors close-up.

using a bucket truck (**Figure 8**).

2. The utility took the neutral conductor and presented for examination and documentation (**Figure 9**).

3. Examination of the trimmed branches on the tree. The diameter of the Ficus tree cuts at the location of the severed streetlight conductor.

4. To examine all sections of downed #4 streetlight conductors in conjunction with the neutral conductor (**Figure 10**).

A survey of the scene to locate the precise positions of poles, conductors, tree branches, neutral conductor defect, and 126-foot conductor break was conducted to present a diagram. This is done between the concrete poles (**Figures 4** and **5**).

A rope copy was made of the 265 feet of streetlight and neutral conductor, including all anomalies (i.e., arc

Figure 9
Severed streetlight conductor.

Figure 10
Examination of conductor.

marks, vegetation contact, corrosion on a ballroom floor to facilitate the preservation of the evidence (**Figure 9** and **11**).

Tests and Examinations

All sections (per inch) of neutral, 3/0 AWG, AAAC and #4 AWG, AAAC conductor were examined visually

Figure 11
Rope copy of conductor with vegetation contact markings.

and with microscopy (**Figure 9** and **10**)

Preliminary Analysis

When a scenario of an electrocution associated with a downed power line is presented, potential factors that may have caused the line to come down and remain energized should be considered, such as:

Wind forces impacting powerline

a. The applicable N.E.S.C. (National Electrical Safety Code) requires overhead distribution lines at this location to be designed to withstand average wind speed of 150 mph (67 mps) at 33 feet (10 m) height). In this area, the winds were reported not to exceed 70 mph in weather records. The rated breaking strength of the #4 conductor is 1,760 pounds. The weight of the 265-foot span of #4 AWG AAAC conductor is 12 pounds (based on 45.4 pounds per 1,000 feet).

b. The possibility of galloping (high-amplitude, low-frequency oscillations of overhead powerlines due to wind) of the conductor occurring was considered and excluded from investigation. This is due to the conductor being supported at various locations by vegetation. Its vibrational amplitude would be limited by intermittent contact with adjacent vegetation.

Short Circuits

a. Close visual and optical examination of the neutral and streetlight conductor revealed a short circuit occurred between the two at the 126-foot location and at other locations. The seven strands (7 x 0.0843 inches) of the #4 AWG streetlight conductor were melted and severed (**Figure 9**). The larger neutral conductor was only one of its seven 0.1672-inch strands severed (**Figure 6**).

b. On the severed conductor, evidence of long-term contact with vegetation (**Figure 11**) resulted in a form of corrosion. The survey was conducted six years after the event and tree trimming.

c. New shoots emanating from the Ficus tree trimming cuts were observed. The diameter of the cuts ranged from 3 to 6 inches, corroborating the extent of branches in contact and in the vicinity of the open conductor. Production of documents revealed trimming had not occurred for at least six years prior to the electrocution. The tree trimming cycle of three years (as set out in the utility standards) was missed at this location (**Figure 12**). Furthermore, the tree trimming cycle does not take into consideration the growth rate of the various vegetation species. A Ficus tree can grow up to 6 feet per year.

d. The primary cause factor for the short-circuit event was due to the lack of vegetation maintenance. The vegetation was not appropriately managed in maintaining a 6-foot clearance between powerlines and trees. According to the utility standards, appropriate vegetation management requires to maintain a clearance of 6 feet between power lines and trees[5]. This distance was not met and was a large factor in causing the short-circuit event.

e. Short circuits caused by conductive flying objects were ruled out due to the lack of flying conductive objects found, seen, or reported. Furthermore, the momentary contact would not be long enough to produce the damage observed.

f. Sustained contact with branches alone at 480VAC would not draw sufficient current to produce the arcing damage observed — only corrosion evidence is attributed.

Lightning damage to conductor

Lightning was reported during the storm. The neutral and streetlight conductor were protected directly from above by the 3-phase, 7,200V circuit and did not trip. This is according to utility and resident reports. Therefore, possible damage to the #4 conductor due to lightning was excluded from the investigation. A Lightning Detection Network search revealed no lightning within the area of the electrocution site. Additionally, the hypothesis of

Figure 12
Ficus branches below neutral 3/0 and #4 streetlight conductor (removed) following the incident and prior to trimming.

conductor damage due to lightning is not consistent with the actual arcing damages observed.

Electrical protection

a. The 480V electrical circuit begins at the 25kVA transformer having a rated secondary current of 52 amps (A). The 52 connected streetlights draw a calculated current of 0.833A each for a total of 52 x 0.833A= 43.318A. The ampacity of #4 AWG AAAC is approximately 60A. The circuit did not exhibit any visual signs of melting or annealing. The 6K-rated fuse on the primary side of the transformer allows a long-time current flow of approximately 180A at 480VAC before operating, according to its 6K time current curve[6]. Since the fuse did not operate, a current flow was maintained. Current overload due to normal lighting load on the secondary side of the transformer did not exist.

b. Winds caused the branch/ branches of the Ficus tree to lift the #4 AWG AAAC streetlight conductor intermittently up into contact with the neutral conductor. Every time the branch made contact, a short circuit of variable duration would occur. The fault current flowed along the #4 conductor to the point of contact with the 3/0 neutral at the 126 feet mark, flowing back along the neutral to the transformer. The cumulative short circuits lasted long enough to melt the seven strands of the #4 AWG AAAC and one strand of the seven larger #3/0 streetlight conductor[1]. This caused the west section of the #4 conductor to fall into the puddle and remain energized.

c. When the still-energized west section of the #4 conductor fell into the puddle, the current path extended from the conductor through water, through the ground back to the grounding rod (**Figure 13**) at the base of the concrete transformer pole. From there, the current flowed up the solid copper #6 AWG bare conductor to the neutral of the streetlight transformer. The impedance of the circuit was high enough (and the current low enough) so as to prevent the transformer 6K fuse from operating on a 480V and less than a 225A fault.

Effect of current on the human body

a. The brothers entered the puddle and approached the unseen conductor lying in about 3 to 4 inches of water. The voltage between their feet, also known as "step potential," was of an approximate magnitude to exceed 85VAC. The impedance between wet foot to foot based on the I.E.C. Standard 479-1-1994 (**Figure 14**) is indicated to be 100% of the wet hand to foot impedance of 850 ohms (for 50% of population) at about 500V (**Figure 15**).

Figure 13
Ground rod at the base of the transformer pole.

Loss of muscle control occurs at approximately 10 milliamps of current, causing the individual to fall. In this case, the brothers fell forward. In both male's cases, the current entered the body and traveled through the heart, with the majority of current exiting through the feet. With the mother falling backward, the current entered the feet and exited from the head. In all cases, electrocution occurred.

b. Electrocution occurs if a current greater than approximately 50mA passes through the heart for

Touch voltage V	Values for the total body impedances Z_T (Ω) that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	1175	2 175	4 100
50	1100	2 000	3 675
75	1025	1 825	3 275
100	975	1 675	2 950
125	900	1 550	2 675
150	850	1 400	2 350
175	825	1 325	2 175
200	800	1 275	2 050
225	775	1 225	1 900
400	700	950	1 275
500	625	850	1 150
700	575	775	1 050
1 000	575	775	1 050
Asymptotic value =internal impedance	575	775	1 050

NOTE 1 Some measurements indicate that the total body impedance for the current path hand to foot is somewhat lower than for a current path hand to hand (10 % to 30 %).

NOTE 2 For living persons the values of Z_T correspond to a duration of current flow of about 0,1 s. For longer durations Z_T values may decrease (about 10 % to 20 %) and after complete rupture of the skin Z_T approaches the internal body impedance Z_i.

NOTE 3 For the standard value of the voltage 230 V (network-system 3N – 230/400 V) it may be assumed that the values of the total body impedance are the same as for a touch voltage of 225 V.

NOTE 4 Values of Z_T are rounded to 25 Ω.

Figure 14
Total body impedances Z_T for a current path hand to hand a.c. 50/60 Hz, for large surface areas of contact in water-wet conditions.

around 1 second or more. This causes ventricular fibrillation, leading to death[3]. The deceased individuals spent a prolonged amount of time, exceeding 1 second, with the current flowing through their hearts.

Conclusion

The lack of clearance between the streetlight conductor and the Ficus tree allowed the tree branches to lift the streetlight conductor into the grounded neutral when wind occurred. The responsibility of maintaining the vegetation to conductor clearance rests with the utility as per the NESC and Public Service Commission. Persistent wind (over time) resulted in repetitive short circuits severing the streetlight conductor, causing it to break and fall into the puddle.

It continued to remain energized, in part, due to the impedance presented by the return-current path. The deceased's legs muscles were subjected to currents that caused loss of muscle control. Thus, the individuals collapsed and were electrocuted in the puddle with lethal currents flowing from head to foot. Cause of death was determined to be electrocution, according to the coroner's report. The utility did not give a reason as to why trimming was not done. In conclusion, to prevent further electrocutions from occurring, it is crucial to maintain tree trimming standards in preventing vegetation contact with powerlines.

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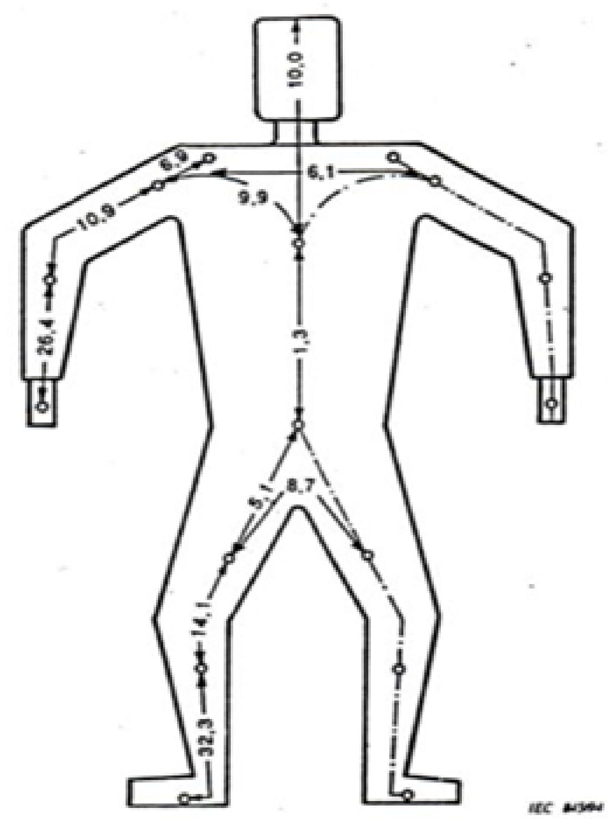

Figure 15
Total body impedance for a current path hand to hand.

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