USING REAL-LIFE CASES TO TEACH STUDENTS ABOUT ELECTRIC BURNS

Part II Secondary burns, including arcing burns

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ABSTRACT

We consider the topic of non-contact electric burning (arcing burns) and secondary electric burning events. Our Electrical Engineering students and our Biomedical Engineering students learn from these real-life cases both the proper protocols to follow for electric safety as well as the basic Physics behind electric burning events. Protocols involve the use of the NEC (National Electric Code) to define safe procedures for the implementation of even the simplest electric circuit. Real-life cases involve electric fires and arcing, as well as water-induced fires and power line burns to humans.

INTRODUCTION

We have already covered the cases of the electric burning of human flesh, where contact is made. See our previous paper on this subject. In this paper, we cover secondary burning effects, including arcing burns and other non-contact burns.

ANALYSIS OF FOUR REAL-LIFE BURN CASES

Case 1 – A short creates 4000 amps

This may sound like fantasy, but the following is a true story, and (worse yet) some form of this story happens regularly at many different facilities [1]. A man was working in a factory that employed 50 people in various jobs on heavy machines (lathes, milling machines, etc.). He can be described as a "Mr. Fixit". A large milling machine was powered by 3-phase AC. Voltage was standard 440. Current was 250 amps per phase. The machine was running hot. It drew excessive current. Every so often, it popped the same circuit breaker. The problem was easy to identify. There were 3 circuit breakers in the panel that fed the machine, one for each phase. The circuit breakers were a little larger than a human fist. Metal tabs protruded out from the edge at all 4 corners. To place these into operation, one tightened a screw that held each of these tabs firmly to the back base plate. The bad breaker had one screw that had never been tightened down fully. Over time, a layer of oxide grew on the tab. This was seen visually. The whole circuit breaker had to be un-screwed, removed, and a new breaker put in and screwed down. See Figure 1.

Here is the problem. The contractor who put in the electrical system did NOT put a shutoff at the panel that fed the machine. This is against the laws of electrical safety propounded by the NEC (National Electric Code [2]). In order to kill the power to the milling machine, the main shutoff had to be turned off. The whole factory had to go dark. Twenty machines (plus computers and other devices) would go off until the one circuit breaker on this one machine was replaced. The president of this company dictated that all power would go off on Saturday. Until then, the milling machine could run hot.

Our Mr. Fixit chose to disobey the president. He felt that the machine needed attention now. He put on gloves rated at 600 volts. Recall the voltage per phase was nominally 440 or maximum RMS of 480. So, the gloves were a good idea to prevent electric shock. He worked under tension. He carefully removed the bad circuit breaker. He drove to a supply house and purchased a new circuit breaker. He carefully started to put the new circuit breaker into the panel. While he was screwing down one of the screws, his hands (whose muscles were stressed) dropped the screwdriver. The screwdriver created a short circuit.

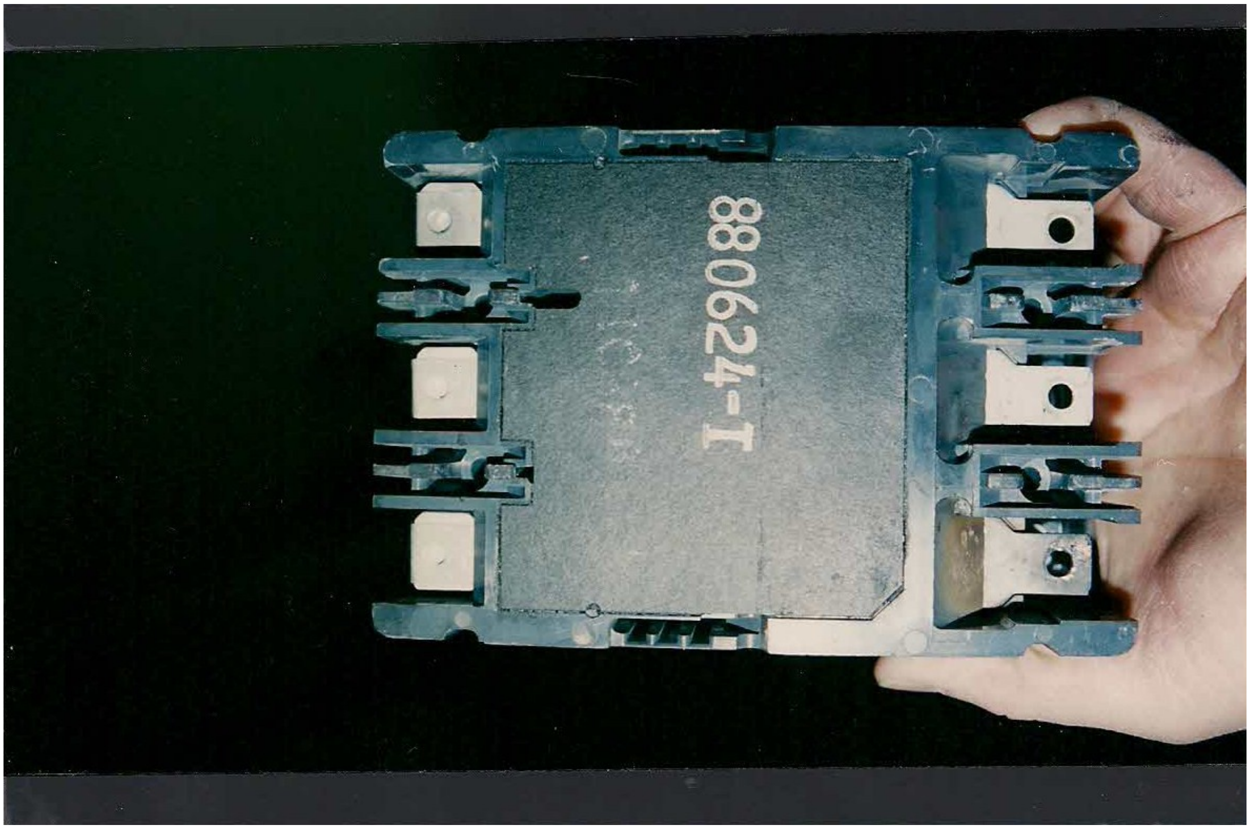

Figure 1: Defective circuit breaker with oxidized tab at bottom right.

Miraculously, the man did not receive even the slightest jolt of electricity: NO shock; NO hint of a possible electrocution. However, two other things happened.

The electricity blew out the main panel but not before it blew out the power transformers on the poles outside of the factory. In other words, the power transformers became fuses for this accident. These power transformers are rated to sustain 4000 amps.

There was such a surge in power at the panel where Mr. Fixit was working that copper and steel (1/8 inch thick) vaporized into a plasma. Figure 2 shows the plaster wall facing the power panel. Black colors are due to plastic and steel being vaporized. Orange colors are due to copper vaporization. Just to be clear. The copper and steel did NOT melt. They vaporized. Not only did the vapor coat the wall surrounding the panel, it also coated Mr. Fixit. He was burned over 90% of his body. He was in the hospital for 6 months in intensive care. The electric burn he received had nothing to do with making contact with the electric source, since it was an arcing burn. It just points to the fact that even when electricity does not enter your body, you can receive a serious burn.

Figure 2: Steel and steel vaporized on to wall (black and purple). Copper (orange) vaporized on to wall also.

A corollary to this is the damage done when someone tries to “jump” the battery of a friend’s car. Should the 2 cables come in contact there will be extensive sparking and melting of metal. This is not good. But then again, this same feature is apparent in the electric welding of metal pieces in the construction of cars and planes. To sum up: under certain conditions it is good to dump a large current into the melting or vaporization of metal. But when dealing with large current sources, one should be aware of the tremendous power to burn and take precautions accordingly. A shutoff at all major machines and sub-panels not only need, it is prescribed by the laws governing safety [2, 3].

Case 2 -- Home fires via evaporation from aquariums.

Electricity and water do not mix. There are at least half dozen fires associated with large home aquariums that we are aware of intimately, and many more occur each year that are reported in contractor news [4]. The problem is that you have a great deal of electrical appliances in any large aquarium: filters, fans, aerators, heaters, and lights. These must be submerged in water and also plugged into the home's wall outlet. Over the years, the safety of these appliances in terms of electric leakage has become very, very good. They must be UL approved, and the incidence of shock to the human is almost non-existent. However, as much as the appliance manufacturers guard against electric shock, they cannot protect one from the homeowner's misuse that leads to serious fires.

In one case, a fluorescent lamp had been built into the ceiling overlooking the aquarium. Over time, the natural evaporation from the water of the aquarium collected on the lamp and even permeated through the ceiling to the wire powering the lamp. The process was slow. Water droplets that had collected on the exposed portion of the lamp were few, and these were quickly re-evaporated into the surrounding air. Even fewer were the water droplets that penetrated through the seam where the lamp housing was fixed into the ceiling. These collected around the wiring. They did not have the chance to re-evaporate. Also, over time the few drops that did evaporate left very fine dust behind, the kind of dust found even in the cleanest air and constituted of a host of particles which make the water conducting. In essence a thin film resistor was formed between the line voltage (120 volts AC) and ground. This resistor was not a dead short; if it had been a short, many amps of current would have been drawn and the fuse box would have shut down power, and nothing would have happened. Rather, the resistor let a trickle of current through. Over time, this "resistor" went from a large value to a small value. At about 5 amps of current, the temperature surrounding the wire reached 451 degrees Fahrenheit, the flash point of paper and most wood products. The wooden ceiling beams caught fire, and soon the rest of the house caught fire [4].

In yet another story, a homeowner had hired an electrician to hook up his aquarium. There were no fewer than 12 appliances serving a 200 gallon tank located in the living room. All of the appliances were of top quality. The homeowner had located the 6 power supplies in a cabinet under the aquarium. The cabinet had doors to enclose these power supplies. A fire broke out in this enclosed cabinet. The fire consumed the wooden cabinet. Since the aquarium was sitting on top of the cabinet, it became "effectively" a pot of boiling water. The thermal stress caused the aquarium to fracture and break apart. The water put out the fire. Several very important things were noticed in the ensuing investigation. First, there was no fire damage to the house, apart from the wooden cabinet that caught fire, and this cabinet was cheap and easy to replace. However, the water damage and the smoke damage required the homeowner to rip out walls and floors and ceilings. He sustained $95, 000 in damages, even though no fire damage occurred.

Also, why didn't the fuse box stop the flow of electricity and prevent the fire from occurring in the first place? It is advantageous to consider the timeline here. The aquarium is installed and working. About 6 months go by without incident. Then, the homeowner smells something burning. He calls the electrician. The electrician finds all of the circuits working properly. He does not notice the smell. (Maybe his nose is not as sensitive.) Water vapor is collecting in the enclosed cabinet. It collects on the wires and power supplies. These become hot. But they are all made extremely rugged according to UL specifications. Even after the fire has damaged their housing, they are tested and found to work properly.

But this leaves only two possible causes for the fire. Was one of the power supplies sitting on the cabinet shelf in such away as to drive up the heat in the area of the wood. The answer turns out to be NO. The power supplies were all mounted by the electrician to preclude heating the wood of the cabinet in any way. Air flow around the power sources was maintained at all times.

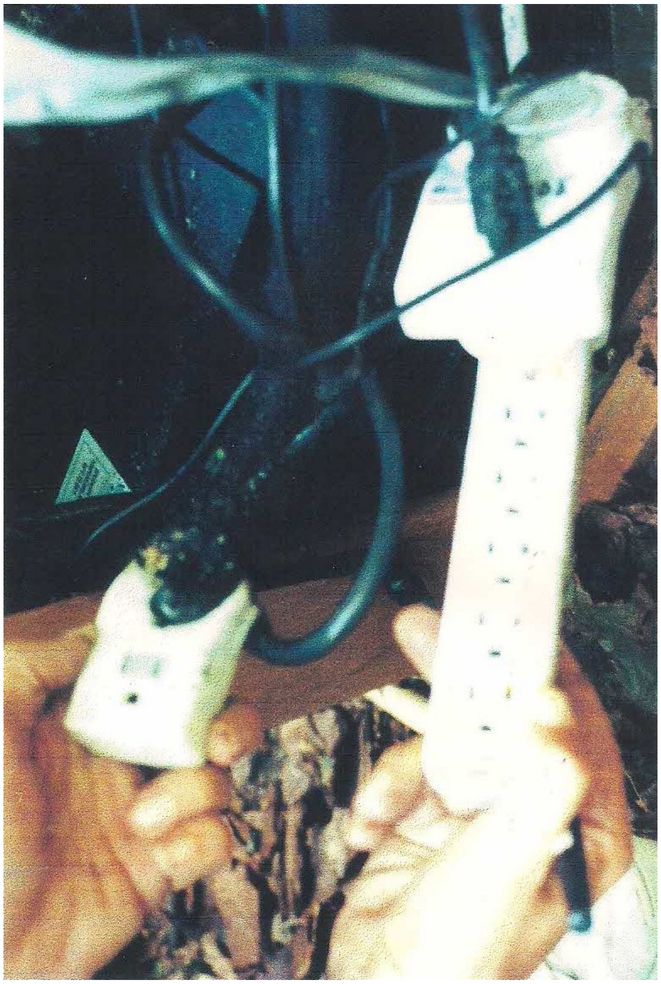

Figure 3: Two power strips involved in an aquarium fire. Strip on the right is intact. Strip on the left has disintegrated to a 'nub'.

After the electrician had first hooked up the power sources and appliances, he directed the homeowner to connect 12 electric plugs to his house line. All together, these 12 sockets totaled less than 10 amps. But how do you connect 12 plugs into a wall outlet which has the standard 2 sockets? The homeowner bought two power strips from a hardware store. He plugged the 12 plugs into these, and then he plugged the two strips into the wall outlet. Both of these terminal strips had written on them DO NOT USE IN A WET OR DAMP ENVIRONMENT. The homeowner was found to be guilty of causing this accident, though one could argue it was somewhat the fault of the electrician who did not guide him in this phase of the hookup.

Over time, the water vapor built up around several of the outlets located on one of the power strips. A resistor was formed between line voltage and ground. Over time, this large resistor became smaller. Eventually, when 5 amps flowed continuously, the environment reached the flash point of plastic (around 700 to 800 degrees F [5]). The power strip caught fire. See Figure 3, which shows both power strips. The strip on the right is still intact after the fire. The strip on the left is burned completely in the middle and we only have the “nub” left for examination.

Case 3 -- Man redecorates kitchen and dies in fire.

A man was 84 years old and still living in his own home. His married daughter looked in on him every now and then. He decided to redecorate the kitchen by hiring a contractor to rip out the kitchen cabinets, stove, refrigerator, and put in everything new. His daughter also supported this idea; she realized that this would be good for her father’s comfort, and should the house be sold, it would bring in a higher sale price.

Figure 4: Damage of fire caused by fridge wire under microwave cabinet was small. However, the owner died of smoke inhalation. NOTE: fire extinguisher on top of stove, un-used.

After the contractor had finished the job, all looked good and worked perfectly. Three months later, there was smoke in the kitchen. The man smelled the smoke and went to get a small extinguisher he had. The fire was contained to a small corner of the kitchen where the new cabinets started from the wall. It could have been easily contained. But the man was 84 and frail. He could not release the safety latch on the fire extinguisher. It was still on stove when the fire department arrived.

The man then rushed as quickly as possible to his bedroom on the second floor. He called the fire department, and they arrived in about 5 minutes. However, the smoke from the fire was quickly traveling upstairs. When the firemen arrived, the man was passed out on his bedroom floor. He died later at the hospital.

The fire itself was small. One row of wall cabinets was damaged. A microwave oven underneath the cabinets was lost. The refrigerator was slightly blackened but functional, except for the cord leading to it. See Figure 4. The investigation found that a #12 gauge wire was run under the cabinets to the refrigerator. See Figure 5. Typically, the fridge drew 10 amps. The wire could safely carry 20 amps. Yet, the cord was the site of the ignition of the fire. How can the cord have gotten hot enough to ignite a fire when the current was only half the rated maximum? Or to put this another way, how could the cord heat up enough to cause the fire when the heat generated was only ¼ of the rated safe maximum?

Figure 5: Fridge wire (long straight wire) was found as the point of ignition for the kitchen fire.

The cord started the fire due to the phenomenon of pyrolysis. The term pyrolysis has several definitions, especially in the subject of Chemistry. See [6]. For our purposes, it means a "slow burn". We are used to thinking of the flashpoint of burning. For paper and most wood and wood products, ignition is at 451 degrees Fahrenheit. Temperatures under this value are considered too cool to burn or too cool to ignite a burn. In pyrolysis, a high temperature (but lower than the ignition temperature) heats up the material, and in the process it makes it more easily combustible by breaking down its structure. The process can go on for hours or weeks or even months. At some point the wood will ignite, and the temperature of ignition is lower than the normal value (451 F). When the wire was run from the far wall to the refrigerator, the kitchen cabinets were placed directly on top of them. This is sloppy carpentry on the part of the contractor, since it required extra steps in leveling the cabinets. The cabinets essentially flattened the copper wire. But apart from the sloppy carpentry, there was the additional problem of heat build up. The wire made intimate contact with the base of the wood cabinet. Over time, this wood came closer to the ignition point. After 3 months the wood ignited into a fire.

It should be pointed out that the NEC has a rule regarding the contact of cabinets and wire run in this fashion [2, 3]. The contractor must "notch" the bottom base of the wood cabinets. The wire can then run under the cabinets with a layer of free air surrounding it. Any heat built up can then be easily dispersed, even in areas where air flow is stagnant.

Case 4 -- Whose trees are they?

A wealthy man lives on a 2 acre estate outside of New York City. He is in the process of selling his house. He calls an electrician to come to his house because the power is out. When the electrician arrives, the man is not home, but his house is open. There is a guest house in back of the main house. It is locked but the electrician can clearly see no one inside. He does see smoke several hundred yards away coming from the woods. The weather is cold and damp, and there is a layer of snow on the ground, so there is no danger of a forest fire. The electrician calls the police.

The police/fire/first-aid crews find the homeowner or what is left of him. He is on his property in the woods, one hundred yards from the house. He is burned so badly that most of his bones are showing. Positive identification can only be made later from dental records. There is a 5,000 volt power line broken but lying on top of the man. See Figure 6. Before the rescue crew can approach, they must tell the power company to kill power to the line. There is a series of poles (aka telephone poles or power poles) from the main road. They are on the owner's estate leading through the woods to the guest house and from there to the main house.

Analysis of the accident itself is bizarre. At one point, the police consider a charge of murder. According to one accusation, someone killed the man (maybe hit him on the head) and then dragged his lifeless body to the woods. But then, the murderer must climb up and cut the power line such that it lands on the body. It is well known by OSHA and other safety agencies [7] that the safe distance from a 5,000 volt source is 10 feet. If you get closer than 10 feet and if you are somehow grounded, then electricity can arc through the air and into your body. If a murderer tried to cut the power line, he would die before he got close enough to touch it.

Another theory is that the owner (who was over 80 years old) decided to go out for a walk around his property. However, the woods surrounding his property were not cleared. There was debris everywhere to the point that one had to clime over stumps and brush and fallen trees. It was not a pleasant walk even for a young man. So, even if he decided to go for this stroll, how could he be standing under the precise point where the power line would snap and land on him?

Figure 6: Body of the man burned by 5000 Volt power line falling on him.

There was one theory that seemed to make the most sense, given the bizarre circumstances and the lack of hard evidence. A tree breaks and falls on the power line. The power line is accompanied by several other wires, including a phone wire and another wire from the cable TV company. A tree is weakened by disease and age and falls. It lands on the power bundle. But the wires do not break. They support the tree. There is a break in the junction box from the tension of the tree on the wires. The house loses power. The homeowner calls the electrician. While waiting, the homeowner sees smoke in the woods. He goes to investigate. Even though the tree is supported by the wires, the power wire is broken at the junction box and at that point there would be sparking and smoke as the live line made erratic connections to ground. The owner gets close to get a better look. At that point the power wire snaps. In the fashion of a whip it springs out and lands on the homeowner. Note: the two low power cables (phone/cable TV) did not snap. They just stretched more and more as the full weight of the tree came to rest on them. They were still connected from pole to pole (though bowed in the center) when the rescue team arrived. See Figure 7. The homeowner may have been electrocuted as well as burned. There is no way to tell. The outer body was so badly burned, that death could have been by electrocution or burning or both. See Figure 6. Figure 7 shows the fallen tree, the snapped power wire, and the overly stretched TV/phone wires.

Figure 7: Fallen tree with broken power lines and stretched cable lines.

The question remains: whose fault is it. The cause of this accident was the tree falling. What does the law say about this? Surprisingly, there is no national law codified into a document like the NEC which explains the responsibility for the trees near a power line. There are, however, laws in almost every state governing the position and shape of trees near a power line [8]. Since this accident happened in New York State, it was governed by the laws of New York State [9]. These stated that it was the power company's job to maintain safety. The power company had to warn errant homeowners about their trees proximity to a power line. If the home owner took no action, the power companies could turn off electricity to a home, even if the electricity was deemed necessary for some emergency situation in the home. Alternatively, the power company could trim the trees on the owner's property and force him to pay the bill for this service. Although the homeowner owned the trees, they effectively belonged to the power company.

CONCLUSION

It is clear that even non-contact electric burns are both common and frightening in their effects. Simple safety measures include several things:

(i) Kill the power to a circuit that you will be repairing or investigating.

(ii) Understand that you do not have to spill water on an electric circuit to cause trouble; evaporation/condensation can be invisible dangers in any damp environment.

(iii) Heat build-up and the reduction of the ignition temperature for a burn or fire can occur where pyrolysis has allowed a material to become very warm over a very long period of time. A safe circuit becomes very dangerous over time.

(iv) Trim trees and keep other objects a safe distance from any power line.

REFERENCES

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[2] National Electrical Code 2008, National Fire Protection Association, ISBN-13: 978-087765790-3 and ISBN-10: 087765790-4.

[3] Handbook for Electrical Safety in the Workplace, R. Jones, K. Mastrullo, and J. Jones, National Fire Protection Association Inc. (2004), ISBN 0-87765-581-2.

[4] “The case of the unheard smoke detector,” EC&M, 24, December 1997.

[5] Handbook of Tables for Applied Engineering Science, 2nd ed., CRC Press (1973), ISBN 0-87819-252-2.

[6] See for example Pyrolysis-Wikipedia on the web.

[7] See for example the OSHA standard 29CFR 1910.333(c 3) and the OSHA standard 29CFR 1926.550 (a15) and on the web see the sites www.ansi.org/standards and www.techstreet.com

[8] There are many dozens of pertinent references for the laws governing trees near a power line. Type in the words “power line trees” into a good search engine, and you will find laws governing this issue in every state and many counties and cities.

[9] See reference [8] to find the laws governing the state of New York, as well cities and counties within the state. Also, the two most prominent power companies in New York State are NYSEG (New York State electrical and gas) and Con Ed (Consolidated Edison). Using a strong internet search engine, type in NYSEG PSC 119 or Con Edison PSC 9, where PSC stands for

public service charter. Also, public charters are available from the rates and regulatory commission in Binghamton, NY, attn: Mr. James Lahtinen.