# Real Life High Voltage Accident Cases – Teaching Electrical Safety

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**Abstract –** We discuss the engineering principles of Hi-voltage (any voltage above 600 volts). We cite 4 examples that typify some of the problems facing the Engineer and technician working with Hi-voltages, including geometry considerations, the need to follow proper protocol and the laws (both scientific and political) governing Hi-voltage. Poor design considerations in capacitor construction is the first case we consider, as well as the lack of proper protocols in discharging same. In the second case, a warning can be made that one should never get too close to a Hi-voltage line, unless the power is cut. In the third case, following simple rules in measurement of an unknown voltage could avoid a serious accident. In the fourth case, a high voltage shows up in a low-voltage circuit. These unfortunate cases are used as teaching tools to impart details of electrical safety in common industrial setting.

*Keywords:* High voltages; Real-life accident analysis; High voltage accidents

## INTRODUCTION

High voltage is a source of interest to both the engineer and to the layman. Interest ranges from the sight of speeding electrified commuter trains to horrible accidents when humans contact high voltage. In this article we cite 4 cases of high voltage accidents. Each accident teaches something different about electricity and electric safety.

Let us first begin with some clarifications. By formal definition, high voltage is defined as any voltage above 600 volts. Below 600 volts, one should consult the NEC (National Electric Code) for the rules of electrical installation and safety [3, 26]. Above 600 volts, the better safety code is written by OSHA (Osha). This should not in any way diminish the danger of low voltage circuits. People die in their homes every day from electrocution caused by 120 and 220 volt sources [24]. Statistically, high voltage deaths are only about 1/3 of the total electrocutions surveyed each year [25]. Furthermore, we have personal experience of visiting factories and other sites where electricity is introduced in to an area that is frequented by many people; often these sites have prominent warning signs: HIGH VOLTAGE, even if the level is merely 220 volts.

As a key to understanding High Voltage, we must consider the human being as a resistor. Adults can be modeled successfully as a 500 ohm resistor; this represents the core of the adult and ignores the skin resistance. The core value is determined by blood, bone, and tissue and not the skin surface, which can be as little as a few ohms or many hundreds of thousands of ohms [2, 7, 11, 15]. The resistance of dry skin is generally 1000 to 100,000 ohms, but for voltages of 300 or larger, the skin is considered breached by the electric current after only one second, and the flow of current is only impeded by the 500 ohm internal resistance [12].

The phenomenon of arcing or flashover must also be considered [33, 34]. In this case, electricity leaves its source and travels through the air to connect with the human. It should be noted that the insulating properties of air are extremely good. The breakdown of air (even if the air is saturated with moisture) is at least twice what it is for glass. In other words, an “air” shield protects you better than a glass one. See [23]. But for arcing to be considered and avoided, even this may not be good enough to protect in all cases. A better insulator is Sulfur hexafluoride. The

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fluorine atom has a valence of -1, i.e. it is not stable until it can capture one electron in to its outer shell. Furthermore, Fluorine is the most violent reactor of all of the Halogens (i.e. elements with valence -1). Sulfur has 6 electrons in its outer shell. Normally, Sulfur reacts to capture 2 electrons to stabilize in to a compound. For example, CdS or Cu2S are examples of semiconductors where the Sulfur has captured two electrons from the cadmium or copper and thus formed a stable compound via valence bonding. With SF6, the reaction expected is “backwards”. The Sulfur is stripped of all 6 of its outer electrons. The violent reacting Fluorine is subdued and remains quiet and stable. In fact the compound is so stable that it is better than air and is used as the insulating material in many very high voltage applications, including the construction of capacitors used in Hi-Pot-testing. The dielectric breakdown is nominally 30 times greater than that of dry air [4, 5, 16, 17].

Hi-Pot is another term familiar to the High Voltage engineer. Hi-Pot or hipot is an abbreviation for high potential or high voltage testing. Suppose you have a circuit breaker to be used to break the circuit in a 250,000 volt line. This might be tested with DC at a few Pico-amps but up to 300,000 or even 500,000 volts. Often the rule-of-2 applies where possible. The rule-of-2 says that if any device (circuit breaker, capacitor, meter, inductor, etc.) is to be operated safely and without breakdown at a voltage X, then it should be stressed, under test, up to AT LEAST a voltage 2X (or even as high as 4X according to some engineers). The rule of 2 is NOT an official scientific principle like Ohm’s Law. Rather, design engineers often use 2X as the test to prove the reliability of a product under a stress X. A quick check of the internet under the topic “reliability” verifies the rule of 2 (and the rule of 3 and even the rule of 4). In electronics design and particularly in the design of power electronics, the test stress is more likely 2X. See for instance the electronics books [6] and [13]; see also, the spec sheets for various Fluke multimeters, which are pertinent to Case #3 discussed in this paper; these show a maximum voltage for most meters of 1000 and an over-voltage of an additional 1000 volts [14].

Back-emf (or back-electromotive force) refers to a voltage generated “backwards” from the direction that the processing normally proceeds in. This often involves a motor or other mechanical moving object that can act as a generator. In the forward direction, electricity converts to mechanical motion or mechanical work. In the backward direction, a voltage is fed from the motor back into the power source.

Throughout the rest of this article, we will be talking about real-life cases analyzed by us. To protect a person’s right to anonymity, we will not give the real identity of any of the people and companies discussed.

## REAL LIFE CASES

### Case #1: A Circuit breaker at a substation must be able to stand a stress of 250,000 volts

We start our analysis at the highest voltage normally available to most power engineers. In New York State, a power company is testing a new circuit breaker. The breaker must be able to interrupt power to 3-phase electricity with an RMS value of 250,000 volts. Hence the breaker is 3 breakers operating in parallel. Part of the breaker is a “snubber” circuit (An electronic sub-circuit used to regulate very high voltage and current changes in a circuit) [20, 30]. Recall that we are dealing with 3 states here: the “off” or zero-voltage state, the “on” or 250,000-volts state, and the intermediate or transitional state. It is the intermediate state that is most dangerous. If you build a 5 volt logic circuit in the lab and leave it on at 5 volts, the circuit is relatively free of being damaged. If you turn it on and off rapidly, you can produce spikes of 10 volts or more, and this can act to destroy the circuit board. With High Voltage, the danger is much greater. If there is a spike to 500,000 volts or several million volts, the electricity can jump the ceramic insulators and travel up to 30 feet in air to electrocute someone. Therefore, a snubber is an ideal and mandatory safety feature of the circuit breaker.

In the course of the testing procedure, several “barrel” transformers were charged (along with parallel capacitors) to about 25,000 volts apiece. These were then switched in to a “series” configuration generating the requisite 500,000 volt test voltage. Current was no larger than a pico-amp. A company technician was in a lift bucket when a “basketball” of light flew through the air and hit him and left him for dead. He suffered burns and muscle and organ damage as a result. He did not die, but he experienced body tremors (the “shakes”) for several years after the accident. He also suffered post-traumatic stress disorder. The effects on a human of a high voltage shock from arcing are discussed in [9, 18]. This worker’s accident was the second such accident to occur in a 2 year time period when testing this particular circuit breaker. What problem in the circuit breaker was the cause of these 2 accidents?

The circuit breaker was originally built with a single capacitor in parallel with the remaining components of the breaker. The value of the capacitor was 2 nF. This capacitor was expected to be stressed up to 500,000 volts without breakdown of the insulator. A new design engineer later revised the circuit to employ two capacitors in series. This new series arrangement was put in parallel with the remainder of the breaker. Each capacitor was only to be stressed to 250,000 volts. Each capacitor had twice the surface area of the original capacitor they replaced. Hence, each had a value of 4 nF, and their series combination was 2nF, the same as the original capacitor [19, 27]. Since the voltage stress on each was to be 250,000 instead of 500,000 as it had been for the original capacitor, the need to spend money to make the capacitors "rugged" to voltage stress was reduced. The money spent on building a capacitor to operate safely at a voltage will increase by 4 each time you double the maximum voltage stress of the capacitor, since construction costs are proportional to storage capacity (energy) and this in turn is proportional to the voltage squared [19, 27]. Consequently, there is a big savings in decreasing the voltage stress on a capacitor.

During the testing, "barrel" transformers are used to transform ordinary electricity (single phase 120 volts) to 25,000 volts per phase. These are then put in series and rectified to the DC value of voltage up to 500,000 volts. Before the circuit breaker was stressed, the capacitors were first stressed. Since the line is 3-phase, each phase was stressed to 500,000 volts. In the ideal case, two capacitors in series split the voltage evenly. But two capacitors in series is a very "bad" architecture. If two equal resistors are put in series, the voltage in the middle is always half the applied voltage, or if you include experimental error, the voltage in the middle is half the applied voltage plus/minus a small percent. Capacitors can be thought of as infinite ohm resistors. In actual fact, the resistance is many billions of ohms and not infinite. See [19, 23, 27]. If it were possible to construct each half of the capacitor at exactly 4 nF and if it were possible to maintain the shunt resistance of each capacitor at exactly the same value, then this accident would not have happened – initially the voltage of the high-end plate is 500,000 and the voltage of the middle plate between each capacitor is exactly 250,000. After the high-end plate is discharged to ground, the voltage of the middle place automatically goes to zero. This can be proven by simple calculations [19, 27]. See, also the Appendix at the end of this paper. If, however, the capacitors are mismatched or if the shunt resistance of each capacitor is slightly different for each capacitor, then a residual voltage resides on the middle plate after the top plate is discharged. The middle plate between the capacitors must be discharged or a voltage of several thousand volts can exist. If we assume a 1% mismatch in the capacitors involved in this accident, then this voltage is 5000 volts, but whatever its exact value, it will be in the range of one or more kilovolts, based on similar arcing incidents at other substations [21, 22, 29]. Indeed, this was the cause of the 2 accidents cited here. We show in our Appendix that a mismatch of 1% in resistance and capacitance will result in a voltage of 1% of 500,000 (i.e. 5000 volts) on the middle plate, even after discharging the top and bottom plates.

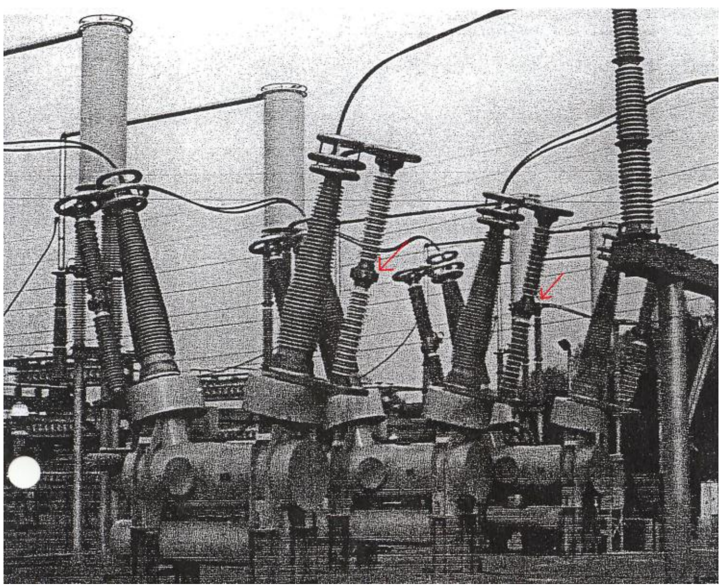

Figure 1. 3-phase circuit breaker, 250,000 Volts. Note – Capacitor that caused accident labeled with the arrow on the right. Accident occurred for the hipot test of the second phase. No accident occurred from testing the first phase (left arrow). The third phase (no arrow indicated) was not tested, since the accident precluded this.

In this accident, a company worker was in a lift bucket above ground. He was approximately 10 feet from the capacitor. The capacitor for phase #1 was tested up to 500,000 volts DC. It was gradually brought down. A grounding stick was placed on the high voltage end of the capacitor, while the low voltage end was at ground. But NO protocol was followed for the center point (i.e. for the point between the two caps in series). Nothing happened.

By luck, the capacitor mismatch was small enough that the extra voltage at the middle plate was low, i.e. low enough so that it did NOT cause any trouble. We estimate that the mismatch was 0.1% or less – see the Appendix. The Hi-pot test continued for the #2 phase of the circuit breaker's capacitor. After 500,000 volts was reached, a grounding stick was placed on the high end. The middle point again was not involved. Suddenly, from the middle point a ball of light the size of a basket ball emerged. It struck the employee. He did not die. But he required emergency care, and his burns and muscle spasms lasted for many years, precluding him from the work for which he was trained.

**Analysis of this case:**

IN THEORY, the voltage at the middle point between two equal capacitors in series is zero. But geometry and other inconsistencies in design can make the capacitors un-balanced to the point of a slight mismatch. The resistors are the cause in that they allow un-equal voltages to form. But it is the capacitors charge storage ability that maintains this voltage imbalance when the high side of the capacitor is grounded. The worker thought that with the high and low sides of the capacitor pair at zero volts, he was safe. A simple check of the mathematics [19, 27] involved for 2 capacitors in series being charged by a DC voltage reveals the existence of a high voltage charge between the capacitors, even after the high and low ends are shorted to ground. The strength of this voltage depends on the degree of mismatch between the individual capacitors. Hence, testing the first-phase breaker produced no harmful results: the structural mismatch and the residual voltage were small enough to dissipate through the capacitors shunt resistors without arcing through the air. But the voltage for the second breaker was significant enough to cause the arcing that was noted, and this was estimated by comparison to similar accidents to be one or more kilovolts [21, 22, 29]. It should also be noted that after the top and bottom plates were grounded, the charge and hence voltage on the middle plates would have dissipated to ground over time through the resistors shunting each capacitor, with the shunt resistors being the leaking resistance through the dielectric SF6. However, since the values of shunt resistance were large, this would have taken about 10 minutes or more, and this amount of time was not part of the protocol for the hipot test. A quicker and safer protocol would have been to discharge the middle plates to ground.

**Conclusion:**

Keep all components in a Hi voltage circuit simple and rugged, and do NOT ever put two capacitors in series, unless you are prepared to ground the middle when not in use. But in general, 2 capacitors in series is a very bad idea.

**Second Conclusion:**

Even if the voltage levels are trivial (say 5 volts), it is always a bad idea to put 2 capacitors in series without shunting each capacitor by precision resistors. Suppose, for example, the leakage resistance of the first capacitor is X and the leakage of the second is 10X, where X is in billions of ohms. Then, the voltage splits 10-to-1 and not 1-to-1 as expected. If these capacitors are shunted by very large external resistors (say 10 megohm), then the voltage splits 1-to-1, since 10 meg <<X for any good capacitor, and therefore, the 10 meg resistors control the splitting of the voltage in an exact fashion.

**Case #2: A sign hanger gets too near the high voltage in a telephone pole on a city street**

A sign hanger is working on the outside wall of a building housing a factory in New York. The contractor has his worker go up in a bucket boom (aka cherry picker). The contractor is licensed by the city. His project is near a power line that feeds power to the factory. The voltage in the power line is 13,000, 3-phase. A transformer on the pole converts this to 220/120 volt at 3-phase, and sends this in to the factory. The worker is very successful in completing the work on the outside wall. He finishes over 90% of the sign. Then, suddenly, he slumps over in the lift bucket. He is being electrocuted via asphyxia [2, 8, 34]. He can not breathe. A co-worker is located on the roof of the factory at the same level as the first worker. He reaches out toward the bucket to grab the first worker. But then, the co-worker suddenly is struck with muscle pain and burned over the greater part of his stomach. Electricity is now forming 2 circuits. It leaves the pole, travels through the air, and goes into the first man. At this point, the electricity splits. Some of it leaves the first man by his upper torso and enters the second man who is grounded by contact with metal capping at the roof ledge. The electricity also leaves the first man at various points on his body and enters the bucket of the boom which is in contact with ground. The truck that supports the boom has metal feet placed down on the flat sidewalk for added mechanical strength. Later, after the truck is moved, there are burn marks on the sidewalk where the feet were placed in contact with the sidewalk. This is proof that electricity went through the boom to ground.

Figure 2. Telephone pole with 3-phase 13,000 Volt power cable near building (right) where accident occurred.

**Analysis of this case:**

Simply stated, the sign hanger was too close to the power source. His boss (a licensed sign hanger) failed to measure the proper and safe distance to keep from the power line. Alternatively, his boss could have contacted the power company to shut off the power, and he did not. The power company had the power wires close to the factory because the wall nearby was a non-maintenance wall, i.e. there was no indication of any activity that was to be carried on near that wall. As an example, a wall with a door or window is a maintenance wall. It would be expected that people would be entering the door or standing near an open window. Similarly, after the sign was installed, it too became a maintenance wall. But these facts should have been reported to the power company before the sign was placed.

**Conclusion:**

Contact the power company before you work near a hi-voltage line (any line with voltages of 600 volts and up). Alternatively, if you are using a boom or ladder or scaffolding, it is always a good thing to isolate it from ground. However, this might not be something that is always practical in the field.

**Case #3: Master Electrician uses ordinary handheld voltmeter to measure 4000 volts**

This case is very sad. It was totally avoidable. It produced only minor injury, but this in turn led to the death of a young man with a wife and children.

A Master Electrician can train someone who has no knowledge of electricity and turn that person in to an electrician like himself. He is the Master of his trade. He was the victim of this accident.

The Master Electrician is hired to work on staff at a large warehouse in New Jersey. There is almost a million square feet of space in this warehouse. It is so large that many smaller factories could conceivably be stored within its structure. The warehouse is undergoing change. There are over 300 different electric closets, and each closet has a multiple of different voltages in each of them. All of the voltages are low voltage (nominal 120, 240, and 480 volts, either single phase or 3-phase) with one exception. There is a 3-phase source of 2300 volts. It is generated at a local facility in a building next to the factory. There is a chain link fence around this building. It is not the type of place that you can just wander in to.

The power from this source is fed into the warehouse and into one particular closet, almost identical to dozens of other electrical closets near it. Of the 300-plus electric closets, this is the only one that is high voltage. There is a large sign on this closet that reads: “Danger 2300 volts”. There is a small sign (about one inch square) that reads the same thing. The closet is locked with a padlock. This dangerous voltage obeys the Lock-Out-Tag-Out protocol enforced on all dangerous voltages.

The Master Electrician is comfortable with all of the low voltages. His Fluke meter has a maximum rating of 1000 volts (DC/RMS AC). With a relaxed attitude, he randomly opens many different electric closets and measures a host of voltages in the course of his daily troubleshooting. There is NO set of master schematics for the factory, so our electrician is putting together his own set.

Over time, the large sign that reads “Danger 2300 volts” either falls off the cabinet or is removed. The padlock is opened on the cabinet and later disappears. There are almost 1000 workers at this facility; consequently, it is hard to point a finger at anyone person. This sloppiness has now left 2300 volts inside a cabinet that anyone can open. The small warning sign (one inch square) remains, but the large sign is gone.

In the course of his duties, the Master Electrician comes to the cabinet. As a Master Electrician, he is duty bound to read all he can before he opens the cabinet. Because he is in a hurry, he does not take notice of the one inch square sign. The cabinet is not locked. He assumes that the voltages inside are low. He hooks his Fluke meter to the first leg of a 3-phase arrangement. At this point, he could still come out of this okay. Protocol dictates that you measure each UNKNOWN voltage with respect to ground. If he had done this, he would have 2300 volts sitting across his multimeter. The rule of 2 applies. The electrician’s meter is capable of safely measuring 1000 volts. It can go up to 2000 volts without breaking. Beyond 2000, there is the real chance of serious damage. At 2300 volts, his meter should “smoke” and cause problems, but that is all. We verified this from testing in the laboratory, and our results are supported by the specs given for most Fluke meters, including the model involved in this accident [14].

Instead of hooking his meter leads between ground and one leg of the 3 phases to measure 2300 volts, our Master Electrician hooks his two meter leads across two different phases. This is a shortcut. By doing so, he can cut his testing time in half; if the voltage is proper, he can verify 2 phases with one measurement. But this is dangerous, if the voltage is unknown.

Figure 3. Bright yellow fluke multi-meter is badly blackened (burnt) as a result of measuring 4000 Volts.


Figure 4. A sampling of the more than 300 electrical closets at a very large food warehouse in New Jersey.

**Analysis of this case:**

A voltage of approximately 4000 volts spans the electrician's meter. Note: for any two phases in a 3 phase system, the phase-to-phase voltage is the single phase voltage (2300) multiplied by the square root of 3, or approximately 4000 volts. This large voltage causes a massive current to travel into the meter. The meter is instantly burned and on fire. The current does not stop there. It continues to travel into the electrician's work gloves and into his hands and chest. He is severely burned. Eventually after a very long illness, he will die. Note: his work gloves are rated at 800 volts – they are safe for low voltages but they are not safe for high voltages.

**Conclusion:**

Follow the proper protocol when measuring any unknown voltage. Do not assume that your measurements are safe for the voltage you think you are measuring. Always tell yourself things like "suppose this voltage is much higher" or "suppose the label on the voltage is wrong". Also, note that many electricians now use proximity voltage testers to assess power of an unknown source. See [1, 14]. These often fail to tell the exact voltage of the source, but they can determine the order of the voltage as being very low or simply low or high or very high. But these testers are incredibly safe in that there is NO need to actually touch or sample any electricity from the circuit under test.

**Case #4: A landscaper receives 13,000 volts from a low voltage source**

In the three previous cases, it is obvious that there was high voltage present. Even in the third case, the victim did not think he had a high voltage because of the sloppiness in the lock-out-tag-out procedures being followed and because he was not observant of the small warning sign that was in place. Yet, a high voltage was present, and with less sloppiness, this would have been apparent.

In this case, there is NO expected high voltage. A landscaper is up on a ladder using an electric chain saw to cut branches. NOTE: this is not a recommended practice, since there is ample opportunity to lose ones balance and control of the saw. But routinely, people who prune and cut trees work on them while on a ladder. For our present study, we are not concerned with cases of falling off the ladder due to simple loss of balance. Our accident is more complicated—it is electrical in origin.

At some point, the landscaper is cutting a thick branch. About halfway through the cut, the branch "binds". It grabs the teeth of the chainsaw and holds them motionless. There is a great deal of energy generated as electricity is being converted by a motor into mechanical work or energy. When the teeth are suddenly brought to a stop, this energy must go somewhere. Most of the energy is dumped back from the motor into the electric circuit. This voltage is called a "back EMF" [10]. It obeys the laws of Maxwell [31], but it is not a commonly expected form of electricity, except where motors/generators are involved [32].

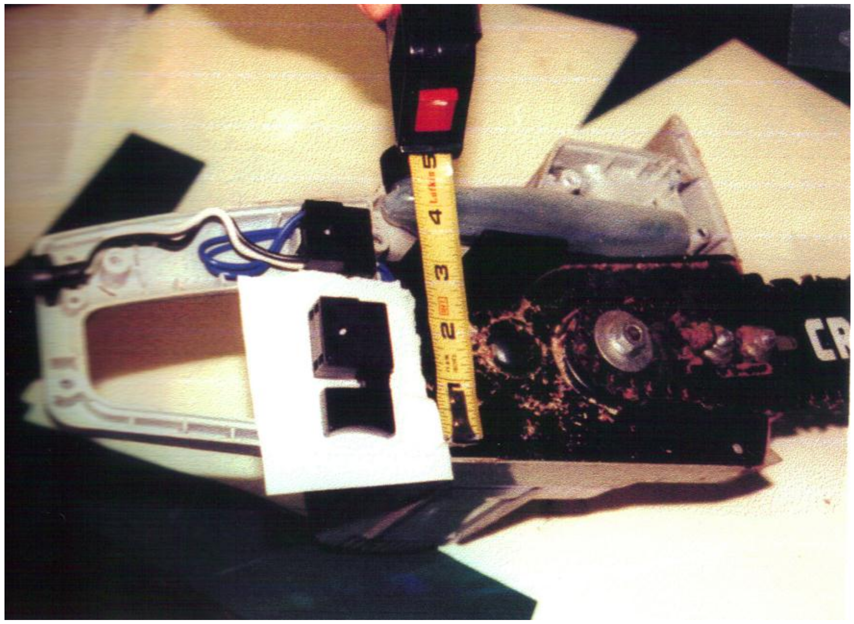

Figure 5. Chain saw with the cover removed.

**Analysis of this case:**

Figure 5 shows the chain saw with the cover removed. Except for the on-off switch and the motor, there are no electrical/electronic components in the chain saw. A black wire and a white wire enter the switch from a 120 volts AC source. Two blue wires leave the switch and go to the motor. A second switch is shown on a sheet of white paper for comparison – note the "fat" trigger button at the bottom of this second switch and the narrow neck connecting the button to the switch. A back EMF comes from the motor (acting as a generator) when the teeth of the chain saw are suddenly stopped. This was recorded as 13,000 volts. The saw was designed to withstand voltages several times greater than the 120 applied. However, it could not withstand the 13,000 volt back EMF. This leaked out through the casing of the saw and into the gloved human operator. Our results show that this voltage could sustain a current of 191 mA for at least 10 seconds. This would have been enough to kill the human [8]. However, in this case the "wobbly" ladder became a safety feature. The human lost his balance and fell at the instant of being shocked. He broke one leg, but overall there was no permanent harm done to him due to electric shock.

**Conclusion:**

What is most amazing about this case is that we analyzed the plastic used to protect the human from unintended leakage currents. The point of greatest leakage for this accident is around the switch at the neck that connects the switch to the trigger button. The landscaper is touching the switch-button and applying a great pressure at the time of the accident. By making the plastic of the neck thicker, the voltage (even at 13000) can be prevented from leaking to the human. Our measurements showed that increasing the neck thickness by 1/16 inch could have shielded the human from the 13000 volts. This would add only pennies to the overall cost of the chainsaw. (To find the thickness of plastic needed to provide a safe shield to 13,000 volts, one can use the value of dielectric breakdown [23] to come up with the value of 0.3 to 0.6 mm.).

## APPENDIX

Consider 2 capacitors in series. The first capacitor has value C with one plate grounded and the second plate attached to the first plate of the second capacitor. The second capacitor has a value of capacitance ($C + \Delta C$), with one plate tied to the voltage source (assume the source is DC) and the other plate ties to the first capacitor. If the capacitors are perfectly matched, then $\Delta C$ is zero. Also, each capacitor is shunted by a resistor. If there is no external resistor connected to the capacitors, then the resistance across each capacitor is the value of the leakage resistance caused by conduction through the dielectric separating each plate of the capacitor. If there are external resistors attached in parallel with each capacitor, these would have a resistance smaller than the leakage resistance (since leakage resistance can be of the order of billions of ohms for a good capacitor). Let R be the resistance of the first capacitor and $(R + \Delta R)$ be the resistance of the second capacitor. Now, consider that the series combination is charged to a voltage V. The voltage of the middle plate where the 2 capacitors are tied together is $V/(2+\Delta R/R)$. If V is 500,000 and if $\Delta R/R$ and $\Delta C/C$ are 1 %, then the voltage at the middle plates is $V/(2+\Delta R/R)$ or 250,000, minus 1244. For all intents and purposes, the middle plate is approximately half the voltage applied. Now, suppose that the plate with voltage V is removed from the voltage source and grounded. Then, even with 2 plates grounded, the middle plates that form the connection between each capacitor will have a residual voltage of $V[(\Delta C/C)+(\Delta R/R)+(\Delta C\Delta R/CR)]/[2+2\Delta C/C+\Delta R/R+\Delta C\Delta R/CR]$. If we let $\Delta C/C = \Delta R/R = x$, where $x << 1$, then we can expand this expression and keep only terms up to the order x, and this gives the voltage as Vx, or 1% of 500,000, i.e. 5,000 volts. Over time, this residual voltage will dissipate as electric charge "leaks" through the resistors in parallel with each capacitor. But the time for dissipation can be quite large, especially if the parallel resistance is simply the leakage resistance of each capacitor and not a lower value of the added external resistance. Over this time of dissipation, a human near the capacitors is in danger.

Suppose we assume our errors to be smaller: $\Delta C/C=\Delta R/R = 0.1\%$. In this case, the residual voltage of the middle plates, after grounding both of the other capacitor plates, would be 500 volts. This is far safer and much less likely to arc through the air. It is the most likely reason why testing of the first phase voltage of the circuit breaker proved safe, i.e. the resistance and capacitance values were more closely matched. Testing of the second phase of the circuit breaker resulted in a horrible accident, and this is blamed on the higher degree of mismatch.

Given that 2 capacitors will be used as a single unit by placing them in series, a better safety protocol would be to ground not only the high voltage lead (originally tied to V) but also the middle lead (where the plates connect to each other) after hipot testing is completed.

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