The Case of the
FATAL GROUND FAULT

By Mitch Ricketts

Math Toolbox is designed to help readers apply STEM principles to everyday safety issues. Many readers may feel apprehensive about math and science. This series employs various communication strategies to make the learning process easier and more accessible.

Electric shocks claim about 300 lives and cause thousands of nonfatal injuries in the U.S. each year (CDC, n.d.; CPSC, n.d.). Sources of hazardous electric current range from high-voltage power lines to everyday household wiring and plug-in appliances. Figure 1 illustrates a case in which a worker was electrocuted by a ground fault in an electric drill. A ground fault is a defect that permits current to flow to ground through an unintended path, for example, through the external housing of an appliance (and possibly through the body of any person who touches it). Ground faults are among the leading causes of electrical injuries (El-Sherif et al., 2020).

In this article, we will apply Ohm's law to estimate the magnitude of current that may flow through a human body during electric shock. These exercises will help illustrate the range of conditions under which electric current may cause serious injury or death.

Protecting People From Electrical Injury

The science of hazardous electrical exposures is evolving rapidly. The International Electrotechnical Commission (IEC, 2018) international standard IEC 60479-1 summarizes data on the hazards of ventricular fibrillation due to electric shock. Ventricular fibrillation is an abnormal heart rhythm that interferes with the pumping of blood. It is also the main cause of death in fatal electrocutions. Ventricular fibrillation is especially likely when electric current makes a direct path through the heart.

Table 1 (p. 46) describes some physiological effects associated with alternating current (AC). Besides ventricular fibrillation, effects may include involuntary muscular contractions, falls, difficulty breathing, inability to initiate voluntary movements, burns, changes in blood pressure, cardiac arrest and cell damage. (The hazards to property from electrical fires are discussed in Ricketts, 2020, and are not addressed here.)

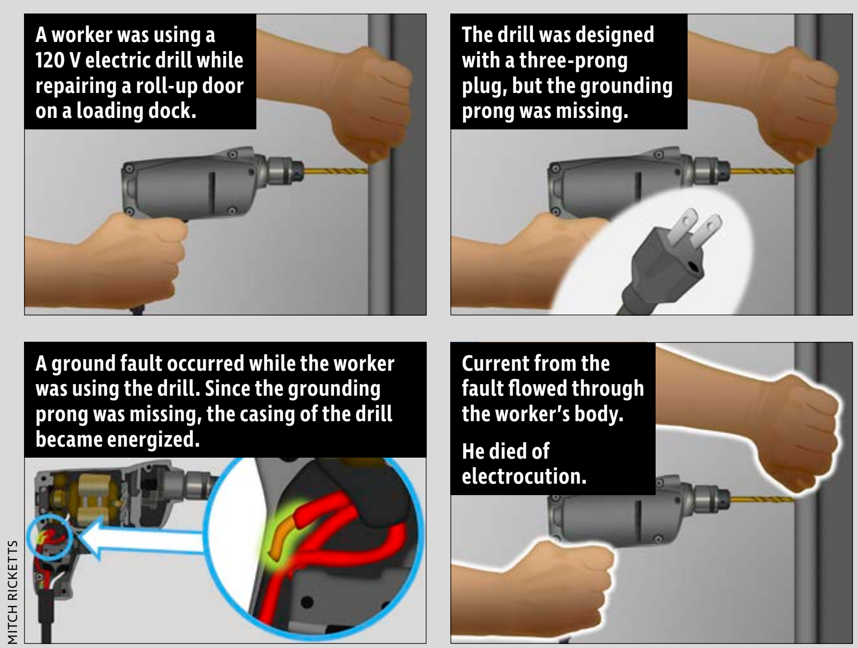
Electric shocks often occur during events involving contact with energized power lines, installation or maintenance of electrical equipment and contact with objects that have been energized through ground faults. The hazards of ground faults can be substantially reduced by equipment grounding, double insulation, ground-fault circuit interrupters (GFCI) and cordless battery-operated tools.

Equipment grounding is an engineering control that connects an object with ground. As shown in Figures 2 (p. 47) and 3 (p. 48), equipment grounding can keep external components near zero volts even when a ground fault occurs. A portable tool with equipment grounding will have a special prong on the plug that is internally wired to the casing of the tool. For a stationary machine, the equipment grounding wire may be permanently bonded with the facility's electrical system.

Equipment grounding protects against the hazards of ground faults, provided a low impedance path to ground is maintained. Equipment grounding may be rendered ineffective if the path to ground is interrupted by damaged, missing or high-impedance components.

As an alternative to equipment grounding, some portable electrical devices incorporate an engineering control known as double insulation. In these devices, external metal parts are separated from internal voltage by an extra layer of insulation or by insulation that is specially reinforced. As shown in Figure 4 (p. 49), these devices are marked either with the words "double insulated" or with the double insulation symbol of a square within a square. There is no grounding prong on the plug of a double-

FIGURE 1
WORKER ELECTROCUTED WHILE USING 120 V DRILL, CALIFORNIA



Note. Adapted from "Inspection Detail (Inspection No. 112033394)," by OSHA, n.d., www.osha.gov/pls/imis/establishment.inspection_detail?id=112033394.

insulated device. Double insulation offers protection against ground faults, provided the tool is not damaged or immersed in water.

A GFCI is an engineering control that monitors electric current and immediately shuts off power if anomalies suggest an electric shock may be happening (Figure 4, p. 49). The quick action of the GFCI greatly reduces the extent of injury when a shock does occur. GFCIs are manufactured as fixed outlets, portable extension cords and even as special breakers for the service panel. GFCIs are used in conjunction with grounded or double-insulated tools in areas where there is an increased risk of electric shock (e.g., outdoors, near water, in damp locations).

Electronic components in GFCIs may fail over time. For this reason, portable GFCIs should be tested before each use and fixed GFCIs should be tested monthly. GFCIs protect only against ground faults, and they will not guard against other shock hazards such as line-to-line shocks and shocks in which the current flows to ground entirely through the neutral wire after passing through a person.

Cordless battery-operated tools replace AC with less hazardous direct current (DC) batteries. As with other controls, there are limitations. For example, the operator may be shocked if the battery-operated tool contacts an energized conductor (as may happen if the drill bit contacts an AC-energized wire).

Ohm's Law Applied to Direct Current

Before delving further into issues involving AC, let's consider how Ohm's law applies to DC. Harmful physiological effects from DC sources occur mainly from high-amperage exposures. Burns are the most commonly reported injuries, but some deaths have also occurred.

In DC systems, Ohm's law helps us understand the interrelationships among three important aspects of electrical energy: voltage, current and resistance. Voltage (measured in volts, V) refers to electric charge, or electromotive force. Differences in voltage create an electric field. This field drives current by exerting force on electrically charged particles such as electrons or chemical ions. Current (measured in amperes, A, or milliamperes, mA) signifies the flow of electrically charged particles. Resistance (measured on ohms, Ω) denotes a material's tendency to oppose the flow of charged particles. Electric current has difficulty passing through materials with high resistance; on the other hand, current passes easily through conductive materials having low resistance.

Ohm's law describes how current is related to voltage and resistance as follows:

$$I = \frac{V}{R}$$

where:

I = current flowing through a conductor, in units of amperes (A)

V = voltage measured across a conductor, in units of volts (V)

R = resistance of a conductor, in units of ohms (Ω)

Calculated example. Let's imagine a battery-operated flashlight. For the purposes of illustration, we'll say the difference in voltage between the battery's positive and negative terminals is 3.5 V. Imagine now that we connect the battery's positive terminal with one of the contacts on the flashlight lamp. Next, we connect the battery's negative terminal with the lamp's other contact. These connections create a continuous 3.5 V electrical circuit, causing current to flow through the lamp. The lamp will exhibit some resistance to the current—for this example, we'll imagine the total resistance is 5 Ω.

Using Ohm's law, we can specify the magnitude of current flowing through the circuit based on the following data:

•The voltage is 3.5 V. This is the value of V in the formula.

•The resistance is 5 Ω. This is the value of R in the formula.

Step 1: Start with the equation:

$$I = \frac{V}{R}$$

Step 2: Insert the known values for voltage (V = 3.5 V) and resistance (R = 5 Ω). Then solve for I:

$$I = \frac{3.5}{5} = 0.7\ A$$

Step 3: The calculation indicates a current of 0.7 A will flow through the circuit. If we wish to convert to milliamperes, we multiply by 1,000 because 1 A is equal to 1,000 mA. In this case, 0.7 A is equal to 700 mA because 0.7 · 1,000 = 700.

Alternate example. Now imagine a different scenario in which a 12-V automobile battery is used to start a car. Also imagine the total resistance of the ignition system is 0.05 Ω. What magnitude of current will flow through the ignition circuit as the car is started?

TABLE 1

POTENTIAL EFFECTS OF ALTERNATING CURRENT

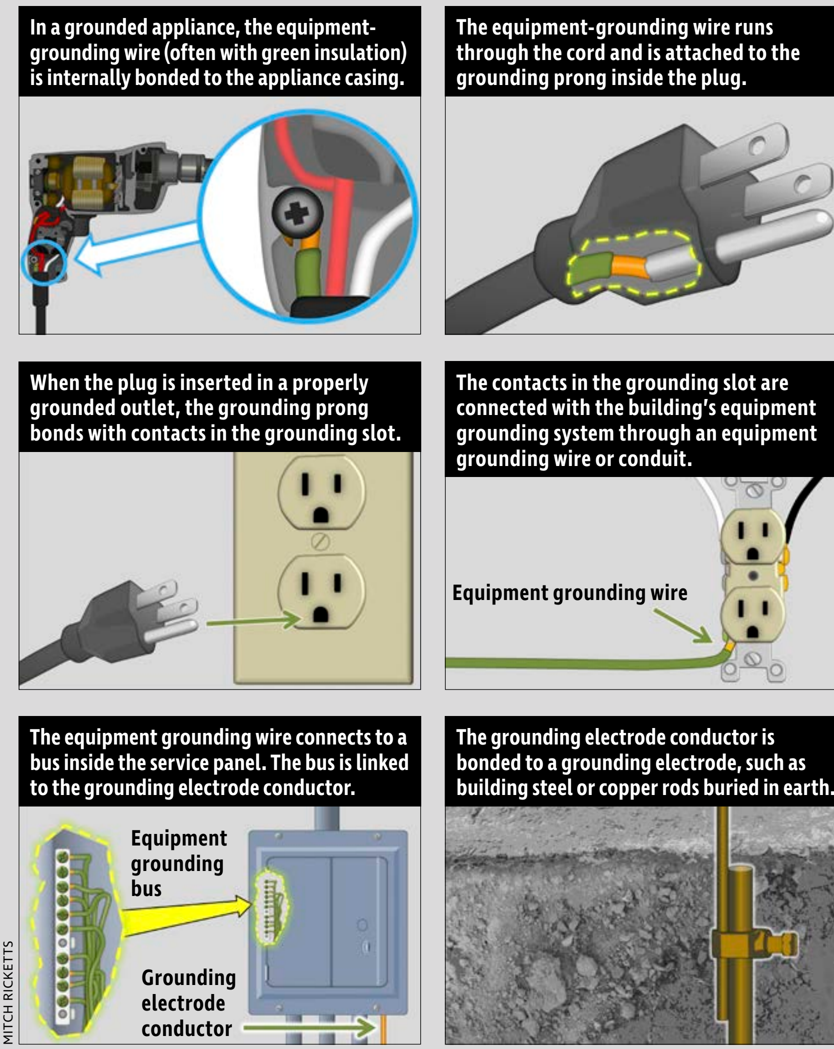
Potential effects of alternating current, depending on conditions of contact, current path, individual physiological characteristics and other factors.

AC current flow, 15 to 150 Hz, in milliamperes (mA)	Effects
0.5 mA	Threshold of reaction: May cause involuntary muscular contractions, including unintended movements that increase the probability of falling.
5 mA (entire population) 10 mA (adult males)	Threshold of let-go: May prevent a person from releasing grip on a conductive object. May also cause difficulty breathing, especially as current increases.
40 to 50 mA (current duration of 1 to 3 seconds or more) 400 to 500 mA (current duration of 0.1 to 1.0 second) 500 mA (current duration of less than 0.1 second)	Threshold of ventricular fibrillation: May be fatal.
15,000 to 20,000 mA (15 to 20 Amperes)	Common circuit breaker opens a circuit.

Note. One milliampere equals 1/1000th of an ampere. Data from "Effects of Current on Human Beings and Livestock—Part 1: General Aspects (IEC 60479-1:2018)," by International Electrotechnical Commission, 2018.

FIGURE 2
EQUIPMENT GROUNDING CONNECTS THE CASING OF AN APPLIANCE WITH EARTH

Simplified depiction of a complete equipment-grounding system. Grounding connections within the service panel will vary according to applicable codes.



Step 1: Begin with the equation:

$$I = \frac{V}{R}$$

Step 2: Insert the known values for voltage (V = 12 V) and resistance (R = 0.05 Ω). Then solve for I:

$$I = \frac{12}{0.05} = 240\ A$$

Step 3: The calculation indicates that a current of 240 A will flow through the ignition circuit. Multiplying 240 A by 1,000, we find this current is equal to 240,000 mA.

You Do the Math

Apply your knowledge to the following questions. Answers are on p. 55.

1. Imagine we use a 19.5-V battery to power a laptop computer. Also imagine the total resistance of computer circuits during a complex calculation is 4 Ω. What magnitude of current will flow through the computer during the calculation? Use the formula for Ohm's law.

2. Imagine a portable drill is powered by a 24-V battery. Also imagine the total resistance of the drill is 3 Ω (while boring a 0.5-in. hole through a 2-in. oak board at medium speed). What magnitude of current will flow through the drill while boring this hole? Again, use the formula for Ohm's law.

Ohm's Law Applied to Injuries Involving Alternating Current

In previous examples, we applied Ohm's law to DC circuits. For AC, the equation must be modified if a circuit contains substantial inductive and capacitive reactances. Research has, in fact, shown that human skin exhibits important capacitive properties when exposed to AC; thus, we use a modified version of Ohm's law to understand electric shock in AC circuits. When modified for AC, Ohm's law incorporates the variable, impedance (Z), in place of resistance. Impedance accounts for the combined effects of resistance and any reactances caused by induction or capacitance. The equation is:

$$I = \frac{V}{Z}$$

where:
I = current, in amperes (A)
V = steady-state AC voltage, in volts (V), as a root-mean-square (rms) value
Z = impedance, in ohms (Ω)

In cases of electric shock from AC, the value of impedance must account for both skin impedance and internal body impedance. The sum of skin and internal impedances is known as total body impedance (Z_T). Using this more specific term, the equation becomes:

$$I = \frac{V}{Z_T}$$

where Z_T = total body impedance, in Ω.

Recall that current may flow between two objects that have different voltages, provided the objects are connected by a conductive pathway. With this in mind, imagine an energized electrical wire with a voltage of 125 V AC. Also imagine an equipment grounding wire with a voltage of 0 V AC. Finally, imagine a worker touches the energized wire with one hand, while simultaneously touching the equipment grounding wire with the other. In this situation, the worker's body may provide a conductive path between the two wires. Electric current may flow through the worker's body, with potentially harmful effects.

The severity of any shock will depend on many factors, such as the duration of the shock, the path of current through the body and the magnitude of the current. The last factor, magnitude of current, can be calculated using Ohm's law if we know the touch voltage and the total impedance of a human body. Touch voltage is simply the difference in voltage between an energized object (such as the 125 V wire noted) and any differently charged surface a person may touch (such the 0 V grounding wire).

Under controlled laboratory conditions, the resistivity of a dry sample of skin may be as high as several hundred thousand ohms per square centimeter (Reilly, 1998); however, the total resistance of skin declines dramatically as the area of contact increases. This means a contact area the size of the entire hand offers much less electrical resistance than a contact area the size of a fingerprint. Pressure between the skin and an electrically conductive object reduces resistance even more. This means a tight grip with the hand offers less electrical resistance than a gentle touch. Skin resistance declines even further when skin ducts are filled with sweat. As an example, consider that the palms of the hands are packed with sweat ducts. Also consider that profuse sweating is common during physical activity. Finally, researchers have found that some components of skin resistance actually occur in parallel, reducing total resistance even more.

So far, we have discussed the resistance of skin. Since skin also has capacitive properties, we must consider the broader quality of impedance. Both skin and internal impedances decline as duration of contact, body temperature, voltage and frequency of the AC current increase. Impedance is also affected by the path of the current path through the body because different tissues exhibit different impedances.

Experimentally derived values for total body impedances of living adults are illustrated in Table 2 (p. 50). These values (in ohms) are based on a skin surface area of about 10,000 square millimeters in firm contact with electrically conductive objects. For a hand-to-hand current path, this surface area is comparable to a person gripping a 3-in.-diameter electrically conductive cylinder in each hand.

For a hand-to-foot current path, impedances have been reported as 70% to 90% of the values shown in the table. These estimates assume a skin contact area equivalent to standing with one bare foot on a conductive surface while grasping a 3-in.-diameter conductive object in one hand. Normal footwear will substantially increase hand-to-foot impendence but will not affect hand-to-hand impedance.

In Table 2 (p. 50), dry conditions represent the skin moisture content of a person at rest in a normal indoor environment. Saltwater-wet conditions are believed to reflect the skin moisture of a person who is sweating. Experimentally, saltwater-wet conditions are created by exposing the skin to a 3% saltwater solution for 1 minute.

The percentiles in Table 2 (p. 50) reflect the percentages of the adult population that would not exceed the total body impedances shown. That is, the total body impedances of 5% of the adult population will be equal to or less than those shown for the 5th percentile; the total body impedances of 50% of the adult population will be equal to or less than those shown for the 50th percentile; and the total body impedances of 95% of the adult population will be equal to or less than those shown for the 95th percentile.

Finally, the impedance values in Table 2 (p. 50) are based on an AC frequency of 50 to 60 Hz (60 Hz is the standard frequency in the U.S.).

Calculated example. Let's now return to the fatal electrocution depicted in Figure 1 (p. 45). Certain details were not reported by investigators; therefore, we will base our calculation on a hypothetical example that mirrors some, but not all, of the facts of the case.

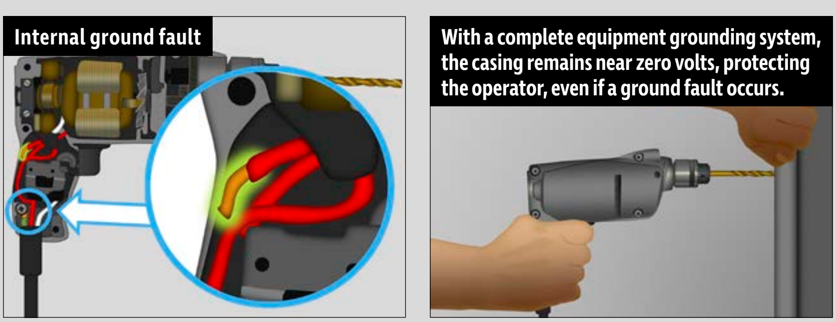
According to the original report, the worker was exposed to a nominal voltage of 120 V AC. Voltage in nominal 120-V circuits may vary from about 110 to 125 V in the U.S. The most similar voltage shown in Table 2 (p. 50) is 125 V, so we will base our calculations on this voltage.

The report did not specify the pathway of current through the body. For our calculations, we will assume a hand-to-hand pathway, with the worker gripping the energized drill in one hand while simultaneously gripping a grounded sur-

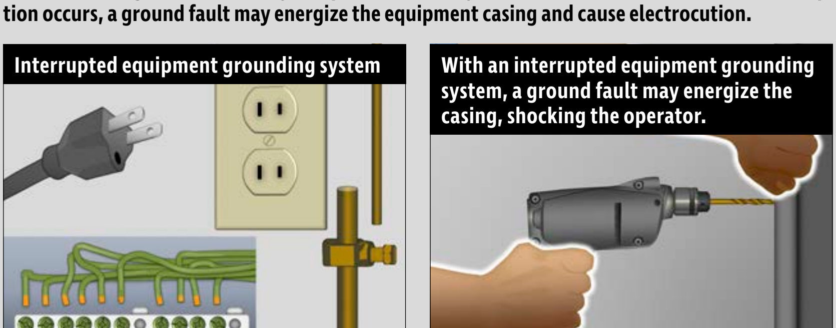
FIGURE 3
COMPLETE VS. INTERRUPTED EQUIPMENT GROUNDING SYSTEM

Equipment grounding protects against ground-fault electrocution if the low-impedance path to ground is maintained.

A ground fault occurs when electric current flows through an unintended path to ground. For example, an energized internal wire may touch the metal casing of an appliance. If the grounding system is complete, the voltage of the casing will remain near zero volts, even when a ground fault occurs.



The equipment grounding system may be interrupted if the plug's grounding prong is removed, if the outlet is ungrounded or if any components of the system are disconnected. When an interruption occurs, a ground fault may energize the equipment casing and cause electrocution.



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face with the other. The report also did not specify the moisture conditions, but we will assume the skin was dry.

Based on these assumptions, we consult Table 2 (p. 50) and find the predicted values of total body impedance as follows for a touch voltage of 125 V with a hand-to-hand current path and dry skin contact:

- Z_T = 900 Ω or less for 5% of the adult population; this is the 5th percentile value of total body impedance in Ohm's law ($Z_{T\ \text{5th percentile}}$ = 900 Ω).
- Z_T = 1,550 Ω or less for 50% of the adult population ($Z_{T\ \text{50th percentile}}$ = 1,550 Ω).
- Z_T = 2,675 Ω or less for 95% of the adult population ($Z_{T\ \text{95th percentile}}$ = 2,675 Ω).

We now have the necessary data to calculate a range of current that may have flowed through the workers body, based on Ohm's law.

Step 1: Start with the equation:

$$I = \frac{V}{Z_T}$$

Step 2: Insert the value we have assumed for voltage (V = 125 V) and calculate the current (I) separately for each percentile based on the impedances (Z_T) listed above. We will round the answers three places to the right of the decimal so we can later convert the currents from A to mA.

For 5% of the adult population, the expected total body impedance is no greater than 900 Ω at 125 V, so the 5th percentile current estimate is:

$$I_{5th\ percentile} = \frac{125}{900} = 0.139\ A$$

(rounded three places past the decimal)

For 50% of the adult population, the expected total body impedance is no greater than 1,550 Ω at 125 V, so the 50th percentile current estimate is:

$$I_{50th\ percentile} = \frac{125}{1{,}550} = 0.081\ A$$

(rounded)

For 95% of the adult population, the expected total body impedance is no greater than 2,675 Ω at 125 V, so the 95th percentile current estimate is:

$$I_{95th\ percentile} = \frac{125}{2{,}675} = 0.047\ A$$

(rounded)

Step 3: Based on the calculations, we estimate that 5% of the adult population may experience a current of about 0.139 A or more in this scenario. This current is equal to 139 mA (0.139 · 1,000 = 139). The 5th percentile current is often considered when predicting a typical worst-case scenario of electric shock.

Some people may experience a lower current in our scenario. In this regard, the calculations indicate a current of at least 0.081 A (81 mA) is likely to be experienced by 50% of the adult population. We may consider this to be the median current experienced by a population of adults.

Finally, the calculations indicate a current of at least 0.047 A (47 mA) may be experienced by 95% of the adult population. The 95th percentile current is often considered when predicting a typical best-case scenario of electric shock.

Referring to Table 1 (p. 46), the magnitudes of electric current indicated by our calculations (139, 81 and 47 mA) may be sufficient to prevent a worker from letting go of a conductive object and to induce difficulty in breathing. Furthermore, ventricular fibrillation and death are possible if the duration of current is greater than 1 second.

Alternate example. Now imagine a different scenario in which an electric clothes dryer has been installed without proper equipment grounding. Also imagine a ground fault energizes the exposed metal parts of the clothes dryer, presenting a shock hazard to anyone who touches it. Next to the clothes dryer is a properly grounded clothes washer with an external voltage of about 0 V. Now, imagine an adult grasps the fault-energized dryer door fully with one hand while simultaneously grasping the properly grounded door of the nearby washer with the other hand.

In the U.S., electric clothes dryers are often designed to operate within a voltage range of about 215 to 250 V AC. The nearest voltage in Table 2 (p. 50) is 225 V, so we'll use this value as the actual touch voltage between the clothes dryer and the washer. Finally, we'll suppose the person's skin has become sweaty while gathering, sorting and loading the laundry. Based on this information, what are the worst-case (5th percentile), median (50th percentile) and best-case (95th percentile) ranges of electric current that may flow through a person?

FIGURE 4

ALTERNATE METHODS FOR CONTROLLING GROUND-FAULT ELECTROCUTION HAZARDS

In many circumstances, ground-fault shocks may be prevented by the use of double-insulated tools, GFCIs or battery-operated tools. Each control has limitations, as discussed in the text.

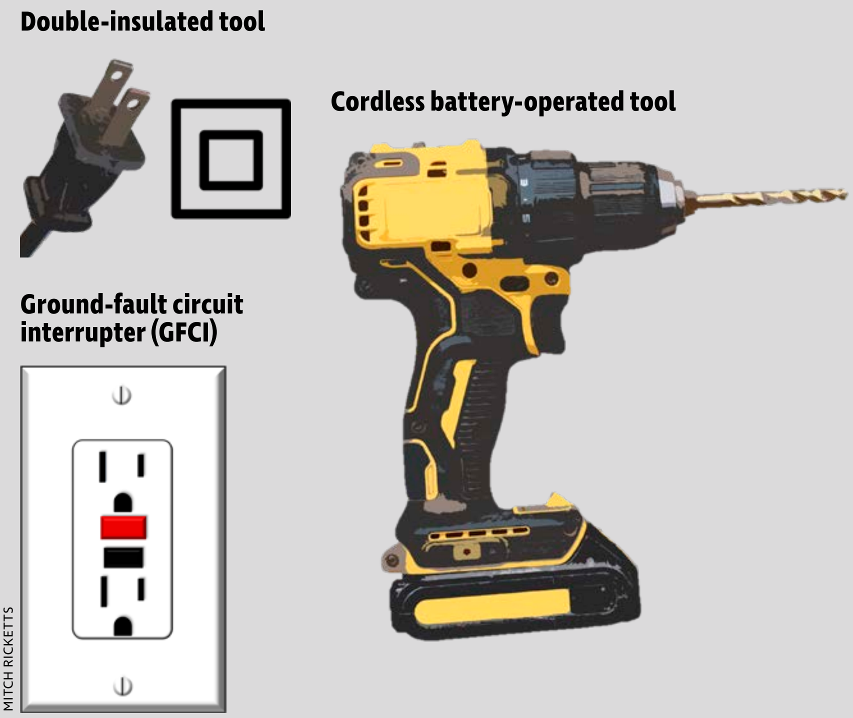

TABLE 2
TOTAL BODY IMPEDANCE, HAND-TO-HAND CURRENT PATH, 50 TO 60 Hz AC

Total body impedances (Z_T) in ohms (Ω) that are not exceeded for 5%, 50% and 95% of the adult population when exposed to a 50 to 60 Hz alternating current for 0.1 second. Values are based on a skin contact area equivalent to grasping a 3-in.-diameter conductive object in each hand. For dry skin conditions, impedances will decrease for contact durations longer than 0.1 second. For all conditions, impedances will decrease for alternating current frequencies higher than 50 to 60 Hz.

	Dry conditions			Saltwater-wet conditions		
Touch voltage (V)	5th percentile (Ω)	50th percentile (Ω)	95th percentile (Ω)	5th percentile (Ω)	50th percentile (Ω)	95th percentile (Ω)
25	1,750	3,250	6,100	960	1,300	1,755
50	1,375	2,500	4,600	940	1,275	1,720
125	900	1,550	2,675	850	1,200	1,620
225	775	1,225	1,900	770	1,115	1,505
400	700	950	1,275	700	950	1,275
1,000	575	775	1,050	575	775	1,050

Note. Data from "Effects of Current on Human Beings and Livestock—Part 1: General Aspects (IEC 60479-1:2018)," by International Electrotechnical Commission, 2018, Tables 2 and 3.

As shown in Table 2, the expected hand-to-hand total body impedance values are no greater than the following for a touch voltage of 225 V AC with a hand-to-hand current pathway and saltwater-wet conditions (due to sweaty skin):

•$Z_{T\ \text{5th percentile}} = 770\ \Omega$
•$Z_{T\ \text{50th percentile}} = 1{,}115\ \Omega$
•$Z_{T\ \text{95th percentile}} = 1{,}505\ \Omega$

We use Ohm's law to calculate the minimum values of total body current for 5%, 50% and 95% of the adult population, as follows.

Step 1: Start with the equation:

$$I = \frac{V}{Z_T}$$

Step 2: Insert the known value for voltage as stated for this scenario (V = 225 V). Then calculate the current (I) separately for each percentile.

For 5% of the adult population, the expected total body impedance (Z_T) is no greater than 770 Ω at 225 V, so the 5th percentile current estimate is:

$$I_{5th\ percentile} = \frac{225}{770} = 0.292\ A$$

(rounded)

For 50% of the adult population, the expected total body impedance (Z_T) is no greater than 1,115 Ω at 225 V, so the 50th percentile current estimate is:

$$I_{50th\ percentile} = \frac{225}{1{,}115} = 0.202\ A$$

(rounded)

For 95% of the adult population, the expected total body impedance (Z_T) is no greater than 1,505 Ω at 225 V, so the 95th percentile current estimate is:

$$I_{95th\ percentile} = \frac{225}{1{,}505} = 0.150\ A$$

(rounded)

Step 3: Based on the calculations, we make the following estimates:

•5% of the adult population may experience a current of 0.292 A (292 mA) or more.
•A current of at least 0.202 A (202 mA) is likely to be experienced by 50% of the adult population.
•A current of at least 0.150 A (150 mA) is likely to be experienced by 95% of the adult population.

Referring to Table 1 (p. 46), we see that each of these currents exceeds the thresholds of reaction and let-go. Furthermore, each estimate may exceed the threshold of ventricular fibrillation if the current has a duration of 1 second or more.

You Do the Math

Apply your knowledge to the following questions. Answers are on p. 55.

3. Imagine a cook is using an all-metal handheld 125-V AC electric food mixer with the equipment grounding prong removed. There is no GFCI near the counter, so the mixer is plugged into a regular (non-GFCI) outlet. A grounded water faucet (with a voltage of 0 V) is located next to the defective food mixer. The cook's skin has become sweaty from working in the hot kitchen. Unknown to the cook, a ground fault has occurred within the mixer. The cook grasps the food mixer in one hand and the faucet in the other, completing a circuit for a hand-to-hand current path through the body. An electric shock ensues. Answer the following questions:

a. What is the worst-case (5th percentile) total-body hand-to-hand impedance, as shown in Table 2, for saltwater-wet (sweaty) skin at 125 V AC?

b. What is worst-case (5th percentile) electric current that may flow through the cook in this scenario? Use the AC formula for Ohm's law, based on the voltage described in the problem and the value of impedance you found for question 3.a.

c. What is the median (50th percentile) total-body hand-to-hand impedance, as shown in Table 2, for saltwater-wet (sweaty) skin at 125 V AC?

d. What is median (50th percentile) electric current that may flow through the cook in this scenario? Use the AC formula for Ohm's law, based on the voltage described and the value of impedance you found for question 3.c.

e. What is the best case (95th percentile) total-body hand-to-hand impedance, as shown in Table 2, for saltwater-wet (sweaty) skin at 125 V AC?

f. What is best case (95th percentile) electric current that may flow through the cook in this scenario? Use the AC formula for Ohm's law, based on the voltage described and the value of impedance you found for question 3.e.

Concluding Comments

The data and calculations presented here are used by standard-setting organizations to establish safety requirements for electrical devices. Knowledge of electrical hazards evolves rapidly, and the information in Tables 1 (p. 46) and 2 will be refined as research progresses. Keep in mind the data in Table 2 were compiled from highly controlled laboratory studies. Real-world exposures are subject to many unknowns and may result in total-body impedances that are higher or lower than those shown in the table.

Also keep in mind that the data have been derived mainly from adults. The data for children are more complex: While children tend to have higher total-body impedances (resulting in lower internal currents), their bodies are more vulnerable to the effects of electricity, even when currents are low.

As yet another example of real-world complexity, consider that total-body impedance varies depending on the path of current through the body. As noted, impedances for hand-to-foot current paths have been reported as only 70% to 90% of the values shown in the table. This will result in internal body currents that are substantially higher, compared with our hand-to-hand calculations. Although footwear may dramatically increase the total-body impedance for hand-to-foot current paths, it offers no protection for many other current pathways, such as hand-to-hand, chest-to-hand or hand-to-knee (as when kneeling). Furthermore, the protective value of footwear is reduced if a worker is standing in wet grass or water (Reilly, 1998).

To sum up, the information examined here can increase our understanding of electrical hazards, but uncertainties dictate that workplace calculations should never be used as an argument for permitting unsafe work practices or for keeping defective equipment in service.

How Much Have I Learned?

Try these problems on your own. Answers are on p. 55.

4. Imagine we use a 9-V battery to power a home smoke detector. Also imagine we push the detector's "test battery" button, which causes the test light to flash. Finally, imagine the total resistance is 642 Ω during the battery test. What magnitude of current will flow through the test circuit? Use the DC formula for Ohm's law.

5. Imagine a homeowner is checking a malfunctioning water pump located near a chain-link fence at a backyard swimming pool. The pump is hardwired to a 225-V AC electric circuit. The pump was originally grounded by means of metal conduit that has since become damaged and disconnected. The discontinuous conduit leaves the pump with no effective equipment grounding system. It is a cool morning, and the homeowner's skin is dry. With one hand, the homeowner grasps a post of the chain-link fence. The post is grounded, so its voltage is 0 V. With the other hand, the homeowner grasps the pump motor. A ground fault occurs within the pump, delivering an electric shock through a hand-to-hand current path. Answer the following questions:

a. What is the worst-case (5th percentile) total-body hand-to-hand impedance, as shown in Table 2, for dry skin at 225 V AC?

b. What is worst-case (5th percentile) electric current that may flow through the homeowner in this scenario? Use the AC formula for Ohm's law, based on the voltage described in the problem and the value of impedance you found for question 5.a.

c. What is the median (50th percentile) total-body hand-to-hand impedance, as shown in Table 2, for dry skin at 225 V AC?

d. What is the median (50th percentile) electric current that may flow through the homeowner in this scenario? Use the AC formula for Ohm's law, based on the voltage described and the value of impedance you found for question 5.c.

e. What is the best-case (95th percentile) total-body hand-to-hand impedance, as shown in Table 2, for dry skin at 225 V AC?

f. What is the best-case (95th percentile) electric current that may flow through the homeowner in this scenario? Use the AC formula for Ohm's law, based on the voltage described and the value of impedance you found for question 5.e. **PSJ**

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Online
11/2-11/4: National Ergonomics Conference and Ergo Expo. Continental Exhibitions Inc.; (212) 370-5005; www.ergoexpo.com.

Online
11/3 ● Measuring Safety Culture. ASSP; (847) 699-2929; www.assp.org.

Online
11/4 ● Strategic Skills for Improving and Maintaining Safety, Health and Evironmental Performance. ASSP; (847) 699-2929; www.assp.org.

Online
11/5 ● Emotional Fatigue (Burnout Syndrome): Strategies to Manage Chronic Stress in Healthcare Providers and First Response Personnel. Learn strategies to identify and manage sources of unmanaged stress at the individual level. The session introduces recognized model for actions that organizations can use to influence a healthier and more mindful workplace. ASSP Healthcare, Environmental and Public Sector practice specialties; https://bit.ly/3m237HY.

Online
11/15 ● Math Review. ASSP; (847) 699-2929; www.assp.org.

Online
11/15-11/16: HazWOPER Refresher 8-Hr. Argus Pacific; (206) 285-3373; www.arguspacific.com.

Online
11/16: Hazardous Waste Management. Environmental Resource Center; (800) 537-2372; www.ercweb.com.

Online
11/16-11/18 ● Corporate Safety Management. ASSP; (847) 699-2929; www.assp.org.

Online
11/16-11/18: Hazards 31: Process Safety Conference. IChemE; www.icheme.org/career/events/hazards-31.

Online
11/16-12/6 ● Math Review, CSP and ASP Exam Preparation. ASSP; (847) 699-2929; www.assp.org.

DECEMBER 2021

Online
12/6-12/7: Hearing Conservation. Acoustic Associates; (847) 359-1068; www.acousticassociates.com.

Online
12/6-12/9 ● CSP Exam Preparation. ASSP; (847) 699-2929; www.assp.org.

Online
12/7-12/9: Shutdown and Turnaround Management. Fleming Gulf; +971 4609 1570; https://fleming.events.

Online
12/7-12/16: National Conference on Worker Safety and Health. National Council for Occupational Safety and Health; www.coshnetwork.org.

Online
12/9-12/10: Ex4OSH 2021 conference: Expanding Occupational Safety and Health. The University of Texas Health Science Center at Houston School of Public Health; (713) 500-9032; https://sph.uth.edu.

Online
12/10: Flagger Certification. Evergreen Safety Council; (800) 521-0778; www.esc.org.

Online
12/10-12/17: Safety Hazard Awareness for Contractors. Carolinas AGC; (704) 372-1450; www.cagc.org.

Manchester, VT

November 15-16
ASSP Region VIII New England Area Professional Development Conference
This event features a keynote by Deborah Roy, M.P.H., R.N., CSP, COHN-S, CIT, FASSP, FAAOHN, Evolving Your Safety Practice and Our Profession. The conference features 15 courses, including “Make Your Safety Training Stick,” by Linda Tapp, “The Unacceptable Risk of Carbon Dioxide,” by Fred Straub, Ph.D., M.S., CSP, ARM, and “Developing a Culture of Caring in Construction,” by Shawna Fraser Nagle, M.S., CSP, CHST, CUSP. Network with others and join for coffee, a raffle and a silent auction. **ASSP New England Area; (401) 935-6648; https://region8.assp.org**

WILL SWANN/UNSPLASH

Math Toolbox, continued from pp. 45-51

Answers: The Case of the Fatal Ground Fault

You Do the Math

Your answers may vary slightly due to rounding.

1. $I = \frac{V}{R} = \frac{19.5}{4} = 4.875\ A\ (4{,}875\ mA)$ (rounded three places past the decimal)

2. $I = \frac{V}{R} = \frac{24}{3} = 8\ A\ (8{,}000\ mA)$

3.a. 850 Ω

3.b. $I_{5th\ percentile} = \frac{V}{Z_T} = \frac{125}{850} = 0.147\ A\ (147\ mA)$ (rounded)

3.c. 1,200 Ω

3.d. $I_{50th\ percentile} = \frac{V}{Z_T} = \frac{125}{1{,}200} = 0.104\ A\ (104\ mA)$ (rounded)

3.e. 1,620 Ω

3.f. $I_{95th\ percentile} = \frac{V}{Z_T} = \frac{125}{1{,}620} = 0.077\ A\ (77\ mA)$ (rounded)

How Much Have I Learned?

4. $I = \frac{V}{R} = \frac{9}{642} = 0.014\ A\ (14\ mA)$

5.a. 775 Ω

5.b. $I_{5th\ percentile} = \frac{V}{Z_T} = \frac{225}{775} = 0.290\ A\ (290\ mA)$ (rounded)

5.c. 1,225 Ω

5.d. $I_{50th\ percentile} = \frac{V}{Z_T} = \frac{225}{1{,}225} = 0.184\ A\ (184\ mA)$ (rounded)

5.e. 1,900 Ω

5.f. $I_{95th\ percentile} = \frac{V}{Z_T} = \frac{225}{1{,}900} = 0.118\ A\ (118\ mA)$ (rounded)