CHAPTER 3

High-Voltage Electricity Safety

Courtesy of Yves Racette, Y.Racette Consulting

OBJECTIVES

After studying this chapter, you will be able to:

- Identify the categories of vehicles using high-voltage electricity.
- Categorize high-voltage electricity by IEC CAT number.
- Outline how electrical energy can cause injuries and fatalities.
- Define *ventricular fibrillation*.
- Explain the difference between *arc flash* and *arc blast*.
- Explain the term *distributed capacitance*.
- Identify the specialty personal protective equipment that must be worn when working on high-voltage equipment.
- Identify the appropriate lockout, tag-out precautions for working in a high-voltage work area.
- Prepare a safe high-voltage working environment.
- List CAT III tools required for working in a high-voltage environment.
- Outline the cleaning precautions required for high-voltage chassis.
- Outline precautions for welding on a high-voltage chassis.
- Describe EESS architecture and explain how cells, strings, packs, and banks are arranged to supply high-voltage circuits.
- Identify the causes of lithium-ion cell *thermal runaway*.
- Identify the methods used to safely charge high-voltage electric vehicles.

TECHNICAL TERMS

arc blast
arc flash
automated external defibrillator (AED)
capacitance
defibrillator
distributed capacitance
electric shock
electrocution
hot stick
Institute of Electrical and Electronic Engineers (IEEE)
International Electrotechnical Commission (IEC)
low voltage (LV)
National Electrical Code (NEC)
thermal runaway
ventricular fibrillation

Why Read This Chapter?

If you are targeting a career as an electric vehicle repair technician, there are many technicians already working in the industry who would tell you that this is the most important chapter in this text. While *Chapter 2, General Service Facility Safety,* covered general shop safety, this chapter very specifically addresses how technicians should regard personal and personnel safety when working with high-voltage circuits on electric vehicles. There is no room for error when working in close proximity to high-voltage electricity. A single error while working with high-potential electricity can result in a career-ending injury or even death. The fundamental message is to always err on the side of caution. There are usually no second chances when taking a risk with a high-voltage circuit.

3.1 Safety Issues

With the rapid rise in the number of electrically powered vehicles on our roads today, every automotive and commercial vehicle technician should have a basic understanding of electric powertrains. In this text, the term electric vehicle (commonly referred to as EV) will be used when describing any type of vehicle that uses an electric powertrain.

Although manufacturers have designed EV powertrains to maximize safety when performing maintenance procedures, technicians should always be mindful that there is *potential* danger when working with high-voltage (HV) electricity. Vehicles with electric powertrains are often serviced alongside vehicles with mechanical powertrains; therefore, every automotive technician today should understand how to identify HV circuits and observe the required precautions when working in close proximity to electric vehicles.

Warning

According to the Occupational Safety and Health Administration (OSHA), any voltage higher than 50 volts can be hazardous to health. For our purposes in this text, an HV circuit is one in which voltage values exceed 50 volts.

The following are vehicle classifications that use HV powertrains:

- Battery electric vehicles (BEVs)
- Hybrid-electric vehicle (HEVs)
- Plug-in hybrid electric vehicles (PHEVs)
- Fuel cell electric vehicles (FCEVs)

A cutaway view showing the layout of the BMW FCEV powertrain used in the BMW iX3 is shown is **Figure 3-1**. The BMW fuel cell is rated at 125 hp (175 kW) and the traction motor is capable of outputting 374 hp (275 kw).

Tech Tip

The acronym EESS (electrical energy storage system) will be used throughout this text to refer to the vehicle HV battery system.

Caution

When performing a simple task such as an oil change on the internal combustion engine (ICE) of a hybrid drive vehicle, you are working in close proximity to potentially lethal electrical energy. It is very important that you understand how to work safely on vehicles with electric powertrains. Do not leave it up to others to make this call for you, as the consequences could be lethal.

3.2 Understanding Electrical Energy

According to OSHA, ***electrocution*** is death by electrical energy. A significant proportion of electrocution deaths that occur in the United States and presumably worldwide occur in experienced electricians. If any group of persons should understand the potential dangers and how to avoid them, it should be those trained and qualified tradespeople. Most of these accidents occur as a result of complacency

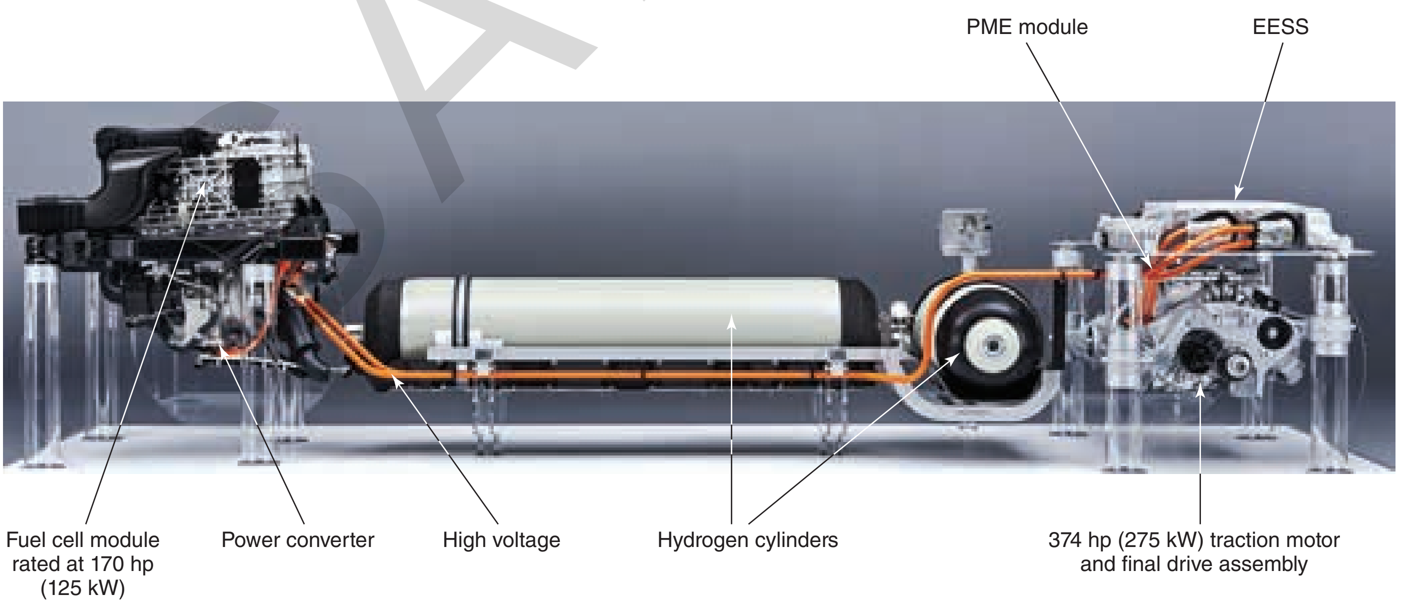

Figure 3-1. In this BMW FCEV powertrain, orange high-voltage cables connect the electrical energy storage system (EESS) with the fuel cell, power management electronics (PME) module and traction motor.

on the part of a skilled worker. Virtually all deaths and injuries caused by electricity are avoidable. They are caused by persons shortcutting or completely avoiding the safety procedures that all workers should follow.

> **Fact**
> As defined by OSHA, electrocution occurs when electrical current passes through or over a worker's body, resulting in a fatality.

3.2.1 Effects of Electrical Current

The first thing every technician should understand is just how little electrical energy it takes to cause an injury All trained vehicle technicians understand Ohm's Law, but ask a group of automotive technicians how much electrical energy it takes to cause an injury, and you are unlikely to get a response. Here is a reminder of Ohm's Law:

$$E \text{ (volts)} = I \text{ (amps)} \times R \text{ (ohms)}$$

Using Ohm's Law, you can calculate the amperage produced by some typical circuits to evaluate their danger potential. For purposes of the calculation shown below, we will assume that direct current (dc) is applied to the circuit. If we use a 1,000-ohm resistor in each of the following dc circuits, we can calculate the amperage as follows:

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

Electrical supply at 50 volt-dc:

$$I = \frac{50 \text{ V}}{1{,}000 \text{ ohms}} = \mathbf{50 \text{ mA or } 0.500 \text{ A}}$$

Electrical supply at 200 volt-dc:

$$I = \frac{200 \text{ V}}{1{,}000 \text{ ohms}} = \mathbf{200 \text{ mA or } 0.200 \text{ A}}$$

For common workplace three-phase feed at 440 volt-ac:

$$I = \frac{400 \text{ V}}{1{,}000 \text{ ohms}} = \mathbf{440 \text{ mA}}$$

Effect on the Human Body

Most people are surprised when they learn how little electrical energy is required to cause injury or death. For example, painful shocks can be felt at currents at an amperage as low as 3 mA, while loss of muscle control can result from currents as low as 10 mA. See **Figure 3-2**.

> **Caution**
> The ***National Electrical Code (NEC)*** is the benchmark for safe electrical design to protect people and property from electrical hazards. The NEC considers 5 mA the upper safe limit for human exposure to electrical current. It is important for technicians to understand that voltages in hybrid and electric drive trains can exceed 900 volt-ac with a lethal amperage. Humans have worked safely around HV electricity for two centuries, but safety rules must be obeyed.

3.2.2 Defining High Voltage

The general definition of HV is any electrical pressure that exceeds 50 volts. However, it should be noted that if a person's skin is wet or compromised at the electrical contact point, lower voltages are capable of inflicting injury. It is important to understand that when working around HV circuits, the potential for injury is not limited to self-injury, but can also injure anyone else in the vicinity and even damage property.

> **Caution**
> Technicians working on, or exposed to, vehicles with HV circuits should be familiar with the PPE requirements. HV is classified by OSHA and the ***Institute of Electrical and Electronic Engineers (IEEE)*** as any voltage exceeding 50 volts. Automobiles, commercial vehicles, and off-highway equipment described as hybrid-electric, hydrogen fuel cell, and all-electric use HV circuits, sometimes exceeding 900 volts and this could go higher as EVs become more common.

> **Fact**
> The Institute of Electrical and Electronic Engineers (IEEE) is commonly referred to as I-triple E.

Amperage (mA)	Effect
1	Sensed by the average human body
2 to 10	Causes a minor shock
10 to 25	Loss of muscle control; may cause muscle seizures or convulsions
25 to 75	Can be severely painful; may result in burns or death
75 to 300	A fraction of a second pulse is usually fatal

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Figure 3-2. Effect of electric current on the human body. Even a small amperage can cause serious injury or death.

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Figure 3-3. High-voltage warning triangle shown on a Chanje EV delivery van. This HV warning triangle is recognized internationally as a warning for HV circuits.

All personnel who are exposed to HV vehicle circuits should be trained even when not directly working on electrically related tasks. Technicians should be constantly alert and never take anything for granted. The safety precautions outlined in this text are designed to help technicians understand what is required to work on HV systems, but do not constitute training. Areas on a vehicle and in a shop that are noted as containing HV circuits are required to display a yellow placard with an HV warning triangle, **Figure 3-3**.

3.2.3 Cost of Electrical Injuries

A common consequence of a severe electrical shock is a burn injury. Of the top 10 most frequently cited OSHA categories of workplace injuries, three are electrical. Workplace data show that 97% of electricians have been victims of electric shock or injury severe enough to be reported. In the United States, every 30 minutes during a typical workday a worker suffers from an electrically induced injury serious enough to require time off from work. Medical costs for a single severe electrical burn injury have been known to exceed $4 million. Work-related injuries can cost businesses in the following ways:

- Medical costs
- Fines
- Equipment damage
- Increased insurance premiums
- Legal fees
- Lost business

3.2.4 Defining Electric Shock

An ***electric shock*** is the physical effect of an electric current entering the body. The consequence of an electric shock ranges from high-voltage, low-current, static electricity discharge, to more severe and potentially lethal power-line incidents, industrial equipment accidents, and lightning strikes. The biological effect on the shock victim depends on the amount of current passing through the body. The most serious damage occurs along the electrical path from the point of entry to its exit. The consequences of electric shock depend on the person's age and level of physical fitness.

From a medical standpoint, electrical shock injuries can be classified in the following groups:

- Burns at the current entry and exit points
- Permanent loss of hearing
- Muscle seizures
- Convulsions
- Brain damage
- Ventricular fibrillation

Ventricular Fibrillation

Ventricular fibrillation occurs when the heart muscle ceases to pump and instead quivers erratically due to the scrambling of its rhythmic electrical pulses. When an electric shock results in death, it is usually due to ventricular fibrillation or severe brain damage. Depending on the severity of an electrical discharge, a ventricular fibrillation event can sometimes be stabilized by a ***defibrillator***. A defibrillator is a medical device that administers an electrical shock to the chest area across the heart that may correct fibrillation.

Service facilities should be equipped with a defibrillator, preferably an ***automated external defibrillator (AED)***. An AED is a portable defibrillator that automatically diagnoses a cardiac arrhythmia condition and pulses electricity through the chest to correct it. See **Figure 3-4**. A minimum amount of training is required to operate the device safely. In an EV repair facility, at least one person should be trained.

Fact

OSHA recommends the use of AEDs in the workplace. However, there are OSHA-approved state regulation plans that mandate the use of AEDs in certain workplaces.

Caution

Voltage values as low as 50 volts on dry skin are known to cause ventricular fibrillation. Voltage values as low as 40 volts applied to wet skin or open wounds have caused fatalities.

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Figure 3-4. It is important that an automated external defibrillator, similar to this one, be in close proximity to where work is being done on the shop floor.

3.2.5 High-Voltage Characteristics

Both high-voltage alternating current (ac) and direct current (dc) circuits are used on EVs. The human heart is actually a simple, muscle-driven pump. When the human heart is subject to an ac electric shock, it poses a greater risk than dc. An ac electric shock tends to induce a rapid series of muscle contractions. For example, when a human hand is exposed to an ac shock, it can freeze the muscles in the hand causing it to involuntarily clasp the source. The same ac voltage applied to the heart muscle results in fibrillation.

When the human heart is subject to a dc electric shock, it is more likely to stop the heart. Once the current source is removed, a stopped heart muscle has a better chance of resuming a normal beat pattern than a fibrillating heart.

3.2.6 Unwanted Discharge of Electrical Energy

High voltage electrical energy can behave in ways that are not always predictable. Technicians working on or around HV circuits should understand the nature of these high-electrical energy discharge events, and how to protect themselves. In this respect, wearing the appropriate HV personal protection equipment (PPE) is essential, even when working around equipment that has been identified as *neutralized* according to lockout, tagout (LOTO) standards (see *Chapter 2, General Service Facility Safety*). The following terms should be understood by anyone working with HV circuits:

- Arc flash
- Arc blast
- Distributed capacitance

Arc Flash

Arc flash is the release of a massive amount of electrical and heat energy triggered by a circuit fault. Arc flash consists of both thermal and acoustical energy and can result in temperatures exceeding 34,000°F (19,000°C). These temperatures can vaporize metals as well as produce blinding light, explosive hot air expansion, shrapnel, pressure, and sound waves. Technicians working on live automotive HV circuits are required to protect themselves from an arc flash event. A warning sticker is required to be displayed where there is a circuit capable of producing an arc flash in the event of a malfunction. See **Figure 3-5**. When working on circuits denoted by this warning sticker, it is recommended that technicians wear proper PPE. See **Figure 3-6**.

Arc Blast

An ***arc blast*** is a more severe thermal event than arc flash as it releases more pressure, sound, and light energy. Blast pressures can exceed hundreds or even thousands of psi/MPa accompanied by sound levels exceeding 140 decibels. An arc blast can also propel shrapnel at speeds of 700 mph (1,125 kph). A noise level of 140 decibels can permanently destroy hearing. An arc blast event occurs when a high-load electrical path is suddenly interrupted, and a new pathway is created. An arc blast can be generated by current overload, mechanical failure, or accidental contact causing a short

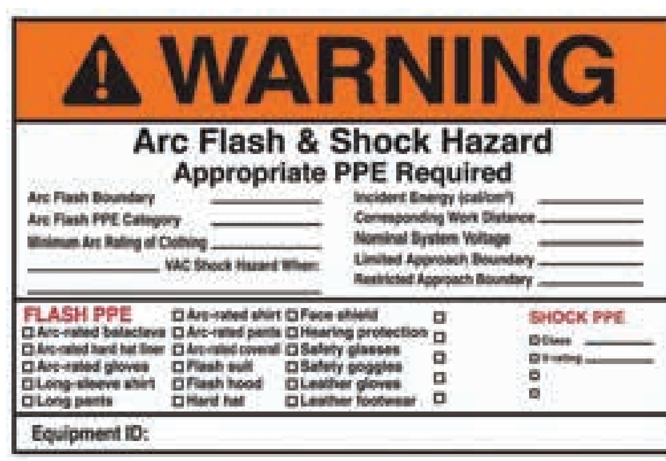

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Figure 3-5. Warning stickers are required on circuits where there is a potential of an arc flash. When warning stickers are displayed on an HV circuit, the PPE requirements are indicated.

A Nutthapat Matphongtavorn/Shutterstock.com B Goodheart-Willcox Publisher

Figure 3-6. For added protection against an arc flash, it is recommended that technicians wear (A) an arc flash suit combined with (B) an arc flash face shield and helmet.

circuit that can convert a work area into a disaster zone. An arc blast is unlikely to be produced by EVs. Technicians, however, should be aware of this condition as the grid to EV charging stations can deliver extreme HV and currents.

3.2.7 Capacitance

Automotive technicians should be familiar with the definition of ***capacitance***, a term used extensively in both low voltage (LV) and HV electrical circuits. By definition, capacitance is the ability of a conductive material to hold an electrical charge. There are three general types of capacitance:

- Self capacitance
- Mutual capacitance
- Distributed capacitance

Self Capacitance

Any substance that can be electrically charged can be said to have self capacitance. In this instance, the voltage difference can be measured between the substance and ground. A material with a high self capacitance is capable of holding more electric charge at a given voltage than one with low capacitance.

Mutual Capacitance

Mutual capacitance is the principle on which a capacitor functions. A typical capacitor consists of a pair of conductors that are used to separate an electric charge: one of the conductors is positively charged and the other negatively charged. The two conductor plates are isolated from each other and sandwich dielectric material. The capacitance of the device is proportional to the surface area of the two plates and inversely proportional to the separation distance between them. The ratio between the positive and negative charges on either conductor is specified as the potential or voltage of the capacitor.

Distributed Capacitance

In HV electrical circuits, an undesirable form of self capacitance exists that is not loaded into actual capacitors. The presence of high potential electrical circuits in close proximity to each other can produce mutual capacitance values between different points on a chassis in a scenario known as ***distributed capacitance***. Distributed capacitance is an undesirable characteristic of HV vehicle circuits that can be stored into any conductors (vehicle frame, circuits, etc.) and discharged *after* the HV chassis has supposedly been electrically neutralized. Technicians should understand distributed capacitance because it can be lethal.

Original equipment manufacturers (OEMs) use design features and double-insulate chassis frames to minimize distributed capacitance effect, but as of yet, there has not been a discovery to eliminate the condition. EVs store electrical energy in batteries and capacitors, which are referred to as the chassis EESS.

In a vehicle EESS, both the negative and positive poles are permanently connected to the chassis by distributed capacitance effect despite double insulation. This means that if a body comes into contact with the vehicle's chassis, any touch to either the negative or positive potential voltage of the EESS can discharge the stored capacitance.

Depending on the level of capacitance on a given vehicle, the effect can be severe or even lethal. Unprotected contact with potential live points of EESS HV power and chassis should be avoided. The bottom line is that technicians are reminded that wearing appropriate HV PPE is essential, even after verifying that circuits have been neutralized.

3.2.8 Voltage Alert Sensors

A contactless voltage alert sensor is a pocket tool that is designed to sense the presence of voltage potential in a conduit or component without making direct contact with its wiring or conductive elements. The contactless Fluke voltage alert sensor shown in **Figure 3-7** is CAT III rated.

3.3 General High-Voltage Safety

High-voltage electrical circuits are categorized by the ***International Electrotechnical Commission*** (commonly known as the IEC) as follows:

- **CAT 1**—includes household devices such as computers, lighting, televisions, and refrigerators. Circuit-protected by fuses or virtual fuses.
- **CAT II**—includes household devices such as motorized equipment (vacuum cleaner) and heater elements. Circuit-protected by breakers.
- **CAT III**—includes household equipment such as HVAC systems and electric dryers. Circuit-protected by breakers. Most current EV high-voltage systems are classified as CAT III level electrical systems.
- **CAT IV**—power grid electrical supply.

Courtesy of Tony Martin

Figure 3-7. A contactless Fluke voltage alert sensor can safely identify the presence of voltage in a supposedly neutral circuit.

Figure 3-8 and **Figure 3-9** show IEC CAT classifications. Depending on the vehicle charging options, an EV or PHEV vehicle charge socket would be classified as CAT II or CAT III.

3.4 High-Voltage PPE Checklist

When working with HV circuits, it is important to make sure you follow the PPE recommendations from the previous chapter, but also include the following required PPE items. All PPE items must be inspected for cleanliness, perforations, and other damage prior to each work session. CAT III and CAT IV PPE is date stamped and is required to be tested periodically depending on the manufacturer's instructions.

In addition, it is important to note that HV PPE has a finite lifetime: this means that it must be either replaced or tested after its expiration date. The re-test or expiration date is usually clearly displayed on the equipment. **Figure 3-10** lists the IEC rating categories that relate to HV EV system service work.

3.4.1 Protective Clothing

When working with HV circuits, nonsynthetic clothing and fire-resistant shirts, pants, and overall are recommended.

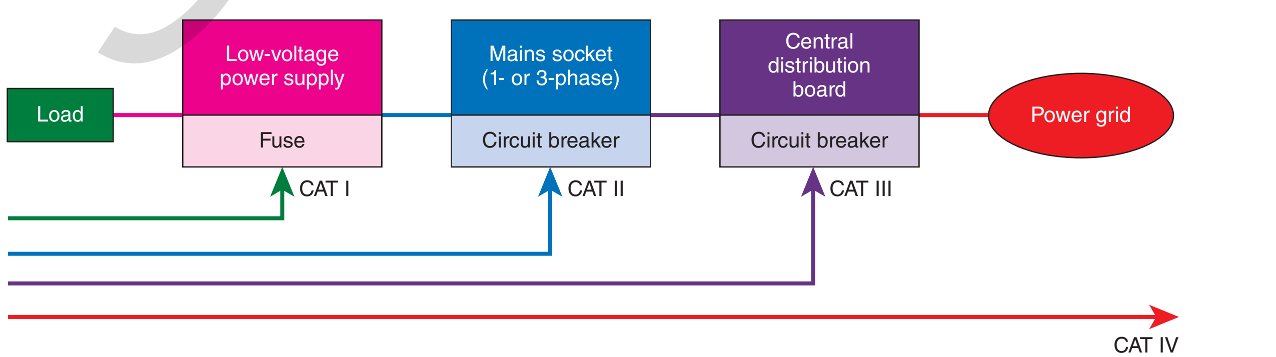

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Figure 3-8. IEC CAT classifications showing how CAT IV grid-supplied electricity is transformed down to an ac 120-volt load.

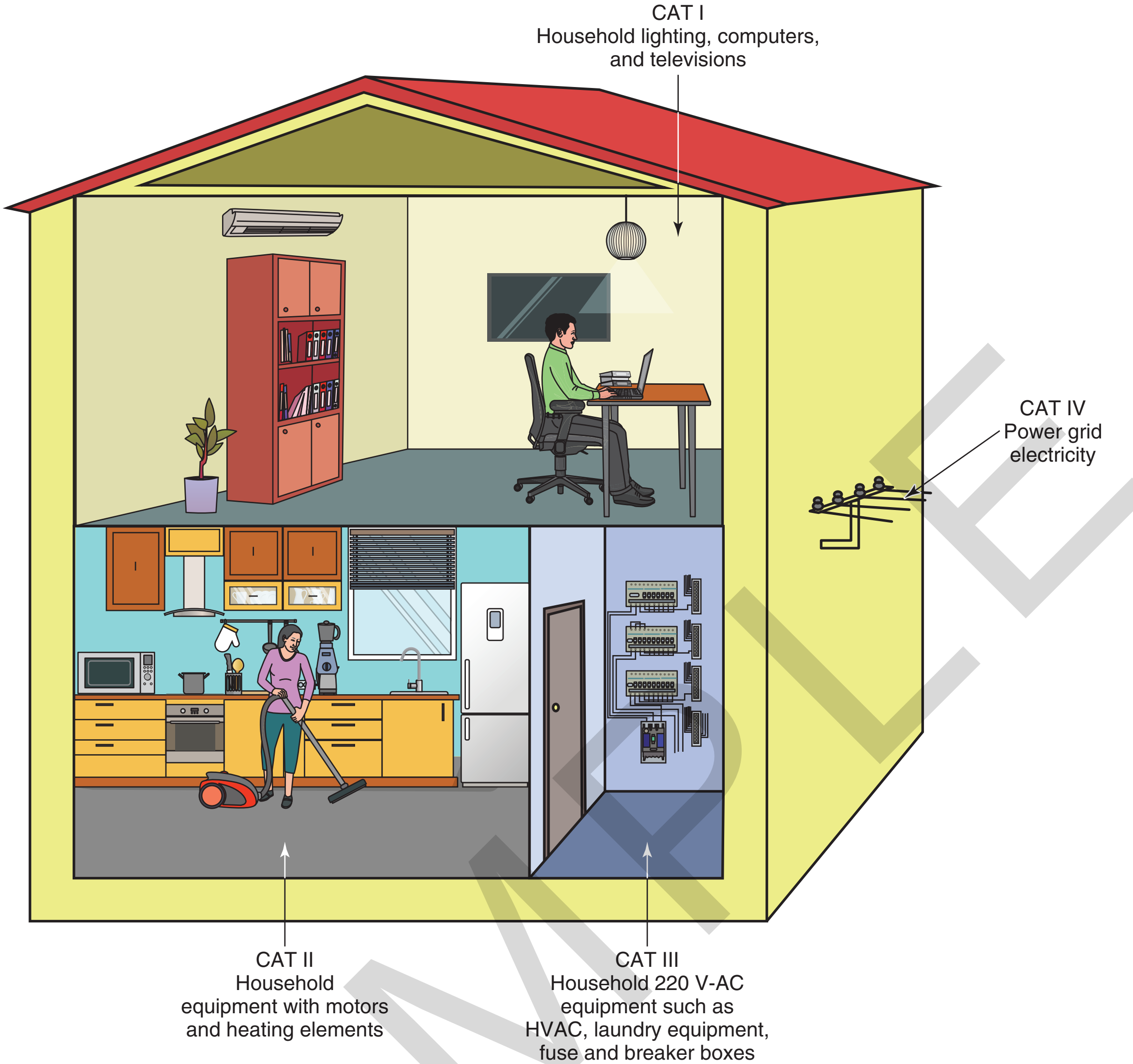

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Figure 3-9. IEC CAT designations using typical household examples: grid electricity is progressively transformed down from grid-supplied voltages to low-energy devices, such as household lighting.

IEC PPE Rating	Alternate Current (volts)	Direct Current (volts)
Class 00	500	750
Class 0 (best for auto EV work)	1,000	1,500
Class 1	7,500	11,000

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Figure 3-10. HV PPE ratings: certified maximum voltage protection.

> **Warning**
> Workers with medical electronic implants, such as heart pacemakers, should *never* work on HV circuits because these devices are susceptible to failure by electromagnetic radiation.

3.4.2 Footwear

Safety boots with an electrical hazard (EH) rating or orange omega indicating that they meet ASTM F2413-05 standards for electrical hazards should be worn. Alternatively, safety overshoes meeting ASTM F1117

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Figure 3-11. ASTM-approved HV overshoes can be worn over CAT III rated footwear for extra protection.

standards meet compliancy standards when they are used over street shoes. See **Figure 3-11**.

3.4.3 High-Voltage Class 0 Rubber Glove Set

An HV Class 0 rubber glove set consists of a pair of rubber gloves and a pair of leather gloves, as shown in **Figure 3-12**. The rubber glove set should be rated to ASTM D120 standard, Class 0. The gloves are required to be electrically tested every 6 months and stamped with the test date.

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Figure 3-12. A Class 0 glove set that is CAT III rated. The correct way to wear these gloves is to place the leather gloves over the rubber gloves.

Testing a Set of High-Voltage Gloves

Class 0 HV glove sets must be tested every 6 months for leaks. This is done by using a standard Class 0 glove test kit, as shown in **Figure 3-13**.

To test a set of HV gloves:

1. Draw the rubber glove over adapter ring and secure it with the hook and pile strap.
2. Place the adapter on top of the glove inflator.
3. Hold adapter, place the inflator bellows against any hard surface, and pump.
4. Remove inflated glove and adapter from the test kit.
5. Inspect glove to check for leakage.

This procedure also appears on the test kit, as shown in **Figure 3-14**.

How to Wear Class 0 Gloves

Class 0 HV gloves can only protect the wearer if they are properly worn. See **Figure 3-15**. The table shown in **Figure 3-16** lists the ASTM labeling for HV rubber gloves.

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Figure 3-13. A—A standard Class 0 glove test kit. B—An assembled glove test ready for use.

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Figure 3-14. Class 0 glove testing instructions are displayed within the test kit for easy referral.

3.4.4 Safety Glasses and Face Shield

The use of safety glasses is required and they must be entirely nonconductive. **Figure 3-17** highlights the hinge points on a pair of HV certified safety glasses. For additional protection, the use of a face shield is also recommended.

3.4.5 Hot Stick

A hot stick certified to ASTM F 711 standard must be positioned close to the place of work. The hot stick should be made of nonconductive fiberglass and labeled with a test date. A ***hot stick*** has the appearance of a shepherd's hook with an extra-long handle: it is usually called a shepherd's hook on the shop floor, but the ASTM term is *hot stick*. Testing is required every 2 years. The device should only be used in an emergency, such as removing a person or article that comes into contact with an HV circuit.

Handling a Hot Stick

A hot stick or shepherd's hook is nonconductive and is usually equipped with a rubber hand shield (quillion). When using a hot stick, full HV PPE is required and the hand should be placed close to the base and behind the hand shield, **Figure 3-18**. **Figure 3-19** shows the appropriate shop placement of a hot stick while work is being performed on the HV system on an EV.

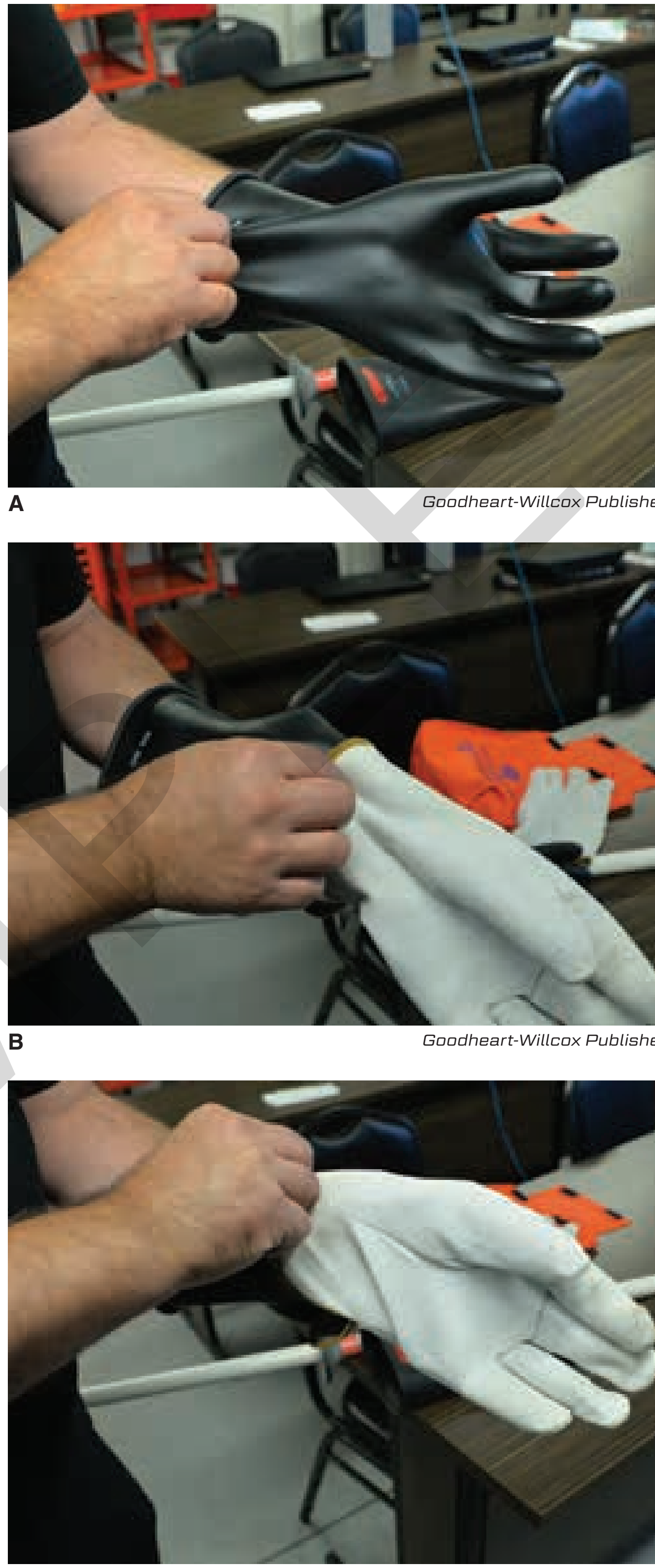

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Figure 3-15. A—To properly wear Class 0 gloves, the rubber gloves are placed on the hands first. B—Then, the leather gloves are placed over the rubber gloves. C—Once the gloves are on, ensure that the gloves fit snug over the fingers.

Class	Color	Proof Test (voltage ac/dc)	Maximum Use (voltage ac/dc)	Insulating Rubber Glove Label
00	Beige	2,500/10,000	500/750	ASTM D120 10 Class 00 Type 1 Max use volt: 500 volt ac
0	Red	5,000/20,000	1,000/1,500	ASTM D120 EN 0903 10 Class 0 Type 1 Max use volt: 1,000 volt ac
1	White	10,000/40,000	7,500/11,250	ASTM D120 EN 0903 10 Class 1 Type 1 Max use volt: 7,500 volt ac
2	Yellow	20,000/50,000	17,000/25,500	ASTM D120 EN 0903 10 Class 2 Type 1 Max use volt: 17,000 volt ac
3	Green	30,000/60,000	26,500/39,750	ASTM D120 EN 0903 10 Class 3 Type 1 Max use volt: 26,500 volt ac
4	Orange	40,000/70,000	36,000/54,000	ASTM D120 EN 0903 10 Class 4 Type 1 Max use volt: 36,000 volt ac

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Figure 3-16. ASTM labeling chart for defining the high-voltage protection of natural rubber electrical insulating gloves.

⚠ Caution

Most body jewelry (external and internal) is made of conductive materials. Ensure all jewelry is removed before working on HV circuits.

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Figure 3-17. When selecting a pair of HV safety glasses, check for metal at the hinge points and in the frame arms. The glasses should be clean, dry, and free of grease and oil.

3.5 Electric Vehicle Safe Work Practices

Operators and technicians should understand the following general safety guidelines when working on EVs:

- Safe operation of EVs and their subsystems requires anyone working on the vehicles to understand the behavior of its high-voltage electricity, capabilities, and limitations.

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Figure 3-18. When holding a hot stick, it is recommended to place your hand behind the hand shield, close to the base of the stick.

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Figure 3-19. A hot stick should be placed in close proximity while working on an EV.

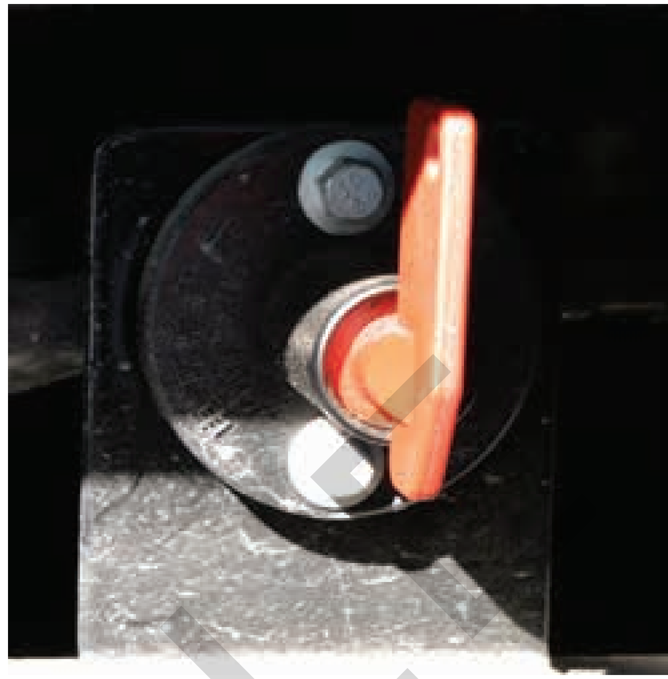

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Figure 3-20. Isolation switch on a BYD truck chassis.

- Safety guidelines must be followed. Failure to strictly observe the safety instructions defined by the manufacturer can result in injury, death, and damage to the vehicle.
- The number one rule is to wear the recommended HV PPE in the appropriate manner. An example of a common abuse is wearing a hinged face shield raised in the up position where it will not provide protection to the face.
- Automotive technicians working on HV powertrains should be familiar with OSHA guidelines regarding HV safety.
- On no account should any untrained technician attempt to service or repair an EV. The training should be vehicle-specific. You may know the HV circuits of a Nissan Leaf, but that does not qualify you to work on a Chevrolet Bolt or a transit bus.
- Ensure that the EV LOTO procedure at your facility is being observed. This is especially important when taking over a work procedure that another technician initiated. Verify that the EV is electrically isolated. The ignition should be off. Open the service/maintenance switch and the main battery switch. The OEM service literature may also advise technicians to open the LV battery switch. Depending on the specific EV, fuses or open circuit breakers may need to be removed. After isolating the vehicle, physically LOTO the switches with a personal lock. The location and nomenclature of isolation switches varies by each manufacturer. **Figure 3-20** shows the location of an isolation switch on a transport truck.
- Reference the OEM safety instructions and service literature before commencing work on a HV vehicle.
- Warning labels are usually posted in the vicinity of all HV components and cables. Refer to Figure 3-5. Use extreme caution when working in these areas, even after you have been appropriately trained.
- HV components are often located in relatively inaccessible areas of EVs. These locations include underneath the vehicle floor or below the rear passenger seat in automobiles. In transit or commercial vehicles, they are located on the roof or rear engine compartment. This is done for safety reasons, but it can make it awkward for technicians to access these areas. It is recommended to check the OEM recommendations before accessing these components.
- Beware of the color orange: orange-colored cables, paint strokes, and connector tags are used to denote HV currents. See **Figure 3-21**. Do not get closer than 2 inches from HV components or cables unless you are trained to work on that specific vehicle.

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Figure 3-21. The orange paint strokes on the junction box coupler and fasteners indicate the presence of high voltage. In addition, they act as a method to reveal tampering.

> **Tech Tip**
>
> Before working on any HV vehicle system, make it a habit to examine everything connected to your body that can conduct electricity. This includes clothing, anything attached to your body (such as jewelry), and even the contents of your pockets (including your cell phone). An HV safety personal audit should also include items such as belt buckles, the hinges on safety glasses, and surgical implants. In the case of the latter, if you have a surgical implant such as a pacemaker it is advisable not to work in close proximity to HV circuits. Make a habit of asking yourself this vital question every time you are about to work on an HV circuit: "Am I a conductor or an insulator?" Then do everything to ensure that you are an insulator.

> **Caution**
>
> If you have a titanium surgical implant (used as a reinforcement for severe bone fractures) you may have been told that it is nonconductive. This is true for CAT I or II voltages. However, titanium is a metal and therefore is a conductor. It is not what you would call a good conductor, but working on CAT III or IV voltage systems is not recommended.

3.6 High-Voltage General Work Area Preparation

In addition to wearing the appropriate PPE when working on HV chassis systems, the work area and vehicle should also be checked as follows:

- Ground the chassis before attempting to hoist an EV. When preparing to work on an EV that will remain on the shop floor, verify that the vehicle wheels are chocked and the shop policy LOTO procedure is observed. For example, a steering wheel cover should be placed over the vehicle's steering wheel, **Figure 3-22**. A LOTO "Do Not Start" tag should be added to the LOTO ignition circuit.
- Verify that the EESS is properly isolated and LV circuit switches are open (OFF): physically lock out these switches if possible.
- Inform the supervisor in your work area that you will be working on an HV system. When working on any of the HV circuit components you should have an assistant act as an observer. Never work alone on HV circuits and keep an eye out for your partner.
- Verify that no residual voltage exists in a circuit before taking over a job from another technician.
- Never reach into a live HV area with both hands—keep one hand in your pocket behind your back. Using one hand minimizes the chance of providing an electrical current path through your heart.
- Ensure that a nonconductive hot stick is close to the work area.
- Use superior quality insulated tools that are rated for HV use. These tools are insulated with plastic or rubber handles. See **Figure 3-23**. Additional HV electrical specialty tools will be described in *Chapter 13, Specialty Tools, Circuit Isolation, and First Responder Practices.*
- When working on HV circuits, use a digital multimeter (DMM) and test leads that are CAT III 1,000 volts-dc certified. See **Figure 3-24**. Make it a habit of testing HV components and cables before touching them, even when wearing Class III glove sets.

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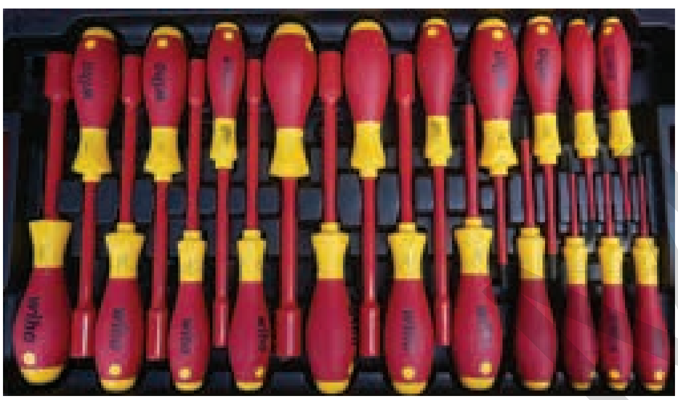
Figure 3-22. LOTO steering wheel cover and a roll of HV caution tape should be used to cordon off any HV work area.



A

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B

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Figure 3-23. A—CAT III-rated insulated socket wrench set. B—Insulated screwdriver set for electrical work.

- Use CAT III-rated alligator clips, probes, test leads, and attachments that are designed to enable one-handed operation of the DMM.

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Figure 3-24. The Fluke 88 is an example of a CAT III-approved DMM to test circuits to verify that no residual HV is present.

- Wear an arc flash suit when working on HV battery banks, power management electronic (PME) modules, disconnect panels, or HV switches.
- Ensure that all EESS disconnect switches are open and the HV LOTO routine has been observed. After de-energization, be sure to check system voltages again to confirm. A lockable LOTO multi-hole hasp and tag enables up to three technician locks to be installed at the same time. See **Figure 3-25**.
- Position HV signage in any area that HV vehicles and equipment are being maintained or repaired.
- Never assume that a vehicle circuit is electrically safe simply because it is not running and electrical disconnect switches are opened. Test every circuit before beginning work.
- Designate a person who is trained in first aid and CPR and is trained to use the shop defibrillator. This person should not be working on the job, but present in the work area. The defibrillator should preferably be an AED, such as the unit described earlier in this chapter.
- Every service facility engaged in servicing and repairing vehicles with HV circuits must have a written and displayed emergency safety and rescue plan that includes emergency services phone numbers.

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Figure 3-25. A lockout clip and a tag. A technician can write a cellphone number or name in the Remarks field on the label. Up to three padlocks can be attached to the hasp clip when multiple technicians are working on a vehicle or machine.

> **⚠ Caution**
> Remember the one-hand rule when testing for voltage in HV circuits: One hand on the DMM probe, one hand behind your back.

> **⚠ Caution**
> Before moving or towing a disabled EV, the OEM towing instructions must be referenced. Rotating the wheels on a supposedly neutralized EV can generate dangerously high voltages. See *Chapter 13, Specialty Tools, Circuit Isolation, and First Responder Practices*, for a description of the correct procedure.

3.7 High-Voltage Testing

When performing a high-voltage test, two technicians must be present. One should be designated the *checker* and the other the *recorder*. Two people are required to ensure the safety of themselves and anyone in the vicinity of the work being performed. Both the designated checker and recorder must be wearing the required PPE. The checker will perform the DMM measurements while the recorder writes them down. Both the checker and the recorder must have received HV training.

3.7.1 High-Voltage Checkout Preparation

The checker and recorder must accurately determine exactly what the objective of the procedure is before beginning the task.

1. Install safety tape/barricade with warning lights and signs indicating "Danger High Voltage" around the vehicle perimeter.
2. Perform the required LOTO procedure and ensure that the procedure is cheat-proof. The lockout clip can be padlocked with a unique personal lock and labeled with a tag containing the technician's name and cellphone number.
3. Check that there is no standing water below the vehicle.
4. Safety caged ladders and scissor lifts should be used to access exterior areas of vehicles.
5. Body harnesses and lanyards must be worn to access the rooftop area on buses or trailer units for service and maintenance.

Caution
Fall-arrest equipment is required by OSHA to prevent a worker from falling to the ground. This is especially important when working around HV electricity. The OSHA regulation stipulates that a worker must be fall-arrest protected if they are working 6 feet or more from ground level. When working on a roof of a bus, for example, a fall-arrest system consists of a worker body harness, a shock-absorbing lanyard, and an anchor point capable of sustaining 5,000 lbs (2,258 kg) of force.

6. Perform as many of the system checks as possible with the HV power OFF and proven as de-energized by voltage measurement.
7. When it is at the point to test an energized HV system, the Working Live procedure must be followed.

Tech Tip
Be considerate when installing lockout hardware on vehicles. It is good practice to always identify yourself on the lockout tag and include your cell phone number.

Fact
According to OSHA data, between 150 and 200 workers die every year due to workplace falls. Remember, every death is preventable.

3.7.2 Working Live Procedure

Implement the following PPE and LOTO requirements:

1. Before energizing an HV circuit, perform a workplace inspection of the entire work area ensuring that HV compartments are secure and that no test equipment, tools, or other nonsystem objects are going to interfere with the procedure. In addition to the regular PPE, determine whether full face and head protection is required.
2. Perform the required HV procedure exactly according to the OEM service literature instructions.
3. Both the checker and the recorder must work together. If either is called away from the place of work, the work must cease, and both workers leave the work area together.

Caution
EV battery packs, strings, and banks continue to be live after they have been isolated. When EESS subcomponents are serviced, they should be handled with full PPE both within the vehicle and in the parts departments. This will be further demonstrated in *Chapter 14, Electric Vehicle Service and Diagnostic Routines*. New battery modules are usually shipped at a 50% state-of-charge (SoC).

3.8 Everyday Tasks

The following HV safety procedures must be observed when common tasks are performed on HV chassis.

3.8.1 Power Washing

Review the shop PPE protocols.

› Do not direct a power wash wand into the underhood engine compartment on a truck or the rear engine compartment on a bus.
› Avoid directing water onto the electronics, orange cables, junction boxes, HV boxes, and connecters. Use air pressure regulated to 30 psi (200 kPa) to remove dirt from electrical components.
› Dry off areas that have been wet by the cleaning process. This can be done with shop air regulated to 30 psi (200 kPa).

3.8.2 Cleaning Low-Voltage Batteries

Implement the LOTO and PPE requirements. Ensure that the ignition circuit is open (OFF). The term ***low voltage (LV)*** usually refers to a vehicle circuit of 12 volts or 24/36 volts in some commercial vehicle and military applications. In the latter, it results from a series connection of two or three 12-volt batteries.

1. Switch the LV disconnect switch to the OFF position and lock out.
2. Switch the HV disconnect switch to the OFF position and lock out.
3. Locate the LV battery(s). The location varies by chassis type (auto/truck/bus) and OEM. For example, the LV battery in an EV passenger vehicle can be located under the hood or in the trunk. In HEVs, the battery may be charged by either an internal combustion engine (ICE) or EV-driven alternator. LV batteries on a transit bus can be located either on the curbside, street side, or rear engine compartment. Open the compartment doors to expose the batteries. In trucks, LV batteries may be located in chassis-rail-mounted compartment(s) or under the hood: remove the covers.

4. It is usually safe to use a power washer on LV batteries, as long as the pressure wand is not directed near or onto orange cables, orange wiring, fuse boxes, power management electronic modules, or other control module housings. If unsure, do not power wash. Brush on an alkaline solution (water with a little baking soda) and use low-pressure air to blow off any accumulated dirt.
5. When a slide-out battery tray is used, remove the retaining nut and pull out the battery tray. In most trucks, LV batteries are sufficiently exposed after the covers have been removed. The power wash wand nozzle should not be used at a distance closer than 6 feet from the batteries. An older steam pressure washer should not be used to clean batteries.
6. After cleaning, air-dry or low-pressure air-dry the batteries prior to replacing the covers/reinstalling sliding shelves and closing the compartments.

3.8.3 Cleaning the Underside of Vehicles

The procedure to follow when cleaning the underside of EVs depends on the chassis. It is usually safe to power wash the underside of most passenger vehicles. Transit buses can store the critical HV battery banks and components on the roof, in the “engine” compartment, or under the chassis floor. Commercial vehicles, such as trucks, usually store the HV battery bank modules under, or alongside, the chassis frame rails.

> **Warning**
> Before cleaning the underside of any vehicle, it is recommended to review the OEM service manual.

Implement the LOTO and PPE requirements, but if the service technician is working underneath a hoisted vehicle, a bump hat (cap) should also be worn. Ensure that the ignition circuit is open.

1. Raise the vehicle on the hoist using the proper procedure. When using independent multi-post lift systems, ensure they are properly phased and tested by hoisting the vehicle just a couple inches to verify that the chassis remains level. When raised to the appropriate height, ensure that the hoist(s) are mechanically locked.
2. Some OEMs recommend that only low-pressure water be used for cleaning the vehicle’s underside. When washing down the vehicle, focus on the traction motor(s) and frame area. If the vehicle is equipped with a drive shaft, differential, or transmission, remove road dirt from these components.
3. After cleaning, be sure to remove any standing water under the vehicle before lowering it onto the shop floor.

3.9 Welding on High-Voltage Vehicles

Welding on passenger EVs is not common, but electric welding abuses on commercial vehicles cost the industry millions of dollars annually in damaged components and lost time. OEM service literature must be consulted before welding on a chassis. Some general guidelines are provided below.

3.9.1 Electronic Precautions

When beginning either a stick arc, tungsten inert gas (TIG), or metal inert gas (MIG) welding procedure or when plasma cutting, large voltage spikes are created. These voltage spikes can destroy electronic modules and sensors in the networks of low- and high-voltage electrical systems used in automobiles, trucks, off-road equipment, or bus chassis.

An extensive suite of electronic components is used in current vehicles that share a common chassis ground circuit. Simply disconnecting the battery cables does not guarantee sufficient protection. Most OEMs recommend disconnecting electronic module grounds from the chassis ground circuit prior to undertaking any procedure that involves an electric arc. Depending on the chassis, this process may be significantly more time-consuming than the actual welding job.

> **Caution**
> Most modern welding equipment operates on closed circuit voltages (CCV) of 24 volts or less. The danger to electronic circuits occurs when an electric arc is struck: this subjects the chassis to open circuit voltages (OCV) of 60 volts or higher. A momentary spike of OCV can destroy electronic devices.

> **Warning**
> When planning to weld on an HV electrical vehicle chassis, both a trained HV vehicle technician and the welder should be involved in decisions on how the sensitive electronic components should be isolated from danger.

3.9.2 General Welding Precautions

Implement the LOTO and PPE requirements.

1. Switch off all vehicle electrical loads. Ensure that the vehicle ignition system is open and observe the shop LOTO procedure.
2. Switch the LV battery isolation/disconnect switch to the OFF/OPEN position and lock out.

3. Switch the HV isolation/disconnect switch to the OFF/OPEN position and lock out.
4. Advise an EV-trained co-worker that you are going to be welding so that someone is keeping an eye on you. Advise the co-worker that eye protection is required during the procedure.
5. Set up safety measures appropriate for the environment where you will be welding. This includes activating the ventilation system, suction snorkels, and air monitoring equipment. In some cases, this may include wearing a breathing apparatus.
6. Check to verify that there are no highly flammable mixtures in the general work area. Remove them if necessary.
7. Locate the ground clamp as close as possible to the weld area. Ensure the welding ground clamp is of adequate size and ensure that it makes a good connection to the ground surface. If necessary, remove any paint or coatings so that bare metal is exposed at the ground contact point.
8. Never attach a ground clamp to a chassis ground terminal bar because that is likely also the ground point for an electronic module.
9. When welding has to be performed on different areas of the chassis, relocate the welding ground clamp as necessary so that it is always as close as possible to the contact point of the electric arc.
10. Ensure that the welding station electrical cables are not positioned close to any of the chassis electrical wiring harnesses.
11. Finally, check that no flammables on the chassis are located close to the weld area. Remember that the intense heat of arc welding will travel some distance away from the point of the weld. Be especially aware that no plastic conduit or hoses are close to the weld area.

⚠ Caution

In order to meet the shop HV LOTO standards, technicians may be required to have more than one personal lock. If more than one technician is working on a vehicle, a multi-hole hasp capable of holding two or more locks should be used. A hasp is a slotted, hinged metal plate that forms part of a fastening for a door or lid: it can be fitted through a loop and secured with a padlock.

3.10 EESS Safety

The types and operating principles of EESS used in EVs are covered in detail in *Chapter 7, Electrical Energy Storage Systems,* and *Chapter 9, Drive Train Electricity and Electronics*. It is important for technicians to understand that numerous types of capacitors, lithium-ion cells (commonly referred to as li-ion) and solid-state batteries are used in EVs today and are likely to be joined by more in the future as electrical energy storage technology evolves. The term *cell* in electricity is defined as an electrical storage device consisting of electrodes interacting within electrolyte. Li-ion battery cells are commonly used in today's vehicle EESS. Technicians should be aware that each category of li-ion battery outputs marginally different cell voltages. Becoming familiar with the specific types of batteries used in a chassis is important. In addition, some battery cell chemistries are volatile and potentially dangerous. This means that the battery cells used in EVs have to be monitored and managed by the EESS management electronics.

3.10.1 EESS Voltages

The cells used in EESS store relatively low-voltage potentials. Currently, each li-on or solid-state cell is rated at voltage values ranging between 1.5 and 3.5 volts. In order to produce operational voltages of 600 volts or greater, these cells must be arranged in a series to form packs, then strings. In vehicles that require higher energy density, the EESS uses packs in series, after which the strings can be looped in parallel to achieve the required energy density. The progression is as follows:

› Individual cells each with low voltage potential typically around 3 volts-dc.
› Packs consisting of many cells in series (to increase voltage).
› Strings consisting of multiple packs arranged in series (also to increase voltage).
› Banks consisting of two or more strings arranged in parallel (to increase energy density).

3.10.2 EESS Precautions

Lithium-ion batteries tend to get plenty of media exposure when subject to a thermal event, such as a cell phone bursting into flames or a fire on-board an aircraft fuselage. However, they are integrated into every aspect of our lives. In addition to the cell phone, they are used in cameras, computers, watches, automobiles, and just about any device with rechargeable batteries. They can generally be regarded as a safe technology, but when we group them into high-voltage EESS modules, their danger potential is obviously increased. When it comes to emphasizing safety, every handling precaution must err on the side of caution. This can have the effect of making battery technology sound more dangerous than it actually is.

Every technician working on or around HV batteries should know how to safely handle batteries and be aware of their potential for danger. See **Figure 3-26**. *Chapter 13, Specialty Tools, Circuit Isolation, and First Responder Practices*, will address how to respond to potentially dangerous battery failures.

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Figure 3-26. A lithium-ion battery pack consisting of dozens of cells arranged in series: the warning label identifies both the HV and li-ion safety precautions.

Safe Handling

When servicing a li-ion battery bank on a vehicle, you will be warned by a sticker that informs you "Read and observe the handling instructions for this battery bank. Failure to do so can result in failed batteries, electric shock, fire, explosion, and serious personal injury or death." This warning means that you should be trained to work on HV vehicle systems.

The following is an example from a battery manufacturer regarding safe handling for its batteries. Before beginning, ensure that the appropriate PPE is worn and, if a vehicle is involved, that the LOTO procedure is observed.

- Battery packs and EESS modules are typically shipped at a 50% SoC and may be safely put into service without any additional charging.
- Batteries can only be recharged using OEM-approved charging stations and cables.
- Never charge an EESS if the unit is visibly damaged.
- Never charge an EESS if the cell voltage drops below the minimum specified for the cell type.
- Do not allow battery packs, strings, or EESS modules to become wet with any liquid substance. Never place wet battery packs, strings, or EESS modules into a vehicle.
- Do not expose a battery bank or charging station to excessive heat or flame.
- Avoid doing anything that might short-circuit the bank terminals.
- Do not drop EESS components.
- Puncturing, tampering with, or attempting to open the battery subcomponents can cause short circuits, thermal runaway, and the release of potentially harmful materials.
- Spent or damaged battery packs should be recycled. Before recycling, EESS modules must be electrically discharged, the terminals sealed, and then packaged using the vehicle manufacturer guidelines. This usually involves evacuating the EESS subcomponents, bagging them in shipper-approved plastic, and then delivering them to a certified recycling facility or to the manufacturer.

> **⚠ Caution**
>
> Should a fire occur in an EESS on the vehicle or stored battery packs, immediately call the fire department. An EESS explosion can be lethal and requires intervention by fire suppression experts, not by service personnel. Appropriate responses to potentially dangerous battery events are discussed in *Chapter 13, Specialty Tools, Circuit Isolation, and First Responder Practices*.

3.10.3 Thermal Runaway

Thermal runaway usually begins with a single cell failure, specifically when cell heat rise exceeds the heat dissipation rate. This can result in a "domino effect" and a thermal event. See **Figure 3-27**. The most common root cause of lithium cell failure is a manufacturing defect in a single cell in which the chemistry is unbalanced. The battery banks on electric vehicles (EVs) are both cooled and monitored, along with being equipped with the electronic ability to "rest" cells that are evaluated as being in a potential overheat condition. Almost all EV battery modules are equipped with an excess of cells required for the specified output voltage to enable individual cells to be "rested" by the battery management system.

Other root causes include:

- Design defect
- Failure of battery cooling circuit
- Failure of battery monitoring electronics
- Poor handling and storage practices
- Exposure to extreme heat (direct sunlight)

The chances of thermal runaway vary depending on the cell characteristics used in EESS batteries. This will be further explained in *Chapter 7, Electrical Energy Storage*. Some more recent lithium-ion battery chemistries pose almost no thermal runaway risks, while others in common use are integrated with sophisticated cooling systems and use precision cell-by-cell temperature monitoring.

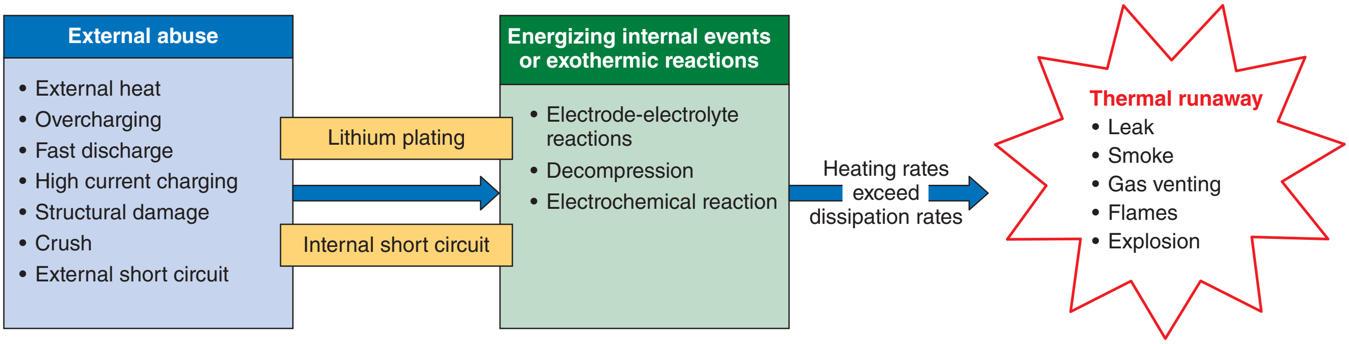

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Figure 3-27. Potential causes and event sequence of thermal runaway.

3.10.4 High-Voltage Charging Safety

The process of connecting an EV to a charging source generally has to be undertaken by technicians not trained in HV safety measures. As a result, manufacturers have taken measures to ensure that the procedure can be undertaken with minimal risk. The procedure varies by vehicle type and manufacturer. Charging procedures will be covered in detail in *Chapter 11, Charging and Hydrogen Refueling.* In North America, manufacturers are beginning to standardize charging hardware and software. Most automobiles and pick-up trucks can be hard-wire charged from an ac or dc source at 120 volts, 220 volts, or 480 volts. **Figure 3-28** shows the Volkswagen Global Test Center EV charging station in Arizona: a glimpse of what might become more common in the not-so-distant future.

Charging an EESS using a 120 volts-ac source might take days; therefore, higher voltage options are preferable. Some current vehicles can be inductively charged. This is arguably the safest method. A universal CCS Type 2 charging coupler is slowly becoming a universal standard, but not all manufacturers adhere to its use. *Chapter 11, Charging and Hydrogen Refueling,* addresses EV charging procedures in detail. See **Figure 3-29**.

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Figure 3-28. The Volkswagen Global Test Center EV charging station in Maricopa, Arizona.

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Figure 3-29. CCS Type 2 HV charging coupler that is commonly used to charge an EESS. This coupler is designed so both the plug and the socket are electrically neutral during coupling and uncoupling.

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Figure 3-30. A lockable charging coupler cabinet located on a commercial electric vehicle.

> **⚠ Caution**
>
> While the use of PPE is not required to couple most EVs to a charging station, each manufacturer has specific guidelines that must be observed during the process. For example, even though the EV chassis and the charging station electrical circuits are isolated during the process of physically coupling the two systems, it is recommended that there should be no standing water around the area that the technician occupies during the process, or moisture of any kind on the coupling units. After coupling, switching on the charge station initiates the process.

Charging Commercial Vehicles

Charging commercial vehicles is normally undertaken at high voltages because both time and the energy recharge rate are factors. In most cases, the vehicle coupling point is weather-protected by a boxed compartment with a lockable door, as shown in **Figure 3-30**. Transit bus and commercial fleets usually have HV charging banks with multiple charge units. **Figure 3-31** shows a single charge module used in a transit bus depot. Commercial vehicle charging stations are engineered by the electrical utility supplier because significant grid upgrades are required to supply a fleet of buses. Transit buses can also be charged using stationary overhead pantographs. Charging methods and charge station requirements and safety are covered in detail in *Chapter 11, Charging and Hydrogen Refueling.*

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Figure 3-31. A single module HV transit bus charging station. To avoid standing water around the charge dispenser, the station is elevated. Bus drivers must receive safety training prior to recharging their vehicle.

Summary

- BEV, HEV, PHEV, and FCEV chassis all use HV powertrains.
- According to OSHA, electrocution is death by electricity.
- The IEEE and OSHA state that any electrical pressure value greater than 50 volts can be hazardous to humans.
- Understanding HV electrical safety is critical for working on all types of EVs.
- Electrical energy is classified by the IEC using CAT numbers, ranging from CAT I (lowest) to CAT IV (highest).
- Uncontrolled electrical energy can cause injuries and fatalities that begin with minor shock, progress through loss of muscle control, and can result in ventricular fibrillation or brain damage.
- *Ventricular fibrillation* may result from an electric shock that causes the human heart to flutter erratically and can be lethal. A defibrillator such as an AED should be accessible in any service facility in which EVs are worked on.
- Arc flash is the release of electrical energy caused by an electrical fault releasing thermal and acoustical energy.
- Arc blast is a more severe event than arc flash: it produces explosion blast pressures of thousands of psi and sound levels that may exceed 140 decibels.
- *Distributed capacitance* is a condition caused by the presence of high potential electrical circuits in close proximity to one another that produce capacitance values between different points on a chassis.
- Technicians working on HV vehicle circuits should understand the potential dangers of distributed capacitance and always wear the appropriate PPE.
- Appropriate PPE for working in an HV work area includes wearing nonsynthetic clothing, orange omega-rated footwear, nonconductive safety glasses, and Class 0-rated gloves that are CAT III compliant.
- Appropriate LOTO devices for working on HV vehicle systems include ground cables, wheel chocks, steering wheel cover, ignition circuit "do not start" hasp, and technician-specific, personal lock, and battery disconnect switch lockout.
- An essential HV LOTO requirement is to open LV circuit, HV circuit, and chassis electrical isolation switches: these should be physically locked out if possible.
- Tools required for working in a vehicle HV environment should be insulated and rated at IEC CAT III or better.
- Preparations to work in an HV environment include hazard communication procedures, including posting HV placards, informing a supervisor or colleague of the work to be performed, and working with a colleague close by.
- When cleaning or welding close to HV circuits, the work area should be properly prepared and make yourself aware of the location of all of the HV components. When arc welding, place the welding ground clamp as close to the weld area as possible.
- Lithium-ion battery cells are commonly used in today's vehicle EESS. In order to produce operational voltages of 900 volts or greater, these cells must be arranged in a series to form packs, then strings.
- *Thermal runaway* is caused in a lithium-ion battery when cell heat rise exceeds the dissipation rate, resulting in a thermal incident.
- The various methods used to recharge EVs include plug-in, inductive (wireless), and pantographs.

Review Questions

Answer the following questions using the information provided in this chapter.

1. What is the upper *safe* limit of amperage that an average human body can sustain according to the NEC?
   A. 2 mA
   B. 5 mA
   C. 10 mA
   D. 50 mA
2. According to OSHA, when an individual is *electrocuted*, which of the following best describes that person's condition?
   A. The individual has been injured by an electric shock.
   B. The individual has received an electric shock.
   C. The individual is dead.
   D. All are correct.
3. Which of the following voltage values is considered by the IEEE and OSHA as the low threshold to be potentially harmful to humans?
   A. 12.6 volts
   B. 50 volts
   C. 110 volts
   D. 220 volts
4. Technician A says that a hydrogen fuel cell powertrain contains HV circuits. Technician B says that an automobile hybrid-electric powertrain contains HV circuits. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both A and B
   D. Neither A nor B
5. What CAT designation does a household vacuum cleaner fall under?
   A. CAT I
   B. CAT II
   C. CAT III
   D. CAT IV

6. When working on HV vehicle electrical systems, what minimum category of tooling and PPE protection gear should be used?
   A. CAT I
   B. CAT II
   C. CAT III
   D. CAT IV
7. Which of the following certifies that footwear is safe to work on HV vehicle electrical systems?
   A. A steel toe
   B. An orange omega symbol
   C. A green UL certification symbol
   D. All of the above
8. What is the reason for working one-handed and keeping one hand in a pocket behind your back when working on HV circuits?
   A. If one hand gets burned off, you'll still have one good hand.
   B. The back pocket of a pair of coveralls is a good ground point.
   C. The spare hand can be used to grab an iron safety rail in the event of an electric shock.
   D. If exposed to an HV shock, it minimizes the chance of the current passing through the heart.
9. Why should technicians always wear CAT III-certified PPE when working on HV vehicle systems even after the electrical circuits have been tested to be neutral?
   A. Lighting might strike the vehicle.
   B. It impresses supervisors.
   C. A thermal runway event could occur.
   D. For distributed capacitance protection.
10. Which of the following best defines *ventricular fibrillation*?
    A. A heart murmur
    B. The consequence of an electrical short circuit
    C. The result of an electrical shock that stops a heart from beating
    D. A medical tool designed to reactivate a heart that has stopped beating
11. The acronym AED stands for ______.
    A. alternating electrical current discharge
    B. automated external defibrillator
    C. accidental electrical discharge
    D. automatic eddy dissipation
12. For which of the following conditions is an AED used?
    A. Heart fibrillation
    B. Heart defibrillation
    C. Heart bypass surgery
    D. Energizing a dead battery cell
13. When a thermal runaway occurs in a li-ion battery, which of the following is the most likely cause?
    A. Manufacturing defect in a single cell
    B. Breakdown of the battery bank cooling system
    C. Exposure to external high temperatures
    D. Deficit of electrolyte in a cell
14. Technician A says that an *arc flash* event is relatively harmless because the electrical energy is released mainly as light. Technician B says that *arc blast* can be deadly because it releases enough heat energy to vaporize metals. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both A and B
    D. Neither A nor B
15. Which of the following is the minimum hand protection when working with HV circuits?
    A. Uncured cowhide welding gloves
    B. Corrosive-protected rubber gloves
    C. Class E-rated gloves
    D. Class 0-rated gloves
16. Which of the following specifications should be used when selecting a wrench to work on a vehicle HV electrical component?
    A. OSHA certified
    B. ASTM certified
    C. Insulated and UL certified
    D. Insulated and CAT III rated at 1000 volts
17. Technician A says that the fastest way of charging an EV automobile is by connecting to a household 120-volt supply. Technician B says that some current EVs can be recharged wirelessly. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both A and B
    D. Neither A nor B
18. Technician A says that some current EVs are capable of being inductively recharged. Technician B says that wireless charging is also known as inductive charging. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both A and B
    D. Neither A nor B

Critical Thinking

1. Consult the OSHA website and locate the potential fine of a first violation if an unqualified worker were to rewire or splice a 120 volt-ac electrical extension cord in the workplace. How much more could that fine be if it was a second offence?
2. Referencing the OSHA site, make a list of everyday electrical safety violations that could result in a fine, then (honestly) underline those you have broken in the past.