S.16 - Safety Aspects of Battery Electric Vehicle (BEV)

## **Preface**

The following Recommended Practice is subject to the Disclaimer at the front of TMC’s Recommended Maintenance Practices Manual. Users are urged to read the Disclaimer before considering adoption of any portion of this Recommended Practice.

## **Purpose and Scope**

This Recommended Practice provides a comprehensive template for service providers and fleets, equipping them with the necessary knowledge to safely handle battery electric vehicles (BEVs) during service events. It aims to identify and address potential safety concerns that may arise. By implementing this Recommended Practice before conducting any repairs on a BEV, it ensures the provision of safety education and assurance. The goal is to establish a systemized approach where safety remains a top priority throughout the entire service event.

## **Introduction**

Battery electric vehicles (BEV) are becoming more prevalent in our industry; thus, the need to understand safety aspects are paramount as this new technology continues to emerge. This Recommended Practice provides a systematic approach to understanding battery electric vehicle (BEV) safety and addresses what a service provider and fleet needs to know so everyone facilitating a repair will stay safe.

**Disclaimer:** This Recommended Practice serves as a valuable resource for service providers and fleets working on battery electric vehicles (BEVs). However, it is important to note that this Recommended Practice does not supersede any guidelines, policies, or instructions set forth by the respective company, manufacturer, or any other relevant authority. It is essential to adhere to the specific guidelines provided by your organization or the manufacturer when performing any service event on a BEV. This Recommended Practice is intended to complement and enhance existing guidelines, emphasizing the importance of safety throughout the service process.

## **Safety/Occupational Safety and Health Administration (OSHA)**

 To safely service high voltage vehicles each service facility / organization must:

• Understand and follow applicable Authority Having Jurisdiction (AHJ) control of hazardous energy standards and safety regulations

• Ensure employees are trained on types of energy, hazards, and methods to control hazardous energy

• Understand, create, and enforce control of hazardous energy / high-voltage vehicle service safety protocols

• Make appropriate safety equipment available to employees: high-voltage Person Protective Equipment (PPE), locks, lock boxes, sign-out sheets, etc.

## **Electrically Safe Work Condition Defined**

An electrically safe work condition is not a procedure; it is a state wherein all hazardous high-voltage electrical conductor(s) or circuit part(s), excluding inside the high-voltage battery pack, to which a technician might be exposed are disconnected or isolated from energized high-voltage parts, locked/tagged in accordance with Occupational Safety and Health Administration (OSHA) regulation 1920.147, tested to ensure the absence of voltage, and maintained in a deenergized state for the purpose of temporarily eliminating electrical hazards for the period of time for which the state is maintained.

Although the high-voltage systems of most Battery electric vehicles (BEVs) normally do not need to be disabled when performing routine non-high-voltage related maintenance, high-voltage systems must be de-energized and verified safe before high-voltage cables or components that are high-voltage related are disconnected or removed.

A safe work environment includes a readily accessible electric shock first aid station near the BEV service bay. This station should have unrestricted access and be equipped with a first aid kit, burn kit, AED Defibrillator, and an insulated retrieval hook. Consult your local vendor for the specific contents of the first aid and burn kits.

## **Awareness – Identifying the potential hazards**

Battery packs in battery electric vehicles (BEVs) can range in voltage from 100 volts and higher with larger trucks and busses exceeding 1200 V DC.

**Electrical Isolation and Handling Procedures of Battery (Modules, Bricks And/or Sections)**

Lithium-ion (Li-ion) batteries are high energy per unit mass dense arrays that contain flammable electrolytes and toxic substances like nickel, cobalt, lithium, and manganese, and if damaged, incorrectly charged, or overheated, can lead to toxic release, explosions, and fires. Lithium-ion batteries are dry cell batteries containing an electrolyte, considered corrosive, toxic, and flammable.

**Lithium-ion (Li-ion) Battery Characteristics:**

• High power-to-weight ratio.

• High energy efficiency.

• Higher temperature performance.

• Low self-discharge.

The Battery Management System (BMS) monitors the battery state-of-health, temperature, and cell voltages. Battery electric vehicles (BEVs) have integrated air--or liquid--cooling systems designed to keep the battery temperature low while the Battery electric vehicle is running or charging, preventing excessively high temperatures; some incorporate battery heating systems as well to keep the high-voltage battery within its optimum efficiency range. Most vehicles will have a Battery Management System (BMS) that should indicate temperature concerns. Optimum temperature efficiency range can vary based on battery manufacturer, please refer to manufacturer for battery specific ranges. A crash or an overcharging event can cause Battery electric vehicle batteries to ignite.

Depending on the high-voltage components, the external packaging of the battery pack and electrical system components may be constructed with tough, Ingress Protection (IP)-rated casings ranging from IP65 to IP68, which provide dust and water protection. The battery and components must be inspected to ensure that there are no cracks in the housings or defective seals which may allow water and dust to penetrate.

**Hazard Awareness:**

Working on or near high voltage energized electrical equipment or systems presents electrical hazards, such as shock and arc flash and blast. These high voltages are dangerous if proper safety precautions are NOT followed.

Potentially dangerous electrical currents can be produced or carried by any of these distinct types of high-voltage components:

1. High-voltage battery pack.

2. Battery Management System (BMS).

3. High-voltage battery charging equipment.

4. High-voltage cables, orange in color, connecting components.

5. Inverter power electronics.

6. Capacitors inside the vehicle’s inverter-rectifier assembly.

7. DC/DC converter.

8. Modules/electronic control unit(s).

9. Electric motor(s), also known as motor-generator(s) – (Regenerative braking).

10. Air conditioning compressor.

11. High-voltage heater(s).

Identifying vehicles with high-voltage systems is the first step to ensure the safest environment possible and reduce injury. Vehicles with high-voltage systems in some cases can be identified by:

* Vehicle badging and labels.
* Under hood high-voltage warning labels and cables.
* Batteries on roof or along frame rails (on trucks and busses).
* A charging port (on some, but not all, vehicles).

**Accident Risks:**

The vehicle has redundant systems that are designed to prevent shock and reduce fire hazard exposure to occupants and first responders. However, if the battery is compromised and internal components are punctured, crushed, or damaged, a safety risk could be created. The Lithium-ion (Li-ion) battery pack may contain stranded energy if there is stored energy in the battery or capacitors after an accident.

Stranded energy can release a dangerous level of high voltage, from 100 V DC or greater. Sizzling or popping noises, leaking, dripping fluids, a chemical smell, smoke, or sparks from the battery area are indicators of a shorting condition. Emergency responders should be notified.

Thermal runaway is an event described by National Fire Protection Association, NFPA, as an uncontrollable self-heating of a battery cell that begins when the heat generated within the battery exceeds the amount of heat that can be safely dissipated to ambient surroundings. In an accident, an overheated damaged cell may generate toxic and flammable gases that could reach a level high enough to ignite.

Lithium-ion (Li-ion) batteries can be very difficult to extinguish once they are on fire; the main goal of emergency personnel is to cool the battery by flooding the battery compartment with water.

It is imperative to ensure battery electric vehicles, that have been in an accident, are parked away from buildings, vehicles, and other structures. It is recommended to have an isolation area on the property to park known accident battery electric vehicles.

## **Personal Protective Equipment (PPE) and procedures**

This standard refers to general guidelines and procedures and are specific to battery electric vehicle (BEV).

Some battery electric vehicle (BEV) manufacturers may limit the required use of personal protective equipment (PPE) by a technician, instead relying on the integration of safety systems in the vehicle to ensure that high-voltage components are de-energized by using a scan tool or electronic means.

***Disclaimer: It is highly recommended that the technician SHALL refer to the employer’s or original equipment manufacturers (OEM) specific guidelines, procedures, and training when selecting the appropriate and recommended personal protective equipment.***

Personal protective equipment (PPE) is not all that is recommended to keep technicians safe. It is imperative that all technicians remove ALL conductive items from their person (watches, rings, chains, body piercings, metal hair accessories, etc.) prior to working on any battery electric vehicle (BEV).

Personal protective equipment does NOT eliminate risk or injury, it is designed and engineered to limit burn injuries to a second-degree level which is curable and characterized by blisters.

It is imperative that technicians are protected from burns due to an arc flash energy converting to heat and light energy.

Heat energy, measured in calories, is used to assess the effectiveness of personal protective equipment (PPE). The onset of second-degree burns may occur at 1.2 calories per centimeter squared per second (1.2/cm2 /s) on the “Stoll” curve, the relationship between heat energy transfer and time. One calorie is equal to holding the tip of one’s finger over a flame for one second.

***NOTE:*** *If an article of clothing is labeled as flame-resistant and not arc-resistant (AR rated), it does not mean that it is flame proof.*

**PPE Material – Arc flash flame-resistant**

Technicians working on or near the high-voltage battery of a battery electric vehicle (BEV) or energized high-voltage components of a battery electric vehicle, SHALL wear approved arc flash flame-resistant personal protection equipment (AR/FR PPE) clothing, made of natural fibers such as cotton, not polyester.

It is possible that a uniform manufacturer may incorporate a polyester blend in clothing which could prove dangerous if involved in an arcing incident. NOTE: High-voltage personal protective equipment (PPE) stamped with certification dates SHALL NOT be used if they have expired certifications.

**Electrical Insulating Gloves**

Class 0 Electrical Safety Gloves (Recommended) Electrically insulated rubber gloves (sometimes called lineman's gloves) SHALL be worn on both hands when working near ALL Battery electric vehicle (BEV) high-voltage components, when energized, and always when working with the vehicle’s high-voltage batteries.

Insulated gloves offer personal protection against electrical shocks when working on or near live conductors and SHALL comply with IEC 60903 (International Electrotechnical Commission) and American Society for Testing and Materials (ASTM) D120 standards.

Fully insulated gloves SHALL be stamped with a rating appropriate to the system voltage, have a red-colored label with a voltage range and have an expiration date indicating a laboratory test within the last 12 months per OSHA 1910.137.

The length is important because 12-inch rubber gloves have a rolled cuff, so the lower arm will be protected when testing using a meter.

Always store the gloves flat, in a protective bag with the open cuff down, and not rolled or folded.

**NOTE:** *Ordinary latex, nitrile, and neoprene gloves SHALL NOT be used as a substitute as they are not thick enough and do not provide sufficient protection from the shock hazard.*

**Testing Procedure:**

To make the testing easier, one person at the shop should oversee all rubber glove testing. Employers should stock two pairs of gloves, alternating them when one pair is received and ship the other pair back for testing. This will help to ensure the test has been done within the defined timeframe.

According to OSHA 1910.1376, Table I-5, rubber insulating gloves must be tested before first issue and every six months thereafter and, upon indication that insulating value is suspect, after repair, and after use without protectors. For insulating gloves, the standard clarifies that if the gloves have been electrically tested but not issued for service, they may not be placed into service unless they have been electrically tested within the previous 12 months. Under regular use, the best practice is to test gloves as frequently as monthly.

**NOTE:** *Refer to glove manufacturer’s information for use and re-certification requirements. Before each use, and whenever there is a reason to believe they may have been damaged, electrical insulating gloves SHALL be visually inspected for cuts, splits, cracks, ruptures, tears, pinholes, or damage and surface defects, and inflated to detect air leaks using a pneumatic glove pump or air tested using a rollup method, prior to and immediately after each use. If each glove holds air, the user is safe to continue using the glove. The technician SHALL NOT use shop compressed air to test gloves and SHALL NOT wear gloves that are damaged.*

**Approved Leather Over-Gloves**

The technician SHALL wear proper mechanically protective over-gloves meeting ASTM F696 and/or ASTM F3258 to protect the rubber insulating gloves against mechanical hazards, prevent damage, and protect against electrical arcing.

Over-gloves should be inspected for damage and contamination prior to and after each day’s use, and NOT be used if contaminated. Grease or metal shavings are conductive and could result in a hazard or fire when exposed to high voltage.

**Insulating Sleeves**

Insulating sleeves meeting ASTM D1051 MAY be used if work practices cannot prevent touching energized parts using gloves alone; refer to OSHA 1910.137 for additional information.

**Protective Footwear**

Technicians MAY wear shoes or boots that are rated per OSHA 1920.136 and ASTM 2413-117 for electrical hazard when working in proximity to an energized battery electric vehicle (BEV).

They must be kept dry to insulate the wearer from electric shock and rated appropriately for the proper kV and Hz of specific vehicles for 1 minute or provide continuous protection for up to 750 volts and be clean and free of oil or conductive debris such as metal shavings.

**Insulated Retrieval Hook** **(Shepards Hook)**

An insulated retrieval hook, also known as a “Shepards Hook” or “Rescue Hook” provides electrical insulation protection using a closed-cell, non-conductive, foam-filled tubular fiberglass pole, safeguarding individuals assisting others that may become disabled from electrical shock. When responding to emergency situations in or around a battery electric vehicle (BEV), while helping to withdraw injured workers out of a hazardous area, an insulated retrieval hook may be used. The shop MAY have an Insulated Retrieval Hook available for use in an emergency, OR individuals SHALL be professionally trained on how to separate a person from an active circuit in case of electrocution (using equipment such as an electrically insulated gloved assistant or a body tackle impact).

**Insulating Rubber Apron**

The technician MAY wear an approved electrical safety apron when appropriate, certified to ASTM F2677 standards.

**Safety Glasses or Goggles**

Technicians working on or around battery electric vehicles (BEVs) SHALL wear eye protection or safety glasses when exposed to electrical hazards or electrical arc, in compliance with OSHA 1910.133(a): “The employer shall ensure that each affected employee uses appropriate eye or face protection when exposed to eye or face hazards from flying particles, molten metal, liquid chemicals, acid or caustic liquids, chemical gases or vapors, or potentially injurious light radiation.” – OSHA 1910.133(a)(1), and “The employer shall ensure that each affected employee uses eye protection that provides side protection when there is a hazard from flying objects. Detachable side protectors (e.g., clip-on, or slide-on side shields) meeting the pertinent requirements of this section are acceptable.” – OSHA 1910.133(a)(2).

Polycarbonate lenses are stronger than glass and plastic lenses and can absorb a greater impact. Look for an ANSI Z87+ marking. OSHA 1910.133 requires ANSI Z87.1-2010 or newer standards be met. If these are worn throughout the day, look for anti-fog, anti-scratch, anti-static, and 99.9% UV protection coatings.

**Hearing Protection**

The technician MAY use appropriate hearing protection (ear canal inserts) when servicing energized components and high-voltage battery packs.

**Face Shields – Arc Class 2 (Recommended)**

The face shield provides forehead protection, has a full 180° field of vision, and is rated for arc thermal protection values. Shields are used for thermal isolation and are flame-resistant.

The face shield must have an arc thermal performance value (ATPV) rating of 9.9 calories/cm2 and is National Fire Protection Association (NFPA) 70E arc Class 2 and ANSI Z87 impact protection certified.

The technician SHALL wear a face shield to protect their eyes from any “flash over” or arc flash that can occur if electrical arcing is produced when working on energized components or battery electric vehicle (BEV) batteries.

Face shields should be cleaned and stored properly immediately after use.

**Rubber Insulating Matting** – **Class 0 mats (Recommended)**

Rubber insulating matting, or switchboard matting, MAY be used when working on energized high-voltage components, high-voltage batteries located in and/or outside the vehicle. These mats are non-conductive and designed to insulate technicians, protecting them from deadly shocks generated through high-voltage contact.

Class 0 mats are recommended for their properties, including but not limited to

* flame retardant
* oil/acid resistant
* tested to 5 kV for up to maximum working Voltage 1,000 Volts-AC.
* proven to have a high dielectric strength.

To provide a large margin of safety, the Class 0 mats are rated much higher than the recommended voltage exposure. These mats are true electrical safety mats that meet ASTM D178-01 or D1048 specifications and SHALL be certified by the International Electrotechnical Commission (IEC), IEC61111.

**Insulated Hand Tools**

The following requirements SHALL apply to insulated tools:

* Rated for the voltages on which they are used, both DC and AC.
* Designed and constructed for the environment to which they are exposed and for the intended way they are to be used. They are designed for use ONLY on high-voltage systems and should not be used in any other repair applications.
* Inspected prior to each use. The inspection SHALL look for damage that could limit the tool from performing its intended function or could increase the potential for an incident.
* Protected from damage to the insulating material.

When working on energized high-voltage components or high-voltage batteries of battery electric vehicles (BEVs), the tools and handling equipment required by the vehicle manufacturer SHALL be insulated and meet the Standard Specification for Insulated and Insulating Hand Tools, ASTM F1505-10, OSHA 1910.335(a)(2)(i)8, and IEC 61243-19.

 **Physical Barriers, Signage, and Boundary Guarding**

A defined combination of safety signs, cones, tape, tags, and a magnetic decal identifying whether the vehicle is energized or non-energized SHALL be used to warn individuals about electrical hazards that might endanger them and to mark off battery electric vehicle (BEV) service areas where necessary. Such signs and tags SHALL meet the requirements of applicable state, federal, or local codes and standards.

Barricades SHALL be used along with signs and tags to prevent or limit access to work areas containing live activated components operating at 30 V AC rms or 60 V DC or more and attendants shall be used when signs and barricades do not provide sufficient warning and protection from the electrical hazards.

Conductive barricades SHALL NOT be used where it might increase the likelihood of exposure to an electrical hazard.

As required by the vehicle manufacturer, the technician SHALL maintain a defined safety zone around the work area and place warning signs when high-voltage system repairs are left unattended.

**Shop Safety Alerting Techniques**

Traffic in the area can pose a substantial hazard. This includes foot traffic, as well as vehicles and other types of shop equipment. Barriers, barricades, signs, and an attendant may be needed to prevent intrusion into the work zone.

The technician(s) SHALL be responsible for safety and security when a Battery electric vehicle (BEV) enters the work area.

## **Addressing a Thermal Event**

Any time there is a vehicle fire, there are a lot of carcinogens that are released, battery electric vehicles are no exception, and have more carcinogens released and are harder to contain or extinguish.

It is imperative that respiratory protection is used by any individual near a thermal event.

It is best practice that when calling for emergency assistance to communicate the fire is from or near a battery electric vehicle (BEV).

It is recommended to remove the vehicle from the shop when, and only when, the ability to do easily and without extreme safety risk exist.

**NOTE:** *This does not supersede any guidelines, policies, or instructions set forth by the respective company, manufacturer, or any other relevant authority.*

The danger with lithium ion when it comes to fires is that at high temperatures, the battery breaks down into both oxygen, and combustible fuel, meaning it creates its own fuel and oxidizer.

As firefighters have discovered in recent years, lithium-ion battery fires are prone to reigniting. That is because the lithium salts in the battery are self-oxidizing, which means that they can't be "starved out" like a traditional fire.

Firefighters should apply water until conditions are dormant and no visible flame, gas or smoke is being released from the cell.

When attacking the vehicle fire, understanding that once the contents of the fire are extinguished, sustained suppression on the battery pack may be necessary. Use a large volume of water such as multiple 1 3/4-inch handlines to suppress and cool the fire and the battery. Put water on the burning surfaces.

The most common solution (at present) to effectively put out a battery electric vehicle (BEV) fire is to use lots of water to cool down the battery material and starve it of oxygen by smothering it from atmospheric air.

## **Pre-Service Inspection**

The below list recommends pre-service inspection areas to be completed at bare minimum prior to vehicle being pulled into shop for maintenance or repairs. Any vehicle that has questionable results should not be brought into a building to be worked on.

* Check and document current battery voltage.
* Inspect and document any damage to battery or electrical cables.
* Was the unit driven in or towed in?
* Are there any Battery Management System (BMS) alerts?
* Are battery temperatures within specifications?
* Has vehicle been flooded?

## **Training**

It is recommended to complete training from the Original Equipment Manufacturer (OEM) and/or obtain the xEV Safety Certification from the National Institute for Automotive Service Excellence’s (ASE). The ASE certifications currently available are:

1. xEV Industry Standards – Complete Document for Level 1 and 2
2. xEV Electrical Safety Awareness Certification – Level 1 Standards
3. xEV Technician Electrical Safety Certification – Level 2 Standards

It is recommended that all individuals that COULD come into contact or work around a battery electric vehicle obtain, at minimum, the ASE xEV Electrical Safety Awareness Certification. This is not limited to technicians only.

## **De-energizing the high voltage cables/ system**

*These procedures are generic; the technician SHALL refer to the original equipment manufacturers (OEM) recommended repair and de-energizing procedures before proceeding.*

**De-energizing Procedure**

1. De-energize the system.
2. Ensure the system cannot be reactivated.
3. Using a CAT III 600 V, CAT III 1000 V, or CAT IV 600 V digital multimeter (DMM), verify that no voltage is present at the contactors following the Absence of Voltage Verification Process described later.

 **Prior to Service or Repair:**

*This section will reference the ASE technician level that is recommended. This does not supersede any Original Equipment Manufacturer (OEM) training recommendations and requirements.*

Prior to working on or around high-voltage components, the properly trained person (ASE Level 2) SHALL disable the high-voltage electrical system following the original equipment manufacturers (OEM) recommended procedures for disconnecting (de-energizing) the high-voltage battery pack.

The technician SHALL not work alone.

The technician SHALL remove all jewelry, watches, belt buckles or conductive items, as well as anything metallic that can fall out of any pocket and wear appropriate personal protective equipment (PPE). Reference section 4 for in-depth PPE information)

The vehicle SHALL be secured according to the original equipment manufacturers (OEM) instructions. For example: in park, wheels chocked, parking brake applied, and the vehicle system(s) de-energized/disabled.

The keyless fob, if equipped, SHALL be secured outside of key detection range by placing the key fob and/or high-voltage battery disconnects in a secured container.

The technician SHALL NOT touch the conductor terminals, or a damaged conductor, until the deenergizing procedure is completed, and the confirmation test proves that high voltage is no longer present in the conductors.

**Safety Steps Prior to Making Contact**

To safely de-energize high-voltage circuits, the properly trained person (ASE level 2) SHALL:

* Always work on de-energized circuits.
* Ensure that the work environment around the vehicle is safe, clean, dry, and has adequate lighting.
* Remove any jewelry, watches, belt buckles or conductive items, as well as anything metallic that can fall out of any pocket.
* Not work alone.
* Secure the work environment to keep non-trained people away from the area.
* Never leave a battery electric vehicle (BEV) system unattended without the proper signage and barricades.
* Understand the original vehicle manufacturers (OEM) approved high-voltage system de-energizing procedures for the specific vehicle that is being serviced.
* Inspect all required personal protective equipment (PPE) and tools.
* Wear appropriate personal protective equipment.
* Use a digital multimeter (DMM) rated above the working voltage to at least CAT III 600 V, CAT III 1000 V, or CAT IV 600 V.
* Select test leads and accessories that are CAT-rated to match or exceed the CAT rating of the test tool they are using with at least one insulated alligator clip for the COM connection.

***NOTE:*** *One electrical lead equipped with an insulated alligator clip allows the technician to use one hand for the measurement. Connect the lead with the alligator clip to one of the circuit’s terminals or ground, then place the other lead in contact with another terminal to make the reading. No more than one hand should be holding a lead or touching vehicle ground at any time.*

**Absence of Voltage Verification Process**

After all required safety precautions have been carried out, original equipment manufacturers (OEM) service information may direct the technician to take a voltage reading with an appropriate meter to verify that all sources of high voltage have been isolated or discharged, sometimes referred to as a live-dead-live (LDL) test.

The technician SHALL wear appropriate personal protective equipment (PPE) during the “absence of voltage” test.

The technician SHALL follow the original equipment manufacturer (OEM) recommended procedure to verify absence of voltage prior to any work being performed.

If service work requires exposure or disconnecting of high-voltage (cables, the technician will need to verify that no voltage is present by taking a reading between high-voltage cable ends as well as between each high-voltage cable end and vehicle ground.

Example – Absence of Voltage Verification Process (LDL test):

1. Identify and find the terminal locations, referenced in the original equipment manufacturers (OEM) recommended procedures/ service information as the high voltage test locations.
2. Inspect the multimeter and test leads to ensure operational readiness.
3. Rotate the function select switch to the DC measurement function.
4. Wearing the correct personal protective equipment (PPE), measure a known fixed voltage, low voltage 12- or 24-volt battery or a proving unit if available, to verify that the meter is reading correctly. A proving unit is a portable, pocket-sized, battery-powered voltage source.
5. Confirm there is no high voltage remaining at the terminal locations, referenced in the manufacturer’s recommended procedures/service information as the high voltage test locations. This measurement should read zero volts.
6. As a last step, verify the operational readiness using the known fixed voltage source or proving unit to verify the meter is still reading correctly. Only at this point can personal protective equipment be removed.

NOTE: If the vehicle has been de-energized correctly, and if no faults are present in its electrical system:

• No current will be produced by its motor-generators, as they will not be mechanically turning and will have no access to external current sources, except in the case of permanent magnet motors which transfer mechanical energy into electrical energy without an external current source.

• No current will be available at its capacitors, which will have been discharged during the prescribed time interval.

• No current will be present in the vehicle’s high-voltage cables, BUT the vehicle’s high-voltage battery WILL remain charged, and is thus a potential current source, although it will be isolated from the rest of the system.

**High-Voltage Interlock (HVIL)**

One or more interlock circuits may be integrated into some of the high-voltage components of many electrified vehicles. An interlock circuit is configured as a series circuit with multiple connectors or switches connected to a low-voltage (5V or 12V) power source.

When all connectors are fully seated, and all switches are closed, there will be current through all components in the interlock circuit. This current results in a specific voltage drop across computer monitoring circuits. If any connector in the interlock circuit is removed, the interlock circuit opens. An open interlock circuit causes a different voltage drop across the computer monitoring circuit.

When an open interlock circuit is detected, the high-voltage contactors in the battery housing are immediately commanded open. An active discharge of the high-voltage bus is also commanded and will complete in less than one second.

If the high-voltage system is successfully de-energized utilizing the procedures in the service information, the interlock circuits will never be needed. The interlock circuits provide an additional layer of high-voltage safety for those not following the procedures outlined in the service information.

**Lockout/Tagout (LOTO)**

Lockout/tagout procedures exist to protect technicians from potentially fatal electric shock. The technician should not risk someone re-energizing their work environment.

The technician SHALL maintain control of any removed fuses, relays, or manual service disconnect (MSD) in a secured location under lock and key (if possible) to prevent others from reinstalling these items without their knowledge.

The properly trained person (ASE Level 2) SHALL de-energize the high-voltage circuit whenever possible and verify it is de-energized before starting work. If an advanced trained person (ASE Level 3) technician must work on a potentially energized circuit, a job hazard analysis SHALL be completed, and the appropriate personal protective equipment (PPE) SHALL be utilized.

Lockout is used in uncontrolled environments.

Tag outs are used in controlled environments with an established group policy for the treatment and use of the tagout.

**One-Hand Rule**

When working with live circuits, only a single hand should be touching a lead, the vehicle, or the ground at any time. This prevents the technician from contacting a circuit and sending electricity through their body if isolation is lost.

**Do Not Work Alone**

The properly trained person (ASE level 2 and/or Level 3) SHALL never work on a high-voltage vehicle without first notifying someone who is trained in dealing with high-voltage safety procedures.

**Do NOT Back-Probe High-Voltage Connectors**

The technician SHALL NOT back-probe high-voltage connectors as this will introduce a path for moisture intrusion.

Do not use any sprays, including cleaning sprays, around high-voltage circuits, as this may energize the ionized air surrounding the circuit, making it conductive. Remember that a 400 V DC circuit has a far greater capacity to produce an electrical arc than a 12 V DC circuit. Although the internal AC voltages in some inverters are much higher, the voltage outside the inverter never exceeds high-voltage battery voltage.

Use electrical tape to insulate any exposed high-voltage terminals that have been disconnected.

**Plan and Document the Work**

Measurements of potentially live high-voltage, high-current circuits require planning and focus.

* Until an “absence of voltage” test is performed, always assume that the circuit is live, even if the system has been properly de-energized and is free of faults.
* Prepare the environment, brief others, and have an action plan for all contingencies.

**Example – Finalize the Work**

Any high-voltage connection that is secured with a threaded bolt or nut must be torqued to the original equipment manufacturer (OEM) specification, and not over-torqued. The quality and cleanliness of the electrical connection and its resistance to corrosion depends on proper torque.

Ensure that a part or a tool has not been left in the repaired area.

If the vehicle’s high-voltage system has a removable manual service disconnect (MSD), it must be seated firmly and correctly when re-installed.

The low-voltage battery should not be re-connected until the vehicle’s high-voltage manual service disconnect or switch has been returned to its original position and any removed access covers have been reinstalled.

Once the vehicle has been reassembled and the low-voltage battery connected, the vehicle should be powered on and checked for codes and/or READY status. Some Battery electric vehicle (BEV) systems will set codes whenever the system has been disturbed or shut down, so codes may need to be cleared. All electrical systems (such as power windows) that utilize memory need to be initialized and retrained.