GM GENUINE PARTS | ACDelco

SAP0201SM

HYBRID & ELECTRIC VEHICLE OPERATION, DIAGNOSIS, AND REPAIR

Table of Contents

COURSE INTRODUCTION 1-5

INTRODUCTION TO HEVS AND BEVS 2-1

PROPULSION TYPES 3-1

- Conventional Powertrain 3-1
- Battery Electric Vehicle Powertrain 3-1
- Hybrid Electric Vehicle Powertrain 3-2
- Plug-In Hybrid Electric Vehicle Powertrain 3-3

DRIVE SYSTEMS 4-1

- Series Drive Systems 4-1
- Parallel Drive Systems 4-1
- Series-Parallel Drive Systems 4-2
- Battery Electric Vehicle Drive Systems 4-3

HYBRID LEVELS 5-1

- Mild Hybrids 5-1
- Full Hybrids 5-6

HYBRID DRIVE MODES 6-1

- Initial Start-Up 6-1
- Auto-Stop 6-2
- Acceleration 6-2
- Cruising Speed 6-2
- Deceleration 6-3
- Regenerative Braking 6-3

HEV / BEV ELECTRICAL CIRCUITS 7-1

- Direct Current (DC) 7-1

Alternating Current (AC) 7-1
Low Voltage Circuits 7-2
SAFETY 8-1
Workplace Safety 8-1
Personal Protective Equipment (PPE) 8-2
Digital Multimeters 8-6
HIGH VOLTAGE DISABLING / ENABLING 9-1
Manual Service Disconnect 9-1
Scan Tool High Voltage Disabling 9-3
Manual High Voltage Disabling 9-5
High Voltage Enabling 9-6
SYSTEMS AND COMPONENTS 10-1
High Voltage Batteries 10-1
Motor / Generators (MG) 10-16
Power Electronics 10-27
HV Cables, Contactors, and Interlocks 10-32
Plug-In Charging 10-46
Air Conditioning Compressor 10-66
HVAC Service 10-67
Auxiliary Transmission Fluid Pump 10-68
Brakes 10-68
Ignition Operating Modes 10-68
RANGE 11-1
Range Factors 11-2
Diagnosing Range Concerns 11-4
POST COLLISION INSPECTION 12-1
ADDITIONAL RESOURCES 13-1
ACRONYMS 14-1

COURSE INTRODUCTION

COURSE DESCRIPTION

This Instructor-led training seminar provides an overview of hybrid and electric vehicle designs, operation, and servicing. Diagnosing and servicing Hybrid Electric Vehicles (HEV) and Battery Electric Vehicles (BEV) requires an in-depth understanding of their design and operation. This course covers the operation of HEV and BEV propulsion systems, driveline configurations, high voltage batteries, drive motors / generators, and charging systems. The course also covers HEV and BEV servicing procedures including high voltage safety, high voltage disabling / enabling, loss of isolation diagnosis, and range related conditions.

COURSE OBJECTIVES

Upon completion of this course, you will be able to demonstrate an understanding of the following key points:

- Hybrid and Battery Electric Vehicle configurations, components, and operation
- Diagnosing and servicing Hybrid and Battery Electric Vehicles
- Operation and features of high voltage battery charging
- Drive motor and generator operation

CAUTION STATEMENT

To reduce the chance of personal injury and/or property damage, carefully observe the instructions that follow.

The materials presented in this course are for training purposes only. They are not intended to replace established service procedures or information provided by vehicle Original Equipment Manufacturers (OEMs). You are responsible to ensure compliance with any such procedures or information.

This training program is intended for use by professional, qualified technicians. Attempting repairs or service without the appropriate training, tools, and equipment could cause injury to you or others. This could also damage the vehicle or cause the vehicle to operate improperly. Proper vehicle service and repair are important to the safety of the service technician and to the safe, reliable operation of all motor vehicles. If you need to replace a part, use the same part number or an equivalent part. Do not use a replacement part of lesser quality.

Some of the service procedures described in this training require the use of tools that are designed for specific purposes. Accordingly, any person who intends to use a replacement part, a service procedure, or a tool that is not recommended by the OEM or ACDelco, must first establish that there is no jeopardy to personal safety or the safe operation of the vehicle.

ACDelco shall not be responsible for any damages, in whole or in part, from your use of this training material.

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ACDELCO MISSION STATEMENT

ACDelco's mission is to ensure aftermarket service professionals have the skills necessary to safely and effectively diagnose and repair customer vehicles utilizing engaging education methods within an industry-leading training portfolio.

INTRODUCTION TO HEVS AND BEVS

Vehicle propulsion technology is changing at a rapid pace and the future is electric. All major automobile manufacturers currently offer a Hybrid Electric Vehicle (HEV) and/or Battery Electric Vehicle (BEV) in their portfolio. The number of vehicles that will be powered by a hybrid or electric powertrain will increase dramatically in the coming years. Understanding how these vehicles operate, and the unique service requirements that come along with them, is critical to servicing these vehicles correctly.

Figure 2-1, Chevrolet Bolt EV

NOTES

PROPULSION TYPES

There are two major electric vehicle driveline categories: HEVs and BEVs. Each have their own characteristics and differ significantly from a conventional powertrain configuration.

CONVENTIONAL POWERTRAIN

Vehicle movement is accomplished by rotating the vehicle drive wheels. On a conventional vehicle, the torque needed to rotate the drive wheels is generated by an Internal Combustion Engine (ICE). The ICE uses a fuel source such as gasoline or diesel fuel to generate the energy used to rotate the engine's crankshaft. Motion from the rotating crankshaft is then transferred through the transmission and driveline components to the drive wheels. The use of fossil fuels like gasoline and diesel result in an environmental impact that HEVs and BEVs help to reduce or eliminate.

Figure 3-1, Conventional Powertrain

BATTERY ELECTRIC VEHICLE POWERTRAIN

A BEV uses electrical energy stored in an onboard battery pack as its power source. Electrical energy from the battery is used by the vehicle's Motor / Generator (MG) to create the rotational motion and torque needed to propel the vehicle. These vehicles produce no tailpipe emissions. However, a BEV's range is limited to the battery's state of charge and capacity, amongst other external factors. Once the battery's energy is depleted, it must be recharged by connecting the vehicle to the municipal electrical grid.

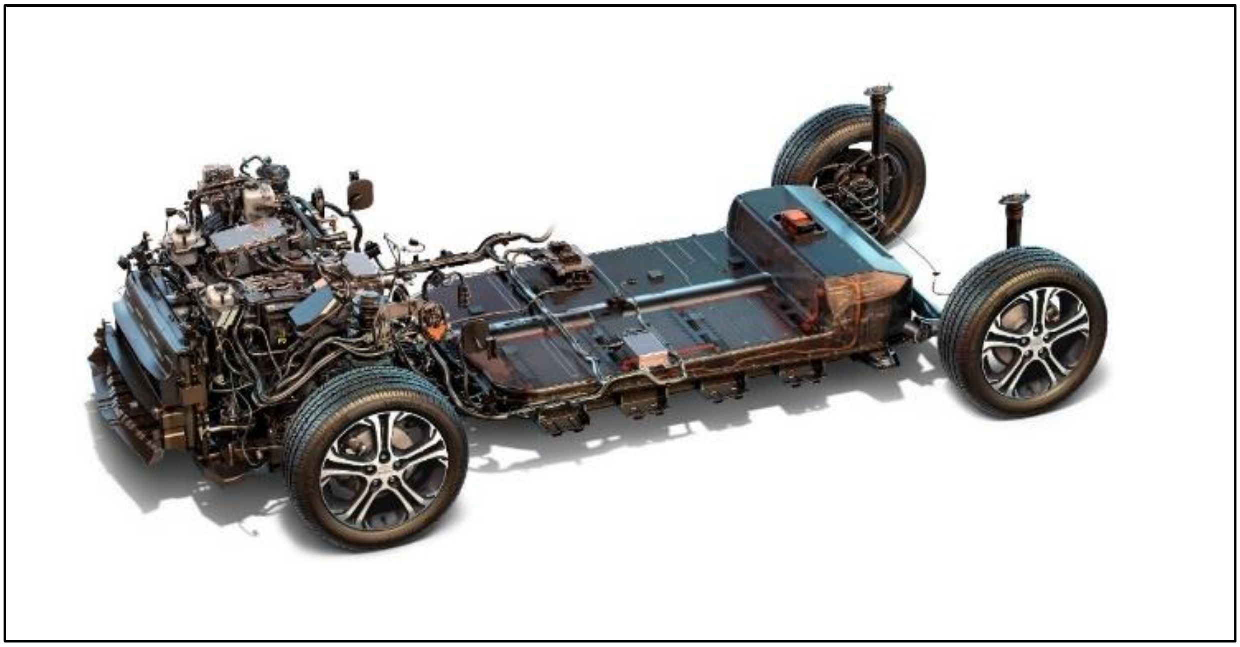


Figure 3-2, Battery Electric Vehicle Powertrain

HYBRID ELECTRIC VEHICLE POWERTRAIN

Unlike a conventional powertrain or a BEV, the power needed to propel a HEV comes from two different sources: an ICE and an electric MG. There are several different classifications and configurations of HEVs. Some HEVs can drive short distances on electrical power alone, while some only assist the ICE. All HEVs share the common goal of improving fuel economy over a conventional powertrain. Fuel savings are achieved by using electrical energy to supplement the fuel consumed by the ICE. Most of the torque delivered by the MGs occurs at launch or during hard acceleration when additional torque is needed, and ICE fuel economy is at its lowest. In addition to propulsion, HEVs use the ICE as an onboard generator to recharge the High Voltage (HV) battery.

Figure 3-3, Hybrid Electric Vehicle Powertrain

PLUG-IN HYBRID ELECTRIC VEHICLE POWERTRAIN

Plug-In Hybrid Electric Vehicles (PHEVs) operate just like HEVs. PHEVs incorporate an onboard generator to recharge the high voltage battery but also have the ability to charge the battery using external charging equipment like a BEV. PHEVs have a larger battery than a typical HEV which allows them to travel further using only electricity. Recharging the battery from the grid rather than the vehicle's ICE, can further improve fuel economy, reduce emissions, and lower operating cost.

PHEV examples include:

- 2018 - 2019 Cadillac CT6
- 2011 - 2019 Chevrolet Volt
- 2017 - 2021 Chrysler Pacifica
- 2016 - 2021 Hyundai Ioniq are examples of PHEVs

Figure 3-4, Chevrolet Volt, Plug-In Hybrid Electric Vehicle

PHEVs typically have an electric only range of 20-50 miles. It is important to note that the ICE may not run until the HV battery state of charge is low. If the vehicle owner regularly charges the HV battery from the grid and does not drive the vehicle long enough between charges, the ICE may not run at all. This can lead the driver to believe there is a fault with the ICE.

Long periods of time with no ICE operation can also lead to poor ICE lubrication and stale fuel. Some vehicles will intermittently start and run the ICE to maintain proper engine lubrication or to burn off stale fuel. A maintenance message will be displayed on the vehicle information center alerting the driver of the need to run the ICE.

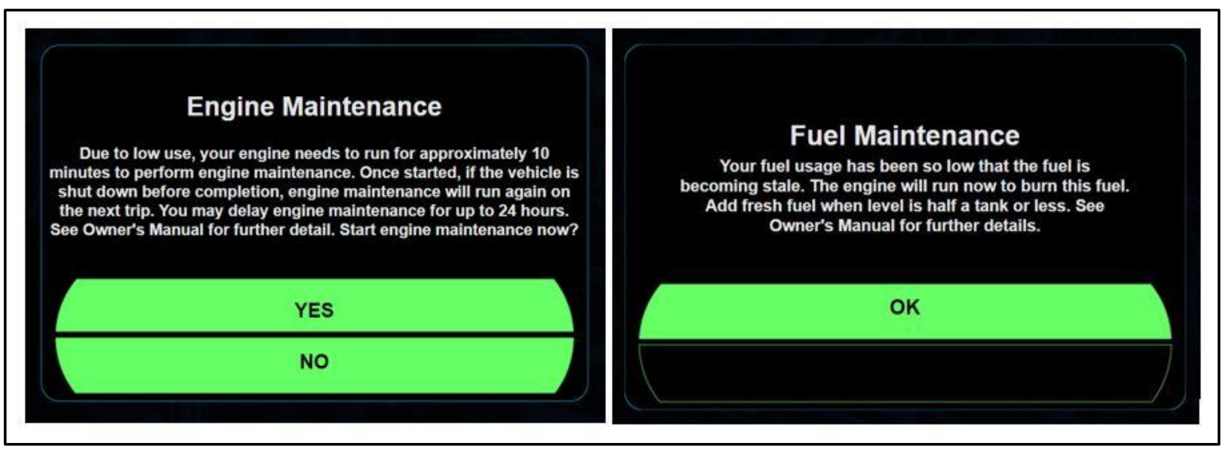


Figure 3-5, Maintenance Mode Displays

DRIVE SYSTEMS

The drive system describes how propulsion and high voltage battery recharging is accomplished. On HEVs, the ICE and the MGs must work together to achieve this. BEVs do not utilize an ICE. There are four common HEV drive systems: Series, Parallel, Series-Parallel, and Battery Electric.

SERIES DRIVE SYSTEMS

In a series drive system, all propulsion torque is provided by the electric MGs. There is no physical connection that will transfer mechanical torque from the ICE to the drive wheels. The ICE only powers a generator used to charge the HV battery. On vehicles with two MGs, the ICE may also act as a generator and provide electrical energy directly to the drive motor to propel the vehicle. Because only the electric MG provides propulsion, these vehicles are often looked at as BEVs with an onboard generator and may also be referred to as an Extended Range Electric Vehicle (EREV). The 2011-2019 Chevrolet Volt and 2013 - present BMW i3 (with range extender) are examples of this type of HEV.

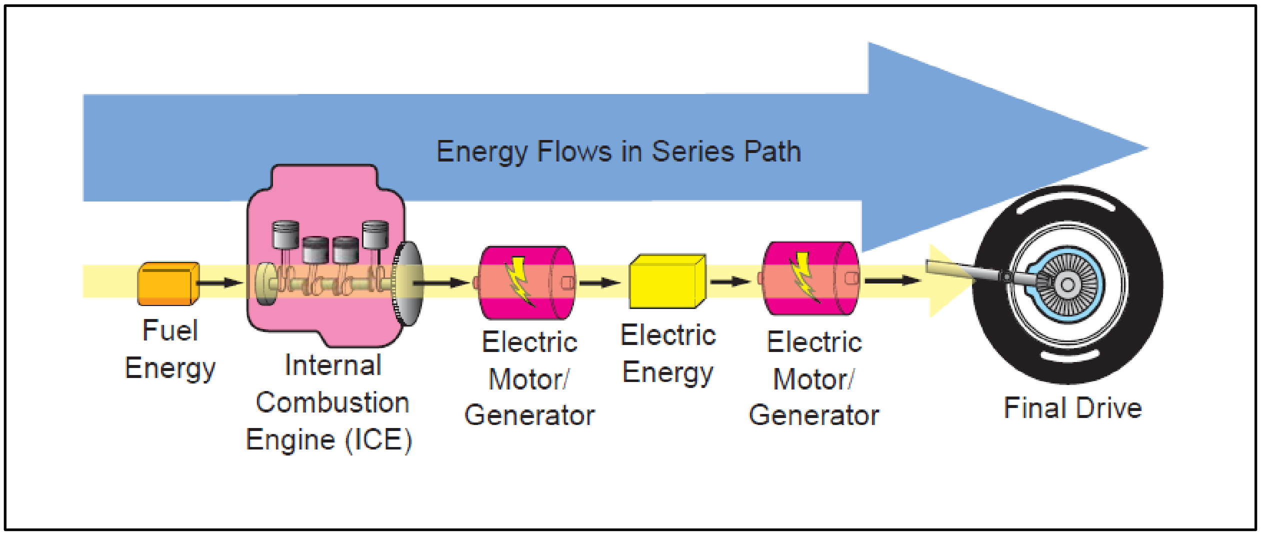


Figure 4-1, Series Drive System

PARALLEL DRIVE SYSTEMS

Parallel hybrid drive systems combine the output torque from two different power sources, the ICE and the MG, to propel the vehicle. The ICE is typically the primary source of power. The MG is used to assist the ICE in producing the required torque. This allows for a smaller ICE to be installed in the vehicle which improves fuel economy and reduces tailpipe emissions. The location of the MG in a parallel system can vary from vehicle to vehicle. On most vehicles, the MG is mounted to the front of the engine and assists in turning the ICE's crankshaft by means of an external drive belt. On some vehicles the MG is located between the ICE and the transmission.

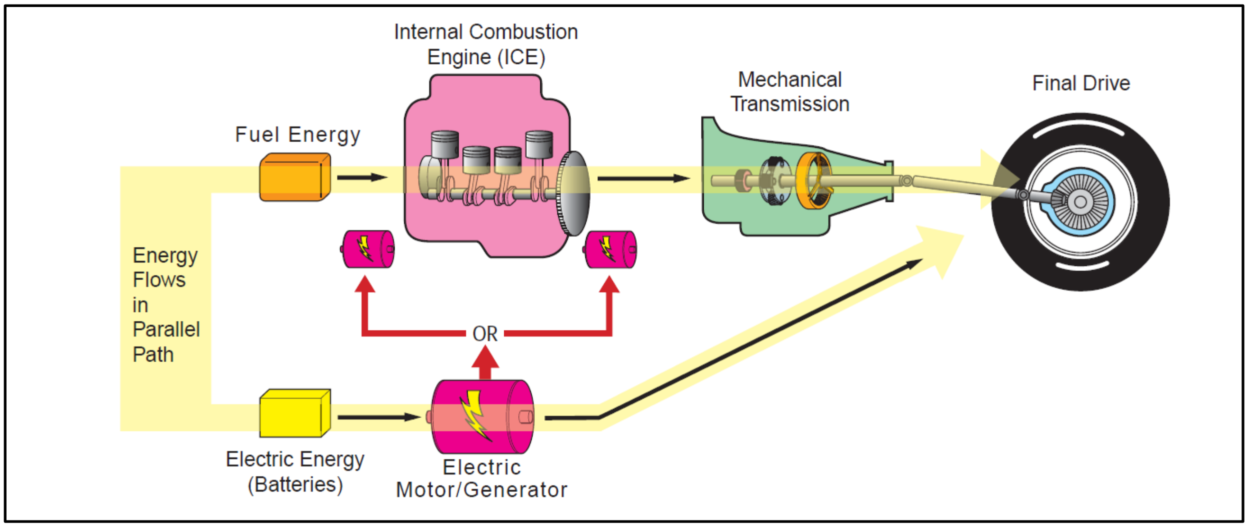


Figure 4-2, Parallel Drive System

SERIES-PARALLEL DRIVE SYSTEMS

The series-parallel drive system, also known as a powersplit drive system, combines characteristics of series drive systems and parallel drive systems. Depending on vehicle demand, a series-parallel system can use the MG or the ICE to propel the vehicle. The MG is also used to charge the battery and provide torque to assistance the ICE. To accomplish this, series-parallel systems have two MGs. Depending on driving conditions and vehicle demands, either or both MGs may be used as a generator to recharge the high voltage battery or as a motor to provide, or assist with, propulsion.

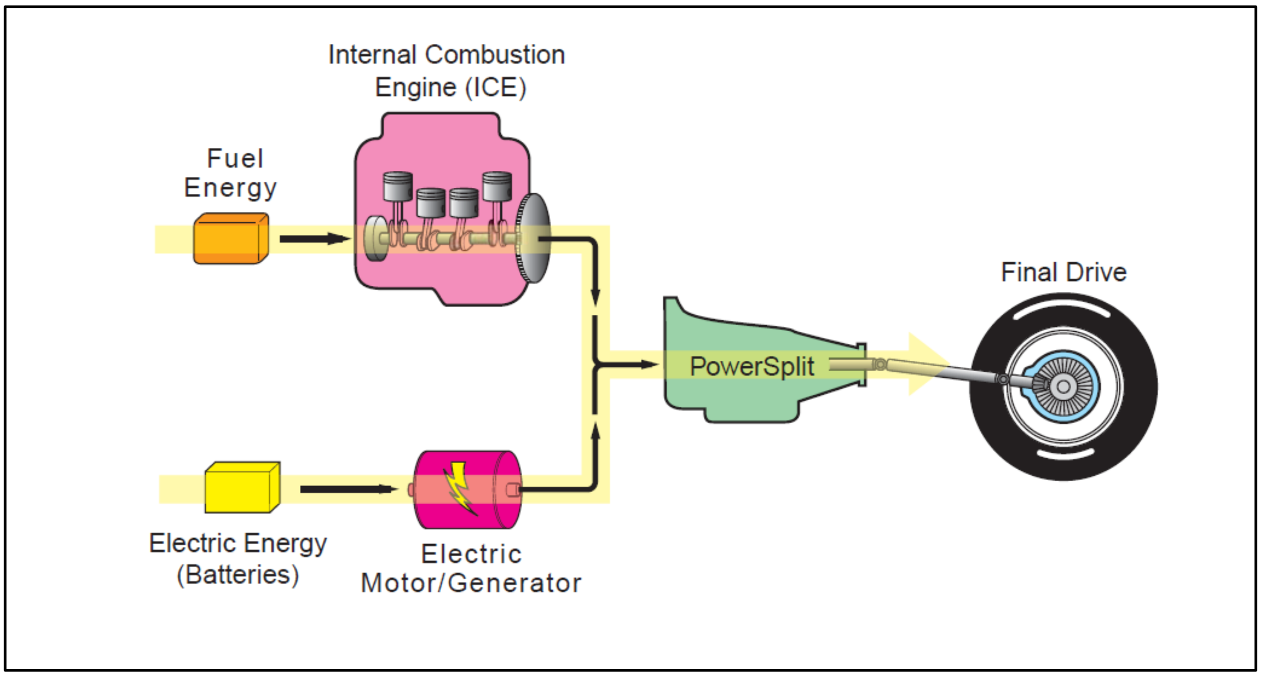


Figure 4-3, Series-Parallel Drive System

BATTERY ELECTRIC VEHICLE DRIVE SYSTEMS

BEVs do not utilize an ICE. All energy used to propel a BEV comes from the electrical energy stored in the high voltage battery pack. The onboard electronics transfer electrical current from the battery to the MGs which propel the vehicle. Because there is no onboard ICE to act as a generator, BEV batteries must be recharged by connecting (plugging) them to the electrical grid.

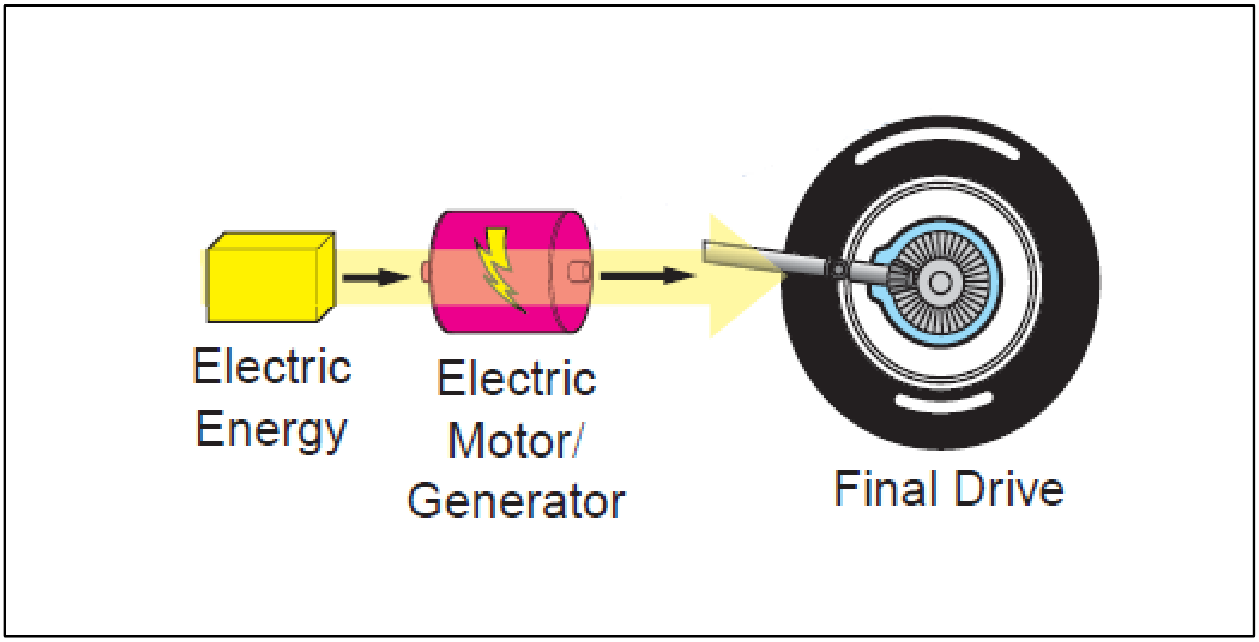


Figure 4-4, Battery Electric Vehicle Drive System

NOTES

HYBRID LEVELS

In addition to the vehicle drive system, HEVs can be further classified by the level of assistance the hybrid system provides. The two most common hybrid levels are:

- Mild hybrid
- Full hybrid

MILD HYBRIDS

Mild hybrids do not use the MG to provide direct propulsion. Instead, mild hybrids use the MG to assist the ICE by providing additional torque when needed. In this way, the electric motor can be thought of as working similarly to how a turbocharger boosts engine output on a conventional engine. Additionally, mild hybrids include a start / stop feature that allows the ICE to turn OFF when the vehicle comes to a stop. The high voltage electric motor is then used to quickly restart the ICE at takeoff. Furthermore, the MG can be used as a generator to recharge the high voltage battery and to supply current to the low voltage battery and vehicle electrical system.

The MG on most mild hybrids is mounted to the front of the engine and uses a special belt drive system to assist the ICE. On other vehicles, such as the Honda Insight and Civic Hybrid, the MG is located between the ICE and the transmission.

Belted Mild Hybrid Systems

Most mild hybrid vehicles use an MG mounted to the front of the ICE which takes the place of a conventional alternator. Current from the high voltage battery is routed to the MG at takeoff and whenever additional engine power is needed. During coast down, braking, and certain cruise speeds, the MG acts as a generator to recharge the high voltage battery. Belted hybrid systems utilize a unique belt drive and tensioner system that allows the belt to be driven in either direction and to withstand the additional load created by the MG unit. The heavy-duty belt and tensioner deliver torque from the MG to the ICE when the MG is acting as and motor. When the MG is operating as a generator, the belt and tensioner system transfer torque from the ICE to the MG.

The belted hybrid drive system consists of the following components:

- Motor / Generator unit
- Wide, reinforced drive belt
- Heavy duty idler pulley and tensioner bearings
- Linear, hydraulic belt tensioner
- Spring tensioner
- Pivoting bracket and pulley(s)

Examples of belted mild hybrids include:

- 2007 – 2013 Saturn Vue and Aura

- 2008 – 2012 Chevrolet Malibu
- 2012-2014 and 2018 Buick LaCrosse
- 2013-2014 Chevrolet Malibu
- 2014 Chevrolet Impala
- 2012-2014 Buick Regal
- 2016-2018 Chevrolet Silverado and GMC Sierra
- 2019-2020 RAM 1500 eTorque
- 2019-2021 Jeep Wrangler eTorque

Figure 5-1, Belted Hybrid Drive

Belt tension for the belted hybrid drive system uses two tensioners: a linear tensioner, also known as a hydraulic tensioner, and a spring tensioner. The two belt tensioners provide proper belt tension in both directions of movement. When the MG is being driven as a generator, the belt is tight against the spring tensioner, and the linear tensioner extends to remove any slack from the belt. When the MG is acting as a motor and driving the ICE, the belt is tight against the linear tensioner and the spring tensioner removes any slack from the belt.

Servicing Belted Hybrid Drive

Due to the high load requirements of the MG drive belt, servicing a belted hybrid drive system requires special repair procedures. Refer to service information for procedures specific to the vehicle being serviced. In general, drive belt replacement involves the following steps:

1. Remove any accessory drive belts needed to access the MG drive belt.

2. Compress the spring tensioner using a breaker bar to turn the tensioner assembly counterclockwise until the holes in the assembly line up and allow a punch to be inserted.

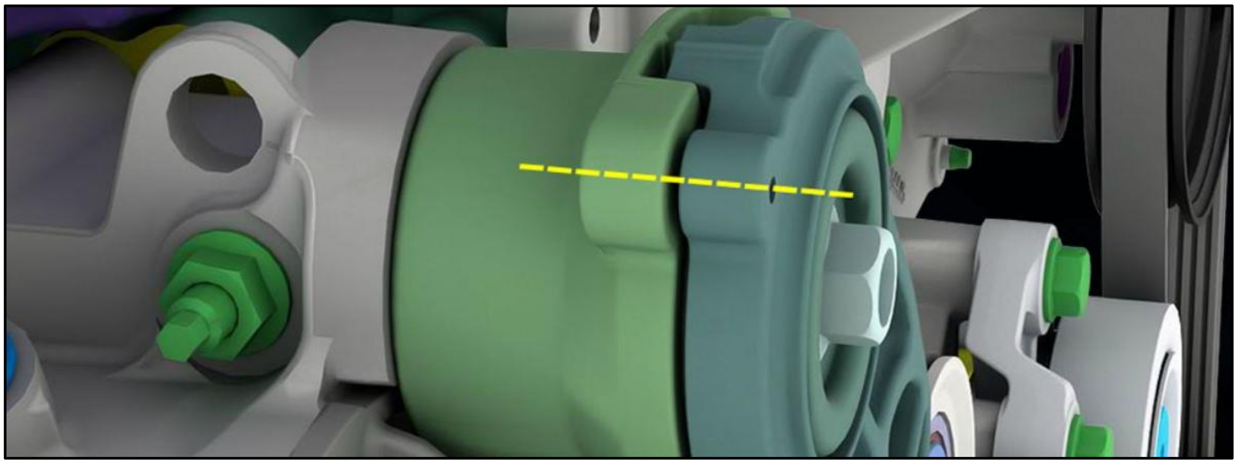


Figure 5-2, Spring Tensioner Compressed

3. Slowly compress the linear tensioner using a special spring compressor. Once the tension has been removed, the belt may be removed from the pulleys.

Figure 5-3, Linear Spring Tensioner Compressor

4. Replace the drive belt.

5. Install the new drive belt and slowly release tension on the spring compressor.

When replacing the linear tensioner, note that the new linear tensioner may have a metal retaining sleeve over the spring. Remove this sleeve after the installation of the linear tensioner and the drive belt. Before installation, ensure that the bolts are in good condition and are free of foreign substances. Always torque the bolts according to specification. After installing the belt, use the tensioner spring compressor to compress the tensioner slightly, and remove the metal sleeve to allow the tensioner to operate properly.

CAUTION: Failure to remove the sleeve will result in damage to the belt and improper operation of the system.

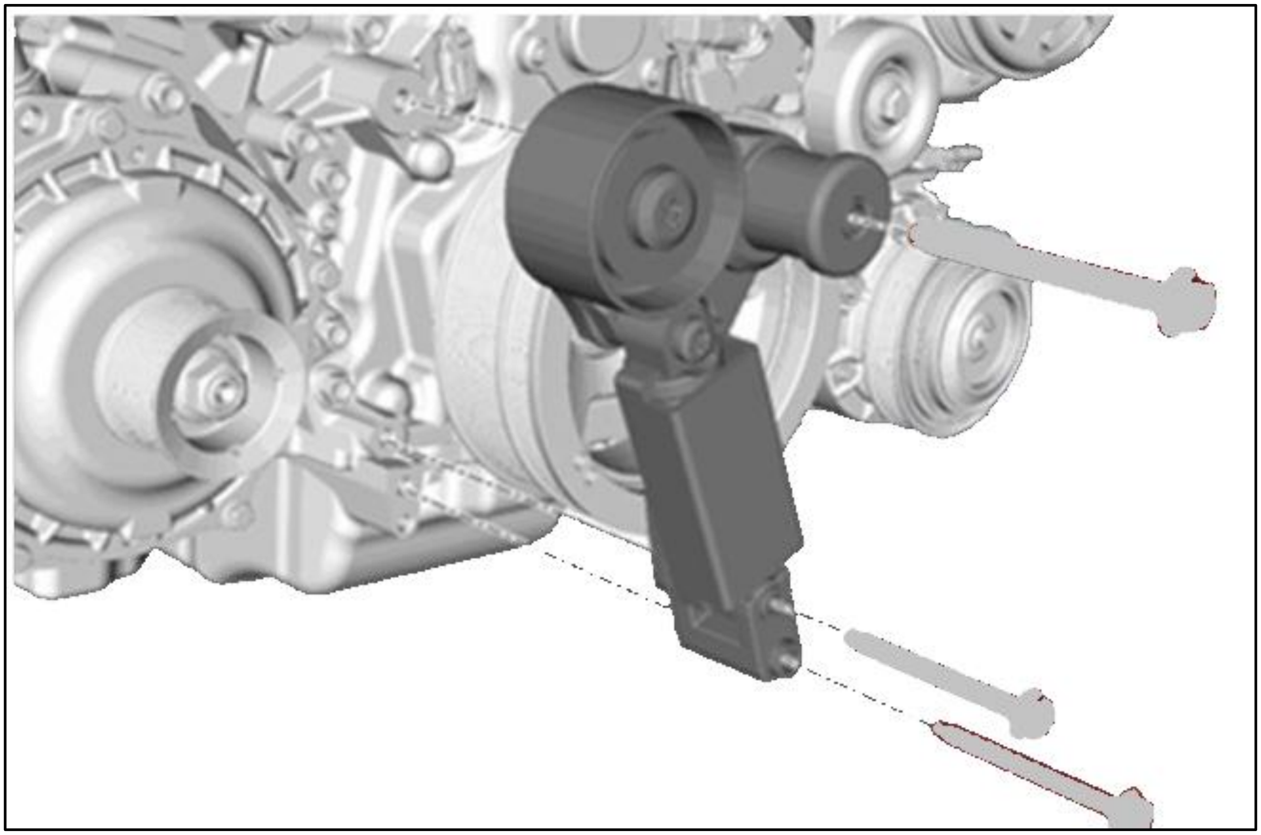


Figure 5-4, Linear Spring Tensioner with Sleeve

Integrated Motor Assist

Integrated Motor Assist (IMA) systems utilizes an MG mounted between the engine and transmission. The MG's rotor is connected directly to the engine's crankshaft. Whenever the ICE is running, the rotor within the MG is rotating. Like all mild hybrids, the MG can assist the ICE but cannot propel the vehicle on its own.

Figure 5-5, Honda IMA Assembly

CAUTION: If the ICE, transmission, or IMA motor needs to be removed, a special tool (Honda TN 07YAC-PHM010B) is needed to remove the rotor. The IMA uses permanent magnets which could cause the rotor to be suddenly pulled into the IMA stator during removal if the correct tool is not used.

Figure 5-6, Honda TN 07YAC-PHM010B

FULL HYBRIDS

Like mild hybrids, full hybrid vehicles can perform start / stop functions and assist the ICE by providing additional torque to the drive wheels. However, full hybrids utilize a much larger battery than mild hybrids and one or two large MGs housed within the transmission. The larger battery and MGs give full hybrid vehicles the ability to drive in “all-electric” mode when certain vehicle and driving conditions are met.

HYBRID DRIVE MODES

HEVs operate in different drive modes depending on vehicle demands. Each mode seeks to improve fuel economy by maximizing energy usage in the most efficient way. The six hybrid driving modes are:

- Initial Start Up
- Auto-Stop
- Acceleration
- Cruising Speed
- Deceleration
- Regenerative Braking

Figure 6-1, Hybrid Power Transfer

INITIAL START-UP

On most HEVs, a standard 12V starter is used to initially start the ICE. Once the vehicle has met certain operating criteria such as engine temperature, transmission temperature, and low-voltage battery state of charge, the vehicle’s auto-stop feature will be enabled.

AUTO-STOP

The auto-stop system allows the ICE to shut down automatically when the vehicle stops moving. This conserves the fuel that would otherwise be wasted while idling.

After an auto-stop, the driver releases the brake pedal and power from the high voltage battery is used to rotate the MG. Torque from the MG is used to restart the ICE and may provide brief electric only propulsion. The MG's torque also helps to provide a smooth transition from ICE OFF to ICE ON operating mode.

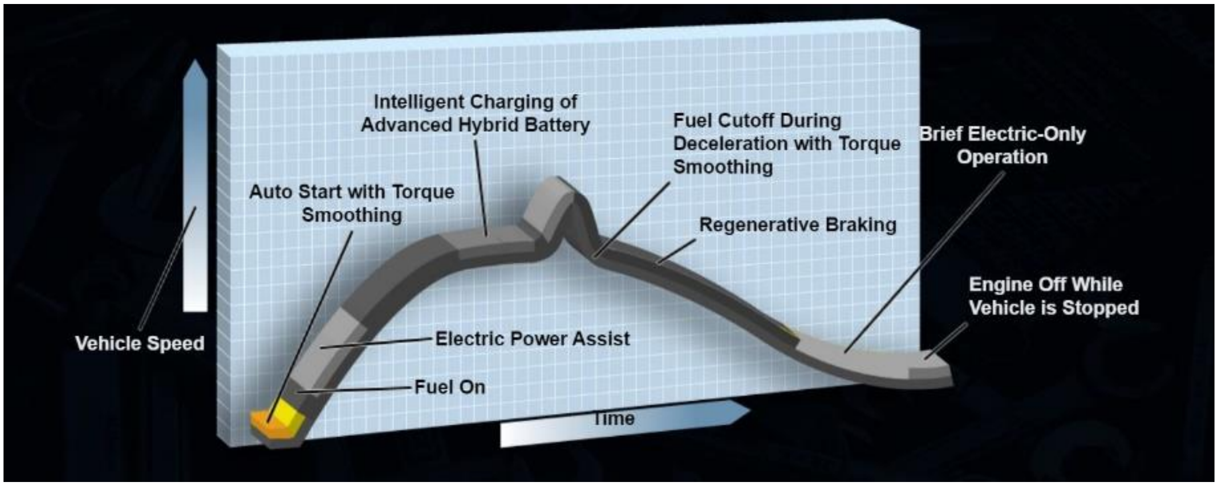


Figure 6-2, Auto-stop Drive Mode

ACCELERATION

During acceleration and high load driving conditions, the ICE and the MGs work together to send torque to the drive wheels. The vehicle's power electronics determine how much torque is needed and use a blend of the ICE's output along with the MG's output to meet the vehicle's needs. Once the additional output is no longer needed, the vehicle will transition to using only the ICE.

CRUISING SPEED

When electric power assist is not required to assist the ICE in propelling the vehicle, the MG can operate as a generator to charge the high voltage battery. On a parallel drive system, output from the ICE may be split and used to drive the MG and propel the vehicle at the same time. On series-parallel systems, the ICE will drive MG1 to recharge the battery while MG2 is used to provide propulsion. This normally occurs when the vehicle is lightly accelerating or under steady-state cruise, and the battery charge is lower than desired.

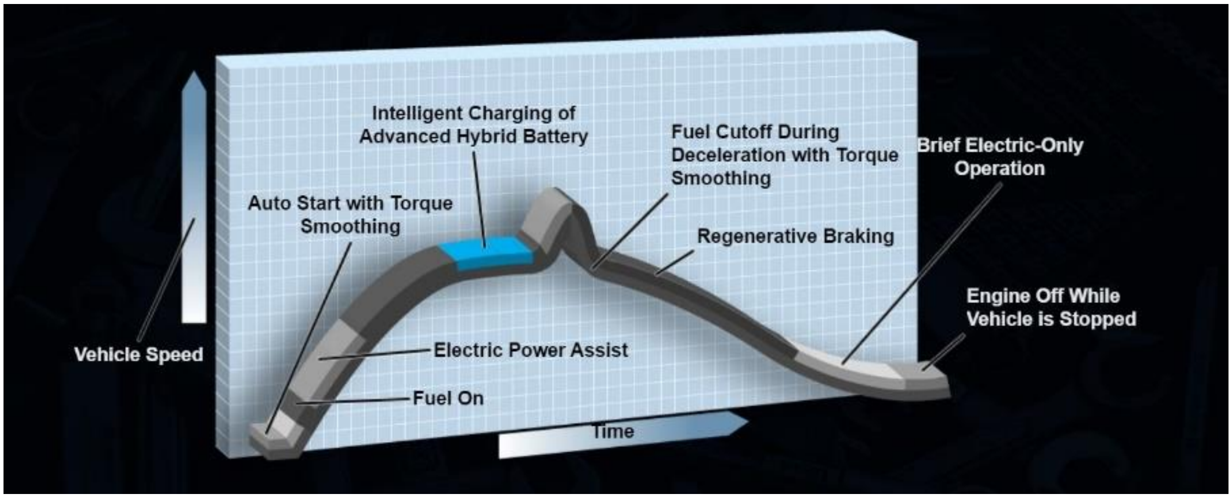


Figure 6-3, Cruise Speed Drive Mode

DECELERATION

When the driver releases the accelerator pedal, the engine control module may cut off fuel completely. This saves fuel by turning off the ICE when it is not needed.

REGENERATIVE BRAKING

When the brakes are applied, the power electronics may use regenerative braking to slow the vehicle. Regenerative braking is the process of capturing kinetic energy that would normally be lost during braking and delivering the reclaimed energy to the high voltage battery. Regenerative braking is achieved by using the vehicle's motion to transfer energy back through the vehicle's drivetrain and into the rotor of the MG. The spinning rotor causes the MG to act as a generator. Magnetic force within the MG resists the turning force of the rotor which causes the vehicle to slow down.

Figure 6-4, Regenerative Braking Display

Blended Braking

Blended braking uses a combination of conventional hydraulic friction braking and electric regenerative braking. This maximizes battery charging and braking ability.

The hybrid control module monitors the battery's State of Charge (SOC) and temperature to determine how much energy can be stored in the battery. When the brake pedal is applied, the hybrid control module determines a braking strategy that blends the regenerative braking with friction braking to slow and stop the vehicle.

The hybrid control module will use 100% regenerative braking as long as it can provide the necessary force to slow and stop the vehicle. At low speeds, generally under 5 MPH, the MG may not be turning fast enough to provide braking force, and the hybrid control module requests that friction brakes be applied. Depending on the SOC of the battery, operator-requested braking force, and vehicle speed, the hybrid control module may request any mix of regenerative and friction braking.

A brake pedal simulator provides pedal feedback similar to a conventional braking system. In the event of a system malfunction, the brake pedal can activate the master cylinder directly when the pedal is depressed fully.

Regen on Demand

If equipped, certain vehicles like the Chevrolet Bolt, offer a "regen on demand" feature. This feature allows the driver to use paddles on the steering wheel to command the vehicle to go into regenerative braking mode and slow the vehicle down. This can be convenient during stop and go driving.

Figure 6-5, Regen on Demand Switch

One Pedal Mode

Some vehicles have a “one pedal mode” feature. When enabled, one pedal driving mode enables the vehicle to slow down and come to a complete stop without using the brake pedal in certain driving conditions. When in this mode, the accelerator pedal will act as the accelerator and brake pedal. The further the driver depresses the accelerator, the harder the vehicle accelerates. The further the driver releases the accelerator pedal, the harder the vehicle decelerates using regenerative braking. When the battery is fully charged, the ability to use one pedal mode to slow down or stop the vehicle may be reduced.

One pedal mode should not be used on wet, snowy, or icy roads, or on steep hills. The brake pedal should still be used for emergency braking.

Figure 6-6, One Pedal Mode Switch

NOTES

HEV / BEV ELECTRICAL CIRCUITS

Understanding HEV and BEV operation requires an understanding of electrical principles and how they are applied in HEVs and BEVs.

DIRECT CURRENT (DC)

In Direct Current (DC) electrical circuits, electricity flows in only one direction. It can also be said that DC circuits have a single polarity with one part of the circuit always being positive and one part of the circuit always being negative. Conventional automotive electrical circuits mainly use DC electrical circuits. HEVs and BEVs use separate high voltage and low voltage DC electrical circuits. Current flow to and from the high voltage battery moves in only one direction, just as it does in a conventional automotive DC electrical circuit, only at a much higher voltage level. The low voltage electrical circuits work just as they do on a conventional vehicle.

High voltage DC electrical circuits do not use the vehicle chassis for a ground path. Instead, there are dedicated high voltage cables used for the positive and negative (ground) circuits.

ALTERNATING CURRENT (AC)

Alternating Current (AC) repeatedly changes the direction of current flow, or polarity, as electricity moves through the circuit. This is seen as a sine wave on an oscilloscope. There are no dedicated positive or negative cables in an AC circuit.

Electricity from the municipal power grid uses single-phase AC. This is seen as a single sine wave on an oscilloscope. HEVs and BEVs use 3-phase AC which works in the same manner as single-phase with the exception that 3-phase AC uses 3 overlapping circuits to produce smoother, more powerful MG performance. MGs use 3-phase AC to propel the vehicle when acting as a motor and generate 3-phase AC when acting as a generator.

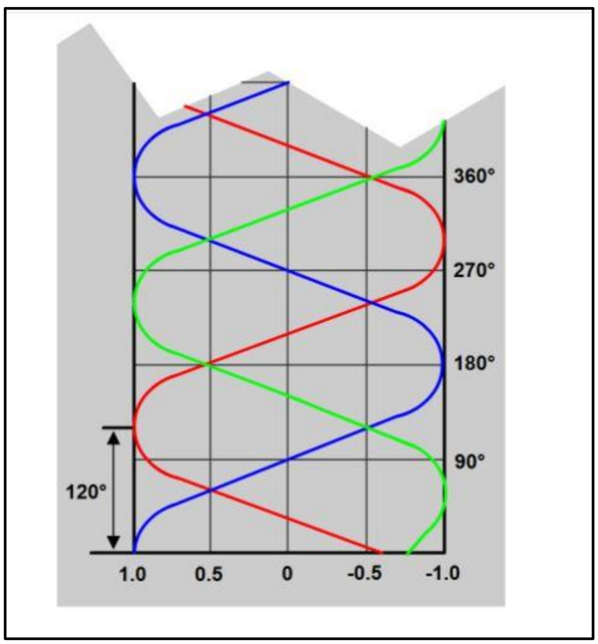


Figure 7-1, 3-Phase AC Sine Wave

WATTAGE

Wattage is a measurement of electrical power. Wattage is calculated by multiplying a circuit's voltage by its amperage. High voltage batteries and chargers are often rated by how many watts of power they can produce over one-hour of time. High voltage battery output is measured in kilowatts, or thousands of watts, per hour. As an example, the Chevrolet Bolt EV battery produces 65 kilowatts per hour (kWh).

LOW VOLTAGE CIRCUITS

HEVs and BEVs also use a 12V battery and electrical circuits to power the conventional vehicle systems such as the radio, wipers, instrumentation, windows, and door locks. These systems are diagnosed in the same way as a conventional vehicle's electrical system. A high voltage DC to low voltage DC conversion occurs to provide current to the low voltage system. DC to DC conversion will be discussed later in this course.

The low voltage battery on most HEVs and BEVs is an Absorbent Glass Mat (AGM) battery. AGMs are lighter, smaller, spill-resistant, and less susceptible to heat than flooded batteries. This allows for placement inside the vehicle due to space restrictions under the hood and makes them well suited for use in HEVs and BEVs.

HEV and BEV charging systems are diagnosed differently than conventional vehicles, but the low voltage batteries themselves are not. If the low voltage battery needs to be tested, ensure that the battery test equipment is compatible with AGM batteries.

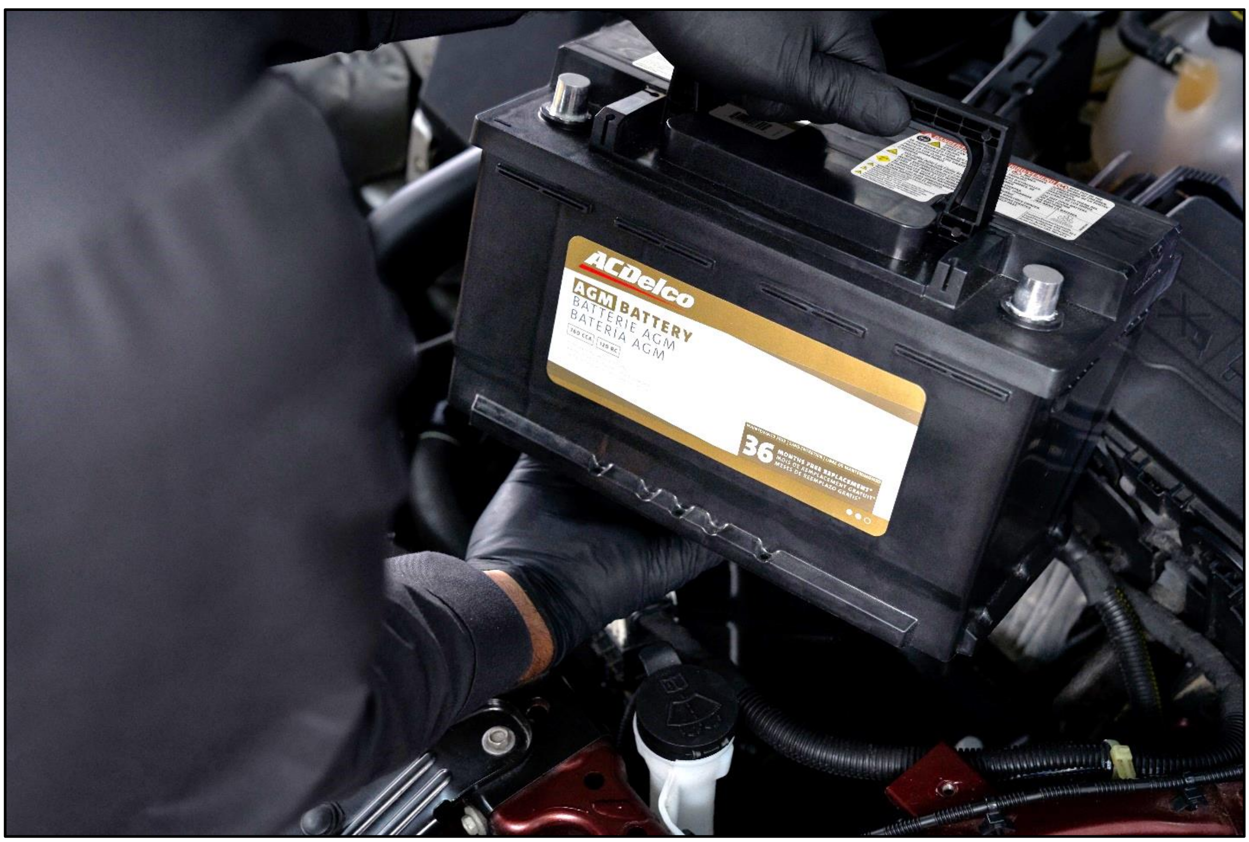


Figure 7-2, AGM Battery

SAFETY

HEVs and BEVs use high voltage, high current, electricity as their energy source. High voltage can cause electrical shock, burns, or even death. Proper use of Personal Protective Equipment (PPE) and following OEM service procedures is critical to ensuring technician safety.

Some electric vehicle batteries can produce up to 186A of DC. By comparison, most household electrical circuits carry 15A of AC.

Bodily Effect	Gender	DC	60 Hz AC	10 kHz AC
Slight sensation at point(s) of contact	Men	1 mA	0.4 mA	7 mA
	Women	0.6 mA	0.3 mA	5 mA
Threshold of bodily perception	Men	5.2 mA	1.1 mA	12 mA
	Women	3.5 mA	0.7 mA	8 mA
Pain, with voluntary muscle control maintained	Men	62 mA	9 mA	55 mA
	Women	41 mA	6 mA	37 mA
Pain, with loss of voluntary muscle control	Men	76 mA	16 mA	75 mA
	Women	51 mA	10.5 mA	50 mA
Severe pain, difficulty breathing	Men	90 mA	23 mA	94 mA
	Women	60 mA	15 mA	63 mA
Possible heart fibrillation after 3 seconds	Men	500 mA	100 mA	
	Women	500 mA	100 mA	

Table 8-1, Bodily Effects of Electrical Shock

WORKPLACE SAFETY

Before beginning any work on a HEV or BEV, ensure that you have taken the steps to verify you are working in a safe environment. This includes:

- Shop is clean and free of clutter
- Floor is free from standing water
- Place safety cones around the vehicle to alert others that you are working on high voltage

- Removing all jewelry and piercings
- Belt buckles removed or covered
- Pockets empty of tools or any conductive material
- Use the “One Hand” rule whenever possible:
    - Work with only one hand
    - Keep other hand behind your back
- After removing ring-terminal style high voltage wires, protect and insulate the terminal ends immediately with high voltage terminal covers or UL® listed insulation tape rated at a minimum of 600V

PERSONAL PROTECTIVE EQUIPMENT (PPE)

The correct PPE must be worn when working on high voltage vehicles. Standard PPE includes safety glasses with side shields and rubber soled shoes. Rubber soled shoes provide slip resistance and additional electrical insulation. Additionally, non-synthetic clothing (cotton) is recommended.

High Voltage Insulation Gloves

Special high voltage insulation gloves with leather outer gloves must be worn whenever working on a system or component where high voltage may be present. The American Society for Testing Materials (ASTM) classifies electrical safety gloves into five categories according to their insulating properties. Servicing high voltage vehicles requires class 0 gloves which can protect up to 1,000V AC or 1,500V DC.

Figure 8-1, High Voltage Insulation Gloves

Electrical insulation gloves consist of two parts, the leather outer shell and the rubber inner shell. The leather outer shell provides no protection from electricity, but it does protect the rubber inner glove from being damaged by sharp objects. Gloves should be stored in the box or bag provided by the manufacturer. Direct sunlight will dry out the rubber and cause it to crack. The gloves should never be stored when folded, compressed, or inside out, as this will cause the gloves to crease and crack. Never use either part of the electrical insulation gloves for anything other than working with high voltage. Contaminating the gloves with engine oil or chemicals will degrade the rubber and reduce the insulating properties.

The label on the gloves provides several important pieces of information, including the size, class rating, and manufacturer. Class 0 gloves have a red-colored label. A beige label indicates class 00 gloves, which do not provide sufficient protection. The glove color is not an indication of the protection they provide.

Electrical Insulation Glove Classes			
Class	Maximum AC Voltage	Maximum DC Voltage	Label Color
00	500	750	Beige
0	1,000	1,500	Red
1	7,500	11,250	White
2	17,000	25,500	Yellow
3	26,500	39,750	Green
4	36,000	54,000	Orange

Figure 8-2, Electrical Insulation Glove Classifications

New gloves may be used up to 12 months from the date of manufacture if they are removed from an unopened box. When the gloves expire, they must be recertified every 6 months. When the gloves are recertified, the date of recertification is stamped on the glove, near the label. The timeframe for using the gloves starts on the date stamped on the glove, not the date of purchase.

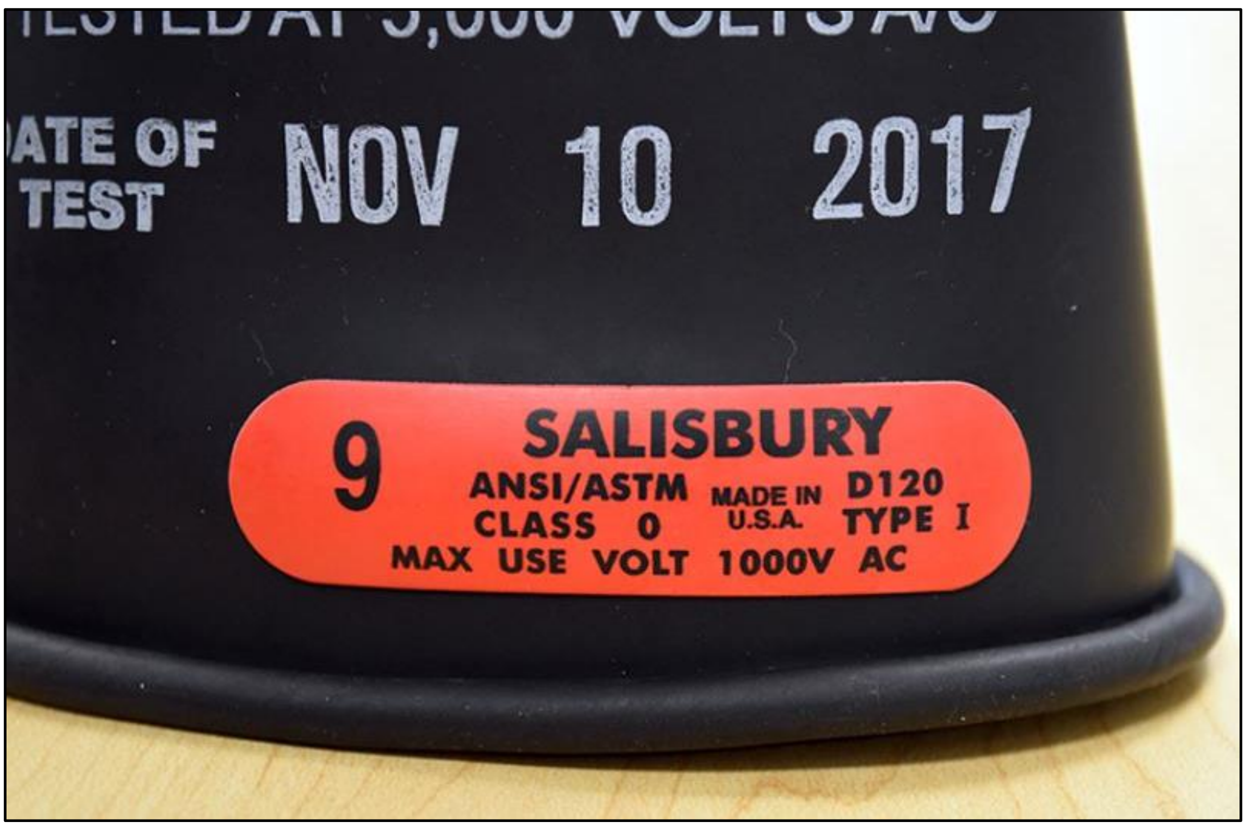


Figure 8-3, Electrical Insulation Glove Label

Before each use, determine that the gloves are the correct classification and have current certification. Next, physically inspect the gloves. The outer leather gloves protect the insulating gloves and do not provide any electrical protection. However, they should be inspected, as imbedded wires or metal shavings in the leather gloves may damage the inner electrical gloves. Furthermore, the outer leather gloves should be discarded and replaced if they become contaminated with oil or other petroleum products that may damage or react with the rubber electrical gloves.

Inspect the inner rubber electrical glove for abrasions, nicks, or cuts before every use. Small cracks may be caused by extended exposure to Ultraviolet (UV) light. Inspect for swelling caused by exposure to oil or other petroleum products.

Fill the glove with air and roll the cuff to trap the air. Place the inflated glove by the cheek and ear to feel and listen for any air leaks. Inflated gloves make it easier to notice small holes or other physical damage. This process should be repeated with the gloves turned inside out. Some manufacturers make gloves using two different colors on the inside and outside. The color difference makes identifying damage easier. The outside color layer is very thin, so any damage to the outer layer will expose the inner color.

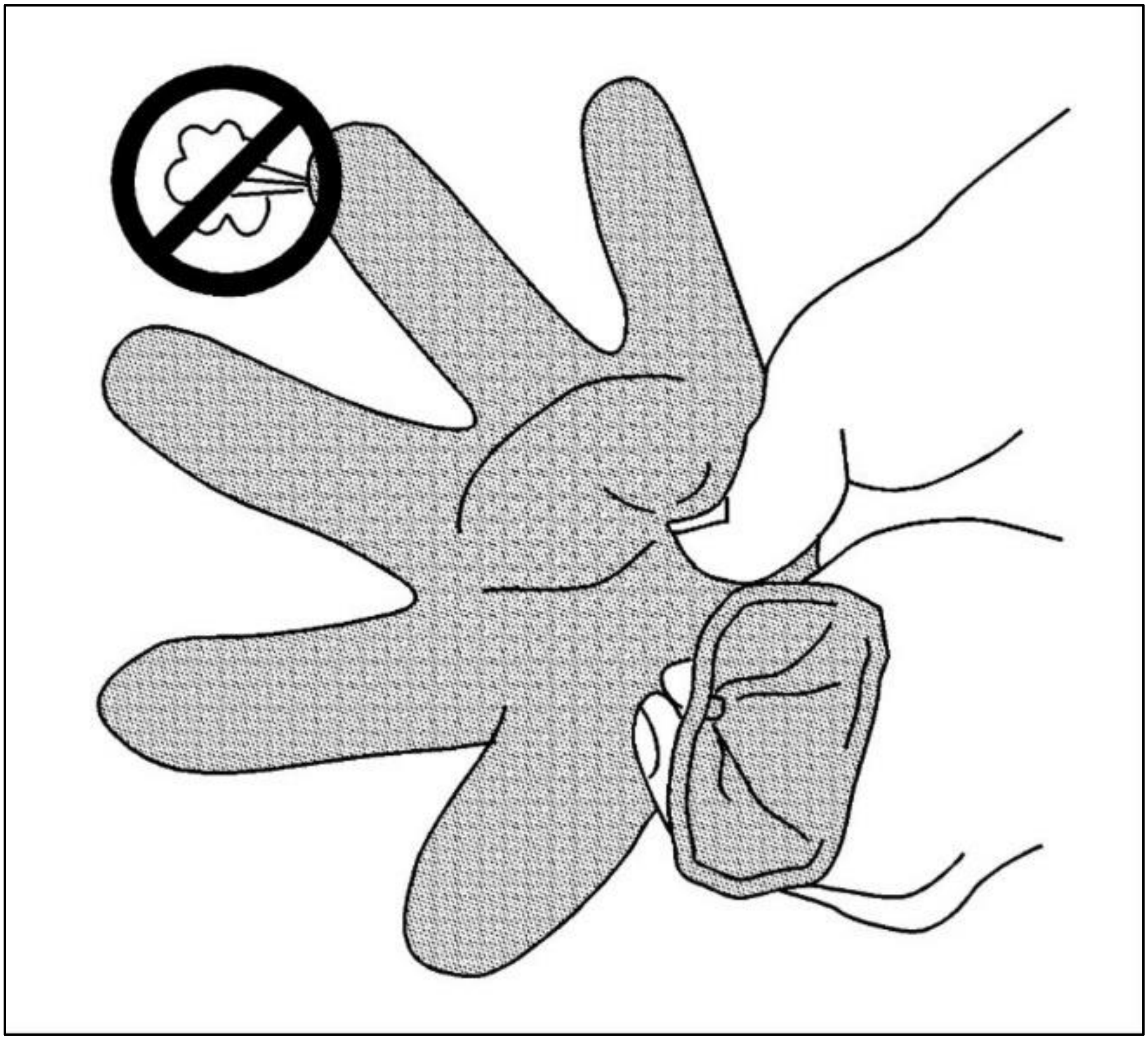


Figure 8-4, High Voltage Glove Inspection

DIGITAL MULTIMETERS

Digital Multimeters (DMMs), and DMM test leads, have two ratings: a voltage rating and a category rating. The voltage rating is the meter's maximum working voltage. The category rating details the safety precautions that are built into the meter for handling transient voltage spikes and preventing arc flashes. Transient voltages spikes may occur when operating, powering up, or powering down electrical circuits. These transient voltages may be much higher than the rating for the circuit. Arc flashes occur when the voltage is high enough to jump through the air from one conductor to the next. Only DMMs with a Category III 1,000V rating should be used when working on HEVs and BEVs.

Figure 8-5, CAT III Digital Multimeter

Category I

Category I meters are designed for use on electronics and circuits that already have protections built in against transient voltage spikes.

Category II

Category II meters are designed for use on single-phase receptacles, appliances, portable tools, and similar loads. However, if the item being tested has a circuit longer than 10 meters, a meter with a higher category rating should be used.

Category III

Category III meters are designed for use on three-phase circuits, like those used in hybrid MGs. Most automotive applications, including non-hybrid vehicles, require a Category III meter because of transient voltages. These voltages are generated in the ignition system on a gasoline engine and when the coils found in solenoids and Air Conditioning (A/C) compressor clutches turn off and the field collapses.

Category IV

Category IV meters are designed for use outside or within electric utility plants or power stations. Outdoor wiring is always considered Category IV, even if cables are buried. These circuits have the capability of large transient voltage spikes when lightning strikes near or on the cable.

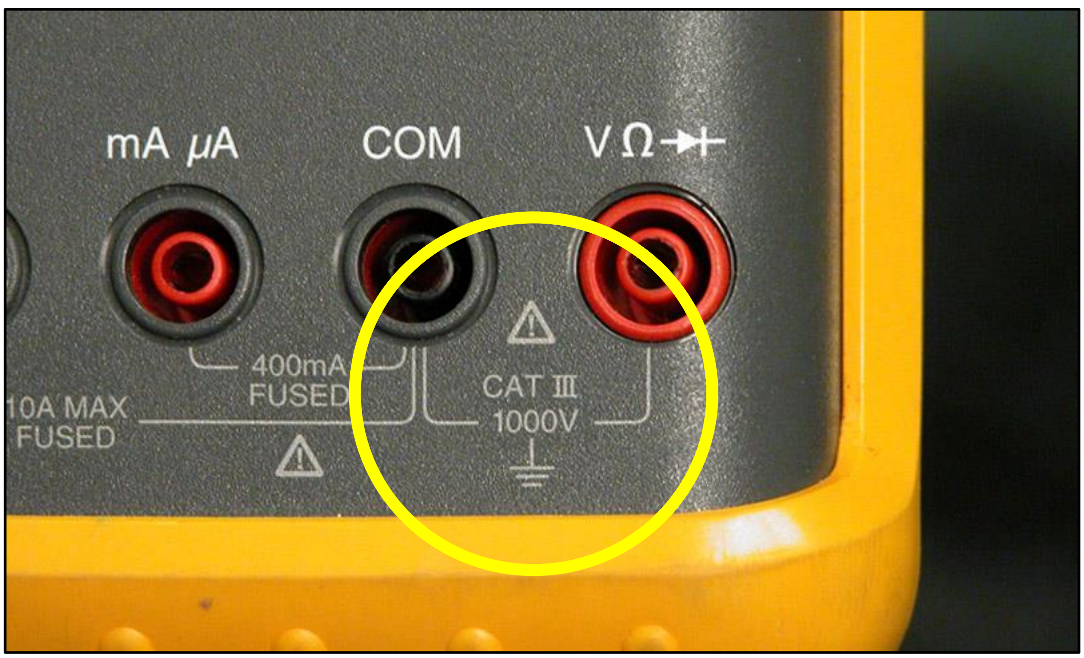


Figure 8-6, DMM Category and Voltage Identification

DANGER: The category and voltage rating of both the meter and the leads must meet or exceed the OEM's recommendation.

Using the proper meter and leads is important for both the technicians' safety and for the protection of the meter. Refer to service information for the vehicle being serviced to determine the proper category and voltage ratings for the meter and leads. The DMM used to check voltages on a hybrid system must be rated at Category **III** 1000V, unless specified otherwise by the OEM. Both the category and voltage must meet or exceed the specifications.

Many leads have probe tips that can be removed and potentially lost. These tips are not just to protect the probe during shipping, they are to protect the user from arc flash or arc blast. The tips reduce the exposed metal which makes it more difficult for the leads to ionize the air and cause a flash or blast. To meet the category or voltage rating stamped or engraved on the lead, the probe tip must be properly installed and undamaged.

Note: When using a meter and leads, the category and voltage rating of the lowest rated component becomes the rating for the assembled parts.

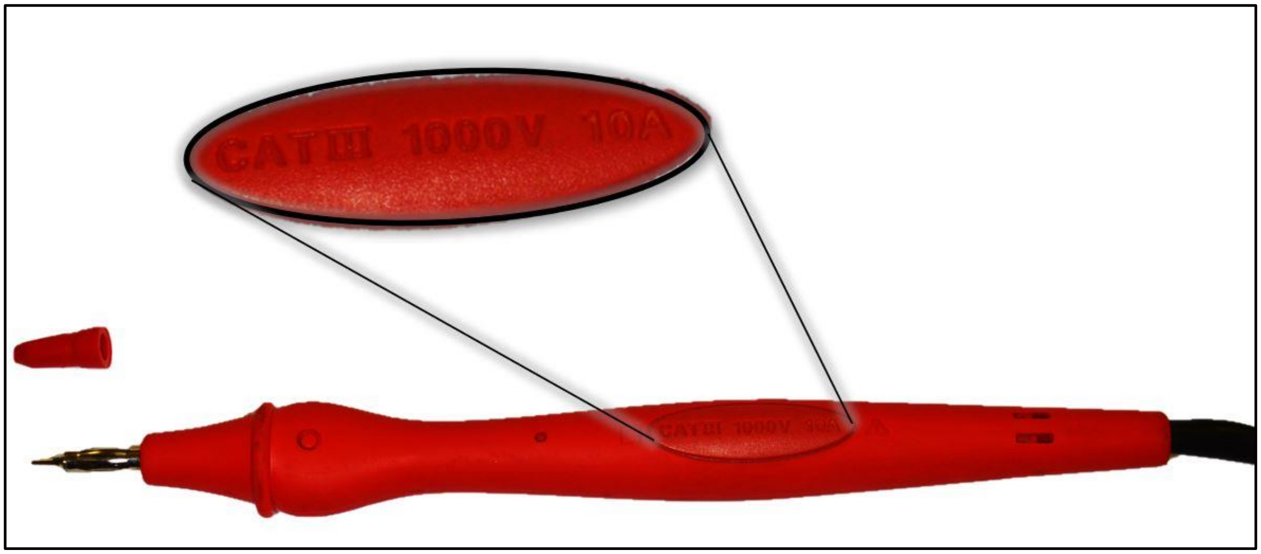


Figure 8-7, CAT **III** DMM Lead and Probe Tip

HIGH VOLTAGE DISABLING / ENABLING

Before performing any service to the high voltage system on a HEV or BEV, the high voltage system must be disabled. High voltage disabling causes the contactors within the battery pack to open and tests to ensure that no high voltage exists outside of the battery pack. Until the high voltage disabling procedure is complete, and you have verified that high voltage is no longer present, you should assume that dangerous high voltage still exists, and all workplace safety precautions must be followed.

DANGER: The High Voltage Disable procedure, regardless of the method, only de-energizes the high voltage circuits and components outside of the Hybrid / EV battery pack, dangerous voltage levels always exist within the Hybrid / EV battery pack.

MANUAL SERVICE DISCONNECT

The Manual Service Disconnect (MSD) is removed as part of the high voltage disabling procedure. Removing the MSD is a redundant method of disabling high voltage when performing service on the high voltage system and should never be used as the primary high voltage disabling method.

The MSD is located electrically near the middle of the battery. The MSD connects multiple battery sections or modules together in series. When removed, the current path is interrupted which reduces the potential voltage inside the battery assembly to approximately one half the total pack assembly voltage.

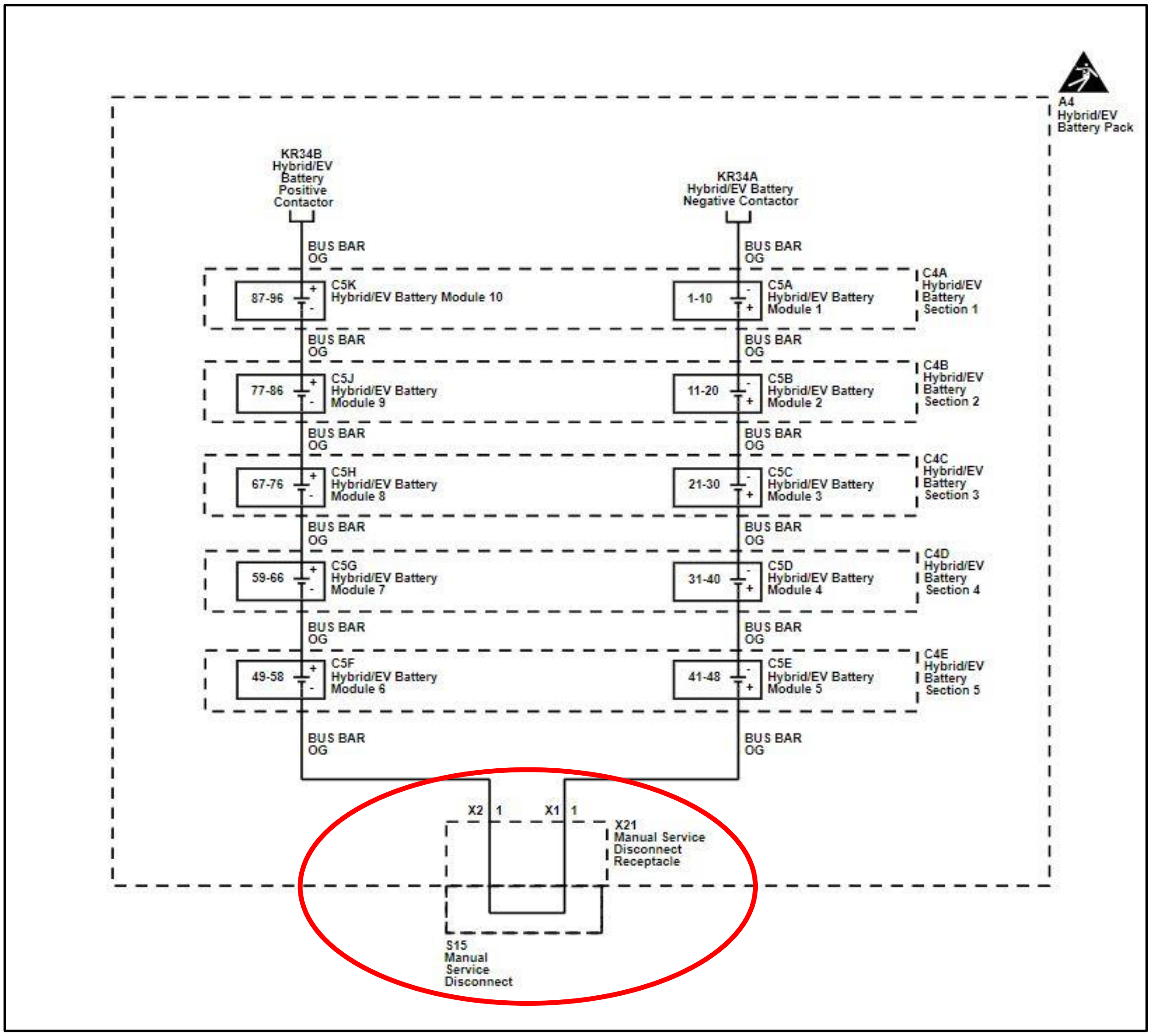
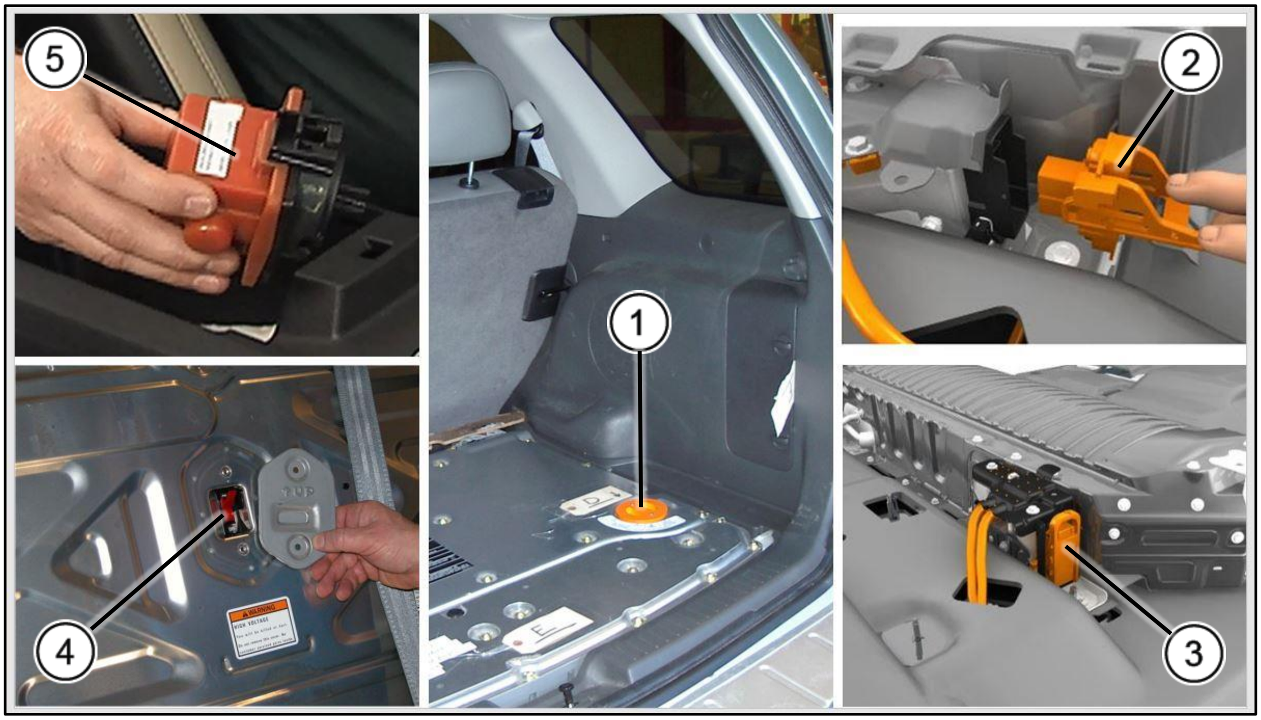


Figure 9-1, Chevrolet Bolt MSD Wiring Diagram

Technicians must remove the manual disconnect plug, toggle the lever, or turn the switch off when servicing the high voltage system. The MSD interrupts the current path within the high voltage battery assembly, but it does not physically disconnect the high voltage battery from the vehicle.

Depending on the vehicle, the battery disconnect may be accessed through the trunk, by removing the back seat, or through the center console. It will be necessary to locate and use the MSD when performing the high voltage disabling procedure. Opened or disconnect switches should be secured in place using tie straps to prevent anyone from engaging the high voltage system while the vehicle is being serviced. Plug-style MSDs that are removed from the vehicle should be secured in a locked drawer.



1. Ford Escape MSD Switch	2. Ford Fusion MSD Plug	3. GMC Sierra MSD Plug
4. Toyota Prius MSD Switch	5. Chevrolet Volt MSD Plug	

Figure 9-2, Manual Service Disconnect Examples

SCAN TOOL HIGH VOLTAGE DISABLING

There may be two available methods for disabling the high voltage system: the scan tool method, and the manual method. Always refer to service information for the correct disabling procedure for the vehicle you are working on.

On certain vehicles, such as the Chevrolet Bolt EV, the high voltage system can be disabled using a scan tool. The scan tool disabling procedure should be used whenever possible. The vehicle performs the following functions when using the scan tool disabling procedure:

- Checks that specific codes have run and passed
- Verifies the isolation resistance
- Opens the contactors
- Sets secure codes to prevent unintended enabling of the system

Below is an example of how to perform the high voltage system scan tool disabling procedure on a 2022 Chevrolet Bolt EV using an MDI interface and GDS2 scan tool software:

1. Ensure the 12V battery is fully charged and tested prior to continuing.
2. Disconnect and remove all 12V Battery Chargers and the Charge Cable from the X98 Hybrid Battery Charger Receptacle.

3. Access the GDS2 scan tool High Voltage Disable Procedure located under HPCM2 Control Functions.

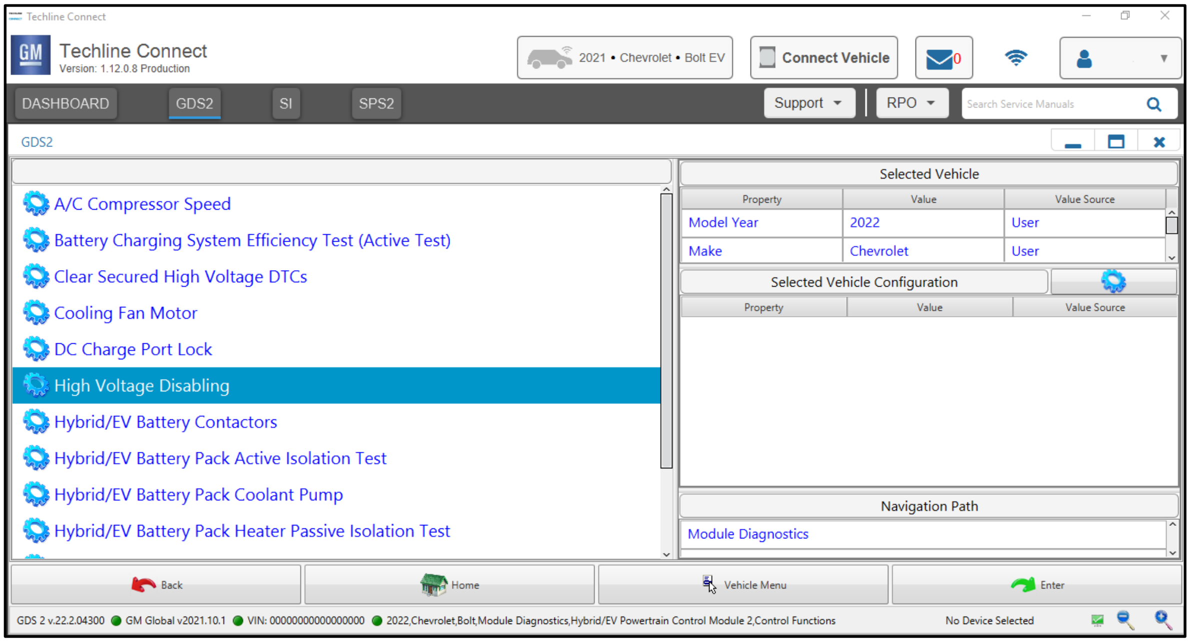


Figure 9-3, GDS2 High Voltage Disabling Function

4. Perform the actions as specified within the GDS2 scan tool procedure.

Note: If at any point the GDS2 scan tool displays a "PROCEDURE UNSUCCESSFUL" warning message or you lose communication, stop the GDS2 procedure and proceed to manual disabling procedure.

5. WHEN INSTRUCTED by the GDS2 procedure, remove the S15 Manual Service Disconnect. Place the S15 Manual Service Disconnect in a secure place outside the vehicle.

6. Cover the exposed high voltage opening with UL® listed, or equivalent, insulation tape rated at a minimum of 600V.

7. Verify the GDS2 scan tool procedure completed successfully by observing the GDS2 scan tool "PROCEDURE COMPLETE" message followed by a "CHECK VEHICLE'S HIGH VOLTAGE STATUS" message. Verify these messages are combined with ALL the following conditions:

   a. A Continuous Audible Vehicle Response of the Pedestrian Alert alarm.

   b. DIC message.

   c. High Voltage Inverter Voltage parameter on scan tool indicates system high voltage is less than 10V.

8. If the procedure successfully completed, turn the vehicle power mode to OFF.

Note: Disconnecting the 12V battery is the only method to deactivate the audible vehicle response. If the 12V battery is reconnected while the S15 Manual Service Disconnect is removed, the audible vehicle response will continue for several minutes.

9. Disconnect the 12V battery. Refer to Battery Negative Cable Disconnection and Connection.

Note: Perform the Clear Secured High Voltage Diagnostic Trouble Codes (DTC)s GDS2 scan tool procedure to re-enable the high voltage system upon completion of the required vehicle servicing.

10. The high voltage circuits and components OUTSIDE of the Hybrid / EV battery pack are now disabled / discharged.

MANUAL HIGH VOLTAGE DISABLING

Refer to vehicle specific service information for manual disabling procedures. Below are the general steps that should be followed to manually disable the high voltage system:

1. The vehicle must be disconnected from all external power sources. On plug-in hybrid and electric vehicles, the charge cord must be unplugged from the vehicle. Disconnect any 12V battery chargers from the vehicle.
2. Turn the key to the OFF position, remove the key from the ignition, and secure the key in a locked drawer. If equipped with the Passive Entry Passive Start (PEPS) system, push the start / stop button and ensure the vehicle powers down. Move the fob away from the vehicle and secure it in a locked drawer at least 5 meters (15 feet) away from the vehicle.
3. After removing the fob, test the vehicle and verify that the vehicle will not power up. This ensures that another fob was not left in the vehicle. Securing the key or fob ensures that other persons will not attempt to start the vehicle while the high voltage system is being serviced.
4. Disconnect the 12V battery. The contactors for the high voltage battery require power from the 12V battery to operate. Disconnecting the battery ensures the contactors will not close while the system is being serviced.

DANGER: It is possible for a contactor to fail in the closed position. Do not assume that disconnecting the 12V battery removes all high voltage from the vehicle.

5. Remove the manual disconnect plug or open the disconnect switch. If equipped with a disconnect plug, the plug should be secured in a locked drawer to prevent anyone else from installing it while the high voltage system is being serviced. If equipped with a switch, the switch should be wire-tied open to prevent anyone from closing the switch while the high voltage system is being serviced.
6. Wait at least 5 minutes after removing / opening the disconnect. Most high voltage systems contain capacitors that may remain charged for several minutes.
7. While wearing high voltage insulation gloves, use a meter to confirm that no high voltage is present. Confirming that no voltage is present requires using the Live-Dead-Live test. To complete this test, set the meter to DC voltage. Test the meter on the 12V battery. A reading of 12V indicates the meter is working properly. Test the high voltage circuits for the presence of high voltage. Generally, a reading under 3V is considered dead. Finally, retest the meter on the 12V battery. This confirms that the meter did not fail while testing for high voltage. Readings over 3V on a high voltage circuit may indicate that a high voltage contactor is stuck closed. Consult Service Information for instructions related to voltage readings over 3V on the high voltage circuits.

HIGH VOLTAGE ENABLING

Always refer to service information for specific high voltage enabling procedures. Below are the general steps that should be followed to enable the high voltage system after a repair:

1. Ensure the 12V battery is disconnected.
2. Inspect for the following:
   a. Verify that all tools or loose components have been removed
   b. Inspect any disconnected HV Battery Positive and Negative cable seals for being deformed, missing, or damaged. Replace any seals that are deformed, missing, or damaged
   c. Verify high voltage system integrity and that all connectors are installed
   d. Install any components or connectors that have been removed or replaced during diagnosis or service
3. Install the manual service disconnect.
4. Connect the 12V battery.
5. Place the vehicle power mode into service mode.
6. If required, reprogram any modules that were replaced.
7. If the HV contactors are in a “lockout” state, perform the “Clear Secured High Voltage DTCs” procedure.
8. Clear all DTCs.
9. Road test the vehicle and verify no DTCs are set.

SYSTEMS AND COMPONENTS

There are several unique systems and components used in the operation of HEVs and BEVs. These include:

- High voltage batteries
- Motor / Generator (MG) unit
- High voltage cables and contactors
- Power Electronics
    - AC to DC rectifier
    - DC to DC convertor
    - DC to AC inverter
- Plug-in battery charger (PHEV & BEV)
- High voltage air conditioning compressor
- Transmission auxiliary pump

HIGH VOLTAGE BATTERIES

The high voltage battery provides the electrical energy needed by HEVs and BEVs. Like all batteries, high voltage batteries use a reversible electrochemical reaction to convert chemical energy into electrical energy and vice versa as the battery is continuously charged and discharged.

High voltage batteries differ considerably in terms of materials, voltage, size, shape, and location. These factors are determined by available technology, vehicle hybrid level (mild hybrid, full hybrid, or BEV), drive type (series, parallel, or series parallel), and power requirements. Because of their size, larger battery packs, like those used in BEVs and PHEVs, are often a structural part of the vehicle.

Battery Construction

Like a standard 12V automotive battery, high voltage batteries are constructed of a series of positive and negative plates separated by an electrolyte solution. The battery plates are grouped together to form cells. Several cells are connected in series to increase the voltage and form a battery module. Battery modules are then connected in series to further increase the voltage and create a battery section. Lastly, battery sections are connected together to form a battery pack.

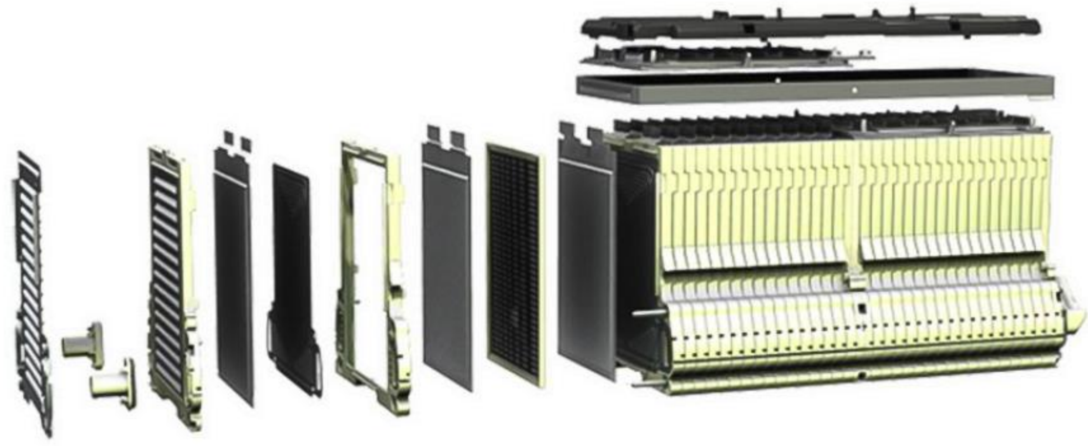


Figure 10-1, Chevrolet Volt Battery Section

Battery Materials

Battery plates can be made from several different materials. The materials used in battery construction are used to identify the battery. For example, a typical 12V car battery is referred to as a lead-acid battery because the plates are constructed of different types of lead submerged in an acid-based electrolyte solution. Two commonly used materials in high voltage battery construction are Nickel-Metal Hydride (NiMH) and Li. Each material has advantages and disadvantages over the others.

Nickel-Metal Hydride (NiMH)

NiMH battery cells are commonly used in high voltage battery systems. By comparison, NiMH batteries are lighter in weight than lead acid and other previous battery technologies. This reduced size and weight and makes it feasible to package them into a vehicle for an electric propulsion system.

NiMH battery chemistry can develop a memory, reducing the usable capacity of the battery. NiMH cells have a limited number of times they may be charged and discharged before there is a noticeable loss of capacity. NiMH batteries have a relatively high self-discharge rate, which causes them to lose energy over time when not in use.

Individual NiMH battery cells have a nominal voltage of 1.2V each. Six cells are combined in series to form a module with a nominal voltage of 7.2V.

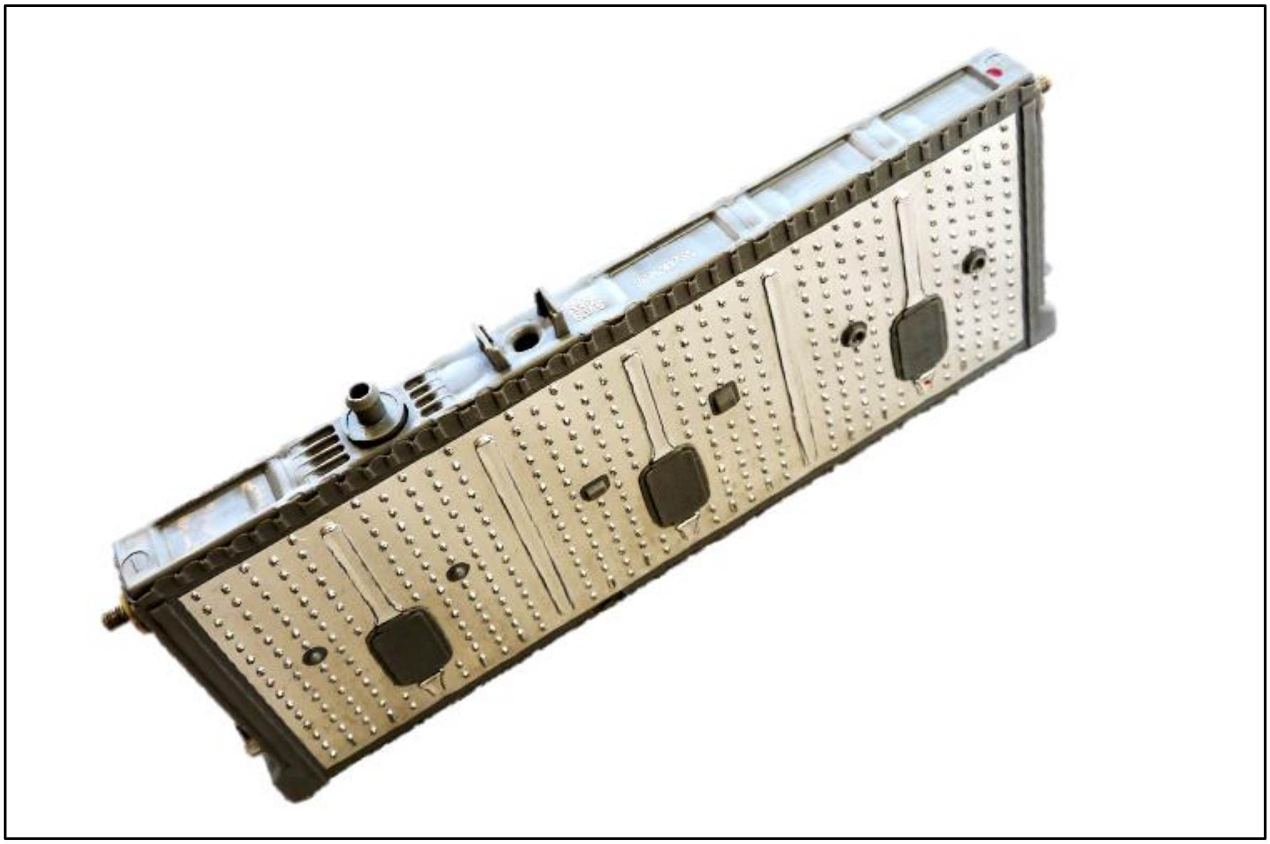


Figure 10-2, NiMH Battery Cell

Lithium-ion (Li)

When compared to NiMH cells, Li cells have a higher energy density, no memory effect, cycle life 3 to 4 times longer, and a very low self-discharge rate. However, Li batteries are not tolerant of high temperatures, over charging or deep cycling. Li batteries require close monitoring to prevent the batteries from overheating, overcharging, or excessively discharging.

Li battery cells have a nominal voltage of 3.7V. Prismatic Li battery cells have a protective polymer-coated aluminum cover encasing each cell to help prevent gas from venting and improve battery cooling efficiency. 1 to 3 cells have the tabs at the top welded together in parallel to form groups. This does not affect the voltage but increases the storage capacity of the group.

Li battery assemblies may also use round cells. The cells consist of the materials spiral-wound inside a sealed canister. Each cell has a nominal voltage of 3.7V, the same as the prismatic cells.

Figure 10-3, Li Battery Cell

Ultium

General Motors (GM) will release its latest design in high voltage battery technology in the 2022 GMC HUMMER EV and 2023 Cadillac Lyriq. GM refers to the new battery design as “Ultium”. The Ultium battery uses nickel, cobalt, manganese, aluminum (NCMA) chemistry. The new chemistry results in higher output and longer range. This battery design is expected to be rolled out across multiple vehicle platforms in the near future. Ultium batteries use small, pouch-style cells that can be stacked vertically or horizontally inside the battery pack. This allows engineers to optimize battery energy storage and layout for each vehicle design.

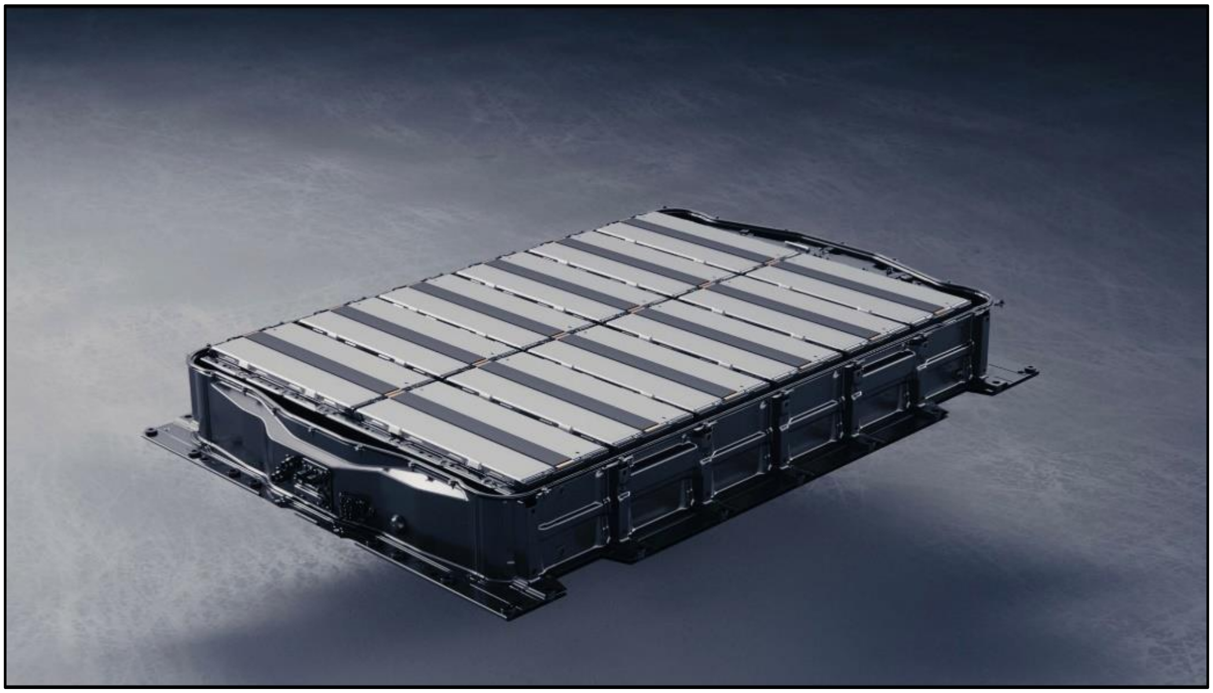


Figure 10-4, Ultium Battery Pack

Battery Size and Location

HEV and BEV batteries vary considerably in terms of size, voltage, and location. The batteries found in mild hybrid batteries are much smaller than those found in full hybrids which are smaller than the ones found in BEVs.

The battery pack on most HEVs are found in the trunk, under the rear seat, or behind the rear seat. Some HEV battery packs, like those found on PHEVs and EREVs, are located in the undercarriage and may be a structural part of the vehicle.

Mild HEV Battery Packs

Mild hybrid batteries operate at a lower voltage than full hybrids and BEVs, but mild hybrid batteries can still contain dangerous voltage levels. High voltage PPE must be worn whenever the battery pack needs to be handled, including safety glasses and Class 0 high voltage gloves. Examples of mild hybrids and their battery voltage include:

Year	Make	Model	Battery Voltage
2007-2009	Saturn	VUE Green Line Aura Green Line	36V
2008-2010	Chevrolet	Malibu Hybrid	36V
2016	Chevrolet	Silverado Hybrid	86V
2019-2021	Jeep	Wrangler eTorque	48V
2012-2014	Buick	LaCrosse Hybrid	115V
1999-2006	Honda	Insight	144V

Table 10-1, Mild Hybrid Electric Vehicle Examples

Mild HEV batteries are heavy. The use of special equipment may be needed for removal and installation. When removing a HEV battery pack, ensure that the pack does not get tilted more than 80 degrees. Always refer to service information for proper lifting and handling methods.

Figure 10-5, Chevrolet Malibu Battery Pack

Full Hybrid and BEV Battery Packs

Full hybrids, including PHEV, and EREV, and BEV battery packs are much larger and heavier than those found on mild HEVs. These batteries often make up the entire undercarriage of the vehicle. The battery packs can weigh up to 1200 lbs. (544 Kg) and require special tools, equipment, and training to handle. Do not attempt to remove a high voltage BEV, PHEV, or EREV battery unless you have completed the necessary training and have the right equipment such as:

- Specialized Lifting Tables
- High Voltage Battery Lift Bar Tilter
- Hanging Bars and Shackles
- High Voltage Battery Lift Bar Tilter Eye-Nut Kit
- Battery Lifting Strap

Full hybrid batteries utilize very high voltage. High voltage PPE must be worn whenever the battery pack needs to be handled, including safety glasses and Class 0 high voltage gloves. Examples of BEV batteries and their voltages include:

Year	Make	Model	Battery Voltage
2011 - 2019	Chevrolet	Volt	355V
2010 – 2015	Toyota	Prius	201.6V
2017 – Present	Chrysler	Pacifica Hybrid	360V
2013 – 2020	Ford	Fusion Hybrid	300V

Table 10-2, Full-Hybrid Electric Vehicle Examples

BEV batteries also utilize very high voltage. High voltage PPE must be worn whenever the battery pack needs to be handled, including safety glasses and Class 0 high voltage gloves. Examples of BEV batteries and their voltages include:

Year	Make	Model	Battery Voltage
2017 - Present	Chevrolet	Bolt EV	350V
2017 - Present	Tesla	Model 3	350V
2012 – Present	Tesla	Model S	375V
2010 - Present	Nissan	Leaf	350V
2018 – 2019	Kia	Soul EV	375V
2021	Ford	Mustang Mach-e	450V

Table 10-3, Battery Electric Vehicle Examples

Battery Monitoring

A Battery Energy Control Module (BECM) monitors critical battery information like battery pack voltage, cell voltage, battery current, and battery temperature. The control module uses this information to detect faults and improve performance.

Voltage Monitoring

The BECM uses individual sense wires to measure voltage at different points within the battery pack. On some vehicles the BECM monitors the voltage level of each cell using sense wires connected to the positive post of each cell. Li batteries that have cells connected into groups are monitored as a group. Cell groups are typically comprised of three individual cells. Additionally, the vehicle control modules measure overall pack voltage using sense wires attached to the high voltage positive connections.

A DTC can set if the pack or cell voltage measures higher or lower than expected, or if the overall pack voltage does not equal the sum of the individual cell, or cell group, voltages. If the vehicle control modules determine that the voltage of a cell or cell group is out of range, the control modules may attempt to perform cell balancing. Typically, the voltage difference between the highest voltage cell and the lowest voltage cell must be within 0.3V. A high voltage differential affects the capacity of the battery. Battery cells, modules, or sections with an excessive voltage differential are considered “out of balance”.

If a battery is allowed to operate out of balance, the usable capacity would be lost. For example, if two of the three battery sections were fully charged to 80% but the third section could only be charged to 60%, the overall capacity would be reduced by 20%. As the vehicle is driven, the battery's usable charge is fully depleted when the third section is at 20% and the other sections still have a usable charge. This scenario results in an overall usable charge of only 40% of the battery's total capacity. This greatly reduces the vehicle's range.

Early hybrid vehicles did not use cell balancing. On these vehicles, the battery pack required replacement when out of balance cells affected performance. As battery technology improved, a cell balance strategy was developed where energy was bled off using resistors and the cell sense wires. This removed energy from the high voltage cells, balancing the voltage with the lower voltage cells. This wasted the excess energy in the form of heat. The most recent hybrids now use a strategy where the excess energy in the cell group with the highest voltage is transferred to the cell group with the lowest voltage. The battery interface control module uses internal gates to transfer the energy between cell groups.

If the vehicle electronics are not able to properly balance the battery cells, there is likely a fault internal to the battery pack. Internal pack service requires special training, tools, and equipment and is not covered in this course.

Current Monitoring

In addition to voltage monitoring, the control module may use a current sensor to measure the amount of current flowing in and out of the battery. The current sensor is often integrated into the contactor assembly and measures the amount of amperage flowing through the negative battery cable. High voltage current sensor is similar to low voltage current sensor used on some conventional 12V batteries. A control module provides a 5V reference and low reference circuit to the current sensor. The current sensor interprets the current flowing through the cable and provides a return signal voltage back to the control module. As an example, the 2018 Chevrolet Malibu Hybrid provides a signal voltage greater than 3.24V when the battery is being charged and less than 3.24V when the battery is being discharged. Excessive current flow, or a correlation fault between expected and actual current flow will set a DTC P0AC1 or P0AC2. Diagnosing these DTCs requires disabling the high voltage system and removing the battery cover. Always wear proper PPE and follow service information for high voltage disabling instruction and testing.

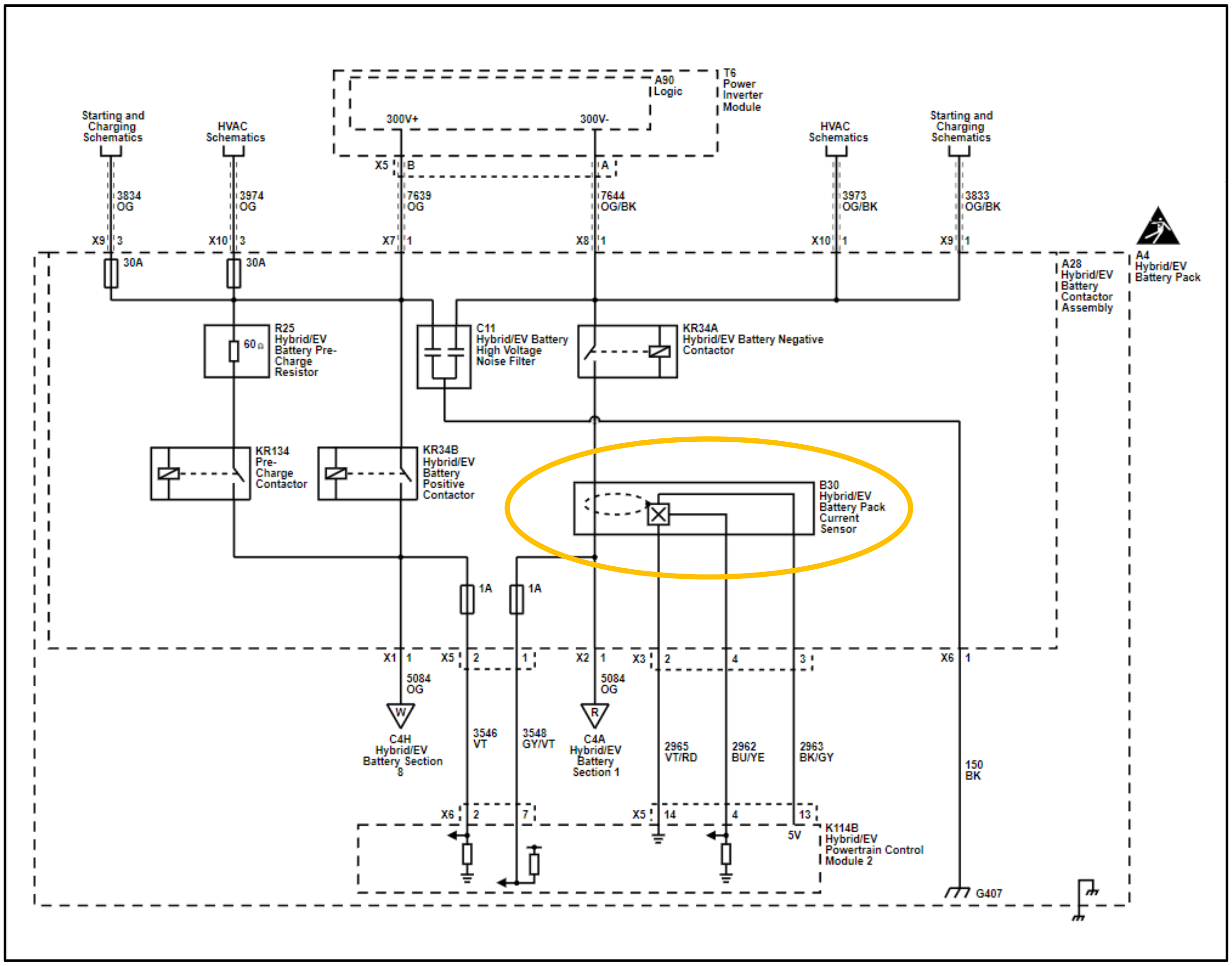


Figure 10-6, Battery Current Sensor Wiring Diagram

Battery Thermal Management

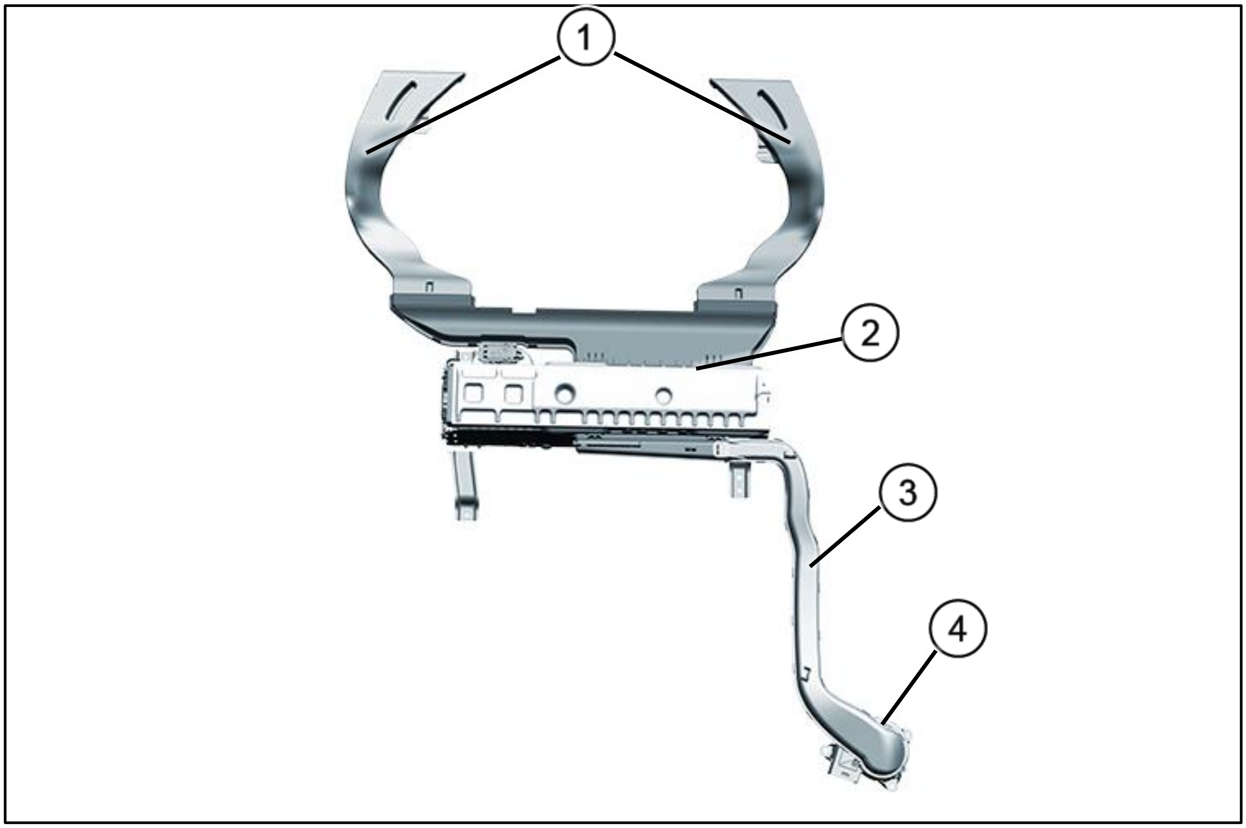
The battery thermal management system is designed to maintain an optimal battery temperature between 68˚F (20˚C) and 104˚F (40˚C) for maximum performance. Charging and discharging batteries generates a lot of heat. High voltage batteries can be either air or liquid cooled. Some systems also use a heater to warm the battery if needed. The battery thermal management system may operate whenever the vehicle is in operation. In addition, on PHEV and BEV, the system operates when the vehicle is plugged in and the battery is charging.

The BECM monitors battery pack inlet and outlet temperature sensors, and temperature sensors within the battery pack to determine when pack heating or cooling is required and to identify a fault within individual cells, or cell groups, that could lead to an overheat condition.

Air Cooled Batteries

Small battery packs used in mild hybrids are air cooled. An air cooled high voltage battery contains a fan and ducting that routes cabin air through the battery to maintain optimal battery temperature. In addition to the sensors that detect battery temperature, two sensors detect air temperature. One sensor is typically positioned near the battery cooling fan air inlet duct. A second air temperature sensor is typically positioned in the battery cooling air outlet duct.

A battery control module uses temperature sensor inputs to adjust fan speed using pulse width modulation. The system requests the battery cooling fan to be turned on when the hybrid batteries exceed a specific temperature. While the battery cooling fan operates, a small amount of fan noise may be audible and will vary depending on battery temperature. The fan in an air cooled battery pulls air through the battery assembly. This maintains a negative pressure inside the case and any gasses released by the battery are vented outside the vehicle.



1. Inlet Ducts	2. Battery Pack	3. Outlet Duct
4. Fan		

Figure 10-7, Battery Cooling Ducts

The duct system must be properly attached with the seals in place. Any loose connections will reduce air flow and cause overheating. Additionally, blocked air inlets may reduce airflow and cause the battery to overheat. Air ducts, seals, and filters should be inspected whenever a battery overheat condition is suspected or an overheat DTC is retrieved.

Figure 10-8, Clogged Battery Air Filter

Liquid Cooled Batteries

Larger batteries used in full-hybrids and BEVs are liquid cooled. A typical liquid cooled high voltage battery uses a dedicated cooling system to regulate the hybrid battery assembly temperature. The battery cooling system is separate from the engine cooling system on hybrid vehicles and may be separate from the system used to cool the power electronics. The battery cooling system typically includes a radiator, coolant chiller, electric water pump, surge tank, flow control valve, an air separator, and an electric heater.

The hybrid / EV powertrain control module monitors battery coolant temperature, battery cell temperature, refrigerant temperature, refrigerant pressure, and the battery coolant level. The hybrid / EV powertrain control module determines the amount of battery cooling required and turns on the battery pack coolant pump, radiator fan and high voltage A/C compressor. If pack heating is required, the high voltage hybrid / EV battery pack coolant heater is turned on. The battery pack cooling system may be active when the vehicle is operating, during charging, or when the vehicle is OFF.

Battery Chiller

Some high voltage battery cooling systems use the air conditioning system to help maintain battery temperature. If the hybrid battery exceeds a certain temperature, like during charging, the main high voltage circuit allows the A/C compressor to operate. Refrigerant from the A/C system is routed through a high voltage battery coolant chiller which removes heat from the battery coolant. The high voltage battery coolant chiller shares the compressor and condenser with the HVAC system but has its own Thermostatic Expansion Valve (TXV) and coolant to refrigerant heat exchanger (chiller) which functions like an evaporator. When operating the cabin HVAC system in Fan Only Mode, it is normal to feel cold air through the HVAC vents during chiller operation.

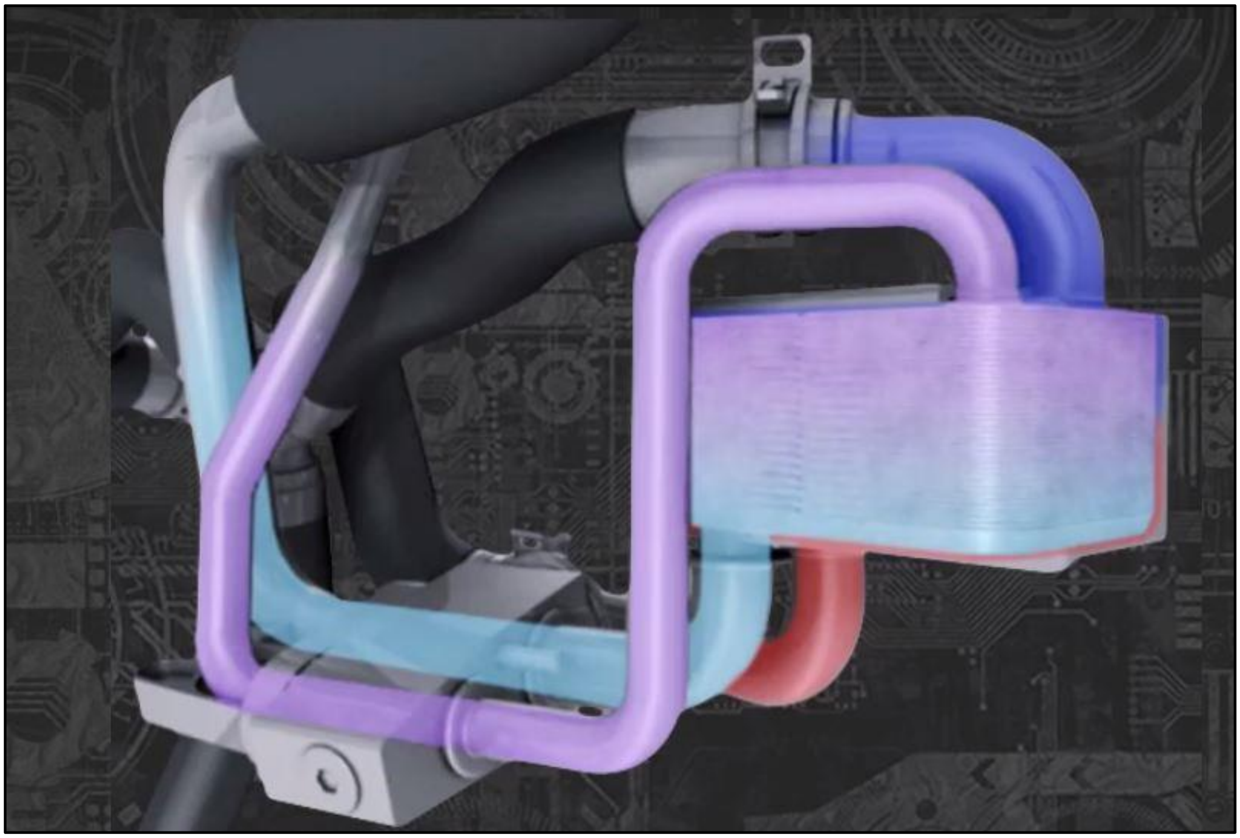


Figure 10-9, Battery Chiller

Battery Heaters

Some battery cooling systems include a heater within the high voltage battery assembly. The heater utilizes a high voltage heater coil to preheat the battery in cold climates for optimal performance. The heater is typically located on the coolant inlet side of the high voltage battery assembly.

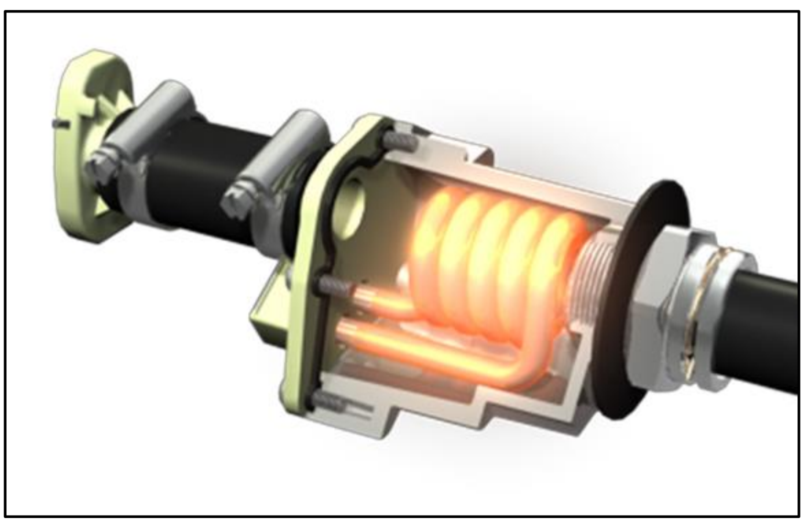


Figure 10-10, Battery Coolant Heater

Air Separator

Ensuring all air is removed from the cooling system is critical to proper battery cooling. The coolant / air separator allows air to purge out of the coolant. The separator consists of a hollow chamber with three coolant hose connections. As coolant passes through the air separator, trapped air rises through the top of the separator and to the surge tank. The liquid coolant then returns to the coolant pump.

Figure 10-11, Coolant / Air Separator

Cooling System Service

There are special service requirements related to the HEV / BEV liquid cooling system. HEVs typically have independent cooling systems for the battery pack, the power electronics, and the ICE. Each of these systems may have its own water pump and may have its own radiator. A leak in any one system will not affect the other cooling systems. All three cooling systems must be carefully inspected if the vehicle was involved in a collision or any time a coolant leak is suspected.

1. ICE Coolant Reservoir	2. Power Electronics Coolant Reservoir	3. High Voltage Battery Coolant Reservoir

Figure 10-12, Hybrid Coolant Reservoirs

DANGER: Do NOT attempt to repair an Li Hybrid / EV Battery Pack when an internal coolant leak is evident. The Hybrid / EV Battery Pack must always be replaced as an assembly. Failure to replace a coolant contaminated Hybrid / EV Battery Pack may result in fire, which can cause severe injury or death.

If the cooling system needs to be serviced, a 50/50 mix of new coolant and deionized water must be used. Impurities found in non-deionized water and used coolant can cause corrosion and result in diminished performance. GM premix coolant DEX-COOL®, part number 12378390 can be used without the need to obtain deionized water or perform any mixing.

If an overheat condition is found, inspect for a coolant leak. If no leak is found, there may be a restriction preventing proper coolant flow. Use the following steps to isolate a cooling system restriction:

1. Ensure the coolant level is full.
2. Using a scan tool, turn on the drive motor battery coolant pump.
3. Quickly remove and reconnect coolant hoses in the following order and inspect for coolant flow:
    a. drive motor battery coolant pump (to tube)
    b. drive motor battery coolant cooler inlet hose (pump outlet to tube) from the drive motor battery coolant cooler inlet hose (tube to cooler inlet)
    c. drive motor battery coolant cooler inlet hose (tube to cooler inlet) from the coolant cooler
    d. drive motor battery coolant inlet hose from the drive motor battery
    e. drive motor battery coolant outlet hose from the drive motor battery
    f. drive motor battery coolant outlet hose (drive motor battery to tube) from the drive motor battery coolant outlet hose (tube to drive motor battery reservoir)
    g. drive motor battery coolant outlet hose (tube to drive motor battery reservoir) from the radiator surge tank
    h. drive motor battery coolant pump inlet hose from the drive motor battery coolant pump
    i. drive motor battery coolant cooler inlet hose
    j. drive motor battery coolant cooler inlet hose
4. Replace any component that does not allow coolant flow.

It is important to purge the air from the cooling system after service. Using the GM *GE-47716* Vac-N-Fill Coolant Refill Tool, or equivalent, with the proper adaptors, is required to ensure the system is properly filled.

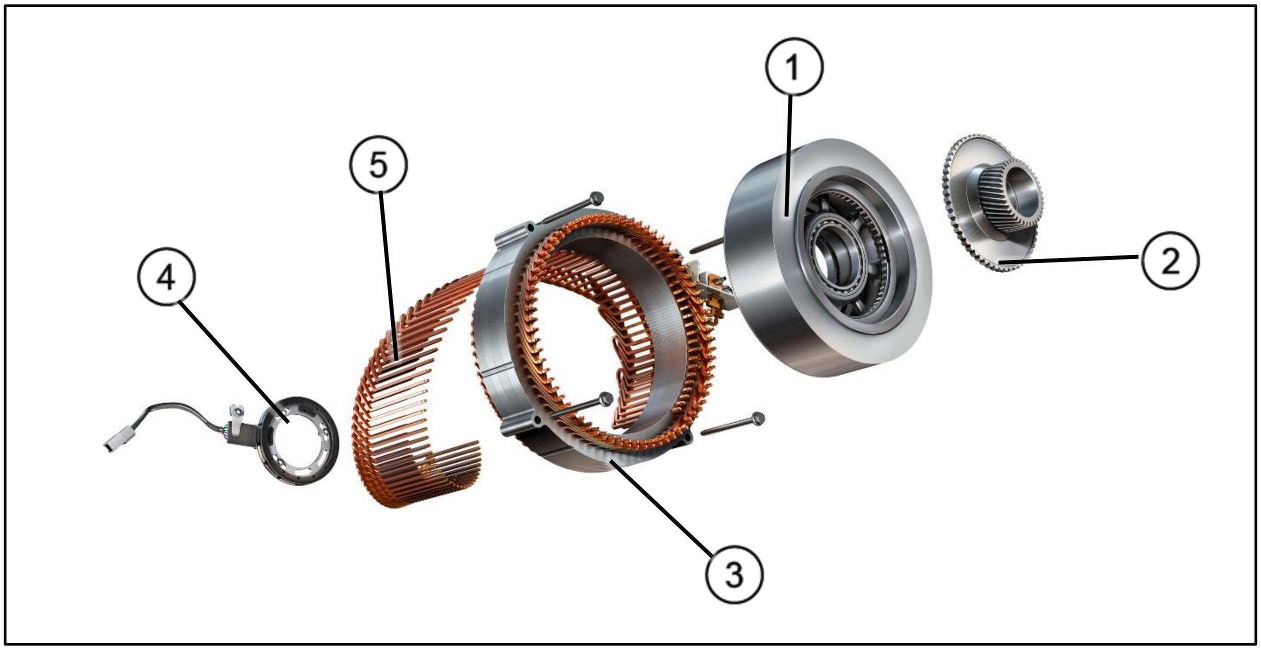
It is also important to never add stop leak coolant additive to any of the vehicle cooling systems. The battery and power electronics contain very small cooling passages that can be clogged by cooling system additives. If stop leak coolant additive was added to a HEV / BEV cooling system, affected components may need to be replaced, up to and including the battery pack.

Figure 10-13, Vac-N-Fill Tool

MOTOR / GENERATORS (MG)

HEV / BEV MGs are dual purpose components that use electrical energy to create mechanical motion (kinetic energy) when operating as a motor or use mechanical motion to create electrical energy when operating as a generator. The kinetic energy produced by the MG is used to propel the vehicle. The electrical energy produced by the MG is used to recharge the HV battery. In this way, the MGs become the heart of HEV and BEV operation.

The MG is located inside the transmission on full hybrids and BEVs. The MG is attached to the front of the ICE or located between the ICE and the transmission on mild hybrids.



1. Rotor	2. Sun Gear	3. Stator
4. Resolver	5. Stator Windings	

Figure 10-14, Motor / Generator Components

MG Components

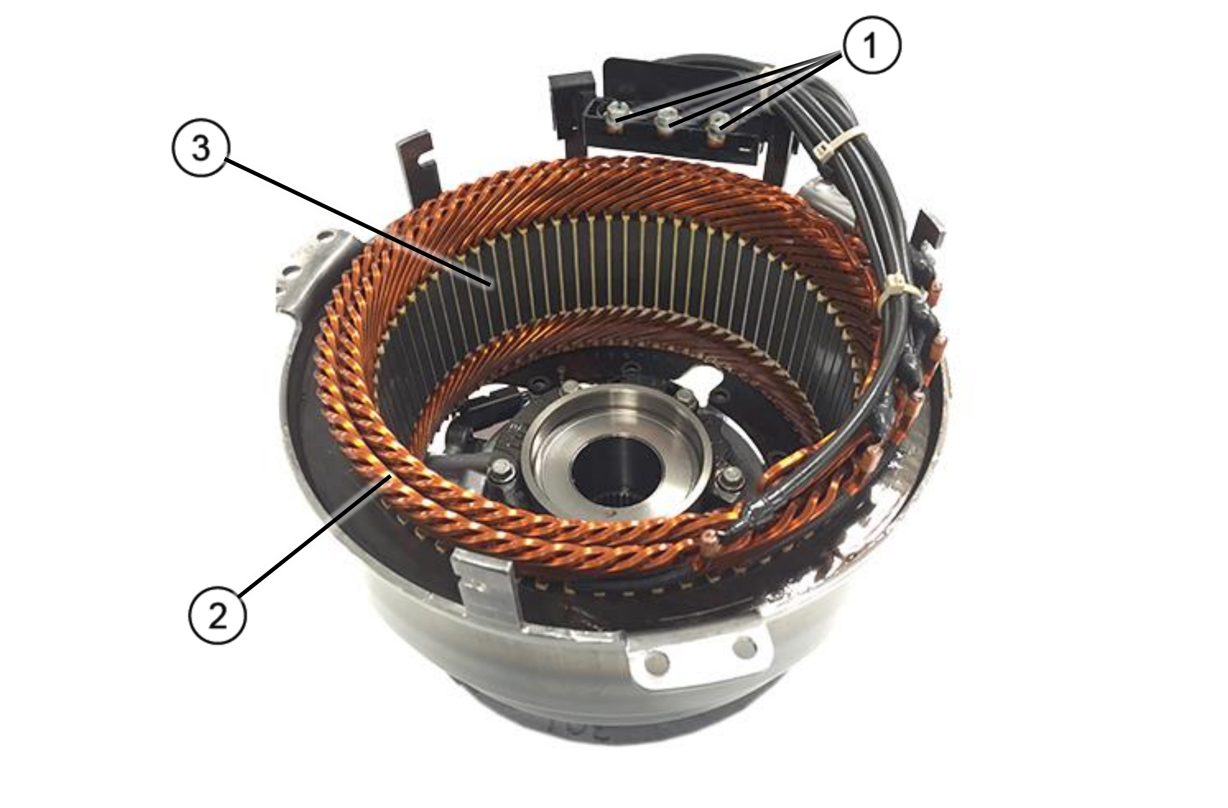
HEVs and BEVs use 3-phase AC MGs which consist of three main components: the stator, the rotor, and the resolver or encoder. MGs use the principle of electromagnetism to convert electricity into motion.

Stator

The stator is the stationary component in the MG. The stator consists of a group of individual windings called stator poles. Stator poles are arranged around the inside diameter of the MG housing.

When operating as a motor, electrical current flows through the stator poles and a magnetic field is created. Stator poles are wired in pairs so that opposing magnetic poles are created on opposite sides of the stator housing. The Power Inverter Module (PIM) controls which stator poles have current flowing through them and therefor which poles are magnetized. As current flows through the stator windings a rotating magnetic field is created within the stator. The rotating magnetic field creates movement of the MG's rotor.

When operating as a generator, moving magnetic lines of flux from the rotor cut across the stator poles and windings to induce an electrical current.



1. 3-Phase Wiring Terminals	2. Stator Windings	3. Stator Poles

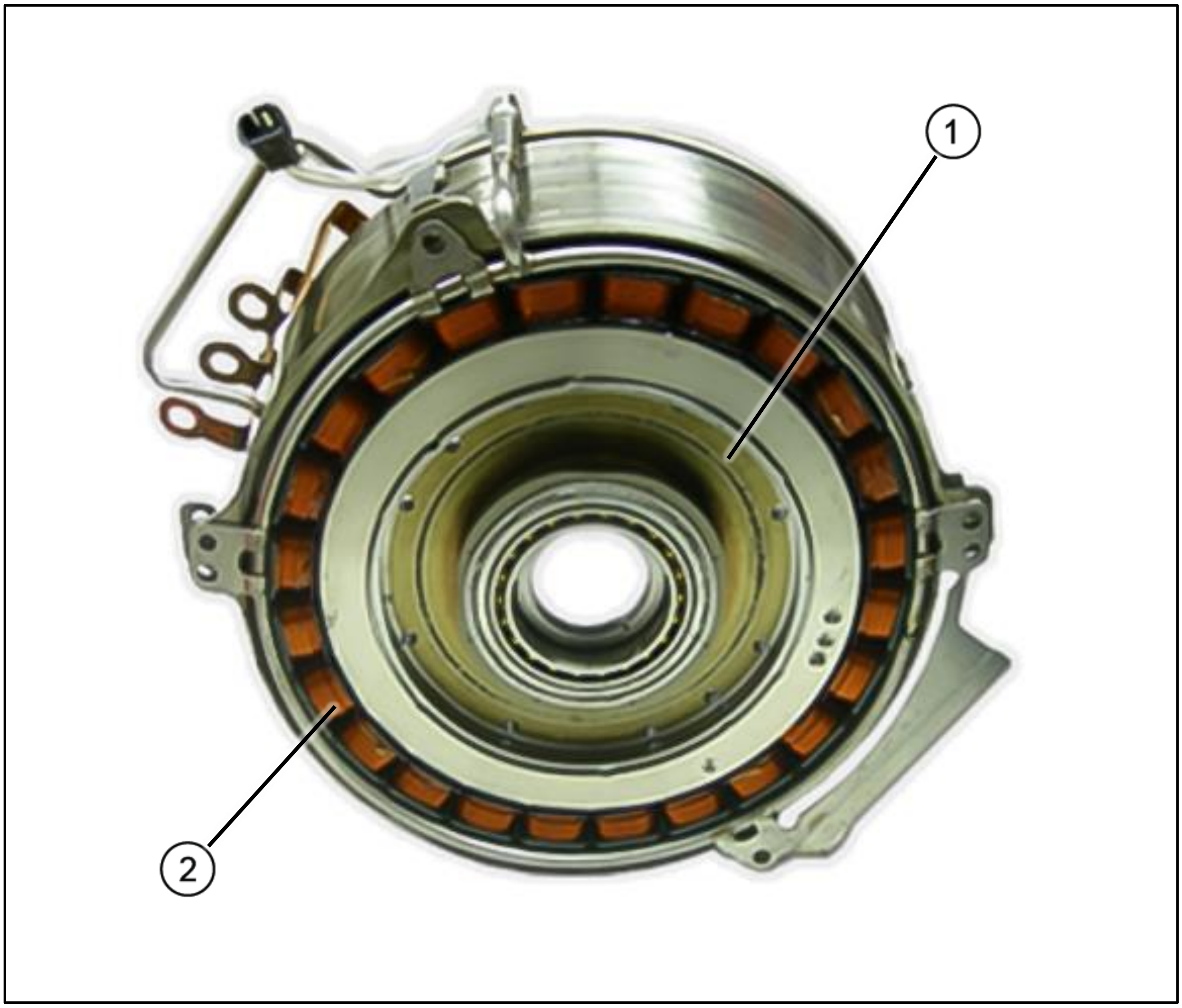
Figure 10-15, Stator

Rotor

The rotor is a component that rotates within the stator assembly. Alternating north and south magnetic poles are arranged around the outer diameter of the rotor.

When operating as a motor, the rotating magnetic field within the stator attracts and repels the magnetic fields of the rotor which causes the rotor to rotate. The rotating motion of the rotor is transmitted to the drive wheels to provide vehicle propulsion.

When operating as a generator, the rotor is mechanically driven by the vehicle's drive wheels during regenerative braking, or by the ICE when the HV battery state of charge is low, and all requirements have been met.



1. Rotor	2. Stator

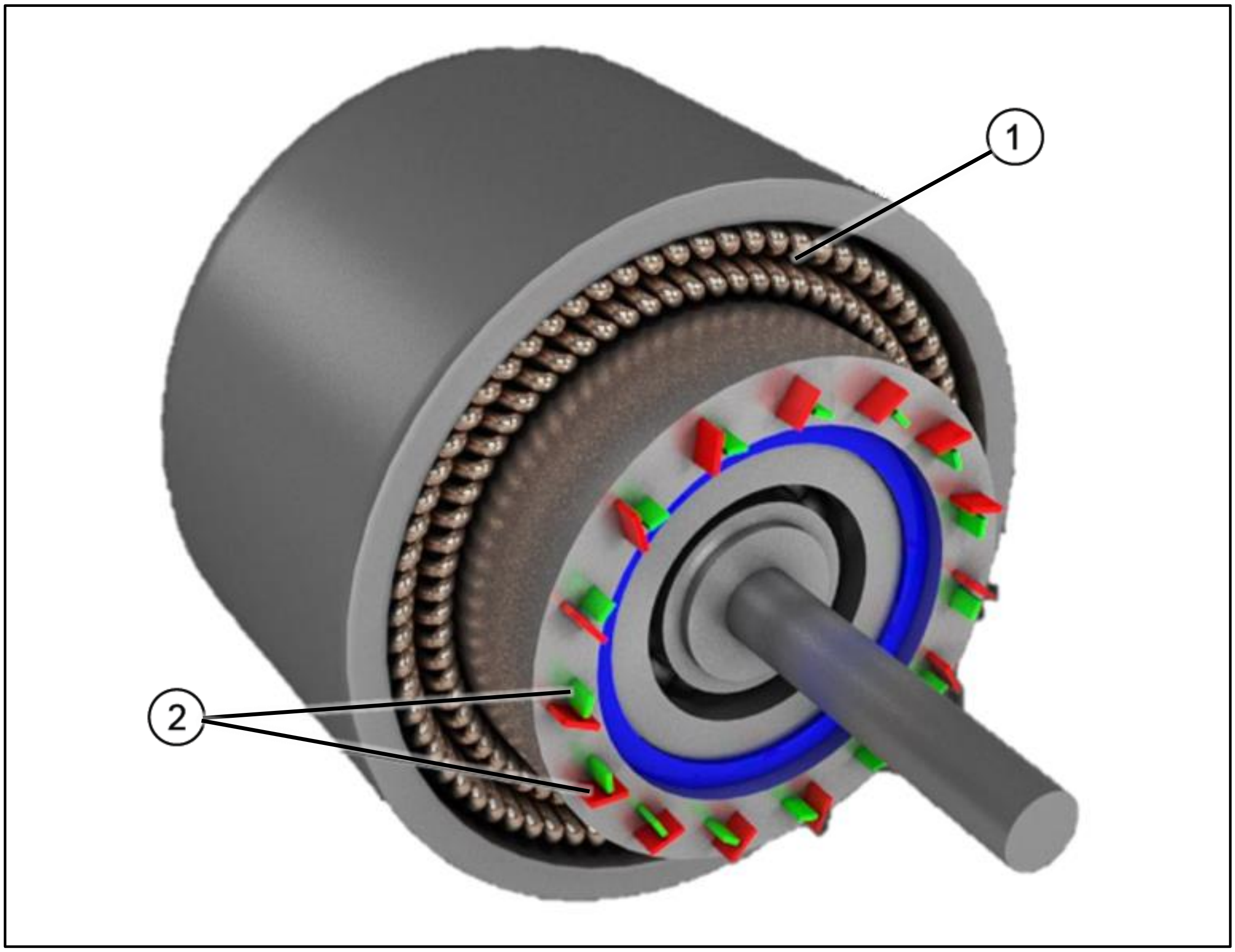
Figure 10-16, Motor / Generator Assembly

Rotor / Motor Types

The MG type is defined by the type of rotor that is used in the MG. Three common types of HEV and BEV MGs are the permanent magnet, slip ring, and induction motors.

Permanent Magnet MGs

The rotor in a permanent magnet MG has high-strength permanent magnets affixed to a shaft. The permanent magnets are oriented in such a manner that the north and south poles of the magnets alternate.



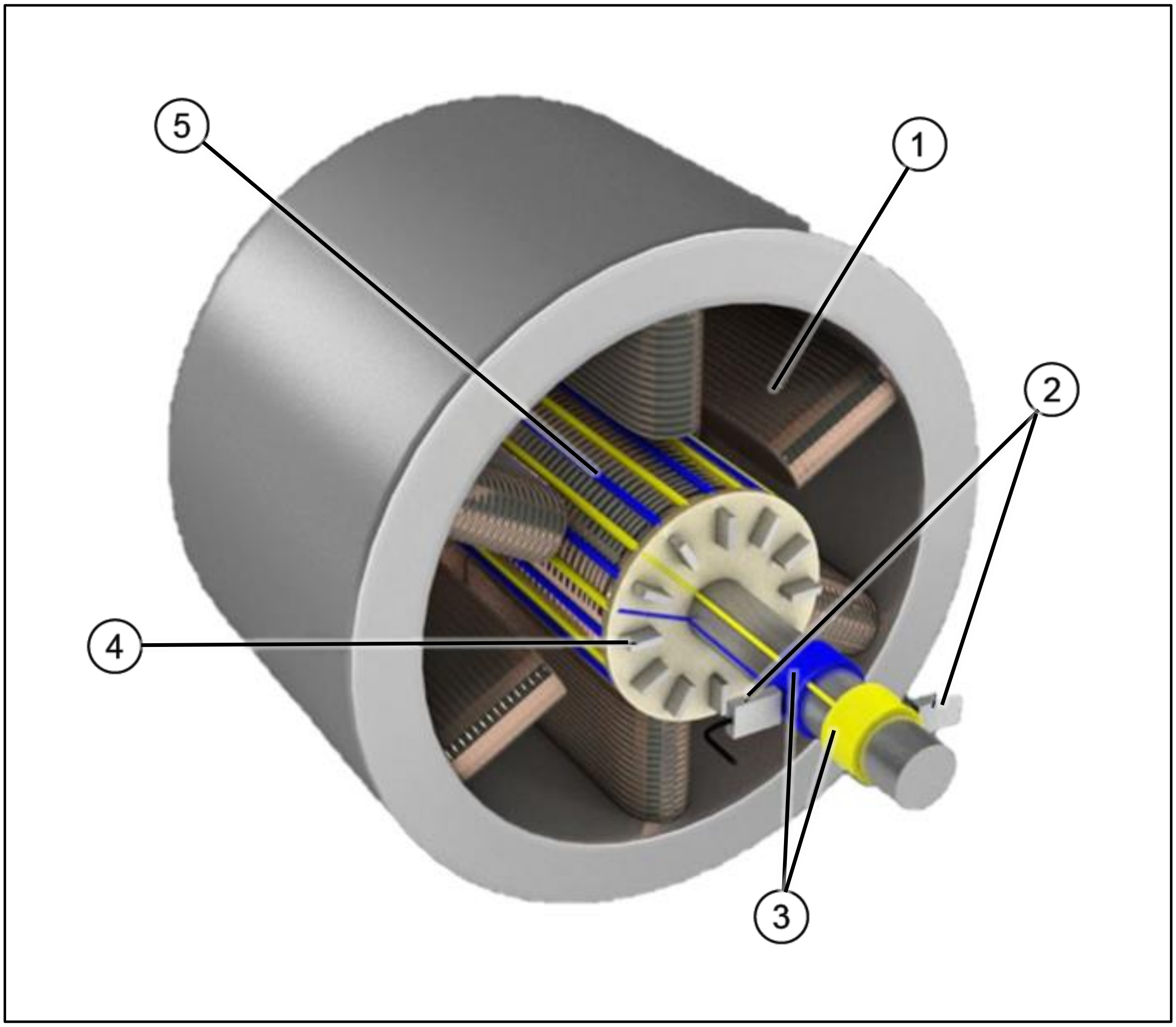
1. Stator Windings	2. Rotor Magnetic Poles

Figure 10-17 Permanent Magnet Motor

Slip Ring MGs

A slip ring design creates magnetism in the rotor by flowing electrical current through windings within the rotor. Slip rings and spring-loaded brushes mechanically connect the moving rotor and windings to the vehicle wiring. As electricity flows through the rotor windings, magnetic fields are created. The magnetic fields within the rotor winding attract and repel against the rotating magnetic field of the stator. Magnetic rotor poles are added to the slip ring design to increase efficiency.

Slip ring motors are often found on belted hybrid drive system MGs.



1. Stator Windings	2. Brushes	3. Slip rings
4. Rotor Poles	5. Rotor Windings	

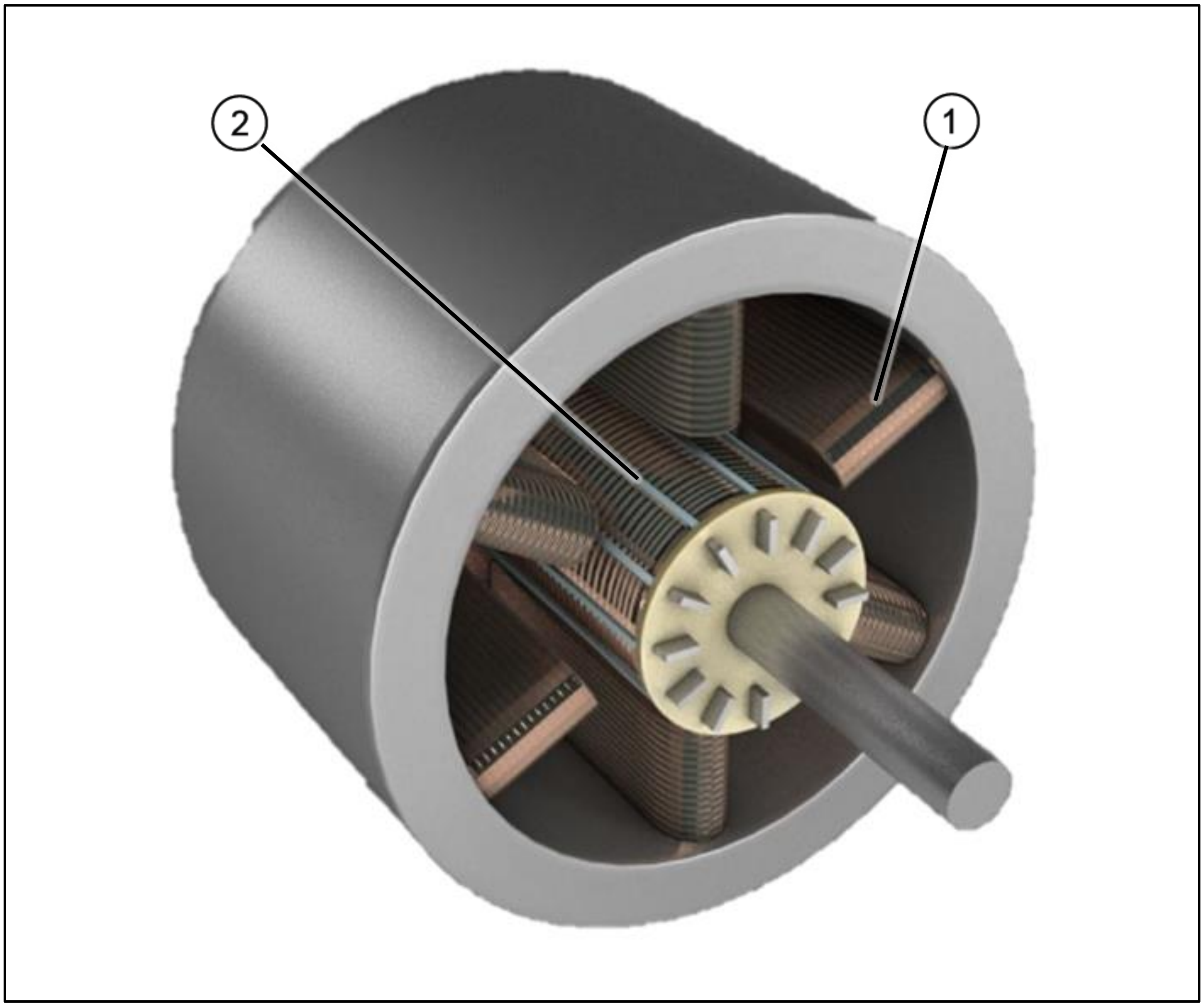
Figure 10-18, Slip Ring Motor

Induction MGs

Induction is the process of using magnetism to induce an electrical current into a winding. When a winding passes through a magnetic field, electrical current is induced in the winding.

In an induction MG, the rotor is typically constructed of aluminum bars connected at each end by shorting rings. The bars are located inside a stack of laminated steel sections that mechanically connect the bars to the shaft. The bars are electrically insulated from the laminated steel sections. The moving magnetic field of the stator induces an electrical current within the rotor bars. Current flowing through the rotor bars creates a magnetic field around the rotor bars. The magnetized rotor bars attract and repel the stator magnetic fields which causes the rotor to turn.

When operating as a generator, current is applied to the stator windings while turning the rotor. This establishes a magnetic field. The rotor is then driven by the vehicle drive wheels which causes the magnetic lines of flux from the rotor to cut across the stator windings. The magnetic field cutting across the stator windings generates a voltage in the stator.



1. Stator Windings	2. Rotor Magnetic Poles

Figure 10-19, Induction Motor

Resolvers and Encoders

There are two basic types of motor position sensors used: resolvers and encoders. Resolvers are commonly used with permanent magnet motors because they provide precise position and speed data. Encoders are used with induction motors to provide speed and direction information.

Resolvers

The resolver provides rotor speed, direction, and position to the control module to correctly phase or apply current to the motor stator windings.

The resolver consists of an exciter coil, two sense coils, and an irregularly-shaped ring. The resolver is serviced as one assembly. The resolver fits over the end of the rotor shaft and attaches to the MG housing. The exciter coil and two sense coils are offset 90° from each other and are attached to the stator housing. The irregularly-shaped ring rotates along with the rotor shaft.

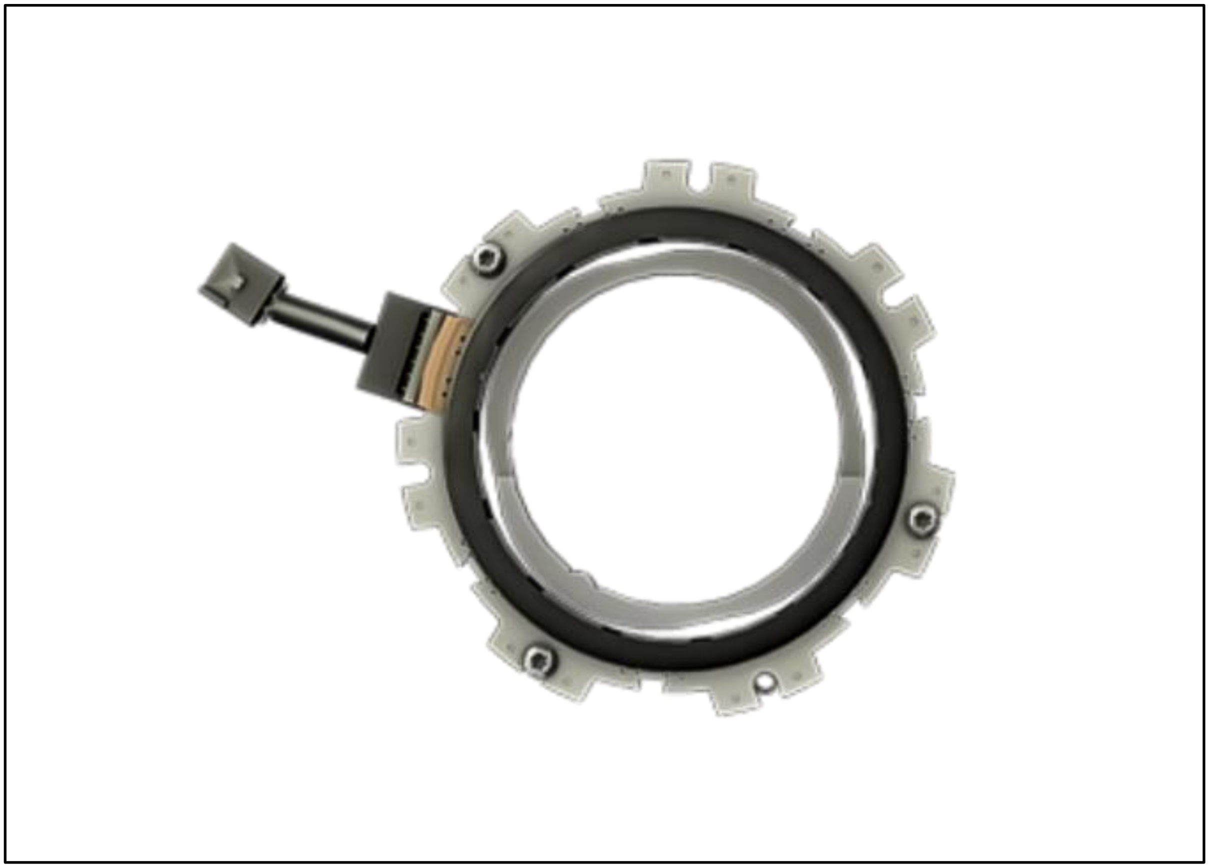


Figure 10-20, Resolver

The motor control module outputs 5V AC, 10-kilohertz (kHz) excitation signals to the exciter coil. The excitation signal creates a magnetic field that surrounds the two sense coils and the irregularly-shaped metallic rotor. The metallic rotor is attached to the MG rotor shaft. Movement of the irregularly-shaped ring causes the magnetically induced return signals of the driven coils to vary in size and shape. Each of the sense coils output a waveform to the motor control module. One sense coil outputs a sine wave, and the other sense coil produces a cosine wave. A comparison of the two driven coils signals allows the motor control module to determine the exact position, speed and direction of the drive motor rotor.

Encoders

The encoder consists of a tone ring mounted to the rotor and a sensor housing mounted to the stator housing. The sensor housing contains two hall effect sensors offset by 50%. This offset allows the motor control module monitoring the sensor to determine both speed and direction of the motor.

Figure 10-21, Encoder

MG Diagnosis

The vehicle control module(s) continuously monitor the status of the MGs and MG control circuits. A fault with any of the MG control circuits will likely set a DTC. Check all control modules for DTCs if a problem related to propulsion or HV battery charging exists. Additionally, many of the MG operating parameters can be monitored using a scan tool. This can be helpful when diagnosing intermittent faults.
The following is an example of the MG related scan tool data for a 2018 Chevrolet Volt:

Parameter	System State	Expected Value	Description
Operating Conditions: Vehicle ON / Closed Throttle / Park or Neutral / Accessories OFF, unless otherwise noted			
Drive Motor 1 Current	—	Varies	This indicates the DC current consumed by hybrid electric motor 1.
Drive Motor 1 Inverter Status	—	Varies	This indicates the state of the Motor 1 Inverter.
Drive Motor 1 Inverter Supply Voltage Circuit	—	Varies	This indicates the voltage on the DC bus at the inverter for motor 1. This should be equal to the voltage measured at the inverter for motor 2.
Drive Motor 1 Control Module Negative Supply Isolation Voltage	—	Varies	This indicates the high voltage negative to chassis voltage as measured for motor 1.
Drive Motor 1 Control Module Positive Supply Isolation Voltage	—	Varies	This indicates the high voltage positive to chassis voltage as measured for motor 1.
Drive Motor 1 Phase U Current	—	Varies	This indicates the current flow to phase U of electric motor 1.
Drive Motor 1 Phase V Current	—	Varies	This indicates the current flow to phase V of electric motor 1.
Drive Motor 1 Phase W Current	—	Varies	This indicates the current flow to phase W of electric motor 1.
Drive Motor 1 Position Sensor Offset Learn Status	—	Varies	This indicates the status of the resolver offset learn for electric motor 1. This will update based on any resolver learn, whether performed automatically as part of normal vehicle operation or as the result of a device control.

Parameter	System State	Expected Value	Description
Drive Motor 1 Speed	—	Varies	This indicates the speed, in revolutions per minute, of hybrid electric motor 1 as determined from the resolver.
Drive Motor 1 Temperature	—	Varies	This indicates the temperature for motor 1.
Drive Motor 1 Torque	—	Varies	This indicates the torque value for motor 1.
Hybrid / EV Powertrain Control Module High Voltage Circuit	—	Varies	This displays the high voltage circuit voltage as detected by the hybrid powertrain control module which detects voltage in a range from 0–655.35 V.
Ignition 1 Signal	—	Varies	This parameter displays the voltage of the ignition feed circuit of the hybrid powertrain control module.

Table 10-4, 2018 Chevrolet Volt MG Scan Tool Data

Motor / Generator Servicing

The MG is located inside the transmission on full-hybrid HEVs and BEVs. On most vehicles, the MG assembly, rotor, and stator can be replaced without replacing the entire transmission. Electrical failure of the stator or rotor is rare. However, debris from an internal transmission failure can damage the rotor, stator, or resolver. If servicing a HEV or BEV for an internal transmission failure, the MG rotor, stator, and resolver should be carefully inspected for damage.

It is also important to note that MG stators and rotors are very heavy. Special tools are often required to remove and install these components. Always refer to service information to identify any special tools.

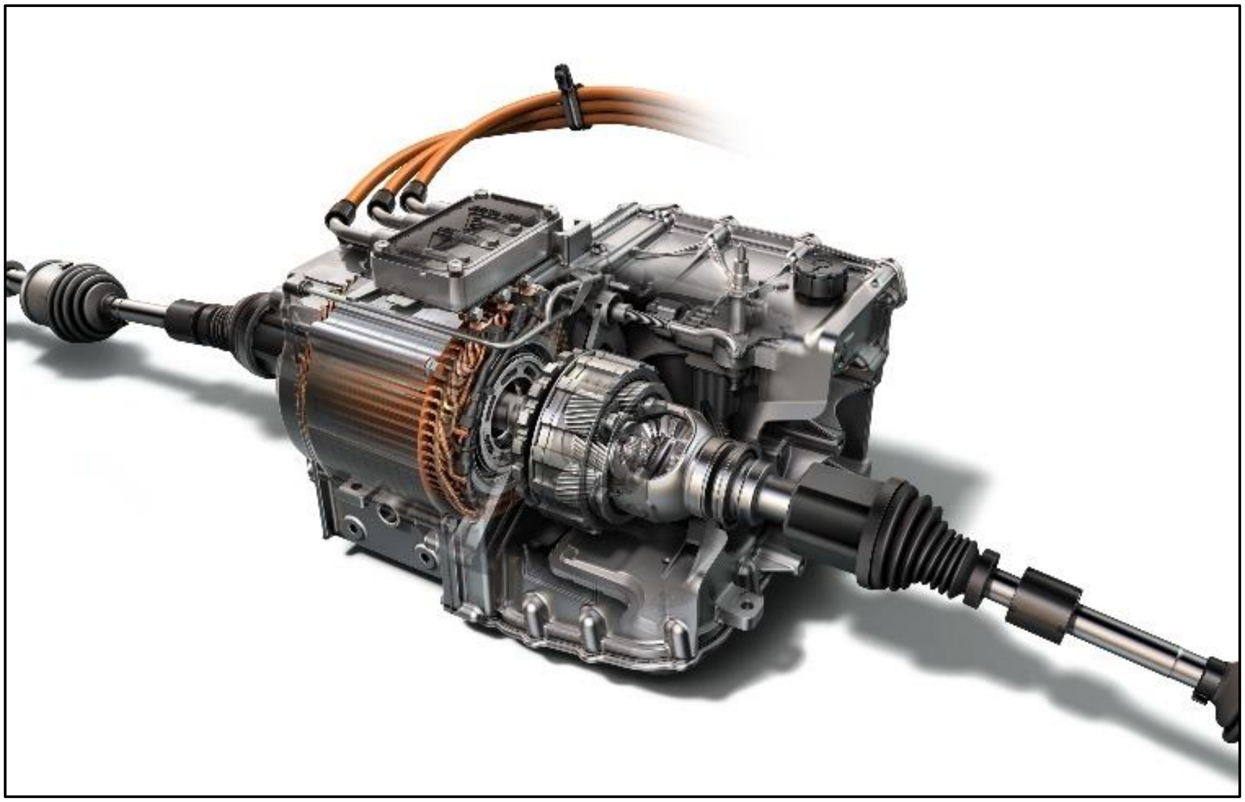


Figure 10-22, Motor / Generator within Transmission Housing

POWER ELECTRONICS

The power electronics monitor and control the flow of electrical power throughout the vehicle. The power electronics consists of the electronic control modules and their related wiring. The primary functions include:

- Rectifying AC voltage to DC voltage from the generator to store in the battery
- Inverting DC voltage from the battery to AC voltage to operate motors
- Converting high voltage DC to low voltage DC to charge the 12V battery and operate vehicle systems

In addition, the power electronics monitor MG speeds and direction, battery temperatures and voltages, and test for a loss of isolation.

Managing the power electronics requires several Electronic Control Units (ECUs) to work in conjunction with each other. Across the various vehicle manufacturers there are several different names for the ECUs that perform these functions. As an example, common General Motors HEV / BEV ECUs include:

- Power Inverter Module (PIM)
- Hybrid / EV Powertrain Control Module 1
- Hybrid / EV Powertrain Control Module 2

- Battery Energy Control Module (BECM)
- Accessory Power Control Module (APCM)
- Engine Control Module (ECM)

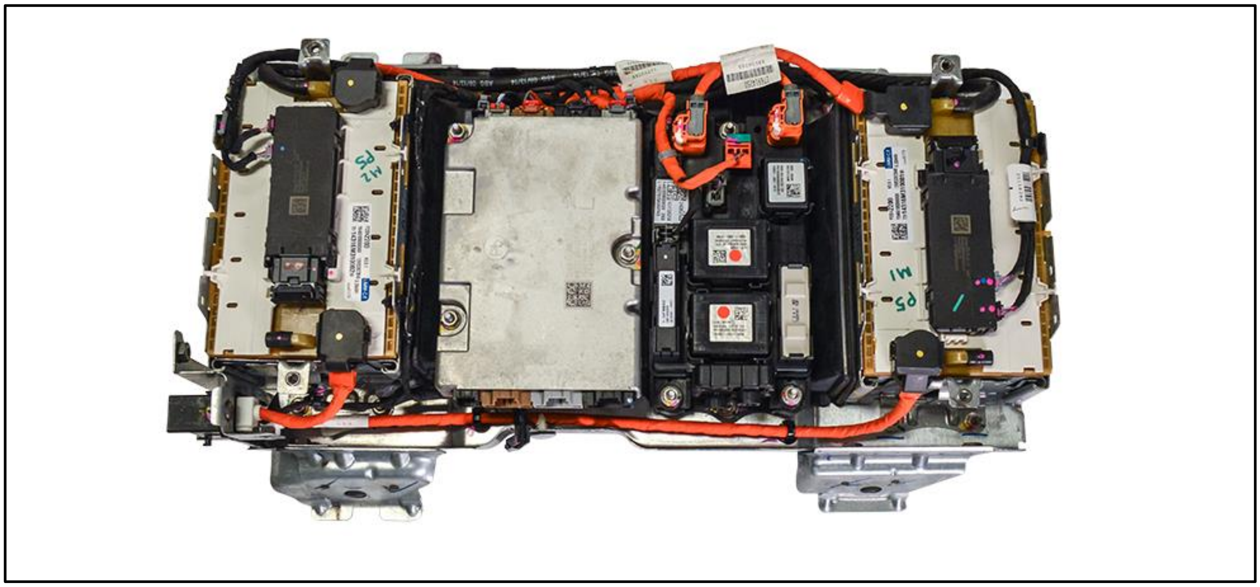


Figure 10-23, Power Electronics

AC to DC Rectification

When the MG is acting as a generator, it is producing AC voltage. The power electronics must convert AC into DC to recharge the battery. Converting AC to DC is done through rectification. Rectification occurs when AC is passed through a rectifier bridge consisting of six diodes. As each phase of AC current passes through the rectifier bridge, the diodes allow current flowing in one direction to pass through while blocking current flowing in the opposite direction. This results in current flowing out of the rectifier bridge in only one direction, thus creating DC. This is the same process used to convert AC to DC within a conventional vehicle's alternator.

DC to AC Inversion

Power inversion is the process of changing DC into AC. DC voltage stored in the battery must be inverted into AC voltage for use by the motor(s). Power inversion is accomplished with the use of Insulated Gate Bipolar Transistors (IGBT)s. Some systems also include a boost converter to increases the voltage level from the battery.

Inversion is accomplished by the PIM switching ON and OFF select pairs of IGBTs. This allows current to flow through a select pair of stator windings. The PIM determines which IGBTs to connect to battery positive and which to connect to battery negative at any given time. By doing so, the control module can alternate the flow of current through the stator windings. Additionally, the control module will cycle the IGBTs in sequence to invert DC into 3-phase AC.

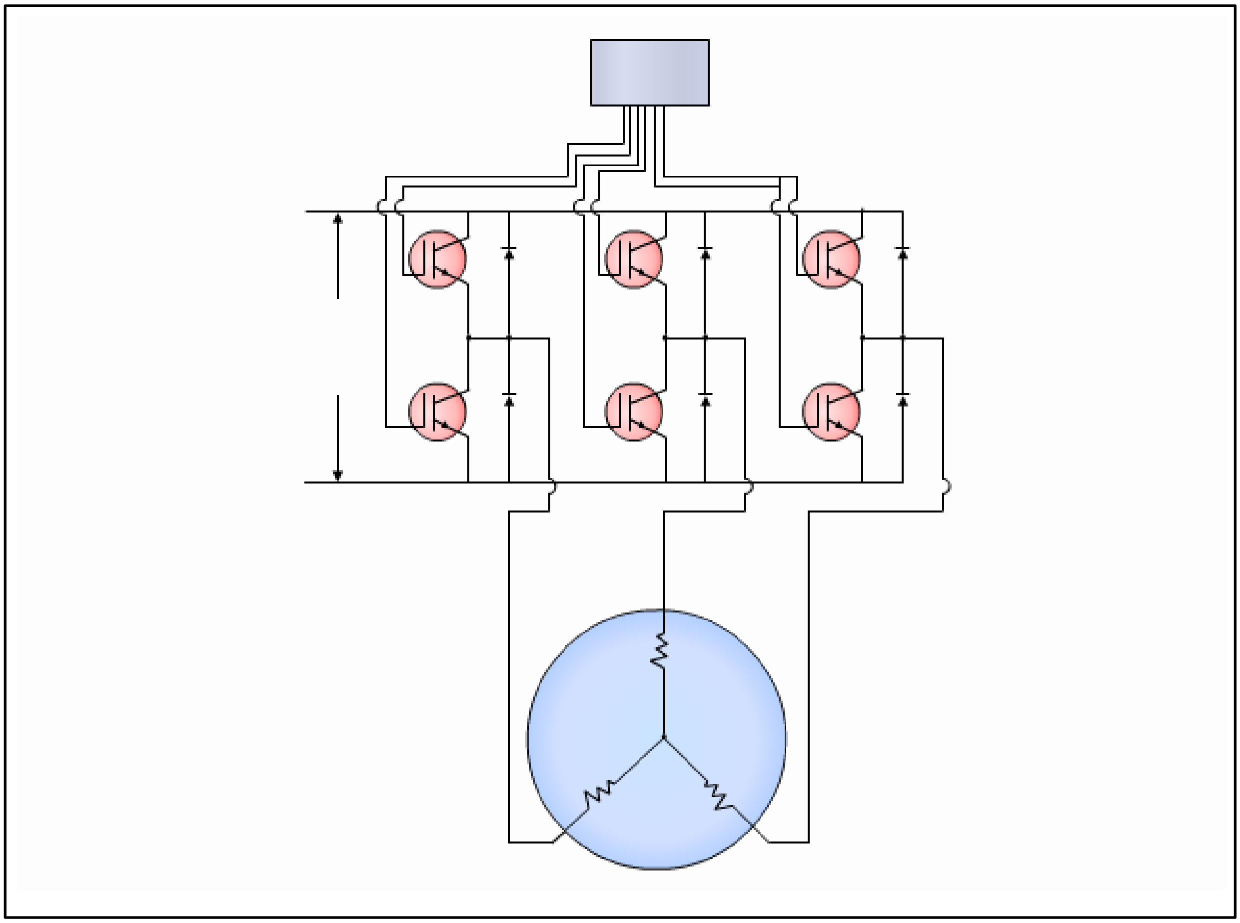


Figure 10-24, IGBT Wiring Diagram

DC to DC Converter

HEVs and BEVs do not have alternators like conventional vehicles. High voltage DC is converted to low voltage DC to recharge the 12V battery and power the low voltage electronics. DC to DC conversion is performed by a DC to DC converter, sometimes referred to as a 14V Power Module or Accessory DC Power Control Module.

The amount of voltage supplied to the low voltage system will vary based on the needs of the vehicle. During low-demand situations where the 12V battery is fully charged, the DC to DC converter may suspend charging. This is normal operation and no repair is needed.

On some vehicles, the DC to DC converter will maintain the 12V battery even when the ignition is OFF. For example: the 2022 Chevrolet Bolt EV will check the 12V battery state of charge every 6 hours when the vehicle is connected to the charge cable and every four days when the vehicle is not connected to the charge cable. The DC to DC converter will charge the 12V battery as needed.

The ECM uses two circuits to control and monitor the state of the DC to DC converter:

- Status circuit
- Control circuit

The status circuit functions much like the F-Terminal circuit on a conventional alternator. A high side driver in the DC to DC converter applies a duty cycled voltage to the ECM. The duty cycle indicates the DC to DC converter internal temperature and operational condition.

The control circuit functions much like the L-Terminal circuit on a conventional alternator. A high side driver in the ECM supplies varying voltage signal to the DC to DC converter. The DC to DC converter adjusts its output based on this signal. A carbon pile tester with an ammeter should be used to test the DC to DC convertor's output.

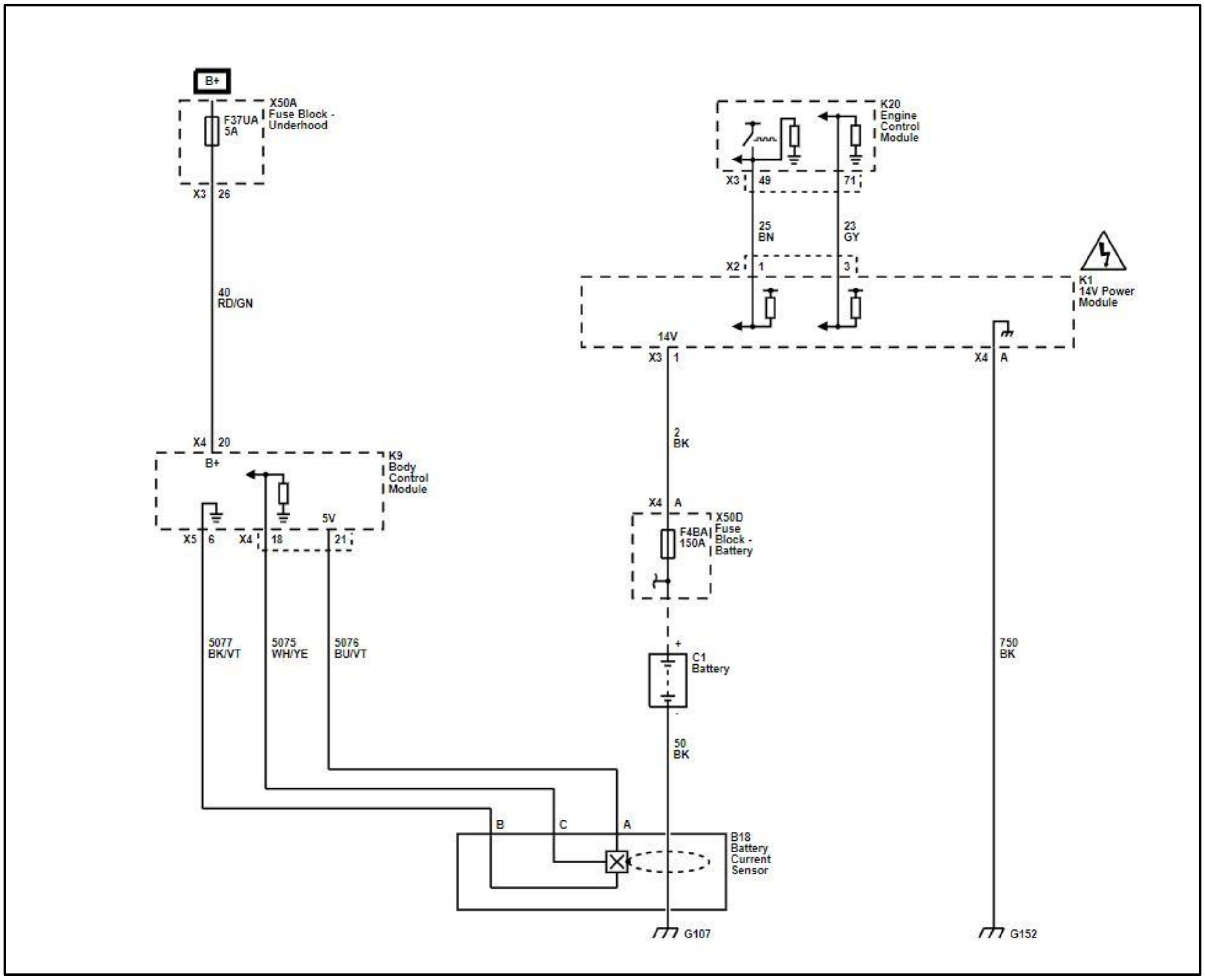
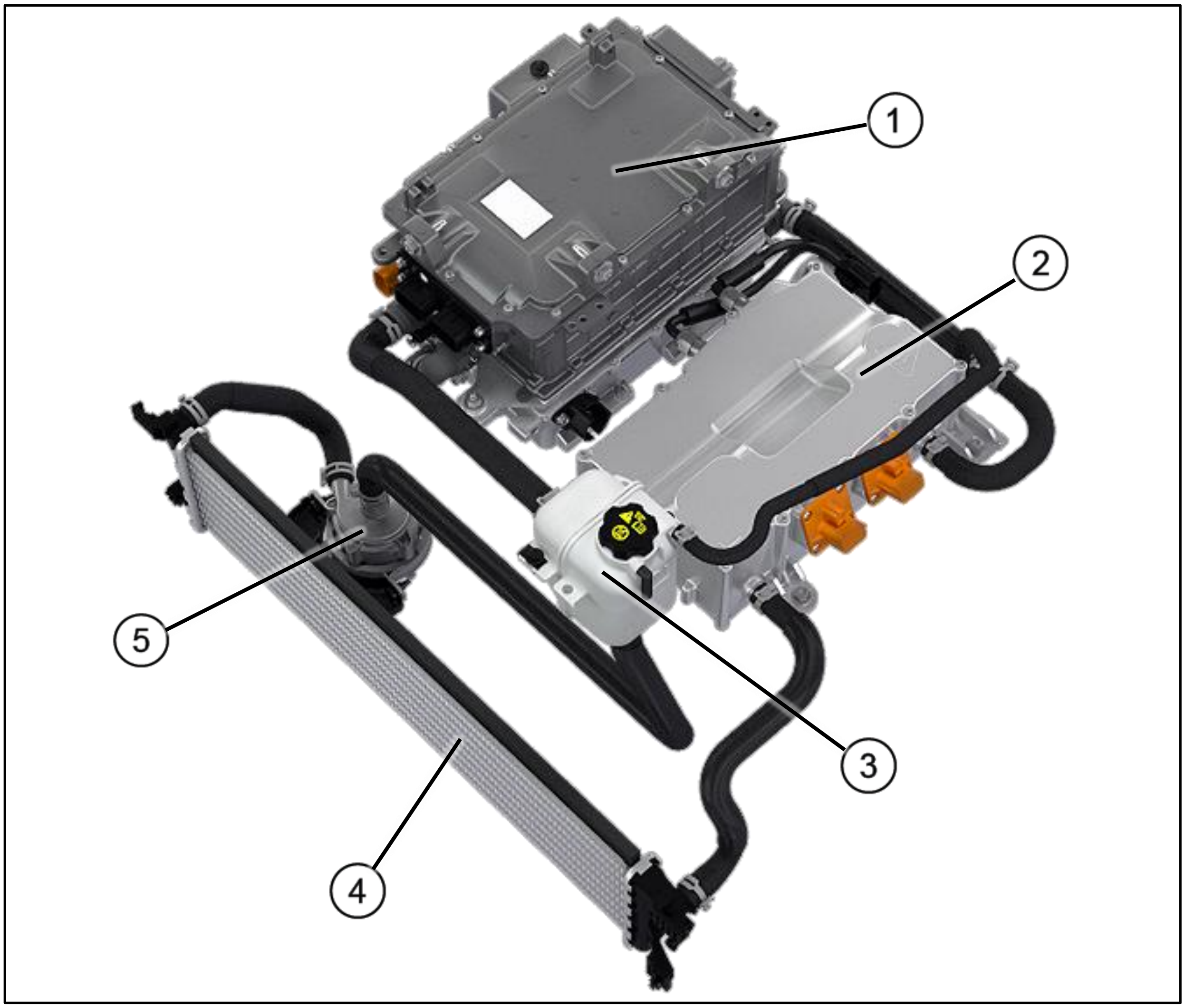


Figure 10-25, Low Voltage Charging System Diagram

Power Electronics Cooling

Power inversion, rectification, and conversion processes generate heat. On mild hybrid vehicles, the power electronics are often located on top of, or next to, the high voltage battery. On these vehicles, the power electronics are air cooled using the same fan and ductwork as the battery.

Full hybrids, BEVs, and some mild hybrids utilize liquid cooled power electronics. Like the high voltage battery cooling system, the power electronics use a dedicated cooling system which includes a separate electric water pump, hoses, fan, radiator, reservoir, and temperature sensors. The water pump runs whenever the vehicle is ON.



1. Power Inverter Module	2. Battery Charger	3. Power Electronics Coolant Reservoir
4. Power Electronics Radiator	5. Air Separator	

Figure 10-26, Power Electronics Cooling System

HV CABLES, CONTACTORS, AND INTERLOCKS

Safely routing current from the high voltage battery to the various components and systems within the vehicle requires the use of specialized cables (wiring), contactors, and a high voltage interlock system.

Voltage Range and Identification

Vehicle electrical circuits can be classified into one of three categories based on their voltage range: low voltage, intermediate voltage, and high voltage. Wiring, connector, and component labeling is color coded to identify the operating voltage range.

Voltage Classification	DC Voltage Range	AC Voltage Range	Color Code	Example Vehicles
Low Voltage	30V or less	15V or less	No Color Code	Conventional Vehicles
Intermediate Voltage	30V - 60V	15V – 30V RMS*	Blue	• Saturn Vue and Astra Hybrid • Chevrolet Malibu • Chevrolet Silverado and GMC Sierra
High Voltage	Over 60V	Over 30V RMS*	Orange	• Chevrolet Volt • Buick LaCrosse • Cadillac ELR • Chevrolet Bolt EV
*Root Mean Square (RMS) represents the effective voltage when measuring AC. RMS voltage is lower than the peak voltage				

Table 10-5, High Voltage Cable Identification

Before working on any components identified as high voltage, PPE must be worn, and the high voltage system must be disabled using the OEM high voltage disabling procedure.

High Voltage Cables

The high voltage cables and connectors on HEVs and BEVs are colored orange to warn of their potential danger. Orange high voltage cables connect the high voltage battery to all the high voltage components on the vehicle. Orange high voltage cables also connect the 3-phase high voltage AC terminals of the PIM to the MG terminals. Ensure that the high voltage system is disabled prior to disconnecting any high voltage wiring cables.

HEVs and BEVs do not use the vehicle chassis as a ground path. All current to and from the battery flows through the high voltage cables.

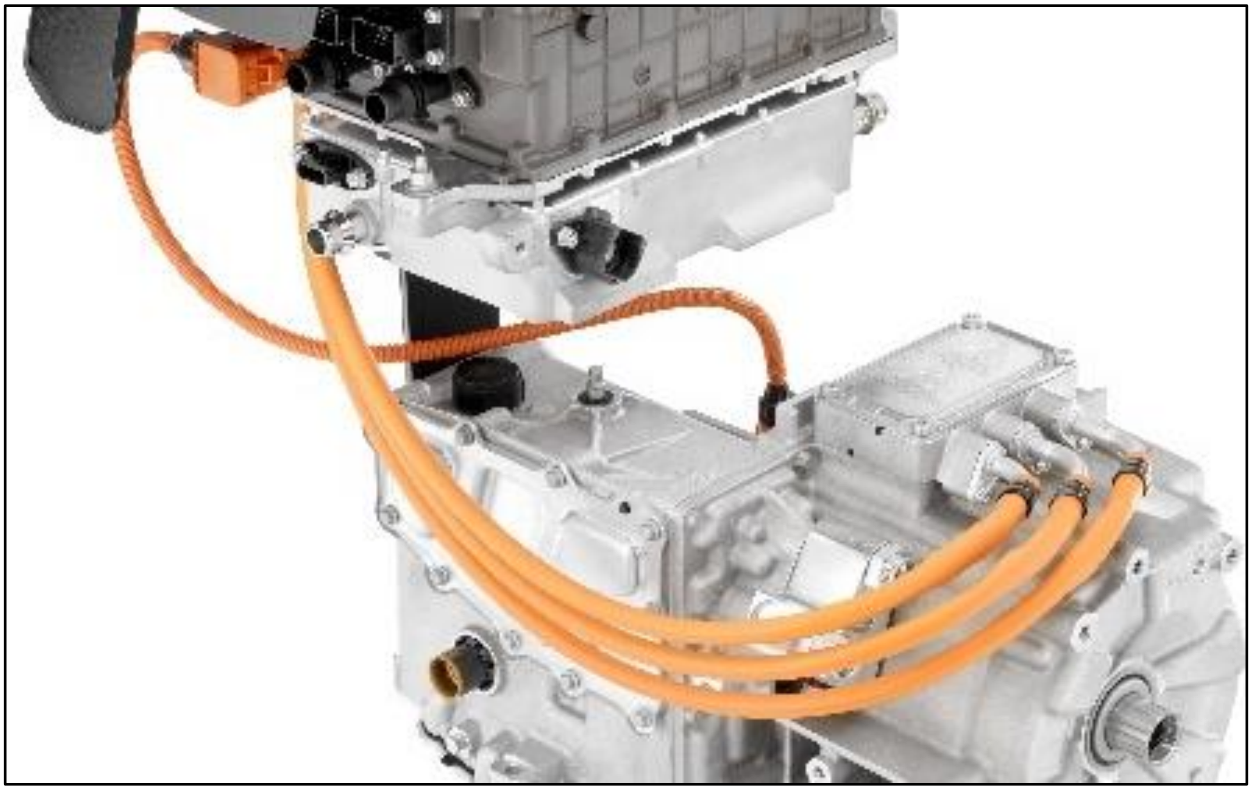


Figure 10-27, High Voltage Cables

High Voltage Connectors

High voltage connectors securely connect the high voltage wiring and components together. HV connectors include a Connector Position Assurance (CPA) lock to ensure a good electrical connection and to prevent components for being accidentally disconnected.

There are several different styles of connectors used on HEVs and BEVs. Using the correct method of disconnecting and reconnecting these connectors is critical to prevent damaging the connector or component. Ensure that all connector seals and locks are in good condition and properly installed. Always refer to service information for the correct disconnecting and connecting procedures.

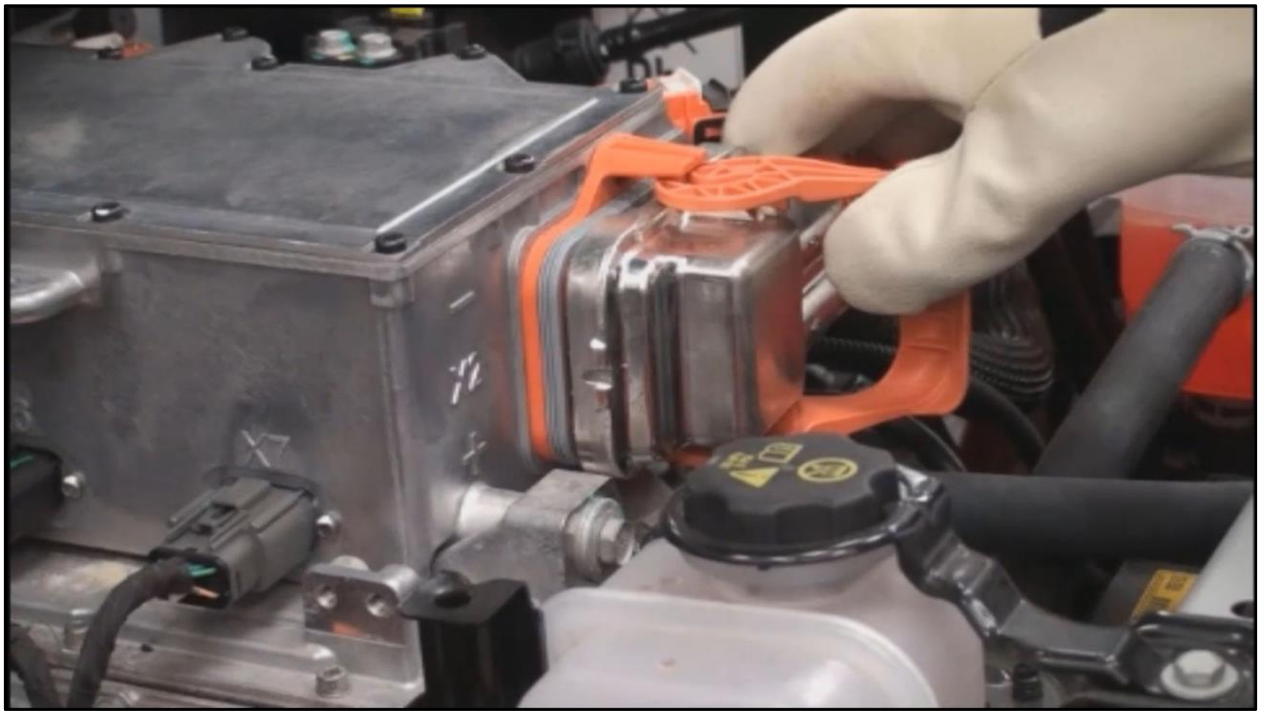


Figure 10-28, High Voltage Connector

High Voltage Contactors

The high voltage contactors turn on to complete the connection between the high voltage battery and the vehicle. The high voltage contactors turn off to contain the high voltage within the battery assembly. Contactors can be thought of as very large relays. Like relays, contactors use a small amount of current to control a large amount of current.

Some contactor systems use field effect transistors, which function as high current solid-state switches. High voltage transistors are often used to control the battery high voltage heating circuit because the battery heater may need to be energized when the vehicle is powered off.

The high voltage battery contains several contactors. All hybrid electric vehicles have three basic contactors: high voltage positive, high voltage negative, and a pre-charge contactor. Plug-in hybrid electric vehicles and battery electric vehicles have additional contactors for the plug-in charging system. These may include a charging high positive contactor and a charging high negative contactor.

The high voltage positive contactor connects the high voltage battery positive terminal to the high voltage positive battery cable. The high voltage negative contactor connects the high voltage battery negative terminal to the high voltage negative battery cable. The pre-charge contactor circuit contains a resistor to allow the voltage on the circuit to build slowly. Depending on the system design, the pre-charge contactor may be located on the positive or negative side of the high voltage system.

The contactors must be opened and closed in a specific sequence to avoid arching and potential voltage spikes which could damage components. For the purpose of demonstration, we will assume the pre-charge contactor is located on the negative side of the circuit.

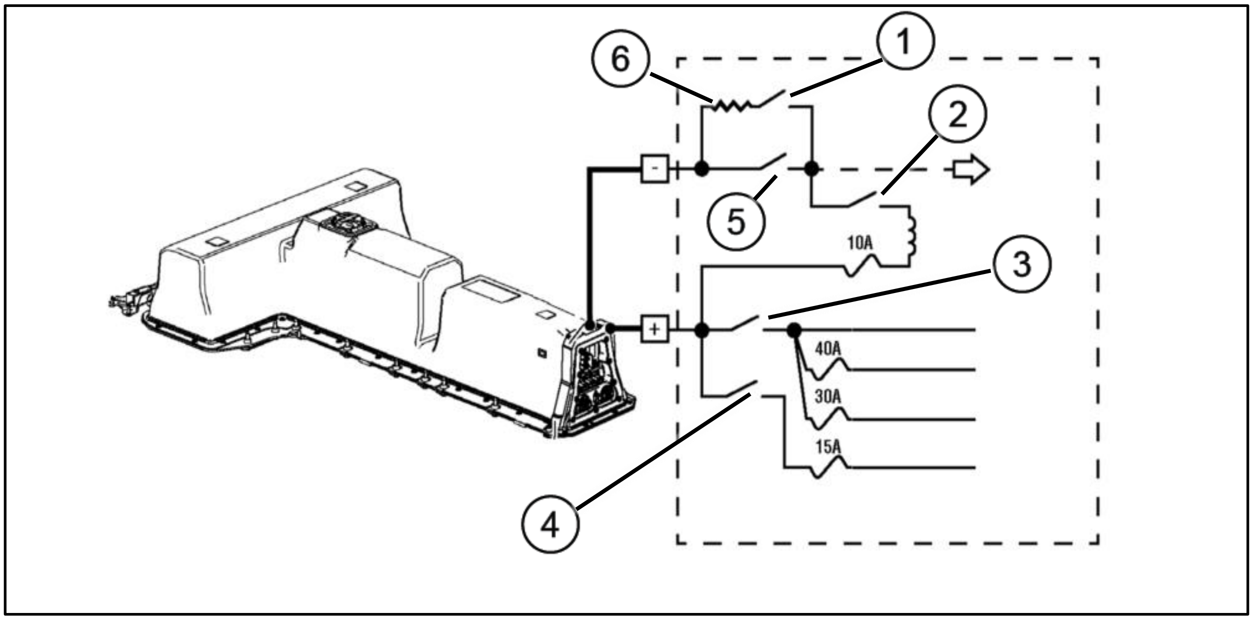
Step 1: The plug-in charger positive contactor and the main positive contactors close first.

Step 2: The pre-charge contactor is closed. This completes the circuit between the high voltage battery negative terminal and the high voltage negative cable through the pre-charge resistor. The pre-charge resistor limits current flow to allow the high voltage system voltage to come up slowly and stabilize.

Step 3: Once the voltage on both sides of the main negative contactor is equalized and stable, the main negative contactor closes. Equalizing the voltage before closing the contactor prevents arcing that could damage the contacts.

Step 4: Once the main negative contactor is closed, the pre-charge contactor is commanded open.

The vehicle will have no electric propulsion if the high voltage contactors fail to close. HEV vehicles may still have propulsion using only the ICE. If the contactors fail to open, high voltage will always be present outside of the battery. The vehicle closely monitors voltage levels at the PIM to determine if the contactors are working properly. Contactors that fail to open will cause a loss of isolation DTC to set.



6. Pre-charge Contactor	7. Battery Heater Contactor	8. Positive Contactor
9. Plug-In Charger Positive Contactor	10. Negative Contactor	11. Pre-charge Resistor

Figure 10-29, Chevrolet Volt High Voltage Contactor Diagram

High Voltage Lockout

The power electronics may monitor for high voltage safety conditions such as airbag deploy events and certain high voltage system faults. When the system identifies one of these conditions, a DTC may set and the vehicle is placed into a 'high voltage lockout' state. While in the lockout state, the high voltage contactor relays are prevented from closing.

The purpose of the high voltage lockout state is to allow for high voltage system inspection prior to re-enabling. A complete inspection of the high voltage system and components must be performed if the vehicle has been involved in a collision.

The following conditions may result in a HV lockout state without a corresponding DTC:

- High voltage component replacement
- Low 12V battery event
- SPS programming event
- Airbag deployment / crash event detected: The Inflatable Restraint Sensing and Diagnostic Module may or may not set a DTC but will continue to broadcast a crash event status until reset

On some vehicles, such as the Chevrolet Bolt EV, the “Hybrid / EV Battery Contactor Open Reasons” may be available on a scan tool to identify all past events that commanded the contactors open. The parameters can only be reset by either reprogramming the hybrid / EV powertrain control module 2 or by performing the scan tool Hybrid / EV Battery Contactor Open Reasons Reset function. The parameters should be reset to “NO” once all diagnostic procedures are successfully completed.

On the Chevrolet Bolt, the Clear Secured High Voltage DTCs procedure must be completed when the following components, as applicable, are replaced:

- K16 Hybrid / EV Battery Energy Control Module
- K112A – K112H Hybrid / EV Battery Interface Control Module
- A4 Hybrid / EV Battery Pack
- K114A Hybrid / EV Powertrain Control Module 1
- K114B Hybrid / EV Powertrain Control Module 2

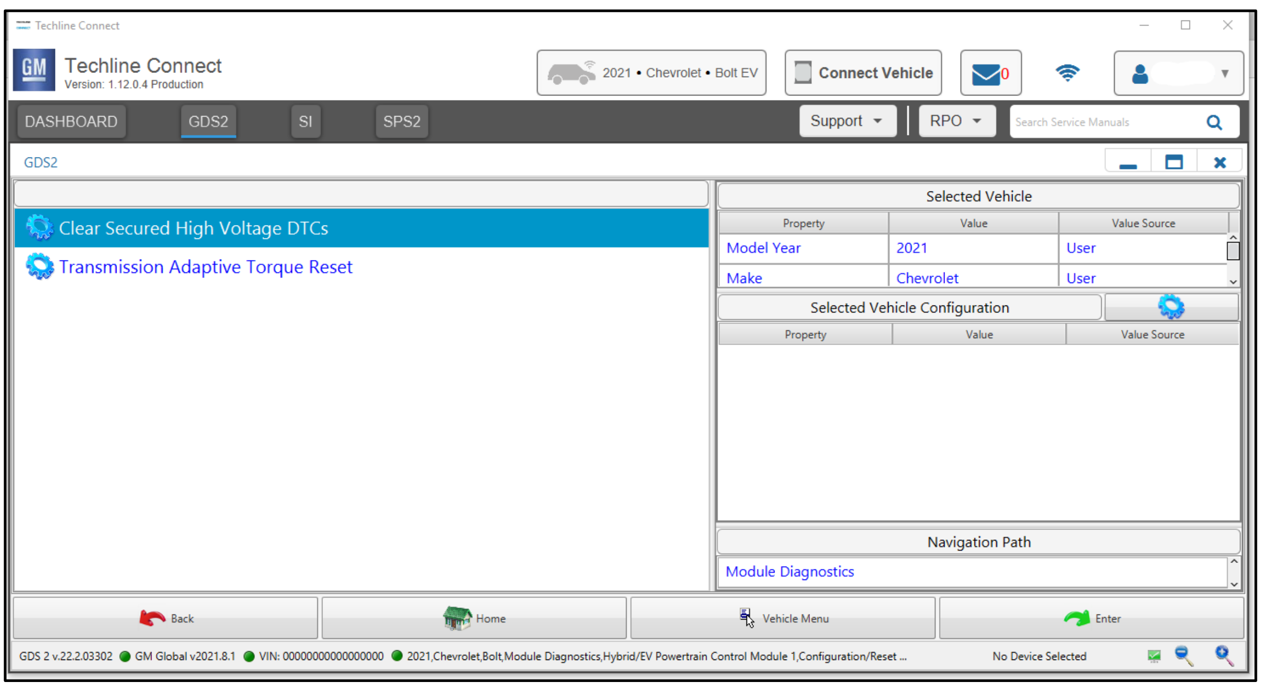


Figure 10-30, GDS2 Clear Secured High Voltage DTCs Function

A scan tool DTC Clear attempt prior to performing the Clear Secured High Voltage DTC output control will result in a Conditions Not Correct error message. The Clear Secured High Voltage DTCs output control will clear all powertrain DTCs.

Clearing powertrain DTCs will set the Inspection / Maintenance (I/M) system status indicators to NO.

High Voltage Interlock

Hybrid and electric vehicles are commonly equipped with a continuous circuit that connects in series through certain high voltage components and connectors. This continuous circuit is referred to as the High Voltage Interlock Loop (HVIL). The purpose of the interlock circuit is to interrupt high voltage whenever a high voltage access cover or connector is removed.

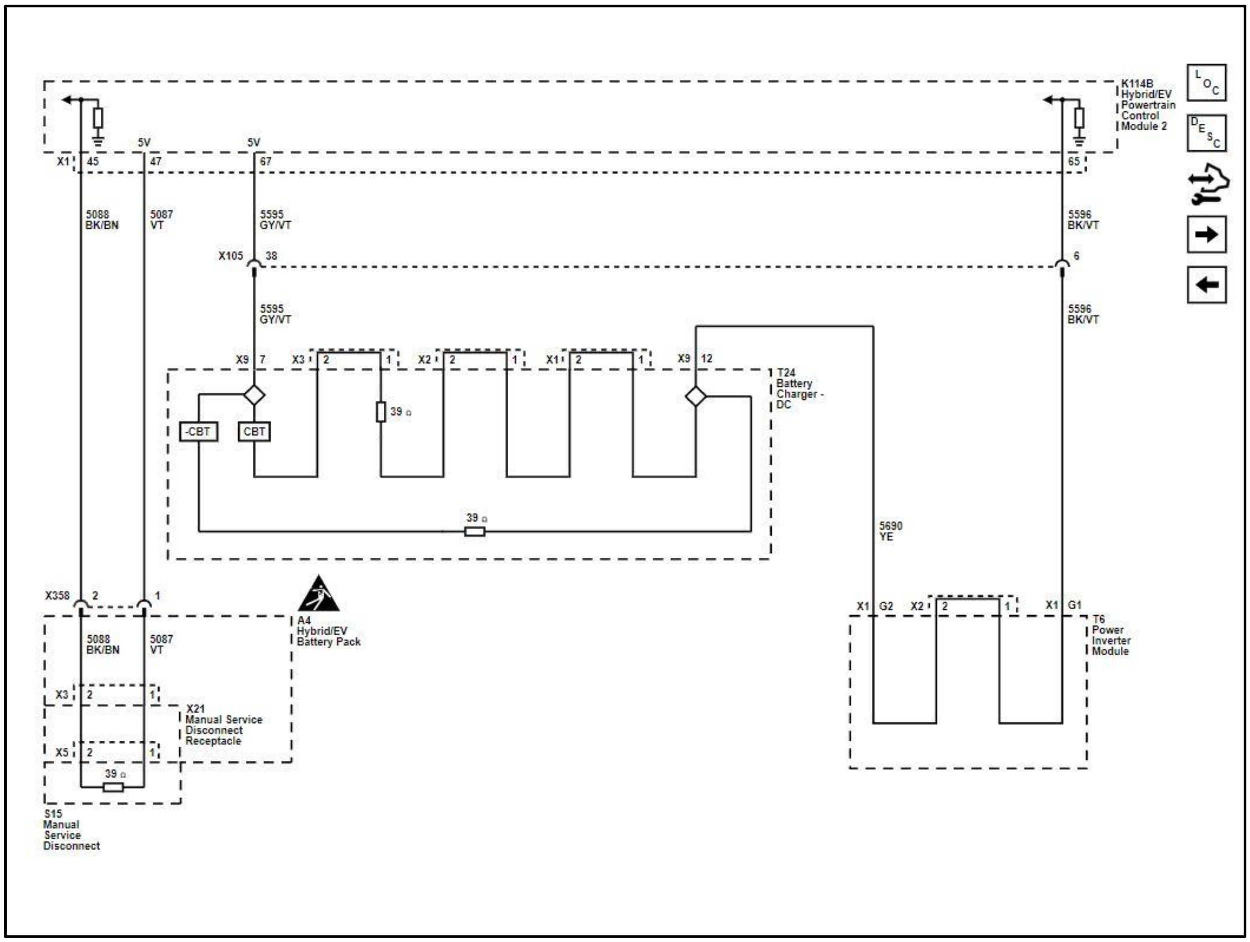


Figure 10-31, Chevrolet Bolt EV High Voltage Interlock Wiring Diagram

The interlock circuit is monitored by a control module which opens the high voltage contactors when the interlock circuit is opened at any point. This prevents accidental exposure to high voltage if a high voltage component is disconnected without first performing the high voltage disabling procedure. The HVIL is a safety feature and should never be relied upon as a substitute for proper high voltage disabling.

There may be a second interlock circuit to monitor the integrity of the high voltage charger circuits on PHEVs and BEVs.

The control module responsible for monitoring the interlock loop sends out a 5V reference signal and monitors the return voltage. If the interlock loop is disrupted, the control module will command the contactors open.

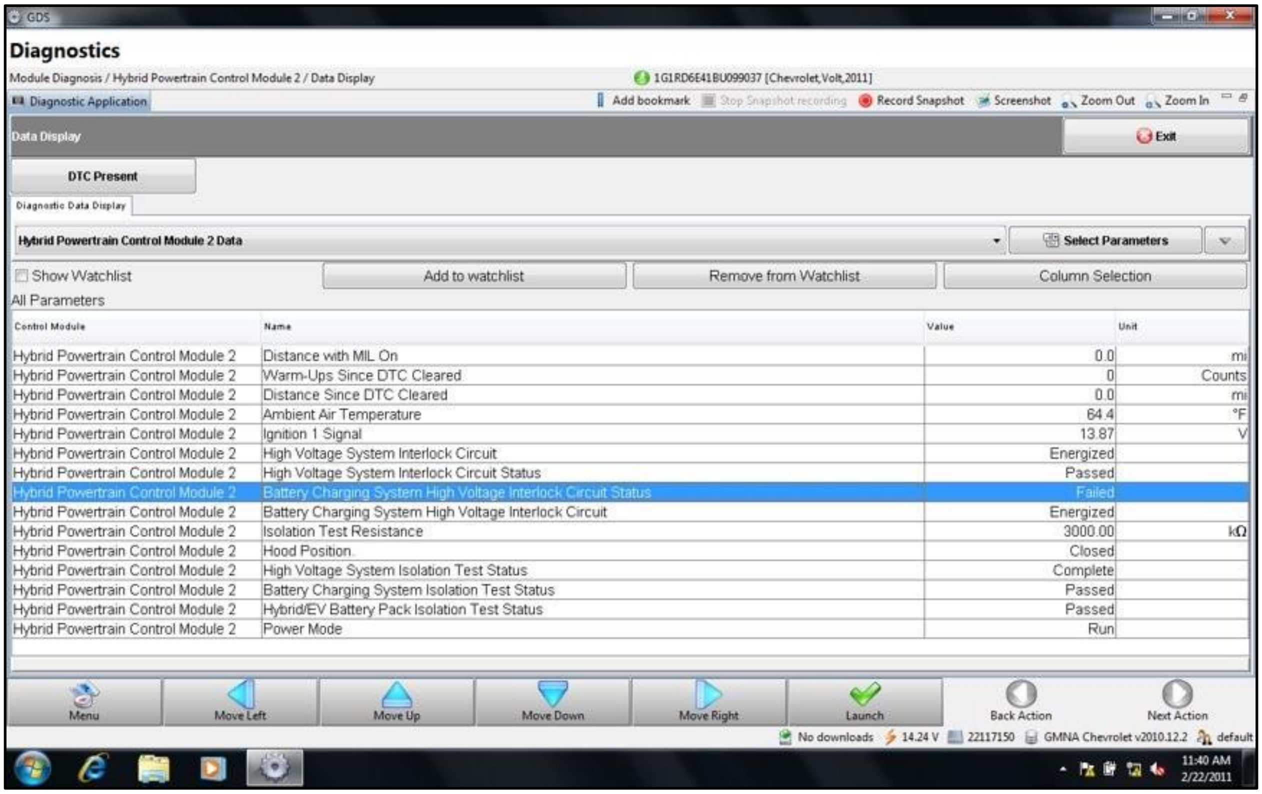


Figure 10-32, Chevrolet Volt GDS2 HVIL Data

Loss of Isolation

All high voltage should be isolated from the rest of the vehicle and exist only within the high voltage components and cables. HEVs and BEVs do not use the vehicle chassis as a ground path. Any high voltage existing outside of the high voltage cables and components is considered a loss of isolation.

Passive and active chassis isolation detection is used to identify a loss of high voltage isolation.

Passive Isolation testing

Passive isolation detection is performed whenever high voltage is supplied to the power inverter module. A pair of resistors connects the high voltage positive circuit to chassis ground and another pair of resistors connects the high voltage negative circuit to chassis ground within the PIM. The PIM uses voltage sense wires, connected between the resistor pairs on each circuit, to monitor the high voltage positive and negative circuits for continuity to chassis ground.

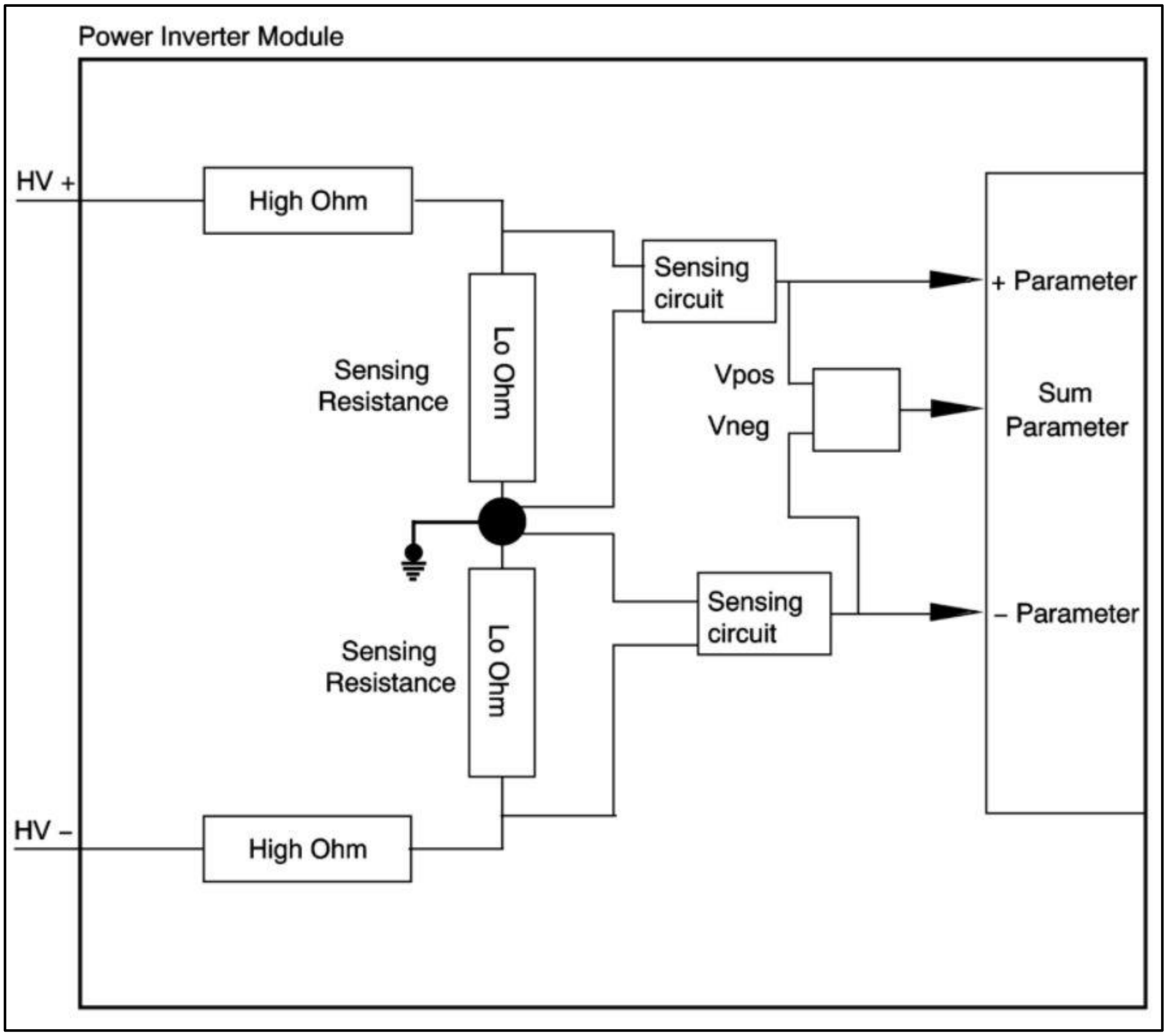


Figure 10-33, Passive Isolation Circuit

A scan tool can be used to monitor the high voltage isolation circuits. When continuity to chassis ground does not exist, the positive isolation voltage, and the negative isolation voltage should each read approximately half of the battery's total voltage. Any electrical connection between either of the high voltage circuits and chassis ground causes a shift in the isolation voltage readings. The voltage reading will decrease on the circuit with the isolation loss. The circuit without a loss of isolation will have an increase in voltage.

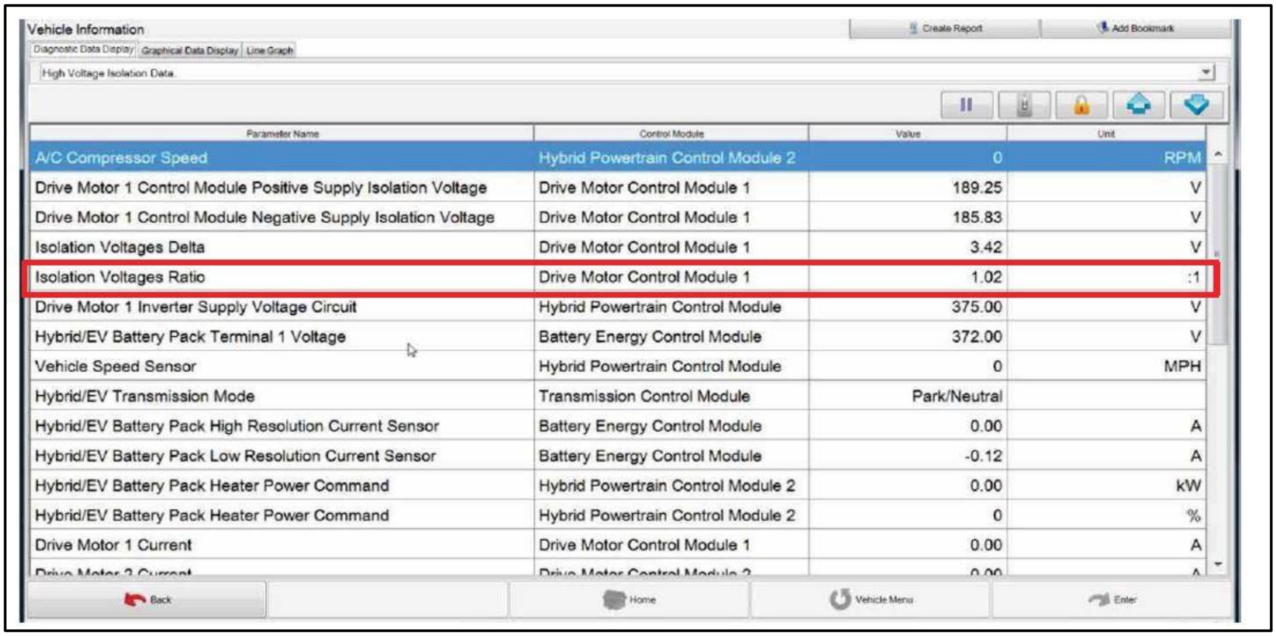
Isolation Loss between HV Components and Chassis, Positive Side*

Isolation between HV Bus and Chassis	Normal Vehicle	10M	5M	1M	500K	200K Approximate DTC set	100K	None – Direct Short
Positive Isolation Parameter*	198V	180V	165V	110V	75V	35V	20V	0V
Negative Isolation Parameter*	192V	210V	225V	280V	315V	355V	370V	390V
Difference Between Parameters	0–15V	30V	60V	170V	240V	320V	350V	390V

*Typical values observed with a fully charged pack, 390V. A short to the positive bus is shown, a short to the negative bus would display inverted voltages of similar value.

Table 10-6, Passive Loss of Isolation Scan Tool Data Parameters

When the voltage shift exceeds a set ratio of 4.53:1, DTCs P1AF0, P1AF2, or P1E22 will set. These readings can be observed using a scan tool.



Parameter Name	Control Module	Value	Unit
A/C Compressor Speed	Hybrid Powertrain Control Module 2	0	RPM
Drive Motor 1 Control Module Positive Supply Isolation Voltage	Drive Motor Control Module 1	189.25	V
Drive Motor 1 Control Module Negative Supply Isolation Voltage	Drive Motor Control Module 1	185.83	V
Isolation Voltages Delta	Drive Motor Control Module 1	3.42	V
Isolation Voltages Ratio	Drive Motor Control Module 1	1.02	:1
Drive Motor 1 Inverter Supply Voltage Circuit	Hybrid Powertrain Control Module	375.00	V
Hybrid/EV Battery Pack Terminal 1 Voltage	Battery Energy Control Module	372.00	V
Vehicle Speed Sensor	Hybrid Powertrain Control Module	0	MPH
Hybrid/EV Transmission Mode	Transmission Control Module	Park/Neutral	
Hybrid/EV Battery Pack High Resolution Current Sensor	Battery Energy Control Module	0.00	A
Hybrid/EV Battery Pack Low Resolution Current Sensor	Battery Energy Control Module	-0.12	A
Hybrid/EV Battery Pack Heater Power Command	Hybrid Powertrain Control Module 2	0.00	kW
Hybrid/EV Battery Pack Heater Power Command	Hybrid Powertrain Control Module 2	0	%
Drive Motor 1 Current	Drive Motor Control Module 1	0.00	A
Drive Motor 2 Current	Drive Motor Control Module 2	0.00	A

Figure 10-34, GDS2 Scan Tool Isolation Voltage Ratio

Diagnostic Tips

Certain isolation loss concerns may only appear during high moisture environmental conditions. Drive the vehicle thru an underbody spraying-style car wash while monitoring the delta between the “Positive Supply Isolation Voltage” and the “Negative Supply Isolation Voltage” scan tool parameters.

Isolation loss might only occur when a high voltage device is active. If a component, such as the cabin heater, has a loss of isolation, it will only be detectable when the cabin heater is turned on. Using a scan tool, operate each HV component while monitoring the delta between the “Positive Supply Isolation Voltage” and the “Negative Supply Isolation Voltage” scan tool parameters.

Active Isolation Testing

Active isolation testing monitors the high voltage battery pack and the charging system HV circuits for a loss of isolation. The control module injects an AC signal onto one side of the high voltage system and monitors the return signal on the other side of the high voltage system. The difference between the injected and returned signal is used to calculate a resistance-to-chassis value. When resistance-to-chassis decreases below a set value, DTCs P0AA6 or P0DAA will set. A coolant leak internal to the high voltage battery pack is a common cause for DTCs P0AA6 and P0DAA.

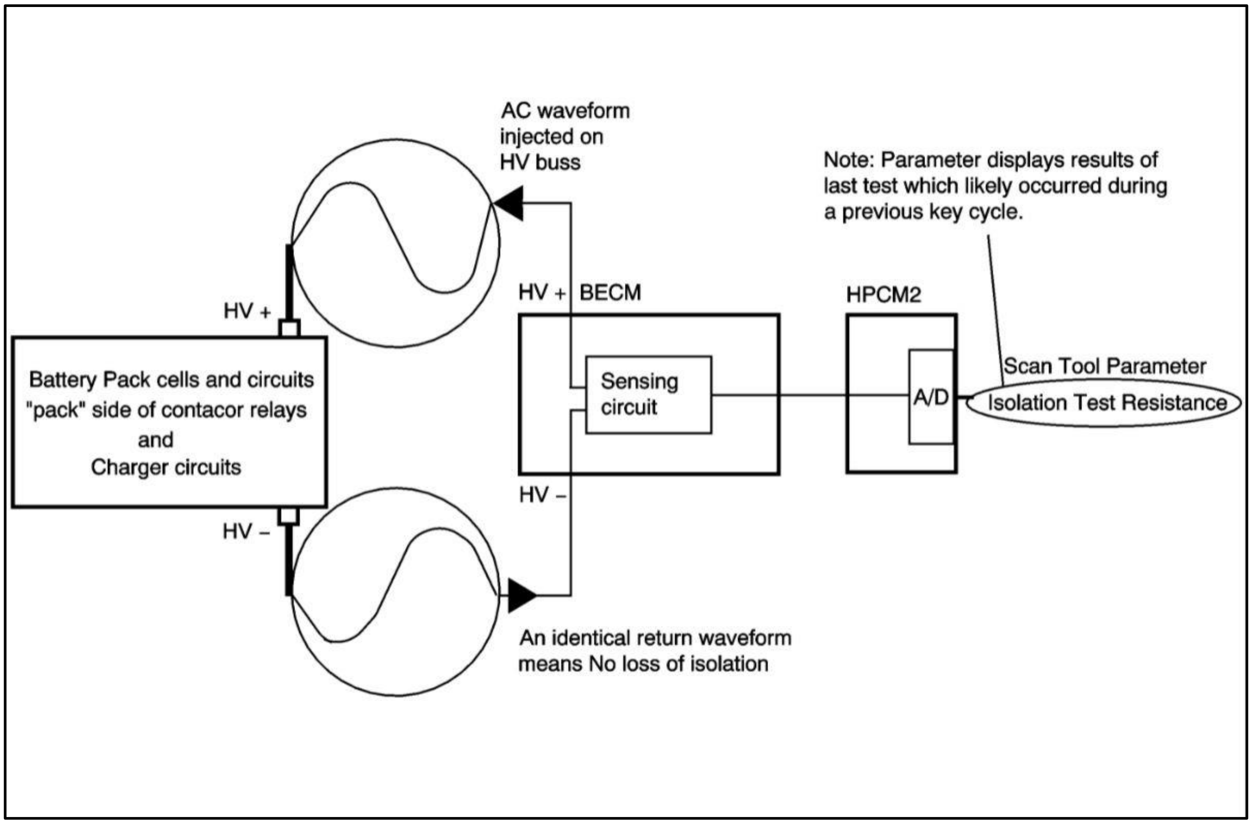


Figure 10-35, Active Isolation Circuit

Active isolation testing occurs when the main high voltage contactor relays are open. For this reason, most testing of the Hybrid / EV battery pack occurs just after the vehicle is shut off following a drive trip. Testing of the charging circuits will also occur whenever the charge cord is connected to the vehicle. The “Isolation Test Resistance” scan tool parameter indicates the resistance-to-chassis calculation determined when the last Active isolation test was performed.

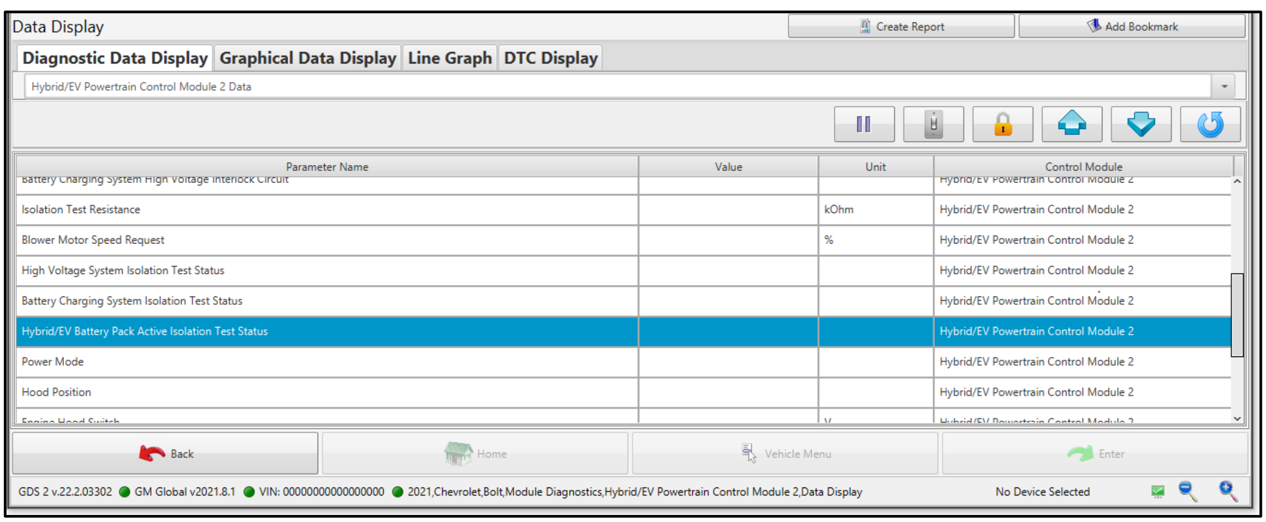


Figure 10-36, GDS2 Scan Tool Active Loss of Isolation Parameter

Loss of Isolation Diagnosis

DANGER: Until you are able to verify that no high voltage exists outside of the battery pack, it should be assumed that dangerous voltage is present and all high voltage precautions should be followed including wearing class 0 gloves and all required PPE.

Circuit and component diagnosis may be required to find the cause of a loss of isolation. Loss of isolation faults may only be detectible when high voltage is present. Using a high voltage insulation testing DMM, such as the Fluke 1587 and the associated test leads, are required to accurately test high voltage circuits and components for a loss of isolation. Insulation testing DMMs work by supplying high voltage through the meter leads to determine circuit resistance. There are many loss of isolation faults that cannot be found using a standard DMM. When using an insulation test meter, it is important to note the following:

- An insulation test can only be performed on inactive circuits
- An insulation testing multimeter may display unfamiliar results
- Using the wrong meter settings or ports will result in incorrect readings

Figure 10-37, Fluke 1587 Insulation Test Meter and Leads

Insulation meter setup

1. Connect the meter leads to the insulation testing DMM using only the ports located in the bottom left of the meter. These ports are marked with + and – symbols.

Figure 10-38, Fluke 1587 Insulation Test Meter Ports

2. Rotate the knob all the way clockwise to the 50V to 1000V Insulation setting. The meter will display a series of dashes.

Figure 10-39, Fluke 1587 Insulation Test Meter Settings

3. Ensure the meter is set to the 500V range. If not, press the RANGE button until 500V shows in the display.

4. With both test leads held apart from each other and not in contact with any object, press the INSULATION TEST button. The meter should display 550MΩ. This is the expected reading for an open circuit.

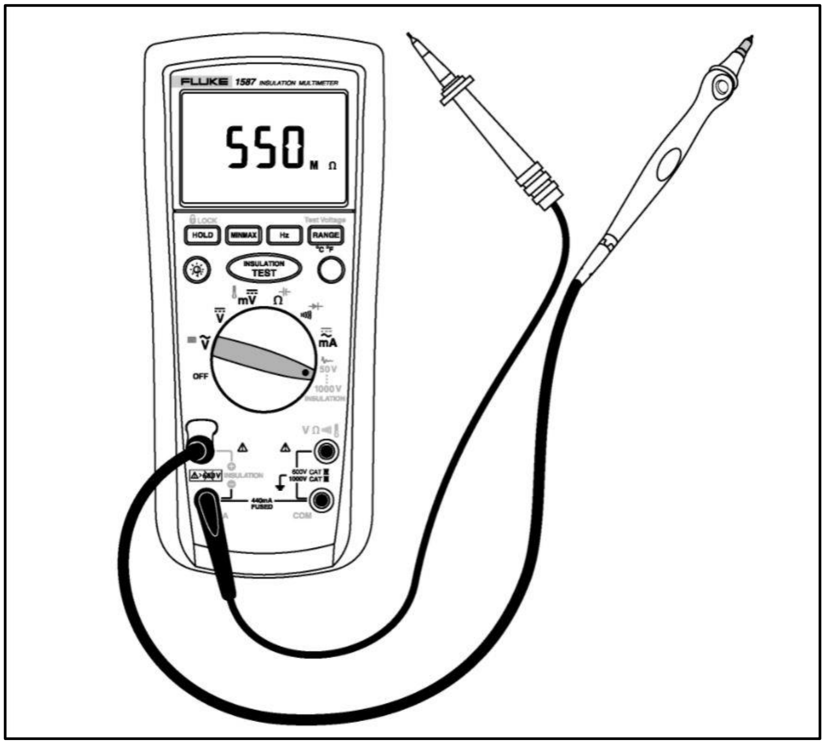


Figure 10-40, Fluke 1587 Insulation test Meter Open Circuit Verification Testing

5. Connect the test leads together and press the INSULATION TEST button. The meter should display 0.0Ω. This is the expect display when there is no resistance between the leads.

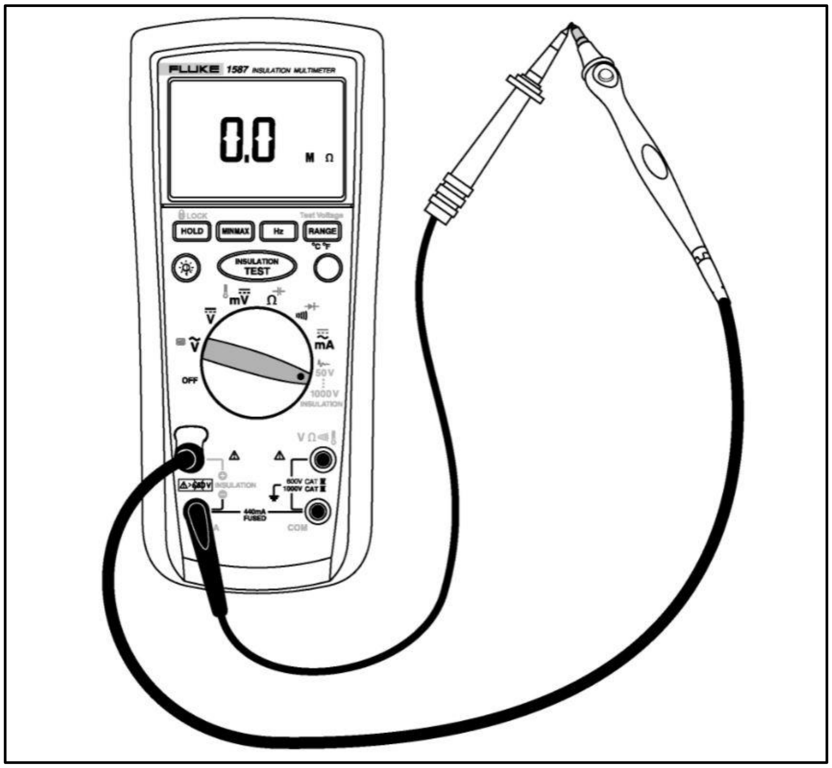


Figure 10-41, Fluke 1587 Insulation Test Meter Closed Circuit Verification Testing

Circuit Testing with an Insulation Meter

After completing the high voltage disabling procedure and setting up the insulation test meter, the insulation meter can be used to locate the cause of the isolation loss. Remember that the insulation meter will supply high voltage in an attempt to detect a breakdown in the insulation.

General loss of isolation circuit testing consists of isolating (disconnecting) the high voltage cables and components, using the insulation test meter to supply high voltage into the component being tested, and measuring for the presence of high voltage outside of the insulated areas. This is done by setting the meter to the 500V scale and connecting the red meter lead to the terminal of the cable or component, and the black lead to the cable or component's chassis ground point and pressing the TEST button. A meter reading of 550MΩ indicates an open circuit. A meter reading less than 550MΩ indicates continuity and a source of isolation loss. Always refer to service information for the vehicle you are working on.

Any damaged high voltage cables or components should be replaced. Never attempt to repair these items.

Figure 10-42, Loss of Isolation Testing

PLUG-IN CHARGING

The high voltage battery on PHEVs and BEVs can be recharged by connecting, or plugging in, the vehicle to the municipal electrical grid. Plug-in charging requires on-vehicle and external charging equipment to work together to transfer electricity from the grid to the battery. There are different charger levels and charger connection types available.

Figure 10-43, Charge Cable Connection

The high voltage battery charging system consists of four main components:

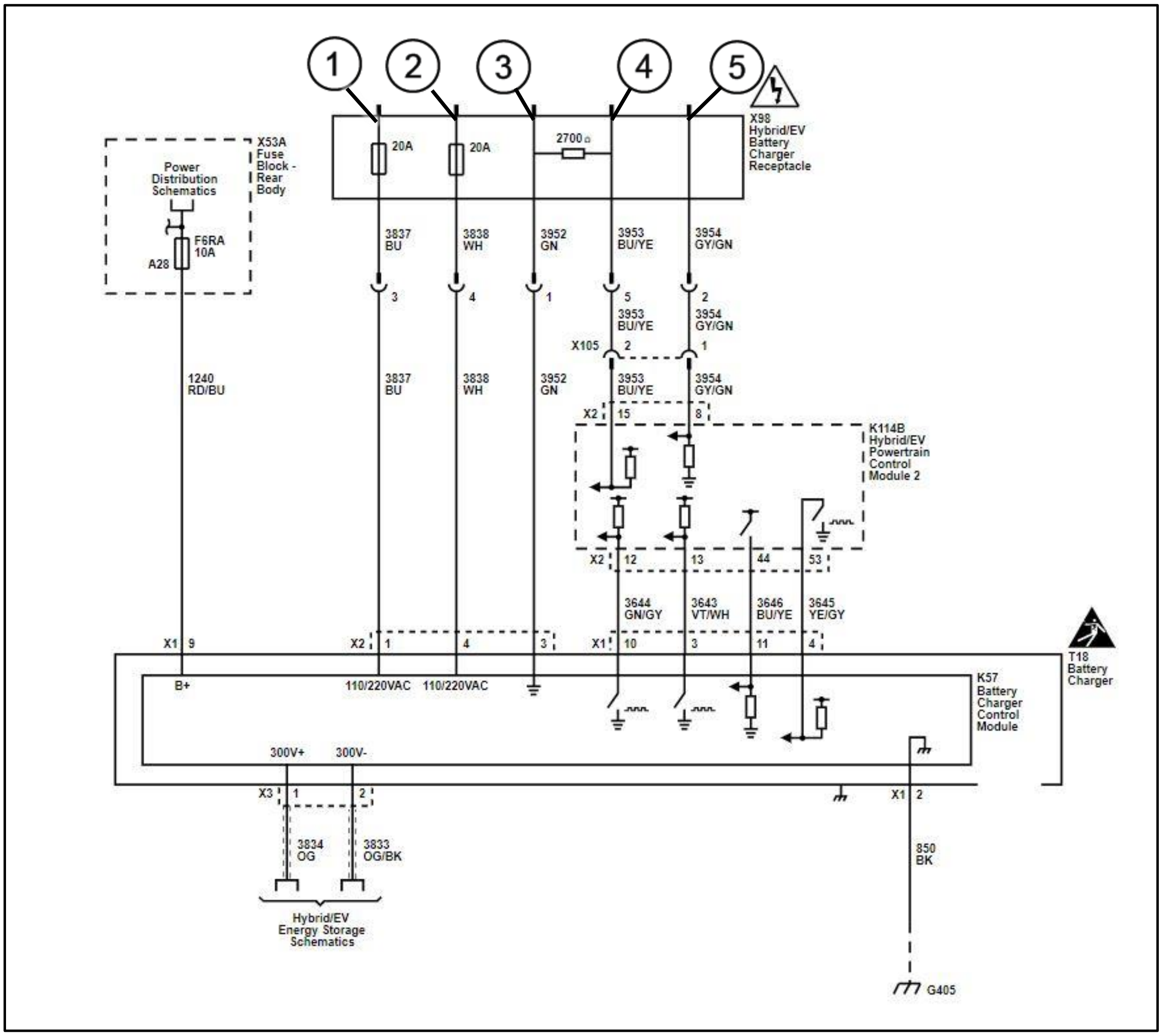
1. The on-vehicle battery charger, often referred to as the drive motor battery charger.
2. The off-vehicle charging equipment:
    a. Drive motor battery charger cable, often referred to as the cord set.
    b. Optional, permanent 220V–240V charge station.
3. The vehicle's battery charger receptacle, often referred to as the drive motor battery charger receptacle.
4. The hybrid / EV battery pack.

1. Battery Charger	2. Charge Port	3. High Voltage Battery

Figure 10-44, On-vehicle Charging Components

Onboard Battery Charger

Alternating current from the municipal grid must be rectified to direct current and amplified for storage into the high voltage battery. This change takes place within the vehicle's onboard battery charger. The vehicle's power electronics detect when the vehicle has been connected to the charge cord. Once connected, the power electronics monitor the battery state of charge and communicate with the battery charger and the charge cord assembly to control the charge rate and battery charge level. As an example, the 2018 Chevrolet Volt uses the Hybrid / EV Powertrain Control Module 2 to monitor the battery state of charge and communicate with the battery charger and the charge cord.



1. Hot L1 Terminal	2. Neutral / Hot L2 Terminal	3. Ground Terminal
4. Proximity Sense Terminal	5. Pilot Terminal	

Figure 10-45, Onboard Battery Charger Wiring Diagram

Additionally, the low voltage battery state of charge is maintained while connected to the charge cord. The onboard battery charger is a serviceable assembly that internally contains several micro-processors and two separate HV chargers. One of the high voltage chargers is used while charging with a 120V level 1 charge source, and both are used with a level 2 240V charge source. The battery charger is liquid cooled as part of the power electronics cooling loop.

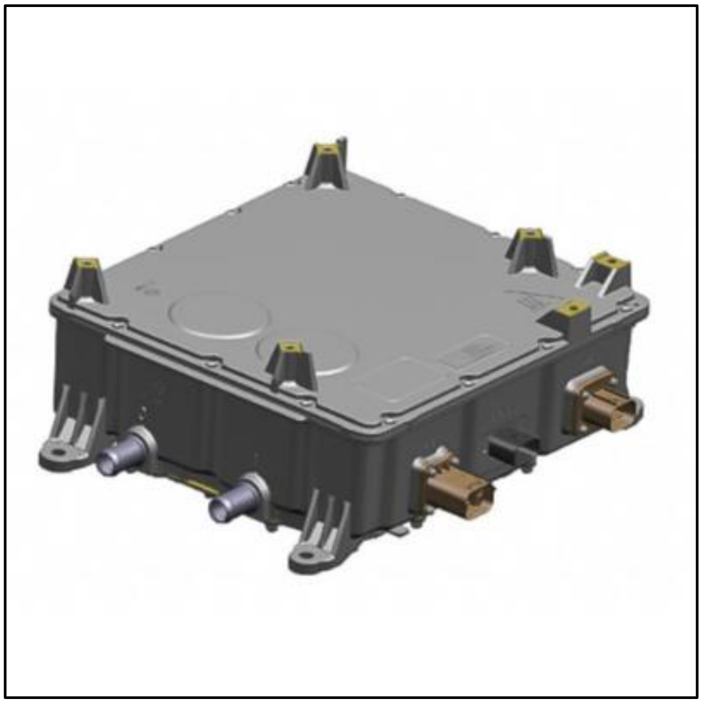


Figure 10-46, Onboard Battery Charger

External Charging equipment

There are three common charging levels in use: Level 1, Level 2, and DC Fast Charge. Each charging level provides different battery charge time depending on the equipment's capability, the battery state of charge, battery capacity, and the battery type. Each charging level has different functionality and connections.

There are also less-common charger types, and more are in development.

Each charging level requires specific offboard charging equipment. The external charging equipment will interface with the vehicle to charge the battery, communicate the battery state of charge, determine charge rate, and detect faults.

Charging Level	Vehicle Range Per Hour of Charging	Source Voltage	Source Amperage
Level 1 AC Charging	4 mi / 1hr @ 1.4 kW	120V	20A
	6 mi / 1hr @ 1.9kW		
Level 2 AC Charging	10 mi / 1hr @ 3.4kW	208 / 240V	20 – 100A
	20 mi / 1hr @ 6.6kW		
	60 mi / 1hr @ 19.2kW		
DC Fast Charging	24 mi / 20min @ 24kW	208 / 480V 3-Phase	20 – 400A
	50 mi / 20min @ 50kW		
	90 mi / 20min @ 90kW		

Table 10-7, Charging Level Outputs

DANGER: Improper use of portable electric vehicle charge cords may cause a fire, electrical shock, or burns, and may result in damage to property, serious injury, or death.

- **Do not use extension cords, multi-outlet power strips, splitters, grounding adaptors, surge protectors, or similar devices.**
- **Do not use an electrical outlet that is worn or damaged or will not hold the plug firmly in place.**
- **Do not use an electrical outlet that is not properly grounded.**
- **Do not use an electrical outlet that is on a circuit with other electrical loads.**

Warning: When using electric products, basic precautions should always be followed, including the following:

- **Read all the safety warnings and instructions before using this product. Failure to follow the warnings and the instructions may result in electric shock, fire, and/or serious injury.**
- **Never leave children unattended near the vehicle while the vehicle is charging and never allow children to play with the charge cord.**
- **If the plug provided does not fit the electrical outlet, do not modify the plug. Arrange for a qualified electrician to inspect the electrical outlet.**
- **Do not put fingers into the electric vehicle connector.**

Level 1 Charge Cord

A level 1 charge cord is provided with the vehicle. The level 1 charge cord has a standard 110V household electrical plug on one end. The other end of the charge cord set has a connector that mates with the vehicle's battery charger receptacle. On average, level 1 chargers provide 4-6 miles of range per hour of charging. This type of charge cord can output between 1.4 kilowatts (kW) and 1.9 kW which works well for "topping off" the battery.

Figure 10-47, Level 1 Charge Cord

Level 1 charge cords have two indicator lamps that provide charging status. These indicator lamps can help identify issues related to battery charging.

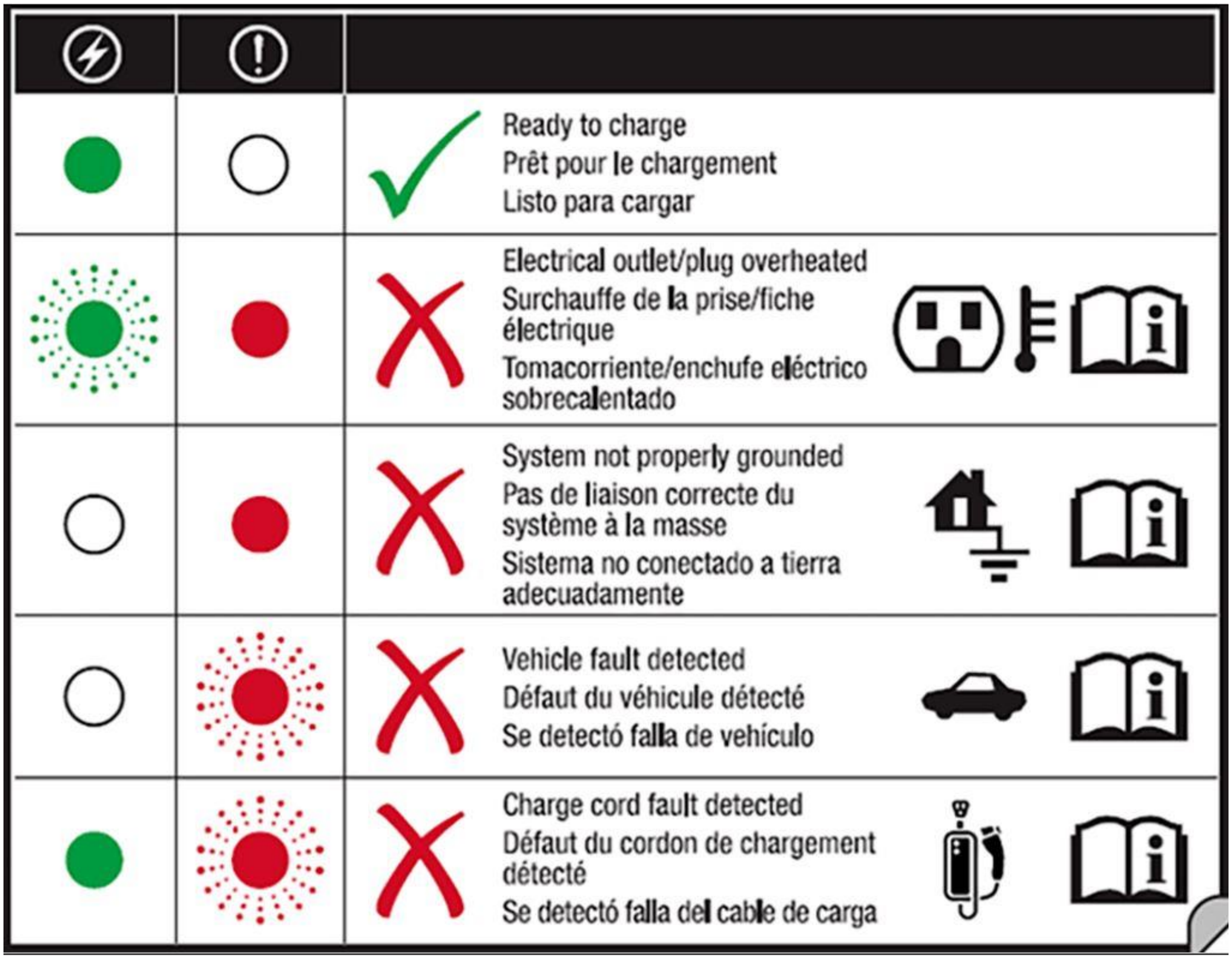


Figure 10-48, Charge Cord Indicator Lamp Chart

Level 2 Charge Cord

Level 2 charge cords use 240V electrical service as a power supply. These units are normally hardwired to the electrical panel at the owner's home or a standalone unit found at many workplaces, shopping centers, and public charging stations. Level 2 charge cords require professional installation. There are a variety of level 2 charge cords available on the market. These chargers can vary slightly in terms of cost, features, and output. Some level 2 charge cords provide 80A of output but a typical level 2 charge cord outputs 30-40A. Average level 2 charge cords deliver between 3.4 kW and 19.2 kW which equals 10-20 miles of range per hour of charging.

Figure 10-49, Level 2 Charge Cord

Some portable charge cords can plug directly into a 110V outlet for level 1 charging or into a 240V outlet like those used on electric clothes dryers and ovens for level 2 charging. However, these units provide a lower output than a permanently installed level 2 charge cord.

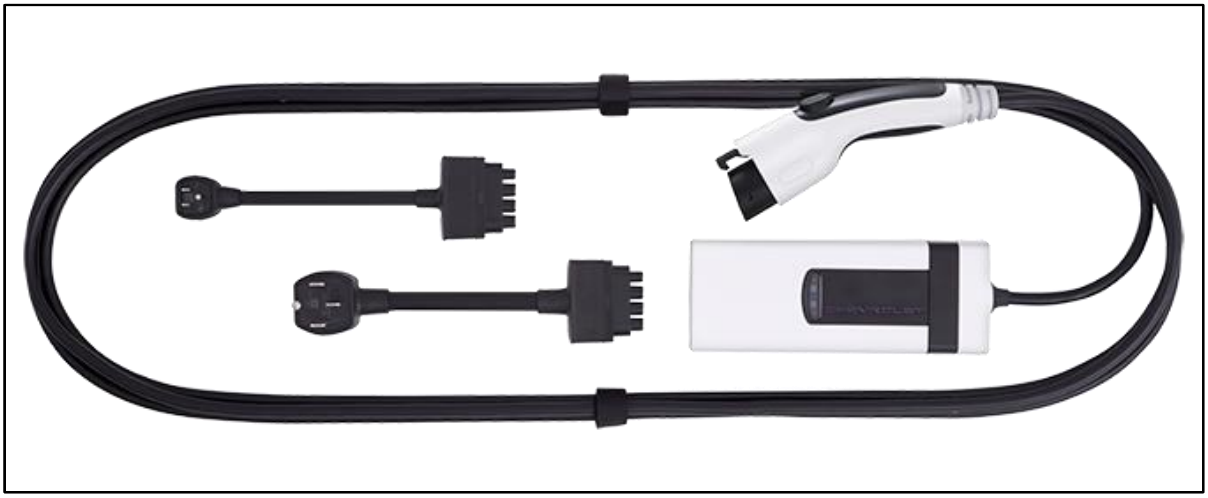


Figure 10-50, Level 1 and 2 Portable Charge Cord

DC Fast Charger

DC fast charging is available on certain vehicles. Unlike level 1 and 2 chargers, the vehicle does not need to rectify AC into DC when using a DC fast charger. Rectification is done within the DC fast charge station. DC fast chargers use 480V 3-phase AC as their power source. For safety reasons, the vehicle latches and locks the charge cord to the receptacle during charging. The charging process must be stopped before the charge cable can be removed. The charging process can be canceled on the charging station or through the vehicle’s driver interface.

DC fast chargers are only available for use at certain public charging stations. This type of charger is normally used when the battery has less than 50% charge. DC fast chargers can output between 24 kW and 90 kW of power. This allows DC fast chargers to charge a battery to 80% in about 20 minutes. As of 2020, over 15% of chargers in the United States were DC fast chargers.

Certain isolation faults can cause DC fast charging to be disabled. The DC Charging Disabled Reset procedure must be completed after the isolation faults have been repaired.

The DC Charging Disabled Reset procedure requires a scan tool sequence and can be completed using the following steps:

1. Vehicle in Service Mode.

2. With a scan tool, select DC Charging Disabled Reset in the Hybrid/EV Powertrain Control Module 2 Configuration / Reset Functions, Reset Functions list.

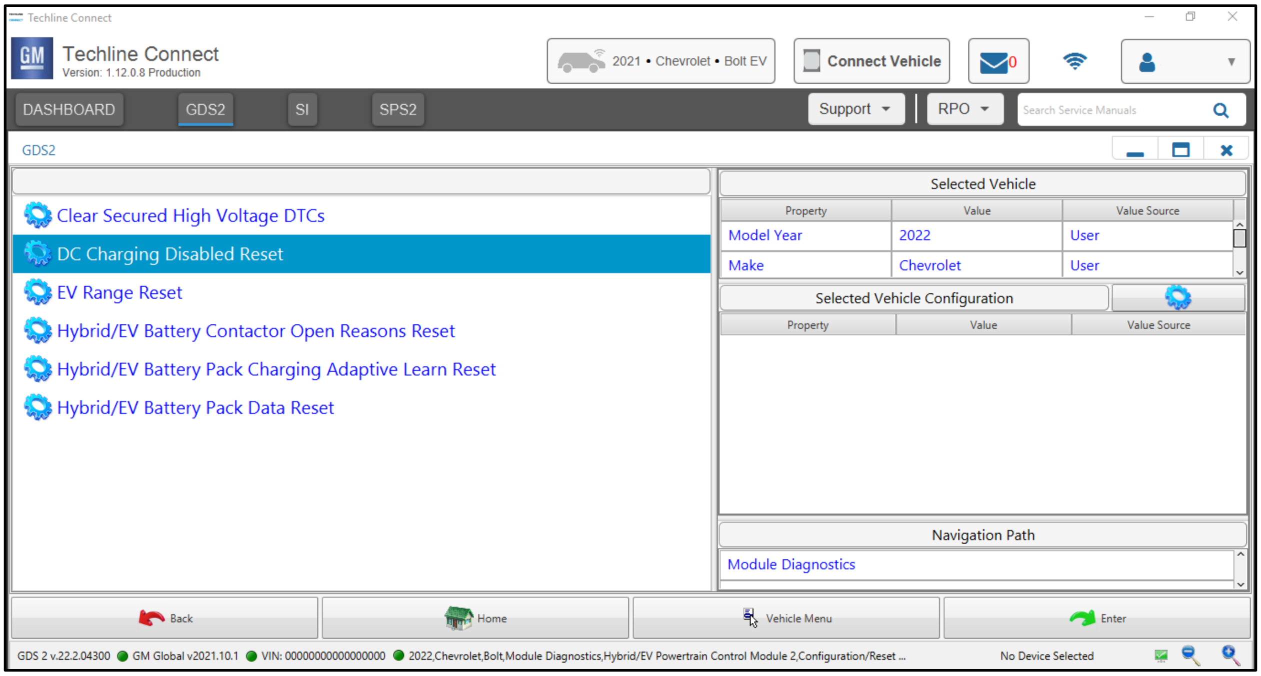


Figure 10-51, GDS2 DC Charging Disabled Reset Function

3. Follow the scan tool directions to complete the procedure.
4. With a scan tool, clear any DTCs that may be set.
5. Vehicle OFF, wait 5 minutes.
6. The vehicle must be driven at a speed greater than 3 km/h (2 MPH) to re-enable DC Charging.

Less Common Charger Types

Extreme Fast Chargers (XFC) have been developed. These chargers can output up to 350 kW of power. However, most PHEV and BEV batteries are not capable of accepting this high of a charge rate. As vehicle and battery technology advances, XFCs may become more common.

Inductive (wireless) chargers have become available. These chargers consist of a wireless receiver installed into the vehicle's charging system and a transmitter mat connected to a 240V outlet. When the vehicle is parked over the transmitter mat the mat induces an electrical charge into the receiver which is used to recharge the battery.

Battery Charge Port

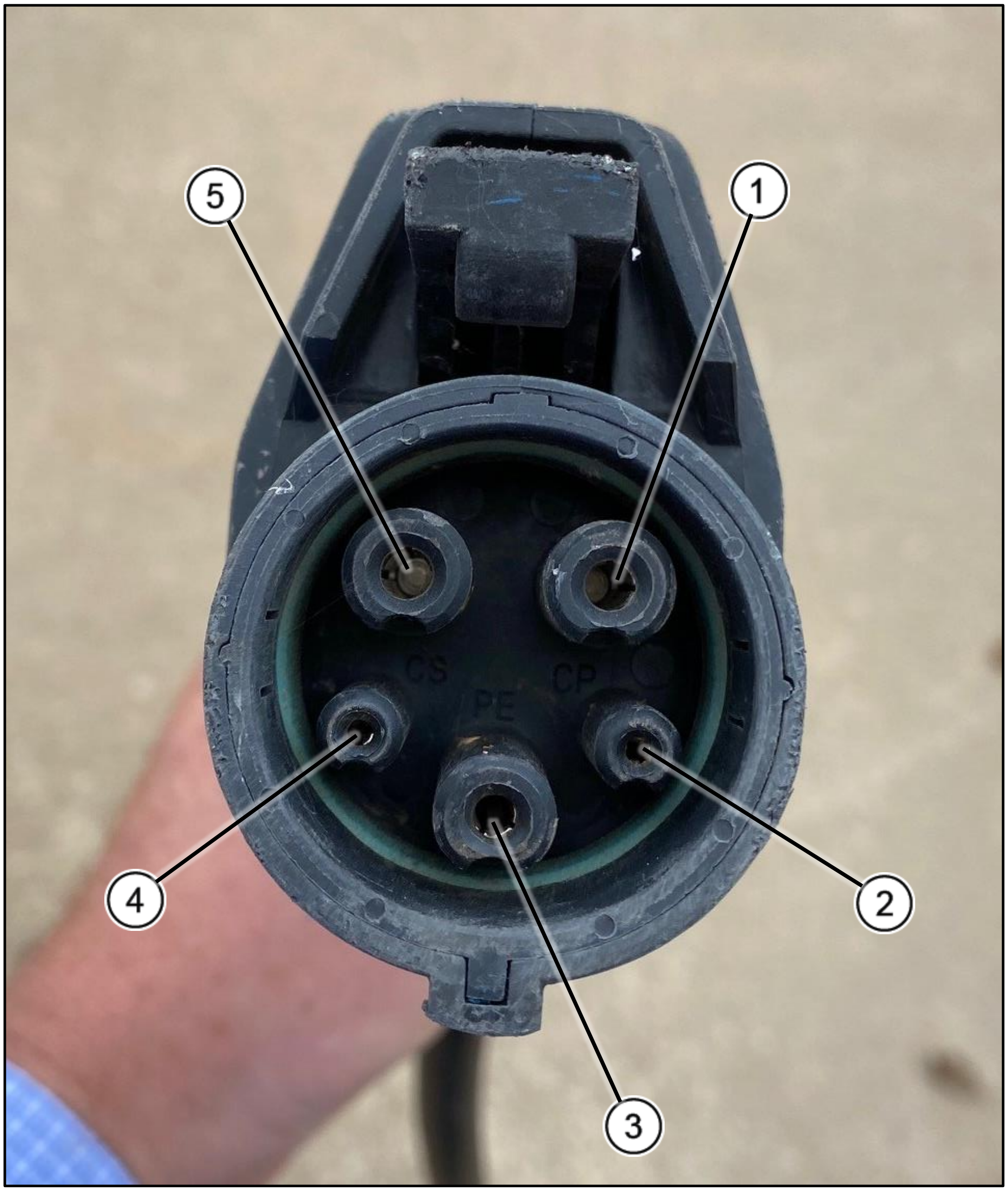
The battery charge port is the connection point where the off-board charger connects to the vehicle. The charge port is sometimes referred to as the charge receptacle. The charge port is normally located on the front fender of the vehicle but may be found at the front center of the vehicle or on the rear quarter panel. A charge port door, like the fuel door found on conventional vehicles, protects the charge port from damage and debris. The charge port door may include a locking mechanism to prevent tampering.

There are 5 common types of charge ports in use today. J1772 and J3068 charge ports are used for level 1 and level 2 charging. Combined Charging System (CCS), and Tesla chargers provide level 1, level 2, or DC fast charging. CHAdeMO charge ports are used for DC fast charging only. There are a few less common charging ports, but we will not be discussing them in this course.

J1772 Charge Port

Most PHEVs and BEVs sold in the United States use a charge port that meets the SAE J1772 standard for level 1 and level 2 charging. This connector provides compatibility between any vehicle utilizing a J1772 charge port and any J1772 charger. The J1772 does not provide DC fast charging capability.

The J1772 connector contains five terminals. Three of the terminals transfer AC voltage from the charge cord to the on-vehicle battery charger. The other two terminals are used for communication between the vehicle and the charge cable. The vehicle control modules measure internal voltages and current within the battery charger and charge receptacle to verify they are within the proper range.



1. Neutral / Hot L2 Terminal	2. Pilot Terminal	3. Ground Terminal
4. Proximity Sense Terminal	5. Hot L1 Terminal	

Figure 10-52, J1772 Charge Cord Terminals

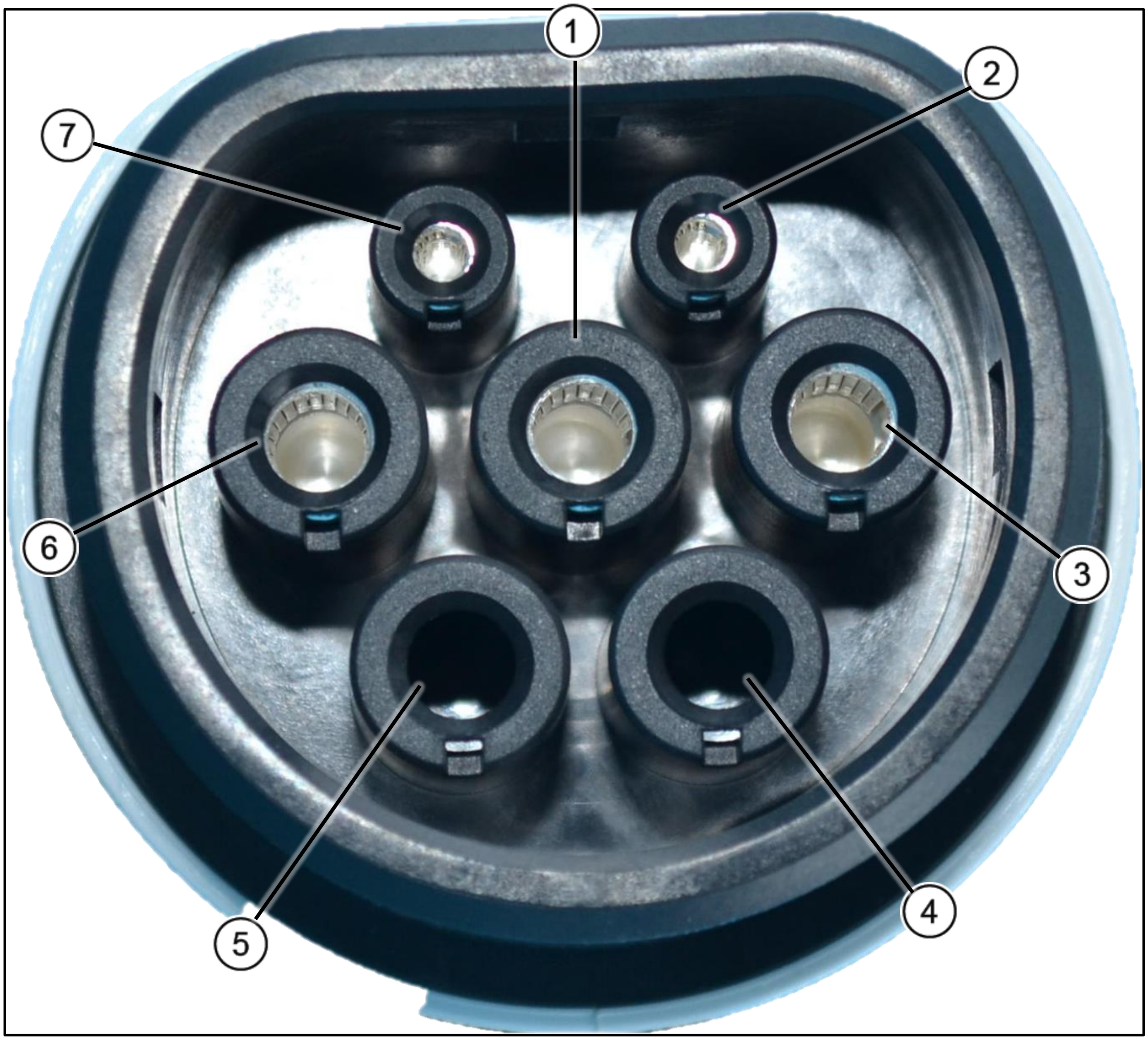
Combined Charging System (CCS)

CCS charge ports combine a J1772 connector with a DC fast charge connector. This gives the ability to use the J1772 portion of the connector for level 1 and 2 charging, or the DC fast charge portion of the connector for fast charging if the option is available.

Figure 10-53, CCS Charge Cord Connector

J3068 Charge Port

SAE J3068 charge port connectors are popular on vehicles in Europe, Australia, and South America. J3068 charge ports are often referred to as Type 2 chargers. J3068 chargers can use a single phase or 3-phase power supply. J3068 charge ports are compatible with 208V, 480V, or 600V AC. J3068 can charge at a higher rate than a J1772 charge port. Adaptors are available to connect a J3068 charge cord to a J1772 vehicle if needed.

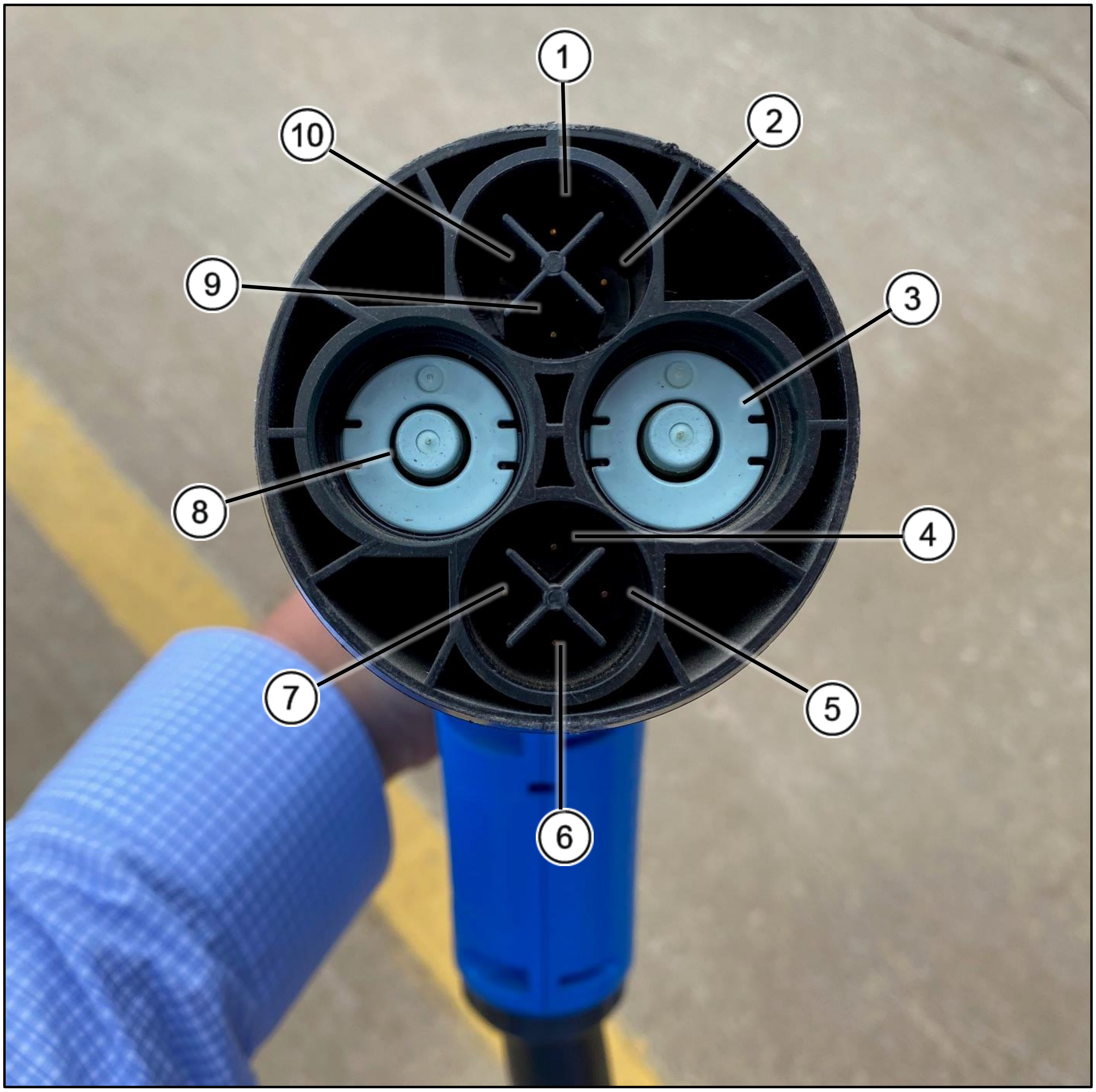


1. Ground Terminal	2. Proximity Sense Terminal	3. Neutral Terminal
4. AC Phase 3	5. AC Phase 2 Terminal	6. AC Phase 1 Terminal
7. Pilot Terminal		

Figure 10-54, J3068 Charge Cord Connector

CHAdeMO Charge Port

CHAdeMO charge ports are very common in Japan and have limited usage in Europe. CHAdeMO style charge ports are rare in the United States. CHAdeMO charge ports have ten terminals used to enable charging, detect the presence of the charge cable, and transfer DC voltage to the battery. Unlike CCS charge ports, CHAdeMO charge ports can only be used for DC fast charging. Vehicles with CHAdeMO charge ports will also have a J1772 or J3068 charge port to accommodate level 1 and level 2 charging.



1. Ground Terminal	2. Charger Start / Stop 1	3. DC Positive
4. Connection Check Circuit	5. CAN Bus High	6. Charger Start / Stop 2
7. CAN Bus Low	8. DC Negative	9. Charging Enable / Disable
10. Not Used		

Figure 10-55, CHAdeMO Charge Cord Connector

Tesla Charge Port

Tesla uses a unique charge port. Tesla chargers (referred to as “super chargers” by Tesla) will only connect to Tesla vehicles. However, there are adaptors which allow Tesla vehicles to use a J1772 or CHAdeMO charge cables. Tesla charge ports are capable of level 1, level 2, or DC fast charging.

Figure 10-56, Tesla Charge Cord Connector

Battery Charge Rate Factors

Aside from the type of battery charge cord used, there are other factors that can affect battery charge rates and battery charge levels. These include:

- Capacity of the battery
    - Larger batteries take longer to charge than smaller batteries
- Battery state of charge
    - The more depleted a battery is, the long it will take to fully recharge
- Battery charger capability
- Electrical source capability
- Battery temperature
    - Cold batteries take longer to charge compared to warm batteries

As batteries near full capacity, the battery charger will reduce the charge rate supplied to the battery. Typically, this occurs when the battery reaches 80% of its capacity. Reducing the charge rate as the battery nears its full capacity helps to increase the battery's life span.

Charge Status Indicator (CSI)

The battery charging status can be monitored in several ways. Most vehicles have a Charge Status Indicator (CSI) light on the instrument panel or near the charge port. The indicator light illuminates to show that the vehicle is charging. The indicator may also communicate the battery state of charge. For example, the Chevrolet Spark EV uses the following indicator displays:

- Solid Green – The vehicle is plugged in; the battery is fully charged
- Short Flashing Green – The vehicle is plugged in; the battery is not fully charged. The flash rate increases from one to four flashes as the battery charges
    - One flash: 0–25% Charge, Two flashes: 26–50% Charge, Three flashes: 51–75% Charge, Four flashes: 76–100% Charge
- Long Flashing Green – The vehicle is plugged in; the battery is not fully charged. The battery charging is delayed
- Solid Yellow – The vehicle is plugged in but is not charging. It is normal for the CSI to turn yellow for a few seconds after plugging in a compatible charge cord but should change to green once the vehicle begins charging. The CSI may stay solid yellow longer depending on the vehicle and if there is a total utility interruption. This may also indicate that the charging system has detected a fault and will not charge the battery

Figure 10-57, Charge Indicator

Battery charging can also be monitored from the vehicle's information center displays or from a smart phone app when available.

Public Charging

The majority of PHEV and BEV charging occurs at home or at work. However, there may be times when these options are not available, and a public charging station must be used.

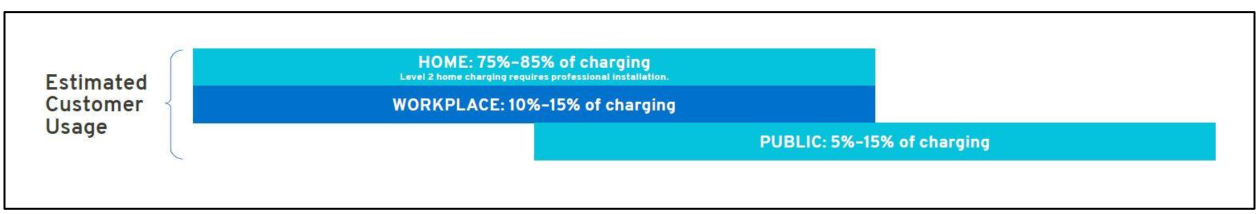


Figure 10-58, Charging Location Percentages

As of 9/22/21 there are over 94,000 public EV charging outlets at 47,433 charging stations across the U.S. and Canada. These numbers continue to increase dramatically. The abundance of public charging outlets makes it convenient to charge the vehicle during long trips. When using a public charging station, the owner will generally pay per the kWh of electricity used. Public charging stations provide level 2 or DC fast charging connections.

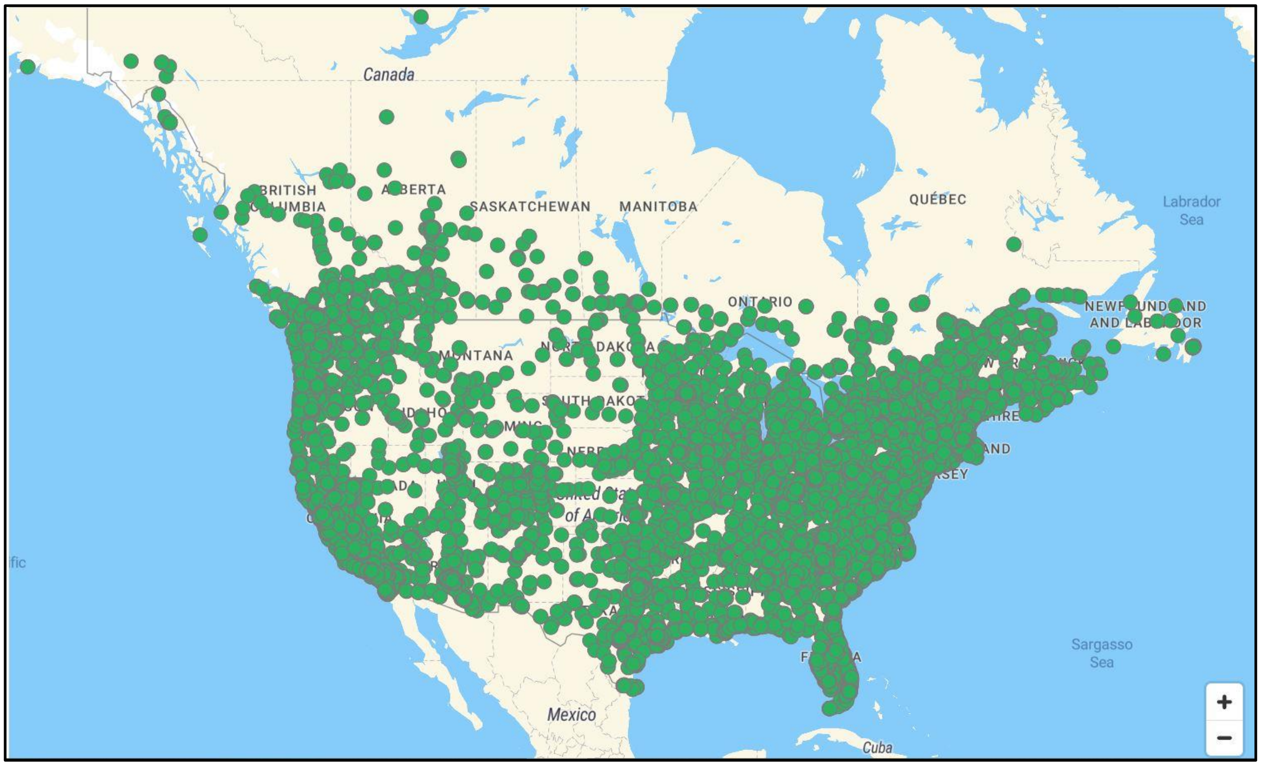


Figure 10-59, Public Charging Locations

Owners can locate public charging stations using on-vehicle applications, smartphone apps, or websites like www.plugshare.com, www.chargeplug.com, or www.electrifyamerica.com.

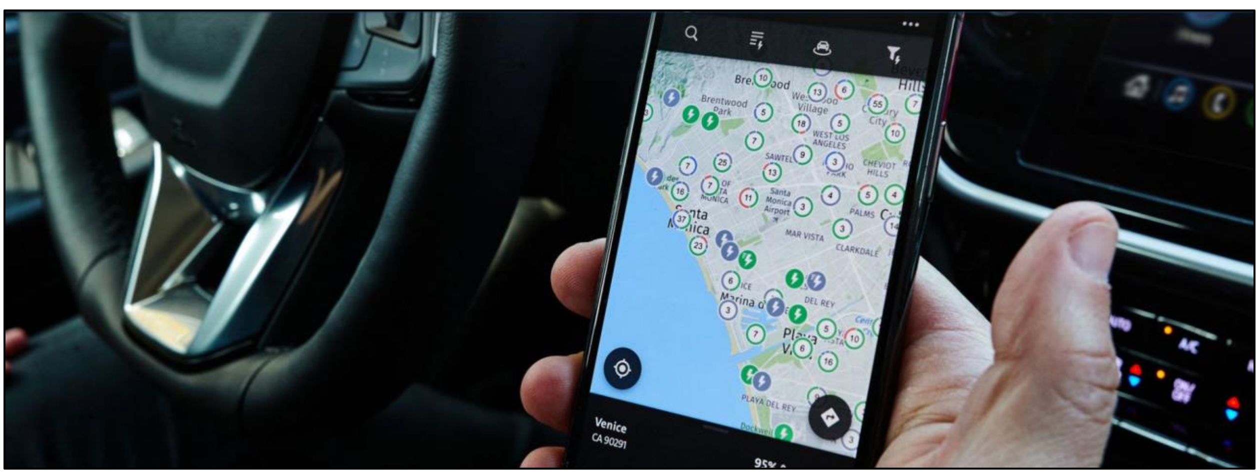


Figure 10-60, Charging Station Locator App

Charging Options

High voltage batteries do not need to be completely depleted before recharging can be performed. The battery can be recharged anytime the state of charge is less than 100%. Due to fluctuations in electricity prices, it may be beneficial to charge the vehicle at certain times of the day. Electrical cost is generally lower at night when usage is low. BEVs and PHEVs can be personalized to charge only during certain times. Owners can connect the vehicle to the charge cord at any time, but battery charging will not begin until the programmed start time. When charging does not begin immediately after the vehicle is plugged in, the owner may believe that there is a problem with the offboard charger.

Vehicle charging personalization includes options like:

- Immediately upon plug-in
- Delayed based on departure time or electric rates
- Target charge level for needed range

The vehicle may also be customized to recognize when the vehicle is connected to the owner's home charger. When connected to the home charger, the vehicle will follow the programmed charging schedule for that location. When connected to a charge station other than the home charger, charging will begin immediately.

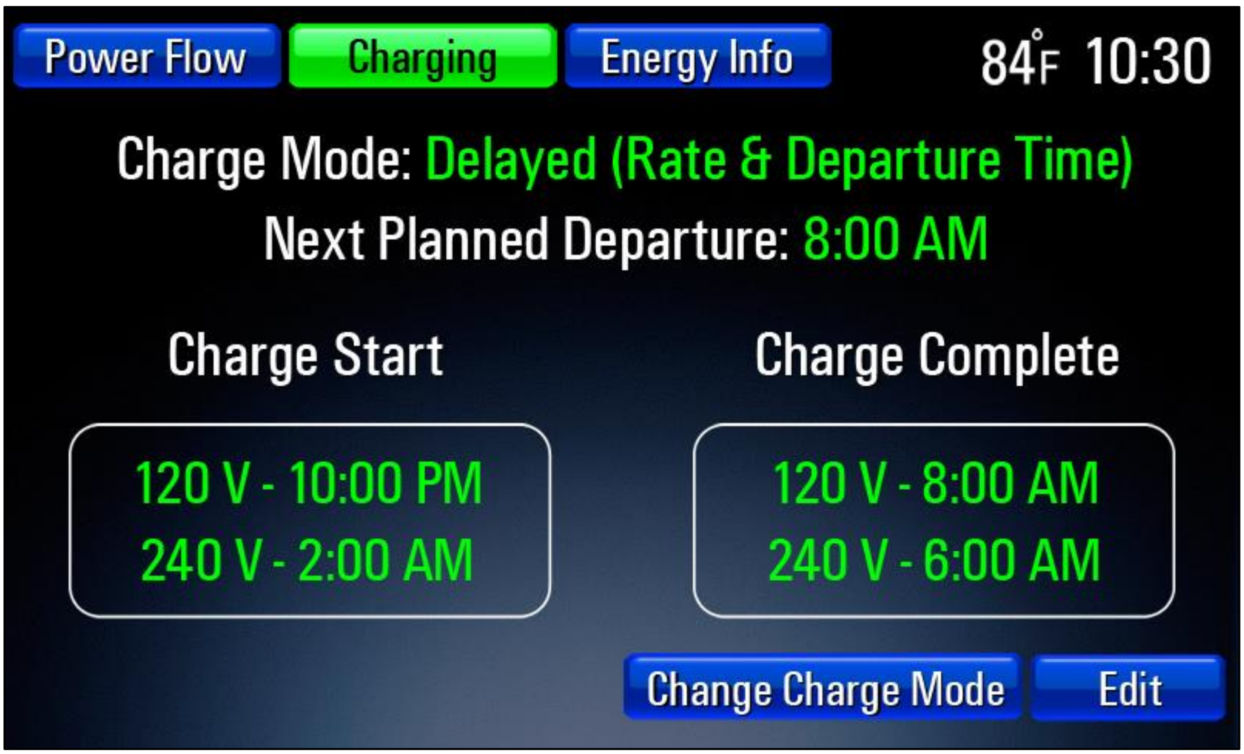


Figure 10-61, Charge Mode Display

The vehicle's power electronics automatically limit the amount of charge that the battery will accept and determine how depleted the battery can become before propulsion is no longer possible. These buffers extend battery life and prevent potential damage caused by overcharging or over depleting a battery. In addition to the fixed buffers, owners may be able to set limits on how much charge the battery will accept. By limiting the battery's operating range to between 20% and 80% of its capacity, battery life can be further extended.

AIR CONDITIONING COMPRESSOR

Most HEVs and all BEVs utilize a high voltage electric A/C compressor. Electric A/C compressors are direct coupled and do not need a clutch. Electric A/C compressors can run at any speed which maximizes their efficiency and performance. Vehicles that use a battery chiller also use a control module to monitor refrigerant pressure sensors, duct temperature sensors, ambient temperature sensors, passenger temperature sensors, battery cell temperature sensors, battery coolant temperature sensors, and battery coolant pump status to determine A/C compressor demand.

High voltage A/C compressors have DC to AC inverters built into them. These compressors internally invert DC from the high voltage battery into 3-phase AC used by the compressor's electric motor. High voltage current only flows to the A/C compressor when it is operating. A loss of isolation within the A/C compressor or cables may only be detected when the pump is commanded ON.

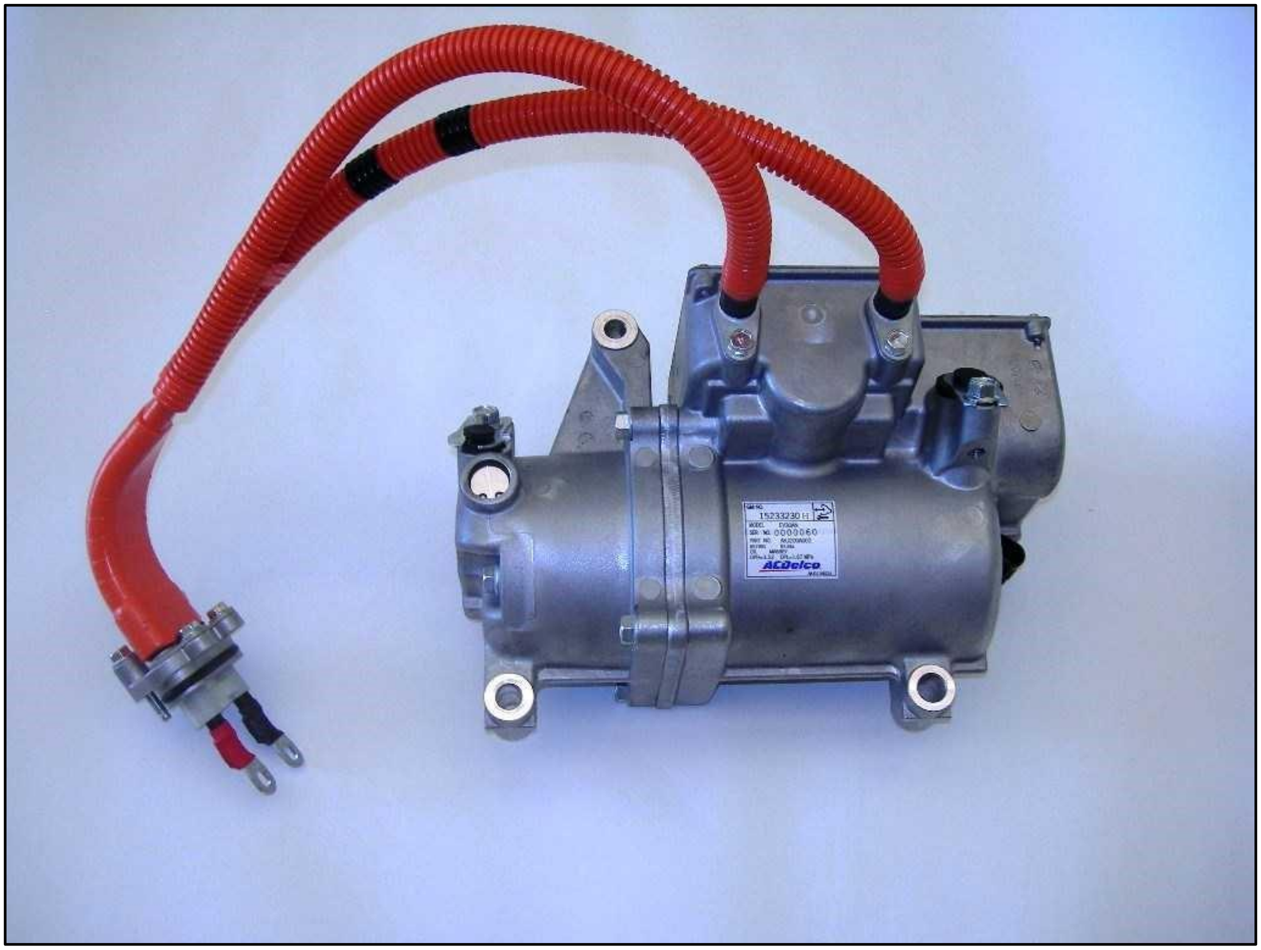


Figure 10-62, Electric Air Conditioning Compressor

HVAC SERVICE

Electrically driven compressors use Polyolester (POE) oil instead of the Polyalkylene Glycol (PAG) oil used in conventional compressors. POE oil is not electrically conductive, but PAG oil is. Using PAG oil in an electric compressor can cause a loss of isolation. Dedicated equipment must be used to service HEV and BEV air conditioning systems to prevent cross-contamination of refrigerant oils.

Figure 10-63, POE Oil

HEVs and BEVs may also use a high voltage electric coolant heater to warm the coolant that flows through the passenger compartment heater core and/or battery pack. On HEVs, the electric coolant heater may only be active until the ICE reaches a specific operating temperature.

AUXILIARY TRANSMISSION FLUID PUMP

On a vehicle with a conventional powertrain, the transmission fluid pump is driven by the ICE. HEVs use a high voltage auxiliary transmission fluid pump to maintain transmission line pressure for lubrication, cooling, and clutch application whenever the ICE is not operating. The auxiliary transmission fluid pump is controlled by the PIM and only has electrical current flowing to it when operating. A loss of isolation within the auxiliary transmission fluid pump or cables may only be detected when the pump is commanded ON.

BRAKES

HEVs and BEVs are designed to recover as much energy as possible through regenerative braking. As a result, the friction brakes are used much less than in a conventional vehicle. Because HEVs and BEVs use the friction brakes less, and typically at lower speeds, the friction material wears very slowly.

Some regions have environmental conditions that may cause the vehicle to require brake service prior to the pads wearing out. Road salt in northern areas and sea spray near coastlines may cause the brake hardware to corrode. This can cause calipers to stick and possibly bind. Regenerative braking may cause brake problems to go unnoticed until an emergency stop is required. Another possibility is that the brakes fail to release, which can cause noise or pulling. Brake drag caused by a sticking caliper will not only increase wear on friction material but could also cause reduced fuel economy.

IGNITION OPERATING MODES

Operating mode refers to the ignition status or, power mode, of the vehicle. On a vehicle with a conventional powertrain, it is easy to recognize when the ICE is running or when the key is ON but the engine is OFF. Since the ICE does not always run on a HEV and BEVs do not have an ICE, it may be difficult to recognize the operating mode.

Vehicle In Service Mode

When diagnosing or testing HEVs and BEVs, it is important to be in “Vehicle In Service” mode. In this mode, the HV contactors are closed however vehicle propulsion is disabled. To enter “Vehicle In Service” mode, start with the vehicle OFF and press and hold the vehicle power button for at least 5 seconds without the brake pedal depressed.

Once in “Vehicle In Service” mode, the following conditions are present:

- The vehicle will not charge if the charging cable is attached. Attach the charging cable to the vehicle before entering the Vehicle In Service Mode to charge the vehicle
    - The T18 Battery Charger is disabled during a programming event
    - The T18 Battery Charger support for the 12V battery is limited while the vehicle is charging and in Service Mode
- Vehicle in Service Mode should not be active for more than 5 minutes without having a battery maintainer attached to the 12V battery
- The HV MAIN contactor relays will be enabled for 15 minutes. Even though the HV main contactor relays are closed, both propulsion and the K1 14V Power Module are disabled for the duration of Vehicle In Service Mode

RANGE

Range refers to how far a HEV or BEV can travel on electric only power. Poor range is one of the leading concerns for HEV and BEV owners. Concerns over running out of battery power while driving (commonly referred to as “range anxiety”) is often quoted as a reason some people are hesitant to purchase a BEV. Range is less of a concern on HEVs since they have an onboard generator.

The available range can vary greatly amongst BEVs. Some BEVs like the 2020 Mini Cooper SE provide an EPA estimated 110 miles of electric range, other vehicles such as the 2021 Tesla Model 3 Long Range has an EPA estimated 353 miles of range.

The vehicle’s estimated range will be displayed on the instrument panel. The displayed range is a prediction based on battery capacity, current ambient temperature, and climate control settings as well as past driving technique and terrain conditions. It is normal for the displayed value at full charge to adjust while the vehicle is driven. The range estimate is constantly being recalculated. The displayed electric range can vary seasonally, monthly, and daily based on several factors.

Figure 11-1, Available Range Display

RANGE FACTORS

Range is affected by many factors. Several of the aspects that affect EV range are the same that affect fuel economy on a conventional vehicle. The vehicle's information center may display how these factors are affecting the vehicle's range. These include:

- Battery size
- Battery materials
- Vehicle weight
- Terrain
- Temperature and weather
- HVAC settings
- Driving habits
- Battery age and capacity
- Vehicle maintenance and condition

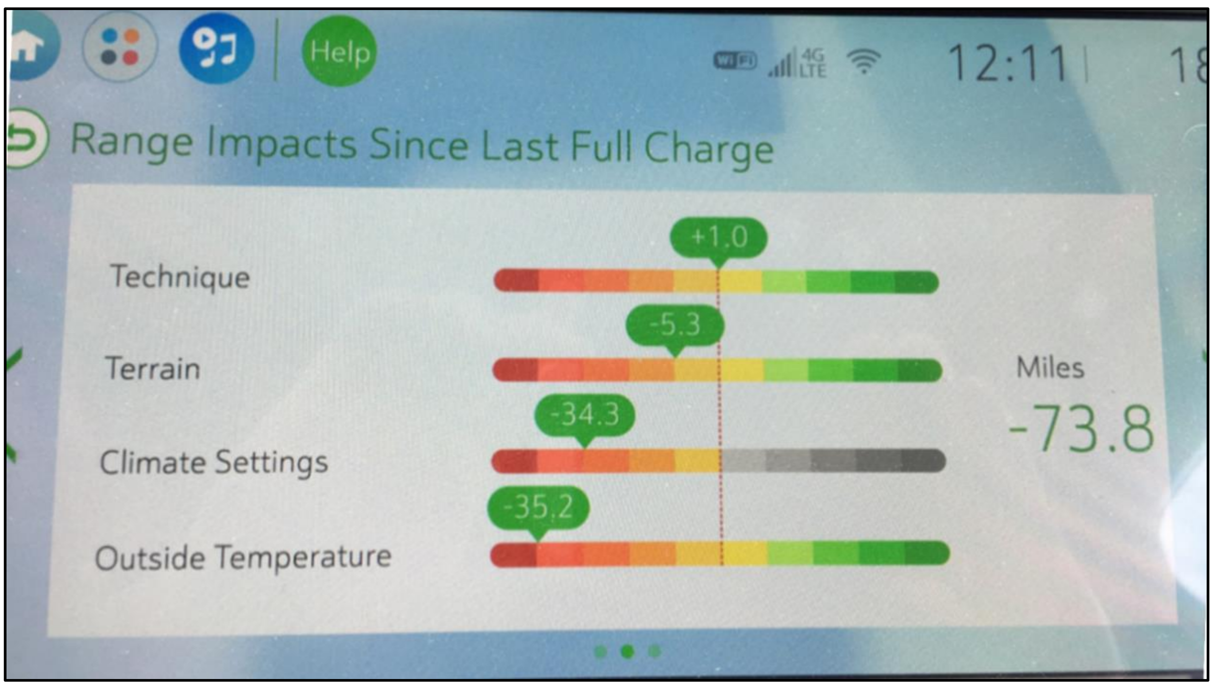


Figure 11-2, Range Impact Display

Battery Size

The larger the battery is, the more capacity the battery has. This enables the vehicle to travel further on a full charge. Battery size is directly related to how much propulsion the electric drive system provides.

BEVs have larger batteries than PHEVs which have larger batteries than full hybrids which have larger batteries than mild hybrids. Adding size increases a battery's range but it also increases the vehicle's weight and extends the amount of time needed to recharge the battery.

Battery Materials

As previously discussed, Li batteries have better range than NiMH batteries. GM's Ultium battery technology will further improve on battery range.

Vehicle Weight

As with a conventionally powered vehicle, more energy is required to move large amount of mass compared to a small amount of mass. Adding cargo and passengers to a vehicle will decrease the available range.

Terrain

Driving in mountainous or hilly terrain can decrease the available range. Owners who travel from relatively flat regions to hilly regions may notice their range decrease.

Due to regenerative braking, BEVs typically have better range during city driving than highway driving.

Temperature and Weather

Temperature can have a significant effect on range. A vehicle's range can vary by 70 miles due to mild temperature changes in warm climates. Cold climates can reduce the range by more than 70 miles.

If the vehicle is equipped with a battery pack heater, keeping the vehicle connected to the charge cord will allow the heater to run and keep the battery warm. Keeping the battery warm will improve charging time as well vehicle range.

Driving in snow, rain, or strong headwinds may also decrease the vehicle's range.

HVAC Settings

Air conditioning and electric heaters consume a large amount of electrical energy. Preheating or precooling the vehicle while it is connected to the charge cord can lessen the amount of electrical current the battery needs to provide to condition the vehicle's interior. Using heated or cooled seats to maintain passenger comfort will consume less energy than running the vehicle's heater or air conditioner to adjust air temperature. Driving with the windows down at high speeds may increase drag and reduce range.

Using the rear window defogger when it is not needed can decrease range.

Driving Habits

Aggressive driving uses more energy than conservative driving. Different drivers may notice a difference in their achievable range in the same vehicle. Using slow, smooth acceleration and maintaining speeds below 55 MPH will help to maximize vehicle range.

If equipped, using features like One Pedal Mode and Regen on Demand will increase the amount of electrical energy that gets replenished while driving.

Battery Age and Capacity

Capacity is the amount of energy a cell group can deliver at a given voltage. Capacity is the deciding factor in determining maximum possible vehicle range when the HV Battery is new and as it ages. Capacity is affected by many factors: number of charge cycles, temperature over time, rate of discharge and the natural chemical process over time. These factors can all cause a gradual decrease in capacity.

Because the cell groups are wired in series the available capacity in the battery pack is determined by the cell group with the lowest capacity. The performance of the battery pack is not affected by the capacity, however the range, or number of miles the vehicle can travel, is directly affected by capacity. The vehicle uses the lowest cell capacity as part of the displayed estimated range available.

Vehicle Maintenance and Condition

As with a conventional vehicle, proper maintenance will also ensure maximum range. Ensuring that tires are properly inflated and not worn, vehicle alignment is correct, and the vehicle closeout panels are in place and undamaged will help with range concerns. Additionally, aftermarket equipment like light bars and cargo racks can resist airflow and reduce range.

DIAGNOSING RANGE CONCERNS

On some vehicles, like the 2019-2022 Chevrolet Bolt EV, a scan tool can be used to display the Battery Cell State of Charge Variation within the Hybrid / EV Powertrain 2 data parameters. This scan tool parameter can be used to differentiate an individual cell group capacity concern from an overall pack capacity concern. If a reduced range concern has been caused by something affecting all cell groups equally, such as temperature, discharge rate, driving style, age, or capacity loss, this parameter will indicate a low value. If a single cell group is affecting the battery capacity this parameter will indicate a higher percentage value.

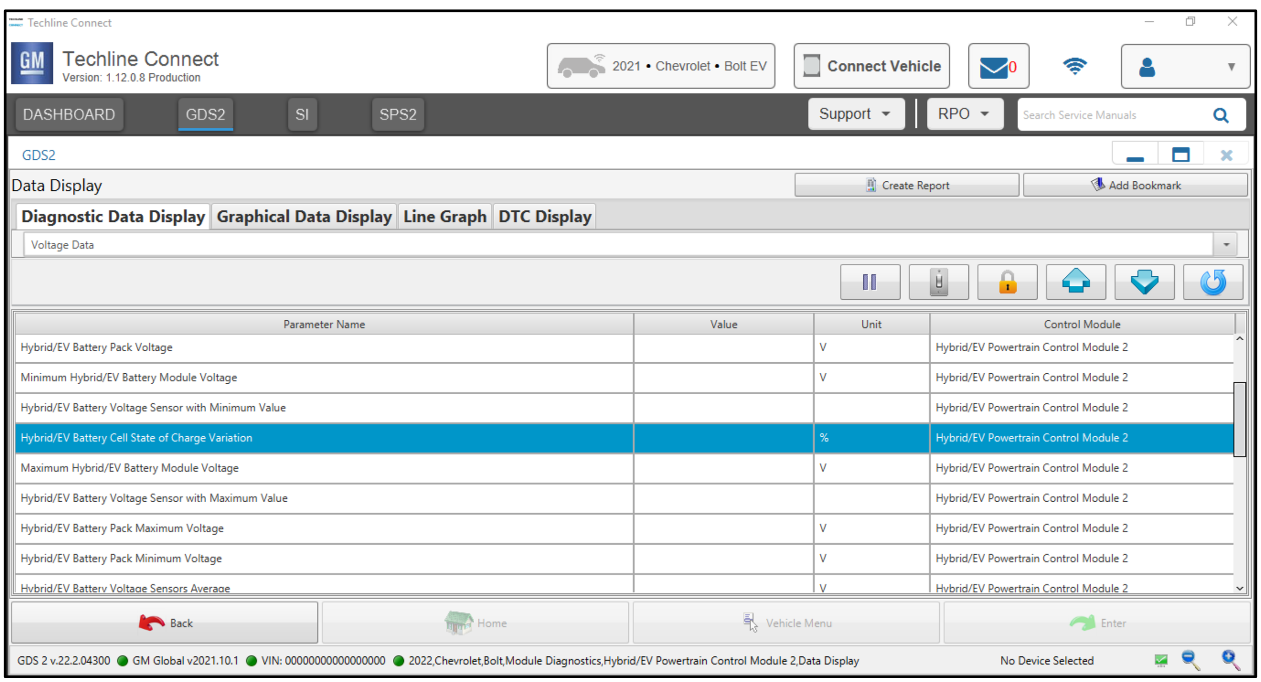


Figure 11-3, GDS2 Battery Cell State of Charge Variation

The following system verification steps can be performed on a 2019-2022 Chevrolet Bolt EV. Similar steps may be available for other vehicles:

1. Verify that no DTCs are set. Diagnose any DTCs before proceeding with this procedure.

Note: Battery minimum state of charge must be 30% or greater before proceeding.

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2. Verify the battery charge cord is not connected.
3. Vehicle ON.

Note: If the parameter is not available, program the hybrid / EV powertrain control module 2 with the latest software.

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4. Verify with a scan tool, the hybrid / EV powertrain control module 2 Hybrid / EV Battery Cell State of Charge Variation is greater than 6.5%. If the value is greater than 6.5%, an individual cell group capacity concern exists, and the battery sections or assembly will need to be replaced.
5. Determine if the hybrid / EV powertrain control module 2, hybrid / EV battery pack, or ALL battery sections were recently replaced. If so, verify the battery capacity was properly reset following these repairs.
6. Verify with a scan tool, the hybrid / EV powertrain control module 2 Hybrid / EV Battery Capacity parameter is greater than the New Vehicle Limited Warranty Minimum Capacity (approximately 40% of its original capacity).
7. If the parameter value is less than the minimum capacity, the hybrid / EV battery has less than the minimum capacity as expressed by the New Vehicle Limited Warranty. Replacement of the entire A4 hybrid / EV battery pack is required in order to increase electric vehicle range:
   a. Replace the A4 hybrid / EV battery
   b. Perform the Diagnostic Repair Verification after completing the repair
8. If the battery capacity meets or exceeds the minimum expected capacity as expressed by the New Vehicle Limited Warranty, the effect of vehicle settings, driving technique, terrain, or outdoor ambient temperature may be impacting vehicle electric range:
   a. Provide to the vehicle operator the current battery pack capacity of the vehicle and the minimum capacity value, which is the point below which the battery would be replaced under warranty per the warranty guide for that vehicle
   b. Verify the vehicle setting Hill Top Reserve / Target Charge Level is not selected. If Hill Top Reserve / Target Charge Level is selected, advise the vehicle operator that Hill Top Reserve / Target Charge Level activation limits how full the hybrid / EV battery pack is allowed to charge
   c. Once Hill Top Reserve / Target Charge Level is verified, review with the vehicle operator the likely factors external to the battery pack that are impacting vehicle electric range.

Also available on the Chevrolet Bolt EV is historical range data. The Bolt EV stores eight months of historical data for four individual factors which are accessible in GDS2 under the Energy Usage History Data screen under the HPCM2 module. The 2017 and 2018 model years display this data as a unitless score. Beginning in the 2019 model year, this data is displayed in units of distance impact. The average score from each of the last eight months is available to show which factor, if any, has changed over time. History 1 is the average from the last 30 days. History 8 is from eight months ago. This data can be used to show how range vary with the seasons. This historic vehicle data, along with driving tips to maximize range in the SI procedure, may be printed out to share with the customer.

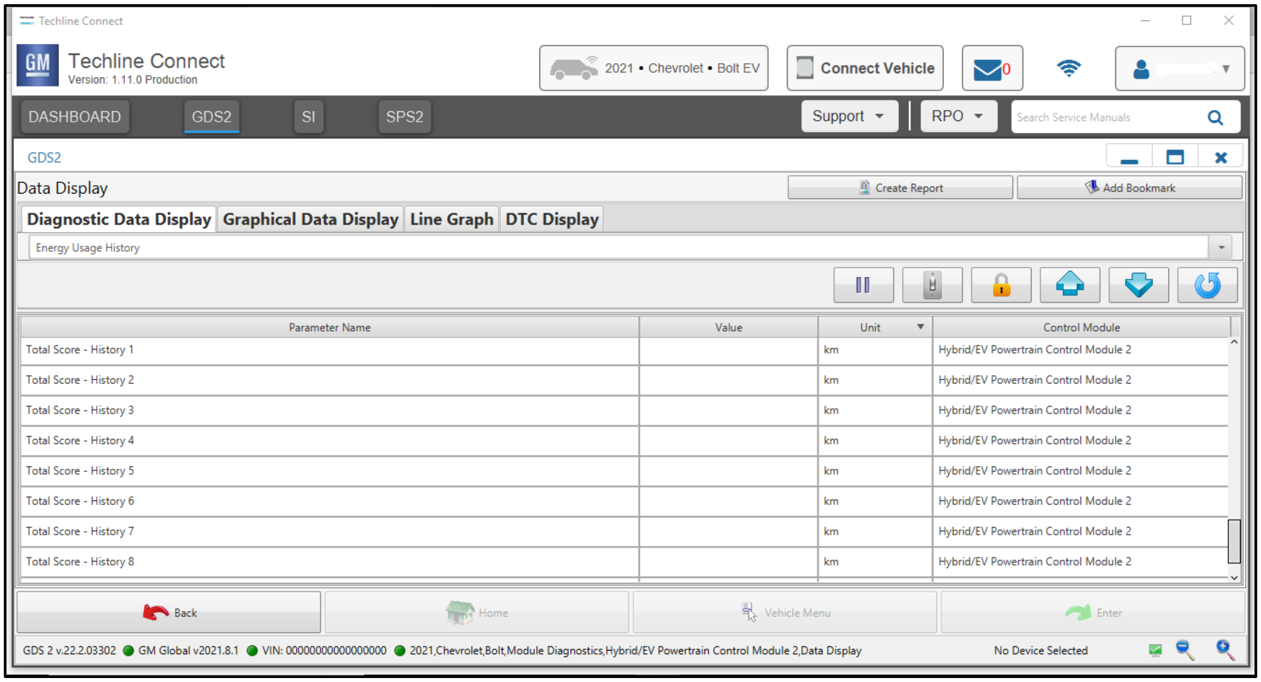

Figure 11-4, Scan Tool Range History

POST COLLISION INSPECTION

HEVs and BEVs that have been involved in a collision must be carefully inspected to ensure all systems and components are returned to their original condition.

DANGER: Damage to an Li hybrid / EV battery pack could result in fire, loss of electrical isolation or exposure to high voltage. Until the high voltage system inspection has been completed, store the vehicle with hybrid / EV battery pack installed outside in a secure area away from buildings and other vehicles and protected from rain, snow, and other moisture. Remove the hybrid / EV battery pack high voltage manual disconnect lever and store it in a secure place outside the vehicle. Cover the exposed high voltage opening with UL® listed, or equivalent, insulation tape rated at a minimum of 600 V.
Failure to follow these precautions could result in personal injury, death, and property damage.

Recall that the supplemental inflatable restraint sensing and diagnostic module determines the severity of a collision with the assistance of impact sensors located at strategic points on the vehicle. The power electronics may open the high voltage contactor relays, placing the vehicle in a high voltage lockout state and disabling the vehicle whenever a crash event of sufficient intensity has been detected.

The high voltage system and Hybrid / EV battery pack inspection process consists of two levels of inspection:

- Component Initial Inspection
- High Voltage Operation Inspection

Component Initial Inspection

Component initial inspection identifies damage to high voltage components, including the battery pack caused by:

- Fire
- Collision
- Flood
- Coolant loss

Danger: Always perform the High Voltage Disabling procedure prior to servicing any High Voltage component or connection. PPE and proper procedures must be followed.

Always follow service information for the correct inspection procedures for the vehicle being inspected. Below are the general steps to follow for a high voltage component initial inspection:

1. Disconnect the 12V battery.

2. Remove the S15 Manual Service Disconnect. If vehicle damage does not allow for access to the S15 Manual Service Disconnect, remove the damaged portion of the vehicle until such time as the S15 Manual Service Disconnect can be removed.

3. Inspect the Hybrid / EV battery pack for evidence of exposure to fire, either directly or in close proximity.

    a. If exposure to fire is evident: Depowering of the Hybrid / EV battery pack is recommended. Maintain post-crash 50 foot vehicle isolation until depowering completion.

    b. If not exposed to fire: Continue to step 4.

4. Inspect the Hybrid / EV battery pack enclosure for damage including foreign object intrusion.

    a. If damage is evident: Depowering of the Hybrid / EV battery pack and/or damaged module section is recommended. Maintain post-crash 50 foot vehicle isolation until depowering completion.

    b. If not damaged: Continue to step 5.

5. Inspect the vehicle for exposure to water at a level higher than the vehicle rocker panel.

    a. If the vehicle was exposed to flood: Remove the battery drain plug, capture and discard any drained fluid. Lift the vehicle rear slightly to assist in fluid extraction.

        i. If fluid is present: Depowering of the Hybrid / EV battery pack is recommended. Maintain post-crash 50 foot vehicle isolation until depowering completion.

        ii. If fluid was not present, install a new drain plug and continue with inspection.

    b. If the vehicle was not exposed to flood: continue to step 6.

6. Inspect the battery coolant system for proper level.

    a. If battery coolant level is low: Verify if the low coolant is the result of system damage external of the battery pack.

        i. If the cooling system external of the A4 Hybrid / EV Battery Pack is not damaged and/or leaking, remove the battery drain plug, capture and discard any drained fluid. Lift the vehicle rear slightly to assist in fluid extraction.

            1) If fluid is present: Depowering of the Hybrid / EV battery pack is recommended. Maintain post-crash 50 foot vehicle isolation until depowering completion.

2) If fluid is not present: Install a new drain plug and continue with inspection.

ii. If the cooling system external of the A4 Hybrid / EV Battery Pack is damaged and/or leaking. continue to step 7.

b. If the battery coolant system is at the proper level, continue to step 8.

7. Inspect each high voltage component listed below for visible damage:

- Battery Pack Coolant Heater
- Electric A/C Compressor
- 14V Power Module
- Coolant Heater Control Module
- Manual Service Disconnect
- Power Inverter Module
- Battery Charger
- Transmission case
- All High voltage orange cables

a. If any high voltage component inspection failed and Hybrid / EV battery Depower is recommended.

i. Disconnect the damaged components from the high voltage bus before attempting in-vehicle depowering of the Hybrid / EV battery pack. In extreme cases depowering may need to occur by connecting directly within the Hybrid / EV battery pack with the cover removed. See Battery Depower below.

b. If any high voltage component inspection failed and Hybrid / EV battery Depower is NOT recommended, perform the High Voltage Disabling procedure and replace the damaged components before attempting to operate the vehicle.

8. Once you have confirmed or repaired all high voltage component visual integrity, perform High Voltage Operation Inspection below.

Battery Depower

Depowering of the battery:

- Will NOT reduce battery voltage to a safe level. The battery will contain high voltage after depower procedure is complete
- Reduces the state of charge to the lowest level thus reducing the likelihood of a battery fire
- Requires special tool EL-50332, or equivalent, battery service tool

- Allows for future recovery of the battery after an internal battery inspection and/or repair is completed

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Note: Depowering is not required if hybrid / EV battery pack voltage as either monitored by the hybrid powertrain control module 2 scan tool Hybrid / EV Battery Pack High Voltage parameter or measured with a DMM directly across the battery terminals is 285V or less.

Note: With a full state of charge, the depower process for the complete Hybrid / EV battery pack make take up to 20 hours to complete. You may stop or pause the process at any time.

Depowering can occur with the battery pack in or out of the vehicle. However, we will only be discussing in-vehicle depowering in this course. Working inside of the battery pack requires additional training and equipment. We will review the depowering process using GM's EL-50332 battery service tool and related adaptors.

You can configure the EL-50332 connections to the Hybrid / EV battery pack at any of the following locations:

- High Voltage Battery Charger connection under hood with EL-50332-335*
- High Voltage connection at Hybrid / EV Battery Pack with EL-50332-335*
- Directly at battery section / cell module terminals with EL-50332-170
    - *Also requires connection to the contactor relay control circuits with EL-50332-325

The EL-50332 can be 12V powered for instances when outlet power is not available. Use the following to operate from a 12V power source:

- EL-50332-160 12V Auxiliary Power Cable
- EL-50332-165 12V Auxiliary Clamps Adapter Cable

In-Vehicle or Hybrid / EV Battery Pack Cover Installed Depower Instructions

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Note: The EL-50332 will close the Hybrid / EV battery pack contactors. The following precautions must be taken:

- Verify the vehicles high voltage system integrity prior to enabling high voltage.
- Disconnect visually damaged high voltage components / cables from the high voltage system before attempting in-vehicle depowering
- Access to the hybrid / EV battery pack low voltage connectors must be available
- Wear your Personal Protective Equipment for the duration of the battery depower event.

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1. Ensure the integrity of the vehicles high voltage system.
2. Connect the EL-50332 to the contactor control circuits at the hybrid / EV battery pack low voltage connectors with the EL-50332-270 interface module and 50332-325 harness.
3. Connect the EL-50332 to the applicable high voltage connector.

4. Install the manual service disconnect lever.

5. Follow the EL-50332 on-screen prompts until depower is completed.

6. **Note:** Post-crash 50 foot vehicle isolation is no longer required upon successful depower completion.

7. Remove the manual service disconnect lever.

8. Replace any damaged components noted in the High Voltage Component Inspection before attempting to operate the vehicle.

9. Perform the High Voltage Operation Inspection before attempting to operate the vehicle.

Figure 12-1, EL-50332 Depowering Tool

High Voltage Operation Inspection

After the component initial inspection is complete, perform the High Voltage Operation Inspection to:

- Check for DTCs
- Check for crash event detection
- Check air bag deployment status
- Clear secured high voltage DTCs if necessary

Note: The vehicle must have a functioning 12V system and serial data communications to continue.

1. Verify you have successfully passed the Component Initial Inspection. If the Component Initial Inspection has failed or not been performed DO NOT CONTINUE. Restart the Inspection procedure.

2. Install the Manual Service Disconnect.

3. Connect the 12V battery.

4. If applicable, put the vehicle in service mode and use a scan tool to review the “Hybrid Battery Pack Contactor Open Reasons” data list. Verify if either the Crash Event Detected or Air Bag Deployed parameters indicate YES.

    c. If either parameter displays YES: The high voltage contactors may be prevented from closing. The vehicle will not start. Perform the Clear Secured High Voltage DTCs procedure and proceed to the next step.

    d. If BOTH parameters indicate NO: With a scan tool check for the following HV system DTCs: Contactor DTCs P0AA1, P0AA4, P0AD9, P0ADD, P0AE4, P0D0A, P0D09, P1EBD, P1EC0, P1EC3, Isolation DTCs P0AA6, P1AE6, P1AF0, or P1AF2, Precharge DTCs P0C76, P0C78 or P3061.

        i. If any DTCs are set: Perform the applicable DTC diagnosis / repair.

        ii. If any of the listed DTCs have not run: Review the applicable Conditions for Running the DTC.

        iii. If all the specified DTCs have ran and passed: High Voltage System Inspection passed.

Additional Inspection

In addition to the high voltage system, it is important to ensure that all vehicle systems are restored after a collision. For HEVs and BEVs, the following items should always be inspected and serviced as needed:

- First responder cut points
    - May have been used to disable the high voltage system after a collision
- Under body closeout panels
- High voltage warning and cut point labels

Figure 12-2, First Responder Cut Point Label

NOTES

ADDITIONAL RESOURCES

GM Genuine Parts

- Source for Genuine GM parts and information
- http://www.genuinegmparts.com/

ACDelco.com

- Access to GM Training, GM Tech Info for the aftermarket
- http://www.acdelco.com/

NOTES

ACRONYMS

AC – Alternating Current

A/C – Air Conditioning

AGM – Absorbent Glass Mat

APCM – Accessary Power Control Module

ASE – Automotive Service Excellence

ASTM – American Society for Testing and Materials

BECM – Battery Energy Control Module

BEV – Battery Electric Vehicle

CCS – Combined Charging System

CPA – Connector Position Assurance

CSI – Charge Status Indicator

DC – Direct Current

DMM – Digital Multimeter

DTC – Diagnostic Trouble Code

ECM – Engine Control Module

ECU – Electronic Control Unit

EREV – Extended Range Electric Vehicle

GM – General Motors

HEV – Hybrid Electric Vehicle

HVAC – Heating, Ventilation, and Air Conditioning

HV – High Voltage

HVIL – High Voltage Interlock Loop

ICE – Internal Combustion Engine

IGBT – Insulated Gate Bipolar Transistor

I/M – Inspection / Maintenance

IMA – Integrated Motor Assist

kHz - Kilohertz

kW – Kilowatts

kWh – Kilowatt hours

Li – Lithium Ion

LoI – Loss of Isolation

MG – Motor / Generator

MSD – Manual Service Disconnect

NCMA - Nickel, Cobalt, Manganese, Aluminum

NiMH – Nickel Metal Hydride

OEM – Original Equipment Manufacturer

OSHA – Occupational Safety and Health Administration

PAG – Polyalkylene Glycol

PEPS – Passive Entry / Passive Start

PHEV – Plug-in Hybrid Electric Vehicle

PIM – Power Inverter Module

POE – Polyolester

PPE – Personal Protective Equipment

SAE – Society of Automotive Engineers

SOC – State of Charge

TXV – Thermostatic Expansion Valve

UV – Ultraviolet

XFC – Extreme Fast Charger

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