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# ELECTRIC VEHICLE TECHNOLOGY

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# HV AND BEV SAFETY

All-electric vehicles, PHEVs, and HEVs have high-voltage electrical systems that typically range from 100 to 600 volts and can deliver enough current to kill instantly. Therefore, it would be best to take extra precautions when working on any of these vehicles, whether on the engine, the body, or anywhere near the battery pack or cables.

This is often incorrectly interpreted to mean that a couple of amps at 115 or 230 volts aren't potentially injurious or lethal. On the contrary – electrocution resulting in injury / death can occur with as little as 60 volts at just under 1 amp of current.

This utility lineman (below) working with hundreds of volts and hundreds of amps around a transformer is using every safety procedure his trade prescribes. Taking short cuts to save time can lead to a very tragic ending.


On HEVs such as the Cadillac Escalade hybrid, a warning label, (left) indicates the HV system can carry the same 'hundreds of volts and hundreds of amps' and potentially tragic results if all safety precautions are not practiced;

## CAUTION

***The degree of injury / likelihood of death that can occur when unsafe hybrid / electric vehicle service methods are performed depend on several factors, including;***

***The electrical current's path travels through the victim's heart. (in one hand and out the other).***

***If the technician's hands are 'stuck' on the conductive circuit. (muscle contractions) .***

***Heightened conductive conditions such as standing in water.***

***Conductive tools in the hand(s) of the victim. Insulated tools should be used when working with high voltage.***

***Conductive items on victim's person including jewelry, watches, etc. and even an open cut. Note - blood is conductive.***

***Other conductive factors such as standing water on the shop's floor.***

***Metal in plasma form flying through air can be the result of arcing caused by a component, loose connection or conductive tool on a high voltage connection shorting out.***

***To prevent exposure to serious dangers for eye injuries always wear safety glasses when servicing high voltage systems.***

## Electrical Burns

Electrocution, where the heart stops, is only one of many possible injuries sustained when proper safety practices are not utilized while working on high voltage circuits encountered on hybrid electric vehicles.

Electrical burns is only one of the many possible injuries that can result when the body comes in contact with high voltage. As the current travels through the body's tissues, it creates internal burns that can sometimes be so severe that amputation is the only suitable treatment.

Entrance and exit wounds (like gunshot wounds) are also sometimes experienced by electrocution victims.

# HV AND BEV SAFETY

### Voltage Cable Coloring

Blue Cables – 42 volts (Caution).

Orange Cables – Above 60 volts (Extreme Caution).

The degree of injury rises as the voltage, current and conditions listed in the chart above increase.

### Muscle / Bone Injury:

Surface and internal tissue burns.

Broken bones and muscle damage resulting from falls.

At 16 mA, the muscles clamp on to whatever the person is holding.

### Nervous system effects:

Breathing can stop at 30 mA.

Ventricular fibrillation can occur at 75 to 100 mA.

### Where the Hazards Are

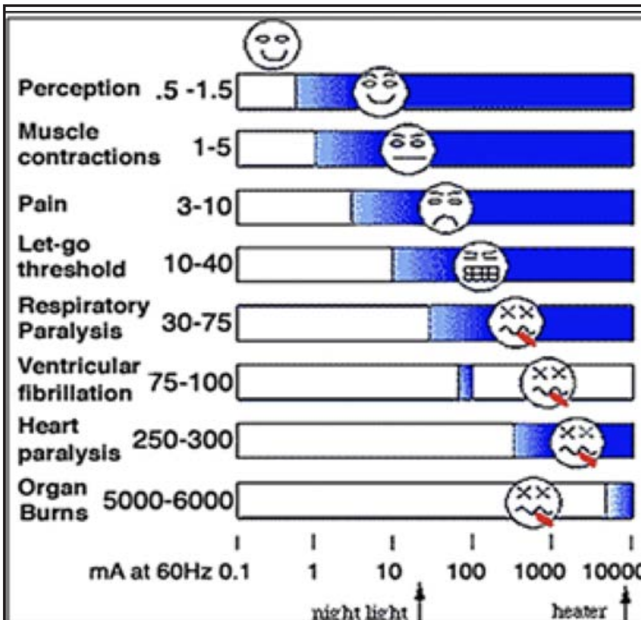
Relays (sometimes called contactors) Inverters and converters are involved with high voltage hybrid electric vehicle operation.

High voltage capacitors – typically, there are 3 of these capacitors, and they are mounted in the inverter.

High voltage air conditioning compressors – mounted on the gasoline engine.

The hybrid electric vehicle battery pack - is typically in the rear of the vehicle.

The motor-generator(s) – typically in the transmission but could be a belt-driven accessory on the front of the engine.




*Injury vs Voltage/ mA Level Chart*

Blue cables are for vehicles with an intermediate-high voltage of fewer than 60 volts. Typically these are mid-2000 era GM BAS (Belt Alternator/Starter) systems used on Saturn Vue, Aura, and Chevy Malibu. Blue cables represent a hazard but are not necessarily deemed as a potential for injury or death due to their lower voltage.

Li-Ion battery packs can pose a fire hazard if improperly handled. Accidents or improperly followed service producers that cause a Li-Ion battery pack to be mechanically, thermally, or electrically damaged may lead to electric shock and fire. Use an ABC or BC fire extinguisher on Li-Ion battery pack fires. Never use a D-type extinguisher.

# HV AND BEV SAFETY

## How to Safely Handle the Hazards

In general, only the high voltage components require special safety attention when servicing a hybrid electric vehicle. However, when servicing conventional components such as subsystems on the gas engine side of the powertrain, 12-volt components in various body systems, or accessories and components on the vehicle's chassis, there are no high voltage-related safety precautions required.

When servicing any component with a high voltage orange cable routing to it, a component with a high voltage warning label on it, or remove any orange cable or component that is in the way of a conventional non-high voltage component, the manufacturer's safety precautions should always be followed to the letter.

## High Voltage Service Disconnects / Plugs

## What They Really Do

Hybrid electric vehicle manufacturers typically have a high voltage service disconnect plug or switch on or near the high voltage battery pack. These service disconnect plugs/switches vary in shape, location, and actuation/removal procedure depending on the hybrid electric vehicle manufacturer.

It is important to remember that the high voltage service disconnect plug does NOT render the high voltage hybrid battery pack internally safe. Instead, the service disconnect cuts the voltage within the battery pack in half.

Hybrid electric vehicle high voltage battery packs are typically made up of modules containing six cells. On NiMH battery packs, each cell, when fully charged, is more than 2.1 volts.

The cells are wired internally within each module, giving each module a voltage level of 12.6 volts or slightly more significant. Each module assembly is then connected in series with the other module assemblies.

Since most hybrid electric vehicle battery packs are rated more than 150 volts, removing the high voltage battery's service disconnect plug will still leave at least ½ of that voltage available within the battery pack. For the high voltage battery pack example of 150 volts, ½ of that would be 75 volts – enough to be still considered potentially injurious or lethal.

The high voltage service disconnect plug/switch does NOT render a hybrid electric vehicle's high voltage battery pack safe.

If you were to remove the battery pack from the vehicle and remove the protective covers from the high voltage battery pack, connections internal to the battery pack would still pose a potentially harmful or lethal threat to anyone coming in contact with those connections.

## High Voltage Battery Pack Operation

Hybrid electric vehicle high voltage service plugs/switches provide some degree of safety from the battery pack's output connections (orange cables) leading from the battery pack to the other parts of the vehicle.

High voltage/high amperage relays (often referred to as contactors in industrial electrician circles) located on or near the high voltage battery pack are commanded to turn on, connecting the voltage present internal to the hybrid battery pack to the vehicle's high voltage systems (and orange cables) throughout the vehicle.

## High Voltage Safety Interlock

Before the battery pack is energized, high voltage relays are commanded to power up, and an electronic control module (ECM), is powered via the vehicle's 12-volt system. The ECM monitors the vehicle's systems and ensures there are no high voltage fault areas that could present a safety hazard to the occupants and any technicians working on the vehicle before turning on the high voltage relays.

One such high voltage fault is the high voltage level available to the side of the relays connected to the battery pack if the available voltage is not within a specified limit, (such as would be the case if a high voltage service disconnect plug/switch were to be removed/turned off) the module assumes an electrical fault within the high voltage system on the hybrid vehicle and inhibits the closure of the high voltage relays.

## INTERLOCK SAFETY NOTE:

Never assume that removing/switching off a hybrid electric vehicle's high voltage service disconnect plug/switch renders the vehicle safe from any high voltage present throughout the vehicle. High voltage capacitors could malfunction and remain charged up.

The battery pack's high voltage relays could be stuck shut, or the module controlling them could malfunction, despite the high voltage battery pack's internal voltage only being ½ of its standard rating due to the removed/switched off high voltage service disconnect.

## HV AND BEV SAFETY

### CAUTION

**ALWAYS WEAR PROPER SAFETY EQUIPMENT AND USE A PROPERLY RATED VOLTMETER TO TEST COMPONENTS ON THE HIGH VOLTAGE SIDE OF THE HYBRID ELECTRIC VEHICLE PRIOR TO SERVICING ANY HIGH VOLTAGE COMPONENTS. VOLTAGES SHOULD BE LOWER THAN 15 VOLTS PRIOR TO REMOVING / SERVICING THOSE COMPONENTS.**

### Create a High-Voltage Buffer Zone

When working on a gas-electric hybrid, set up a high-voltage buffer zone of about three feet (1 meter) around the vehicle's perimeter using suitable caution tape or floor placards, as illustrated below.



Avoid steel workbenches, large metal equipment, co-workers, or any other potential conductors of electricity in the buffer zone. Also, take the time to move objects or park the hybrid vehicle away from potential conductors.

If you back your body into a good conductor, such as a steel workbench, with your arm touching a high voltage source, you could be electrocuted or severely injured as the voltage travels through your body to the ground.

### Wear Insulating Gloves and Use A CAT III Meter

Always wear thick rubber insulating gloves when working on hybrid power cables and other hybrid components. The high voltage in hybrid vehicles can arc through cloth or thin rubber gloves, causing serious injury or death. Make sure you use OSHA approved “lineman gloves” or gloves with an approved insulation value of 1000 volts.

Periodically inspect your insulating gloves for tears or splits, especially in the fingertips. To check the condition of insulating gloves, grasp a glove by the cusp and fold it over a couple times to seal air inside the glove.

With the glove filled with air, check for air leakage and flaws. If the glove leaks air, it can also leak voltage. If your gloves are worn or damaged, discard them and purchase new ones.

# HV AND BEV SAFETY

## Class 0 / 1000 volt gloves are required anytime a technician;

**1. Removes a HV service plug**

**2. Tests for the presence of HV**

**3. Handles HV battery packs (anytime)**

**4. Handles orange HV cables (that have not been tested and could be live)**

**5. Handles inverters, converters & compressors (that have not been tested and could be live)**

**6. Handles Motor / Generators**

Test HV Class 0/1000 volt gloves EVERY TIME you put them on. Inspect them for cracks, holes, chemical or ozone damage and then test them by either rolling them up to see if the ends hold air or blowing into them like a balloon to ensure they hold air.

Even a pinhole can allow an electrical arc from high voltage to shock/injure the wearer. EVERY 6 MONTHS send the gloves off to be professionally tested to a certified company. i.e. www.glovetesting.com

Always inspect the Class III/1000 volt approved leads and probes for damage prior to using on HV circuits/components as well.

The reason for the rescue hook tool is simple. An electrical shock victim often can’t let go of whatever is causing their electrocution due to muscle contractions.

If another person attempts to rescue the victim being shocked by physically touching them, the rescuer can also be injured or even killed. This insulated hook/pole can be hooked around the victim so that the rescuer remains safe. The poles come in 6 and 8 foot length variations.

Other common sense safety precautions would include servicing and storing hybrid vehicles in dry locations (not standing in water) and storing HV battery packs removed from hybrid vehicles in a secure, dry and cool place.

There should be a lock on the room/cabinet where batteries are stored as well as a “Danger – High Voltage” sign to warn untrained personnel to stay away from these potentially dangerous components.

## HEV Service Disconnect Procedure

You need not worry about disconnecting the HV system on a HEV when performing routine part removal on items that are not related to the HEV’s HV system. HOWEVER – whenever working around the following components the service disconnect plug should be removed;

1. HV battery packs (anytime)
2. Orange HV cables
3. Inverters, converters & compressors

## HV AND BEV SAFETY

### How to perform a HEV high voltage system power-down.

1. Turn off ignition / press power button off.

2. Remove key from vehicle (smart key systems used in some HEVs may still allow power ups if key is in vehicle)

3. Disconnect 12-volt battery.

This is an extra precaution to increase safety. If the HEV's HV system has been powered down, electronic modules that turn on the HV relays cannot do so if they don't have 12 volts to power themselves up.

4. Remove/switch off the OEM HV battery disconnect service device. NOTE: This function cuts the HV battery pack voltage in half. If an electronic module responsible for controlling the HV relays will see the HV battery voltage level is too low and not turn on the HV relays. However, HV battery packs even at ½ voltage still contain enough voltage to be a safety hazard. DO NOT handle the HV battery pack without Class 0/1000 volt safety gloves even with the service switch turned off/service plug removed.

5. Test the part being removed / serviced for high voltage with a Cat III/1000 volt meter. Anything less than 15 volts means you can remove the safety gloves and complete whatever recycler task you need to do.

**!!!!!!!!!!!!!!!!!!!!!!!**

**If you are in any way unsure of how to power down the High Voltage System of an HV or BEV vehicle, ALWAYS refer to the OEM information and follow the manufacturers procedure TO THE LETTER!**

**!!!!!!!!!!!!!!!!!!!!!!!**

# COURSE OBJECTIVES AND INTRODUCTION

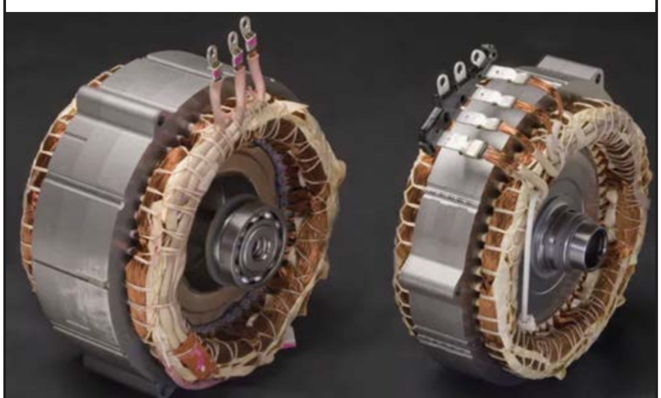
## COURSE OBJECTIVES

**By the end of this course you should be able to:**

- **Identify all parts of a three-phase motor.**
- **Differentiate the operation between permanent magnet motor & induction motor.**
- **Identify the interaction of three phase motor with gear train.**
- **Evaluate motor windings using specialized equipment.**
- **Analyze motor and bearing failures.**

## INTRODUCTION

Three-phase motors are used exclusively in HEV/BEV applications. There are typically 1-4 motors per vehicle. The electric motor provides two functions, motor mode, and generator mode. The motor mode provides output to rotate a gear or shaft.



*Three Phase Motor Assembly (Typical)*

The motor also provides energy to charge the high voltage battery in generator mode. The three-phase motors are brushless in design and rely on an inverter to drive the motor through induction.

Three-phase motors have been in use in the commercial industry for years. One of the differences in the automotive field is the motors are associated with gearboxes and operate while immersed in oil in most applications. In other applications, the motor is sandwiched between the engine and transmission and is not in direct contact with the internal gears of a transmission.

For example, the transaxle models may house one or two electric motors inside the unit and the gear train, including the differential. The motor-generator comprises two primary parts, the 3-phase stator winding assembly and the rotor assembly, much like a standard low voltage alternator.

The basic principle of an alternator is to convert mechanical energy to electrical energy. A coil of windings is energized to make a magnetic field and rotate. We will have a North and South pole with this energized coil of windings through the stator windings, which are three-phased or separate windings spaced at 120 degrees intervals.

When we pass through the North pole, we will create a positive voltage, and when passed through the South pole, we emit a negative voltage. This is known as alternating current.

The stator windings are held stationary while the rotor assembly is free to rotate at varying RPMs. The higher the RPM, the greater the voltage will be. We limit both voltage and AC using the other components such as the voltage regulator and rectifier with diodes.

The stator windings will use a standard core flux to enhance current flow. The amount of voltage sent to the rotor assembly through its slip rings will affect AC voltage output.

Since the rotor assembly is not a permanent magnet in an alternator, we need to supply voltage to its slip rings to create a magnet. Think of this principle much like if we coil a wire around a screwdriver tip and attach the two ends of the coil to a 9-volt battery, we will create an electromagnet that will magnetize our tool's tip. In a hybrid MG, the main difference is that the rotor assembly is a permanent magnet.

The MG assembly in an electric drive vehicle still uses the concept of a magnetized rotor assembly spinning within the stator windings, which are three-phased equally spaced 120 degrees apart.

This will still create AC voltage, and depending on whether we are trying to drive the vehicle or charge the battery, it may be converted to DC voltage.

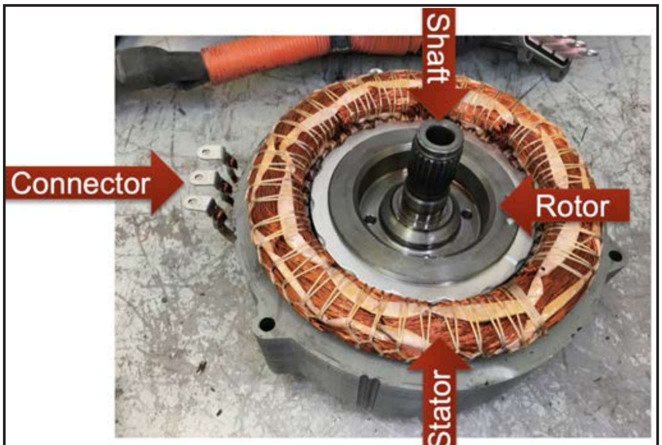
Not all three-phase motor designs are the same so we will point out the main components and the operation in this section.

# CHAPTER 1 - THREE PHASE MOTOR DESIGN

## Main Components

- Stator.
- Rotor.
- Shaft.
- Bearings.
- Three phase connector ends.
- Position sensor.

Electric motors consist of five main parts: the stator, rotor, shaft, bearings, and three-phase connector. The stator consists of a stator frame, three-phase windings, and the connector end.




*Three Phase Motor Main Components*

The rotor and shaft perform the work. The rotor is supported by bearings and rotated by the magnetic field created in the stator windings. The shaft is the output and is typically splined.

## Rotor

Key Points:
- Rotor performs the work.
- Rotor interacts with gear train.
- Gear transmits power through gear train.

The rotor performs the work. The rotor interacts with the gear train transmitting torque to the appropriate gear. In this example, the rotor engages with a splined shaft with a gear attached to the shaft.

*Rotor and Shaft (Removed)*

The gear train typically starts the internal combustion engine and delivers power to the wheels. The pathway that propels the vehicle starts at the largest electric motor's rotor and continues through the gear train to provide a gear reduction to the differential and out to the tire-wheel assembly.

## Gear Train

Many technicians think the electric motor is a direct drive unit, but the electric motor interacts with a gear train to propel the vehicle and start the ICE.

*Gear Train*

Pictured above is a Honda dual-mode transaxle. The gear train resides on one side of the case and the electric motors on the other side.

# CHAPTER 1 - THREE PHASE MOTOR DESIGN

The first part installed into the case is the counter or (Transfer gear), the second part is the differential assembly, the third part installed is the overdrive gear, the fourth part is the large motor shaft with attached parking gear, and the fifth part is the overdrive clutch. The last part is the generator shaft.

### Stator

Key Points:

- The stator consist of windings.
- Windings run through the housing.
- There are three separate windings.

*Stator Assembly*

as three phases. The windings form loops and run through the stator housing. In three-phase motors, there is no permanent ground.

The wires are insulated from each other, and the wires are also insulated from the stator housing.

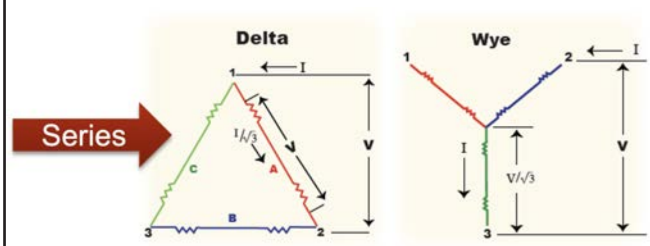
The three phases terminate with three eyelet connectors and are attached to the inverter. The inverter controls the speed and torque of the motor.

### Winding Configuration

Key Points:

- Wye or Delta windings.
- Poles-How many windings per phase.
- Windings may be in series or parallel.
- Common pole designs are 2-4-6-8.

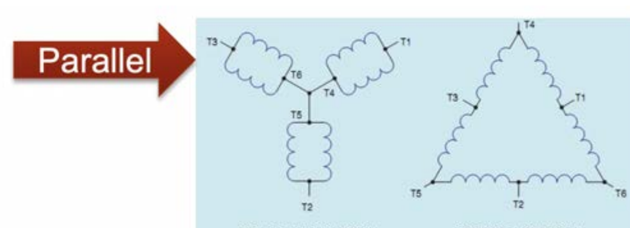
The three windings can fall into two different configurations, Wye or Delta type. The picture shows the Delta winding forms a triangle with no center point. The Wye winding is in a Y shape and has a center point where all windings meet. The center point is known as the neutral.




*Series Winding Configuration*

The Delta does not have a neutral point, but the Wye winding does. A separate wire can be attached to the neutral point to have four wires total rather than three. Each leg of the Wye or Delta is considered a phase. Each phase can have multiple windings. In our example, each phase has two windings, which would be referred to as a two-pole, three-phase motor.

Poles come in multiples of two, meaning you can have a 2-4-6-8 and up pole motor. The bigger the motor, the more poles you are likely to have. Dams that use enormous hydroelectric generators may have hundreds of poles. But, as shown, the windings can be wired in series, or the windings can be in parallel.




*Parallell Winding Configuration*

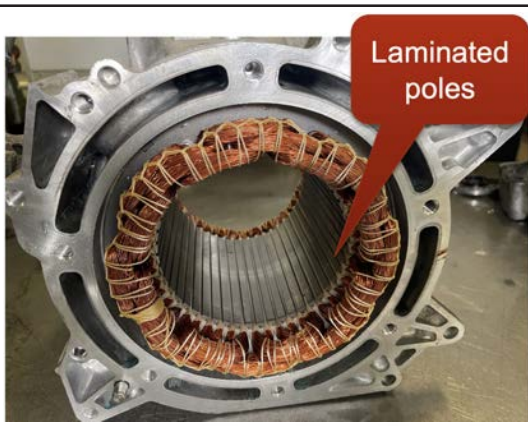
# CHAPTER 1 - THREE PHASE MOTOR DESIGN

## Stator Poles/Laminations

Key Points:

- Stator windings are inserted into slots in the stator.
- Laminations (stator poles) separate the slots.
- Winding may wrap around the poles.
- Winding may sit beside the poles.

The number of stator poles varies depending on the design. For example, the number of stator poles affects the speed of the motor: the more poles, the slower the speed and the smoother the motor operation.




***Laminated Stator Poles (Typical)***

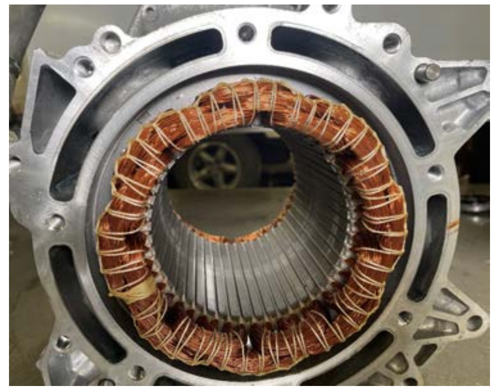
Increasing the number of stator poles reduces the torque ripple effect. The windings from the stator are placed alongside the stator poles, and the windings can wrap around the stator pole or may only lay beside the stator pole, depending on the design.

There is a minimum of stator poles, but the size of the motor dictates the maximum. Minimum stator pole example; Four pole motor has four windings per phase. 4 windings X 3 phases=12 stator poles minimum.

The stator is not limited to 12 poles. It can have many more poles. The rule is you can divide the number of stator poles by six.

## Stator Wire

The stator wire on early models was typically stranded, as was most of the industrial three-phase motors.



***Strand Wound Stator***

Some manufacturers in later designs have switched to bar wound stator wiring. The bar wound stators are more efficient and may not suffer insulation breakdown as fast.

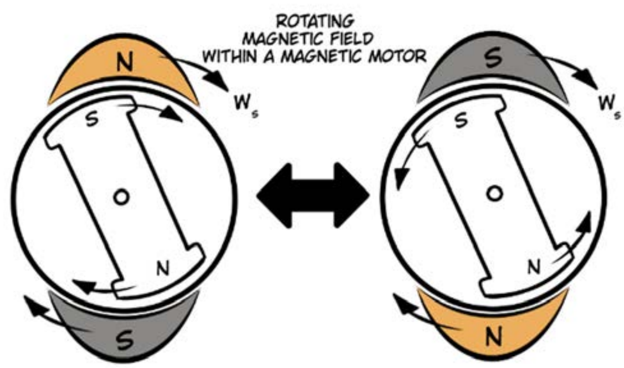
***Bar Wound Stator***

# CHAPTER 1 - THREE PHASE MOTOR DESIGN

## Motor Design

Key Points:

- Permanent magnet type (Synchronous).
- Rotor is magnetic.
- Induction type (Asynchronous).
- Rotor is non-magnetic.
- Rotating magnetic field produces rotor rotation.




*Rotating Magnetic Field*

HEV/BEV electric motors fall under two basic types. A permanent magnet is also referred to as a synchronous type motor. In a synchronous motor design, the internal rotor is a permanent magnet. The magnets may be embedded into the rotor, or the magnets may be externally mounted on the rotor.

The stator's magnetic field and the rotor's magnetic field rotate at virtually the same speed in a synchronous motor.

The rotor is not magnetic in an induction motor until the stator induces a charge into the rotor. The stator's magnetic field always leads the rotor's magnetic field in this design.

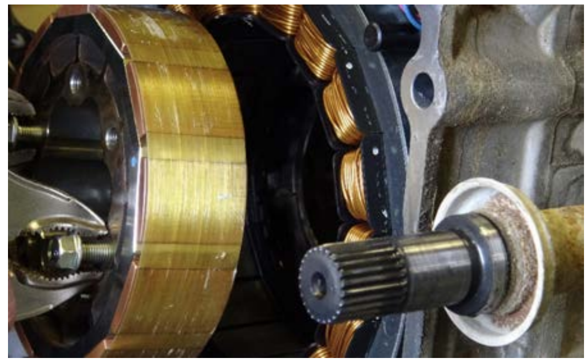
The difference in speed between the two magnetic fields is slip speed. Permanent magnet motors are slightly more efficient than induction motors.

Early Tesla models tend to use induction motors, but even Tesla is starting to switch to permanent magnet motors. Tesla Model 3 implemented a permanent magnet motor in the front and an induction motor in the rear.

## External Magnets

Key Points:

- External magnets.
- Magnets are glued and wrapped in place.



*Honda IMA External Magnetic Rotor*

The example shown is from a Honda IMA system. The magnets are mounted externally. The magnets are glued and wrapped into place.

This type of design is a little crude and is not as efficient as embedded magnets.

A certain amount of torque ripple or cogging effect may be experienced with this design. The interaction of magnetic fields causes the torque ripple or cogging effect. Torque ripple is commonplace with permanent magnet rotors.

The magnetic poles line up and create a force of attraction; it takes a certain amount of force to break that attraction which creates a slight slow down and speed up of the rotor. This is known as torque ripple or cogging.

Manufacturers are continually improving their new designs to reduce the amount of torque ripple.

# CHAPTER 1 - THREE PHASE MOTOR DESIGN

## Permanent Magnet

Key Points:
- Example: Imbedded magnets below the surface of rotor.
- Magnets are equally spaced around the rotor.
- Magnets interact with stator's magnetic field.
- Stator's magnetic field rotates causing rotor movement.

***Nissan Leaf PM Rotor***

In the example shown, the magnets are embedded below the surface forming magnetic poles around the rotor surface.

Manufacturers vary the number of magnets around the rotor, and some may use magnets in pairs.

The magnetic poles in the rotor react to the rotating magnetic field created by the stator. The rotor changes speed based on the frequency of the stator's magnetic field.

The rotor's output torque is varied by the amplitude of the voltage and amperage supplied to the stator.

## Rotor Magnets

Key Points:
- Electrical steels are stacked together to create the core of the rotor.
- Steels have slots that magnets fit into.
- This is an embedded type magnetic rotor.

***Toyota Style Rotor Magnet (Typical)***

Embedded magnets fit down into electrical steels. Toyota uses one set of magnets forming a V shape right below the rotor's surface. Most manufacturers use Neodymium iron bore magnets.

Neodymium magnets are the strongest magnets available. Embedding the magnets at an angle, as shown in the picture, reduces torque ripple and makes the motor operate much smoother.

Electrical steels are made with low carbon iron and silicon alloys.

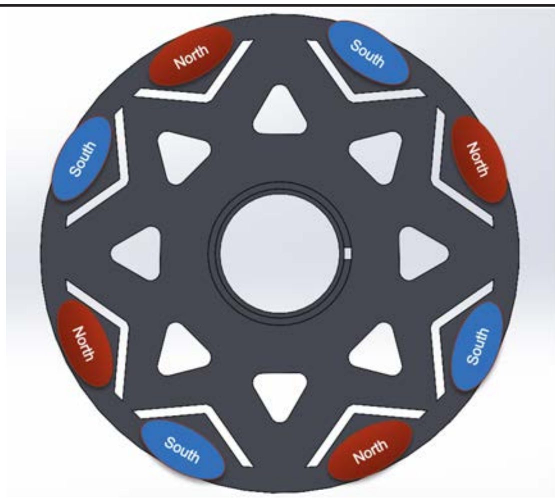
This mixture in the steels reduces eddy currents. Eddy currents are created when a conductor rotates inside a magnetic field.

Eddy currents create a magnetic field that opposes the stator's magnetic field. Magnet placement can reduce eddy currents which will increase motor efficiency.

# CHAPTER 1 - THREE PHASE MOTOR DESIGN

## Rotor Magnetic Poles

Key Points:
- Each magnet pair form either a north or south pole.
- Poles alternate around the rotor.




**Rotor Magnetic Poles**

In the example shown, we have two magnets forming a V. Each set of magnets that form a V takes on a north or south pole.

The poles alternate around the rotor. Toyota's design uses two magnets to form a pole.

The Chevy Bolt and Tesla use four magnets, two magnets stacked on top of one another to create a magnetic pole, and this produces more torque and a more negligible cogging effect from the motor.

Industry Info: In magnets, red indicates a north pole and blue indicates a south pole.

## Magnet Design

Key Points:
- Slot size increased.
- Tesla & Chevy Bolt stack two magnets.
- Two magnets on top of one another.
- Reduces torque ripple.
- The magnets run the length of the rotor.


**Slotted Magnet Design**

Some manufacturers like Chevy (Bolt) and Tesla increase the slot size in the electrical steel. The slot size has been increased to accommodate extra magnets.

Two magnets are stacked together into one slot, and the magnet pairs run the length of the rotor to form a magnetic pole.

This two-layer V arrangement helps diminish pole-to-pole variation in the magnetic field, which reduces torque ripple.

The two-layer design also reduced bridge stress by reducing the centrifugal force applied to the outer edge of the electrical steel.

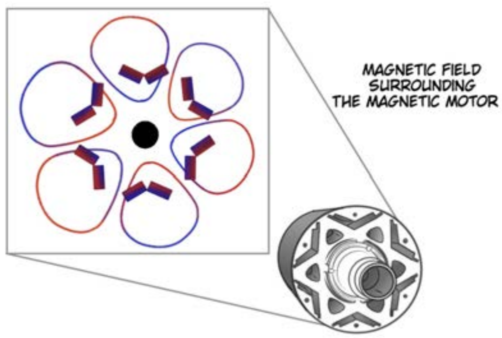
The reduced bridge stress allows for higher RPM without rotor destruction.

Instructor notes: The bridge is the material left from the outer edge of the slot to the edge of the electrical steel.

# CHAPTER 1 - THREE PHASE MOTOR DESIGN

## Embedded Magnets

Key Points:
• Magnets form north and south poles at the surface.
• The angle of the magnets shifts the magnetic field slightly.
• Magnets run the length of the rotor.

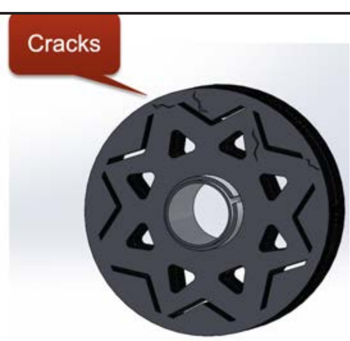



*Embedded Magnet Design*

In the application shown, we have stacked two magnets on top of one another; Tesla and the Chevy Bolt use this design. The blue loop on the magnets represents the south pole, and the red loop represents the north pole. The south and north poles alternate around the rotor. The stator can produce a firing order that can drive the rotor at varying speeds and torque.

## Rotor Failure

Key Points:
• On early internal PM motors, RPM was limited.
• Centrifugal force would cause magnets to break steels.
• Toyota early motors - 6500RPM limit.
• Late Toyotas - 17,000 limit.




*Cracks Indicating Rotor Failure*

One issue with permanent magnet motors is high RPM can cause magnets to break through the electrical steel due to centrifugal force.

The magnets are in close proximately to the surface of the rotor, and there is not a lot of material at the bridge gap holding them in place. Early Prius electric motors were limited to 6500RPM due to this design, but the rotor was redesigned and upgraded to 10,000RPM, and then upgraded to 17,000 RPM.

## Tesla IPMsynRM

Key Points:
• Tesla invented extreme high-speed motor.
• Permanent magnet type motor.
• Carbon wrapped rotor to retain magnets at high speed.
• Tesla late model motor - 20,000RPM plus.


*Tesla High-Speed Rotor*

Tesla designed an interior permanent magnet synchronous reluctance motor (IPMsynRM).

Previous permanent magnet motors suffered a lower RPM rating due to the magnets breaking out of the electrical steels at high speeds.

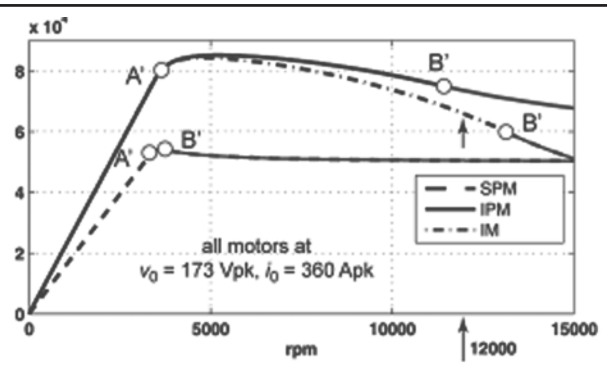
Tesla employs a carbon wrap around the rotor to hold the rotor together at high speeds.

Tesla motors using this technology can withstand RPM ranges beyond 20,000 RPMs.

# CHAPTER 1 - THREE PHASE MOTOR DESIGN

## Tesla IPM

Key Points:
• IPM motor has a higher torque band than an induction motor.
• Surface mounted magnets.
• The IPM is NOT an Induction motor.
• Induction motor suffers torque losses at higher speeds.
• Induction motors approximately 2% less efficient than IPM.



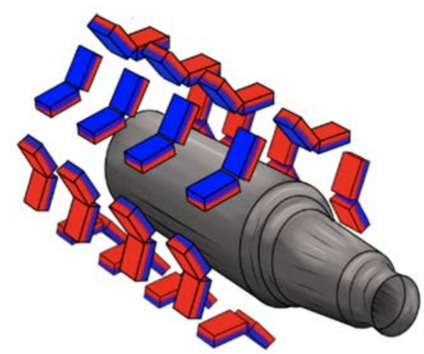

*Tesla IPM Effiiciency*

Tesla has designed a new interior permanent magnet motor. Tesla is switching from induction motors to permanent magnet motors because the IPM is more efficient.

Induction motors suffer more torque loss at high speeds than permanent magnet motors. Induction motors are approximately 2% less efficient than permanent magnet motors at higher speeds. Interior magnet motors also outperform surface-mounted magnets motor.

## Magnetic Strength

Key Points:
• Magnets may degrade due to high temperature.
• Testing magnetic strength requires a Tesla or Gauss meter.
• Magnets may weaken over time due to excessive heat.
• Each magnet may not degrade at the same rate.
• This may cause an imbalance in the magnetic field.



*Magnetic Poles*

### GAUSS MEASUREMENTS IN COMPARISON

- 0.5 Gauss – Earth's magnetic field at its surface
- 100 Gauss – A typical refrigerator magnet
- 1,100 Gauss – Magnetic rubber grade Y
- 3,700 Gauss – Ferrite (Ceramic) magnets
- 11,000 Gauss – Samarium cobalt grade 2:17 magnet
- 12,500 Gauss – Alnico grade 5 magnet
- 13,000 Gauss – Neodymium grade N42 magnet

*Gauss Measurements*

The magnetic strength of a magnet is measured in Gauss or Teslas. One Tesla equals 10,000 Gauss. Magnetic strength can be measured with a Gauss meter.

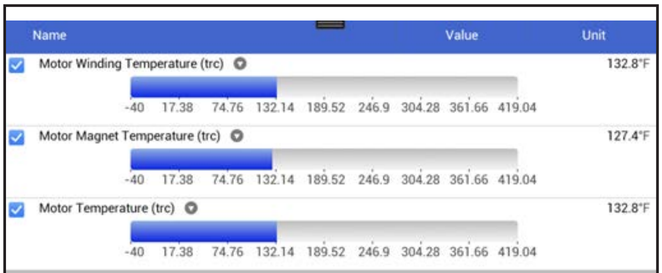
A Gauss meter is not typically a meter in most shops and may weaken over time from overheating.

Magnet strength may vary between magnets, creating an imbalance between the magnets. The imbalance causes a cogging effect during motor operation.

# CHAPTER 1 - THREE PHASE MOTOR DESIGN

## Monitor Temperature

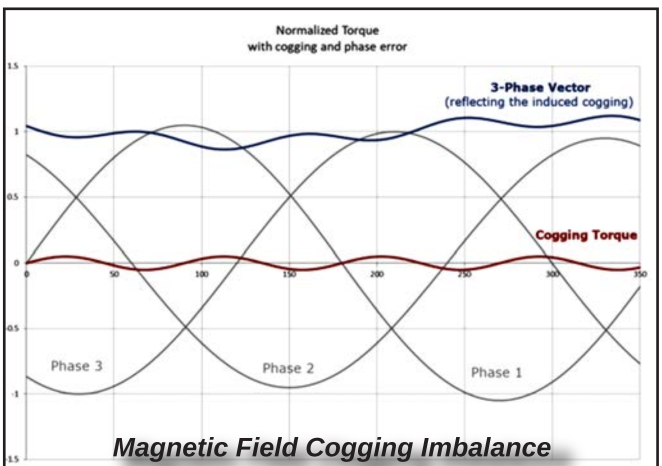
This scan data shot was taken from a Honda dual motor. The temperature is referencing the large traction motor that drives the vehicle. The winding temperature and motor temperature are measured with a sensor located near the motor and windings, but the sensor is not embedded. The magnet temperature is calculated and not measured.




*Honda Dual Motor Temperature Readings*

## Magnetic Field Imbalance

Key Points:
- Causes torque ripple or cogging effect.
- Shudder.
- Surging.
- Fish bite feel.
- 8-12 magnetic poles in rotor is fairly normal.
- Rotor magnets can always be divided by two.




*Magnetic Field Cogging Imbalance*

A cogging effect can be felt during operation. It may feel like a slight shudder, fish bite, or surging. Rotors may vary the number of magnetic poles depending on the size of the motor and the manufacturer. Rotors may have 8-12 magnetic poles. Rotor magnets can always be divided by 2.

## Rotor Removal

Key Points:
- Magnetic rotors are hard to remove from stator.
- Magnetic attraction retains them inside the rotor.
- Place coffee can or pipe under rotor.
- Push stator straight down to separate.

*Magnetic Rotor (Removed)*

Magnetic rotors are very hard to remove from the stator. The magnetic attraction retains the rotor inside the stator. The rotor can be placed on a coffee can or pipe; press down on the stator to separate the two. It is best to have a padded surface underneath to catch the stator.

Do not pry on the windings to separate the rotor from the stator. It is best to remove the stator and rotor as an assembly from the transmission or transaxle and separate the two on the bench.

## Induction Motors

Key Points:
- Induction motors.
- Rotor is nonmagnetic.
- Aluminum or copper bars travel between shorting end rings.
- Shorting rings on each end.
- Stator creates an electromagnetic induction into rotor.

An induction motor may be called a squirrel cage motor and does not use a magnetized rotor. The rotor is nonmagnetic and is made with aluminum or copper bars that travel to shorting rings at each end of the rotor. Between the bars are steel laminations which improve the magnetic field.

## CHAPTER 1 - THREE PHASE MOTOR DESIGN

*Induction Motor*

The stator windings have current flowing through them, which creates an electromagnetic induction into the rotor bars. The rotor bars form the north and south poles and react to the north and south poles of the stator, which produces rotation of the rotor.

The bars are attached at an angle to help reduce torque ripple. Due to the induced current into the rotor and current flowing through the rotor, there will be an energy loss in this design.

The energy loss is accelerated at higher speeds; therefore, as discussed earlier, the induction motor is not as efficient as the permanent magnet motor.

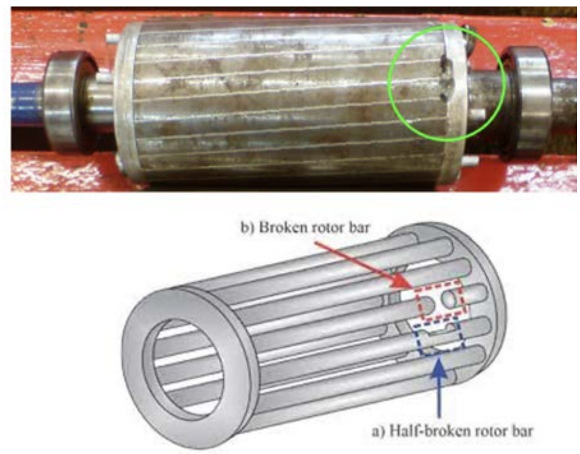
Due to the current flowing through the rotor, the squirrel cage will be insulated from the rotor shaft. The insulation can be made from a phenolic material.

Any current that makes its way to the shaft may damage rotor bearings, and the current can travel through attached shafts, gears, and drivetrain bearings.

### Induction Motor Rotor

Key Points:

- Cracked bars-cracked shorting rings.
- Causes shudder-fish bite-surge effect in drivetrain.




*Induction Motor Cracking*

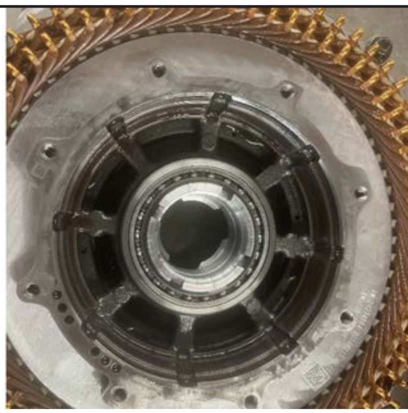
Cracked bars or broken shorting rings can cause a significant torque ripple or cogging effect. For example, the driver may notice a shudder or fish bite sensation when accelerating.

This problem can be seen in the three-phase amperage waveform, which will be explained later.

# CHAPTER 1 - THREE PHASE MOTOR DESIGN

## Rotor Clearance

Key Points:
- Rotor air gap may be approximately .015-.050" by design.
- Rotor clearance variation results from worn bearings.
- If you double rotor clearance you lose magnetic coupling strength by a factor of 4.
- Causes cogging or surging of output pulse & vibration.



*Rotor Clearance*

Another problem that will cause torque ripple or cogging effect is rotor to stator clearance changing. Rotor air gap is typically .015-.050 thousandths by design.

Air gap can change due to worn bearings. If you double the rotor clearance you multiply the magnetic loss by a factor of four.

The changing magnetic field creates a cogging effect that can be felt by the driver. This cogging effect may be felt on acceleration or deceleration.

Vibration is a side effect of rotor air gap changing, the vibration will cause premature insulation break down on the windings. Bearing problems will be discussed in the next section.

## Chapter Assessment

Question 1: Are the motors used in BEV-HEVs AC or DC?

***Answer: AC motors***

Question 2: What is the biggest difference between an induction motor and a PM motor?

***Answer: The rotor is non magnetic in an induction motor and the rotor is magnetic in the PM motor.***

Question: T or F The correct way to remove the rotor from the stator on a PM motor is to pry it out with prybars.

***Answer: False, you may damage the stator by prying on it.***

## Assessment Notes:

# CHAPTER 2 - BEARING ISSUES

## Phase Imbalance

Key Points:
• Utility three phase power is balanced.
• Utility power has a true sine wave with a zero common mode voltage.
• Variable frequency drives (Inverters) cannot obtain a zero common mode voltage.

Phase imbalance can cause electrical discharge into the rotor on a permanent magnet motor. Utility companies that supply three-phase power provide the power as a true sine wave.

The utility power is balanced with a zero common-mode voltage. In a balanced system, the sum of all three phases to neutral voltages is zero.

A common-mode voltage is created due to the imbalance between the phases due to the variable frequency drive of the inverter. The inverter does not create a true sine wave but simulates AC.

The common-mode voltage and current must be dissipated, and it may find a path to dissipate through the rotor and into the shaft.

The current can travel through the rotor's bearings, causing issues. Standard mode voltage can be reduced by shielding the cables and terminating the shielding at both ends.

The shielding will give the common-mode voltage a pathway back to the inverter and dissipate the common-mode voltage, which can extend bearing life. Ensure the three-phase cables have the shielding in place and terminated at each end.

## Rotor

Key Points:
• Permanent magnet motors.
• Rotors are not isolated from shaft.
• Induction motors.
• Rotor is isolated from the shaft.

The electric motor is from a Honda dual-motor transaxle, a permanent magnet type motor. The rotor and shaft are not isolated from each other, so whatever current is induced into the rotor is dissipated through the shaft.

There is a connection between the rotor and the shaft. Bearings support the shaft, and the bearings can suffer from electrical currents flowing from the raceway to balls to the other raceway.


***Honda Dual Motor Rotor Current Test***

Permanent magnet motors have internal or external magnets that are permanently magnetized, so the rotor requires no inductive currents to operate. However, the induction motor's rotor is not magnetized; therefore, currents are induced into the rotor bars creating a magnetic rotor.

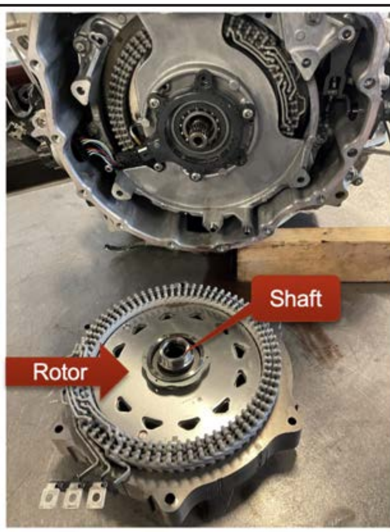
Due to this induction process, the rotor must be isolated from the shaft. Most induction motors have a phenolic material between the shaft and the rotor to provide this isolation.

Extremely high current may cause a capacitively coupled current. A capacitively coupled circuit is when currents can flow through insulated components. The currents can also find their way to other components coupled with the rotor shaft.

# CHAPTER 2 - BEARING ISSUES

## Bearing Failure/Electrical Discharge

Key Points:
• Variable frequency drives (Inverters) simulate AC.
• Cannot obtain a zero common mode voltage.
• The imbalance discharged through rotor.




*Rotor, Shaft and Bearing*

Rotor shaft currents tend to be higher in hybrid and electric vehicles than in industrial motors. The most significant contributing factor is how the current is developed and fed to the electric motor.

The utility three-phase power that feeds an industrial electric motor is more balanced than the simulated AC power produced by an inverter.

The utility power creates a true sine wave that typically results in a zero standard mode voltage, meaning all three phases are balanced . For example, the inverter used in HEV-BEV applications creates or simulates an AC voltage, and it is not a true sine wave.

The inverter type system is a variable frequency drive (VFD). VFD creates an imbalance in the three phases.

The imbalance must be dissipated and usually is dissipated into the rotor. The rotor shaft dissipates the excess voltage through the bearings.

In a balanced system, the sum of all three phases to neutral voltages is zero.

## Bearing Issues

Key Points:
• Rotor shaft becomes charged (Shaft currents).
• 3-5 volts in rotor will not cause any damage.
• Above 6 volts becomes problematic.
• Voltage may spike to 30 volts or possibly several hundred volts.
• Rotor discharges through bearings causes EIBD (electrically induced bearing damage).

*Honda Dual Motor Rotor Shaft Bearing Assy.*

Motor bearing failure is very prominent in hybrid and electric vehicles. However, bearing failure seems to be higher in-vehicle applications than in industrial applications.

For example, electric motors experience an electrical phenomenon called rotor shaft discharge in both applications.

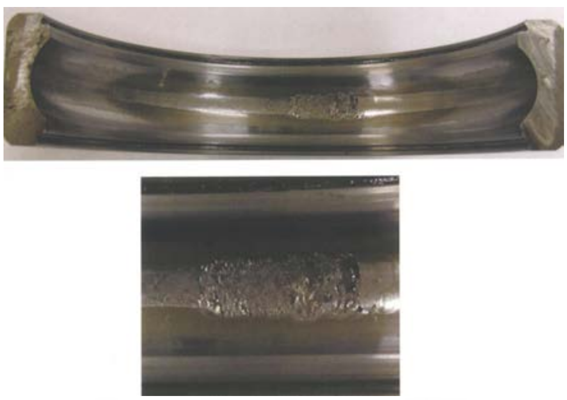
This condition results from the rotor shaft becoming inductively charged, and the excess voltage is dissipated through the bearings.

Low voltage levels in the rotor shaft between 3-5 volts are normal and cause no issues. Voltage levels that exceed 6 volts will be dissipated through the bearings. Voltage levels may spike upward from 30 volts to an undetermined voltage level.

# CHAPTER 2 - BEARING ISSUES

## Bearings (Electrical Discharge Issues)

Key Points:
• Electrical discharge mimics welding.
• Causes micro craters in raceways.
• Changes the metallurgy resulting in brittle spots.
• Bearing failure results from this condition.
• Updated ceramic ball-steel raceway bearings reduce this phenomenon.



*Bearing Race Crater and Pitting*

The electrical discharge through the bearings mimics welding. Tiny micro craters are created on the bearing raceways. The discharge also influences the metallurgy of the bearing causing the bearing to become brittle in spots.

## Bearings (Lubrication Issues)

Key Points:
• Oil lubricant forms an insulation barrier between balls and raceways.
• Dry spots create an area for discharge.
• High currents punch through contaminated oil.
• Sealed bearings with nonconductive dielectric grease reduces discharge.
• Proper maintenance- changing oil and flushing out any metal particles in oil reduces bearing failure.

The lubricating oil forms an insulation barrier between the balls and the raceways. Dry spots create an area for discharge.

The rotor shaft currents may get so high that the current may punch through the oil and discharge anyway; dirty oil containing moisture and metal particles makes it easier for the current to punch through.

Some manufacturers use sealed bearings with non-conductive dielectric grease, reducing the discharge effects. Proper lubricating oil maintenance may reduce this electrical discharge phenomenon as well. For example, in bearings that have undergone electrical discharge, the balls may become frosted or dull grey in appearance. The raceways may be pitted as well.

## Ceramic Balls

Key Points:
• Manufactures may use ceramic balls and steel raceways.
• The ceramic balls reduce or help eliminate the electrical discharge.

Manufacturers may equip their motors with ceramic bearings. The ceramic bearings use ceramic balls and steel raceways. The ceramic balls help reduce or eliminate the electric discharge effect.

## Shaft Brush

Key Points:
• Some manufactures use a set of brushes to dissipate inductive charge.
• Brushes have a service life and must be inspected and replaced.

*Carbon Shaft Brush*

Some manufacturers utilize a set of carbon brushes on the shaft to dissipate the excess charge. The brushes should be inspected at certain intervals and replaced when necessary.

The Nissan leaf uses a brush that contacts the shaft to dissipate any electrical charge that may be present.

# CHAPTER 2 - BEARING ISSUES

## Discharge Meter

Key Points:
• SKF-TKED meter measures how many discharges are occurring near bearing.
• Meter only needs to be in close proximately of bearings to pick up discharge.
• Vibration analysis can also indicate bearing condition or detect premature failure.


*SKF-TKED Bearing Discharge Meter*

The industry offers a tool to determine if electrical discharge is occurring. The tool is offered through SKF. The tool number is SKF-TKED.

The tool needs to be held in close proximately to the bearings. The tool inductively picks up the discharge and counts them.

This is not a tool that a shop is going to buy, it is a tool a maintenance guy would use that oversaw banks of electric motors. A lot of companies mount vibration sensors on their industrial motors and remotely monitor the vibration.

The vibration level increase usually points to an eminent bearing failure, and they can service the bearings before a catastrophic failure occurs.

Industry Info: Tool is around $850.00 -Unique remote solution allows operation at a distance from the motors. This helps protect the user from touching machinery in motion.
• SKF technology.
• No special training required.
• Capable of detecting electrical discharges on a time base of 10 seconds, 30 seconds or indefinite.
• LED backlit screen, allows use in dark environments.
• IP 55 can be used in most industrial environments.
• Supplied standard with batteries, a spare antenna and language free Instructions for use in a carrying case.

Instructor notes: We are not suggesting to buy this tool or it is needed in any way. We are only pointing out that the problem is known in the industry and there is a tool for testing.

## Chapter 2 Notes:

# CHAPTER 3 - RESOLVERS

## Resolvers

Key Points:
• Three phase motors are driven by a rotating magnetic field.
• The control module must calculate the firing order.
• The control module requires the motor position to calculate the firing order.
• Resolvers are used to calculate motor position-speed-direction.
• Resolvers consist of a stator, a rotor and six wires.
• The stator poles react to the motion of resolver's rotor.
• Six wires represent 3 separate circuits.


*Resolver & Stator*

A rotating magnetic field drives three-phase motors. The control module must calculate the firing order to create the rotating magnetic field. The control module needs the input of motor position, speed, and direction.

This feedback sensor is necessary for motor operation. The type of sensor used to determine the speed, position, and direction of rotation is typically a resolver.

The resolver consists of three main parts the stator, rotor, and the six wire circuits. The stator is formed into the resolver housing and has many poles, depending on the design, and rotates inside the stator. The rotor may have two to six sides.

The circuit has six wires and represents three separate circuits. Early design revolvers were installed at the factory, and the hold-down bolts had slots so the resolver could be adjusted. These resolvers were adjusted at the factory, and field adjustment was almost impossible.

If you loosened or removed the early design adjustable resolvers, you needed to replace the case half with the resolver bolted in and timed. The resolver shown is a newer design and is not adjustable, this type can be removed and installed with no problem, and the control module can learn the resolver's position if needed.

## Resolver Location and Adjustment

Key Points:
• Some resolvers are adjustable and are set at the factory.
• Some resolvers are pinned and use scan tool to relearn.

*Honda Dual Motor Resolver*

The resolver shown is from a 2017 Honda dual-motor transaxle. This resolver uses a pin to locate the resolver, so no adjustment is possible.

After resolver replacement or removal and reinstallation, perform a resolver relearn with the scan tool.

# CHAPTER 3 - RESOLVERS

## Resolver Rotor

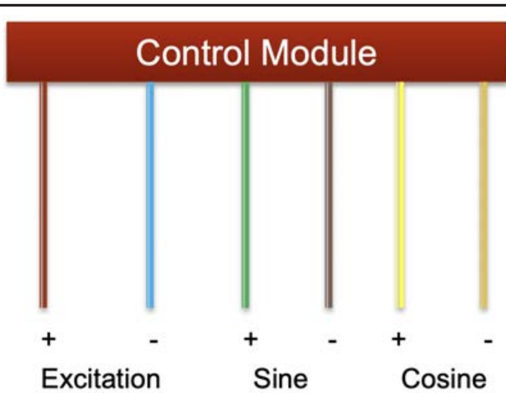
Key Points:
- The resolver rotor in this application is six sided.
- The rotor rotates around the inside of the stator.


*Six Sided Resolver Rotor*

The rotor in this example has six sides but some are elliptical shaped and only have two sides. Others may have four or five sides.

## Resolver Circuits

Key Points:
- Three circuits.
    - Excitation.
    - Sine.
    - Cosine.
- Excitation is a 5-volt AC sine wave.
- Sine and cosine circuits interact with rotor position.



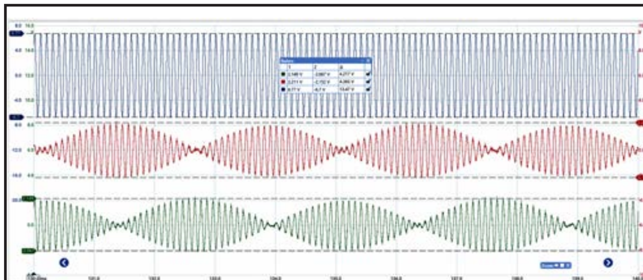

*Resolver Circuit Diagram (Typical)*

An excitation circuit is generated at the control module. It is an AC waveform. The excitation circuit induces a charge into the other two circuits, sine, and cosine. Sine and cosine circuits react to the resolver's rotor movement.

Sine and cosine circuits create an AC waveform that changes in frequency and amplitude as the speed of the rotor varies.

The waveform of sine and cosine are constantly changing, referencing rotor position, but the excitation circuit waveform remains a constant frequency and amplitude.

## Resolver Waveform



*Resolver Waveform (Typical)*

The top waveform represents the excitation circuit. The excitation circuit is wound around each resolver stator pole with the same number of turns per pole.

The control module creates an AC sine wave and sends it down the excitation signal wire. The excitation waveform does not change with rotor position or rotor speed.

The excitation circuit induces a current into the sine and cosine circuits represented in the blue and red waveform.

The sine and cosine circuits are wound around each resolver pole with varying turns, so the sine and cosine circuits change when interacting with the rotor.

The sine and cosine circuit amplitude will change with rotor position, and the frequency will change with rotor speed. Sine and cosine circuits are offset slightly from each other, which can be observed in the waveform.

## CHAPTER 3 - RESOLVERS

### CHAPTER 3 ASSESSMENT

**Question: T or F Ball bearings in electric motors turn faster than ball bearings in conventional vehicles**

***Answer: True, Tesla electric motors may spin up to 20,000 RPMs requiring high speed bearings.***

**Question: Bearing failure may be caused by micro-welding.**

***Answer: True, the rotor shaft becomes charged and causes a micro-welding effect during discharge.***

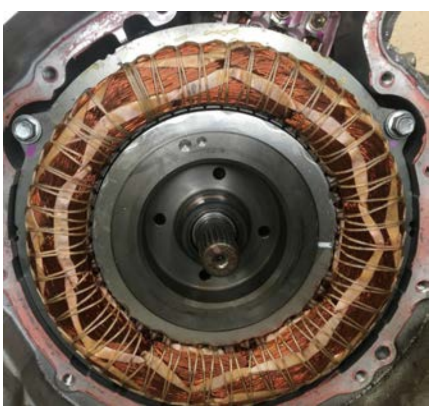
**Question: Resolvers need to be timed or their position needs to be learned.**

***Answer: True, The resolver is timed at the factory or the position is learned after installation.***

## CHAPTER 4 - MOTOR INSULATION

### Winding Insulation

Key Points:
- Wire insulation may be epoxy or amino resin base-enamel base-polymer base.
- Wires expand & contract during operation (High speed camera can detect movement).
- The movement of the wire can rub off insulation.



***Stranded Wound Insulation (2006 Highlander)***

The windings are insulated to prevent electricity transfer from wire to wire or stator frame (Ground). The insulation on the wire may vary from manufacture or build date.

Some common insulation types used are varnish, amino and epoxy resins, enamel, or polymer. Some windings may be coated with 5-7 coats to improve protection.

The application of the insulating material may include varnish dip and bake, atmospheric dipping, vacuum pressure impregnation (VPI), dipping, and trickle/Dip-roll. Vacuum pressure impregnation is an improved process that builds resiliency into the windings.

The most expensive and longest-lasting is ultra seal winding. Ultra seal windings are thoroughly impregnated and seal the wire with high molecular weight thermoset polymer resin.

Windings are constantly moving due to expansion, contraction, and vibration along with chemical exposure and temperature swings, and will suffer from insulation degradation over time.

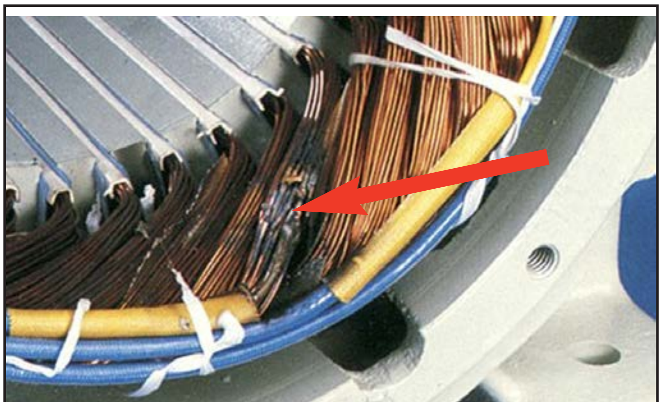
Wire insulation failure has contributed to motor failure no matter what type of insulation process is used.

# CHAPTER 4 - MOTOR INSULATION

## Insulation Degradation

Key Points:
• Low and high temperatures.
• Expansion and contraction.
• Vibration.
• Chemical exposure.
• High switching frequency.
• Voltage spikes.
• Example: Epoxy resins are designed to operate within

-40F to 356F range.



*Degraded/Damaged Insulation*

Low temperatures, high temperatures, wire movement, and chemical exposure can cause wire insulation degradation. The rubbing effect of wire movement can degrade the insulation and allow shorting between wires.

Chemicals can attack the insulation material causing degradation. The insulation has temperature specifications that must be adhered to.

The low temperature is approximately -40 degrees, and the high temperature is approximately 356 degrees Fahrenheit. The insulation material needs to stay within that range, or it will degrade at a faster rate.

Lubrication oil that is neglected can develop acids that may attack the wire insulation and cause premature failure.

Metal particles floating in the oil can become impregnated into the insulation and cause damage. Voltage spikes and high switching frequency can add additional stresses to the wire insulation.

## Partial Discharge (PD)

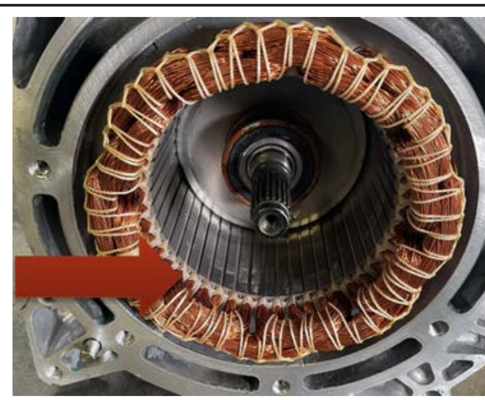
Key Points:
• Partial discharge (PD) is common in motor windings.
• Categorized by magnitude.
• Insulation breakdown allows PD.

Insulation breakdown can cause a condition that allows partial discharge. Partial discharge (PD) is more prevalent than a constant short.

Partial discharge is categorized by magnitude. Partial discharge happens more frequently with systems that use variable frequency drives (VFD). All inverters on the market today utilize VFD.

## Stator Slot Insulation

Key Points:
• Stator slots utilize an insulating paper called NOMEX MYLAR.
• NOMEX MYLAR paper may deteriorate over time due to natural aging or chemical attacks.
• Slot insulation prevents phase to stator housing shorts.
• Paper degradation and contamination may allow a partial discharge to stator housing.
• Complete paper degradation may cause phase to ground short.



*Nissan Leaf Stator Slots*

Stator slots retain the motor windings. The windings must be insulated from the back iron (laminations). Typically, the windings are insulated with NOMEX MYLAR, triple-layer insulation made from a polyester film and overlayed with an aramid paper overlay on both sides.

# CHAPTER 4 - MOTOR INSULATION

Heat, natural aging, chemicals, and winding movement can degrade the NOMEX MYLAR causing a partial discharge or a short to ground.

## Motor Shorts

Key Points:
• Turn to turn short.
• Coil to coil short.
• Phase to phase short.
• Phase to ground short.
• Shorts can be detected with megaohm and milliohm meters.

Motor shorts plague the electric motor industry and can come in wide varieties. Turn to turn short, coil to coil short, phase to phase short, and a short to ground.

The insulation can break down on the wire, allowing it to short, and the slot insulation can break down, contributing to the problem.

Shorts can be detected by megaohm and milliohm testing, which we will cover in the motor testing section.

***Motor Short Testing***

# CHAPTER 5 - MOTOR TESTING

## Testing

Key Points:
Motor testing can be performed with special tools
• Megaohm meter.
• Milliohm meter.
• AT34 handheld tester or equivalent.
• Lab scope-High amp probe.
• Scan tool codes.
<img>

Three-phase motor testing requires special equipment. Stator testing consists of checking for turn to turn, phase to phase, and phase to ground shorts. Some specialized testers can also test the rotor.

The equipment typically needed is a megaohm meter, milliohm meter, AT34 handheld tester, or equivalent for static bench testing, lab scope, and scan tools for on-car dynamic testing.

These tests will be explained in the upcoming slides. Lab scope high amperage testing will be covered in the inverter module.

## Units Of Measurement

Key Points:
• 1 Ohm-1,000 milliohms (m).
• 1 Kilohm-1,000 ohms.
• 1 Megaohm(M) -1,000,000 ohms.
• Gigaohms-1,000,000,000 ohms.
• Millifarad-1 thousandth of a farad.
• Microfarad-1 millionth of a farad.
• Nanofarad-1 billionth of a farad.
• Picofarad-1 trillionth of a farad.

## Motor Testing Requirements

Key Points:
• Motor testing requires an understanding of the following.
• Insulation.
• Impedance-inductance-dissipation factor-phase angle-current to frequency response.
• Winding contamination.
• Partial discharge.
• Capacitance.
• Turn-to-turn shorts.

## CHAPTER 5 - MOTOR TESTING

- Coil-to-coil shorts.
- If you need more information on these subjects, visit aviondemand.com.

Motor testing can get very in-depth. For example, a technician can test for the basics with conventional tools like a milliohm meter and a megaohm meter. A milliohm meter will test the resistance of the windings between the phases.

A megaohm meter will test for a short from winding to ground. A lot of technicians think these are the only test for motor windings. However, more problems may exist in the windings that these instruments may not pick up.

In-depth tests can be run with specialized equipment, and these tests can include Impedance, inductance, phase angle, current to frequency response, dissipation factor, and capacitance to ground. If you want more information on these tests, click the hyperlink. https://aviondemand.com/

### Milliohm Tester

Key Points:
- Uses four lead Kelvin clip testing.
- Very accurate below one ohm.
- Test each phase to each other.
- Compare to spec.
- Should not vary over 5%.

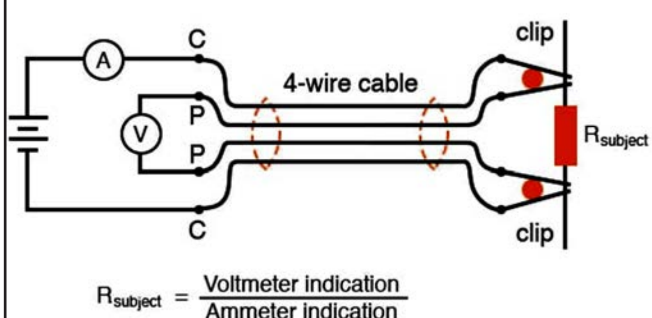
*EXTECH Digital Milliohm Meter*

A DVOM is not accurate enough to test stator windings. Instead, the DVOM outputs approximately 2.7 volts at 1 milliamp. The milliohm tester shown varies the output 1-100 milliamps depending on the testing ohm range.
The accuracy of the milliohm meter shown is within .1 milliohm on the 200-milliohm scale. Accuracy is essential when measuring stator windings. Stator windings are typically less than one ohm. Stator windings should not vary more than 5% between phases.

### Rotor Milliohm testing

*EXTECH Digital Milliohm Meter - Rotor Testing*

### Kelvin Clips



*Kelvin Clip Connection Schematic*

A DVOM outputs the voltage/current and measures the voltage drop with the same two wires, reducing the accuracy.

A milliohm meter uses Kelvin clips which means it outputs voltage/amperage on the two outside wires and measures the voltage drop on the two inside wires.

The jaws on the end of the leads incorporate both leads into one jaw. This type of testing is more accurate than the standard DVOM.

# CHAPTER 5 - MOTOR TESTING

## Megaohm Meter

Key Points:
• Measures insulation leakage.
• Checks for winding to stator housing shorts.
• Meter outputs 50-100-250-500-1000 volts.
• Select output based on testing spec or operating voltage.

*Fluke "Megger" Megaohm Meter*

A megaohm meter, sometimes called a "megger", is used to test the insulation of the windings. The meter injects the voltage you select through the windings and measures the amount of voltage that leaks to the frame/housing of the motor.

The windings will be isolated from the stator frame/housing if the insulation quality is high. The technician must select the output voltage of the megger.

The output voltage spec may be listed as in-service information. If no voltage is found in service information, select the voltage the system operates at, or if you want to stress the system, pick the next voltage level up.

For example, If the operating voltage is 300 volts, select the next level up on the megger. The following voltage level will be 500 volts but do not go to 1,000 volts; this would be too high.

If you select the highest voltage on the megger, it may damage windings and insulation.

The megger comes with a unique set of leads that must be used when performing insulation leak detection.

The red lead is attached to a phase wire, and the black lead is attached to the stator frame/housing. Press the test button on the lead or the test button on the meter.

The selected voltage should not vary, and the ohmic value should be a minimum of 10 megaohms. The windings are shorted if the voltage drops on the meter, and a low ohm value is indicated.

## Megaohm meter Testing

*Megaohm Meter Testing*

You only need to test one phase because they are physically all hooked together but for the sake of this test, we tested all three phases.

# CHAPTER 5 - MOTOR TESTING

## AT34 Tester

Key Points:
- Static and dynamic testing.
- Insulation test - megaohm.
- Winding test - milliohm test.
- Contamination test.
- Differentiate rotor from winding test.
- Current to frequency test.


*AT34 Dynamic Testing*

The AT 34 is designed to test three-phase motors and is optimized for hybrid and electric vehicle motors. The AT34 tests permanent magnet and induction motors.

The first step is to pick the type of motor; PM is a permanent magnet motor, and a generator is an induction motor.

The next step is to attach the yellow lead to the stator housing and the blue lead to the center terminal. The tester will perform the first test, the capacitance and dissipation factor; this test reflects contamination in the windings.

The next test is the insulation test which requires the technician to hold the test button down. Then, the tester injects the selected voltage into the windings and measures any voltage reaching the stator housing.

The next step is to attach the black lead to terminal one and the red lead to terminal three. The tester now tests the milliohm resistance between phase windings.

The results can be viewed at the end of the test. The tester also offers a dynamic test that requires turning the electric motor's rotor.

The dynamic test can verify the rotor does not exhibit any problems. The tester also offers more in-depth testing, explained in the help section.

## Summary

Key Points:
- Pointed out the difference between permanent magnet motors and induction motors.
- Learned how three phase windings work.
- Discovered how the stator and rotor function together.
- Learned how magnet placement is key in rotor design.
- Discovered what type of equipment is needed to test three-phase motors.
- Learned the proper testing procedures to test three phase motors.

## Assessment

**Question: A megaohm meter is used to measure the winding resistance.**

***Answer: False, A megaohm meter measures leakage from windings to ground.***

**Question: How many ohms in a gigaohm?**

***Answer: One billion ohms.***

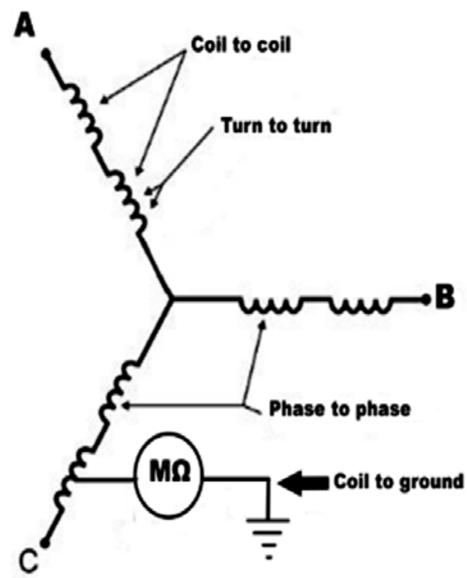
**Question: Why does a milliohm tester use four leads?**

***Answer: It uses four leads to improve accuracy. It sends voltage/amperage out on two of the leads and measures the volt drop with the other two leads.***

# CHAPTER 5 - MOTOR TESTING

## Motor Testing Support

Key Points:
• Coil to coil shorts.
• Turn to turn shorts.
• Phase to phase shorts.
• Phase to ground shorts.




*Motor Short Types*

The picture above illustrates the different types of shorts the motor can have. A DVOM is not accurate enough for testing motor winding resistance.

For example, a milliohm meter can test the resistance of the motor windings. The windings can short, turn to turn, in the same coil or short from one coil to the other, or short from phase to phase.

The milliohm meter will reveal if any of these shortings have occurred in the windings. The milliohm meter will inject one to a hundred milliamps at a particular voltage through the circuit on two leads and measures the voltage drop on the other two leads. Then it will calculate the resistance of the circuit in milliohms.

The windings can also be shorted to the stator housing, which can be detected with a megaohm meter.

The megaohm meter will inject the selected voltage into the windings and measure any voltage present in the stator housing.

## Winding Test

Key Points:
• Resistance.
• Inductance.
• Impedance.
• Open windings.
• Phase angle.
• Current frequency response (IF).
• Insulation resistance.
• Dissipation factor.
• Capacitance to ground.
• Test value static number can also be generated for a known good motor.

Industry Info: The testing process is automatic and requires no user interaction once initiated. As part of this process, the instrument will test all three phases.

Resistance and then current inductance, impedance, phase angle, current/frequency response, and other measurements are made for all phases.

When complete, the user is asked if they want to perform the Dynamic test; if not, the Static test results can be viewed, stored, or uploaded to optional computer software.

The Dissipation Factor (DF) is the ratio between the resistive power loss and the reactive power loss of the insulation material. This is used to detect contaminated or overheated windings.

The insulation to ground test measures resistance of insulation between conductor and ground.

Resistance is measured phase to phase, and its primary purpose is to detect connection problems.

The Static test provides a number we call “Test Value Static” or TVS™, and this can be used as either a reference value or can be compared to a previously stored TVS™ for comparison purposes.

Static- General Principle: For a Symmetric Alternating Current Machine (motor), the rotor position influences the inductances (L), impedances (Z), or phase angles (Fi) of each stator differently, since the rotor position influences the coupling, the L, Z, and Fi between stator windings and rotor winding.

# CHAPTER 5 - MOTOR TESTING

However, due to the symmetry of the motor, the measured/calculated Test Value Static (TVS™) of the stator windings is independent of the rotor position.

Note: In practice, TVS™ may be slightly influenced by the rotor position due to inaccuracies during assembly of the motor or motor parts (manufacturing tolerances), slight differences between stator windings, flaws in the rotor, measurement inaccuracies,

All common types of faults in the rotor and the stator, or windings break the symmetry of the motor. As a result, the TVS™ will change and no longer be independent of the rotor position; consequently, a second TVS™ will no longer be equal to the first TVS™ (TVS2 ≠ TVS1).

Static – Testing Sequence:
The AT33 IND™ outputs a low voltage sinusoidal signal at frequencies of 50, 100, 200, 400, & 800Hz And then does the following:

• Calculates Test Value Static (TVS™) in the “first” rotor position.

• Rotor position has little influence on TVS™ value in a good motor.

• TVS™ is a motor specific parameter.

• TVS™ can be used as a reference (REF) value for detecting fault conditions.

• Can be used as a REF value for that specific motor or other motors of exact same type & manufacturer.

• A subsequent test, the AT34™ calculates a new TVS™ (at any rotor position).

• TVS1 is compared to TVS2.

• A change >±3% indicates a change in the condition of the motor (or connections/cables if testing from the stator or motor drive). Note: Warning alarm of ±3% is based on a dwell.

## Resistance

Key Points:
• Windings or a coil of wire resist being charged.
• Ohms is the measurement used to represent the resistance of the circuit.
• Milliohm meter needed to measure winding resistance.
• Meter sends voltage/amperage through circuit and measures the voltage drop.

Winding resistance is defined as the resistance of a length of copper wire from end to end. Windings offer some resistance to being charged. The resistance can be measured with a milliohm meter.

A milliohm meter will apply a voltage/current through the windings and measure the voltage drop across the entire winding. The result will be given in ohms.

Ohms is the measurement that represents the resistance in the circuit. For example, in a three-phase motor, all windings are the same size wire, and all windings are precisely the same length; therefore, the resistance should be the same and not vary more than 5% from each other.

## Inductance

Key Points:
• Inducing a current into a coil of wire.
• Windings oppose the current.
• Windings produce a back EMF.
• Inductance measured in millihenries.

Inductance (L)- Refers to inducing a current into a coil of wire. As current flows through the windings, it induces current into close proximate windings. The affected windings resist being charged and produce a back electromotive force (EMF). Back EMF is a voltage that appears in the opposite direction of current flow, opposing the current flow.

Inductance or back EMF is measured in millihenries. Inductance is also in play when a magnetic field induces a current into a set of windings.

Industry Info: EMF-Electromotive force is the characteristic of any energy source capable of driving electric charge around a circuit.

# CHAPTER 5 - MOTOR TESTING

## Impedance

Key Points:
Impedance(Z) includes
• Resistance.
• Capacitive reactance.
• Inductive reactance.
• Impedance measured in ohms with a dedicated instrument.

Impedance is a measurement used in AC circuits. Impedance includes resistance, capacitive reactance, and inductive reactance. Impedance is measured in ohms. Inductive reactance and capacitive reactance will be explained in the following pages.

Impedance in an AC circuit could be calculated by dividing the voltage by the amperage. Calculating impedance in a motor circuit in a hybrid or electric vehicle is not feasible.

In these applications, the impedance must be measured by a dedicated instrument.

A DVOM is not capable of measuring impedance, the AT34 motor tester is. You can purchase a specific impedance meter, however, impedance changes with frequency, so the AT34 inputs an AC sine wave at four different frequencies and measures the impedance at each frequency supplied.

The four frequencies are 50-100-200-400 hertz. Impedance is a measurement between all three-phases; the first test is between 3-2, the second test is between 2-1, and the final test is between 1-3 phases.

All phases should be equal and not vary over 5%. Induction motors may fail the test due to imbalances in the rotor. If the test fails, reposition the rotor and see if the test passes. If it does, it was the rotor causing the false reading.

If the test fails after repositioning the rotor, the stator windings fail the test.

Industry Info: AT34-Purchase at future tech training (https://www.futuretechauto.com/ A specific impedance meter, Hioki's LCRmeter IM3523, can be purchased.

## Inductive Reactance

Key Points:
• Reactance is a property that opposes a change in current.
• Reactance can be found in windings and capacitors.
• When reactance is present it causes a 90-degree phase shift between voltage and current.
• In motor windings it will cause current waveform to lag behind voltage waveform by 90 degrees.

Inductive reactance is part of the impedance measurement. Reactance is a property that opposes a change in current. Reactance is present in wires or windings and capacitors.

Due to reactance only affecting changing current, reactance is specific to AC circuits. When reactance is present, it creates a 90-degree phase shift between voltage and current.

If reactance occurs in the motor windings, it is known as inductive reactance. Motor windings that exhibit inductive reactance cause the current waveform to lag behind the voltage waveform by 90 degrees.

## Capacitive Reactance

Key Points:
• Capacitive reactance stores energy in a magnetic field.
• Causes current waveform to lead voltage waveform by 90 degrees.

Capacitive reactance is part of the impedance measurement. Capacitive reactance stores energy in the form of a changing electrical field. Capacitive reactance causes the current waveform to lead the voltage waveform by 90 degrees.

## Dissipation Factor

Key Points:
• Electrical test that defines the overall condition of the insulating material.
• Requires specialized testing equipment.
• Compares resistive current to capacitive current in the form of a ratio.
• New clean insulation measures 3%-5%.
• Dissipation greater than 6% indicates a change in the insulation.

# CHAPTER 5 - MOTOR TESTING

The dissipation factor is an electrical test that defines the overall condition of the insulation. This type of testing requires specialized testing equipment like the AT34 or equivalent.

The test compares the resistive current to capacitive current in the form of a ratio. As insulation ages with time, it degrades, it becomes more resistive, causing the resistive current to increase.

Contamination of the insulation also causes an increase in resistive current. In both cases, this drives the dissipation number higher. Three to five percent is the typical dissipation factor.

Anything more significant than six percent indicates a change in the insulation, indicating a problem. The dissipation factor test should be run at room temperature, or readings may be skewed.

Resistive current means we have a path to the ground to flow electricity through. We would only have a capacitive current with perfect insulation with zero contamination, but those conditions do not exist in the real world.

Industry Info: NEMA electrical standards testing of small motors defines an insulation failure allowing more than 10 milliamps of flow fails the test.

## I/F Test

Key Points:
- I/F-Current/Frequency Response.
- Tests turn to turn or coil to coil faults.
- Low voltage AC signal is applied to the circuit at a specific frequency.
- Current is measured.
- Frequency is doubled for next test.
- Current is measured.
- The I/F reading is the ratio of the current at the doubled frequency to the current at the initial frequency.
- Result is expressed as a ratio.

The I/F test is current/frequency response. The test is designed to find faults in turn to turn or coil to coil windings.

The meter applies a low voltage AC signal to the windings at a specific frequency, and the current is measured.
On the second test the meter doubles the frequency and measures current a second time. The I/F reading is the ratio of the current at the doubled frequency to the current at the initial frequency,

## Phase Angle (Fi)

Key Points:
- Indicates the angular difference between two waveforms of the same frequency.
- Results will be displayed in degrees.
- The phase angle and I/F test are much better indicators of winding faults than a milliohm meter.

When a defect occurs in the winding, the capacitance of the winding changes, and the tester injects two waveforms into the windings at the same frequency. It measures the angular difference between the two waveforms.

The results will be displayed between 0 and 90 degrees. The phase angle test is the amount of lag between the applied voltage and the resulting current. This is a very effective method for identifying winding shorts.

This test is included in the IEEE standard 1415 -2006 sec4.3.20

## Partial Discharge

Partial Discharge is the result of a breakdown in the insulation system. Though it usually starts very small, once it begins the deterioration of the insulation system is progressive. When voltage stress reaches a critical level, Partial Discharge will “bloom” and create a Corona.

The ionized gas of a Corona is chemically active. In air this generates corrosive gases such as ozone (O3) and possibly nitric acid, causing extreme damage to the magnetic device and related circuit. Eventually, Partial Discharge will cause system failure.

# CHAPTER 5 - MOTOR TESTING

## Failure Criteria

| Test Result | Tolerance | Detail |
|---|---|---|
| Resistance (R) | <5% | Likely loose or faulty connections |
| Impedance (Z) and Inductance (L) | <5% | If random wound <1000V, unbalance might be due to rotor position or motor design. If form wound then a fault may have occurred. |
| Dissipation Factor (DF) | >6% | Likely winding contamination or overheated windings |
| Phase Angle (Fi) | +/- 2 digits (degree) from average | Indicates a winding short: 74, 75, 76 OK; 74, 74, 76 suspect; 73, 73, 76 failed |
| I/F | +/- 2 digits (%) from average | Indicates a winding short: -44, -45, -46 OK; -44, -46, -46 suspect; -42, -45, -45 failed |
| TVS | >3% | Likely change in condition of the winding or rotor |
| Dynamic Test | Stator: >1.5% | Likely stator winding issue |
| | Rotor: >15% | Likely rotor issue |
| Insulation Resistance | See INS Guide | Indicates poor insulation to ground (I.e. ground fault) |

***Notes: The failure criteria listed in the chart is for a motor with the rotor installed.***

## Summary

Key Points:
- Inverter converts DC to simulated AC voltage.
- IGBTs have a firing order.
- Boost converter steps up battery voltage.
- Buck converter reduces voltage.
- Capacitors smooth out voltage and store energy.
- Most scopes need an isolator to measure voltage.
- Contactors have a start-up and shut down sequence.
- Meters and amp probes need to meet Cat. 3 specs.

# GLOSSARY OF TERMS

- AC-(Alternating current) Current that regularly changes directions.
- BEV- (Battery electric vehicle) Vehicle powered by high voltage battery and electric motor.
- Boost voltage- Voltage output is higher than voltage input.
- Buck voltage- Voltage output is lower than voltage input.
- DC-(Direct current) Current that flows in one direction.
- Contactors-Similar to a relay but typically has two contacts to pass current rather than one.
- EREV-(Extended range electric vehicle)-Vehicles that can run on gasoline when the battery is low.
- EVSE-Electric vehicle supply equipment.
- Gauss- Abbreviated G is a measurement of a magnetic field.
- HEV-(Hybrid electric vehicle) Utilizes a dual system to promote propulsion, typically an ICE and an electric motor.
- ICE- (Internal combustion engine) Powered by combustible fuel.
- IGBT-Insulated gate bipolar transistor, used to provide a high voltage/current pathway.
- Induction motor-An electric motor that uses a nonmagnetic rotor.
- Isolation- High voltage system is isolated from chassis ground.
- MG-(Motor generator) Electric motor that performs work or generator that provides energy to recharge battery.
- Neodymium- Rare earth magnets that are made from alloys of rare earth elements. They are very strong and brittle.
- Ohms-Defined as an electrical resistance between two points of a conductor.
- PM motor-(Permanent magnet motor) The rotor contains magnets that alternate north and south poles.
- PHEV-(Plug in hybrid vehicle) Contains a high voltage battery that can plugged in to be charged.
- Resistance- It is a measurement of its opposition to the flow of electric current.
- Rotor- Internal component inside an electric motor that is typically splined to a shaft or gear.
- Shorts-An abnormal condition in an electrical circuit where the current flows through an unintended shorter pathway or to ground.
- Stator- A coil of wire that is wound in a Wye or Delta fashion installed in a stationary housing.

# TEST QUESTIONS

1. Hybrid and electric vehicles use what type of motor?

A. Single phase.
B. Two phase.
C. Three phase.
D. Single phase with a magnetic starter.

2. True or false. An induction motor uses neodymium magnets to create a magnetic field around the rotor.

True
False

3. How does the electric motor transmit torque to the axles?

A. Set of gears that includes an internal differential.
B. Direct drive to the axle.
C. Belt drive.
D. Double reduction gear.

4. True or false. A permanent magnet motor uses shorting rings to attach the copper or aluminum bars together.

True
False

5: Rotor to stator clearance by design is between;
A. .002-.005”
B. .005-.010”
C. .010-.015”
D. .015-.050”

6. True or false. Induction rotors are isolated from the rotor shaft with a phenolic material.

True
False

7. Technician A says motor winding resistance should be measured with a regular DVOM.
Technician B says motor winding resistance should be measured with a milliohm meter using Kelvin clips.

A. Only technician A is correct.
B. Only technician B is correct.
C. Technicians A & B are both correct.
D. Neither technician A or B is correct.

8. Technician A says resistance in an AC motor is the same thing as impedance.
Technician B says impedance is a complex measurement that includes resistance, inductive reactance, and capacitive reactance.

A. Only technician A is correct.
B. Only technician B is correct.
C. Technicians A & B are both correct.
D. Neither technician A or B is correct.

9. Technician A says that a megaohm meter should be placed on the highest voltage setting (1,000 volts) to stress the windings on all motors.
Technician B says use the same voltage as the system uses or bump the voltage up to next voltage setting to stress windings.

A. Only technician A is correct.
B. Only technician B is correct.
C. Technicians A & B are both correct.
D. Neither technician A or B is correct.

10. True or false. Bearing failures in electric motors are caused by low oil levels or high mileage only and electrical charges have no effect on bearing failure.

True
False

11. True or false. Resolvers have a three-wire connector and only measure the speed of the rotor.

True
False

## TEST QUESTIONS

12. Technician A says all resolvers are pinned into place and there is no adjustment.
Technician B says some resolvers are pinned into place and others utilize slots for adjustment

A. Only technician A is correct.
B. Only technician B is correct.
C. Technicians A & B are both correct.
D. Neither technician A or B is correct.

13. Test Question
Technician A says windings can only have turn to turns shorts due to how the wire is placed into slots.
Technician B says windings can have turn to turn, coil to coil, phase to phase, and phase to ground shorts.

A. Only technician A is correct.
B. Only technician B is correct.
C. Technicians A & B are both correct.
D. Neither technician A or B is correct.

14. Technician A says magnetite is used to create strong magnets in a PM motor.
Technician B says magnetite is used in induction motors.

A. Only technician A is correct.
B. Only technician B is correct.
C. Technicians A & B are both correct.
D. Neither technician A or B is correct.

15. True or false. PM rotors are easily removed from stators and a small pry bar can be used to assist removal.

True
False

## TEST QUESTION ANSWER KEY

1. Hybrid and electric vehicles use what type of motor?

A. Single phase.
B. Two phase.
***C. Three phase.***
D. Single phase with a magnetic starter.

***Answer: C***
***Three phase AC motors are used in electric vehicles.***

2. True or false. An induction motor uses neodymium magnets to create a magnetic field around the rotor.

True
***False***

***Answer: False***
***A permanent magnet motor uses neodymium magnets not an induction motor.***

3. How does the electric motor transmit torque to the axles?

***A. Set of gears that includes an internal differential.***
B. Direct drive to the axle.
C. Belt drive.
D. Double reduction gear.

***Answer. A***
***There are a lot of different designs on the inside of the transaxles or gearboxes, but none that I have seen use a direct drive from the motor directly to the wheel.***

***Most gearboxes use a set of gears or gear reduction to create a torque increase from the motor to the axles and incorporate a differential assembly like front-wheel-drive transaxles to allow axles to change speeds going around a corner.***

***Like the early Prius, some transaxles did include a chain drive inside the transaxle similar to a transfer case chain, but I have not seen any belt-driven units.***

4. True or false. A permanent magnet motor uses shorting rings to attach the copper or aluminum bars together.

True
***False***

***Answer: False***
***Induction motors use shorting rings to attach the copper or aluminum bars together.***

5: Rotor to stator clearance by design is between;
A. .002-.005”
B. .005-.010”
C. .010-.015”
***D. .015-.050”***

***Answer: D***
***Rotor to stator clearance will change depending on size and type of motor. Most motors will fall into the .015-.050” range.***

6. True or false. Induction rotors are isolated from the rotor shaft with a phenolic material.

***True***
False

***Answer: True***
***The induction motor’s rotor has current flowing through it; however, we do not want it to reach the rotor shaft where the current can dissipate through the bearings and cause bearing failure.***

7. Technician A says motor winding resistance should be measured with a regular DVOM.
Technician B says motor winding resistance should be measured with a milliohm meter using Kelvin clips.

A. Only technician A is correct.
***B. Only technician B is correct.***
C. Technicians A & B are both correct.
D. Neither technician A or B is correct.

***Answer: B***
***A regular DVOM is not accurate enough to measure motor windings.***

## TEST QUESTION ANSWER KEY

8. Technician A says resistance in an AC motor is the same thing as impedance.
Technician B says impedance is a complex measurement that includes resistance, inductive reactance, and capacitive reactance.

A. Only technician A is correct.
***B. Only technician B is correct.***
C. Technicians A & B are both correct.
D. Neither technician A or B is correct.

**Answer: B**
**Even though resistance is part of the impedance measurement it is not the only component.**

9. Technician A says that a megaohm meter should be placed on the highest voltage setting (1,000 volts) to stress the windings on all motors.
Technician B says use the same voltage as the system uses or bump the voltage up to next voltage setting to stress windings.

A. Only technician A is correct.
***B. Only technician B is correct.***
C. Technicians A & B are both correct.
D. Neither technician A or B is correct.

***Answer: B***
***Technician should always stay close to the operating voltage of the system or step the voltage up to the next voltage setting in order to stress the windings when using a megaohm meter.***

10. True or false. Bearing failures in electric motors are caused by low oil levels or high mileage only and electrical charges have no effect on bearing failure.

True
***False***

***Answer: False***
***Bearing failures are often caused by charges that are induced into the shaft and exit out through the bearings causing micro welding in the raceways.***

11. True or false. Resolvers have a three-wire connector and only measure the speed of the rotor.

True
***False***

***Answer: False***
***Resolvers have a six-wire connector, and they measure speed, position and direction.***

12. Technician A says all resolvers are pinned into place and there is no adjustment.
Technician B says some resolvers are pinned into place and others utilize slots for adjustment

A. Only technician A is correct.
***B. Only technician B is correct.***
C. Technicians A & B are both correct.
D. Neither technician A or B is correct.

***Answer: B***
***Some resolvers are pinned and have no adjustment but a relearn may need to be performed with a scan tool upon replacement.***

***Some resolvers are mounted into slots and can be adjusted but the adjustment typically needs to be made at the factory.***

13. Test Question
Technician A says windings can only have turn to turns shorts due to how the wire is placed into slots.
Technician B says windings can have turn to turn, coil to coil, phase to phase, and phase to ground shorts.

A. Only technician A is correct.
***B. Only technician B is correct.***
C. Technicians A & B are both correct.
D. Neither technician A or B is correct.

***Answer: B***
***Windings can have turn to turn, coil to coil, phase to phase, and phase to ground shorts.***

## TEST QUESTION ANSWER KEY

14. Technician A says magnetite is used to create strong magnets in a PM motor.
Technician B says magnetite is used in induction motors.

A. Only technician A is correct.
B. Only technician B is correct.
C. Technicians A & B are both correct.
***D. Neither technician A or B is correct.***

***Answer: D***
***Neodymium is the magnet material typically used not magnetite and induction motors are non-magnetic.***

15. True or false. PM rotors are easily removed from stators and a small pry bar can be used to assist removal.

True
***False***

***Answer: False***
***PM rotors are very hard to remove from stators due to the magnetic attraction. Never use a prybar because you will damage windings.***

## NOTES

## COURSE OBJECTIVES AND INTRODUCTION

By the end of this course you should be able to successfully complete the following:

* Describe the operation of an inverter.
* Define how an IGBT functions.
* Analyze inverter voltage and amperage waveforms.
* Measure the high voltage system for isolation faults.
* Evaluate capacitors.
* Develop a diagnostic plan for DC-DC converters.
* Determine the difference between buck and boost.
* Perform testing on high voltage contactors.

### INTRODUCTION

The inverter is one of the main components in an HEV-BEV; it is needed to power the electric motors for propulsion and provide a regen function to charge the high voltage battery.

The inverter changes the output to the opposite of the input. If DC is the input, then simulated AC is the output. If AC is the input, then DC is the output.

The inverter is a variable frequency drive that uses pulse width modulation to control the electric motors.

The inverter controls the motor torque and speed. The amplitude of the amperage waveform regulates the torque, and the speed is controlled by frequency.

The inverter creates a timed rotating field inside the stator to drive the motor in propulsion mode. The timed magnetic field interacts with the rotor to cause the rotor to rotate.

The rotor is splined or mated to a motor gear to work inside the gearbox. The inverter uses transistors and diodes to perform motor and regen functions.

The inverter is controlled by a control module that receives inputs from various sensors and calculates the necessary speed and torque to match driver demands.

For example, the control module or microprocessor activates the transistors inside the inverter. More electronics may be housed inside the same housing as the inverter, like the DC-DC converter and the boost converter.

Hybrids and electric vehicles store energy in large DC batteries. The batteries can range from 100 volts to 400 volts or more. The electric motors that are utilized in the powertrain are AC motors.

Trying to drive AC motors with DC poses a problem. The inverter is the solution to that problem.
The inverter sits electrically between the AC three-phase motors and the high voltage DC battery.

The control system utilizes two main modes: motor mode and generator mode.

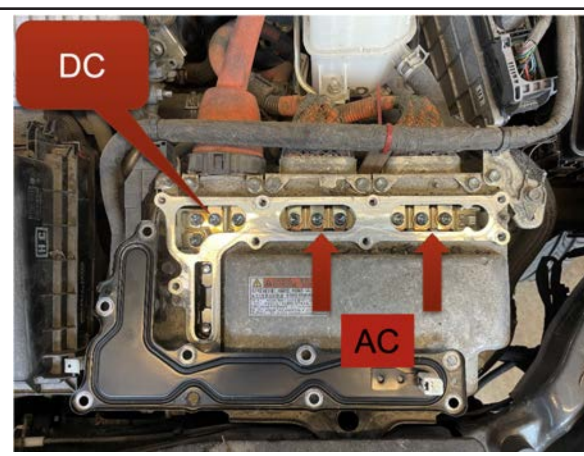
In motor mode, the electric motors are performing work. The DC is input from the high voltage battery to the inverter in motor mode.

The inverter simulates AC voltage and sends it to the three-phase motors to perform work. The AC is generated from the motor-generator in generator mode and is input to the inverter.

The inverter takes the AC, turns it into DC, and sends it back to the battery for storage. The inverter may be mounted inside the transaxle, on top of the transaxle, or remotely mounted in the rear cargo area.

The inverter is one of the main components of the high voltage system.

The inverter in the picture below is from a third-gen Prius. The DC is a two-wire harness that runs back to the high voltage battery. The middle set of three wires is MG1, and the right side is MG2.




***Gen III Prius Inverter Assembly***

# CHAPTER 1 - INSULATED GATE BIPOLAR TRANSISTOR (IGBT)

## IGBT Overview

KEY POINTS:
* The inverter houses high voltage transistors.
* Two common types:
    * IGBT.
    * Silicon carbide MOSFET.
* Transistors are pulse width modulated and controlled.

The inverter houses high voltage transistors. Transistors are solid-state electronic devices used to control the flow of electricity. The transistor is a switch that can state extremely fast.

The transistors used in modern inverters typically fall into insulated gate bipolar transistor or silicon carbide MOSFET. The transistors are pulse width modulated at an extremely high frequency.

IGBT was introduced in the early ’80s. Before the invention of the IGBT, electronics relied on metal-oxide field-effect transistors (MOSFET) and bipolar junction transistors.

The working principle behind an IGBT is to take a small voltage on the control side and control a large amount of amperage on the load side.

## Transistor Design

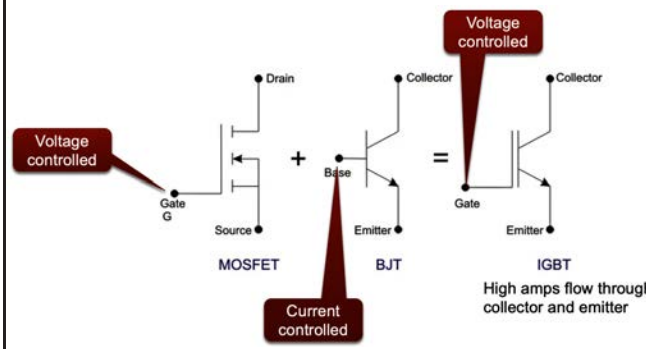
Transistors are made from silicon, a chemical element found in sand. A transistor can be used as an amplifier or a switch. Inside the inverter, the transistors function as switches.

One advantage of a transistor is that it takes the minimal current in the control circuit to handle a large amount of current in the load circuit.

The transistor consists of three parts, the emitter, collector, and base. The control circuit is attached to the base, and the high voltage circuit flows through the collector and the emitter.

There were three standard transistors to choose from when building an inverter. IGBT, bipolar and MOFSET. MOSFETs are voltage-controlled at the base, making them have good switching performance but suffer bad conduction characteristics.

The MOSFET base can be controlled by pulsing small voltages (1-15 volts) to the base.




*MOFSET, BJT AND IGBT TRANSISTORS*

The bipolar suffered from bad switching performance. bipolar transistors are current-controlled at the base and require a lot of current, (10-20 amps) to run, which is not desirable for the inverter application.

The IGBT design took the best design of both the MOSFET and bipolar transistors, improved on the losses, and became an electronics mainstay until today.

Because the IGBT was created from the other two transistors, the symbol for IGBT is a cross of the other two symbols.

A new silicon carbide MOSFET has been designed and is a little more efficient, around 3-5% more than the current IGBT design. One issue has been that the IGBT could not handle high temperatures well.

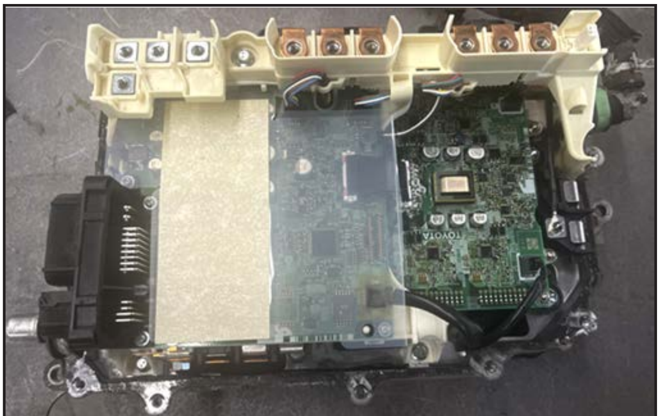
However, the IGBTs have been redesigned to handle a little higher temperature, up to approximately 350 degrees so the control system can increase the amperage to allow a higher output.

## Inverter

The inverter has a DC input from the high voltage battery. The inverter will have a set of IGBTs per three-phase motor. The IGBTs are typically encapsulated in a silicone gel to aid in cooling and provide explosion protection in case of overheating.

The IGBT is mounted to a heat sink with a thin paste layer to help dissipate heat. On some models, the inverter housing may also house the DC to DC converter. Also, processer boards are located inside the inverter, as illustrated on the next page.

# CHAPTER 1 - INSULATED GATE BIPOLAR TRANSISTOR (IGBT)



*INVERTER - EXPOSED PROCESSOR BOARD*

Inverters have several processor boards inside, as shown in the picture.

## IGBT Temperature

Some manufacturers may include an IGBT PID within their scan tool data to monitor temperatures. Test drive and record temperatures; you can examine data to ensure none are getting out of range. Scanners

| Name | Value | Unit |
|---|---|---|
| W Phase Lo Side IGBT Temperature (trc) | 36 | °C |
| W Phase Hi Side IGBT Temperature (trc) | 32 | °C |
| V Phase Lo Side IGBT Temperature (trc) | 35 | °C |
| V Phase Hi Side IGBT Temperature (trc) | 32 | °C |
| U Phase Lo Side IGBT Temperature (trc) | 35 | °C |
| U Phase Hi Side IGBT Temperature (trc) | 30 | °C |
| Motor Inverter Voltage (trc) | 248 | V |
| Traction Motor Speed (trc) | 3589 | rpm |

*IGBT SCAN TOOL PID LIST*

typically allow technicians to record the test drive and review the data as a movie.

## Inverter Temperature

Key Points:
* Inverter temperature per motor inverter.
* MG1 - 82.4.
* MG2 – 86.
* The inverter is liquid-cooled.
* The temperature rises, check the high voltage coolant level and water pump.

The Honda gave us IGBT temperature for the low and high sides per phase, whereas the Toyota Prius only gives us a temperature per motor inverter. If the temperature rises above normal, checking the coolant level in the high voltage system and the water pump operation may be required.

| Name | Value | Unit |
|---|---|---|
| Inverter temperature (mg1) | 82.4 | °F |
| Inverter temperature (mg2) | 86 | °F |
| Motor temperature MG 1 | 78.8 | °F |
| Motor temperature MG 2 | 80.6 | °F |

*MG1 AND MG2 SCAN TOOL TEMPERATURE DATA*

## Inverter Output Levels

Key Points:
* Inverters are sized for output.
* Low output models may be rated at about 50 kilowatts.
* Higher output models may output over 300 kilowatts.

| | EV Type | Motor Type | Power (kW or kVA) |
|---|---|---|---|
| Jaguar I-Pace 2019 [2] | BEV | PMSynRM | 300* kW |
| Nissan Leaf 2019 [2] | BEV | PMSynRM | 140* kW |
| Tesla M3 2018 [2] | BEV | PMSynRM IM | 344* kW |
| Chevy Bolt 2017 [3] | BEV | PMSynRM | 153 kVA |
| Toyota Prius 2016 [4] | PHEV | PMSynRM | 162.2* kW |
| Audi e-Tron 2016 [2] | PHEV | IM, IM | 75* kW |
| BMW i3 2016 [4] | BEV | PMSynRM | 125 |
| Chevy Volt 2016 [5] | PHEV | PMSynRM | 180* |
| Cadillac CT6 2016 [6] | PHEV | IPMSM | 215* |
| Tesla S 2015 [6] | BEV | - | 320* kW |

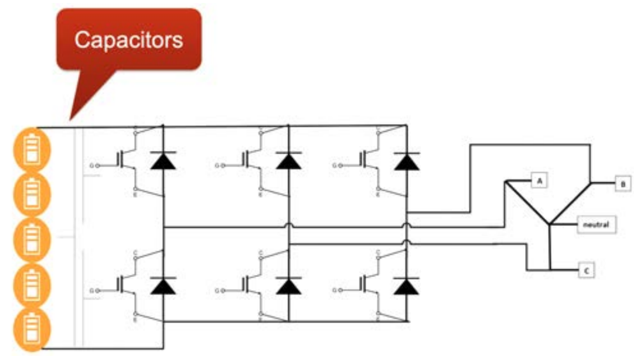
*COMMON INVERTER OUTPUTS*

Inverters vary in output; they are not all the same kilowatts. Some inverters may only output 50KW, and others may output over 300KW. The list above refers to some inverters commonly found in the market.

# CHAPTER 1 - INSULATED GATE BIPOLAR TRANSISTOR (IGBT)

## IGBT Location and Inverter Waveforms

The IGBTs located inside the inverter come in a six-pack design. It takes six IGBTs to control the windings in a three-phase motor. Each three-phase motor requires an IGBT set. As an example, within the Toyota Prius, there would be an IGBT set for MG1, an IGBT set for MG2, and a third IGBT set for the A/C compressor.



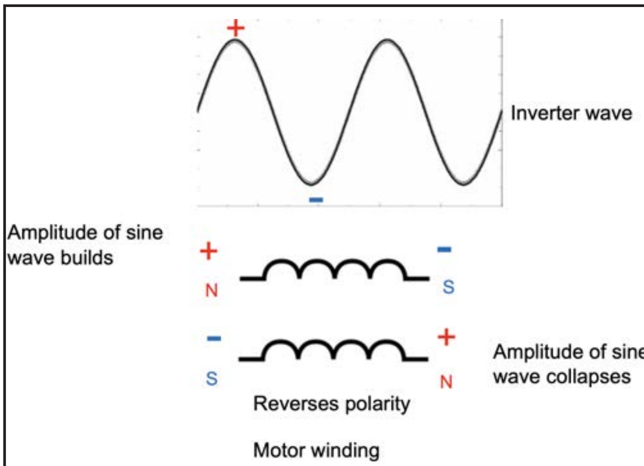

***IGBT Location Schematic - Typical***

A high-speed controller pulses the gate to control power through the switch. There must be at least two IGBTs commanded to complete a circuit.

To create a rotating magnetic field, the high-speed controller must create a specific firing order to interact with the electric motor's rotor. IGBTs are also used in the boost converter. Boost converters usually use a four-pack of IGBTs.

The inverter simulates an AC waveform and sends it to the motor windings. The waveform mimics a sine wave by reaching a high amplitude and then a low amplitude: the voltage and current travel across the windings in the motor. The motor winding will be positive at one end and negative at the other.

The positive side of the winding will correspond with the highest amplitude of the sine wave. The sine wave will collapse and go low, and the motor winding will switch polarity.




***Inverter Waveform(s) - Typical***

The motor windings are continually switching polarity. The current passing through the windings creates a magnetic field. The magnetic north pole will be the positive end of the coil winding, and the negative end will be the south pole.

The magnetic field created in the winding pulls and pushes the rotor to produce work out of the rotor. The north and south ends of the windings constantly switch polarity positive and negative, which means the magnetic fields are also switching polarity.

This gives us a basic understanding of how the windings work inside the stator and how the magnetic fields are associated with current flow.

The sine wave starts to build and becomes more positive; the waveform moves toward its highest amplitude. This makes one end of the winding positive, and the other becomes negative.

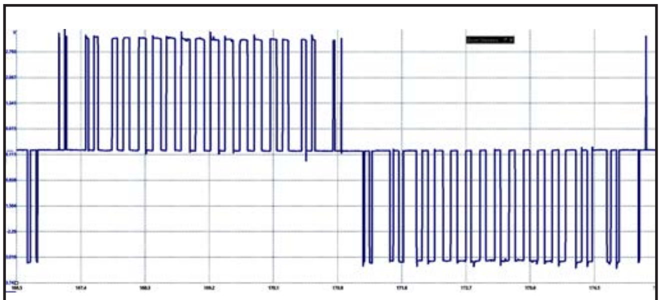
The positive end of the winding takes on a north pole, and the negative end takes on a south pole. When the waveform amplitude drops or collapses, the waveform's amplitude goes low, causing a polarity change in the windings.

When the polarity switches, so does the magnetic field. The magnetic field performs all the work by interacting with the rotor's magnetic field.

# CHAPTER 1 - INSULATED GATE BIPOLAR TRANSISTOR (IGBT)

## IGBT Waveform

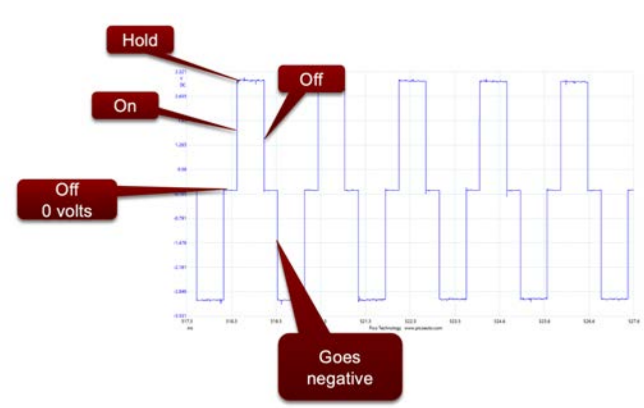
The IGBTs inside the inverter create a voltage waveform to send to the motor. The waveform can take several different shapes. The shapes can be seen by attaching an isolation probe, and a lab scope to two of the three-phase leads. The waveform can be a rectangular, sine wave, or a six-step waveform.



*IGBT Square Pattern Waveform - Typical*

The waveform changes depending on the motor's torque and speed requirements. The rectangular waveform shown is simple; it goes high with more on-time, then low with less on-time. The rectangular waveform is typically usually used in high torque situations.

The sine waveform requires the fastest switching rates to mimic a sine waveform. The sine waveform heats the IGBTs more due to the fastest switching rate. The waveforms are constantly changing, coming from the inverter to the motor.



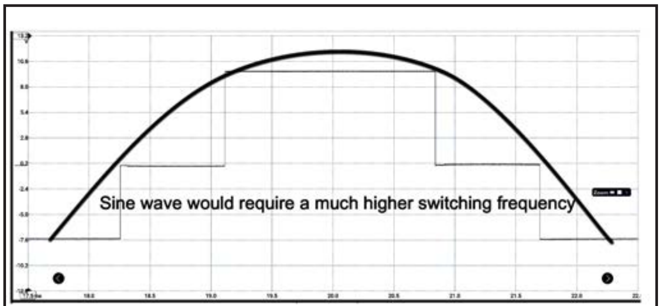

*Six-Step Waveform Anatomy*

IGBT Six-Step Waveform Anatomy

The stepped waveform is created by turning the IGBT on and off and varying pulse width. The six-step waveform switches at a slower frequency than a sine waveform, creating less heat and stress on the IGBTs.

The sixth step also produces slightly more harmonics than the sine wave. Harmonics cause slightly higher temperatures. The stepped waveform is typically used in medium torque situations but can be used anytime.

We traced out a sine wave over the stepped waveform. It is easy to see how the IGBT switching frequency would need to be faster to create a sign wave which will stress the IGBT.

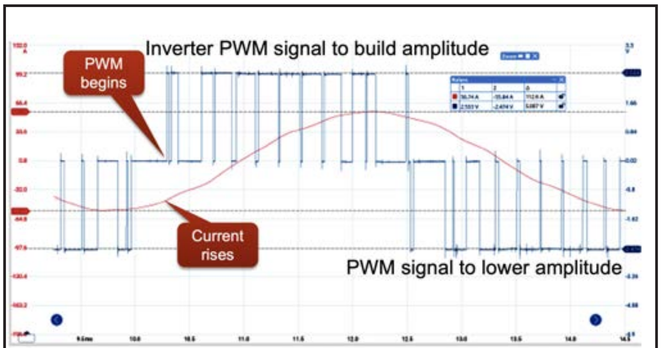



*Sine Wave Over Stepped Waveform*

## Building Amp Sine Wave

The inverter pulses the IGBT on and off quickly to create the voltage signal displayed in blue. The fast rate can be seen at the bottom of the scale.

The scale is in milliseconds. The more time the IGBT is on, the higher the amplitude of the amperage waveform.




*Pulse Width Signal and Amplitude*

# CHAPTER 1 - INSULATED GATE BIPOLAR TRANSISTOR (IGBT)

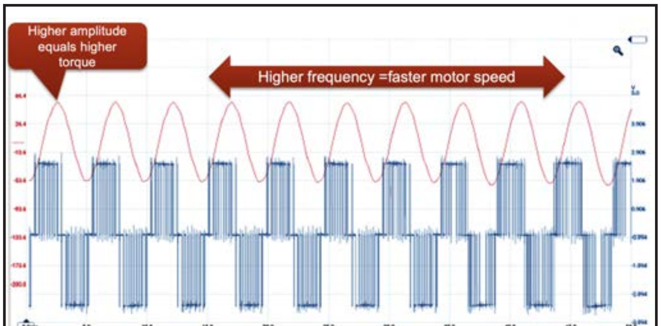
When the controller reaches the desired amplitude of the current waveform, the controller reduces the amount of on-time to the IGBT, and the current waveform collapses. Each time the waveform rises and collapses, the polarity reverses inside the motor windings, as discussed previously.

The inverter simulates a sine wave by pulsing the IGBT on and off, causing the current to rise in the windings. The on-time of the voltage waveform is longer when the current is building. As a result, the on-time is reduced to get the amperage to drop, simulating an AC waveform.

The cursors show the current amplitude, and the voltage waveform is obtained through a Pico isolator that involves attenuation, so the voltage waveforms voltage appears much less than it is. The voltage waveform must be multiplied by 200.

## Motor Torque/Speed

The higher the amplitude of the amperage waveform, the more torque the electric motor produces. The inverter will constantly adjust the amplitude of the amperage waveform to reach the desired torque output. The higher the frequency of the amperage waveform, the faster the motor rotates.



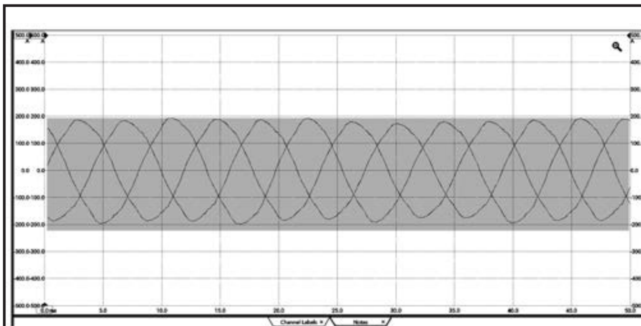

***Higher Amplitude Amperage Waveform***

The inverter can control the motor speed and torque by adjusting the amplitude and frequency of the amperage waveform. The amplitude and frequency of the amperage waveform are controlled by the PWM voltage signal created at the inverter.

The voltage waveform is blue, and the amperage waveform is red. It is easy to see how the inverter's voltage waveform can manipulate the high and low amperage waveform. The voltage is on a 200-1 attenuation.

## All Three Phases

Key Points:
* Three sets of IGBTs are turning on and off.
* Creates three-phase AC to operate the motor.
* Two IGBT’s activated together.

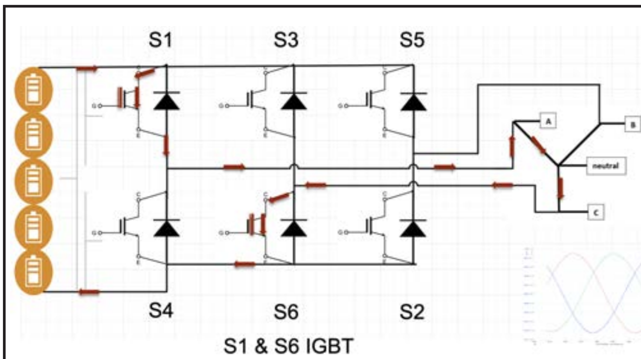


***Three Phase Waveform***

We have concentrated on how the IGBT uses pulse width modulation to create an amperage flow through the motor windings; however, we have limited this information to one IGBT and one-phase winding.

We have three sets of IGBTs and three phases interacting all the time. The waveform above shows all three phases in regular operation. The waveforms are offset by 120 electrical degrees.

## IGBT Sequence




***S1 and S6 IGBT Sequence***

IGBT operation example- IGBT switching is timed to simulate an AC waveform to the motor. All six transistors must be activated twice through a specific sequence to obtain a simulated six-step AC waveform.

The sequence example in the following few images is

# CHAPTER 1 - INSULATED GATE BIPOLAR TRANSISTOR (IGBT)

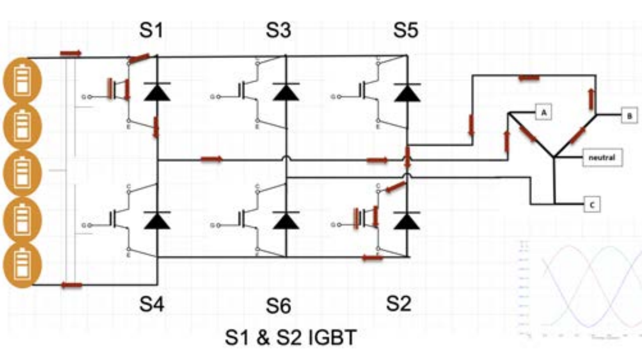
how the six-step voltage waveform is created to make all three amperage waveforms.

Close S1 & S6 allow current flow between phase A and phase A is positive and C is negative.

The batteries are series on the left; the symbol between the batteries and the IGBTs is for multiple capacitors. A bank of capacitors or one big capacitor is usually wired before the IGBTs.

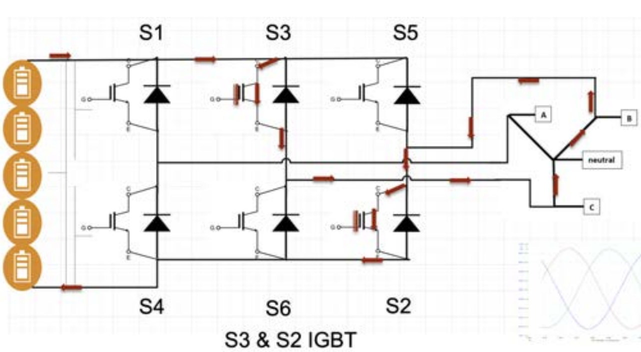
In this example, we only show two windings used to create a complete circuit. In reality, all three windings are in use most of the time. So, if you look at the three-phase waveform, there is voltage in all three legs, only when one leg passes zero voltage. The concept is easier to grasp using two legs, as shown.

S1 and S2 activated hooks phase A to B together. A is positive, and B is negative.




***S1 and S2 IGBT Sequence***

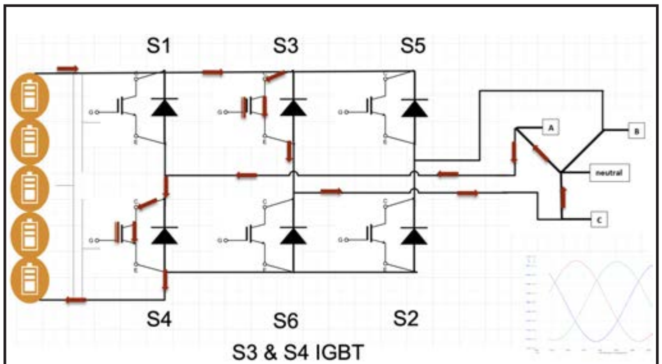
S3 and S2 activated hooks phase C to B together. C is positive, and B is negative.




***S3 and S2 IGBT Sequence***

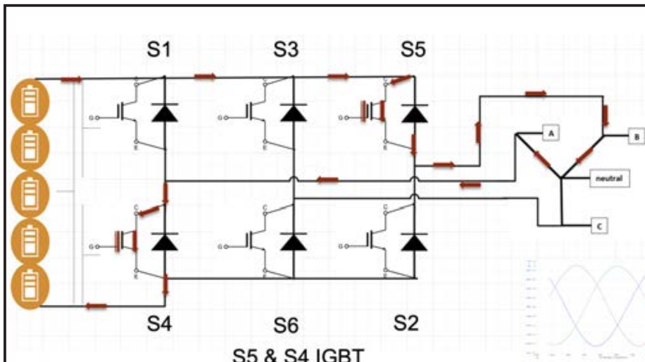
The batteries are connected in series together on the left; the symbol between the batteries and the IGBTs is for multiple capacitors. A bank of capacitors or one big capacitor is usually wired before the IGBTs.

S3 and S4 activated hooks phase C to A together; C is positive, and A is negative.




***S3 and S4 IGBT Sequence***

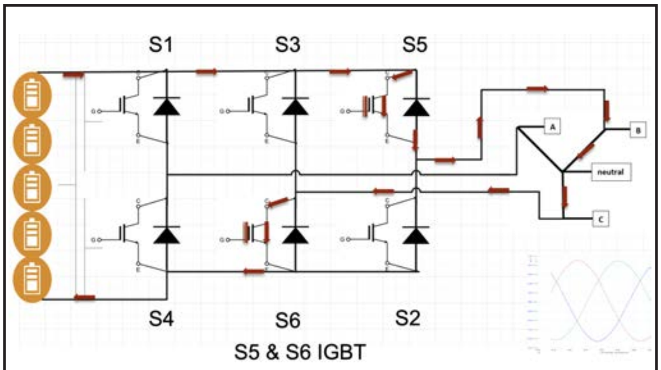
S5 and S4 activated hooks phase B to A together; B is positive, and A is negative.




***S5 and S4 IGBT Sequence***

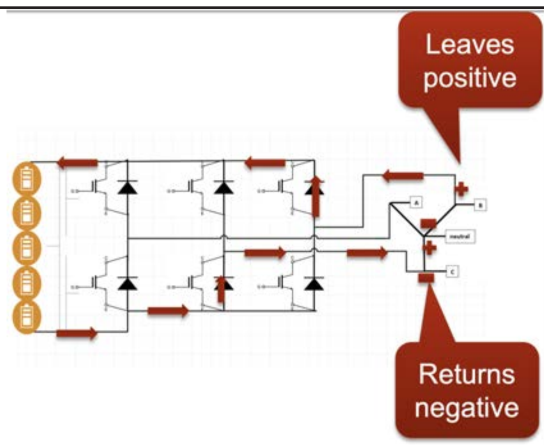
# CHAPTER 1 - INSULATED GATE BIPOLAR TRANSISTOR (IGBT)

S5 and S6 activated hooks phase B to C together. B is positive, and C is negative.




*S5 and S6 IGBT Sequence*

Regen




*S5 and S6 IGBT Sequence*

In regen, the traction motor switches from the motor mode, which was propulsion, to a generator. During deceleration or braking, a negative negative torque is applied to the drivetrain to slow the vehicle down. The diodes change AC to DC to recharge the high voltage battery.

The anode is typically positive, and the cathode is typically negative. For a diode to pass current, the anode must be at least 700mv more positive than the cathode. In our example, voltage is leaving phase B and traveling through a diode to get to the positive side of the battery.

According to voltage laws, the voltage needs to return to its source, so the voltage travels through the battery and finds a negative diode to re-enter the motor windings on the opposing side.

The arrows in the illustration show a complete circuit using the diodes only. The diodes change AC to DC, and the capacitors help smooth the voltage ripple out for consitent DC to charge the battery.

The IGBTs also need to modulate to control the amount of vehicle braking requested. For example, if we let the diodes only handle regen, we would be at a 100% duty cycle, which would put so much negative torque on the vehicle that it may slide the tires, so

The IGBT will modulate how much energy goes back to the battery and how much vehicle braking it provides.

Complete 100 percent regen without any modulation would probably lock the tires up during braking and could also overcharge the battery. However, the concept of regeneration modulation can get confusing. The concept is easier to explain using only diodes.

We use power flow on all of these diagrams with conventional theory rather than electron theory, but you could draw it either way.

Regen Scan Data

The first part of scan data shows speed increasing to 61 mph while the motor torque of MG2 is positive. Positive motor torque on MG 2 indicates we are in motor mode driving the car.

| | | |
|---|---|---|
| Vehicle speed | 55 | km/h |
| State of charge (SOC) | 47.4 | % |
| Regenerative brake torque | 0 | Nm |
| Required regenerative brake torque | 0 | Nm |
| Motor (MG 2) torque | 93.3 | Nm |
| Generator (mg1) torque | -20.2 | Nm |

*Regen Scan Data*

## CHAPTER 1 - INSULATED GATE BIPOLAR TRANSISTOR (IGBT)

When the car reaches 61 mph, we step on the brakes and go into regen. MG2 torque goes negative, indicating MG2 is currently acting as a generator. The required regenerative brake torque indicates how much torque we use to slow the car down. MG2 slows the vehicle down by applying negative torque to the drivetrain.

The control module will monitor the desired braking force from the driver input, and match the negative torque provided by MG2 slowing the vehicle down as commanded by the control module. During the regen event, the battery is recharged, which is reflected by the SOC percentage increasing slightly.

MG2 is applying a positive torque and driving the car on acceleration. Around 61 mph, we hit the brake, and MG2 torque switches to negative, indicating MG 2 is now a generator creating a negative torque on the drivetrain. The engine is spinning MG1, so MG1 is a generator.

MG1 does not assist in regen under regular braking events unless the shifter is placed into B mode, and then MG1 assists in braking and regen functions. B mode was developed for mountain driving to allow MG1 and MG2 to quickly charge the battery during regen to fill the high voltage battery.

### Assessment Chapter 1

Questions

1. What are the three main functions of an inverter?

2. What device inside the inverter controls voltage /amperage to the motors?

3. What are the three typical waveforms created by the inverter and sent to the electric motor?

Answers:

1. What are the three main functions of an inverter?
*1- Change the input to the opposite of the output.*
*2- Control the speed and torque of the motor.*
*3- Create a timed magnetic field.*

2. What device inside the inverter controls voltage /amperage to the motors?

*The device is the IGBT’s*

3. What are the three typical waveforms created by the inverter and sent to the electric motor?

*1-Rectangular.*
*2-Stepped or 6 steps.*
*3-Sine wave.*

# CHAPTER 2 - INVERTER TESTING

Inverter testing consists of watching voltage and amperage waveforms to determine if waveforms are out of phase or possibly different amplitude heights.

An isolation test can also be performed on the high voltage terminals to check for insulation break down causing an isolation failure. In addition, a scan tool can be used to obtain any DTCs that may be helpful in inverter diagnostics.

The boost converter was one part of the inverter with a failure rate. Toyota had a recall to replace the boost converter and reflash the software to cure a boost converter problem.

The IGBTs can overheat and cause failure, and the DC-DC converter may fail in some models it resides inside the inverter. In addition, parts may be available to repair the inverter, or you may have to replace the inverter as a unit.

## Voltage Waveforms

Most scopes do not have a CAT 3 rating, so an isolator probe must go between the scope and the high voltage three-phase inverter terminals. The input of the isolator probe is attached to two of the three-phase terminals at the inverter.

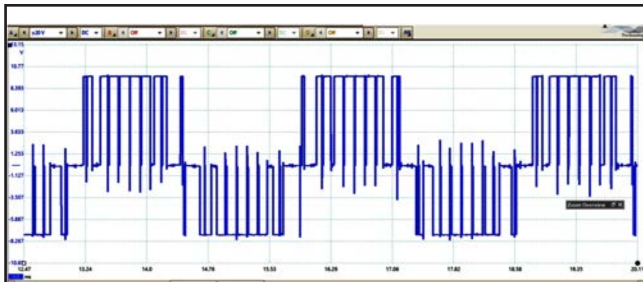

*CAT III Amp Probes - Connected*

The output of the isolator probe is attached to the scope and has two settings for attenuation.

First, select the desired attenuation scale and proceed with testing. Second, the voltage waveforms can now be viewed.

Third, CAT 3-amp probes must be utilized and attached around jumper wires to view the amperage waveforms. In the previous illustration, three CAT3 amp probes are attached to three jumper wires.

This type of testing cannot be performed on all vehicles because some models access points are unavailable. For example, if the inverter is located inside the transaxle housing, there may be no access to the high voltage terminals, so voltage and amperage testing may be impossible.



*Inverter Voltage Waveform*

Attenuator 20:1 setting. The voltage on the scale must be multiplied by 20. The voltage waveform can take several shapes depending on the torque desired output.

As previously described, the voltage waveform is a simulated AC signal sent from the inverter to the three-phase motor. The waveform starts as rectangular and then switches to a stepped waveform.

## Jumper Wires

Key Points
* Usage of jumper wires for amperage testing
* Removing the OEM factory harness.
* Attach jumper wires from the inverter to the harness.
* Placing the amp probes around jumper wires.

To obtain amperage waveforms, a set of jumper wires must be used. First, remove the factory harness from the inverter.

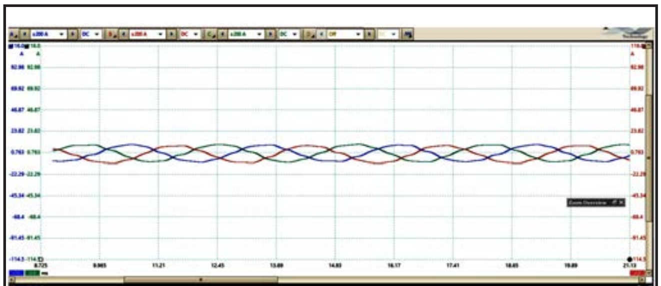
# CHAPTER 2 - INVERTER TESTING

Next, attach the jumper leads between the inverter and the factory harness. Three CAT 3-amp probes can be placed around the jumper leads to obtain amperage waveforms.

Make sure a wire loom protects any bare connections at the harness end. The previous picture shows the amp probes clamped around jumper wires.

## Waveform Live

Below is a waveform of a Prius MG2 while driving. The amperage waveform changes in amplitude; the higher the amplitude, the higher torque of the motor. The amperage waveform also changes in frequency.



*Prius MG2 Live Waveform*

The faster or higher the frequency, the faster the motor is turning. The amplitude of all three phases should be reasonably even.

The above screen capture requires the jumper wires and three Cat 3-amp probes. This waveform was taken from MG2 during a test drive.

The waveforms should be offset by each other, by 120 degrees. If one phase is consistently much lower in amplitude than the other two, this indicates a problem. For example, suppose the waveforms are out of phase with one another; that indicates a problem.

If a problem is detected in one phase, further testing is required. The problem may lie in the inverter, the harness, or the motor. Further testing is required to determine where the fault(s) may lie. DTCs may also help confirm what component is failing.

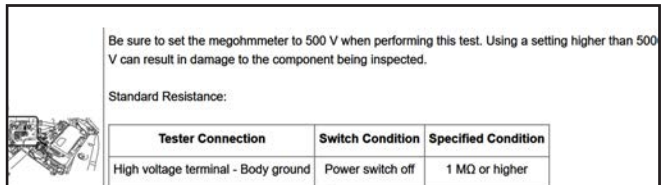
## Isolation Testing


*Isolation Testing*

Isolation testing ensures there is no high voltage leakage to the chassis ground. High voltage tests the insulation characteristics of the high voltage system. You must remove the three-phase motor cables for this test to use a megaohm meter. Test each high voltage terminal with a megaohm meter. Place one lead to the high voltage terminal and the other to the housing.

## Inverter Isolation Test

Key Points:
- Toyota recommends 500 volts for testing the inverter.
- Specification is one megaohm or higher.



Be sure to set the megohmmeter to 500 V when performing this test. Using a setting higher than 500 V can result in damage to the component being inspected.

Standard Resistance:

| Tester Connection | Switch Condition | Specified Condition |
|---|---|---|
| High voltage terminal - Body ground | Power switch off | 1 MΩ or higher |

*Test Procedure (Courtesy Toyota)*

If you have an isolation code, you may need to test the entire high voltage system for an insulation failure. In our example, we will test the inverter. Then, remove the motor harness and test all three terminals one at a time.

# CHAPTER 2 - INVERTER TESTING


*Isolation Test (Example)*

Connect one lead to the inverter housing and the other to a terminal. Select 500 volts and then push the test button. The meter should maintain over 500 volts during the test. The megaohm scale should progressively reach its maximum point and not get hung up and bounce back and forth at one place.

If it hangs up and bounces back and forth, an isolation fault may come soon. In our example, the meter moves smoothly up to the max point of 7.6 megaohms, much higher than the minimum of 1 megaohm.

***Test both sets of motor inverter terminals.***
***Test DC input terminals on the inverter.***
***Use the method shown above for all terminals.***
***Specification is over 1 megaohm.***

Three-phase motors should be higher than ten megohms as a rule of thumb. Most motors will have a much higher reading when the insulation is in good condition. Motors that have been sitting over a long period of time could accumulate moisture through condensation. Excessive moisture could cause a failure with the test. Motors can be dried out and retested.

IEEE1415 testing standard (Governing standard in electrical testing), states that motors ranging up to 100 volts tested at the 500-volt level should have a minimum of 5.0 megaohms of resistance.

Motor experts think this standard is too low and move the standard up to a minimum of 10 megaohms in the field.

All manufacturers use a test to ensure the high voltage system is isolated from the chassis. Some manufacturers offer a PID for isolation of the high voltage system. The example below was from a 2021 Honda dual motor. The “self-test” the system performs came back with a value of 1000 kilohm.

| Name | Value | Unit |
|---|---|---|
| Insulation Resistance of High Voltage Circuit | 1000 | kohm |

***2021 Honda Insight Scan Data***

Toyota uses a PID within their scan data called "Short wave hightest value". With no isolation faults present, the voltage stays at 4.99V. An isolation fault would cause the voltage to drop.

| | | |
|---|---|---|
| Accelerator degree | 0 | % |
| VL voltage before boosting | 226 | V |
| VH voltage after boosting | 243 | V |
| Short wave highest value | 4.99 | V |
| Boost ratio | 0 | % |

***Third Generation Prius Short Wave Highest Value***

The scan data above was taken from a third-gen Prius. The PID that reflects isolation faults is the short wave's highest value.

This PID will remain close to five volts when no isolation faults exist. If there is an isolation fault, the PID will drop from five volts, and a direct short will result in a reading of around 30 millivolts.

Motor Harness Isolation Test

Key Points:
• Tests the high voltage harness.
• Tests from each motor lead to the shielded wire ground.
• Specification is 100 megaohms or higher.

# CHAPTER 2 - INVERTER TESTING

The inverter, the motors, and the harness should all be tested if you have an isolation fault. In this example, we will test the motor harness to the shielding.

The leads are hooked to a motor terminal, and the metal shielding that surrounds the HV cables. The shielding is grounded at the inverter case, and the wiring harness is attached and grounded at the opposite end of the transaxle.


***Motor Isolation Test (Example)***

An excellent place to check for cable insulation breakdown is the shielding. In our example, the meter loads the cable with over 500 volts, the voltage does not drop, and the meter maxes out at 550 megaohms, indicating no leakage in these cables. However, since the shielding is grounded at the other end, there is no need to test from the opposite end.

The specification is 100 megaohms or higher; this cable assembly passed the test quickly.

Chapter 2 Assessment Questions and Answers

**What are the four main ways of testing inverters?**

*1-Voltage waveforms*
*2-Amperage waveforms*
*3-Isolation testing*
*4-DTC*

**To obtain amperage waveforms for motor and inverter, what does the technician need to make and install?**

*The technician needs to make up a set of jumper leads and install them between the inverter and motor harness.*

**What tool is needed to perform isolation or insulation testing?**

*A megaohm meter.*

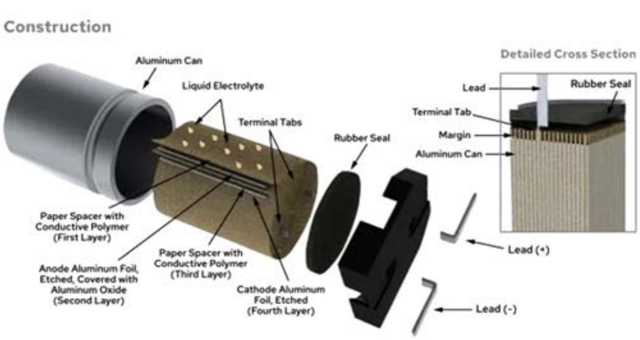
Chapter 2 Assessment Notes

# CHAPTER 3 - CAPACITORS

## Capacitor Design and Construction

Key Points:
- Capacitors store energy, especially voltage spikes.
- They release energy during low voltage spots.
- Storing and releasing energy smooths out the voltage supply.
- Capacitors must be drained before performing work.

Capacitor construction has evolved over the years, so the inside of the capacitor may vary depending on the year developed and application; however, the operation remains the same. Early capacitors comprised two conductive metal plates typically made from aluminum and separated by a dielectric insulating material such as ceramic.




*Capacitor Constuction (Typical)*

Each plate will have a terminal attached, and the terminals will represent the anode and cathode. Electrons build up on one plate, and are released back into the circuit by the other plate. Electrons cannot pass from plate to plate due to the insulating material. Instead, the negative plate becomes charged with excess electrons, and the positive plate lacks electrons.

The positively charged and negatively charged electrons are attracted to one another; however, they cannot reach each other due to the insulating material.

The attraction between the electrons on each plate creates an electrical field that holds electrons in place until a lower voltage in the circuit is reached to release the electrons into the circuit.

The capacitor is continually charging and releasing, and this is how the capacitor smooths out electrical circuits.

The capacitors are wired across the positive and negative sides of a circuit. Capacitors store energy, especially voltage spikes. Capacitors also release the stored energy to smooth out a voltage supply. One note to technicians is that capacitors must be drained of energy before working on the electrical circuits involved with the capacitor.

Disconnecting the service plug and waiting 5-15 minutes, depending on manufacture, before touching electrical circuits is necessary to ensure the technician's safety. There is usually a drain resistor near the capacitor to drain the capacitors to help eliminate the charge.

Small capacitors are inside control modules, and large capacitors are used in the inverter motor control and the DC-DC converter. The DC-DC converter experiences voltage ripple and high voltage spikes; the capacitors stabilize battery voltage and protect the electronics.

## Inverter Capacitors

Key Points:
- Large capacitors are electrically located between high voltage batteries and inverters.
- Physically Located inside inverter housing.
- High ripple absorption.
- Reduces harmonics.
- Specific microfarad rating.

Capacitors provide high ripple absorption, which reduces harmonics. Harmonics are small ripples or noise on the sine wave that travels from the inverter to the motor. Harmonic noise is a fast frequency ripple that creates heat. Capacitors also increase the power factor.


*Panasonic 1086 Microfarad Capacitor*

# CHAPTER 3 - CAPACITORS

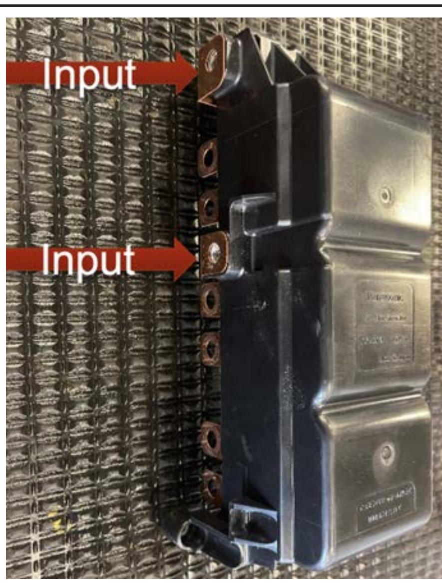
Capacitors start to age and lose some of their ability to reduce the harmonics. Capacitors are also needed to smooth out the large voltage spikes. Capacitors have a specific microfarad rating that is usually stamped on the capacitor.

## Capacitor Bank

Capacitors are not all shaped the same; some are individual designs, and some are molded into one plastic housing.

***Capacitor Bank***

The capacitors in the above illustration are CAN designed capacitors from a Honda IMA inverter. These capacitors are wired in parallel. One metal strap hooks all the positives together, and one strap hooks all the negatives together.




***Nissan Leaf Molded Design Capacitor Bank***

Wired in parallel, you add all the capacitors together to obtain the total capacitance. These capacitors are located on the DC side of the inverter. The two DC battery cables are attached to the capacitor bank. The capacitors are then hooked to the input side of the inverter.

The molded capacitor pack shown is from a Nissan Leaf. The two large terminals are attached to the high voltage DC battery terminals, which we will label as inputs. The input terminals travel down into the potted housing.

All the positive terminals are attached to one input, and all the negative ones are attached to the other. In this aspect, the terminals are attached in parallel; however, true parallel would mean we have only two terminals as outputs and six outputs, so each capacitor works individually. The six outputs attach directly to the inverter.

One of the capacitors is used for the IGBT that runs the single electric motor in the Nissan leaf Transaxle. One capacitor is for the electric A/C compressor, and the other is for the DC-DC converter.

## Verify Capacitance

Capacitance can be measured with a DVOM. Capacitors can be stand-alone units, or capacitors can be wired in series or parallel. Capacitors work the opposite of resistance in electrical circuits when measuring them. You add all the resistances in a series circuit to get a total resistance.


***Capacitance Verification Testing***

# CHAPTER 3 - CAPACITORS

In a parallel circuit, you use a formula to calculate total resistance; however, the total resistance will be less than the least resistor in a parallel circuit.

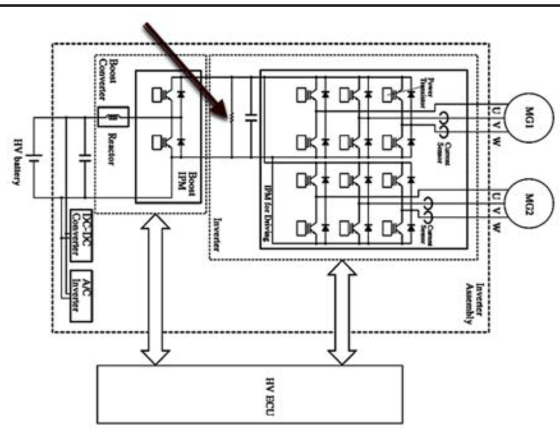
Remember, for capacitors wired in parallel, add each capacitance to obtain the total value. For capacitors wired in series, the total capacitance can be found by adding the reciprocals of the individual capacitances, and taking the reciprocal of the sum.

## The Bleed Resistor

Capacitors can store a fair amount of energy and may deliver a lethal shock; therefore, it is necessary to power the system down correctly and ensure the capacitors are drained before working on the high voltage circuits.The bleed resistor is located inside of the inverter near, and connected to the capacitors.


*Bleed Resistor*

The bleed resistor is used to drain the capacitors after the vehicle performs the power down procedure. In the illustration above, the bleed resistor has an ohmic value of 61.15 Kilohms.




*Bleed Resistor Location (Example)*

After the power is removed from the capacitors, the control module can actively discharge the capacitors through the motor windings.

The bleed resistor offers a passive way to bleed off the capacitors so the system can be safe to work on. The bleed resistor takes a little time to drain the capacitors, so the service information may say wait 5-15 minutes before performing any work on the high voltage side.

## Chapter 3 Assessment Questions and Answers

**What are the two main functions of a capacitor?**

*Capacitors absorb voltage spikes and release energy during low voltage times. Capacitors also smooth out the voltage in the circuit.*

**True or False. Can capacitors be wired in series or parallel?**

*True. Capacitors can be wired in series or parallel.*

**What function does a bleed resistor perform?**

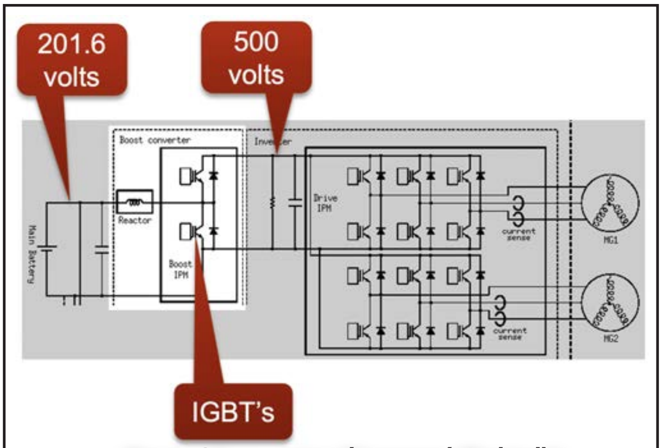
Bleed resistors provide a way of bleeding the energy stored inside the capacitors when system is off.

## Chapter 3 Assessment Notes

# CHAPTER 4 - BOOST/BUCK CONVERTER

## Boost Converters

Key Points:
- Boost converters boost battery voltage higher.
- Example: 2nd gen Prius 201.6-500 volts, Third gen 201.6-650 volts.
- Example Camry: 245 -650 volts.
- The Boost Converter is located inside the inverter, before the IGBTs.




***Boost Converter Diagram (Typical)***

A boost converter boosts the high voltage battery up to a higher level. An example of this would be a 2nd gen Prius; the battery was rated at 201.6 volts; the boost converter would boost the voltage up to 500 volts, and the third-gen up to 650 volts.

Another example would be the Toyota Camry, and the battery voltage was boosted from 245 volts to 650 volts.

The boost converter uses IGBTs or MOSFETs to pulse the circuit on and off, charging up an inductor called a reactor. The output voltage is directly related to the duty cycle of the switching.

One disadvantage of a boost converter is that you lose some amperage as the voltage is boosted. Whenever voltage is boosted, amperage is decreased. This is an unavoidable tradeoff.

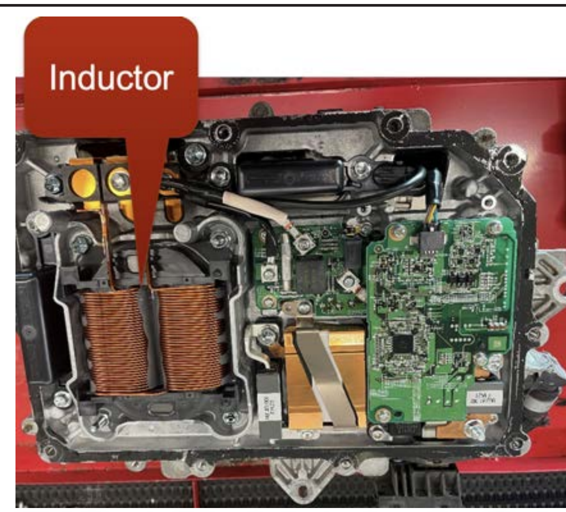
The significant advantage of a boost converter is that the manufacturer can use a smaller battery to save money and weight but still get the required voltage.

In our example, we are achieving 500 volts from the boost converter with a 201.6-volt battery. A 500-volt battery would be much bigger, more expensive, and heavier.

The first generation Prius used a 274-volt battery and no boost converter, so the motors voltage was only 274 volts. The 274-volt battery required ten more modules, making it heavier and more costly than the second-gen battery at 201.6 volts.

## The Inductor

An inductor (reactor) can be charged up and store energy. This energy is stored in a magnetic field. The magnetic field collapses when the circuit is turned off and creates a higher output voltage than the input or supplied voltage.




***2010 Toyota Prius Inductor Location (Typical)***

The inductor is quite substantial, as shown in the picture. The inductor is charged and released continually to create the desired boost voltage.

The boost voltage is regulated and is constantly changing depending on the need. The boost voltage fills the capacitors between the boost converter and the IGBT bank.

# CHAPTER 4 - BOOST/BUCK CONVERTER

## Reactor Voltage/Temperature

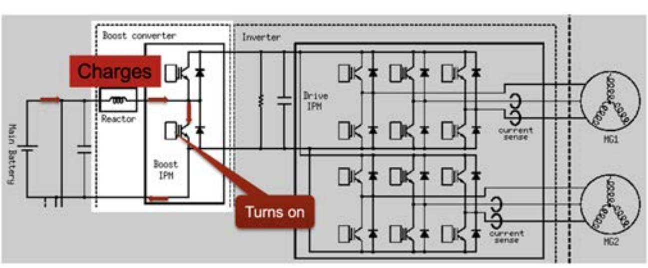
The scan data illustrated below was taken from a 2021 Honda insight. It shows the reactor voltage changes, and scan data as well as reporting the temperature of the reactor (boost converter).

| Name | Value | Unit |
|---|---|---|
| Motor Inverter Voltage (gen) | 216 | V |
| Reactor Temperature Sensor Voltage (trc) | 3.89 | V |
| Reactor Temperature (trc) | 36 | °C |
| Motor Inverter Voltage (trc) | 216 | V |
| Traction Motor Speed (trc) | 0 | rpm |

***Reactor Voltage/Temperature Scan Data***

Not all vehicles that use them give you a temperature PID to review, but the Honda Insight dual motor offers both; when the reactor starts to boost the voltage, the temperature increases.

## Charges

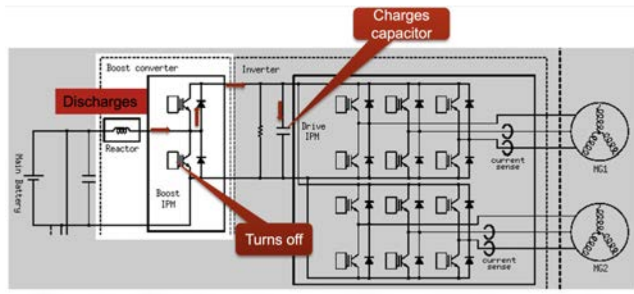



***Reactor Charging***

The motors used in the Prius are 500-volt plus motors and will not be efficient with just 201.6 volts, so the boost converter boosts the voltage from 201.6 to 500 volts.

The reactor is located between the high voltage DC battery and the IGBT set. The reactor is a large inductor that can be charged, and the voltage travels through the reactor when the negative IGBT turns on. The reactor charges up and creates a magnetic field.

## Discharges & Stored Voltage (Spikes)

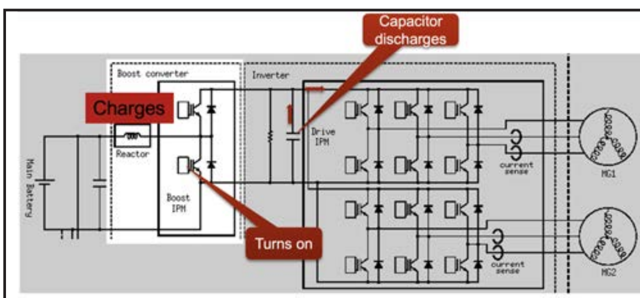



***Reactor Discharging and Stored Voltage Spikes***

When the negative IGBT is shut off, the reactor discharges. The switching happens very fast, creating a series of voltage spikes. The voltage spikes are stored and smoothed by the capacitor.

The voltage is controlled by changing the PWM to the negative IGBT in the boost converter. More voltage equals a higher duty cycle, and lower voltage equals a negative cycle.

## Capacitor Release




***Reactor Discharging and Stored Voltage Spikes***

On the next cycle, the IGBT turns on to charge the inductor, and the capacitor releases the high voltage previously stored to the positive IGBTs to power the motor.

The positive diode keeps the capacitor's high voltage from going backward and the high voltage available to the IGBT pack.

# CHAPTER 4 - BOOST/BUCK CONVERTER

## Boost Voltage

The supplied battery voltage to the boost converter is constantly changing. The battery voltage is 180 volts in capture #1, 206 volts in capture #2.

| Name | Value | Unit |
|---|---|---|
| Accelerator degree | 54 | % |
| VL voltage before boosting | 180 | V |
| VH voltage after boosting | 384 | V |

***Battery and Boost Voltage - Capture #1***

| Name | Value | Unit |
|---|---|---|
| Accelerator degree | 47 | % |
| VL voltage before boosting | 206 | V |
| VH voltage after boosting | 498 | V |

***Battery and Boost Voltage - Capture #2***

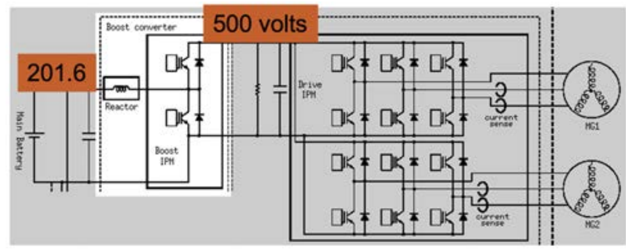
The boost voltage is always regulated to match the desired torque and load; the boost voltage in capture #1 is 384 volts, and 498 volts in capture #2 which is the max on this vehicle. The scan data was taken from a 2009 2nd gen Prius.

Toyota issued a recall that involved re-flashing the software to keep the boost converter from overheating and failing.

When the boost converter failed due to overheating, a "no movement" condition would occur. Under the recall, the boost converter would be covered if this overheating fault caused damage.

## Voltage Reduction

The boost converter is bi-directional, which can boost or buck the voltage. We covered the boost stage now, focusing on the buck stage. In buck mode, the converter must take high voltage created by the electric motors in regen and reduce it down to charge the battery.




***Voltage Reduction (Buck Stage)***

The battery voltage is approximately 201.6 volts, so the converter needs to buck the voltage down close to the rated battery voltage. The voltage is reduced during the buck cycle, but the current increases.

## Chapter 4 Assessment Questions and Answers

**What is the primary function of a boost converter?**

*Boost the input voltage from the battery to a much higher output voltage.*

**What devices inside the boost converter boost the voltage?**

*IGBTs (Transistors) and an inductor along with some diodes.*

**What advantage does a boost converter offer?**

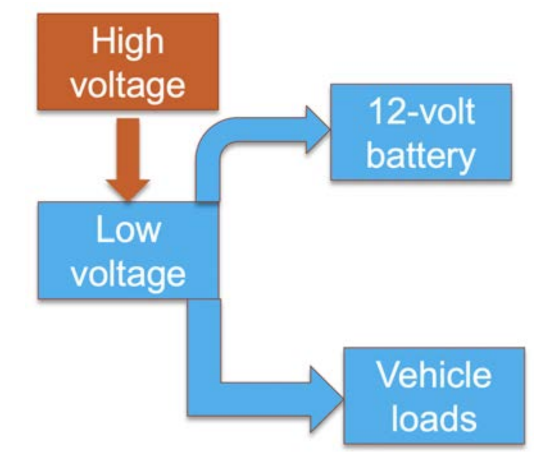
*It allows the manufacturer to use a smaller, lighter battery and improves motor efficiency.*

## Chapter 4 Assessment Notes

# CHAPTER 5 - THE DC-DC CONVERTER

## DC-DC Converter

Key Points
- The DC-DC converter replaces traditional alternator.
- High voltage is converted to 13.8-14.5 volts.
- The DC-DC converter provides the 12-volt circuit with constant power.




*Conversion of High Voltage to Low Voltage*

The 12-volt system used in hybrid and electric vehicles has the exact requirements of a conventional vehicle. It starts with a 12-volt battery that supplies the system with the required voltage and reserve energy.

The battery needs to be charged at a higher voltage than the static battery voltage, and typically the charging voltage will be approximately 13.8-14.5 volts.

The DC-DC converter provides the required charging voltage by the 12-volt system since no conventional alternator is used on these vehicles.

The DC-DC converter receives voltage from the high voltage battery, which could be 100-400 volts or more depending on the manufacturer, and converts it to 13.8-14.5 DC volts. The low voltage charges the 12-volt battery and runs all the 12-volt loads in the vehicle.

The voltage reduction is known as bucking the voltage down. Some DC-DC converters also boost the voltage from the 12-volt side to the high voltage side, offering a jump-start feature. This feature charges the high voltage battery from the 12-volt side. The early Ford escape was one of the vehicles that offered a boost start feature.

The DC-DC converter on most Toyotas resides in the inverter housing at the bottom; however, the Camry DC-DC converter is in the battery pack. In the Chevy Volt and most Ford's, the DC-DC converter is remotely mounted and does not reside in the inverter housing.

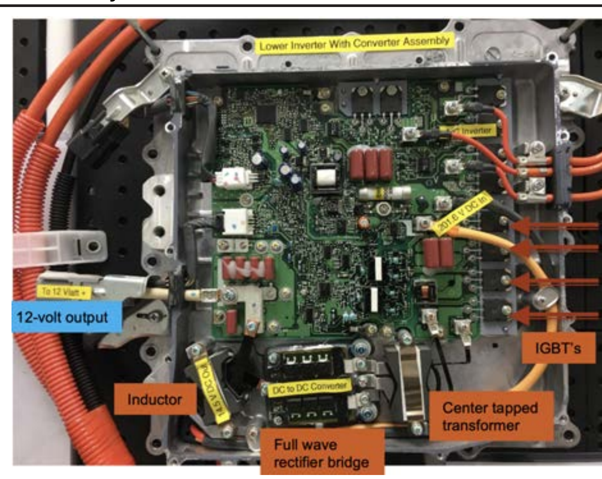
## Jump-Starting With Boost Feature

To jump-start a vehicle with a boost feature built into the DC-DC converter, you must attach a 12-volt charger to the 12-volt battery.

The Ford Escape had a button to push to allow the DC-DC converter to enter jump start mode and charge the high voltage battery. This feature was not used on many vehicles; most DC-DC converters only buck the voltage and do not offer a boost function.

## Components

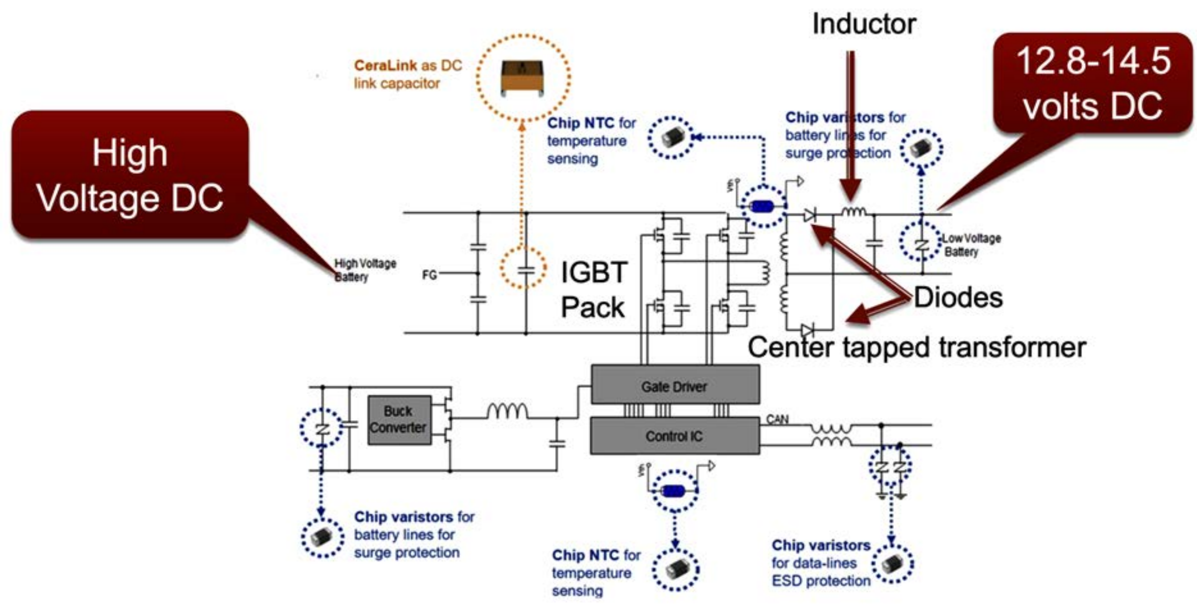
- High voltage input.
- IGBT drive.
- Transformer.
- Full-wave rectifier bridge.
- Inductor.
- Control System.




*DC-DC Converter Components*

The major components of the DC-DC converter are the high voltage system input, IGBT drive, center-tapped transformer, full rectifier bridge, inductor, 12-volt output stud, and control system. These components will be explained on the next page with a diagram.

# CHAPTER 5 - THE DC-DC CONVERTER




*Inverter Operation*

## Inverter Operation

The high voltage DC battery supplies the high voltage. The battery voltage must be reduced to 12.8-14.5 volts.

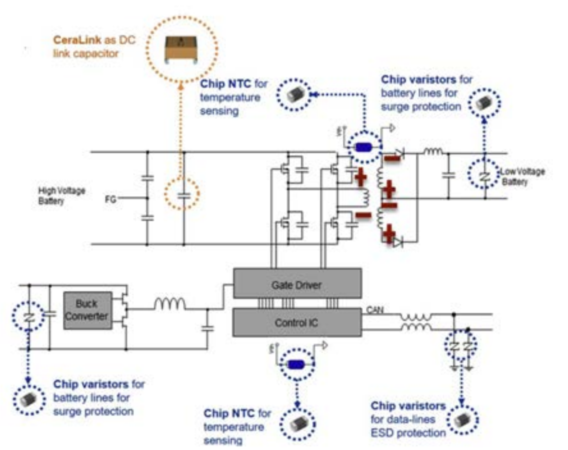
High voltage is fed to a four-pack of IGBTs in the above diagram; however, more IGBTs may be used on other models. The control circuit switches the IGBTs to modulate the voltage fed to the transformer's IGBT side.

## Polarity Switching

The IGBT side of the transformer creates a magnetic field that will be shared with the center-tapped transformer side illustrated in diagram #1.

The magnetic field creates a voltage that the diodes must rectify as it is collapsed. The IGBT side transformer switches polarity from positive to negative and back again.

Due to the polarity switching, we end up with AC voltage. The center tap of the transformer causes each coil of the transformer on the diode side to switch polarities individually.



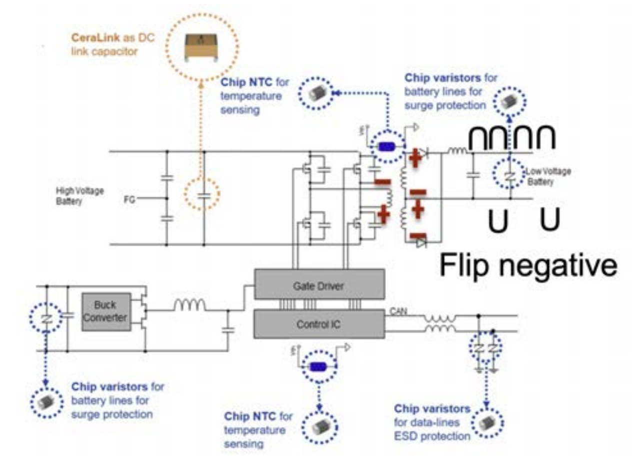

*IGBT and Transformer Diagram #1*

The polarity on each coil of the center tap transformer will be the opposite polarity of the IGBT transformer side coil.

The positive side will create a positive wave, and the negative will create a negative wave, just like an alternator. The negative wave is flipped and added to the positive wave to create a DC signal and full rectification as illustrated in diagram #2.

Once the DC voltage exits the diodes, it travels through the inductor, which acts as a filter to smooth the voltage, and then the voltage exits at approximately 12.8-14.5 volts.

# CHAPTER 5 - THE DC-DC CONVERTER




*IGBT and Transformer Diagram #2*

The voltage is ready to charge the low voltage battery and run all the accessories. The DC voltage should be very smooth with hardly any ripple.

## Scan Data

A scanner can access DC-DC PIDs. Ensure the output voltage is in the normal range. With the key on and no accessories commanded, the voltage may be around 12.8, typically a fully charged AGM battery.

As soon as you go to a ready mode or start to command accessories, the voltage will increase to the 14-volt range. The charge lamp should be off if the system is working correctly.

DC-DC command should be on, indicating we are charging the 12-volt battery and providing energy for the 12-volt system. DC-DC temperature can be monitored for overheating conditions by watching temperature PID.

| Name | Value | Unit |
|---|---|---|
| IGB1Voltage (bat) | 14.32 | V |
| Battery Condition Monitor Module Backup Sou... | 14.31 | V |
| Dc-dc Converter Charge Lamp | Off | |
| History of dc-dc Converter Stop 2 | No | |
| Command to dc-dc Converter | ON | |
| Dc-dc Converter Information | Normal | |
| Dc-dc Converter Input Current | 2.4 | A |
| Dc-dc Converter Temperature | 109.4 | °F |
| Dc-dc Converter Electricity Consumption | 500 | W |

*Scan Data Sample*

Power consumption indicates the current watt output of the DC-DC converter.

The 12-volt system can be loaded slowly using a carbon pile. You can observe an increase in wattage output and ensure maximum output is reached. This data stream can also indicate if the DC-DC converter is malfunctioning.

## DC-DC Testing

DC-DC testing is like testing an alternator. The only difference is that you do not need the engine running. The car must be in ready mode or another mode that allows the DC-DC converter to charge.

*DC-DC Voltage Testing*

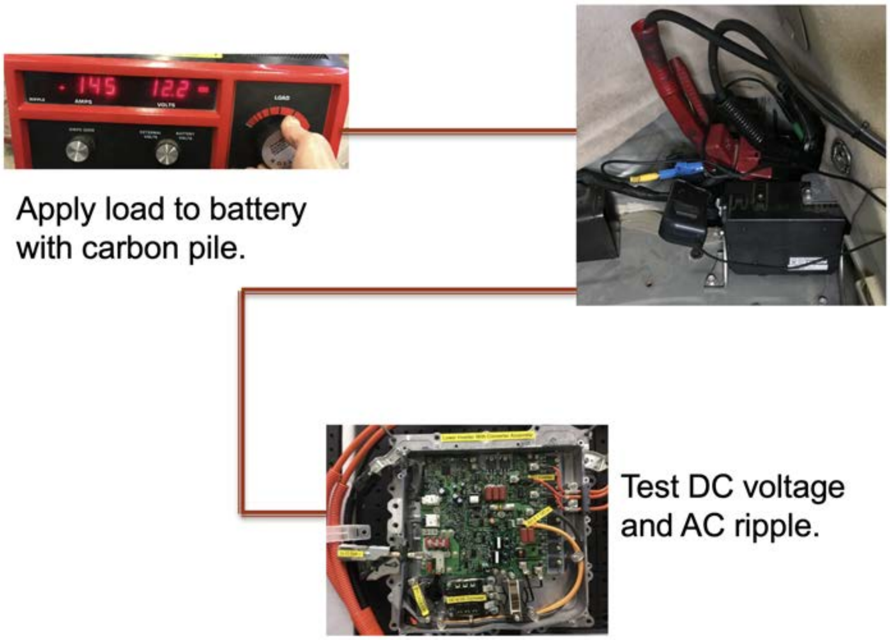
The first step in testing is to attach a meter to battery terminals or DC-DC output terminals. Make sure the voltage is approximately 14-14.5 volts.

Turn on several 12-volt accessories to provide a load on the DC-DC converter. Make sure the voltage on the meter does not start to fall. This is only an initial test. More testing can be performed with a carbon pile, scope, and amp probe.

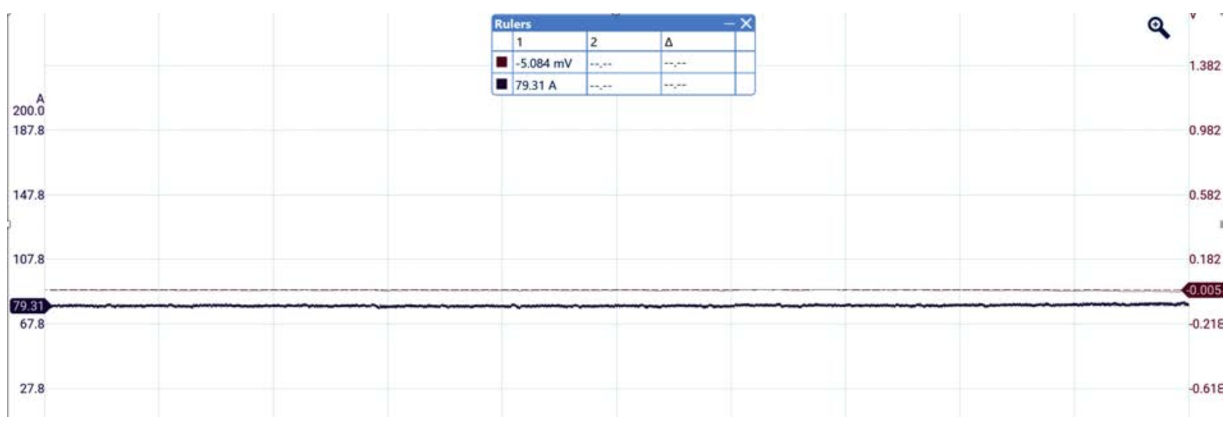
A load must be applied to the 12-volt system to test the DC-DC converter. An easy place to apply a load is the 12-volt battery.

In the following example, we have ttached a carbon pile load tester to the battery. We are applying a load with the carbon pile tester, and the amp clamp of the carbon pile tester is attached to the lead. The carbon pile shows how many amps are coming out of the battery.

# CHAPTER 5 - THE DC-DC CONVERTER




***DC-DC Voltage Testing Using Carbon Pile***




***DC-DC Voltage Shown on a Lab Scope***

Another amp probe is attached to the lab scope and clipped around the output wire of the DC-DC converter near the battery positive lead.

Also, voltage leads are attached from the battery terminals to the lab scope. The lab scope voltage scale is set to the AC 2-volt scale.

When we apply the load slowly, we should see the amperage rise on the DC-DC output. The amperage rises to 79.31 amps in this example.

The AC voltage is negligible at only five millivolts. Compare the amperage output to the specs for the vehicle.

Some DC-DC converters are rated around 100 amps, and some may be 180 amps or higher. Always apply the load slowly because some converters use a dual-stage output, and applying a load quickly can damage the converter. Jump-starting vehicles can also damage the converter.

An amp meter can be placed around this wire to measure DC-DC amperage output. If you place the amp probe near the battery instead of the output port, you may miss some amperage output depending on if there is a splice before the battery that feeds electrical circuits.

# CHAPTER 5 - THE DC-DC CONVERTER

## Testing with a Carbon Pile

Attach a carbon pile to the battery and perform a load test. The amperage on the carbon pile is the amperage coming from the battery. The amperage on the scope is from the inverter. Apply the load slowly to avoid damaging the DC-DC converter.

## Chapter 5 Assessment Questions and Answers

**What is the primary purpose of a DC-DC converter?**

*The primary purpose is to reduce the high voltage of the battery to 13.8-14.5 volts.*

**What devices are used to reduce the voltage?**

*IGBTs, transformers, and diodes.*

**What two ways do I test the DC-DC converter?**

*1. Voltage output.*
*2. Carbon pile load test and measuring amperage output of the converter.*

## Chapter 5 Assessment Notes

# CHAPTER 6 - CONTACTORS

## Contactors

Key Points:
- Contactors provide connection from High voltage battery to inverter and contain the following:
    - A positive contactor.
    - A negative contactor.
    - A pre-charge contactor.
- The control circuit is operated by the 12-volt system.
- Includes a pre-charge resistor.


***Contactor Assemblies***

The high voltage batteries require contactors to establish a connection from the high voltage battery to the inverter.

The contactors also provide a disconnect to ensure we can isolate the high voltage to the battery area. For example, in the gen 3 Prius example above, the system utilizes three contactors and a pre-charge resistor to accomplish this task.

Operation of the contactors and labeling may vary between Prius generations and other manufacturers.

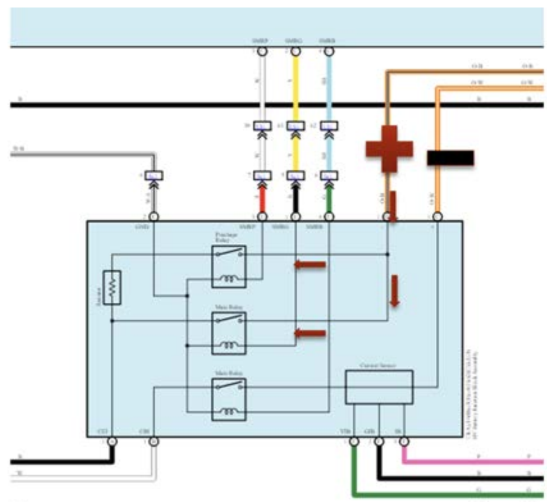
Toyota refers to the contactors as central system relays; Generation one and two referred to them as SMR1, SMR2, and SMR3.

Generation three Prius referred to them as SMRP (System main relay pre-charge), SMRB (System main relay battery) SMRG (System main relay ground).

## Turn-On Sequence

In the third-gen Prius, the positive contactor closes first, then the pre-charge contactor, then the negative contactor, then the pre-charge relay opens.

The capacitors are drained and are empty upon start up. When the contactors close, the capacitors swiftly require a large amount of current.



***Turn-On Sequence Diagram***

If the inrush of current was not slowed, arcing would occur, possibly welding the contacts of the contactor closed.

The pre-charge resistor will slow the inrush of current preventing contact welding. The diagram shows the positive contactor, the pre-charge resistor is on the positive side, and the negative contactor is on the negative side.

# CHAPTER 6 - CONTACTORS

## Welded Contacts

*Welded Contacts*

The above contactor has welded contacts. This could be dangerous to a technician unless the technician checks for the presence of voltage before repair. The vehicle performs a test for this condition on shut down.

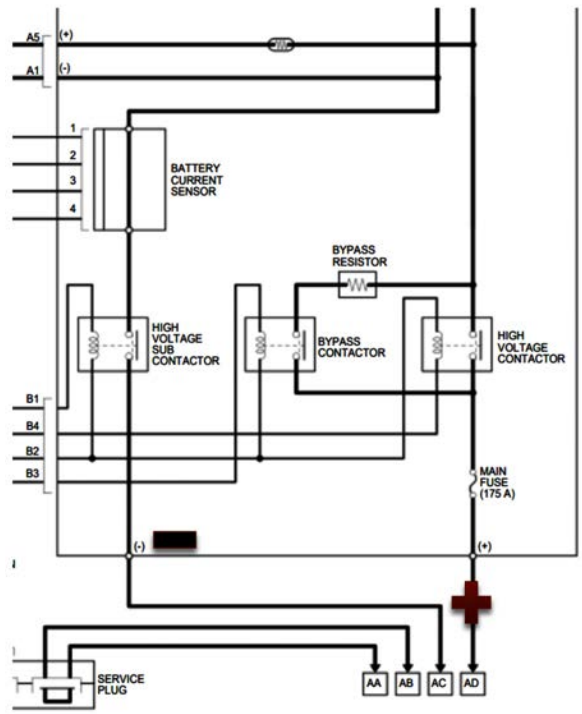
The ready off shut down sequence, opens the negative contactor, and the current sensor detects if the current is still flowing.

Next, the controller opens the positive contactor and closes the pre-charge relay, ensuring no current is flowing. The controller then opens the pre-charge relay. This ready cycle will follow unhindered if the system passes the shut-down process and no DTCs are set.

## System Main Relay Pre-charge (SMRP)

Not all vehicles use the same style of contactors; sometimes, they are referred to as relays. For example, in the 2007-2011 Camry, the system main relay pre-charge(SMRP) is not located with the other two system central relays; it is located inside the DC-DC converter and is a semiconductor style relay.

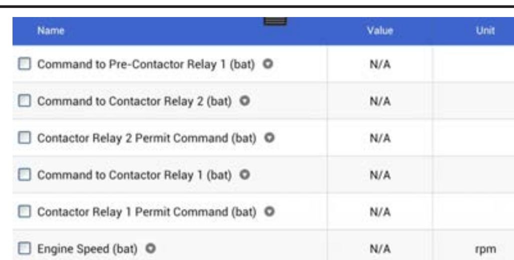
## Honda Insight Dual Motor




*2021 Honda Insight Dual Motor Wiring Schematic*

The diagram above is from a 2021 Honda insight with a dual-motor hybrid system. The wiring diagram is similar to the third-gen Prius. The positive contactor (high voltage) and pre-charge contactor (bypass) are on the positive side. The negative side contactor (sub-contactor) incorporates a battery current sensor.

## Honda Insight Dual Motor Scan Data



| Name | Value | Unit |
|---|---|---|
| Command to Pre-Contactor Relay 1 (bat) | N/A | |
| Command to Contactor Relay 2 (bat) | N/A | |
| Contactor Relay 2 Permit Command (bat) | N/A | |
| Command to Contactor Relay 1 (bat) | N/A | |
| Contactor Relay 1 Permit Command (bat) | N/A | |
| Engine Speed (bat) | N/A | rpm |

*Reactor Discharging and Stored Voltage Spikes*

A scan tool is not fast enough to show each relay coming on at a different time, but it does capture the pre-charge relay going back off at the end of the sequence.

# CHAPTER 6 - CONTACTORS

## Testing


***CAT III Meter***

Testing contactors will require high-voltage gloves and a CAT 3 meter with CAT 3 leads. Test the voltage before the contactors. The voltage before the contactors should represent the battery voltage.

The voltage after the contactors should be zero when the system is powered off. When the system enters ready mode, the voltage after the contactor should be the same as before the contactor.


***CAT III Meter***

Gloves should be tested for holes or leaks on a regular basis. Testing is performed using an inflator. The glove is attached to the inflator in a deflated state. The glove is inflated using the hand held pump as illustrated. A good glove will inflate and hold air.

***Deflated Glove***

***Inflated Glove***

A leather protector should always be worn over the rubber insulating glove to provide protection from cuts, abrasions and punctures.

# CHAPTER 6 - CONTACTORS

## Chapter 6 Assessment Questions and Answers

**How many contactors are typically used?**

*Usually three contactors, Positive side, negative side, and pre-charge.*

**What should the voltage measure after contactors (Inverter side) with contactors off?**

*Zero volts.*

**What is the purpose of a pre-charge relay?**

*To prevent arcing of the contacts during the capacitor fill-up time, arcing can cause contacts to weld together.*

## Summary

- The inverter converts DC to simulated AC voltage.
- IGBTs have a firing order.
- Boost converter steps up battery voltage.
- Buck converter reduces voltage.
- Capacitors smooth out voltage and store energy.
- Most scopes need an isolator to measure voltage.
- Contactors have a start-up and shut-down sequence.
- Meters and amp probes need to meet Cat 3 specs.

## Glossary Of Terms

- AC- (Alternating current) Current that regularly changes directions.
- BEV- (Battery electric vehicle) Vehicle powered by high voltage battery and electric motor.
- Boost voltage- Voltage output is higher than voltage input.
- Buck voltage- Voltage output is lower than voltage input.
- DC- (Direct current) Current that flows in one direction.
- Contactors-Similar to a relay but typically has two contacts to pass current rather than one.
- EREV- (Extended-range electric vehicle)-Vehicles that can run on gasoline when the battery is low.
- EVSE-Electric vehicle supply equipment.
- Gauss- Abbreviated G is a measurement of a magnetic field.
- HEV- (Hybrid electric vehicle) Utilizes a dual system to promote propulsion, typically an ICE and an electric motor.
- ICE- (Internal combustion engine) Powered by combustible fuel.
- An IGBT-Insulated bipolar transistor is used to provide a high voltage/current pathway.
- Induction motor-An electric motor that uses a nonmagnetic rotor.
- Isolation- High voltage system is isolated from the chassis ground.
- MG-(Motor generator) Electric motor that performs work or generator that provides energy to recharge the battery
- Neodymium- Rare earth magnets made from alloys of rare earth elements. They are solid and brittle.
- Ohms-Defined as an electrical resistance between two points of a conductor.
- PM motor- (Permanent magnet motor) The rotor contains magnets that alternate north and south poles.
- PHEV- (Plug-in hybrid vehicle) Contains a high voltage battery that can be plugged in to be charged.
- Resistance- It is a measure of its opposition to the flow of electric current
- Rotor- Internal component inside an electric motor typically splined to a shaft or gear.
- A shorts-An abnormal condition in an electrical circuit where the current flows through an unintended shorter pathway or to the ground.
- Stator- A wire coil wound in a Wye or Delta fashion installed in stationary housing.

## TEST QUESTIONS

Test Questions

**1. Which of the following is a function of the inverter.**
*A. Pass DC voltage from the battery directly to electric motors.*
*B. Pass AC voltage from the battery to electric motors.*
*C. Create voltage to charge a high voltage battery.*
*D. Take DC voltage from the battery, simulate AC voltage, and send it to electric motors.*

**2. Inverters typically use this type of transistor.**
*A. IGBT.*
*B. BJT.*
*C. FET.*
*D. NPN.*

**3. How many Inverter transistors are typically used per motor?**
*A. 2 pack.*
*B. 4 pack.*
*C. 5 pack.*
*D. 6 pack.*

**4. How many electrical phases per motor in HEV-BEV vehicles?**
*A. Single.*
*B. Two-phase.*
*C. Three phase.*
*D. Six phase.*

**5. What type of voltage waveforms does the inverter create for powering the electric motor?**
*A. Straight line DC.*
*B. single phase.*
*C. Sine-6 Step-Rectangular.*
*D. Pulse train.*

**6. Technician A says the frequency of the waveform controls motor speed. Technician B says the amplitude of the waveform controls motor speed. Which technician is correct?**
*A. Technician A only.*
*B. Technician B only*
*C. Technicians A & B are both correct.*
*D. Neither Technician A nor Technician B is correct.*

**7. Technician A says the frequency of the waveform controls motor torque. Technician B says the amplitude of the waveform controls motor torque. Which technician is correct?**
*A. Technician A only.*
*B. Technician B only*
*C. Technicians A & B are both correct.*
*D. Neither Technician A nor Technician B is correct.*

**8. Technician A says that the diodes flip AC voltage to DC voltage during regenerations. Technician B says that the diodes flip DC to AC voltage during regenerations. Which technician is correct?**
*A. Technician A only.*
*B. Technician B only*
*C. Technicians A & B are both correct.*
*D. Neither Technician A nor Technician B is correct.*

**9. Technician A says the inverter has a firing order to control the rotating magnetic field in the stator. Technician B says brushes control the rotating magnetic field in the stator. Which technician is correct?**
*A. Technician A only.*
*B. Technician B only*
*C. Technicians A & B are both correct.*
*D. Neither Technician A nor Technician B is correct.*

**10. Technician A says the stator is the rotating part of the electric motor. Technician B says the rotor is the stationary part of the electric motor. Which technician is correct?**
*A. Technician A only.*
*B. Technician B only*
*C. Technicians A & B are both correct.*
*D. Neither Technician A nor Technician B is correct.*

**11. True or false. An isolation tests the insulation factor of the high voltage side.**
*A. True*
*B. False*

**12. True or false. Capacitors store AC voltage and convert it into DC voltage.**
*A. True*
*B. False*

**13. True or false. To obtain the total capacitance reading of capacitors wired in parallel, you add all the capacitors together.**
*A. True*
*B. False*

# TEST QUESTIONS

Test Questions (continued)

**14. True or false. An AC transformer creates boost voltage in the inverter.**
*A. True*
*B. False*

**15. True or false. Contactors have two contacts, and relays typically have one contact.**
*A. True*
*B. False*

Answers

1. D. Take DC voltage from the battery, simulate AC voltage, and send it to electric motors.

2. A. IGBT.

3. D. 6 pack.

4. C. Three phase.

5. C. Pulse train.

6. A. Technician A only.

7. B. Technician B only.

8. A. Technician A only.

9. A. Technician A only.

10. D. Neither Technician A nor Technician B is correct.

11. A. True.

12. B. False.

13. A. True.

14. B. False.

15. A. True.

# COURSE OBJECTIVES, INTRODUCTION AND HV BATTERY SAFETY

## Course Objectives

This section will cover the design, operation, and testing of HV batteries and their related components. At the end of this section, you should be able to complete the following.

* Describe the basic design of a NIMH battery.
* Determine correct safety practices for high voltage battery testing.
* Define how battery cells, modules, and sections are connected together in series.
* Analyze and scan data to determine good and bad cells.
* Perform testing-balancing-reconditioning on NIMH batteries.

## High Voltage Batteries Safety Equipment

This class will focus on NIMH and lithium battery technology and management systems. We will not cover the battery thermal management systems in this class because that will be covered in a separate module.

## Class 0 Rubber Gloves

| mA | Effect on Human Body |
|---|---|
| 0.5-3 | Tingling sensations |
| 3 - 10 | Muscle contractions and pain |
| 10 - 40 | “Let-go” threshold |
| 30 - 75 | Respiratory paralysis |
| 100 - 200 | Ventricular fibrillation |
| 200 - 500 | Heart clamps tight |
| 1500 + | Tissue and Organs start to burn |

*Effects of Amperage on the Human Body*

Working around high voltage can be very dangerous; therefore, a technician must take precautions when high voltage may be present. The chart above indicates the different amperage levels that affect the human body. The chart is in milliamps; it only takes 3-10 milliamps to cause muscle contractions and only 30-75 milliamps to cause respiratory paralysis.

High voltage can be dangerous when working with HEV or BEV high voltage systems. A technician must wear class 0 gloves rated at 1000 volts AC and 1500 volts DC. The gloves have a one-year shelf life prior to opening in the warehouse or parts store and must be rotated.

Once they are opened, the gloves must be professionally tested and certified every six months. The gloves also need to be air tested before each use. There are several companies that make air testers that will fill the glove up with air so they can be tested. Do not expand the gloves more than 1.5 times their original size when blowing them up.

Leather outers must be worn to protect the rubber gloves from being snagged or cut. The rubber gloves are only a one-time use if you use them without the leather outers.

Glove dust can be sprinkled on hands or in rubber gloves to make it easier to get rubber gloves on or off. Glove dust also cools your hands and absorbs moisture. A pair of inner cotton gloves can also help reduce moisture. Gloves only need to be worn when high voltage is present; after powering down the system and verifying that no voltage exists, gloves can be removed, and you can service a vehicle without the gloves.

A word of caution: Even when the system is powered down, the high voltage battery still has high voltage present, so when servicing the high voltage battery, it is highly recommended to wear the high voltage gloves.

## Glove test

Notes: Test gloves with inflator and check for leaks. After gloves are aired up, move the fingers around, checking for cracking or leaks.

You can spend anywhere from 100 to over 300 dollars on inflators. Salisbury and Cementex are two popular brands.

# COURSE OBJECTIVES, INTRODUCTION AND HV BATTERY SAFETY


*Cementex Glove Tester*
*(Courtesy Cementex)*

## Glove Sizes

Take a soft tape measure and measure the hand, as shown in the picture. The gloves may come in numbered sizes and correlates with your hand measurement.

Gloves may come in lettered sizes; correlate your hand size to the chart. If you are considering wearing inner cotton glove liners, you may want to order the next glove size larger.

If the safety gloves you purchase come in numbered sizes, you can correlate the measurement directly to the numerical size listed for the glove. For example, if the measurement is precisely eight inches (203 millimeters), you would select a size eight glove.

To avoid hand fatigue, order the next larger size for all measurements that are not exact inches/millimeters. If the gloves you are purchasing come in lettered sizes, such as extra-small (XS), small (S), medium (M), large (L), extra-large (XL), or double extra-large (XXL) order according to hand measurement and sizing chart.


| US Sizes | |
|---|---|
| 6 - 7 Inches | XS |
| 7 - 8 Inches | S |
| 8 - 9 Inches | M |
| 9 - 10 Inches | L |
| 10 - 11 Inches | XL |
| 11 + Inches | XXL |

*Glove Sizes and Measurement Chart*

## Insulated Tools

Insulated tools are designed to isolate the technician from harmful high voltage. Insulated tools are rated at 1000 volts but are tested at 10,000 volts. It is recommended to use these tools any time a high voltage is present.

*Insulated Tool Set*

# COURSE OBJECTIVES, INTRODUCTION AND HV BATTERY SAFETY

It is also recommended to use insulated tools when working inside or around the high voltage battery, because the battery always stores high voltage.

There are two basic types of insulated tools. Some tools have insulation added to them, and some insulated tools are composite. Both types are sufficient for isolating the technician from high voltage.

## CAT 3 Meter


*Fluke CAT 3 Meter*

A technician may feel that if the voltage range of the meter is higher than the system that they are working on, the meter would be safe. This is an untrue statement. Meters are subject to being tested and are assigned a category (CAT) rating.

CAT rating ranges from 1-4. The higher the CAT rating, the safer the meter. Meters are designed to the IEC standard. The IEC is the international electrotechnical commission; this organization develops international safety standards for electrical equipment.

Engineers who analyze multimeters found that failed meters were usually exposed to much higher voltages than the technician thought they were measuring. Transient voltage spikes typically damage the meter and put the user at high risk.

An example of a transient voltage spike; An engineer was monitoring the supply circuit of an electric train that ran a 600-volt supply. During the analysis, the engineer found that when the train started and stopped, transient voltages over 10,000 volts were present.

Transient voltages like this can create an arc inside your meter and blow your meter up in your hand, possibly causing injury or death to the user.

***Transient voltage: A momentary high voltage spike.***

## Test Leads

* Meter leads must be CAT 3 (1000 volts) rated.
* To obtain CAT 3 rating, user must leave a twist guard on the tip.
* Leads are CAT 2 with twist guard removed.


*CAT 3 Meter Leads*

Meter leads also need to be rated at the CAT 3 1000-volt rating. In the Fluke CAT 3 test lead example, the leads come with a twist guard at the end that limits the test point exposure. If the twist guards are removed, the leads return to a CAT 2 rating, so beware of that fact.

## PRV240

Key points: Fluke PRV 240
* Validates meter functionality
* Outputs 240AC
* Outputs 240DC
* Battery operated
* Insert meter leads into recessed contacts
* Push lead tips down to make contact

Always ensure all meter fuses are operational and the meter works correctly before connecting the meter to a high voltage circuit.

## COURSE OBJECTIVES, INTRODUCTION AND HV BATTERY SAFETY


*Fluke PRV240 Proving Unit*


*Fluke CAT 3 Meter and PRV240 in use*

The fluke PRV 240 is a meter validation tool. A technician must ensure the CAT3 meter is functioning correctly before attempting measurements on a high-voltage system. An inaccurate meter could lead a technician to believe no voltage was present when in fact, there was. It is absolutely critical to make sure your meter is functioning properly.

The PRV 240 outputs 240 volts AC and 240 volts DC. Select desired AC or DC scale and insert meter leads to the two terminals at the bottom of the tool. Push down on contacts to activate tool output. The tool is battery operated and will provide approximately 5,000 tests on a set of batteries.

### Megaohm Meter

*Megaohm Meter Variations*

Megaohm testers are different from regular meters. The megaohm meter sends voltage out and measures any leakage to ground. The megaohm test is designed to measure the electrical resistance of insulators. Insulation breakdown can cause the voltage to leak from motor windings or cables to ground.

The megaohm meter will evaluate motor windings, high voltage cables, and the inverter. There are three different megaohm meters shown above; the voltage output is selectable on each meter.

## COURSE OBJECTIVES, INTRODUCTION AND HV BATTERY SAFETY

The megaohm tester uses a unique set of leads and its own jacks; there is a different set of jacks for regular voltage testing. The CE meter on the left has 125V, 250V, 500V, and 1000V outputs. The Fluke 1587 in the middle outputs 50-1000 volts. The Bosch on the right outputs 50-1000 volts. The most common test voltage used in the industry is 500 volts. These megaohm meters are multi-purpose. They also function as a voltmeter and offer other functions depending on the manufacturer.

**Assessment**

**Section 1 Questions and Answers**

Question: True or False? The high voltage battery is safe to work on after the service plug is removed.

Question: True or False? Class 0 rubber gloves can only be used once without leather outers.

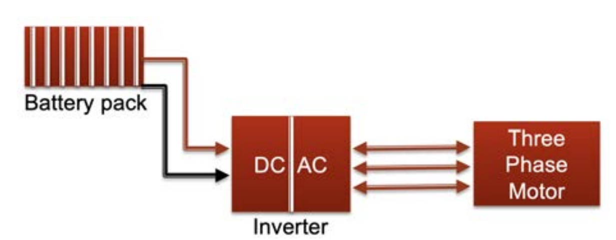
Question: True or False? CAT 3 meters also require CAT 3 leads.

Question: The high voltage battery is safe to work on after the service plug is removed.
**Answer: False. The battery still has energy stored, and if you grab across enough terminals, you could get a lethal shock.**

Question: Class 0 rubber gloves can only be used once without leather outers.
**Answer: True. If leather outer gloves are not used in conjunction with rubber gloves, the rubber gloves are one-time use.**

Question: CAT 3 meters also require CAT 3 leads.
**Answer: True. You need CAT three leads and CAT 3 meters to work on high voltage systems.**

# NIMH BATTERY DESIGN




*Battery Pack Providing Inverter With DC Voltage*

**High Voltage Battery**

The battery pack provides the inverter with DC voltage, so the inverter can provide simulated AC to the electric motor. The battery pack is DC and must be recharged with DC power. The battery pack can be located anywhere in the vehicle. The battery pack is connected to the inverter with one high voltage positive cable and one high voltage negative cable.

Battery packs come in many different sizes and many different voltages. A few voltage examples: The early Subaru hybrid was 100 volts while others have over 400 volts.

**Variants In Voltages/Size/Design**

High voltage batteries vary in total voltage, size, and design. Examples of some of the voltages you will find in NIMH batteries are.

***Early Honda 144***
***Early Toyota 273***
***Toyota second-gen 201.6***
***Toyota Highlander 288***
***Toyota Camry 245 volts***
***Ford Escape 338***
***GM 2 mode 300***
***Higher voltages mean higher horsepower, higher torque availability, and more speed.***

**Two Common Battery Designs**

Cylindrical
- Honda
- Ford

Prismatic
- Toyota
- GM 2-Mode
- Lexus RX-400h

NIMH batteries usually come in two cell shapes, cylindrical or prismatic. Toyota primarily used the prismatic design, and so did the GM 2-mode along with the Lexus RX-400h. Honda and Ford used cylindrical cells. Cylindrical cell design runs a hotter core temperature than the prismatic design therefore, it needs a better cooling system.

The Ford Escape used the AC system to cool the batteries, which worked very well. Honda did not use an AC system to cool batteries and had a lot higher failure rate with their battery packs. Honda underwent lawsuits due to the high failure rate of its packs. The cylindrical batteries are welded together

These are just a few examples of which type of battery some manufacturers use.

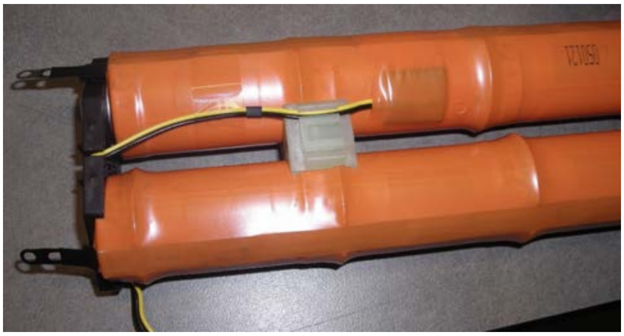
**Series Together Bus Bars**

*Toyota RAV 4 HV Battery Modules in Series*

In a Toyota Rav 4, for example. The modules are all series together to increase the voltage. Each module's positive terminal connects to the next module's negative terminal until the connections reach the end of the section. We have 10 modules series together in this example. Sections are then series together to form a 288-volt battery.

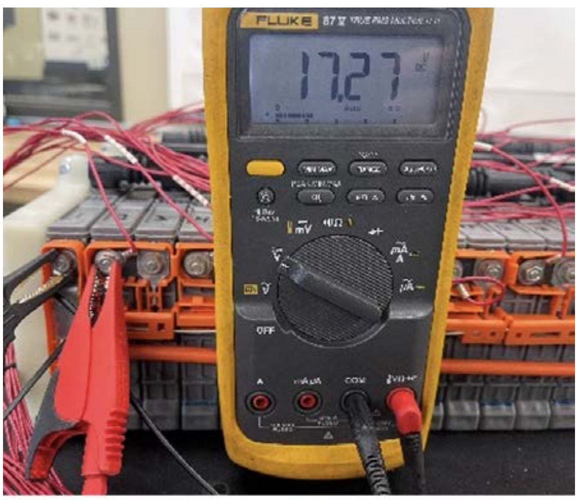
## NIMH BATTERY DESIGN

### Series Together Welded



*Batteries Welded Together in Series*

### Series Voltage Measurements



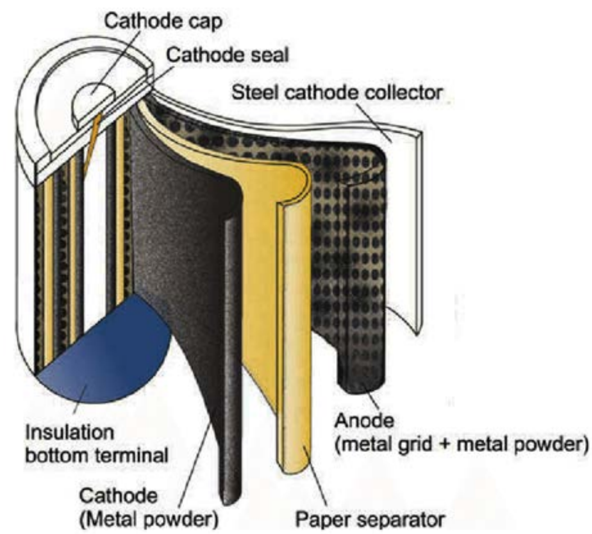


*Voltage Measurements (Series)*

Illustrated left are voltage measurements taken from a HV battery pack where the modules are connected in series together. The voltage increases as you move down the modules. The top picture has two modules' series together at 17.27 volts.

The bottom picture tests all the modules' series together, and the total voltage is 295.7 volts. This battery has 34 modules at 295.7 volts divided by 34 modules equals 8.69 volts per module. 8.69 volts per module divided by 6 cells equals 1.44 volts per cell. That means this battery has a charge in it.

### NIMH Batteries



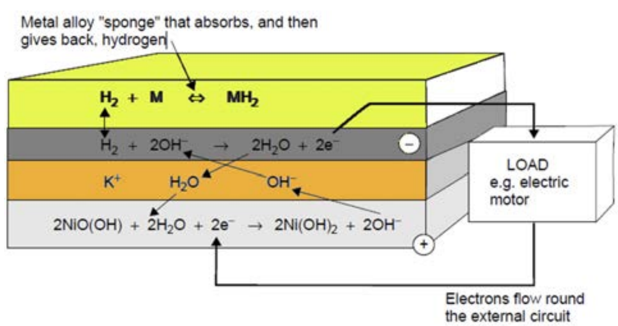

*NIMH Battery Construction (Typical)*

Nickel metal hydride batteries were prevalent in early hybrids and are still in use today; not many are found in EV models. Most EV models use a lithium base battery. The electrode plates are made from porous nickel and metal hydride alloys. The positive electrode has more nickel, and the negative is formed using hydrides.

Rare earth materials like lanthanum, cobalt, neodymium, and cerium are used along with other hydride compounds to make up the negative electrode. The electrolyte used is a potassium hydroxide or sodium hydroxide highly alkaline mixture. The electrolyte is very corrosive and can cause serious burns. A common failure in NIMH batteries is cell impedance increases due to electrolyte dry-out during natural degradation.

# NIMH BATTERY DESIGN

Lanthanum is used in large quantities in nickel metal hydride (NiMH) rechargeable batteries for hybrid automobiles. The negative electrode (anode) in NiMH batteries is a mixture of metal hydrides – typically a rare earth misch metal hydride having praseodymium, neodymium, lanthanum, and cerium.




*NIMN Battery Construction and Load Flow*

The electrolyte material is highly conductive. Hydrogen molecules are constantly moving through the electrolyte during charge and discharge cycles. The battery cases are under slight pressure, and most battery cases are rated up to 40+ psi.

Pressure starts to build during high rates of discharge and recharge due to increased temperature in a sealed battery case with a pressure-controlled vent. The electrolyte is more of a paste and is held in the separator plates with a very small amount of liquid electrolyte.

**! Caution !**

The electrolyte is very caustic and can cause serious burns.

**Human health effects**
Inhalation: The electrolyte inhalation affects the respiratory tract membrane and the lungs. Fumes may cause a cough, chest pain, shortness of breath, and dyspnea (labored breathing). Bronchitis and pneumonia may occur. Possibly could be a carcinogen.

Skin contact: The electrolyte skin contact affects the skin seriously and may cause dermatitis.

Eye contact: The electrolyte that leaks from the battery cell is a strong alkali substance. When it goes into an eye, the cornea may be affected, leading to blindness. Ingestion: Electrolyte ingestion irritates the mouth, and the throat seriously, resulting in vomiting, nausea, hematemesis (vomiting blood), stomach pains, and diarrhea.

**Environmental effects**
Since a battery cell doesn't biodegrade, do not throw it out into the environment. Dispose of properly.

**NIMH Characteristics**

* High energy density
* Low internal impedance
* Wide operating temperature range
* Charges rapidly
* Flat discharge characteristics
* Long cycle life
* Life depletion starts on day one and continues
* Releases energy quickly
* High self-discharge rate
* Slight memory effect
* Cells need to be balanced at certain intervals
* Higher capacity than a similar nickel cadmium
* Environmentally friendly
* Generates heat during fast charge & fast discharge

**Battery Ratings**

| | | |
|---|---|---|
| Vehicle weight | | 1360 kg |
| Engine | displacement | 1497 cc |
| | max power | 57 kW@5000rpm |
| Planetary gear | ratio(ring,planet,sun) | 2.6 (78/23/30) |
| Gear | ratio | 4.113 |
| Electrical Motor | max power | 50 kW |
| | maximum speed | 6000 rpm |
| | maximum voltage in use | 500 V |
| | maximum torque | 400 Nm (0 à 1200 rpm) |
| Electrical Generator | max power | 30 kW |
| | maximum speed | 10000 rpm |
| | maximum voltage in use | 500 V |
| | maximum torque | 160 Nm(0 à 1800 tr/min) |
| NiMh battery | NiMh module number | 28 |
| | nominal energy | 1.3 kWh |
| | nominal voltage | 201.6 V |
| maximum vehicle speed | electric mode | 60 km/h |
| | hybrid mode | 160 km/h |

*Battery Ratings Chart (Gen 2 Prius Courtesy Toyota)*

An ampere is a measurement of current flow in one second. An amp hour is different from an ampere. An amp hour estimates the amount of energy a battery can store or is a way to rate the battery capacity. In simple form, it is how many amps a battery can deliver in an hour.

# NIMH BATTERY DESIGN

Kilowatt-hour is very similar. A watt is obtained by multiplying the amp's time volts. A kilowatt equals a thousand watts. Kilowatt-hour is how many kilowatts the battery can deliver in an hour. High voltage batteries are often rated in kilowatt-hours. Battery chargers are also rated in kilowatt-hours.

Due to the charger and the battery both being rated in kilowatt-hours; you can estimate your charge times by the capacity of the battery and the rating of the charger. If you take the battery capacity divided by the rating of the charger this equals the estimates charging time.

The estimated charging time is not exact, especially on fast chargers; due to the last 20% of the charge being at a reduced rate, so this increases the time to fully charge.

***Conversion:***

***kWh = Amp Hours x Battery Voltage ÷ 1000***

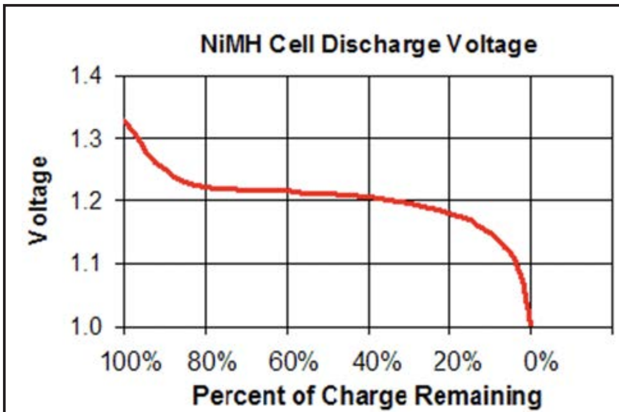
Batteries are rated in specific energy and specific power. Specific energy is expressed as energy per unit weight or volume of the battery. Specific energy is measured in watt hours per kilogram, it reflects how many watts you can discharge out of the battery over time based on the battery weight. Another way to look at it is, the amount of energy that can be stored based on the weight of the battery.

Specific power is expressed as power per unit weight or volume of the battery and measured in watts per kilogram. Specific power is how much power the battery can deliver. SOC (State of charge) is the charge level relative to the battery's capacity.

**Battery Voltage/ SOC**

The nominal cell voltage of NIMH is 1.20 volts per cell at approximately 40% SOC. The voltage increases to 1.35 volts at the upper end of the normal charge. The voltage should never be allowed to dip below 1.0 volts due to causing cell damage at this level.

The cells are series together to obtain total battery voltage. NIMH batteries have a semi-flat discharge rate. The cells voltage does not change much per cell, between 20% and 80%. The total battery voltage fluctuates up and down depending on the state of charge.




***Battery Voltage and State-Of -Charge***

It takes more cells to series together for NIMH than lithium to obtain the same voltage because lithium has 3.7 volts per cell compared to 1.2 volts for NIMH. NIMH is also heavier than lithium due to lithium being the lightest metal on the periodic table.

**One Module Voltage Measurement**


***Voltage Measurement on One Module***

Measure voltage on one module. Place leads across the module. This module measures 8.71 volts which indicates there is a charge in it. The nominal voltage would be 7.2 volts, and 9 volts would be max.

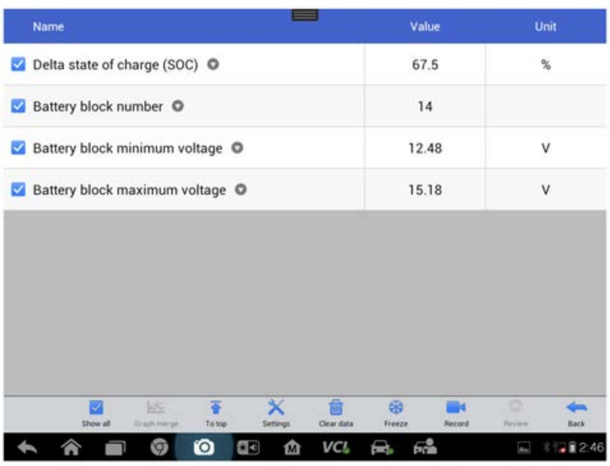
# NIMH BATTERY DESIGN

## State Of Charge

NIMH batteries are typically never charged to 100%. The target for Toyota is usually in the 40% to 80% range, and for Honda may be the 20%-80% range. Cell or block voltages should be even across the board.

The minimum cell or block voltage and max cell or block voltage should also be equal across the board. The resistance per cell or per block should be relatively the same as well. All temperature sensors should be close to the same temperature. All the above information can usually be obtained with a scanner.

## Battery Condition



| Name | Value | Unit |
|---|---|---|
| Delta state of charge (SOC) | 67.5 | % |
| Battery block number | 14 | |
| Battery block minimum voltage | 12.48 | V |
| Battery block maximum voltage | 15.18 | V |



***State-of-Charge Displayed on Scan Tool***

The state of charge found on the scan tool or on display does not indicate if the battery is good or bad, and the total battery voltage does not indicate if the battery is good or bad. It is best to look at block voltages, comparing the highest to the lowest block, and reference the internal resistance readings found on the scan tool.

The scan data shown came from a 2005 second Gen Prius. The state of charge looks normal, however, the block minimum and maximum voltage have a big gap. This battery pack is setting a code and is no good; let's look closer at the scan data.

## Gen 2 Prius (Hands-On)



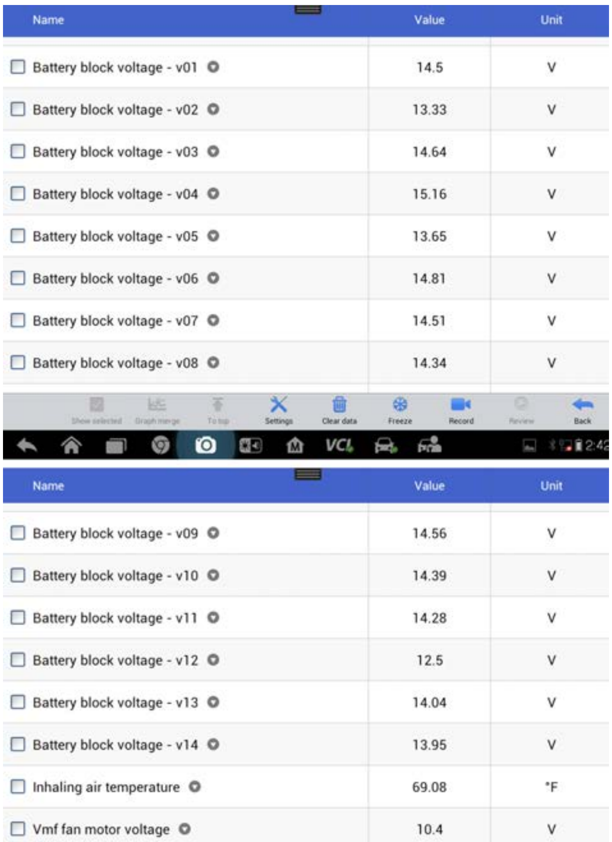
***Total Battery Voltage (Gen 2 Prius)***

The total battery voltage is not far from the published spec of this battery at 201.6 volts. The battery voltage can be measured with a meter, pre-contactor. In this case, our voltage reads 199.3 volts, which may fool a technician into thinking this battery is good when it is not.

## NOTES

# NIMH BATTERY DESIGN

### Scan Data Block Voltages

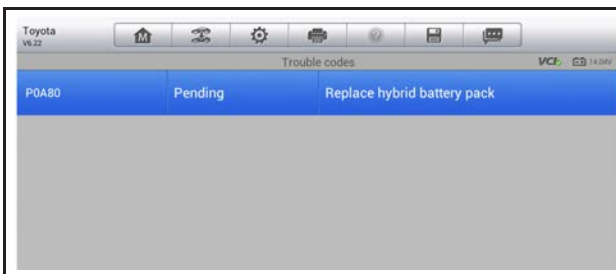


| Name | Value | Unit |
|---|---|---|
| Battery block voltage - v01 | 14.5 | V |
| Battery block voltage - v02 | 13.33 | V |
| Battery block voltage - v03 | 14.64 | V |
| Battery block voltage - v04 | 15.16 | V |
| Battery block voltage - v05 | 13.65 | V |
| Battery block voltage - v06 | 14.81 | V |
| Battery block voltage - v07 | 14.51 | V |
| Battery block voltage - v08 | 14.34 | V |
| Battery block voltage - v09 | 14.56 | V |
| Battery block voltage - v10 | 14.39 | V |
| Battery block voltage - v11 | 14.28 | V |
| Battery block voltage - v12 | 12.5 | V |
| Battery block voltage - v13 | 14.04 | V |
| Battery block voltage - v14 | 13.95 | V |
| Inhaling air temperature | 69.08 | °F |
| Vmf fan motor voltage | 10.4 | V |

*Block Voltages Displayed on Scan Tool*

The highest block voltage in the screen capture above is 15.16, and the lowest is 12.5 volts; that is a huge gap and is an indication that the battery is bad. The next slide shows the code the controller set.

### Bad Battery



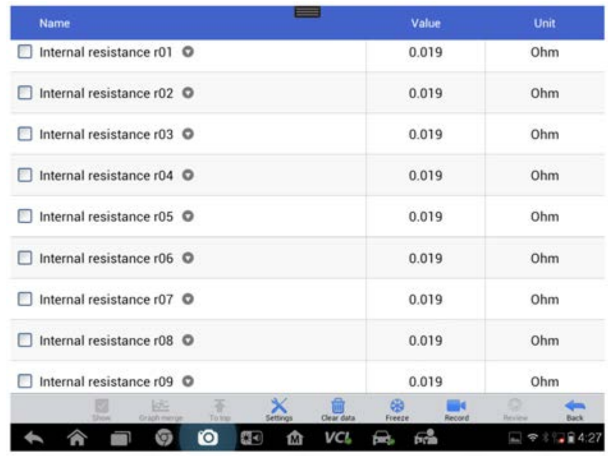
| | | |
|---|---|---|
| P0A80 | Pending | Replace hybrid battery pack |

*Scan Data of Bad Battery*

The computer flags a bad battery due to the variance in module voltages. The computer sets a DTC P0A80 indicating the battery pack needs to be replaced.

The vehicle would not "ready up"; however, with several codes erased, we could finally get it in ready mode, but it would not start the engine, and the controller would take it back out of ready mode.

### Internal Resistance - Scan Data



| Name | Value | Unit |
|---|---|---|
| Internal resistance r01 | 0.019 | Ohm |
| Internal resistance r02 | 0.019 | Ohm |
| Internal resistance r03 | 0.019 | Ohm |
| Internal resistance r04 | 0.019 | Ohm |
| Internal resistance r05 | 0.019 | Ohm |
| Internal resistance r06 | 0.019 | Ohm |
| Internal resistance r07 | 0.019 | Ohm |
| Internal resistance r08 | 0.019 | Ohm |
| Internal resistance r09 | 0.019 | Ohm |

*Internal Resistance Displayed on Scan Tool*

High voltage NIMH batteries have low resistance, so amps can flow in and out of the battery very fast. There are two things that contribute to the internal resistance, which are the physical connections and the cell material.

If connections become contaminated from corrosion, it can affect resistance or electrolyte migration or cause internal cell damage.

All module resistance readings per cell should be very close. Look at scan data and compare all cells together.

### Normal Scan Data

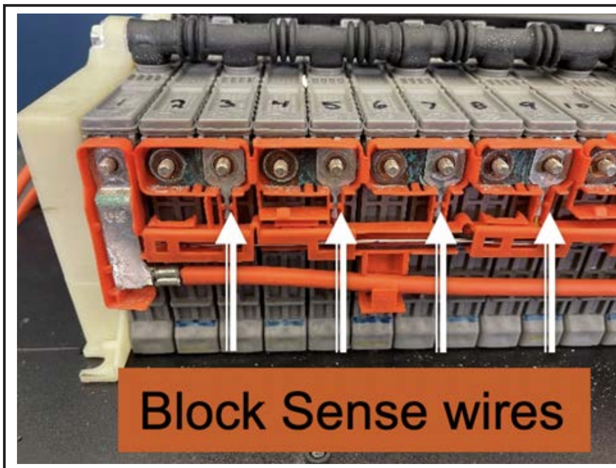
The battery state of charge is 49.5%, which is in our target range. Block voltages consist of two six-cell modules series together. Two modules series together measures 15.75 volts. That means each module measures approximately 7.875 volts, which means each cell measures 1.31 volts; this is in the normal cell voltage range.

There are 28 modules in the battery above, which means there are 14 voltage sense wires to report block voltages. Sensing a block (Two modules) is less expensive than running a sense wire to each individual module.

# NIMH BATTERY DESIGN

| Name | Value | Unit |
|---|---|---|
| Battery (+) | 13.96 | V |
| MIL on engine run time | 0 | Min |
| DTC clear min | 205 | min |
| Battery state of charge (SOC) | 49.5 | % |
| Battery pack current value | 1.46 | A |
| Battery block voltage - v01 | 15.74 | V |
| Battery block voltage - v02 | 15.75 | V |
| Battery block voltage - v03 | 15.74 | V |
| Battery block voltage - v04 | 15.75 | V |

*Scan Tool - Normal Readings*

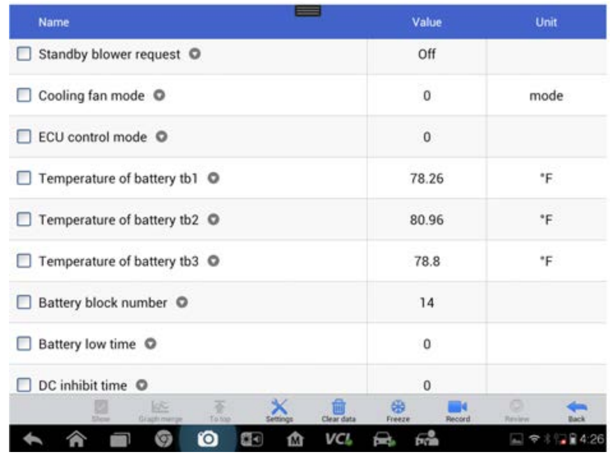



*Block Sense Wire Location*

Voltage per block fluctuates with SOC, according to what we learned earlier. All block voltages should be very close to each other. Block voltage drift indicates a problem.

**Scan Data - Battery Temperature Sensors**

Embedded temperature sensors measure different parts of the battery. All temperature sensors should remain relatively even unless there is a battery issue or cooling problem.



| Name | Value | Unit |
|---|---|---|
| Standby blower request | Off | |
| Cooling fan mode | 0 | mode |
| ECU control mode | 0 | |
| Temperature of battery tb1 | 78.26 | °F |
| Temperature of battery tb2 | 80.96 | °F |
| Temperature of battery tb3 | 78.8 | °F |
| Battery block number | 14 | |
| Battery low time | 0 | |
| DC inhibit time | 0 | |

*Scan Tool - Battery Temperature*

**Ford Escape NIMH Design**

*Ford Escape NIMH Battery Cutaway*

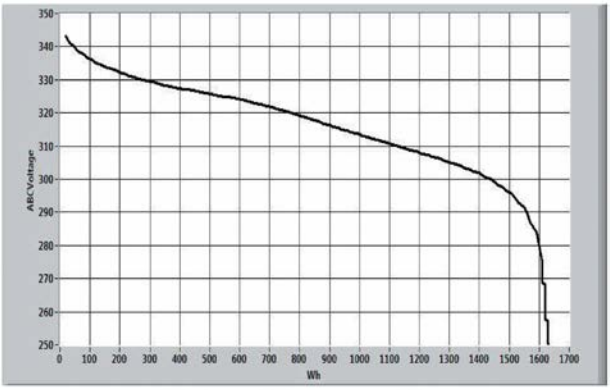
The early Ford Escape used a NIMH cylindrical design with 250 individual cells. Each cell is series together, and the connections are welded. The total battery voltage will fluctuate depending on the charge level and voltage of each cell. The voltage may fluctuate between 300-342 volts, but this battery is a 330-volt battery. The capacity of the battery is 5.5 Amp Hours.

**Total Battery Voltage**

The total battery voltage fluctuates depending on the charge. Example 2005 Ford Escape with 250 cells. If the battery is discharged and the cell voltage is 1.0 volt per cell, the total battery voltage would measure 250 volts.

If the battery was 40% charged with a cell voltage of approximately 1.2 volts, the total battery voltage would be 300 volts. If the battery was close to fully charged at 1.35-1.37 volts per cell, the total battery voltage would measure close to 342 volts.

# NIMH BATTERY DESIGN




*Battery Discharge Rate*

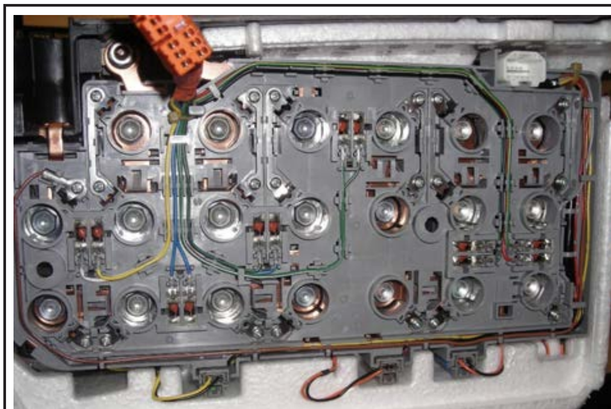
The graph above is battery voltage versus energy discharged. The graph illustrates the measured average energy capacity was 1620Wh. The discharge rate was 5.15 Ah. The cell voltage was 1.37 volts per cell at the beginning of the test, and the battery was discharged to one volt per cell.

## Honda Design

*Honda Cylindrical HV Battery Design*

Honda used a similar design to a Ford with a cylindrical cell that ranges from 1.2-1.35 volts. The cell connections are also welded together, which is typical in the industry. In this design, there are six individual cells series together to form a stick.

Each stick's nominal voltage would measure 7.2 volts. A 144-volt battery would have 20 sticks series together. Instructor Notes: 2005 Honda accord



*Honda Cylindrical HV Battery Design*

The sticks are series together through bus bars located in an end cap.

## Toyota Prismatic Design


*Toyota Prismatic Battery Cutaway*

Toyota used a prismatic design. The prismatic battery module may have a differing number of cells depending on the application. The battery shown has six cells per module, but Toyota also used an 8 cell per module design.

The cell nominal voltage is 1.2 volts apiece, with six cells per module. If you do the math, 1.2 volts x 6 =7.2 volts per module. 7.2 volts x 28 modules =201.6 volts. This battery is from a second gen Prius. The first gen Prius had 38 modules and measured approximately 273 volts.

## NIMH BATTERY DESIGN

### Prismatic Vent

*Prismatic Vent Location*

There are vents located on top of the battery. The battery is sealed, however, in an overpressure event, the vent will open. The battery case will build pressure with heat. The battery, during discharge and charging events, will build internal heat, which will raise the pressure.

The casing vent only opens if the pressure exceeds 43 psi. The pressure under normal charge and discharge cycles will never reach that level.

### Assessment

### Section 2 Questions and Answers

Question: True or False?Higher voltage equals higher torque

Question: True or False? Two basic NIMH battery designs are pouch and cylindrical

Question: What is the nominal cell voltage of a NIMH battery?

Question: True or False?Higher voltage equals higher torque
**Answer: True. The higher the voltage amplitude, the more torque the motor can produce.**

Question: True or False? Two basic NIMH battery designs are pouch and cylindrical
**Answer: False. The two most common designs are cylindrical and prismatic.**

Question: What is the nominal cell voltage of a NIMH battery?
**Answer: 1.2 volts**

### NOTES

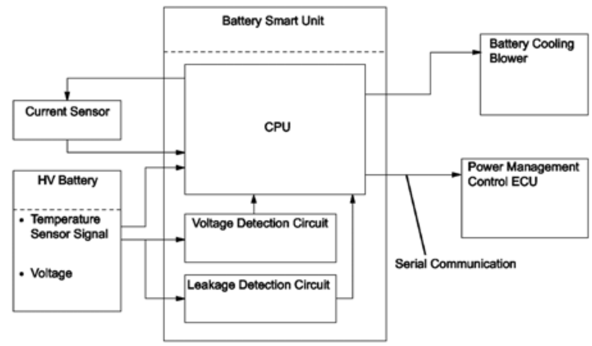
# BATTERY CONTROL SYSTEMS

## Battery Controller


*Battery Controller (Smart Unit) Gen 3 Prius*

The battery controller (Smart unit) has a few responsibilities and may share some of these with other controllers; the controller senses the voltage of the battery blocks or sections, senses the temperature of the battery, evaluates overcharge and undercharge, monitors current flow and direction, and control battery thermal management systems. The control module also monitors for high voltage leaking to the chassis ground.

The orange connector in the computer is the battery sense lines from the high voltage controller, hence the orange color on the connector. The smart unit Is located in the picture by the contactors.
The battery smart unit converts the HV battery condition signals (voltage, current, and temperature), which are needed to determine the charging or discharging values that are calculated by the power management control ECU, into digital signals, and transmits them to the power management control ECU via serial communication.




*Battery Controller (Smart Unit) Communication*

A leakage detection circuit is provided in the battery smart unit to detect any leakage from the HV battery. Furthermore, the battery smart unit detects the voltage of the cooling fan, which is needed by the power management control ECU to affect cooling fan control.

The battery smart unit also converts these signals into digital signals and transmits them to the power management control ECU via serial communication.

## Manual Disconnect

*Manual Disconnect*

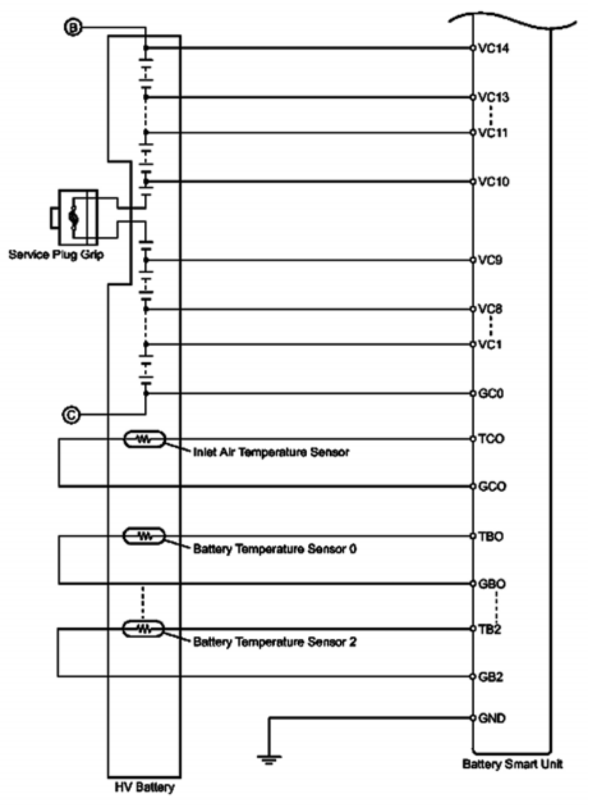
Most high voltage batteries employ a manual service disconnect which will disable the HV battery. The service plug breaks the series circuit in the battery. The service plug often is not located in the middle of the battery. When the service plug is removed, it disables the battery from delivering any current. It is important to remember the battery itself can still be dangerous if handled without proper gloves.

The battery cannot deliver any power out of the negative and positive posts, but the battery is still full of energy.

# BATTERY CONTROL SYSTEMS

Touching across two terminals is approximately 7.2 volts which is not dangerous but moving hands and contacting across 10 modules would be 72 volts which could be hazardous, so wear protective gloves when servicing the battery.

## Service Plug/Fuse/Temp Sensors

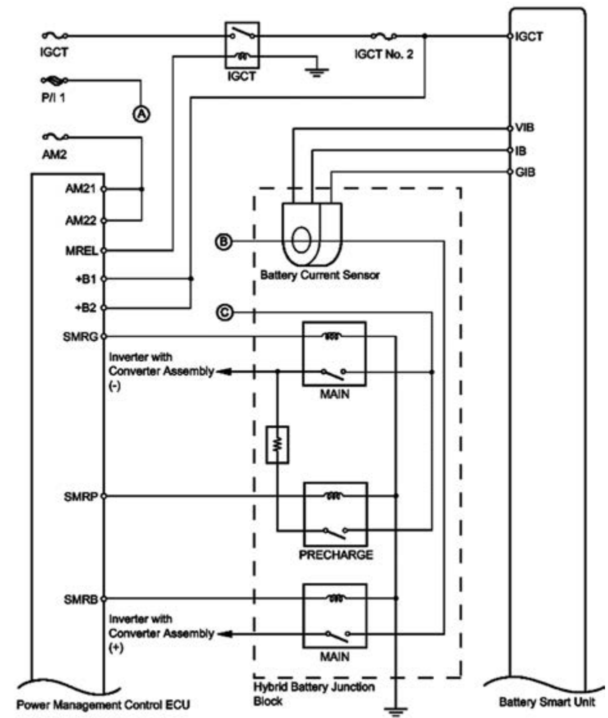



*Service Disconnect Wiring Diagram*

The diagram illustrates how the circuit is disconnected with the service plug removed. The picture shows a fuse inside the service plug. If the fuse blows, the battery will not deliver any power to the contactors.

The diagram also illustrates three embedded temperature sensors to keep track of battery temperature.

## Current Sensors/Contactors




*Current Sensors and Contactors Wiring Diagram*

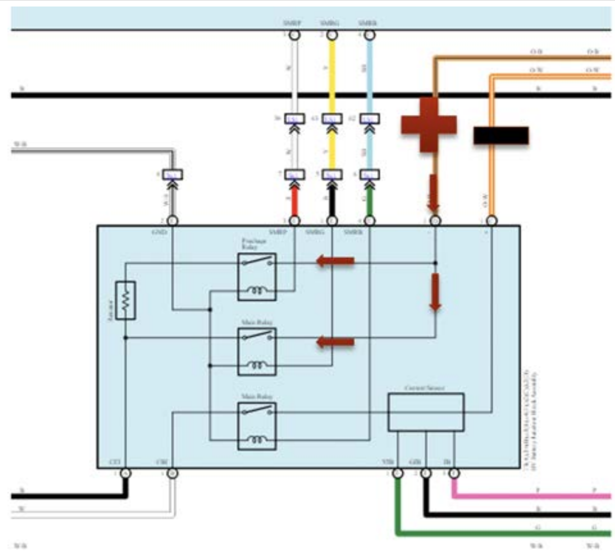
The high voltage batteries require contactors to establish a connection from the high voltage battery to the inverter.

The contactors also provide a disconnect to ensure we can isolate the high voltage to the battery area. In the gen 3 Prius example above, the system utilizes three contactors and a pre-charge resistor to accomplish this task. Operation of the contactors and labeling may vary between Prius generations and other manufacturers.

Toyota refers to the contactors as system main relays. Generation one and two referred to them as SMR1, SMR2, and SMR3. Generation three Prius referred to them as SMRP (System main relay pre-charge), SMRB (System main relay battery) SMRG (System main relay ground).

# BATTERY CONTROL SYSTEMS

## Turn On Sequence (Movie)



*Turn On Sequence Diagram*

In the third-gen Prius, the positive contactor closes first, then the pre-charge contactor, then the negative contactor, then the pre-charge relay opens. The capacitors are drained and empty upon startup. When the contactors close, the capacitors will require a large amount of current swiftly.

The contactor contacts would weld themselves together due to arcing if we did not slow the inrush of current down. The pre-charge resistor will slow the inrush of current preventing contact welding. The diagram shows the positive contactor, the pre-charge resistor located on the positive side, and the negative contactor located on the negative side.

The first-generation Prius was the opposite of the third generation. The first gen turned the negative contactor on along with the pre-charge relay, and then turned the positive contactor on. The pre-charge relay was then turned off.

## Battery Control Module Failures

Battery control modules may fail internally, more specifically, the battery block voltage monitoring circuits. This may cause the battery block voltages to be skewed, typically denoting a bad battery or poor connection.

The controller failure may cause a technician to replace the battery only to find out that did not cure his skewed block voltages. Always verify the block voltages with a meter. Then compare with scan data if the two readings disagree, check the wiring, then replace the controller.

## Assessment

## Questions and Answers

Question: What are three important PIDs that the battery smart unit monitors?

Question: Explain the reason the battery has a manual service disconnect

Question: True or False? The contactors are all switched on simultaneously

Question: What are three important PIDs that the battery smart unit monitors?
**Answer: Current-Temperature-Voltage**

Question: Explain the reason the battery has a manual service disconnect
**Answer: The service disconnect breaks the series circuit inside the battery to ensure no voltage is supplied to the inverter, so the system is safe to work on.**

Question: True or False? The contactors are all switched on simultaneously
**Answer: False. The contactors are turned on in a specific sequence to eliminate high amp arcing.**

# TESTING, BALANCING AND RECONDITIONING BATTERIES

## Battery Concerns

**Key Points**
*** Reduced fuel economy.**
*** Lack of acceleration.**
*** Shorter EV mode.**
*** ICE runs more often.**
*** Erratic battery display**
*** DTCs.**
*** Cell voltage drift.**
*** Internal resistance difference.**

| Block 1 | 16.11 V |
|---|---|
| Block 2 | 16.09 V |
| Block 3 | 16.06 V |
| Block 4 | 15.01V |
| Block 5 | 16.14 V |
| Block 6 | 16.04 V |
| Block 7 | 16.14 V |
| Block 8 | 15.86 V |
| Block 9 | 13.45 V |

***Battery Voltage Block Counts***

Battery concerns may be noticed by the driver or the control module. The driver may notice a reduction in fuel economy, a lack of acceleration, a shorter EV mode, the ICE runs more often, or the bars on the display start high and go low quickly.

A control module may log a code when the block cell voltages start to differ and exceed the code threshold. The voltages listed in the blocks above are starting to drift, with one module being over one volt lower than the average.

## Battery Failures

There are a few different ways the NIMH battery can fail, via an accident, as the top pictures depict. Long-term degradation is another failure type that takes place by electrolyte drying, which causes a cell impedance increase and electrolyte migration out of the battery around the terminals, as shown in the lower picture, or migrating through a porous battery case.

***Battery Failure Due to Damage***

Electrolyte migration causes poor connections and causes shorting pathways to ground. Another failure type is the cells become unbalanced over time.

It is possible that an open may occur but is not common. You can see electrolyte leakage in the bottom picture.

## Service Life

A NIMH battery starts its service life on day one of production, meaning it has an expiration date or a life span. The expectancy can be shortened by allowing the cells to become imbalanced. The cell capacity will diminish over time, the cell voltage will drift out of range, and eventually set DTCs.

Voltage depression or crystal formation occurs inside the cell. It is inevitable that voltage depression will occur, but it will happen faster when the cells become imbalanced.

Some aftermarket companies have developed battery charging systems that can restore cell balance and extend the battery’s life.

# TESTING, BALANCING AND RECONDITIONING BATTERIES

## Balancing In Car

***Balancing the Battery in the Vehicle***

Battery balancing in the vehicle requires a special harness built for that vehicle, so the fan can be operated during the balancing procedure. It is recommended that battery balancing is repeated every 6-8 months to extend the life of the battery and keep the battery operating efficiently. It is recommended to gather all codes before work begins and recheck for codes when the service is complete.

It is also a good idea to take a snapshot of battery module voltages and pay attention to the highest block voltage compared to the lowest block voltage during a test drive.

**Safety Precautions: Never charge when ambient temperatures are over 100 degrees Fahrenheit.**

**Avoid using the charger when the vehicle is parked in direct sunlight.**

**Leave vehicle windows open, if possible, to provide ventilation.**

## Balancing Steps

**Key Points:**
*** Install harness into the vehicle so the cooling fan will be active**
*** First step-filling the battery**
**Voltage will climb**
**May take 4-16 hours**
**Balancing procedure starts**
**Initial balancing 4-12 hours**

Install the harness into the vehicle, the harness is vehicle specific. The harness will activate the cooling fan, so the battery does not overheat. The harness has two white connectors; unhook the fan connector and plug it into the harness, as shown above; the harness then plugs into the fan allowing the fan to be activated.

***Battery Balancing Harness***

The red and black leads with ring terminals attach to the battery at the same spot the voltage leads are attached to, leaving the battery going to the contactors. The orange connector connects to the thunderbolt system so the balancing procedure can be performed.

The car should be turned off while charging. The first phase of charging is 'filling' the battery. When you begin the charging process, the hybrid battery will be between 40%-80% charged (Toyota) or 20%-80% charged (Honda), depending on how full the battery was when you parked the car. During the 'filling' phase, the voltage displayed on the charger will slowly climb steadily from the starting voltage to a 100% charge level, then level off.

The max voltage of your battery will vary depending on the vehicle model, and its overall condition and will likely change from charge session to charge session. It can take 4-16 hours for 'filling' to complete, depending on how drained the battery charge is when you park the car. (Note: no 'balancing' occurs during this 'filling' phase.)

# TESTING, BALANCING AND RECONDITIONING BATTERIES

Once the battery becomes ‘full’, the balancing process will begin. During the “balancing” phase, you will most likely see a steady voltage reading or a very slow oscillation of voltage – perhaps a 1–3-volt swing over several minutes. This means the battery is in the balancing phase. The initial balancing can take 4-12 hours after the filling phase is complete. Subsequent balancing sessions will likely be much shorter, perhaps 4-6 hours after the filling is complete. During balancing, each individual hybrid battery cell is rising to a true 100% state of charge.

As an individual cell reaches its peak voltage, it warms slightly, then the voltage drops as it converts the excess charge energy to heat, then the cell cools and again charges to 100%. The process is repeated over and over. (This is why proper battery cooling is so important).

As the higher voltage cells undergo this cycle, the lower voltage cells continue to fill and “catch up” to the cells that have already reached 100% charge level. This is how the hybrid battery pack becomes re-balanced. Once the voltage no longer fluctuates and/or the desired amount of time has elapsed, the charging and balancing process is complete.

A completely empty pack takes just under 24 hours to reach a full state of charge and balance, depending on cell efficiency. At no time should the combined “filling” and “balancing” times exceed 48 hours.

At this point, you are done charging and can disconnect the charger. If you are reconditioning the pack, this is when you will want to connect the discharger and start draining the pack. Refer to the Prolong Battery Discharger User Guide for the Light bulb discharger User Guide. If you do not discharge the pack, we recommend waiting 30 minutes after disconnecting the charger before driving the vehicle.

Optional Step: If your vehicle allows, you can reset the hybrid system to allow the vehicle to immediately see the new charge level of the battery pack. On the 2000-2006 Honda Insight, The IMA system can be reset by either: (1) removing the IMA fuse for 60 seconds or (2) disconnecting the 12v under-hood battery for 60 seconds.

For all other vehicles, the 12V under-hood battery must be disconnected for at least 60 seconds. Then reconnect the 12V battery/IMA fuse, start the car and allow it to idle. It is normal for the car to show zero or low bars for the hybrid battery and force charge the battery for two to ten minutes after resetting the hybrid system as it recalibrates and recognizes the new charge. The fan must run during the balance procedure, so the harness includes the fan connectors.

**Battery Reconditioning**

***Harness Connection at Fan***

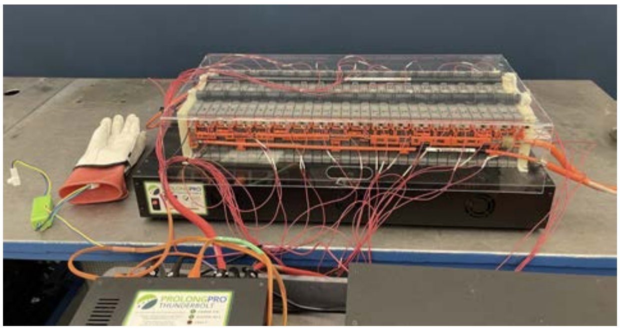
Batteries that need to be removed from the car and reconditioned (Rebuilt) should be allowed to sit for a few days. This will help identify high self-discharging modules. Upon disassembly, using a meter, measure each module’s voltage. Discard any module that is one volt lower than the pack mean; suspect any module that the voltage is .5 volts lower than the pack mean.

Self-discharge test is a hard one to test if you do not have the time: The self-discharge is 5–20% on the first day and stabilizes around 0.5–4% daily at room temperature.

The self-discharge rate varies greatly with temperature, where lower storage temperature leads to slower discharge. At 45 °C self-discharge is approximately three times as fast.

# TESTING, BALANCING AND RECONDITIONING BATTERIES

## Cooling Table



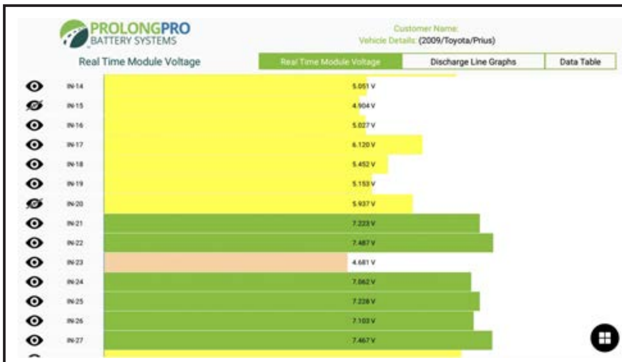
*Battery on Cooling Table*

The battery has been placed on top of the cooling table. The cooling table has fans inside and creates an airflow across the battery during the discharge-recharge-testing procedure. Attach the Prolong leads to the battery following the Prolong procedure. Ensure the battery hold-down bolts have not been loosened. The battery will swell and become damaged if the bolts are loosened.

## Scanning Modules

The software program requires identifying the modules. It is best to take a permanent marker and label each module 1-X starting at the negative terminal. After marking the modules, input each module's serial number into the program; the easy way is to scan the module's QR code, as seen in the illustration. If the module doesn't have a QR code, manually input the module's serial number.

## Battery Reconditioning




*Battery Reconditioning Graph*

The first step is to pre-charge the battery to full, and after that, perform a capacity test. View the module progress during the test. Take note of the lowest and highest module voltage. You can switch from the bar graph above to the line graph seen in the next picture.

## Test Results

*Battery Reconditioning Graph (Line Mode)*

Real Time Module Voltage

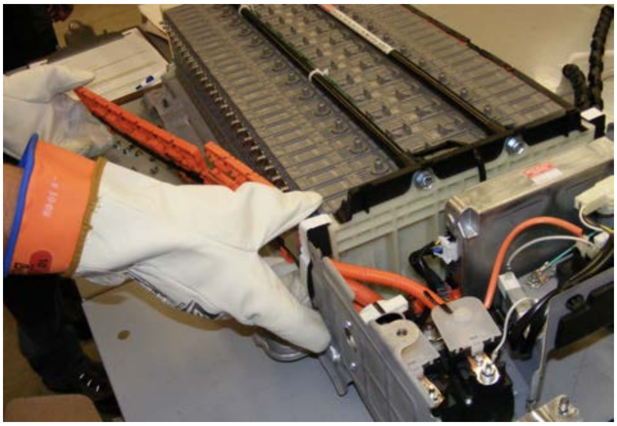
| Capacity Test | | |
|---|---|---|
| CAP | CAPOD | Vend |
| 4.430 | 0.000 | 6.974 |
| 0.011 | 4.419 | 4.082 |
| 4.430 | 0.000 | 6.774 |
| 2.168 | 2.262 | 5.499 |
| 4.430 | 0.000 | 7.077 |
| 4.430 | 0.000 | 6.904 |
| 0.935 | 3.495 | 5.332 |
| 0.124 | 4.306 | 0.048 |
| 2.303 | 2.127 | 5.769 |
| 0.024 | 4.406 | 5.561 |
| 4.430 | 0.000 | 6.614 |
| 4.430 | 0.000 | 6.232 |
| 4.054 | 0.376 | 3.808 |

*Battery Conditioning Test Results*

The test results will be given in three different ways. CAP-Module capacity extracted at 1.0 volt/cell. CAPOD-Module capacity extracted below 1.0 volt/cell average. Vend-Module voltage at the end of the test. Several modules in this test do not pass and will require replacement.

# TESTING, BALANCING AND RECONDITIONING BATTERIES

## Disassemble Battery



*Disassembly of Battery (Note HV Safety Gloves)*

To remove bad modules and install tested good modules, the battery must be disassembled. Remove the bus bars and number modules. The number one module starts at the negative terminal and counts ascending from there.

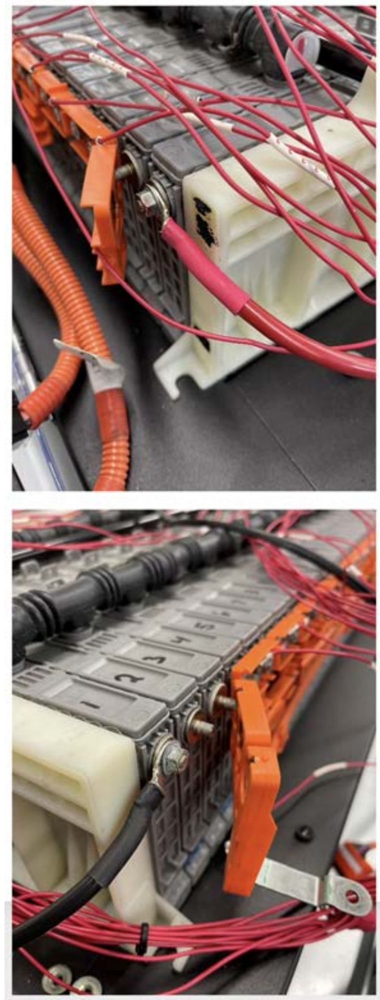
Be aware Gen two and Gen three Prius models are wired opposite of each other. Gen two uses a long negative lead to the contactor, and Gen three uses a short negative lead to the contactor due to the negative post locations being different.

Prius Gen1 – Block 1 is next to the BCM (drivers' side)
Prius Gen2 – Block 1 is away from BCM (passenger side)
Prius Gen3 – Block 1 is next to BCM (passenger side)

## Individual Module Testing

The module tester can test each individual module. The tester applies a high current load (60 amps), and measures voltage drop to obtain internal resistance measurement. This will simulate a current draw that the module experiences during normal operation.

Attach the red lead to the positive terminal and attach the black lead to the negative terminal. Select the battery type, NIMH, Lithium, or AGM. Then select the number of cells in the module. It is important to ensure you select the correct information due to potential module damage and safety concerns. The two tests that can be run are the capacity test and the internal resistance test.



*Module Test Connection Locations*

The test will be aborted if the voltage is too low. Do not charge the module without holding the fixture. The battery module expands during charging due to oxygen release and can damage the case if the sides of the battery are not held with support. Two pieces of wood and bolts can be fabricated to hold the module together.

Instructor Notes: These pictures show the connections to one module from the individual module tester. The modules should never be charged without being clamped so it is best to leave the pack together to perform these tests.

# TESTING, BALANCING AND RECONDITIONING BATTERIES

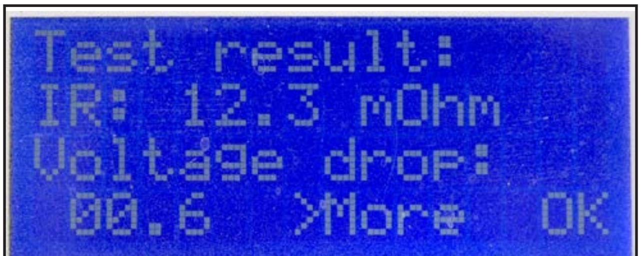
## IR Test Failed


*IR Test Failure*

Testing an individual module with the module tester. The module tester applies a load to the battery and watches the volt drop and does the math to calculate resistance. The voltage falls quickly during the test above, the test cannot run because the battery voltage drops too low.

The battery voltage started out at 8.3 volts and dropped to 5.9 volts. This is a bad module. It had been recharged before the test but failed. A bad module will usually charge up too fast. Just like a sulfated lead acid 12-volt battery, the voltage will come up to spec quickly during the charge, but the battery has no capacity to pass a load test.

## IR Test Passed




*IR Test Passed*

This is a good module. The voltage drop was only .6 volts during the load test, and the resistance reading is fine. Compare all modules to one another.

## Capacity Test Poor Result


*Capacity Test Failure*

The capacity test indicates the beginning voltage, ending voltage, and amp hours of the module. Compare the results of all modules. This module has a .35-amp hour, which is low.

## Select Replacement

To get the best results during battery reconditioning, select modules that closely match the behavior of the good ones in your pack. Try to match the module's internal resistance and capacity to the good modules in your pack.

There are several methods used to determine what location to insert the module. Insert in the same position. You could use the cell stacking method and pair the highest and lowest capacity modules together. Another method is to move the center modules to the outside and the outside module to the center.

## Cleaning the Buss Bars

Buss bars can be cleaned using a white vinegar salt mixture as described below;

¼ cup white vinegar
1 teaspoon table salt
5 minutes or longer as needed
Rinse very well, or they will oxidize!

## Clean Fan Assembly

Fans may be clogged with lint, pet hair and other debris that may cause overheating of the battery and other faults. Fans can become clogged and unbalanced due to lint and pet hair. Clean fan assemblies before reinstalling.

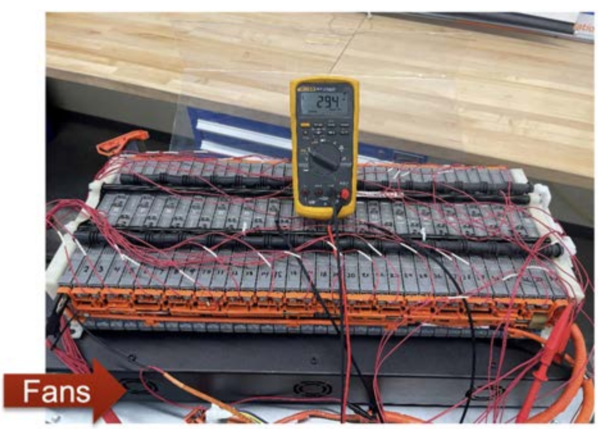
# TESTING, BALANCING AND RECONDITIONING BATTERIES

## Reassemble Battery Pack

Reassemble battery pack and reinstall cleaned bus bars and cleaned cooling fan. Torque battery clamps properly then charge and balance for at least one hour

## Balance Battery Pack

**Key Points**
*** Leave on cooling table.**
*** Discharge battery pack at the same rate as battery capacity.**
*** Battery pack spec 6.5Ah.**
*** Discharge at 6.5Ah.**
*** Battery should discharge to 1.0 volt per cell in one hour.**



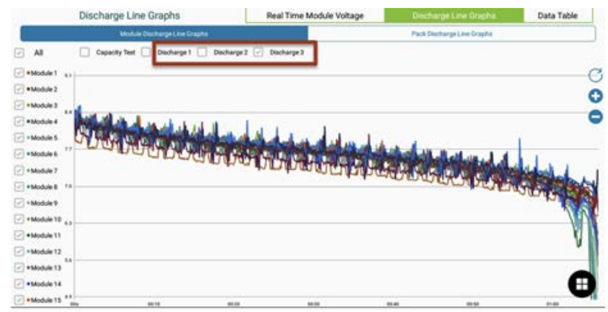

Cooling table
***Balancing The Battery Pack***

1) Reassemble battery & install harnesses onto battery pack & fan
2) Charge & balance for at least one hour. (A 3–4-hour cell balancing is recommended)
3) Discharge the battery at 0.8V/cell average (first discharge).
4) Charge & balance for at least one hour.
5) Discharge the battery to 0.6V/cell average (second discharge).
6) Charge & balance for at least one hour.
7) Discharge the battery to 0.5V/cell average (third discharge).
8) Charge & balance for 4-6 hours to ensure the pack is fully balanced.
9) Disconnect the harnesses and allow the battery to rest for at least 30 min (one hour is recommended) before attempting to start the vehicle.

**Numbers 2-8 are automated with the Prolong thunderbolt system.**

**If capacity is 6.5Ah, discharge at 6.5A should discharge to 1.0V/cell in one hour**
**That is 1C.**

## Good Discharge Result After Recondition




***Result After Reconditioning***

Perform three separate discharge & charge balance procedures.After three discharge-charge and balance procedures, finish off by charging and balancing for 4-6 hours to ensure the battery is full. Let the battery set for a minimum of 30 minutes and preferably one hour before starting the vehicle.

## Assessment

## Questions and Answers

Question: List three things the driver may notice from a degraded battery.

Question: List three failures of NIMH batteries

Question: True or False? No need to balance NIMH batteries due to the battery smart module performs cell balancing monthly

## TESTING, BALANCING AND RECONDITIONING BATTERIES

Question: List three things the driver may notice from a degraded battery.
**Answer: Low fuel mileage-poor acceleration-ICE runs more often.**

Question: List three failures of NIMH batteries
**Answer: Cell drift-crystals form (loses capacity)-electrolyte dry out- terminal leakage (Corrosion).**

Question: True or False? No need to balance NIMH batteries due to the battery smart module performs cell balancing monthly.
**Answer: False. NIMH smart modules do not provide a monthly balancing procedure.**

**NOTES**

# GLOSSARY OF TERMS

AC- (Alternating current) Current that regularly changes directions.

BEV- (Battery electric vehicle) Vehicle powered by high voltage battery and electric motor.

CAT-Category

DVOM-Digital volt ohm meter- multi-function meter that can measure voltage, ohms, amps, and much more.

HEV- (Hybrid electric vehicle) Utilizes a dual system to promote propulsion, typically an ICE and an electric motor.

Induction motor-An electric motor that uses a nonmagnetic rotor.

Isolation- High voltage system is isolated from the chassis ground.

Megaohm-One million Ohms

Milliohm-One thousandths of an ohm

MG- (Motor generator) Electric motor that performs work or generator that provides energy to recharge the battery

Ohms-Defined as an electrical resistance between two points of a conductor.

NIMH-Nickel Metal Hydride-it is a type of battery used in hybrid vehicles

PM motor- (Permanent magnet motor) The rotor contains magnets that alternate north and south poles.

Resistance- A measurement of the opposition to the flow of electric current.

Rotor- Internal component inside an electric motor that is typically splined to a shaft or gear.

**NOTES**

## CHAPTER TEST QUESTIONS

1. List one of the class 0 rubber gloves functions
A. Protect hands from oil and fluids.
B. Protect hands from sharp objects.
C. Protect the user from electrical shock.
D. Keep hands from sweating.

2. HV safety gloves have a shelf life in the parts store. Which of the following is the shelf life?
A. 1 month.
B. 3 months.
C. 6 months.
D. 1 year.

3. Insulated tools are used for which of the following purposes?
A. Removing transaxle bolts.
B. Used in small tight spaces.
C. Used when high voltage is present or possible.
D. When breaking high torque bolts loose.

4. Honda battery cells are what type?
A. Stick.
B. Prismatic.
C. Pouch.
D. liquid filled.

5. Toyota batteries are what cell type?
A. Stick.
B. Prismatic.
C. Pouch.
D. liquid filled.

6. Technician A says a CAT rating determines how fast the meter samples a circuit. Technician B says a CAT rating determines the safety level of the meter. Which technician is correct?
A. Technician A.
B. Technician B.
C. Both Technicians A & B are correct.
D. Neither technician A nor Technician B is correct.

7. Technician A says hybrid battery cells are connected in parallel to increase the capacitance.
Technician B says hybrid batteries are connected in series to increase the voltage.
A. Technician A.
B. Technician B.
C. Both Technicians A & B are correct.
D. Neither technician A nor Technician B is correct.

8. Technician A says a single NIMH battery cell measures 1.2 volts nominal voltage.
Technician B says that if the NIMH cell measures 1.35 volts, it indicates the cell has a charge.
A. Technician A.
B. Technician B.
C. Both Technicians A & B are correct.
D. Neither technician A nor Technician B is correct.

9. Technician A says NIMH cells develop crystals within the cell and lose capacity.
Technician B says NIMH cells have no limit to charge and discharge cycles.
A. Technician A.
B. Technician B.
C. Both Technicians A & B are correct.
D. Neither technician A nor Technician B is correct.

10. Technician A says NIMH batteries never need balanced. Technician B says if you balance the cells every 6 months, it will prolong the battery life
A. Technician A.
B. Technician B.
C. Both Technicians A & B are correct.
D. Neither technician A nor Technician B is correct.

11. True or False? NIMH batteries can be rebuilt by replacing bad modules with good ones.
True
False

12. True or False? The best place to measure the total battery voltage with a meter is at the service plug.
True
False

13. True or False? The battery controller only samples voltage on a couple of cells.
True
False

14. True or False? Toyota NIMH battery modules can be individually load tested and checked for capacity and internal resistance.
True
False

15. True or False? The cooling fans for the high voltage battery should be removed and cleaned occasionally.
True
False

## CHAPTER TEST QUESTIONS, ANSWERS AND RATIONALE

1. List one of the class 0 rubber gloves functions
A. Protect hands from oil and fluids.
B. Protect hands from sharp objects.
C. Protect the user from electrical shock.
D. Keep hands from sweating.

**Answer: C The gloves are designed to protect technicians from high voltage.**

2. HV safety gloves have a shelf life in the parts store. Which of the following is the shelf life?
A. 1 month.
B. 3 months.
C. 6 months.
D. 1 year.

**Answer: D Gloves have a one-year shelf life before being rotated. After opening, the gloves must be tested by an approved facility every 6 months. The gloves must also be air tested and visually inspected before each use.**

3. Insulated tools are used for which of the following purposes?
A. Removing transaxle bolts.
B. Used in small tight spaces.
C. Used when high voltage is present or possible.
D. When breaking high torque bolts loose.

**Answer: C Insulated tools protect the technician from shock when working on live high voltage circuits or around the battery.**

4. Honda battery cells are what type?
A. Stick.
B. Prismatic.
C. Pouch.
D. liquid filled.

**Answer: A. Honda battery cells are of the "Stick" type battery cells.**

5. Toyota batteries are what cell type?
A. Stick.
B. Prismatic.
C. Pouch.
D. liquid filled.

**Answer: B**

6. Technician A says a CAT rating determines how fast the meter samples a circuit. Technician B says a CAT rating determines the safety level of the meter. Which technician is correct?
A. Technician A.
B. Technician B.
C. Both Technicians A & B are correct.
D. Neither technician A nor Technician B is correct.

**Answer: B. The CAT rating determines the level of transient voltage spikes the meter can handle therefore, the CAT rating is related to safety.**

7. Technician A says hybrid battery cells are connected in parallel to increase the capacitance.
Technician B says hybrid batteries are connected in series to increase the voltage.
A. Technician A.
B. Technician B.
C. Both Technicians A & B are correct.
D. Neither technician A nor Technician B is correct.

**Answer: B. The cells are very low voltage and must be series together to obtain high voltage.**

8. Technician A says a single NIMH battery cell measures 1.2 volts nominal voltage.
Technician B says that if the NIMH cell measures 1.35 volts, it indicates the cell has a charge.
A. Technician A.
B. Technician B.
C. Both Technicians A & B are correct.
D. Neither technician A nor Technician B is correct.

**Answer: C. The cells measure 1.2 volts nominal, and anything above that indicates we have added a charge to the battery.**

9. Technician A says NIMH cells develop crystals within the cell and lose capacity.
Technician B says NIMH cells have no limit to charge and discharge cycles.
A. Technician A.
B. Technician B.
C. Both Technicians A & B are correct.
D. Neither technician A nor Technician B is correct.

**Answer: A. As the NIMH cells age, they develop a crystal-like structure in the cell, diminishing battery capacity.**

## CHAPTER TEST QUESTIONS, ANSWERS AND RATIONALE

10. Technician A says NIMH batteries never need balanced. Technician B says if you balance the cells every 6 months, it will prolong the battery life
A. Technician A.
B. Technician B.
C. Both Technicians A & B are correct.
D. Neither technician A nor Technician B is correct.

**Answer: B. It will prolong battery life if the batteries are balanced every 6 months.**

11. True or False? NIMH batteries can be rebuilt by replacing bad modules with good ones.
True
False

**Answer: True**

12. True or False? The best place to measure the total battery voltage with a meter is at the service plug.
True
False

**Answer: False. The contactors are the best place to measure the total battery voltage.**

13. True or False? The battery controller only samples voltage on a couple of cells.
True
False

**Answer: False. The battery controller samples at least half of the modules.**

14. True or False? Toyota NIMH battery modules can be individually load tested and checked for capacity and internal resistance.
True
False

**Answer: True. The individual modules can be tested for capacity and resistance with a special tester.**

15. True or False? The cooling fans for the high voltage battery should be removed and cleaned occasionally.
True
False

**Answer: True. The fans get full of lint, and it is a good idea to clean them occasionally.**

## NOTES

## COURSE OBJECTIVES AND INTRODUCTION

By the end of this chapter, you should be able to understand and complete the following.

- Determine power flow in various transaxle designs
- Perform total gear ratio calculations
- Examine horsepower & torque charts
- Observe the results of back EMF
- Identify proper motor testing techniques
- Perform the park lock release procedure

This class is not meant to be a how-to rebuild your HEV-BEV transaxle. We will not cover special tools needed, bearing preloads, proper assembly procedures, clutch clearances, or things of that nature.

The class is about how many different transaxle/drive axle designs are on the market. It is also meant to reveal that the inside of these transaxles is not scary, and most are very simple.

We will cover power flow, gear reduction, and how torque is multiplied. In the first portion of this class, we will cover the torque and horsepower of electric motors and how it varies from gasoline engine designs. We will also cover why electric motors lose their torque with RPM.

We will start with simple BEV gear trains and migrate to more sophisticated systems as we go. We hope that you will appreciate the knowledge we have presented throughout the class by taking some time to explain the concepts.

## SECTION 1 - GEAR BOX DESIGN /TORQUE/HORSEPOWER RELATIONSHIP

### BEV Design Is Simpler

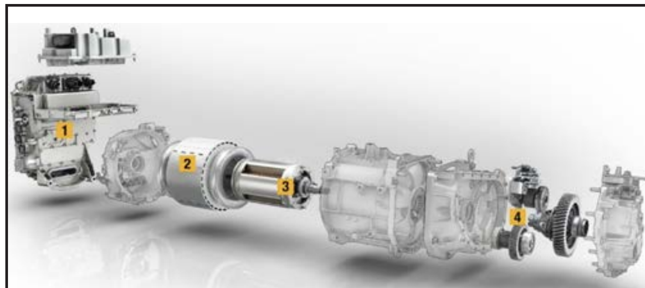
Battery electric vehicles are far more straightforward and have fewer parts than vehicles driven by internal combustion engines. Many systems technicians are constantly working on are gone or missing from the BEV models.

Here are a few missing systems: EGR, EVAP, Catalytic converter, fuel supply, fuel injection, ignition system, and the internal combustion engine. The part that is retained in BEV and HEV is the transaxle. The transaxle design has changed, which will be this class's focus.

### One-speed Gearbox

An internal combustion engine (ICE) operates at its highest efficiency when it is kept in a specific torque band. The ICE-powered vehicles use transmissions to provide mechanical advantage through gear ratios to keep the engine in the desired torque band and to provide low, medium, and high vehicle speeds. Newer conventional transmissions have migrated up to six, eight, and even 10-speed transmissions.

Electric vehicles offer torque in a completely different manner than their ICE counterpart vehicles. Therefore, an electric vehicle can operate efficiently with a one-speed transmission. You would think the vehicle speed would be severely limited with only a one-speed transmission, but that is untrue. The Nissan Leaf and Chevy Bolt can reach speeds between 90 and 100 mph, and Tesla models can reach speeds of 150-200 mph. We will explore how an electric motor develops torque and how the gearboxes interface with the electric motor.



*Renault Battery Electric ZOE System*

The system in the picture is from Renault's battery electric model ZOE. The electric motor is a synchronous design with 65kW output and 220-newton meters of torque. The gearbox is very simple and offers only a single speed. The components of the system are as follows.

1. Power electronic controller
2. Stator
3. Rotor
4. Single-speeded gearbox and differential

## SECTION 1 - GEAR BOX DESIGN /TORQUE/HORSEPOWER RELATIONSHIP

### Torque/Power/HP/Watts

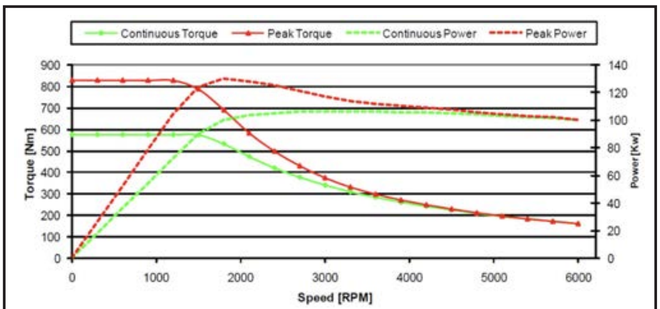
Motor ratings and power graphs may be expressed in many ways; peak torque, continuous torque, peak power, horsepower, and watts are just some ways you will see motor outputs listed. Let us explore the meaning of these outputs.

Power output from the electric motor may be measured in horsepower or kilowatts. One kilowatt is approximately 1.34 horsepower. Internal combustion engines build horsepower with RPM. For example, a gasoline engine needs time to build RPM. Somewhere in the RPM range, typically around 4,000; we will reach max torque.

An electric motor functions slightly differently; max torque and horsepower are available right away at the lower RPM range.

### Torque

Continuous power will be available for as long as we have energy from the battery. Peak torque conditions will drive temperatures up in the motor and inverter, so peak torque time will be shortened to preserve electrical components. Each electric motor's torque curve will vary depending on motor construction and voltage supply.

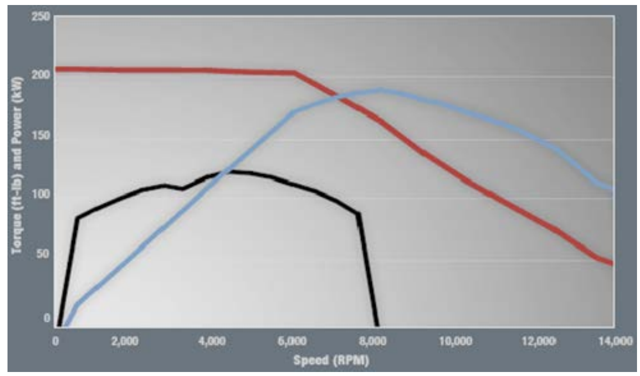



***Electric Motor Torque and Power Characteristics***

A gasoline engine cannot develop peak torque at this low RPM range. Although it varies between engines, gasoline engines usually do not reach peak torque until around 4,000 RPMs, and immediately the torque starts to decline when further increasing RPMs.

### Electric Motor Torque Band

Early gasoline engines developed torque in a narrow band; variable valve timing and other enhancements broadened the torque band quite a bit. However, gasoline engines' torque efficiency was 25-45%. Electric motor torque output does vary with motor design, but electric motors are much more efficient than gasoline engines.




***Motor Torque & Power Curve***

The black line represents the torque capabilities of a gasoline engine, which has little torque at low RPM and can only deliver good horsepower within a narrow RPM range.

In contrast, the red line demonstrates how the Tesla Roadster's electric motor produces high torque at zero RPM, delivers constant acceleration up to 6,000 rpm, and continues to provide high power up to 13,500 RPM.

The blue line shows the shaft power from the Tesla Roadster's electric motor as it builds steadily with increasing speed to a peak of 189 kW at around 8,000 RPM.

The electric traction motor that drives the vehicle is typically around 95-97% efficient at lower RPMs and maintains excellent efficiency up to 5,000-6,000 RPMs. Efficiency does, however, decline with RPMs. The efficiency starts at 95-97% and typically starts to decline around 5,000-6,000RPM with some models starting the decline closer to 3,000 RPMs.

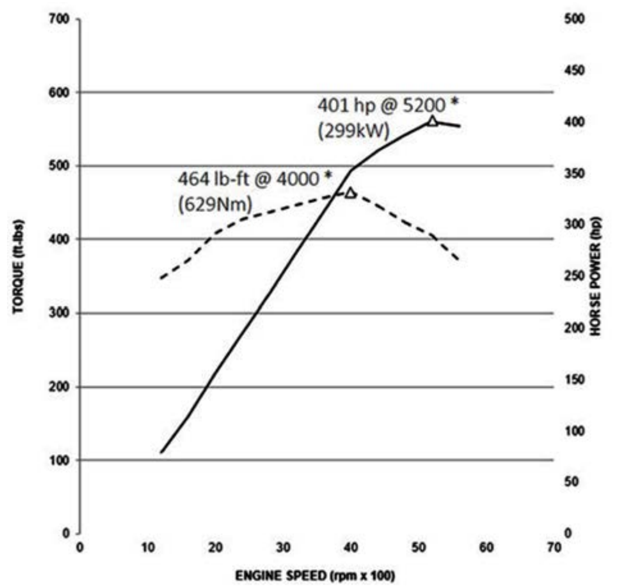
# SECTION 1 - GEAR BOX DESIGN /TORQUE/HORSEPOWER RELATIONSHIP

## Torque/HP

Gasoline engine HP
* Torque x RPM ÷ 5252

Electric motor HP
* Volts X amps X rated efficiency÷746 watts

1 horsepower equals 746 watts (or .746 kilowatts)




***Torque/HP Curve***

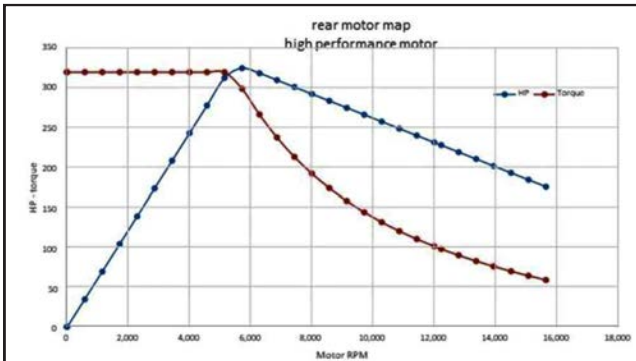
A horsepower is a standard unit used to measure power. Horsepower is the power that a horse exerts in pulling or is described as the rate at which work is performed. One horsepower is the power unit equal to 550 foot-pounds of work per second. One horsepower equals 746 watts. To calculate horsepower in a gasoline engine, multiply torque times RPM divided by 5252. Horsepower climbs with RPM, but torque peaks with volumetric efficiency and then declines. A gasoline engine's horsepower and torque curve differ from an electric motor.

To calculate torque in an electric motor, use the formula volts times amps times rated efficiency divided by 746 watts. Tesla claims its motors are around 90-94% efficient. Most electric motors are between 90-97% at lower RPMs, but the efficiency starts to decline with RPM. Torque is explained as a turning force, and it is calculated by Force multiplied by a distance.

Another example of horsepower would be a hydraulic motor. Hydraulic motor horsepower is calculated by hydraulic pressure in PSI multiplied by gallons per minute.0005834. PSI X GMP X .0005834 = Horsepower.

It is essential to know that horsepower formulas change depending on your working system.

## Back EMF




***Electric Motor Torque/HP Back EMF Map***

The horsepower and torque graphs of electric motors look different from those of a gasoline engine. Electric motors produce maximum torque as soon as it starts to rotate. As the motor rotates, it develops a counter-electromotive force (EMF) in the stator, which opposes the supply voltage.

Anytime you spin a magnet (rotor) inside a coil of wire, you induce a voltage. The voltage induced is counterproductive because it opposes the supply voltage in the stator. The faster you spin the magnet (rotor), the more back EMF is produced.

The opposing back EMF is proportional to motor RPM. It takes more supply voltage to overcome the back EMF, but as RPM increases, we exceed the supply voltage available.

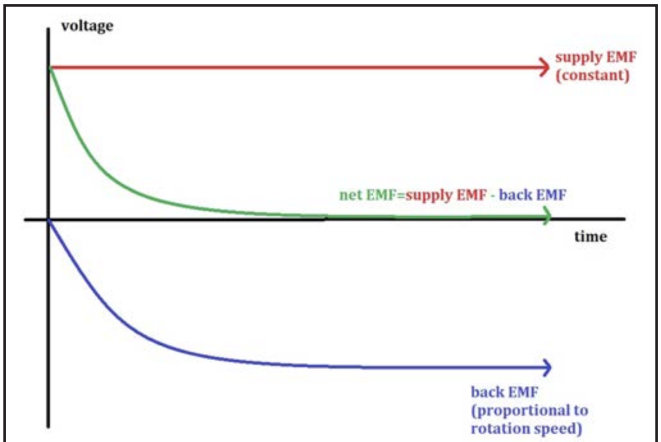
This is why the torque starts to decrease in the chart before 6,000 RPMs and continues to decrease with RPM; the point the torque starts to decrease is also called the “base speed.” When the voltage in future models is increased to 800 volts, the motor’s torque curve will extend to a higher RPM range.

# SECTION 1 - GEAR BOX DESIGN /TORQUE/HORSEPOWER RELATIONSHIP

Back EMF is also a product of how the motor is wound. Motors used in vehicles need a lot of torque down low, so they are wound to produce max torque at low RPMs, which increases back EMF. Motorsport electric motors need to develop power at high RPMs so that the stator would work for less back EMF. Motorsport motors will not have as much torque on the lower end but produce better torque and power at higher RPMs.

Since horsepower is torque times rpm, as the torque drops off and the RPMs go up, horsepower remains flat even after torque begins to drop; horsepower drops off slowly at even higher speeds.

## Net Voltage

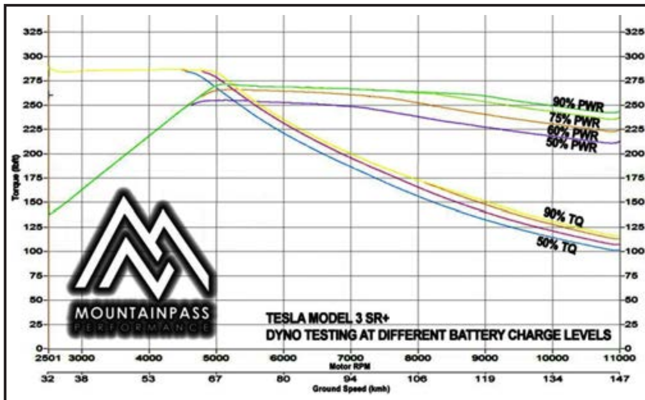



*Supply EMF, Back EMF, Net Voltage*

Motor torque is directly related to the supply voltage. When you increase the supply voltage, it increases motor torque. Motor speed is controlled by the frequency of the AC voltage supply. The inverter controls the AC voltage delivered to the motor and the frequency.

The supply voltage offers maximum torque before the motor starts to spin. This provides good launch performance. You create a net voltage when the motor starts to spin and creates back EMF. Net voltage is obtained by subtracting the back EMF from the supply voltage. For example, if the supply voltage were 200 volts and the back EMF was 50 volts, the net voltage would be 150 volts. The net voltage is really what is driving the motor torque. The faster the motor spins, the more back EMF is created, and the net voltage continues to decrease. This is what causes the torque decline at higher RPMs..

## Charge Level Affect

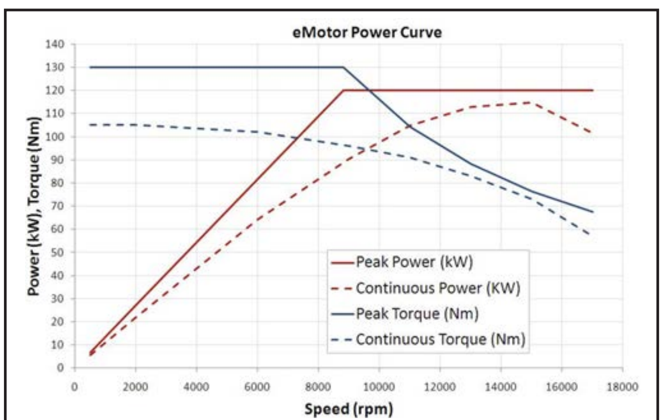



*Tesla Model 3SR+ Dyno Test Graphed Results*

Battery charge levels affect torque and horsepower numbers. In our example, the battery charge lowers peak torque to around 4700 RPMs. Torque with battery charge at 90% stays at peak until approximately 5,000RPMs.

Torque at 50% battery charge only stays at peak torque until approximately 4700RPMs. Torque declines at a uniform rate during the torque decline area as RPMs rise. A higher battery charge level does provide slightly more torque through the torque decline area due to the net voltage being higher.

## Tesla Example




*Tesla Model 3SR+ Power and Torque Curves*

When Dyno testing the Tesla Model 3SR+, you can see the constant torque area and power increases until the torque drops. That is why electric cars have gearboxes. Power is just a product of torque x RPM. You need torque to accelerate.

# SECTION 1 - GEAR BOX DESIGN /TORQUE/HORSEPOWER RELATIONSHIP

**Assessment**

**Questions**

Question: Do gasoline engines & electric motors share the same torque curve?

Question: How does back EMF affect electric motor torque?

Question: Can horsepower be measured in watts or kilowatts?

**NOTES**

**Questions and Answers**

Question: Do gasoline engines & electric motors share the same torque curve?
**Answer: No, the torque curve is different.**

Question: How does back EMF affect electric motor torque?
**Answer: Back EMF increases with motor RPM. Back EMF opposes supply voltage, causing a loss of net voltage and negatively affecting motor torque.**

Question: Can horsepower be measured in watts or kilowatts?
**Answer: Yes, horsepower can be expressed in watts or kilowatts.**

**NOTES**

# SECTION 2 - GEAR RATIO/TOTAL GEAR RATIO

## Gearbox Design

*Turbo 400 GM Gearbox Cutaway*

Conventional gas and diesel vehicles utilize gearboxes to obtain under drive, direct drive, and overdrive gear ratios. Gear ratios perform several purposes, underdrive gears produce a gear reduction or speed reduction, and underdrive gear ratios also increase torque.

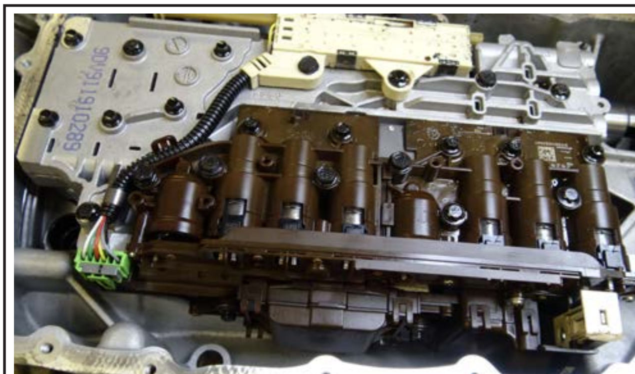
Direct drive gearing provides a one-to-one ratio, and overdrive produces a speed increase but a torque decrease. Gear reduction and torque are the inverses of one another. When we obtain a gear reduction or speed reduction, we get the opposite amount of torque increase. Gear ratios allow a gasoline or diesel engine to stay in the correct torque range of the engine. Newer manual transmissions typically have six or seven speeds. Automatic transmissions have migrated up to 10 speeds.

Conventional automatic transmissions used wet clutches and planetaries to provide the desired gear ratios. Some models use a Constant Variable Transmissions (CVTs) with steel belts and pulleys to offer an almost infinite amount of gear ratios; the gear ratios in these units are constantly changing. Hence the name CVT. BEV and HEV models vary in design but typically do not operate like any previously mentioned units.

**EV-Electric vehicle**
**BEV-Battery electric vehicle**
**HEV-Hybrid electric vehicle**
**PHEV-Plug in hybrid electric vehicle**
**EREV-Extended range electric vehicle**

One benefit of a 10-speed automatic in a pickup truck is keeping the engine in its ideal "power band" for efficiency. According to Car and Driver, the ZF eight-speed makes a truck engine's RPMs drop 25 percent during an average shift. Ford's 10-speed only makes the F-150's RPMs drop 20 percent during an average shift.

## HEV/BEV Gearboxes



*GM 6L90 Transmission (internals)*

BEV-HEV gearboxes are typically less sophisticated than the transmissions of the past. Current conventional vehicles have migrated up to 8-9-10 speed transmissions which are very complicated in design with many parts. The picture is a 6L90 Gm transmission with the TECHM (control module) integral to the transmission.

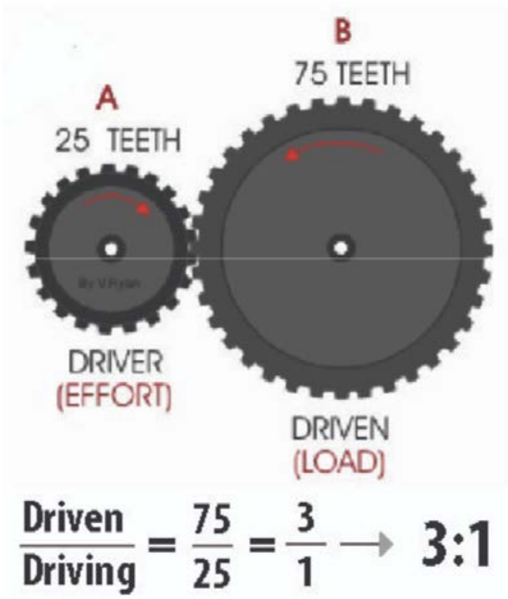
On the BEV side, most manufacturers use a single-speed gearbox; a few use a dual-speed. On the HEV side, they may use a power split device with no wet clutches or electronics, so fewer moving parts and no solenoids or computers to fail.

Some models, like the Chevy Volt, combine traditional parts like wet clutches and planetaries to interact with two electric motors. There are more gearbox designs for HEV and BEV than listed, but these are the most popular.

# SECTION 2 - GEAR RATIO/TOTAL GEAR RATIO

## Gear Ratio Formula

*** Driven gear ÷ Drive gear.**
*** The drive gear is where power is coming from.**
*** Driven gear is receiving power.**
*** Gear ratio example.**
*** Speed reduction.**
*** Torque Increase.**

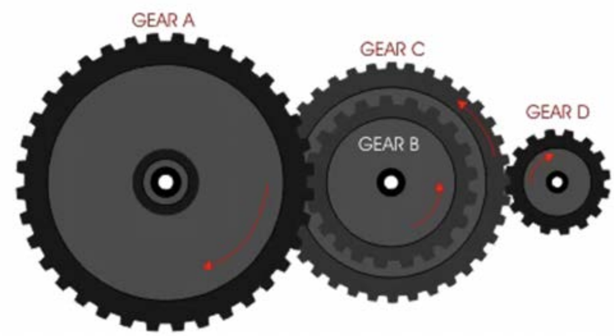



*Gear Ratio*

Gear ratios like the example above provide a speed reduction and a torque increase. The torque increase is the inverse of the speed reduction. Individual gear ratios are determined by driven gear divided by drive gear. The drive gear is often referred to as the input gear, and the driven gear is often referred to as the output gear.

The drive gear is the incoming power initially coming from the electric motor on a battery electric vehicle. The gear set shown is a simple gear set that only allows one-speed reduction. Most HEV and BEVs use a compound gear set to increase speed reduction and torque.

## Compound Gears




*Compound Gears*

When two gears mesh, they start to form a gear train. In a simple gear train with two gears, the driven gear turns in reverse of the drive gear. Compound gear sets, sometimes called multi-stage, are two or more pairs of gears connected in series. Compound gear sets allow the output gear to turn in the same direction as the input gear.

Compound gear trains allow you to multiply gear ratios together. You multiply each gear ratio to obtain the total gear ratio. Compound gear sets allow a speed reduction and a substantial torque increase. The torque increase is usually the most critical aspect in BEV models.

## Total Gear Ratio

The total gear ratio is achieved by multiplying each gear ratio. An example of a conventional 4WD total gear ratio, the Ford Bronco for instance, multiply crawl gear x low range in transfer case x final drive ratio=total gear ratio.

An example of a newer model Ford Bronco with a 4-cylinder engine.
* Crawl gear ratio-6.58.
* Transfer case low range-3.06
* Final drive-4.7
* Formula-6.58 X 3.06 X 4.7 = 94.6
* Total gear ratio 94.6:1

This means that the flywheel on the engine and input shaft of the transmission rotates 94.6 times, and the wheels rotate once when the vehicle is in first gear low range. The Ford Bronco would travel at one mph in crawl gear with the engine operating at 1000 rpm.

## SECTION 2 - GEAR RATIO/TOTAL GEAR RATIO

The 2021 Ford bronco has a 7-speed manual with a granny or crawl gear. The gear shift knob has a C on the handle to indicate crawl gear. rated at 6.588:1 The transfer low range is 3.06:1 Rear differential 4.71:1
6.588 X 3.06 X 4.7 =95:1

Off-road low range gear ratio example-2014 Jeep Cherokee 4-cylinder model-56:1 total gear ratio

Jeep Rubicon with a 4:1 low range transfer case, achieves an 86.24:1 crawl ratio. Wheel torque can be calculated by multiplying the total gear ratio times engine torque. Example on 2021 Ford Bronco: Peak engine torque on four-cylinder 2.3L is 315-pound feet of torque X 95:1 total gear ratio = 29,799 pound-feet of torque delivered to the wheel.

Tire force to ground formula: Wheel torque ÷ Tire radius = tire force to the ground. Ford Bronco example with 33-inch tires. To get the tire's radius, 33 inches ÷2 = 16.5 inches divide by 12 inches/foot to get the equation into feet. 16.5 in ÷12 in/ft = 1.375 ft
29,799 lb.-ft ÷ 1.375 ft = 21,672 pounds of force.

This number of 21,672-pounds of force is almost meaningless because the tire coefficient of friction cannot deliver that much torque without spinning. The tire can deliver around 5,000-foot-pounds of force to the ground, so the total force is not the goal, but the total gear ratio is the goal to achieve the speed reduction. The engine torque is usually limited in the crawl gear ratio due to the torque multiplication factor. The Ford Bronco at 1,000 RPM top speed is one mph in low-range crawl gear.

### Total Torque

Total torque is achieved by multiplying the torque output of the engine times the total gear ratio. In our 2021 Ford Bronco example with a 2.3L EcoBoost engine, the torque rating on regular fuel is 315-pound feet.

The crawl ratio previously figured is 94.6:1
315 lb.-ft X 94.6 =29.799-pound feet of torque available at the wheels and tires. The tires obviously cannot transfer that much torque to the ground due to the coefficient of friction, but that is how much torque is available at the wheel.

### Speed Reduction/Torque Increase

Conventional 4WD vehicles primarily use the total gear ratio for a speed reduction to crawl around the hills primarily, and the secondary benefit is the torque increase. Conversely HEV-BEV uses total gear ratio primarily for a torque increase and speed reduction as a secondary benefit.

### Top Speed Formula

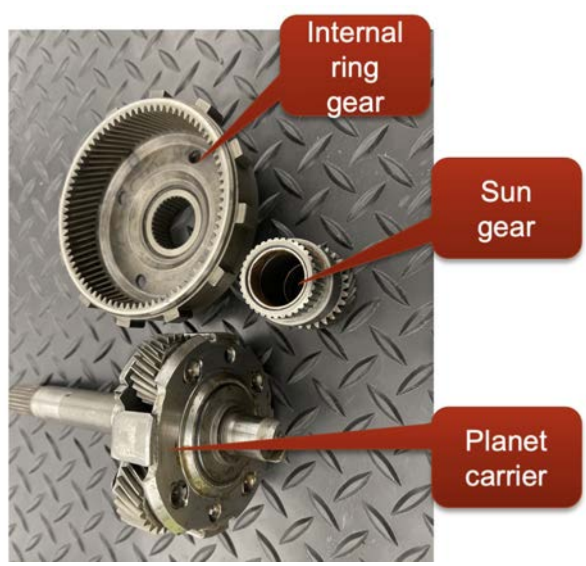
We will see how a one-speed transmission can provide sufficient top speed. We will give you the formula to calculate top speed, and then we will use the formula on a couple of BEV models later in the class.

RPM X 60(min/hour) = RPH (revolutions per hour)
RPH ÷ TGR X TC (tire circumference) = Inches per hour.

Inches per hour ÷ 63,360(inches per mile) = MPH.

RPM x 60 = RPH ÷ TGR X TC = IPH ÷ 63,360 = MPH.

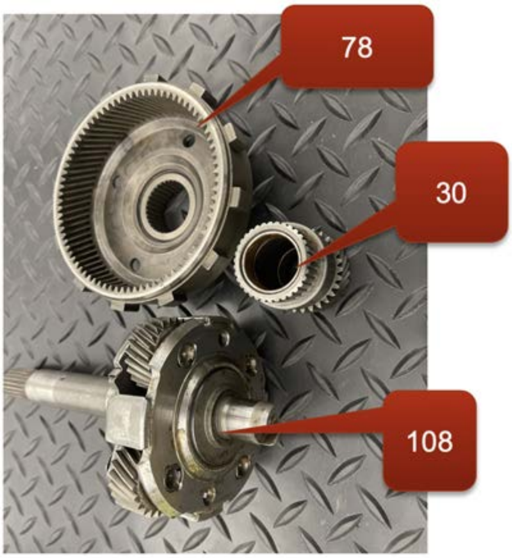
### Planetary Gear Ratio




*Plantetary Gear Disassembled*

Some hybrid transaxles use planetary gears. A planetary gear set consists of three gears a sun gear, an internal ring gear, and a planet carrier.

## SECTION 2 - GEAR RATIO/TOTAL GEAR RATIO




*Plantetary Gear Tooth Count*

We need to count the teeth on the sun gear and ring gear to obtain gear ratios for a planetary gear. Add the tooth count of the sun gear and ring gear together to obtain the tooth count for the planet carrier. Now, we have tooth counts for all three gears. All we need to do is determine which gear is the drive and which is the driven.

* Ring gear 78 teeth
* Sun gear 30 teeth
* Planet carrier 108 teeth
* Drive gear sun
* Driven gear planet carrier
* 108÷30=3.6
* Ratio is 3.6:1

### Assessment

### Questions

Question: T or F BEV-HEV models use traditional transmissions.

Question: T or F Gear ratios are calculated to drive gear divided by driven gear.

Question: T or F Gear reduction and torque numbers follow the same direction.

### Questions with Answers

Question: T or F BEV-HEV models use traditional transmissions.
**Answer: False. BEV models use a one or two-speed unit, and BEV models may use a power split device.**

Question: T or F Gear ratios are calculated to drive gear divided by driven gear.
**Answer: False. The correct formula is driven gear divided by drive gear.**

Question: T or F Gear reduction and torque numbers follow the same direction.
**Answer: False. They are the inverse of one another.**

### NOTES

# SECTION 3 - HIGH SPEED BEARINGS

## Tesla High Speed Bearings

*Tesla High-Speed Bearing Assembly*

High-speed electric cars require the use of precision machined customized bearings. As we noticed earlier, the Nissan leaf's motor max RPM was 10,500, and some Tesla's motors rotate over 20,000 RPM. These are extreme speeds and require high-speed bearings to accommodate this situation.

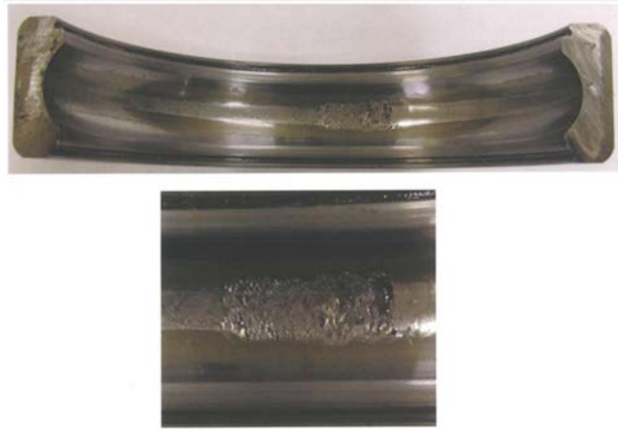
The high-speed bearings are more costly than the standard deep groove steel bearings. Ceramic bearings offer another advantage. They are 40% less dense than their steel counterparts, so they run at a cooler temperature. The ceramic bearings may have up to 10 times the life expectancy of steel bearings at the motor location.

The hybrid ball bearings have ceramic balls made from silicon nitride, the same material as solar panels.
SKF explorer series high precision bearings made for high speed.

## Micro-Pitting

Bearing failures have been familiar with electric motors due to current leaking, or current being induced into the rotor shaft. The current will exit the rotor typically through the bearing, which will cause micro-welding, which results in micro-pitting.

Steel bearings were susceptible to this type of failure. Tesla and other manufacturers use ceramic balls in their bearings. This is done to help reduce or eliminate this issue.



*Micro-Pitting Bearing Failure*

Ceramic balls create a natural insulation effect, thus, not allowing current to travel from raceways through balls, preventing the micro-welding. The bearings are also built on an exact platform allowing machining tolerance to be within 15 microns.

The bearings are rated for high speed due to some of the Tesla motors turning at over 20,000 RPMs. Think of our traditional bearings in the vehicles of the past. Ball bearings in the wheels never turned at these speeds; neither did ball bearings located in gearboxes. The highest speed bearing we had previously, may be found in the alternator. Due to the alternator turning twice as fast as the engine.

## Open Steel Bearings

*Open Steel Bearings*

Open deep groove steel bearings are lubricated by gearbox oil. The oil forms an insulating barrier to resist current flow.

## SECTION 3 - HIGH SPEED BEARINGS

However, dry spots on the bearing allow for electrical discharge, thus, causing the micro-pitting. High voltage electrical rotor charges may punch through oil film when they get high enough, causing micro-welding.

Poor bearing performance can also be attributed to contaminated fluid and metal particles. Changing the oil in the gearboxes and flushing out metal particles may help extend the life of the deeply grooved steel bearings. Open deep groove steel bearings are commonly found in BEV and HEV applications.

Not all BEVs and HEVs use ceramic ball bearings. Many manufacturers still use the open deep groove steel bearings. However, they still need to be high-speed rated.

### Sealed Bearings

*Sealed Bearing Examples*

Sealed type bearings with special dielectric nonconductive grease are the best solution to avoiding electrical discharge through the bearings. The grease must also withstand higher temperatures created by higher RPMs.

This type of bearing is more expensive, so some manufacturers choose to use deep groove steel bearings instead.

### Grounding Brushes

*Grounding Brushes (typical)*

The Nissan Leaf uses brushes that contact shaft and dissipates electrical charge.

Some manufacturers try to reduce or eliminate the electrical discharge by providing a grounding brush to dissipate any electric charge that develops in the rotor and accompanying shafts. The brush contacts the shaft and the transmission case, allowing any charge to travel to the ground without harming the bearings.

### NOTES

## SECTION 3 - HIGH SPEED BEARINGS

### Grounding Strands

*Tesla Grounding Strands*

Tesla uses conductive strands to act as brushes to dissipate shaft currents.

### Motor RPM Limit

**Rotor Limit Examples**

*** Nissan leaf-10,500**
*** Bolt EV-8810**
*** Tesla 20,000 plus**
*** Motor bearings need to be high-speed rated**

Every manufacturer will have a limit on electric motor RPM. The RPM limit has a lot to do with motor construction. The magnets would tend to be thrown out or break out if the RPM limit were exceeded. Many permanent magnet motors have been redesigned to allow for more speed.

### Rotor Failure

One issue with permanent magnet motors is that high RPM can cause magnets to break through the electrical steel due to centrifugal force. The magnets are close to the rotor's surface; there is not much material at the bridge gap holding them in place.

Early Prius electric motors were limited to 6500RPM due to this design, but the rotor was redesigned and upgraded to 10,000RPM and then upgraded to 17,000RPM. An electric motor's RPM limit or redline is mostly its mechanical limit to not fling apart at high RPMs.


*Rotor Failure (cracking)*

The other limiting factor of RPM is that the motor eventually runs out of torque, as previously discussed. Based on back EMF and a limited voltage supply. The RPM is controlled by the frequency of the waveform created by the inverter.

### Tesla IPMsynRM


*Tesla IPMsynRM Coil Wrap*

Tesla designed an interior permanent magnet synchronous reluctance motor (IPMsynRM). Previous permanent magnet motors suffered a lower RPM rating due to the magnets breaking out of the electrical steels at high speeds.

Tesla employs a carbon wrap around the rotor to hold the rotor together at high speeds. Tesla motors using this technology can withstand RPM ranges beyond 20,000 RPMs.

# SECTION 3 - HIGH SPEED BEARINGS

**Assessment**

**NOTES**

**Questions**

Question: True or False. BEV and HEV design vehicles require high-speed bearings.

Question: True or False. High-speed ceramic bearings cost less than conventional bearings.

Question: True or False. Some manufacturers use brushes to dissipate shaft currents.

**Questions with Answers**

Question: True or False. BEV and HEV design vehicles require high-speed bearings.
**Answer: True. The electric motors turn faster than our conventional vehicle bearings.**

Question: True or False. High-speed ceramic bearings cost less than conventional bearings.
**Answer: False. High-speed ceramic bearings are costly, so not all manufacturers use them.**

Question: True or False. Some manufacturers use brushes to dissipate shaft currents.
**Answer: True. The Nissan Leaf and Tesla models use some grounding brush or strand.**

# SECTION 4 - NISSAN LEAF BEV

## Nissan Leaf

**Key Points**

*** Electric drive**
*** One electric motor**
*** 360-volt battery**
*** Motor horsepower-107**
*** Motor torque-187 lb.-ft.**
*** Max RPM 10,500**
*** 8.193 total gear ratio**
*** Top speed 90.1mph**

The Nissan leaf is a 100% electric vehicle with no ICE. The leaf offers a 360-volt battery with one electric drive motor. The motor output torque is 187 lb.-ft. with a 10,500 max RPM limit. The physical top speed is a function of motor RPM limit, tire circumference, and total gear ratio. However, the software can limit the top speed with programming. The top speed is rated at 90.1 RPM.

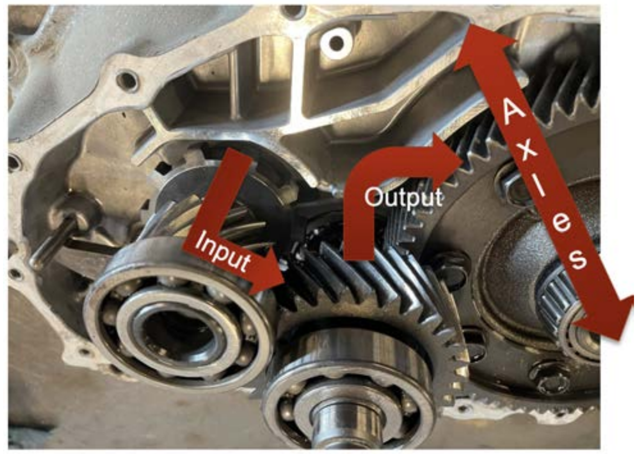
Horsepower and torque ratings are constantly changing depending on the year. The picture is a 2015 Leaf.

## Nissan Leaf Components

*Nissan Leaf BEV Compound Gear Assembly*

The Nissan leaf is a typical electric vehicle with a compound gearbox. The gearbox looks extremely simple, with very few gears. This is a one-speed gearbox. It is not first, second, third, and so on. It only has one fixed ratio. The gearbox consists of an input gear, main gear, differential, support bearings, and a parking mechanism.

## Power Flow




*Compound Gear Power FLow*

The power enters the input gear from the electric motor. The input gear transfers power to the main gear, referred to as a countershaft or transfer shaft. The power then travels to the ring gear. There are no wet clutches, synchro rings, or any shifting mechanisms. The gear ratio is fixed and always remains the same.

| | | |
|---|---|---|
| Reduction gear model | | RE1F61B |
| Gear ratio | | 8.193 |
| Number of teeth | Input gear | 17 |
| | Main gear (IN / OUT) | 32 / 17 |
| | Final gear | 74 |
| Oil capacity (Approx.) | ℓ (US pt, Imp pt) | 1.41 (3, 2-1/2) |

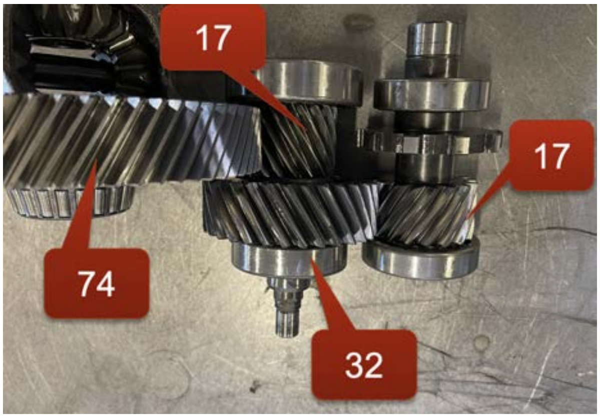
*Nissan Leaf Gear Assembly Specifications*

## Gear Tooth Count

**Input gear-17 teeth.**
**Main gear in-32.**
**Main gear out-17.**
**Ring gear-74..**
**32÷17=1.88235**
**74÷17=4.35.**
**1.88235 X 4.35294=8.193.**

The input gear is the input drive gear and has 17 teeth. The main shaft-driven gear that meshes with the input drive gear has 32 teeth. The main shaft drive gear (Pinion) has 17 teeth, and the differential ring gear (driven gear) has 74 teeth.

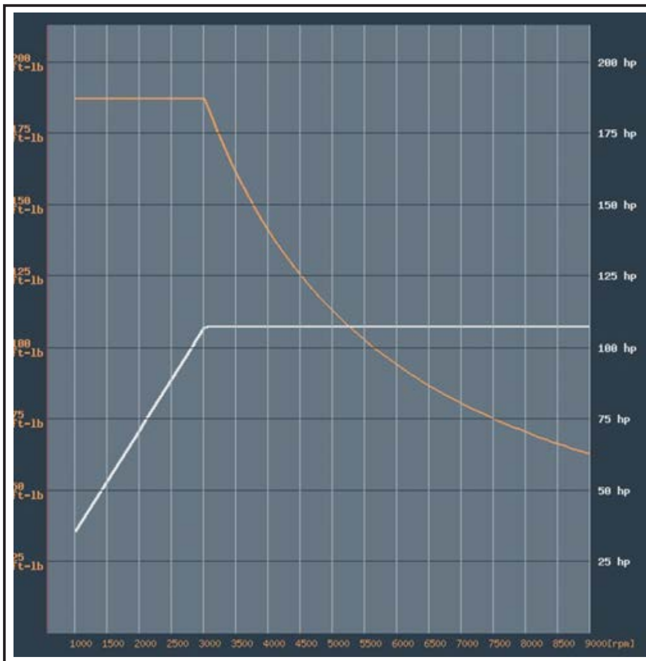
# SECTION 4 - NISSAN LEAF BEV




*Tooth Count*

Using the calculation: driven gear divided by drive gear will give us each ratio. After we obtain each ratio, we can multiply them to obtain a total gear ratio together. The factory specs gave us the total gear ratio in specs. We went through the gears and figured it out ourselves, and our value matched the published value.

**Nissan Specs**




*Nissan Leaf Torque Specifications*

The 2013 Nissan Leaf's motor torque starts at 187 lb.-ft. and starts to drop at around 3,000 RPM. The motor torque is multiplied times the gear reduction to obtain total torque output numbers. Nissan states the top speed is limited to 90 mph, which is close to the powertrain's mechanical limit.

The electric motor that drives the front wheels of the 2015 Leaf puts out 80 kilowatts or about 107 horsepower. Its top speed is capped at 90 mph to conserve energy, but it will propel the 3,200-pound electric car from 0 to 60 mph in less than 10 seconds--hardly blazing but adequate for daily traffic.

Chart numbers
1000 rpm: 254 Nm / 187.3 lb.-ft. / 26.6 kW / 36.2 PS / 35.6 hp

2000 rpm: 254 Nm / 187.3 lb.-ft. / 53.2 kW / 72.4 PS / 71.3 hp

3000 rpm: 254 Nm / 187.3 lb.-ft. / 79.8 kW / 108.5 PS / 106.9 hp

4000 rpm: 191 Nm / 140.8 lb.-ft. / 80 kW / 108.8 PS / 107.2 hp

5000 rpm: 152.8 Nm / 112.7 lb.-ft. / 80 kW / 108.8 PS / 107.2 hp

6000 rpm: 127.3 Nm / 93.9 lb.-ft. / 80 kW / 108.8 PS / 107.2 hp

7000 rpm: 109.1 Nm / 80.5 lb.-ft. / 80 kW / 108.8 PS / 107.2 hp

8000 rpm: 95.5 Nm / 70.4 lb.-ft. / 80 kW / 108.8 PS / 107.2 hp

9000 rpm: 84.9 Nm / 62.6 lb.-ft. / 80 kW / 108.8 PS / 107.2 hp

**Max Torque**

Total gear ratio X motor torque = Max torque

187 lb.-ft. X 8.193 = 1532 lb.-ft. of torque @ 3,000 RPM

62.6 lb.-ft. X 8.193 = 512.9 lb.-ft. of torque @ 9000 RPM

Gear reduction increases torque to make the vehicle accelerate properly. Without gear reduction, 187 lb.-ft. torque available only. With gear reduction, max torque 1532 lb.-ft. torque available.

## SECTION 4 - NISSAN LEAF BEV

The total gear reduction is essential for an electric vehicle to achieve adequate acceleration. Without gear reduction, the Leaf would only offer 187 lb.-ft. torque to the wheels. With gear reduction, the Nissan Leaf offers 1532 lb.-ft. to the wheels.

Without gear reduction, the vehicle would not have adequate acceleration. Hybrid vehicles typically offer less gear reduction due to having the ICE as another input torque source. A hybrid can combine torque from the engine and the electric motor, so they typically offer a lower gear reduction such as a 3 or 4 to one ratio instead of an 8 to 1 ratio, but that is not always true.

### Max Speed

Nissan Leaf motor speed

* 10,500 RPM max speed
RPM x 60 = RPH ÷ TGR X TC = IPH ÷ 63,360 = MPH

* 10,500 x 60 = 630,000 ÷ 8.193 =76,895 x 78.1 = 6,005,499 ÷ 63,360 = 94.78 mph

We can use the max speed formula we learned earlier to determine max speed. The information we need to plug into the formula is the motor RPM limit, the total gear ratio, and tire circumference. The max speed of this 2015 Nissan leaf is 94.78 mph, and Nissan states they limit the speed to 90 mph.

Electric motors tend to be able to reach their redline at high speeds due to the gear reduction staying high, unlike their gasoline counterpart. A gasoline engine typically cannot come close to a red line in overdrive gear, so the max speed is limited on gasoline engines to what RPM the engine can reach in overdrive.

A gasoline engine can easily reach redline in lower gears like first and second, but it becomes increasingly challenging to reach redline as we reach direct and overdrive gears.

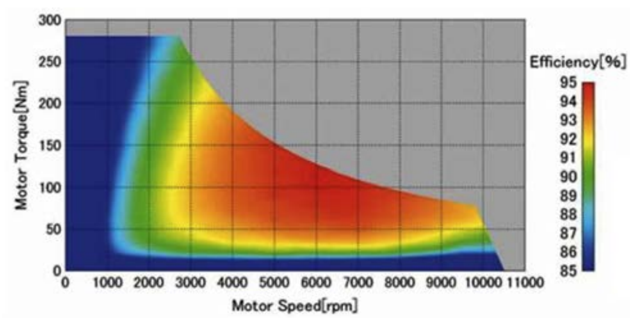
NOTES

# SECTION 5 - CHEVROLET BOLT BEV

## Bolt EV Specs

The 2017 Chevrolet Bolt EV is not a hybrid. It is a pure electric vehicle. Power output is 200 hp(150 kW) with 266 lb.-ft. of torque. The battery is a lithium-ion 60kWh at 350 volts. The total gear ratio is 7.05:1.

## Torque Curve Bolt



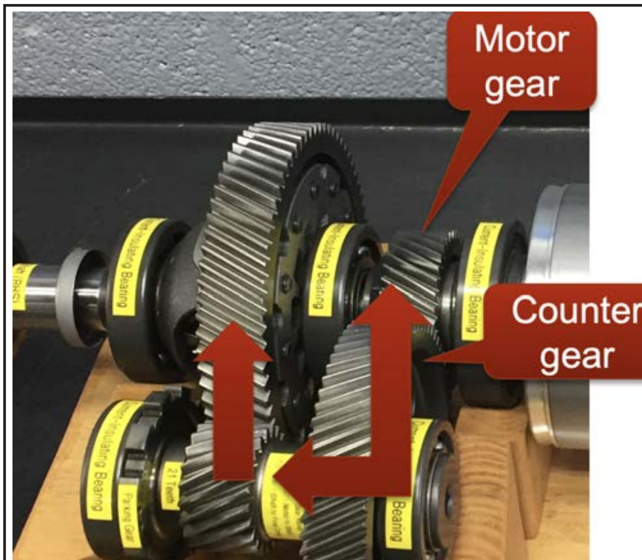

*Chevrolet Bolt Torque Curve Efficiency*

The electric motor torque curve follows the examples we gave earlier; where the torque is high at low RPMs and starts to decline as the motor picks up speed and back EMF is produced. Some of the earlier graphs reflected the decline of around 5,000-6,000 RPM. The Nissan Leaf and Chevy Bolt start to decline at around 3,000 RPM.

## Power Flow


*Chevrolet Bolt EV 1ET25 Gear Assembly*

The 1ET25 gearbox is a compound gear set laid out in extreme simplicity. The Chevy Bolt uses a helical gear design on all gears, including the differential. This is typically done to reduce the unwanted gear whine noise.




*1ET25 Rotational Output*

The bearings located around the motor, countershaft, and differential are ceramic bearings to help reduce the micro-welding effect.

The motor gear meshes and drives the large countershaft gear giving us our first ratio. The small countershaft gear (Pinion) drives the differential ring gear giving us our second gear ratio.

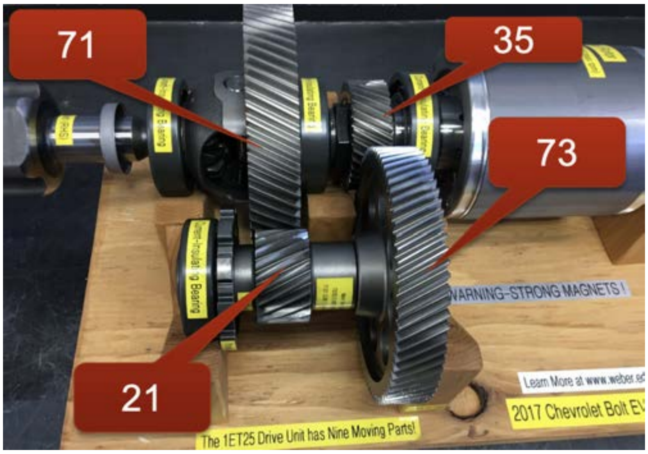
The side gears inside the differential are splined to the axles and deliver power to the axles, carrying the power to the wheels. The differential is an open design allowing for proper cornering.

As previously discussed, the bearings in the motor area are ceramic insulated to avoid micro-welding and premature failure.

## NOTES

# SECTION 5 - CHEVROLET BOLT BEV

## Bolt Gear Ratio




*1ET25 Gear Tooth Count*

The Bolt's electric motor is expected to produce 200 hp and 266 lb.-ft. of torque and is paired to a single-speed transmission with a final drive ratio of 7.05:1. Chevrolet expects the Bolt to do 0-60 in 7 seconds or less, and has a top speed of 91 mph.

Math to obtain total gear ratio. The formula is driven gear divided by drive gear for individual ratios and multiplying all gear ratios together for the total gear ratio.

**73÷35=2.0857**
**71÷21=3.3809**
**2.0857 X 3.3809 = 7.05**

## Total Torque

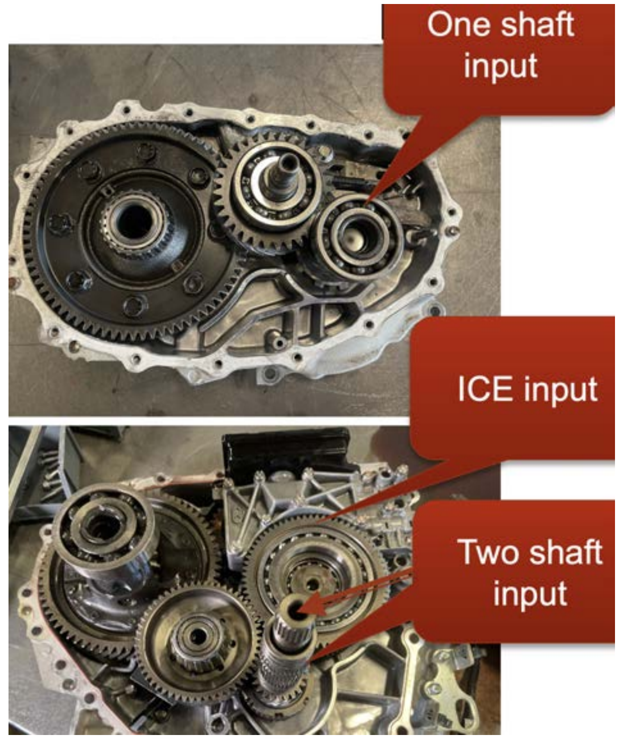
*** Motor Torque X gear ratio = Total torque**
*** Motor torque 266 lb.-ft.**
*** 266 X 7.05 =1875.30**
*** Total torque output to the wheel 1875.30 lb.-ft.**

The Chevy Bolt's electric motor outputs 266 lb.-ft. of torque. We multiply the torque times the total gear ratio to find max torque numbers.

266 lb.-ft. (Torque) X 7.05 (Total gear ratio) = 1875.30 lb.-ft. The Nissan leaf we discussed earlier had 1532 lb.-ft. of total torque.

Shown in the following illustration, the top image is a Nissan Leaf design, and the bottom image is a Honda Dual Motor design.

## HEV Gearbox Design




*Gearbox Design (cutaway)*

HEV and BEV gearboxes differ in design. BEV gearboxes only have one torque input. All the torque comes from a single electric motor. HEV gearboxes have two torque inputs: the electric motor and the ICE. HEV gearboxes usually employ two electric motors instead of one.

The HEV gearbox is a more complex design than the BEV gearbox. The Nissan leaf picture indicates one shaft input from the electric motor. The Honda dual motor has two shafts connected to two different electric motors along with a gear input from the ICE.

In most cases, the BEV gearboxes will have a higher gear ratio than HEV gearboxes, but that is not always the case. HEV gearboxes typically have a lower gear ratio because there are two inputs for torque instead of one. Two torque inputs do not require as much torque multiplication, so the total gear ratio does not have to be as high .

Example: Chevy bolt 7.5:1, Nissan leaf 8.1:1, and Tesla at 9.1:1. The Toyota HEV Gearboxes are usually in the 3.8-4.1 ratio range.

# SECTION 6 - TOYOTA BEV TRANSAXLES

## Toyota Transaxle Identification


***Toyota VIN Plate with Transaxle Code***

Toyota has many different transaxles they use in their hybrid vehicles. Toyota offers a variety of vehicles with hybrid technology. The vehicles range in weight, size, and size of the internal combustion engine. Therefore, their transaxles are not all the same.

We can group Toyota transaxles into generations. We will refer to them as Gen 1 thru Gen 4. Each generation is built on a similar platform, but the parts inside may be bigger or smaller. Additionally, the gear ratio may vary depending on the torque requirements of the vehicle. You can identify the transaxle by looking at the door tag. The door tag with VIN will have an A/TM designation at the bottom.

The A stands for the axle, and the TM stands for transmission. Here is a list of Toyota's transaxles; the list is not complete. It may not list all models the transaxle was used in, but it gives you an idea of how many different designations exist. Toyota hybrid technology is also found in other manufacture's Hybrid vehicles.

**Camry and highlander, Lexus, Avalon, Highlander**
P310-P311-P312-P313-P314 (All similar in design, just different size and torque ratings).
P110-97-2000 Prius (Japan only).
P111-2001-2003 Prius (First gen design).
P112-2004-2009 Prius (Second gen design).
P310-P410-P510 very similar- (Third gen design) .
Highlander-Lexus (Third gen design).
P311-Camry-Lexus HS250h (Third gen design).
P313-Highlander-Lexus RX450h (Third gen design).
P314-Avalon-Camry-Lexus.
P410-Third Gen Prius- 2010-2015.
P411-Prius Alpha/Prius V.
P510-Prius C 2012and up.
P610-Prius-2016-2022 P610-P710-P810 similar in operation (Fourth gen).
P610-2016 & up Prius Prime (Fourth gen).
P710-Rav 4-Camry-Avalon – LexusES300h (Fourth gen).
P711-Corolla-Lexus UX250h (Fourth gen).
P810-Rav 4 Prime-Highlander-Sienna-LexusNX450h (Fourth gen).
P910-Toyota Yaris 2020(Fourth gen).
There is also an L-series for hybrid rear-wheel design platforms. L110-L210-L310.

Prius has five models currently Standard Prius-Prius C-Prius V-Prius prime (plug-in), and a new AWD Prius model.

## Assessment

## Questions

Question: True or False? Can an electric motor reach its RPM max limit throughout the vehicle's speed range.

Question: BEV vehicles tend to have an overall higher gear ratio than HEVs.

Question: True or False? Nissan Leaf's electric motor max speed is 8800 RPM.

## Questions with Answers

Question: True or False? Can an electric motor reach its RPM max limit throughout the vehicle's speed range.
**Answer: True. Unlike its gasoline counterpart, an electric motor can reach the Max RPM limit at top speeds.**

Question: BEV vehicles tend to have an overall higher gear ratio than HEVs.
**Answer: True. BEVs typically have a higher overall gear ratio than HEVs due to only one power source.**

Question: True or False? Nissan Leaf's electric motor max speed is 8800 RPM.
**Answer: False. The Nissan Leaf electric motor max RPM is 10,500.**

# SECTION 7 - TOYOTA HYBRID SYNERGY DRIVE (HSD) - FIRST GENERATION

## First Generation Design

*First Generation HSD Cutaway (power flow)*

Hybrid Synergy Drive (HSD), also known as Toyota Hybrid System II, is the brand name of Toyota Motor Corporation's hybrid car drive train technology used in vehicles with the Toyota and Lexus marques. First introduced on the Prius, the technology is an option on several other Toyota and Lexus vehicles and has been adapted for the electric drive system of the hydrogen powered Mirai and a plug-in hybrid version of the Prius.

Previously, Toyota also licensed its' HSD technology to Nissan for use in its Nissan Altima Hybrid. Its parts supplier Aisin Seiki Co. offers similar hybrid transmissions to other car companies.

HSD technology produces a complete hybrid vehicle which allows the car to run on the electric motor only, as opposed to most other brand hybrids, which cannot, and are considered mild hybrids. The HSD also combines an electric drive and a planetary gearset which performs similarly to a continuously variable transmission. The Synergy Drive is a drive-by-wire system with no direct mechanical connection between the engine and the engine controls. Both the gas pedal/accelerator and the gearshift lever in an HSD car merely send electrical signals to a control computer.

HSD is a refinement of the original Toyota Hybrid System (THS) used in the 1997 to 2003 Toyota Prius. The second-generation system first appeared on the redesigned Prius in 2004. The name was changed in anticipation of its use in vehicles outside the Toyota brand (Lexus; the HSD-derived systems used in Lexus vehicles have been termed Lexus Hybrid Drive), was implemented in the 2006 Camry and Highlander, and would eventually be implemented in the 2010 "third generation" Prius, along with the 2012 Prius C. The Toyota Hybrid System is designed for increased power and efficiency, and also improved "scalability" (adaptability to more significant as well as smaller vehicles). Wherein, the ICE/MG1 and the MG2 have separate reduction paths and are combined in a "compound" gear which is connected to the final reduction gear train and differential. It was introduced on all-wheel drive and rear-wheel drive Lexus models.

By May 2007, Toyota had sold one million hybrids worldwide, two million by the end of August 2009, and passed the 5 million mark in March 2013. As of September 2014, more than 7 million Lexus and Toyota hybrids had been sold worldwide.[6] The United States accounted for 38% of TMC's global hybrid sales as of March 2013.

## Gen 1 Design & Power Flow

**Key Points**
*** P111 gearbox first design Prius (2001-2003).**
*** Gear ratio-3.89:1.**
*** MG1-MG2 (Two motors).**
*** Motors-Inline axis.**
*** Power split device (PSD).**
*** Silent chain and sprockets.**

The first US design Prius employed a P111 gearbox. The first generation ran from 2001-2003. The final drive ratio of this transmission was 3.89:1. There were two motors, MG1 and MG2, arranged in an inline axis. A power split device (PSD) was positioned between the two electric motors. A silent chain and sprockets transferred power from PSD to the rest of the gear train. The first design had an electric-only mode speed restriction due to MG1's 6500 RPM limitation.

# SECTION 7 - TOYOTA HYBRID SYNERGY DRIVE (HSD) - FIRST GENERATION

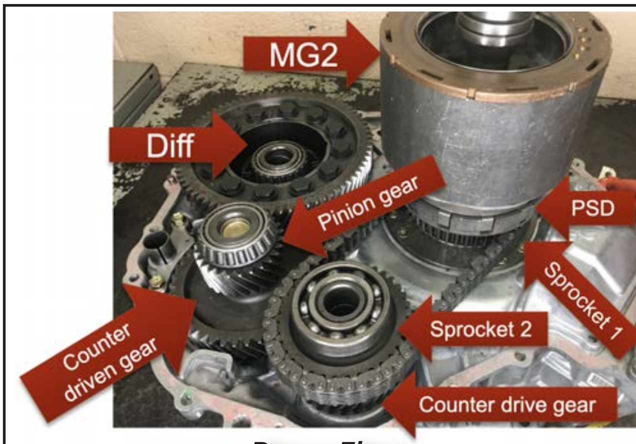
## Electric Motors

**Key Points**
*** MG1-small permanent magnet motor.**
*** MG2-large permanent magnet motor.**
*** Both motors are located internal to the gearbox.**
*** MG1 acts as the starter and generator and assists in varying the gear ratio.**
*** MG2 propels the vehicle in forward and reverse.**


*Motor Generators MG1 & MG2*

Two electric motors reside inside the gearbox. The two electric motors sit on an inline axis. MG1 is the smaller motor to start the ICE, generate electricity, and provide a variable gear ratio. MG2 is the larger motor used to propel the vehicle forward or in reverse. The two motors interact with the power split device to vary the torque to the axles.

## Power Flow



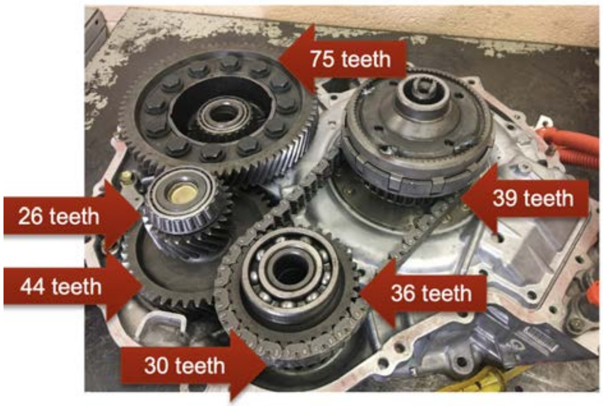

*Power Flow*

The Power split device and MG2 drives sprocket number one are shown in the picture. Sprocket number one rotates the silent chain and drives sprocket number two in the picture. Sprocket number two is attached to the counter drive gear. The counter-drive gear drives the counter-driven gear through a gear-to-gear interaction. The counter-driven gear includes the small pinion gear on one end. The pinion gear drives the differential ring gear, and the differential transfers power to the axles.

## NOTES

## SECTION 7 - TOYOTA HYBRID SYNERGY DRIVE (HSD) - FIRST GENERATION

### Gear Ratio




*First Generation HSD Tooth Count*

*** Sprocket 1 39 teeth**
*** Sprocket 2 36 teeth**
*** 36÷39=.92 (Overdrive) ratio**
*** Counter drive gear 30**
*** Counter driven gear 44**
*** 44÷30=1.466**
*** Pinion gear 26**
*** Differential ring gear 75**
*** 75÷26=2.88**
*** .92x1.466x2.8846=3.89**

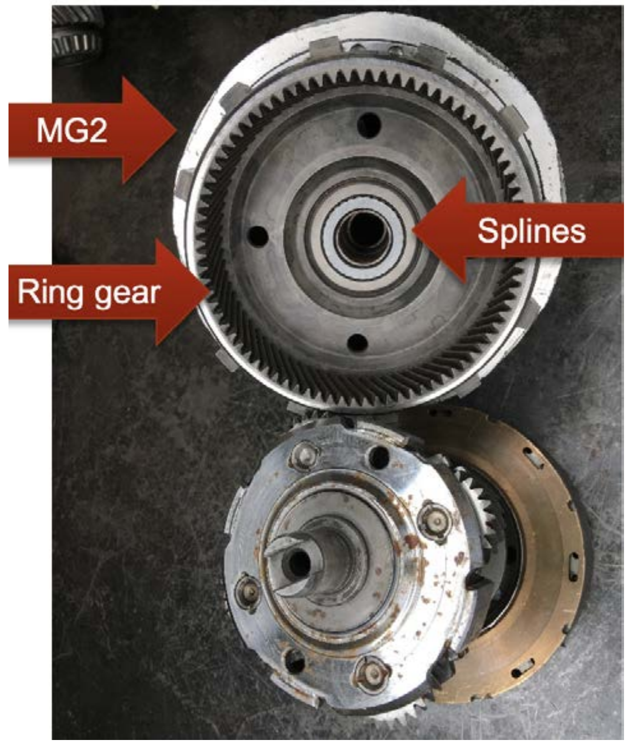
Gear ratio is obtained by dividing driven gear by drive gear. The total gear ratio is obtained by multiplying each gear ratio times each other.

Sprocket 1 has 39 teeth, and sprocket 2 has 36 teeth. 36 ÷ 39 = .92 ratio means the first gear ratio is an overdrive ratio. The counter-drive gear has 30 teeth, and the counter-drive gear has 44 teeth. 44 ÷30 = 1.466 ratio, which is an underdrive ratio.

The pinion has 26 teeth, and the differential ring gear has 75 teeth 75 ÷ 26 = 2.88 ratio. We multiply all the gear ratios together for a final ratio.

**.92 x 1.466 x 2.8846 = 3.89:1 final ratio.**

### Gear Ratio




*MG2 Removed*

**Calculating Gear Ratio**

*** Gear ratio from MG2 is always 3.89:1.**
*** MG2 is splined to the internal ring gear.**
*** Engine adds torque to the internal ring gear.**
*** Engine/MG1 gear ratio is variable.**
*** MG1 constantly varies the ratio/torque.**

MG2 is splined to the internal ring gear of the PSD. The internal ring gear is indexed into the drive sprocket. All power from MG2 and the ICE flow through the internal ring gear. The gear ratio from the internal ring gear to the wheels is 3.89:1 all the time. The gear ratio or torque from the ICE is constantly changing.

We have an overdrive ratio on the sprocket and chain drive in the first rotation. The driven sprocket reaches one complete revolution before the drive sprocket does. The complete revolutions reveal a 3.89:1 gear ratio overall. In electric drive, the gear ratio never changes.

When the engine is running, it adds torque to the ring gear, and the engine speed can continually change

## SECTION 7 - TOYOTA HYBRID SYNERGY DRIVE (HSD) - FIRST GENERATION

RPM along with MG1 speed to continually adjust the torque input to the ring gear from the engine. On the engine side, you could say that is a continuous variable gear ratio, but more accurately it constantly varies the torque.

**Power Split Device**

***Power Split Device (MG2 on top, MG1 on bottom)***

MG2 is splined to the internal ring gear. MG2 drives the internal ring gear, which drives the chain sprocket. If MG2 is turning, the wheels are turning, and vice versa. MG2 propels the vehicle in electric mode forward and reverse. MG1 is splined to the sun gear, which interacts with the planet carrier.

The planet carrier is splined to the clutch plate at the flywheel side. It transmits torque to the engine during cranking and torque from the engine when the  engine is running. The planet carrier on the other end powers the shaft that drives the lubrication oil pump.

MG1 can create a variable gear ratio/torque from the engine side input to the internal ring gear by varying the speed of the sun gear and the engine varying the planet carrier's speed. The engine RPM and MG1 RPM can continuously change to vary gear ratio/torque from the engine side. The goal of varying the gear ratio input from the engine side is to vary the torque input to the internal ring gear and keep from overspeeding MG1.

Since MG2 is splined directly to the internal ring gear and the planet carrier indexes into the internal ring gear from the engine, all torque output travels through the internal ring gear. It is unusual to have two power or torque inputs into one gear, engine and MG2, but that is common in Hybrid design.

The gear ratio from the internal ring gear to the wheels never changes; the gear ratio remains a constant 3.89:1. The only gear ratios involved are on the engine side, and that is only to vary the torque input to the ring gear and control the speed of MG1. The engine can never rotate the ring gear by itself. It can only add torque to the ring gear. MG2 is the force that is constantly driving the wheels.

MG1, in motor mode, rotates the sun gear, which turns the planet carrier. The planet carrier shaft is splined to a clutch disk. The clutch disc is attached to the flywheel. The planet carrier rotates the flywheel to start the engine.

Once the engine is started, the planet carrier is now rotated by the engine, which rotates MG1, and now MG1 switches to a generator. The drive gear in engine cranking is the sun gear, and the driven gear during cranking is the planet carrier. To obtain a cranking gear ratio, divide the driven gear by the drive gear.

108 ÷ 30 = 3.6:1 MG1 rotates 3.6 times for every engine revolution. Toyota states the engine cranks at 1000 RPM so MG1 would rotate 3600 RPM during crank.

The PSD sits between the two motors, as seen here. MG2 is on the bottom, and MG2 is on top. The motors and PSD are on an inline axis.

# SECTION 7 - TOYOTA HYBRID SYNERGY DRIVE (HSD) - FIRST GENERATION

## MG2

MG2 in motor mode propels the vehicle by rotating the internal ring gear connected to the drive sprocket. The drive sprocket rotates the chain, which drives the gear train to propel the vehicle. In regen mode, while breaking, the wheels are driving the sprockets via the differential and countershafts. The sprocket is driving MG2; this causes MG2 to switch from motor mode to generator mode. In generator mode, MG2 can help charge the high-voltage battery.

## Electric Drive MG1 Speed

The 6500 RPM limit on MG1 limits electric drive-only vehicle speed. During electric drive mode, MG2 is driving MG1 2.6 times faster than MG2 is turning. The math associated with this is calculated by calculating the planetary gear ratio from MG2 to MG1. We learned earlier how to calculate gear ratios of a planetary.

Count the teeth on the sun gear (30), add that count to the tooth count on the ring gear (78), and that will give you the tooth count of the planet carrier (108). The next step is dividing the driven gear by the drive gear. The driven gear is the sun gear, and the drive gear is the ring gear.

30 ÷ 78 = .384, which is an extreme overdrive ratio. 1 ÷ .384 = 2.6 That means MG1 will turn 2.6 times for every revolution of MG2.

## Torque Output Electric Drive

| | |
|---|---|
| **Layout:** | front-wheel drive |
| **Engine:** | 1.5-liter / 6.5 amperes (Electric) |
| **Horsepower (lb.-ft @ rpm):** | 70 @ 4500/ 25 kW (34 hp) (Electric) |
| **Torque (lb.-ft @ rpm):** | 82 @ 4200 / 258 lb./ft. (350.0 Nm) 0-400 (Electric) |
| **Transmission:** | CVT automatic |
| **EPA fuel economy, city/hwy:** | 52/45 mpg |

*Torque/Output Specifications*

* MG2-258 lb.-ft. torque output.
* Electric drive only torque output.
* 258 lb.-ft. X 3.89 overall gear ratio = 1003 lb.-ft.
* Engine torque (82 lb.-ft.) split between driving MG1 and adding torque to the internal ring gear.

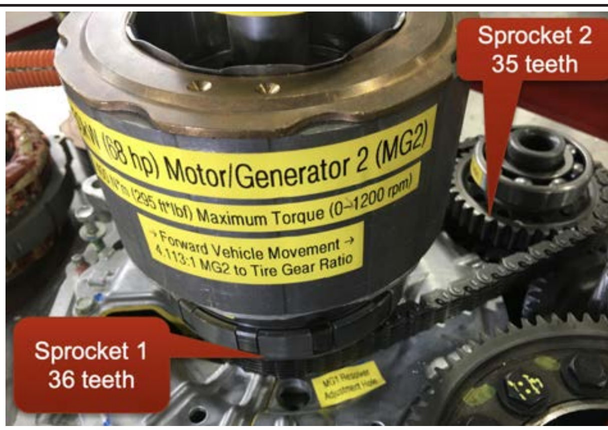
MG2 outputs 258 lb.-ft. of torque. Only multiply the gear ratio times MG2 output for maximum torque in electric drive. MG2 258 X 3.89 = 1003 lb.-ft. torque output. The engine can add torque to that number depending on the engine and MG1 RPM. The engine develops a maximum torque of 85 lb.-ft., split between driving MG1 to generate power and the internal ring gear to propel the vehicle. The total torque is always changing due to MG2 torque declining with RPM and the engine varying the torque input.

## NOTES

# SECTION 8 - TOYOTA HYBRID SYNERGY DRIVE (HSD) - SECOND GENERATION

## Second Generation Design

**Key Points**
*** Second Gen Prius P112.**
*** Slight changes from P111.**
*** Shorter chain.**
*** Different sprocket tooth counts.**
*** Bearing design changes.**
*** MG1 redesign max speed 10,000RPM.**




*Second Generation HSD Cutaway*

The P112 found in the second-generation Prius is precisely like the P111 design, with a few slight changes. The most significant difference being the gear reduction ratio from MG2 to the wheel is slightly different. The main difference is that the sprocket tooth count has changed. The sprocket on the counter drive gear (Sprocket 2) has 35 teeth, whereas the first gen had 36 teeth. The drive sprocket one tooth count has changed as well.

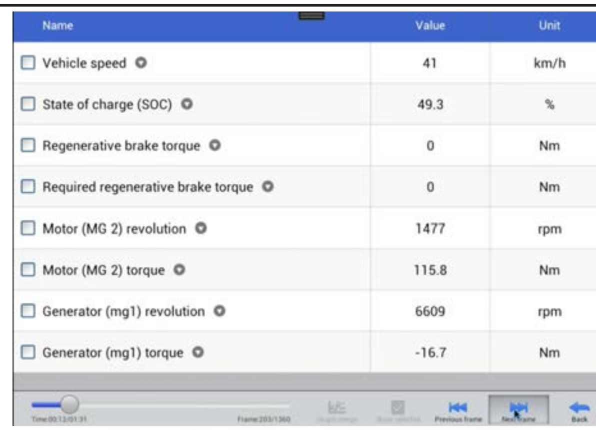
The second-generation sprocket 1 has 36 teeth, whereas the first gen has 39 teeth. The difference in the sprocket ratio is that the second generation has a .97:1 sprocket ratio, and the first gen has a .92:1 sprocket ratio. This means the second generation has a slightly lower ratio from MG2 to the wheels at 4.1:1 compared to the first gen at 3.89:1.

The lower gear ratio gives a little more torque multiplication to improve acceleration. A change in the silent chain length was also necessary to accommodate the different sprocket tooth counts. The first gen P111 chain had 74 links, while the second gen P112 had 72. The first gen used a little different design MG1 than the second gen.

Another improvement in the P112 is that MG1 max RPM has increased from 6,500 to 10,000 RPM.

Lower gear ratio and increased MG2 torque increased overall torque. The first generation P111 output torque in electric mode was 1003 lb.-ft. of torque. The second-generation output torque in electric only mode is 1209.5 lb.-ft.

## Scan Data Torque



| Name | Value | Unit |
|---|---|---|
| Vehicle speed | 41 | km/h |
| State of charge (SOC) | 49.3 | % |
| Regenerative brake torque | 0 | Nm |
| Required regenerative brake torque | 0 | Nm |
| Motor (MG 2) revolution | 1477 | rpm |
| Motor (MG 2) torque | 115.8 | Nm |
| Generator (mg1) revolution | 6609 | rpm |
| Generator (mg1) torque | -16.7 | Nm |

*Scan Tool Data - MG1, MG2 RPM*

MG2 will act in motor mode during acceleration, delivering power to the wheels. In motor mode traveling forward, MG2 RPM will be positive, and the torque will be positive. During deceleration regen, MG2 will switch to generator mode. The RPM will remain positive in generator mode, but the torque will switch to negative.

Scan data positive RPM and positive torque equal motor mode. Positive RPM and negative torque equal generator mode. Decreasing ? RPM and negative torque equal generator? mode. You can observe scan data to determine which mode MG1 and MG2 are in.

# SECTION 8 - TOYOTA HYBRID SYNERGY DRIVE (HSD) - SECOND GENERATION

## Gen 1 & Gen 2 Chain and Sprocket Designs

| | Gen 1 | Gen 2 |
|---|---|---|
| Pinion gear | 26 | 26 |
| Larger gear | 44 | 44 |
| Sprocket | 36 | 35 |
| Sprocket only | 39 | 36 |
| Sprocket gear | 30 | 30 |
| Chain | 74 | 72 |
| Ring gear | 75 | 75 |
| Sun gear | 30 | 30 |
| Ring gear | 78 | 78 |

***GEN 1 vs GEN 2 Sprocket Tooth Count***

Pinion and large gear located on the same shaft. Sprocket and sprocket gear are on another shaft. Chain number indicates links, which include inner and outer links. To obtain the chain's link count, count the outside plates and then multiply twice to include the internal links. The only sprocket  listed in the chart is the sprocket with an internal bearing.

## Gen 1

* Pinion 26
* Larger gear 44
* Sprocket 36
* Gear 30
* Sprocket only 39
* Chain 36
* Ring gear 75
* Sun gear 30
* Ring gear 78

## Gen 2

* Pinion 26
* Larger gear 44
* Sprocket 35
* Gear 30
* Sprocket only 36
* Chain 37
* Ring gear 75
* Sun gear 30
* Ring gear 78

## P112 Design Changes

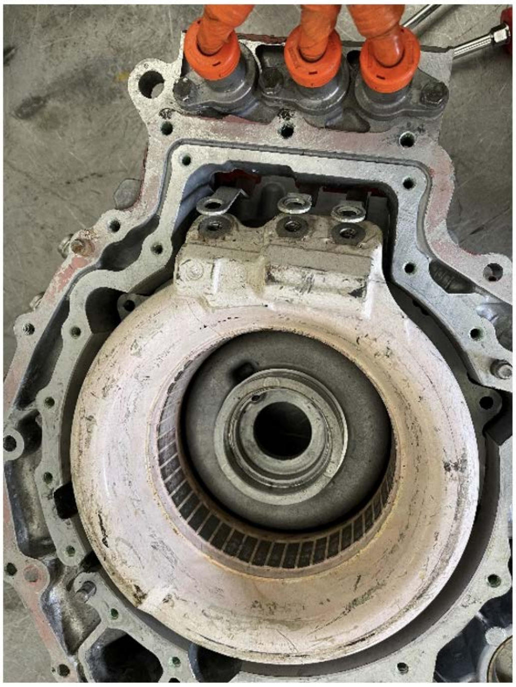
Another small change to the gear train in the second gen P112 is the switch of counter-driven gear bearings. The first gen P111 used tapered roller bearings, whereas the second gen P112 uses ball bearings. The clutch disc that starts the engine and transfers engine power to the PSD also changed slightly. The first design, P111, uses a disc with two damper springs, whereas the second gen P112 only uses one spring.

This change lightened the spring tension up a bit. The spring chain in the second gen flywheel that is 1.5 pounds lighter than the first gen. The case has also changed slightly between first gen P111 and second gen P112. Some changes inside, and the oil pan went away. There are other changes between the first and second designs, but we listed the most important ones.

## NOTES

# SECTION 8 - TOYOTA HYBRID SYNERGY DRIVE (HSD) - SECOND GENERATION

## MG1 Design Change



*First Generation MG1*

*Second Generation MG2*

The first gen P111 used a different style MG1 than the P112 used in the second gen. The P111 stator housing was ceramic, and the second gen P112 was steel.

## Oil Pump Drive

*Gen 2 Oil Pump Drive Shaft (removed)*

The engine oil pump is a small set of gears located outside the case. The oil pump gears can be removed from the rear of the case. The oil pump consists of two gears and is shaft driven. The oil pump shaft is indexed into the planet carrier. The oil pump only turns when the planet carrier turns. The planet carrier only turns when the engine is running. This design is similar to the first three generations.

## Gen 2 MG2 Access

To access MG2 remove the bolts that retain the oil pump. Remove the oil pump and oil pump drive shaft. Remove all the outer rear cover plate bolts. Remove the rear cover; MG2 can be removed by removing MG2 hold-down bolts and disconnecting the MG2 resolver connector. Do not remove inner cover bolts that form a circle; inner bolts secure the MG2 resolver. The resolver will be out of time if you remove the inner bolts. There is no easy way to re-time the resolver in the field.

# SECTION 8 - TOYOTA HYBRID SYNERGY DRIVE (HSD) - SECOND GENERATION

## MG2 Milliohm Test

**Key Points**
*** Zero the leads.**
*** Set meter to 200 milliohm scale.**
*** Test each phase (Three tests in all).**
*** Compare to spec.**
*** All phases should be within 5% of each other.**


***Milliohm Testing MG2***

A DVOM is not accurate enough to test stator windings. The DVOM outputs approximately 2.7 volts at 1 milliamp. The milliohm tester shown varies the output 1-100 milliamps depending on the testing ohm range selected. The accuracy of the milliohm meter shown is within .1 milliohm on the 200-milliohm scale. Accuracy is extremely important when measuring stator windings. Stator windings are typically less than one ohm. Stator windings should not vary more than 5% between phases.

## MG2 Megaohm Test

**Key Points**
*** Measures insulation leakage.**
*** Checks for winding to stator housing shorts.**
*** Meter outputs 50-100-250-500-1000 volts.**
*** Select output based on testing spec or operating voltage.**

A megaohm meter, sometimes called a “megger” is used to test the insulation of the windings. The meter injects the voltage you select through the windings and measures the amount of voltage that leaks to the frame/housing of the motor. The windings, if insulation quality is high, will be isolated from the stator frame/housing. The technician must select the output voltage on the megger.

***Megaohm Testing MG2***

The output voltage spec may be listed in service information; if no voltage is found in service information, select the voltage the system operates at, or if you want to stress the system, pick the next voltage level up.

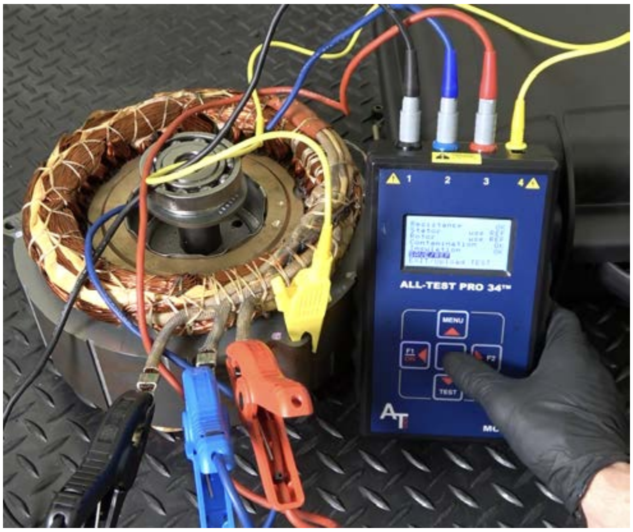
Example: If the operating voltage is 300 volts, select the next level up on the megger, the next voltage level will be 500 volts, but do not go to 1,000 volts this would be too high. If you select the highest voltage on the megger, it may damage windings and insulation. The megger comes with a special set of leads that must be used when performing insulation leak detection. The red lead is attached to a phase wire, and the black lead is attached to the stator frame/housing. Press the test button on the lead or the test button on the meter. The selected voltage should not vary, and the ohmic value should be a minimum of 10 megaohms. If the output voltage drops on the meter and a low ohm value is indicated, the windings are shorted.

## Specialized Motor Testing

**Key Points**
*** Static and dynamic testing**
*** Insulation testing via megaohm test**
*** Winding test via milliohm test**
*** Contamination test**
*** Differentiate rotor from winding test**
*** Current to frequency test**

The AT 34 is designed to test three-phase motors and is optimized for hybrid and electric vehicle motors. The AT34 tests permanent magnet and induction motors. The first step is to pick the type of motor; PM is a permanent magnet motor, and a generator is an induction motor.

# SECTION 8 - TOYOTA HYBRID SYNERGY DRIVE (HSD) - SECOND GENERATION




*Static and Dynamic Testing*

The next step is to attach the yellow lead to the stator housing and the blue lead to the center terminal. The tester will perform the first test, which is the capacitance and dissipation factor; this test reflects contamination in the windings.

The next test is the insulation test which requires the technician to hold the test button down. The tester injects the selected voltage into the windings and measures any voltage that is reaching the stator housing.

The next step is to attach the black lead to terminal one and the red lead to terminal three. The tester now tests the milliohm resistance between phase windings. The results can be viewed at the end of the test. The tester also offers a dynamic test that requires turning the rotor of the electric motor. The dynamic test can verify that the rotor does not exhibit any problems.

## Gen 2 Gear Train Access

To access the gear train, you must separate the two case halves. Remove case bolts and then separate the two halves.

## MG1 Access

**Key Points**
*** Access MG1.**
*** Remove MG1 cover/sprocket support.**
*** Cover has dowel pins.**
*** Do not remove the bolts around the center.**
*** Bolts secure MG1 resolver.**

*Access to MG1*

Access to MG1 requires removing the cover with bearing support. MG1 is located beneath the cover. Again, do not remove the inner bolts that form a circle. The inner bolts secure the MG1 resolver. The resolver will get out of time if you remove these bolts with no effective way of resetting the timing in the field.

## NOTES

# SECTION 8 - TOYOTA HYBRID SYNERGY DRIVE (HSD) - SECOND GENERATION

## MG1 Milliohm Test

**Key Points**
*** Zero the leads.**
*** Set tester to 200 milliohm scale.**
*** Test each phase (Three tests in all).**
*** Compare to spec.**
*** All phases should be within 5% of each other.**


*MG1 Milliohm Testing*

## MG1 Megaohm Test

**Key Points**
*** Measures insulation leakage.**
*** Checks for winding to stator housing shorts.**
*** Meter outputs 50-100-250-500-1000 volts.**
*** Select output based on testing spec or operating voltage.**


*MG1 Megaohm Test*

## Specialized Motor Testing

**Key Points**
*** Static and dynamic testing.**
*** Insulation test via megaohm test.**
*** Winding test via milliohm test.**
*** Contamination test.**
*** Differentiate rotor from winding test.**
*** Current to frequency test.**


*Specialized Motor Testing*

## NOTES

# SECTION 8 - TOYOTA HYBRID SYNERGY DRIVE (HSD) - SECOND GENERATION

## Assemble Gear Train

**Key Points**
*** Gear train, sprockets, and chain.**
*** Assemble in order.**
*** Ball bearings snug fit.**
*** Lubricate the bores of the bearings to aid installation.**

*Assembling Gear Train*

## Notes

## Notes

# SECTION 9 - TOYOTA HYBRID SYNERGY DRIVE (HSD) - THIRD GENERATION

## Third-generation Design

*Third Generation HSD Cutaway*

The third-gen design was introduced in 2006 Highlander and Camry. The third gen made its way into the Prius model in 2010.

## Changes

**Key Points**
*** Eliminated chain**
*** Gear to gear design (1.019 ratio)**
*** Retains power split device**
*** MG2 downsized**
*** Maintain inline axis**
*** Retain MG1 & MG2**

Some notable changes in the third generation are that the chain has been deleted. The gear train now is gear to gear design with a 1.019:1 ratio from outer ring gear to countershaft driven gear. The third design retained the MG1, and MG2 arranged in an inline axis. The planet carrier is still splined to the clutch disc at the engine. MG1 is still splined to the sun gear in the power split device. MG2 is no longer splined to the internal ring gear it is now splined to another sun gear. MG1 speed rating has been updated from 10,000 RPM to 13,500RPM.

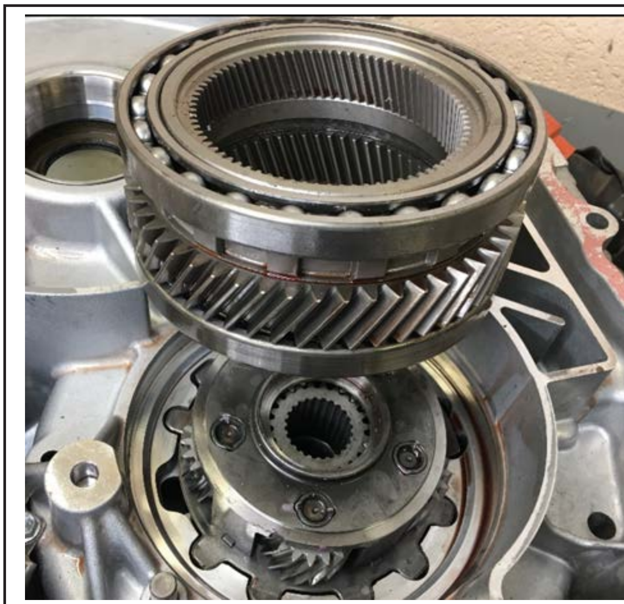
The unit retains the power split device and adds an additional gear reduction planet.
Instructor Notes: missing something here??
Production Notes: Movie- electric drive gear ratio

## Gear Ratio


*Counter Driven Gear and External Gear (ring gear)*

The Common ring gear has an external gear integral to it (Counter drive gear). The external gear has 54 teeth, and the countershaft-driven gear has 55 teeth which give it a 1.019 gear ratio. The earlier models used a chain at this location with an overdrive ratio; the new design has a slight underdrive ratio.

Another planetary has been added to the third gen design. The new planetary set interfaces with MG2. The planet carrier indexes into the case and becomes stationary.



*Third Generation Planetary*

## SECTION 9 - TOYOTA HYBRID SYNERGY DRIVE (HSD) - THIRD GENERATION

The sun gear splines into MG2. The internal ring gear becomes common to the power split device. The gear reduction planetary increases the torque of MG2. The gear reduction and the torque increase are 2.63:1. The torque increase allows for a downsized MG2 and can still increase overall torque output.

### Gear Reduction Planetary

*Third Generation Reduction Planetary*

MG2 in the previous designs is splined into the internal ring gear. MG2, on the third gen design, splines into the gear reduction sun gear. The planet carrier is held stationary by the case.

### Total Gear Ratio

**Key Points**
*** Counter drive gear to the Counter driven gear:**
**——1.019:1**
*** MG2 reduction gear:**
**——2.63:1**
*** Final drive ratio:**
**——3.208:1**

The total gear ratio in the third gen models is quite a bit lower than the two previous generations due to the gear reduction unit used with MG2. The first gear ratio involved is the counter drive gear and counter driven gear; this produces a slight underdrive ratio of 1.019:1. The second gear ratio is from MG2 reduction planetary, which is 2.63:1. The third ratio involved is the pinion gear to differential ring gear which results in a 3.208:1 ratio.

Multiply all three gear ratios to increase the total gear ratio and the total torque.

### Total Gear Ratio/Torque

**Key Points**
*** Electric Drive only**
*** MG2 gear reduction 2.63:1**
*** Final drive gear reduction 3.208:1**
*** Counter drive & counter driven gear 1.019:1**
*** 2.63 X 3.208 X 1.019 = 8.597:1**

Gen one 3.89:1
Gen two 4.11:1
Gen three 8.597:1

Gen one produced a total gear ratio of 3.89:1, and gen two produced a total gear ratio of 4.1:1. Gen three produced a whopping 8.597:1 total gear ratio.

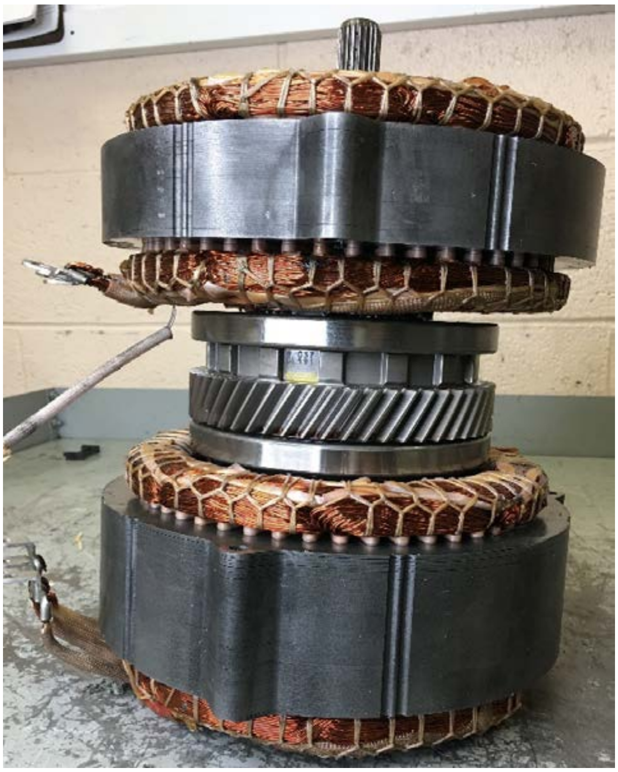
### Common Ring Gear

*Third Generation Common Ring Gear*

It is common in modern automatics for a ring gear to be familiar to two planetary devices. This is referred to as a Lepelletier planetary design. In the third gen design the ring gear is shared between the gear reduction unit and the power split device. The common ring gear is the location where MG2 and the engine combine torque output to the rest of the gear train. The common ring gear has an integral external gear which is called the counter drive gear. The counter-drive gear provides gear-to-gear power transfer to the counter-driven gear.

# SECTION 9 - TOYOTA HYBRID SYNERGY DRIVE (HSD) - THIRD GENERATION

## MG2 - Third Generation



*Third Generation MG2 Assembled*

Even though the third-gen design lowered the torque of MG2 from 295 lb.-ft down to 153 lb.-ft, the overall torque was increased. The gear reduction planet provides a 2.63:1 torque multiplication. 153lb.-ft X 2.63 = 403lb.-ft of torque compared to second gen at 296lb.-ft of torque.

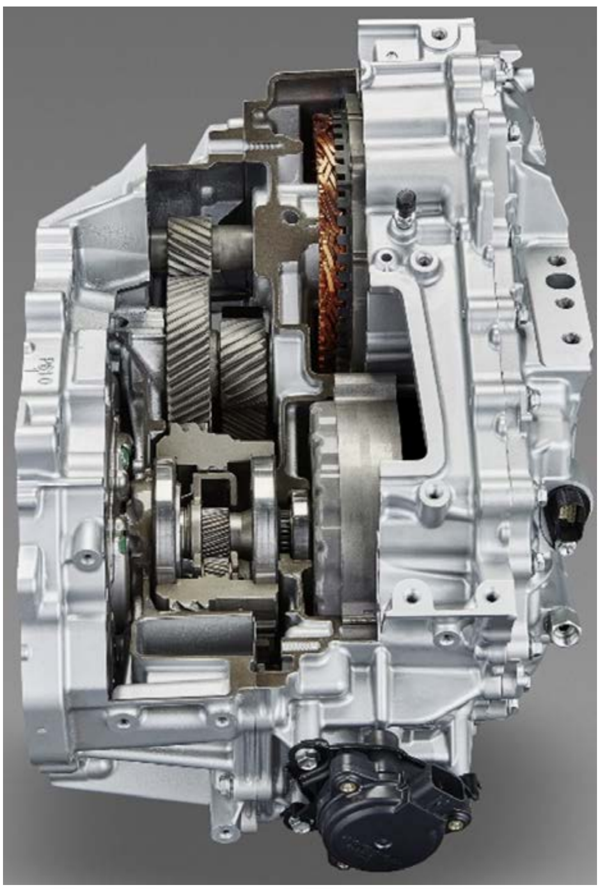
## Notes

## Notes

# SECTION 10 - TOYOTA HYBRID SYNERGY DRIVE (HSD) - FOURTH GENERATION

## 2016-2017 Prius

**Key Points**
*** Retains power split device.**
*** Planet carrier still splines to clutch disc.**
*** Planet carrier still drives oil pump shaft.**
*** MG1 splines to the sun gear.**
*** Parallel axis design.**



*Fouth Generation HSD (2016-2017 Prius)*

The fourth generation retains the power split device. The planet carrier still splines into the clutch disc and drives the oil pump shaft. Any time the engine is running, the oil pump is operational. MG1 still splines to the sun gear.

The common ring gear used in the third generation has been deleted and returned to a single internal ring gear. The power split device operates the same way through all four generations. MG1 and MG2 are no longer located on an inline axis but are now located on a parallel axis.

MG1 is rated at 23KW/31HP 40 Nm/30lb.ft torque. MG1 also helps propel the vehicle under certain conditions.

## Power Split Device


*Single Internal Ring Gear in PSD*

The fourth gen single internal ring gear has an integral parking gear, and an integral external gear called a counter drive gear. This is like the third gen, except that the third gen had two internal ring gears called a common ring gear.

## MG2 Drive Gear


*MG2 Drive Gear*

MG2 splines to MG2 drive gear. The drive gear is supported by two ball bearings. The third gen design MG2 splined into a sun gear of the gear reduction unit. MG2 output rating 53KW/71HP and 163Nm/120lb.-ft of torque. MG1 and MG2 have lower output power in the fourth gen than any other generation previously.

## SECTION 10 - TOYOTA HYBRID SYNERGY DRIVE (HSD) - FOURTH GENERATION

The lower output of MG2 requires torque multiplication to maintain similar power output. MG2 drive gear is small, and the counter-driven gear is large, meaning we have a gear reduction or torque increase from MG2 to the counter-driven gear.

### Counter-Driven Gear

*Fourth Generation Counter-Driven Gear*

The counter-driven gear has two gears integral to the same shaft. The larger gear is the counter-driven gear which mates with the MG2 drive gear and counter drive gear. The counter-driven gear is where all the power from MG2, MG1, and the ICE are combined. The small gear is called the pinion gear and mates with the differential ring gear.

### Electric Drive Torque

*** Total gear ratio from MG2 to wheel**
**——10.838:1 (Prius)**
**——12.3:1 (Prius Prime)**
**——Lower gear ratio makes up for lower torque output of MG2**
*** MG2 120lb.-ft X 10.838 = 1300.56lb.-ft**
*** MG2 120lb.-ft X 12.3 = 1476lb.-ft**

To obtain total torque in electric drive only, you must multiply each gear ratio in use to obtain the total gear ratio. Multiply total gear ratio times MG2 torque output to obtain max torque to the wheels. The chart above does not count the torque the engine is contributing; this is electric drive only.

| | Total gear ratio MG2 | Output torque MG2 | Output torque max |
|---|---|---|---|
| Gen 1 | 3.89:1 | 258 | 1003 |
| Gen 2 | 4.1:1 | 295 | 1209 |
| Gen 3 | 8.57:1 | 153 | 1311 |
| Gen 4 | 10.838:1 | 120 | 1300 |
| Gen 4 | 12.3:1 | 120 | 1476 |

*Electric Drive Torque by Generation*

The torque output of MG2 increased from Gen 1 to Gen 2 and then decreased every generation after that; even though MG2 torque output was decreased, the total output torque increased due to lower gearing. MG1 and MG2 are lighter weight than earlier models along with updated construction allow the rotors to rotate up to 17,000 RPMs.

### Gear Train Interaction

*Gear Train Parallel Design*

The parallel design can be observed in the image above. MG2 is the larger motor, and MG1 is the smaller motor. The counter-driven gear is between the motors and interacts with MG1, MG2, and the ICE. For all generations, if MG2 is rotating, the internal ring gear of the power split device rotates.

# SECTION 10 - TOYOTA HYBRID SYNERGY DRIVE (HSD) - FOURTH GENERATION

## MG1 Speeds Gen 1 through 4

* Gen 1 6,500RPM limit.
* Gen 2 10,000RPM limit.
* Gen 3 13,500RPM limit.
* Gen 4 17,000RPM limit.
* MG1 RPM limit increases allowing for faster EV mode speeds.

## Assessment

## Questions

Question: True or False? First, second, and third-gen mode motors are arranged in an inline axis

Question: What was the purpose of adding a planetary to MG2 in the third design?

Question: True or False? The fourth generation design uses a parallel axis motor arrangement.

## Questions with Answers

Question: True or False? First, second, and third-gen mode motors are arranged in an inline axis
**Answer: True.**

Question: What was the purpose of adding a planetary to MG2 in the third design?
**Answer: MG2 had a lower torque output, so the planet provided a 2.63:1 torque increase to make up for the loss from the motor and improve overall torque output.**

Question: True or False? The fourth generation design uses a parallel axis motor arrangement.
**Answer: True.**

# SECTION 11 - HONDA DUAL MOTOR/E-DRIVE, E-CVT-MMD

## Honda Dual Motor

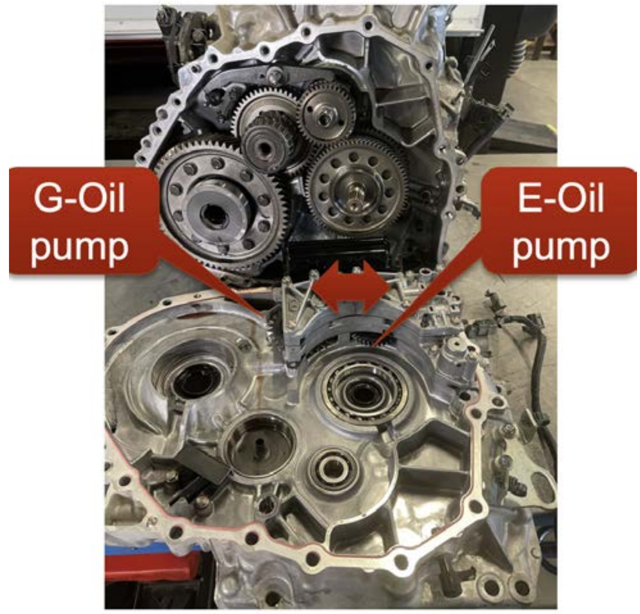
**Key Transaxle components.**
*** Two oil pumps.**
*** Parking mechanism.**
*** Two electric motors.**
*** Clutch pack.**
*** Countershaft.**
*** Differential.**
*** Traction motor shaft.**
*** Generator motor shaft.**
*** Overdrive gear.**
*** Input gear.**
*** Clutch disc assembly.**

***Honda Transaxle Cutaway***

Honda has various names for the new hybrid system, dual motor, E-Drive, e-CVT, and multi-mode drive. The transaxle is where the electric motors reside; the inverter is remotely located, usually above the transaxle. The transaxle consists of two oil pumps, a parking mechanism, two electric motors, a single clutch pack, countershaft, differential, traction motor shaft, overdrive gear, input gear, and clutch disc assembly. We will identify all the parts and the power flow in the upcoming slides. This design is the first one we have covered so far in this class with a multi-disc clutch.

The dual motor found in Insight, Accord, CRV, Clarity, and Clarity PHEV

## Oil Pumps




***G and E Oil Pump Locations***

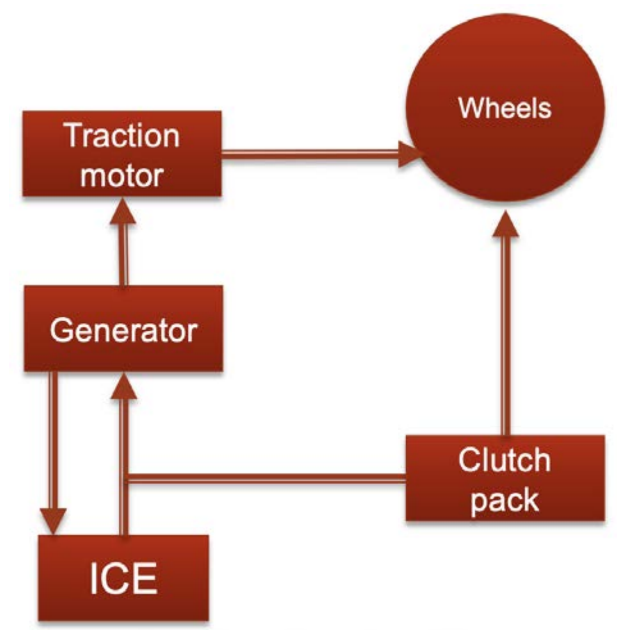
The transaxle utilizes two oil pumps. One oil pump is driven by the engine, which can provide lubrication when the vehicle is stopped. The engine oil pump is driven off the input gear. The other oil pump is driven by the differential.

This oil pump can provide lubrication and create pressure to apply the hydraulic multi-disc clutch pack when the vehicle is moving. There is an external pressure sensor to monitor hydraulic pressure that is located on the outside of the case.

The pump housing also includes a small valve body. The valve body includes two shift solenoid valves to control the hydraulic pressure to the overdrive clutch pack. Shift solenoids A and B are located on the outside of the flywheel housing.

# SECTION 11 - HONDA DUAL MOTOR/E-DRIVE, E-CVT-MMD

## Honda Dual Motor




*Dual Motor Operational Chart*

The ICE can directly drive the wheels via an overdrive clutch. The System is designed to allow electric mode at lower to medium speeds and engine mode at highway speeds. The engine and EV modes will continually switch back and forth at higher speeds depending on the high-voltage battery charge.

The dual-mode design does not combine electric and ICE together to provide power to the wheels unless a quick acceleration event occurs. It is either in electric drive or engine drive most of the time. The internal combustion engine switches the generator into generator mode to power the traction motor and charges the high-voltage battery.

The generator in motor mode starts the ICE. The generator does not power the wheels at any time. The traction motor provides power to the wheels via gear train in motor mode and charges a high voltage battery in generator mode.

## Gear Shift Position

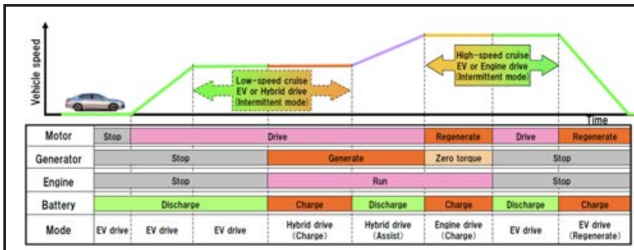
| Position | Description |
|---|---|
| P: PARK | Front wheels locked; the parking brake pawl engaged with the parking gear on the motor shaft. Over drive clutch is released. Traction motor does not rotate. |
| R: REVERSE | Traction motor rotates in reverse direction. The motor shaft drives the countershaft in reverse rotation. |
| N: NEUTRAL | Over drive clutch is released. Traction motor does not rotate. |
| D: DRIVE | General driving; D position/mode has three driving modes; EV drive mode, HV drive mode, and engine drive mode. |

*Shift Position Actions*

The gear selection offers four positions, park, reverse, neutral, and drive. In park, the parking pawl is locked to the parking gear via an electric park motor. To obtain reverse, the large traction motor simply turns in reverse. In the neutral position, the overdrive clutch is released, and power is cut from the traction motor. In the drive position, three modes are available with no driver input, EV drive, hybrid drive, and engine drive mode.

## Three Operating Modes

**Key Points**
*** Electric drive only**
**——ICE off**
**——Large traction motor propels the vehicle**
*** Hybrid drive**
**——ICE on**
**——Generator outputting**
**——Large traction motor propels the vehicle**
*** Engine Drive**
**——ICE propels the vehicle**




*Operational Mode Functions*

Honda's dual motor design is different from Toyota's design. The Toyota design would combine traction motor and ICE torque to propel the vehicle at times. The Honda dual motor either propels the vehicle with a traction motor or propels the vehicle with the ICE it does not combine the two unless a quick acceleration event is occurring.

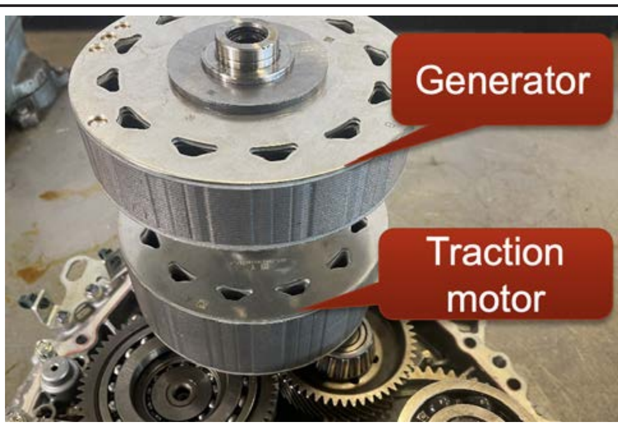
# SECTION 11 - HONDA DUAL MOTOR/E-DRIVE, E-CVT-MMD

The dual motor offers three basic modes of operation: electric drive only, hybrid drive, and engine drive. Electric drive only consists of the traction motor propelling the vehicle using power from the high voltage battery with the ICE off. In hybrid drive, the ICE is running, rotating the generator (small motor) to provide energy to the traction motor, and the traction motor propels the vehicle.

Engine drive, the ICE is running, providing power to the gear train. It is propelling the vehicle via overdrive clutch with no assist from the traction motor, unless a quick acceleration event is occurring. The engine is driving the vehicle, and the large generator can be used to generate power to recharge the high voltage battery if needed. In higher speed driving, the engine will shut off when the high voltage battery is full and switch back to electric drive, and then the engine will restart and return to engine drive when the battery depletes.

Both the engine and electric motor send power through the same gear (counter gear). It would be possible to combine the electric motor and engine power any time the engine is running. Still, Honda seems to use either one or the other. Again, Honda does not combine them except when a quick acceleration event is desired.

**Electric Motors**

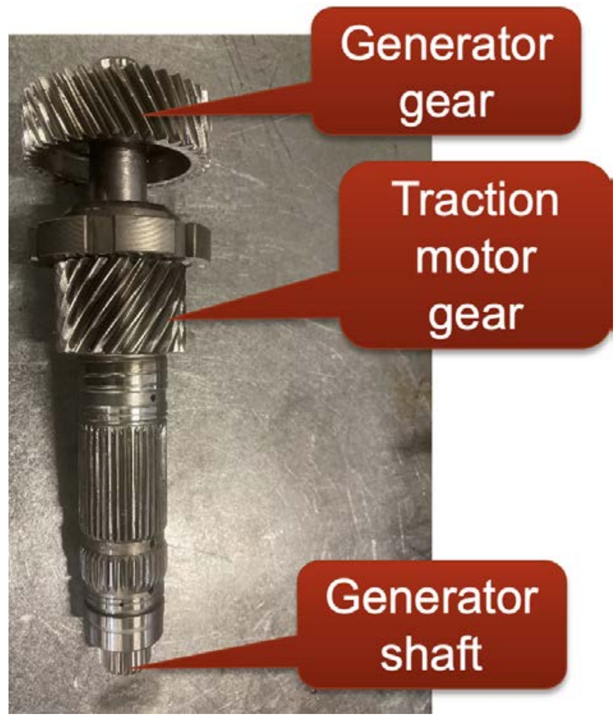



***Generator and Traction Motor Locations***

Two electric motors reside inside the transaxle. The smaller electric motor is a generator and provides the function of starting the ICE and charging the high voltage battery as well as providing power for the larger traction motor.

The larger electric motor provides power to the wheels via the gear train in motor mode and charges the high voltage battery when in generator mode.

**Two Shafts**



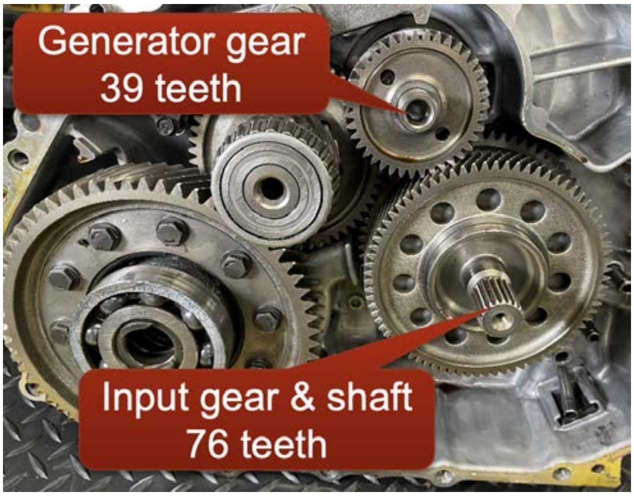

***Generator and Traction Motor Gear and Shaft***

Two shafts interface with the electric motors and the gear train. The generator shaft splines into the small electric motor and engages the input gear. The generator shaft cranks the engine, and after the engine starts, the engine drives the generator shaft to produce power to charge the high-voltage battery and power a large traction motor.

The traction motor shaft splines into the larger traction motor. The traction motor drives the gear train to propel the vehicle down the road. The traction motor shaft also includes the parking gear. Anytime the wheels are moving, the large traction motor is turning.

# SECTION 11 - HONDA DUAL MOTOR/E-DRIVE, E-CVT-MMD

## Engine Crank




*Generator, Input, and Shaft Tooth Count*

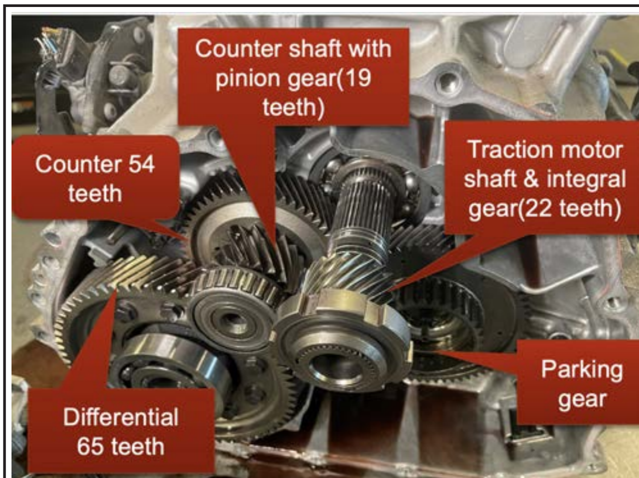
Input shaft splines into the clutch plate. The clutch plate indexes into the flywheel. The generator starts the engine with an 8.44:1 gear ratio. The generator gear (drive gear) has 39 teeth, and the input gear that splines to the clutch plate has 76 teeth (driven gear). 76 ÷ 39 = 8.44 (The gear ratio during cranking the generator turns 8.44 times to every one revolution of the crankshaft.

## Clutch Disc

The input shaft splines into the clutch disc that bolts to the flywheel. The clutch disc is always engaged with no release mechanism. The clutch disc includes damper springs to absorb torque pulsations from the ICE combustion events. The clutch disc provides a pathway for power to flow from the engine to the transaxle and provides a path for power for the generator to crank the engine. The clutch disc is also referred to as the drive disc and provides a torque-limiting function or a breakaway function.

## EV Mode 8.379:1 TGR

The traction motor shaft travels through the case and splines into the traction motor. The traction motor shaft has an integral gear along with the parking gear. When park is engaged, it locks the integral gear, shaft, and traction motor from rotating. The integral gear meshes with the countershaft, which is meshed with the differential, so all these components are locked together in Park and are not allowed to move.




*Transaxle Gear Tooth Counts*

In EV mode, the traction motor gear drives the countershaft large gear, the countershaft small gear (Pinion) drives the differential ring gear, and the side gears inside the differential carrier drive the axles. The gear ratio in the electric drive can be calculated by the formula-driven gear divided by the drive gear multiplied times the next gear ratio.

The traction motor shaft is slid back and is not engaged with the countershaft in this picture, so the shaft can be seen.

**54 ÷ 22 = 2.45**
**65 ÷ 19 = 3.42**
**2.45 X 3.42 = 8.379 (Electric drive only gear ratio)**

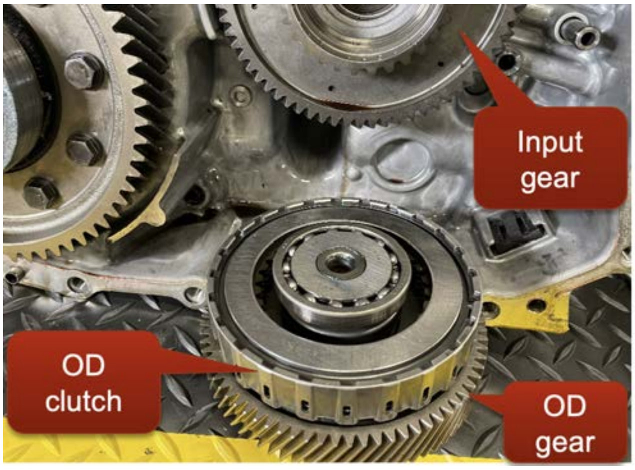
All the Honda models used the differential ratio of 3.42:1 except the 2020 and above CRV, which has a 3.882:1 ratio. The CRV has added one tooth to the ring gear to 66 teeth and decreased the pinion from 19 teeth to 17 teeth.

## Engine Drive

**Key Points**
*** Power flow comes from the engine via input shaft/input gear.**
*** Clutch pack applied.**
*** Engages overdrive gear.**
*** O/D gear meshes with counter gear.**

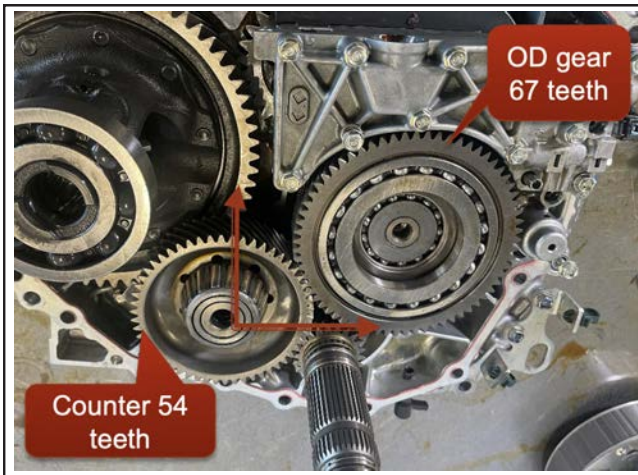
Power flow in engine drive starts at the input shaft/input gear; the input gear and input shaft are integral to one another.

# SECTION 11 - HONDA DUAL MOTOR/E-DRIVE, E-CVT-MMD




*Input Gear, OD Clutch and OD Gear*

The input shaft is engaged to the clutch disc, which is driven by the engine. The input shaft transfers torque to the OD gear via the overdrive clutch. The OD clutch is a multi-disc wet clutch that is hydraulically activated by the pump, valve body, and shift solenoids. The OD gear transfers power to the countershaft, and the countershaft pinion gear drives the differential.




*OD Gear and Counter Tooth Count*

The OD gear (drive gear) meshes with the counter gear (driven gear) to send power through the counter gear to the pinion gear that is located on the same shaft. Then power is sent to the differential. The gear ratio on the engine side is 54 ÷ 67 = .805 This is an O/D ratio for the input to the differential. The differential ring gear has 65 teeth (driven gear), and the pinion has 19 teeth (drive gear). 65 ÷19= 3.42
Total gear ratio 3.42 X .8 = 2.7

**54 ÷ 67 = .805**
**65 ÷ 19 = 3.42**
**3.42 X .805 = 2.75**

To compare with the Honda Accord non-hybrid in a six speed manual transmission, the total gear ratio in sixth gear is 2.82. The hybrid and the non-hybrid are similar in overall gear ratios at highway speeds.

The picture illustrates that no matter if the engine or traction motor, or both are powering the gear train, all the torque flows through the counter gear due to the overdrive gear and traction motor gear both engaging the counter gear.

The arrow in the previous image denotes power flow from overdrive gear to counter shaft.

**Gear Ratios**

*** Engine drive gear ratio for highway driving**
**——2.75:1**
*** Electric drive mode**
**——8.379:1**
*** Engine cranking**
**——8.44:1**

2.75 X 99lb.-ft = 272lb.-ft of torque available in engine drive mode.

The engine produces 107 horsepower and 99lb.-ft of torque. Multiply the engine torque times the total gear ratio to obtain maximum torque output in engine drive mode. 2.75 X 99 = 272 lb.-ft of torque.

**Electric Drive Max Torque**

*** 197lb.-ft X 8.379 = 1650lb.-ft of torque in electric drive.**
*** Electric drive offers more torque to propel the vehicle up to speed.**

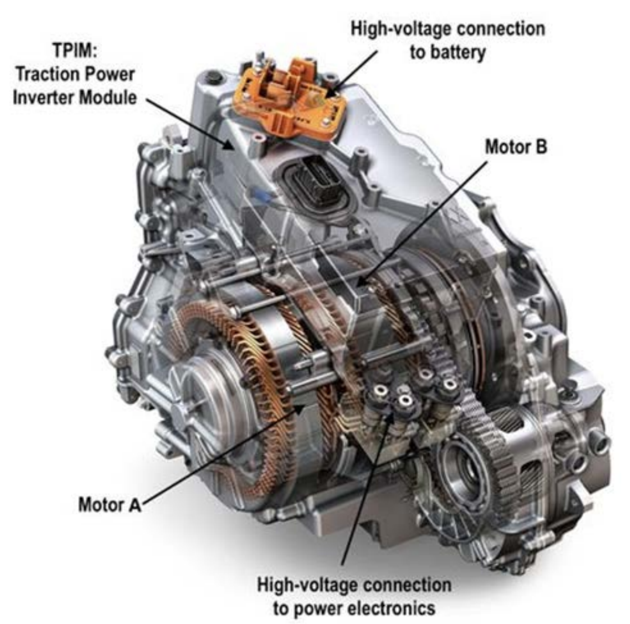
The large traction motor provides 197lb.-ft of torque up to 3,000 RPM. Multiply the torque times the total gear ratio to obtain max torque output in electric drive. 197lb.-ft X 8.379 = 1650lb.-ft of torque in electric drive only up to 3.000 RPM, and then the torque will start to decrease due to back EMF.

# SECTION 12 - CHEVROLET VOLT - SECOND GENERATION

Our goal in this section is to point out the complexity of this transmission compared to all the previous ones we discussed. This is an extended-range vehicle, which is a lot more complicated. The transaxle has three multi-disc wet clutches, two that rotate and one that is stationary. A one-way clutch which we have not seen in any previous designs, two planetaries, chain and sprockets, differential, two motors, a valve body with multiple solenoids along with a line pressure solenoid. This transmission incorporates features from a traditional automatic transmission with features from a hybrid transaxle.

The focus is to point out the complexity of all the parts, how the parts sit in the case along with the name of each part. At the end of the section we show how all the parts interact with each other. Just realize the Chevy Volt could be a four-hour class alone.

**Chevy Volt/Two Generations**




*Chevrolet Volt Transaxle Cutaway (Gen 2)*

The Chevy Volt transaxle is a very complex design. There are two versions available depending on the first or second generation. The first generation featured a 4ET50 transaxle, The transaxle designation number (4) reflects four modes, not four speeds (as other GM transmissions have indicated in the past), an electric transaxle, and 500-newton meters of torque capacity.

The 5ET50 is a five-mode electric transaxle with 500-newton meters of torque capacity.

Never attempt to lift these transmissions alone. They weigh over 400 pounds. The 5ET50 has many updates compared to its predecessor. Extended range operation now has three modes instead of two modes, and EV modes retain two modes, just like the 4ET50. The rare earth materials used in the 4ET50 have been eliminated in the small motor and reduced by 40 percent in the large motor. The 4ET50 only used one planetary, whereas the 5ET50 used two planetary gear sets.

**Comparison of Gen 1 and Gen 2 Voltec drive units**

| | Gen 1 | Gen 2 |
|---|---|---|
| Gear ratio, EV mode | A: 1.45<br>B: 3.24 | A: 2.87<br>B: 3.08 |
| Modes, engine on | 2 | 3 |
| Final drive arrangement | Parallel axis gear reduction | Chain transfer and planetary gear reduction |
| Motor A type | Concentrated winding<br>NdFeB magnet | Distributed bar wound<br>Ferrite magnet |
| Motor A peak torque/power | 186 N·m/55 kW | 118 N·m/48 kW |
| Motor B type | Distributed bar wound<br>NdFeB magnet | Distributed bar wound<br>NdFeB magnet |
| Motor B peak torque/power | 370 N·m/111 kW | 280 N·m/87 kW |
| Final effective drive ratio | 2.16 | 2.64 |
| Power electronics | Separately mounted | Integrated |
| Pumps | 1 engine-driven<br>1 motor-driven | 1 motor-driven |
| Transmission fluid | Dexron VI | Dexron VI |
| Total system mass | 164 kg | 119 kg |

*Gen 1 and Gen 2 Comparison Table*

**Transaxle Components 5ET50**

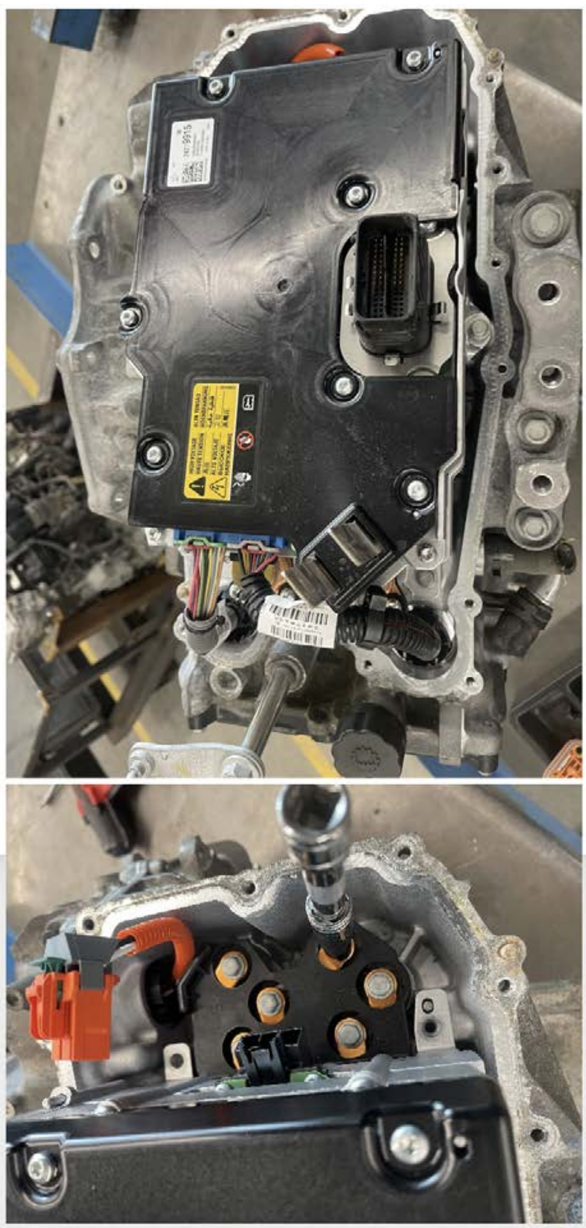
**Key Points**
*** Input flange.**
*** Torque converter dampener with a rotating friction clutch.**
*** One stationary friction clutch and one rotating friction clutch.**
*** Two planetary gear sets.**
*** Two electric motors.**
*** Chain drive.**
*** Hydraulic valve body with solenoid block.**
*** Three-phase electric pump.**
*** Power inverter.**

The Chevy Volt is far more complex and has many more parts than most hybrids. The Chevy Volt also offers more driving modes than most other hybrids.

## SECTION 12 - CHEVROLET VOLT - SECOND GENERATION

The 5ET50MKV has a torque converter dampener with a rotating friction clutch inside, input flange, stationary clutch, rotating clutch, two planetary assemblies, two electric motors, three phase pump, chain drive, hydraulic valve body assembly with solenoid block, and a power inverter. This hybrid transaxle combines features from traditional automatics like valve bodies, planetaries, and multi-disc clutches.

### Electrical Components 5ET50



*Chevrolet Volt 5ET50 Electrical Components*

The power inverter is not remotely located. It is located underneath a large cover at the top of the transaxle; this location eliminates the need for long high voltage cables. The inverter Receives DC from the high voltage battery converting the DC to simulated AC to power the electric motors and the three-phase pump inside. The inverter has very robust electrical connections from the inverter to the motors. The connections are all internal to the transaxle, so that eliminates the possibility of amp testing the motors with amp clamps and scope.

### Valve Body-Solenoid Block

*5ET50 Valve Body-Solenoid Block*

The valve body consists of a control solenoid valve block assembly which contains a fluid temperature sensor, four shift solenoid valves (Pressure control), eight-pin electrical connector. The solenoid valve block bolts directly to the valve body and must be replaced as an assembly. The main valve body houses the line pressure control solenoid valve. The line pressure control solenoid is in the H bore.

# SECTION 12 - CHEVROLET VOLT - SECOND GENERATION

The bores on the main valve body are marked A-H. The line pressure control solenoid is a variable force solenoid that increases and decreases line pressure based on the current flow to the solenoid. Line pressure is used to apply clutch packs, provide lube, and help engage motors.

The line pressure solenoid is tested at the factory using electrical current over fluid pressure. All current to pressure data points are saved and assigned a file number. The file number is stamped on the line pressure solenoid. If a new solenoid is installed, the power control module will need to be reprogrammed with the file number of the newly installed solenoid, or if a new module is installed, the original file number will need to be written into a new module.

## Internal Mode Switch (IMS)

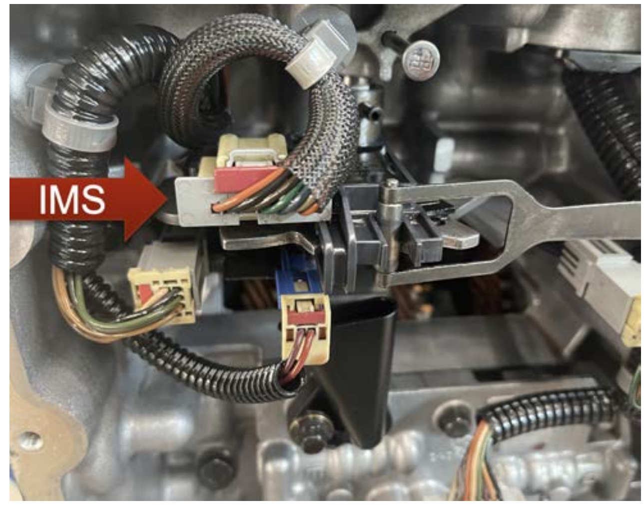
Internal Mode Switch

| Internal Mode Switch Circuits/Parameter | Selector Position | | | | |
|---|---|---|---|---|---|
| | Park | Reverse | Neutral | Drive | Low |
| **Switch Operating Conditions:** Ignition ON, range selector in appropriate gear | | | | | |
| Internal Mode Switch A | High | Low | Low | High | High |
| Internal Mode Switch B | Low | High | High | Low | Low |
| Internal Mode Switch C | High | High | Low | Low | Low |
| Internal Mode Switch P | Low | Low | High | High | High |
| Internal Mode Switch S | Low | High | Low | High | Low |
| Always High status: Open/short to voltage condition<br>Always Low status: Short to ground condition | | | | | |

*Internal Mode Switch (IMS) Function Chart*

GM has relied on an internal mode switch to report gear selection on many models. This is not a hydraulic assembly like some other GM models use. This is an electrical sliding switch. The internal mode switch denotes park, reverse, neutral, drive, and low by switching states from high to low as the internal shift linkage moves. The switches simply change states and can be observed by a scan tool and compared to a chart.

The internal mode switch (IMS) is located on the shift linkage internal to the transaxle next to the valve body. The IMS is a sliding switch that is attached to the rooster comb.

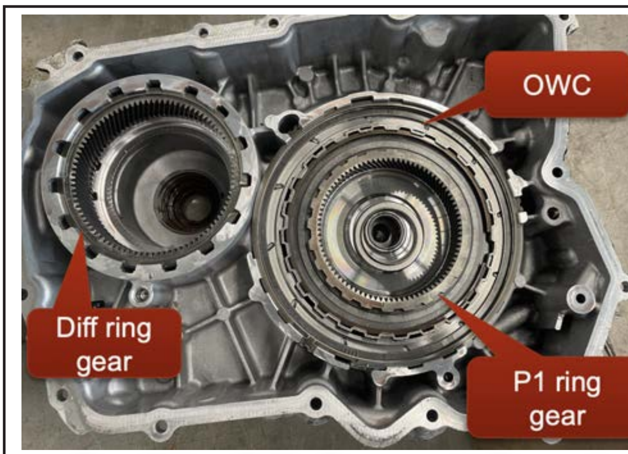



*Internal Mode Switch (IMS) Internal Location*

The driver, via a cable, moves the internal shift linkage to the desired gear.

There is no manual valve in the valve body like a conventional automatic. There are five switches located in the IMS that change states as the shift linkage slides through its range. The switches are labeled A-B-C-P-S. The IMS switches are hall effect designed and supplied with a nine-volt reference signal. The switch states are .7-.96 volts to switch state on, and 1.68-2.38 volts to switch state off. The switch states can be read on a scan tool as stated earlier and can be compared with the chart provided.

## Components




*Case Halves Split - Components Exposed*

Case halves split; this half houses the differential internal ring gear, P1 ring gear, and one-way clutch

## SECTION 12 - CHEVROLET VOLT - SECOND GENERATION

shown in the picture. It also contains the input flange, torque converter dampener, and the bypass clutch not shown in the picture.

The reason some of the parts are not shown is that they are located underneath the one-way clutch and P1 ring gear. They will be shown later.

### Input Flange

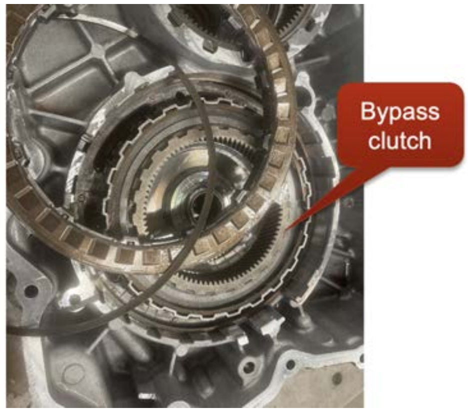
The input flange transfers torque from the engine to the drivetrain and provides a torque path for starting the engine. The front seal sits behind the input flange. The input flange is bolted on from the inside of the transaxle. You must split the two case halves to remove the input flange to replace the front seal.

### Torque Dampener Assembly

*Torque Dampener*

The torque dampener is bolted to the input flange. It contains coil springs that smooth out torque from the engine to the P1 planet.

### Bypass Clutch




*Bypass Clutch*

The dampener bypass clutch directly links the engine to the transmission bypassing the dampener. The bypass clutch is engaged during engine start, and various other conditions refer to operating modes and hydraulic diagrams to determine all conditions when the bypass clutch is applied.

Instructor notes: The picture on left is of the actual clutch assembly. The right picture shows where the clutch is in the front case half.

### One-Way Clutch


*One-way Clutch*

A one-way clutch locks in one direction and transmits torque in the other direction of rotation only; a one-way clutch freewheels in the opposite direction of rotation and transmits zero torque in that direction. One-way clutches have been used in automatic transmissions for years.

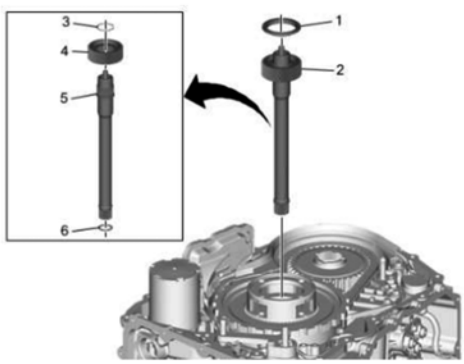
# SECTION 12 - CHEVROLET VOLT - SECOND GENERATION

The one-way clutch in the Volt prevents the engine from turning backward when MGA, (motor generator A), produces torque by freewheeling in that direction.

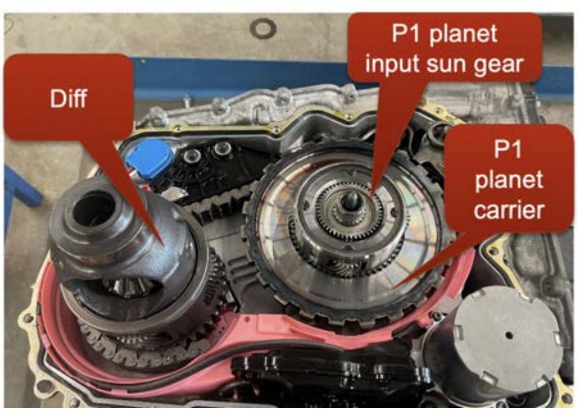
## Components

**Key Components**
*** P1 planet carrier.**
*** P1 Input sun gear.**
*** Travels to MGA.**

**Input Sun Gear Shaft Removal**




*Input Shaft Location*




*Differential, P1 Input Sun Gear and Planet Carrier*

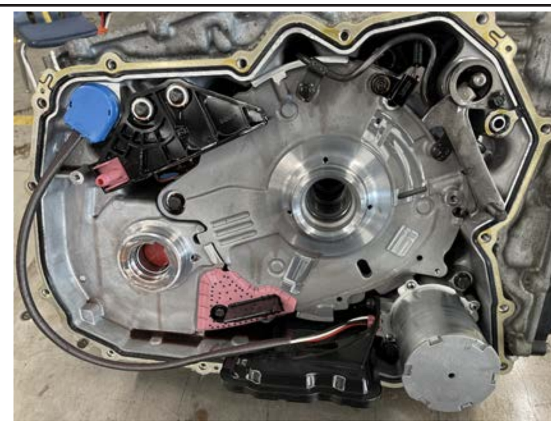
The two planetaries interact with the electric motors and clutches to provide a continuously variable transmission ratio. The input sun gear travels to the rear of the case and splines into MGA. The differential transfers the power from the transmission to the wheels allowing for a difference in speed traveling around corners.

## Chain & Sprockets


*Chain and Sprockets*

The chain and sprockets transfer power from the transmission to the differential.

## Three Phase Pump

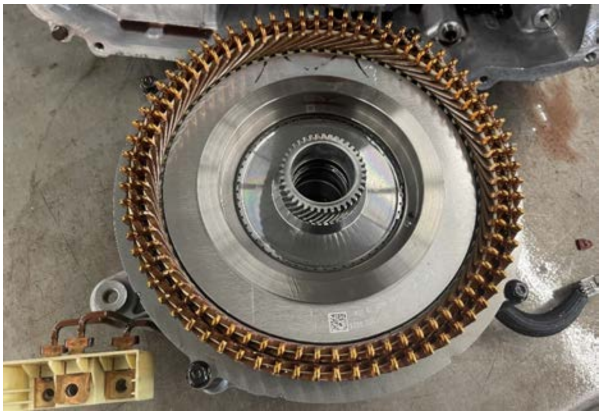


*Three-Phase Pump (installed)*

Three-phase pump driven by high voltage from the inverter. The pump supplies the lubrication and provides line pressure for the multi-disc clutch packs.

# SECTION 12 - CHEVROLET VOLT - SECOND GENERATION

## Motor Generator B



*Motor Generator B (MGB)*

MGB is the larger motor, and the rotor is attached to sun gear. MGB transfers power through the sun gear to the P2 planetary. MGB interacts with MGA for forward driving propulsion, and MGB provides all the power for reverse. MGB may also be labeled drive motor 2nd position.

## P2

*Planetary (P2)*

**Key Points**
*** Located in the rear of the case sits between MGA & MGB.**
*** MGB sun gear engages P2.**
*** Sprocket shaft engages P2 planet carrier splines.**

P2 planetary sits in the rear of the case. MGB sun gear engages P2 planet carrier.

## Motor Generator A

*Motor Generator A (MGA)*

MGA sits in the rear of the case. MGA houses two clutch packs. The variable low and the variable high. MGA may also be labeled drive motor 1st position.

## MGB-Left MGA-Right

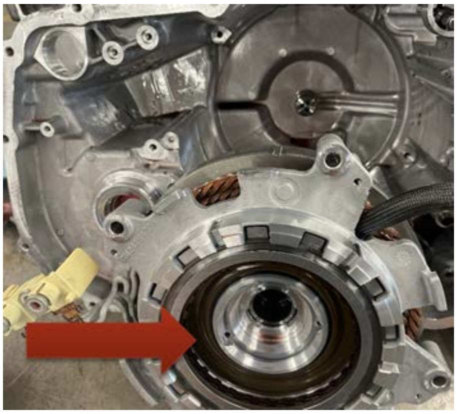
*MGB and MGA Comparison*

MGA is smaller and sits in the rear of the case.

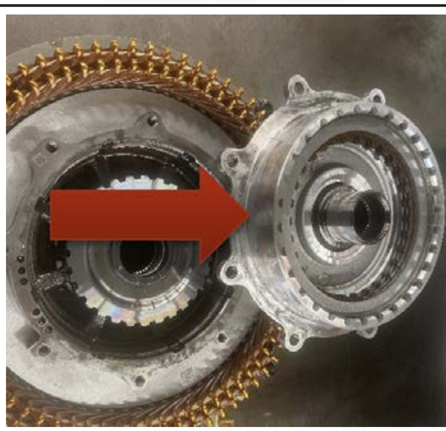
## NOTES

## SECTION 12 - CHEVROLET VOLT - SECOND GENERATION

### Variable Low & High Clutches



*Variable Low Clutch*

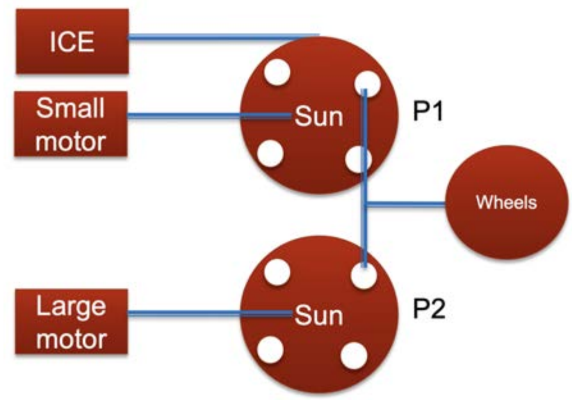


*Variable High Clutch*

The variable low clutch is mounted to the front of the MGA and sits ahead of the variable high clutch that is located on the rear of the MGA; the variable high clutch is in the very rear of the case.

### NOTES

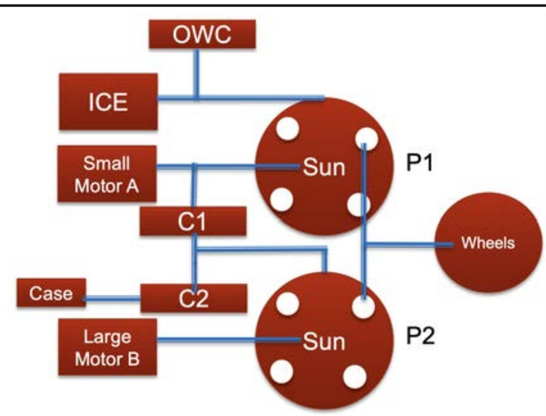
### Powertrain




*Powertrain Flow of Power*

**Key Points**
*** ICE connects to P1 ring gear.**
*** Small motor connects to the P1 sun gear.**
*** Large motor connects to the P2 sun gear.**
*** Planet carriers connected to each other & wheels.**

The engine is connected to the internal ring gear planetary one (P1). The smaller motor MGA is connected to sun gear on P1 through the input sun gear with a long shaft. The large motor houses a sun gear that is connected to planetary 2 (P2). The two planetary carriers are connected to each other, and then they are connected to the wheels. Three clutches control the operation of the unit.




*Powertrain Flow of Power (clutches applied)*

When clutch one (Variable high) is applied, it links the P1 sun gear and the small motor (MGA) to the ring gear of P2.

# SECTION 12 - CHEVROLET VOLT - SECOND GENERATION

When clutch 2 (Variable low) stationary clutch is applied, it links the ring gear of P2 to the transmission case. Connecting the P2 ring gear to the case holds the internal ring gear stationary. The one-way clutch (OWC) prevents the ICE and P1 ring gear from spinning backward.

## 5 Modes of Operation

The 5ET50 has five modes of operation. EV mode-1 motor EV, EV mode-2 motor EV, low extended range, fixed ratio extended range, and high extended range. We will identify all the internal parts and interactions of the components, and then we will explain each mode.

Instructor Notes:
The new transmission now has an integrated inverter eliminating heavy current conducting cables, and the separate inverter assembly that was used in the original design. While the transmission offers increased efficiency and more flexible operating modes, it does this without significantly increasing the parts count. The new transmission has the same number of clutches as the original. Extended range operation now has 3 modes, and EV operation has 2 modes, whereas the original transmission had 2 extended range modes and 2 EV modes.

### Single Motor Electric Vehicle (EV)

Single motor EV operation is used when lower torque is required. This includes reverse gear. The Internal Combustion Engine (ICE) and drive motor A (1) are OFF. The high-range clutch is open, and the low-range clutch is closed. Drive motor B (2) provides torque through the planetary gear set to the wheels.

### Dual Motor Electric Vehicle (EV)

Dual motor EV operation is used when high torque is required at any vehicle speed. The Internal Combustion Engine (ICE) is OFF. Drive motor A (1) and drive motor B (2) are ON. The high-range clutch (C2) is open, and the low-range clutch (C1) is closed. Drive motors A (1) and B (2) both provide torque through the planetary gear sets to the wheels.

### Extended Range Low

Extended range low mode is used when the rechargeable energy storage system (RESS) requires charging at lower vehicle speeds. The Internal Combustion Engine (ICE) is ON. Drive motor A (1) and drive motor B (2) are ON. The low-range clutch (C1) is closed, and the high-range clutch (C2) is open. Drive motor A (1) is generating to charge the RESS. Drive motor B (2) provides torque through the planetary gear set to the wheels.

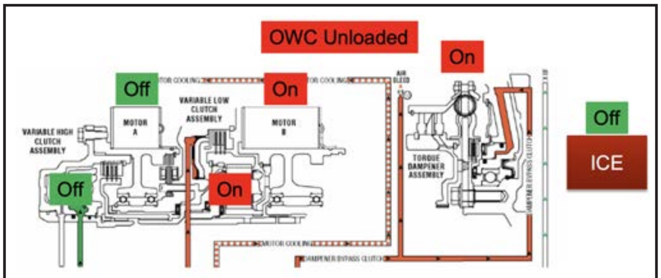
### Extended Range Fixed Ratio

An extended range fixed ratio is used when the rechargeable energy storage system (RESS) requires charging at midrange vehicle speeds. The Internal Combustion Engine (ICE) is ON. The ICE provides power through the planetary gear set to the wheels. Drive motor A (1) and drive motor B (2) are ON. The low-range clutch (C1) is closed, and the high range clutch (C2) is closed. Drive motor B (2) can perform regeneration to charge the RESS in low torque demands or provide torque through the planetary gear set to the wheels in high torque demands.

### Extended Range High

Extended range high mode is used when the rechargeable energy storage system (RESS) requires charging at higher vehicle speeds. The Internal Combustion Engine (ICE) is ON. The ICE provides power through the planetary gear set to the wheels. Drive motor A (1) and drive motor B (2) are ON. The low-range clutch (C1) is open, and the high-range clutch (C2) is closed. Both drive motor A (1) and drive motor B (2) can either operate in regeneration mode to charge the RESS or provide power to the wheels.

## One Motor EV Mode

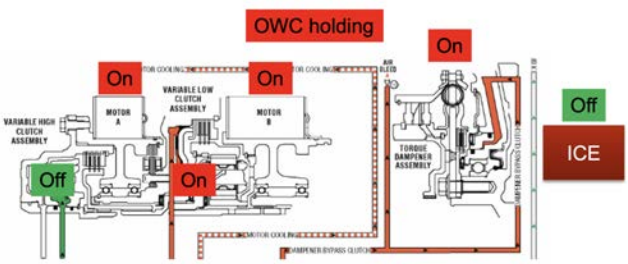



*One Motor EV Mode Diagram*

One motor EV mode ICE is off, MGA is off, the one-way clutch is unloaded, clutch one is released, and clutch 2 is applied. MGB powers the vehicle alone. MGB with attached sun gear drives the P2 planet creating a gear reduction.

# SECTION 12 - CHEVROLET VOLT - SECOND GENERATION

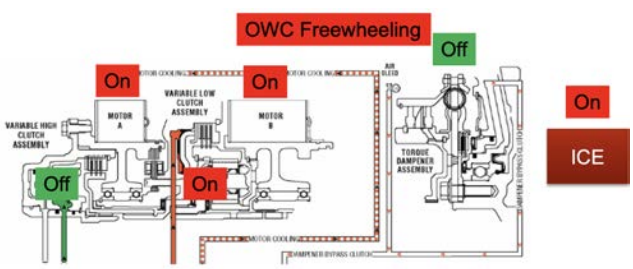
## Two Motor EV Mode




*Two Motor EV Mode Diagram*

Two motor EV mode ICE is off, MGA is on, and OWC is holding, preventing the ICE from rotating backwards. Both motors work in parallel with more peak output coming from MGA. Clutch one is released and clutch two is applied.

## Low Extended Range Mode

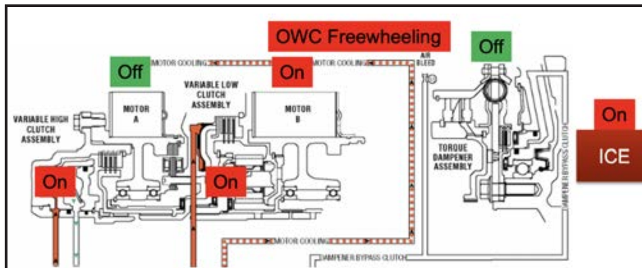



*Low Extended Range Mode Diagram*

Low extended range mode ICE is running, MGA is on generating power, OWC is freewheeling, clutch one is released, clutch 2 is applied, and MGB can power the wheels or generate in regen. In this arrangement, MGB is providing power to the wheels through the sun gear P2. The ICE is splitting its power between MGA for generating and MGB to drive the wheels.

## Notes

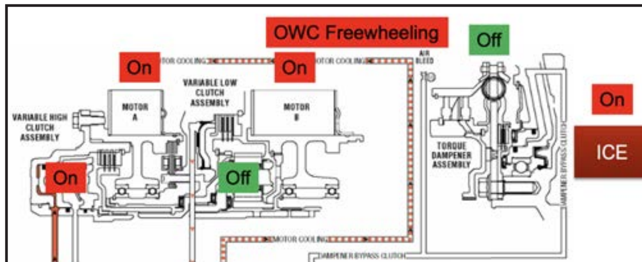
## Fixed Ratio Extended Range




*Fixed Ratio Extended Range Diagram*

Fixed extended range mode ICE is on, MGA is off and held stationary, OWC is freewheeling, clutch 1 is applied, clutch 2 is applied, MGB can provide boost and regen function. In this mode, the ICE output power is sent to the wheels and provides for most of the propulsion; ICE RPM is tied to vehicle speed, MGB provides power to the wheels for a boost when accelerating and becomes a generator on regen braking. During low torque situations MGB can also operate in generator mode charging the high voltage battery.

## High Extended Range Mode




*High Extended Range Mode Diagram*

High extended range mode ICE is on, MGA is on, OWC is freewheeling, clutch one is applied, clutch two is released, and MGB is used for generating and providing a boost during acceleration. In this mode, ICE output is split between the wheels and the ring gear of P2. This arrangement provides a higher gear ratio by controlling MGA speed, and MGB can turn forward slowly or backward to control gear ratios and torque output. The energy provided by MGB during regen braking can be used by MGA or sent to the high-voltage battery for storage.

# SECTION 12 - CHEVROLET VOLT - SECOND GENERATION

## Assessment

### Questions

Question: True or False? Honda dual motor employs an overdrive ICE mode.
Answer: True. When the ICE is powering the vehicle, the transaxle is in an overdrive gear ratio mode.

Question: How many driving modes does the second-gen Chevy Volt offer?
Answer: The 5ET50 provides five modes of operation.

Question: True or False? The Chevy Volt has one planetary gear set.
Answer: False. The 5ET50 has two planetary gear sets.

## Questions With Answers

Question: True or False? Honda dual motor employs an overdrive ICE mode.
**Answer: True. When the ICE is powering the vehicle, the transaxle is in an overdrive gear ratio mode.**

Question: How many driving modes does the second-gen Chevy Volt offer?
**Answer: The 5ET50 provides five modes of operation.**

Question: True or False? The Chevy Volt has one planetary gear set.
**Answer: False. The 5ET50 has two planetary gear sets.**

# SECTION 13 - PARKING MECHANISMS

## Parking Mechanisms

Parking mechanisms, internal parking pawl, and parking gear are like what we have used in traditional automatics. External parking linkage can be a traditional cable or an electric motor.

Chevy Volt gen 2 uses a traditional cable to activate the parking mechanism. The internal linkage consists of a parking pawl that engages into a parking gear and uses a spring to disengage the parking pawl.

## Nissan Leaf

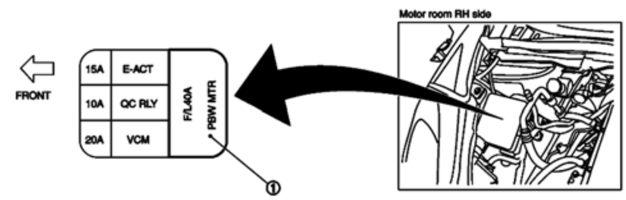
Nissan Leaf Electric Parking Motor

Nissan Leaf Parking Pawl and Gear

Nissan leaf uses an electric motor to activate the internal parking linkage. The internal linkage consists of a parking pawl and a parking gear. The electric motor has been removed and turned around to get a view of the internal splines of the parked motor.

The rotating shaft can be seen in the case. On most models with an electric park motor, if the parked motor fails, you can remove the parking motor and rotate the shaft with pliers to disengage the park.

## Park Lock Release Procedure




Nissan Leaf  Park Release

**Procedure Overview**
**1. Turn the power on.**
**2. Select neutral.**
**3. Apply Park brake.**
**4. Remove fuse or relay in park circuit.**
**5. Release Park brake.**
**6. Turn power off.**
**7. Vehicle should remain in neutral.**

If you need the vehicle to be in neutral with the power off, you can perform a park lock release procedure; this works on most vehicles with an electric park motor. Turn the power on, select neutral, set the parking brake, remove the fuse or relay in the park brake motor circuit, release the parking brake, and shut the power off. The vehicle should remain in neutral at this point. Only push the vehicle slowly at this point to avoid uncontrollable voltage being produced by the traction motor.

1. Turn the power switch ON (Press the power switch twice without depressing the brake pedal). At this moment, check that the parking brake is operated.

2. Shift the selector lever from the P position to the N position (Depress the brake pedal while all doors are closed,
and then release the P position).

3. Remove the following fuse.
• PBW MTR

4. Release the parking brake.

5. Turn the power switch OFF. (Release brake pedal)

## SECTION 13 - PARKING MECHANISMS

6. Move the vehicle while the power switch is OFF.

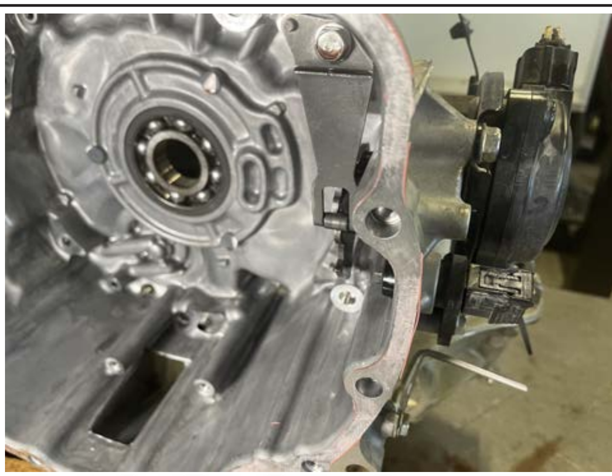
7. Fix the vehicle after moving. (Using parking brake or tire stopper.)

8. Install the fuse that is removed.

9. Turn the power switch ON (Press the switch twice without depressing the brake pedal) and wait for 5 seconds. At this moment, maintain the shift position to the N position. (Charge 12V battery if its voltage is low.)

10. Turn the power switch OFF. (Wait for 5 seconds)

**Honda Dual Motor**



*Honda Dual Motor Parking Motor and Linkage*

*Honda Dual Motor Parking Pawl and Gear*

**AWD Tech Tip**

Key Points
* Typically, AWD requires the same size tires at all four corners.
* Tesla performance model S uses different size tires front to rear.
* Front-245/35ZR21(27.75-inch diameter) spins faster.
* Rear-265/35ZR21(28.3-inch diameter).

**Front diff ring gear-79 teeth.**
**Rear diff ring gear-78 teeth.**

AWD vehicles typically require the same tire diameter at all four corners. This may change with electric AWD vehicles. The Tesla performance S model has 245/35ZR21(27.75-inch diameter). The rear tire is a 265/35ZR21(28.3-inch diameter). The front tires will spin faster than the rear tires. The tire speed difference must be matched with the differential ring gear speed inside the gearboxes. The speed difference is accomplished using gear ratios. The front differential ring gear has 79 teeth, and the rear differential ring gear has 78 teeth.

**Front gearbox tooth count**
Ring gear front-79 teeth (Driven).
Countershaft small gear (pinion) 21teeth (Driven).
Countershaft large gear (Driven) 77 teeth.
Motor gear-31 teeth.
Total gear ratio- 9.3441:1.

**Math Involved**
Motor gear 31 teeth drives counter driven gear 77 teeth which equals 2.4838:1.
The small counter gear (Pinion) 21 teeth drives the ring gear (79 teeth), which equals 3.7619.
2.4838 X 3.7619 = 9.34:1.

**Rear box tooth count**
Ring Gear rear-78 teeth
Countershaft small gear (pinion) 21teeth (Driven)
Countershaft large gear (Driven)77 teeth
Motor gear 31 teeth (drive)
Total gear ratio-9.7344

# SECTION 14 - GLOSSARY OF TERMS AND CHAPTER SUMMARY

EV-Electric vehicle.
BEV-Battery electric vehicle.
HEV-Hybrid electric vehicle.
PHEV-Plug in hybrid electric vehicle.
EREV-Extended range electric vehicle.
TGR-Total Gear ratio.
EMF-Electromotive force.
Power flow- Where power enters and flows through the gearbox.
Regen Braking- Electric motor enters generator mode to recharge high voltage battery during. deceleration/braking.
Gear ratio- Divide driven gear by drive gear to obtain gear ratio.

## Summary

BEV transaxle designs are usually one-speed and much more straightforward than hybrids using one motor. HEV transaxles are more complicated and typically have two motors.

Most transaxles use a gear reduction to increase torque .Some transaxles add one-way clutches, multi-disc clutch packs, and several planetaries, and a few have two oil pumps. Electric motors lose torque at high RPM due to back EMF which reduces net voltage.

## Notes

## Notes

## COMPLETE CHAPTER TEST QUESTIONS

1. List one advantage BEVs have over gasoline designs.
A. Have fewer systems like EGR, EVAP, Ignition, and fuel.
B. Fill up with gas less often.
C. They have more speeds in transmission.
D. Their batteries cost less.

2.Electric motor’s highest torque range occurs at which of the following?
A. High RPM.
B. Low RPM.
C. Mid-range RPM.
D. Reverse RPM.

3. Which of the following is the formula for finding gear ratio?
A. Driven gear tooth count divided by drive gear tooth count.
B. Drive gear tooth count divided by driven gear tooth count.
C. Add drive gear and driven gear tooth counts together.
D. Multiply drive gear tooth count times driven gear tooth count.

4. How many electrical phases per motor in HEV-BEV vehicles?
A. Single.
B. Two-phase.
C. Three phases.
D. Six phase.

5. What is the planetaries’ primary function in these applications?
A. Slow the electric motor down.
B. Increase torque output.
C. Provide an overdrive ratio.
D. Provide parking gear.

6. Technician A says an electric vehicle uses a 10-speed transmission.
Technician B says an electric vehicle uses a three-speed transmission.
A. only.
B. only.
C. A & B are both correct.
D. Neither A nor B is correct.

7. Technician A says the first-gen Prius was all gear-to-gear design inside the transaxle.
Technician B says the first-gen Prius used a chain and sprocket design inside the transaxle.
A. only.
B. only.
C. A & B are both correct.
D. Neither A nor B is correct.

8. Technician A says a Honda dual motor powers the vehicle at low speeds with the ICE.
Technician B says a Honda dual motor powers the vehicle at low speeds with the small motor (Generator).
A. only.
B. only.
C. A & B are both correct.
D. Neither A nor B is correct.

9. Technician A says a Honda dual motor combines the large traction motor and ICE under most driving conditions.
Technician B says the Honda dual motor only uses a large traction motor.
A. only.
B. only.
C. A & B are both correct.
D. Neither A nor B is correct.

10. Technician A says a DVOM is adequate for testing stator windings.
Technician B says you need a milliohm meter for testing stator windings.
A. only.
B. only.
C. A & B are both correct.
D. Neither A nor B is correct.

11. True or false. An isolation test is used to test the insulation integrity of the high voltage side.
True.
False.

12. True or false. A megaohm meter outputs 50-1000 volts into a circuit and measures leakage to ground.
True.
False.

13. True or false? The Chevy Bolt EV has a 3.89:1 total gear ratio.
True.
False.

## COMPLETE CHAPTER TEST QUESTIONS

14. True or false? The Chevy Volt second gen 5ET50 has four modes of operation.
True.
False.

15. True or false? AWD electric vehicles must have the exact tire size front and back.
True.
False.

**Notes**

**Notes**

## COMPLETE CHAPTER TEST QUESTIONS WITH ANSWERS

1. List one advantage BEVs have over gasoline designs.
A. Have fewer systems like EGR, EVAP, Ignition, and fuel.
B. Fill up with gas less often.
C. They have more speeds in transmission.
D. Their batteries cost less.
**Answer: A. BEVs do not have EGR, EVAP, ignition, or fuel systems, so they are more trouble-free in those areas. Also, their transmissions typically have only 1 or 2 speeds.**

2. Electric motor's highest torque range occurs at which of the following?
A. High RPM.
B. Low RPM.
C. Mid-range RPM.
D. Reverse RPM.
**Answer: B. Electric motors build the most torque at the low end; back EMF starts to reduce torque at mid to high RPM range.**

3. Which of the following is the formula for finding gear ratio?
A. Driven gear tooth count divided by drive gear tooth count.
B. Drive gear tooth count divided by driven gear tooth count.
C. Add drive gear and driven gear tooth counts together.
D. Multiply drive gear tooth count times driven gear tooth count.
**Answer: A. Count drive and driven gear teeth, and then divide driven gear by drive gear.**

4. How many electrical phases per motor in HEV-BEV vehicles?
A. Single.
B. Two-phase.
C. Three phases.
D. Six phase.
**Answer: C.**

5. What is the planetaries' primary function in these applications?
A. Slow the electric motor down.
B. Increase torque output.
C. Provide an overdrive ratio.
D. Provide parking gear.
**Answer: B. The primary function of the planetaries we have shown in the class was to increase torque output.**

6. Technician A says an electric vehicle uses a 10-speed transmission.
Technician B says an electric vehicle uses a three-speed transmission.
A. only.
B. only.
C. A & B are both correct.
D. Neither A nor B is correct.
**Answer: D. An electric vehicle usually uses a one or sometimes a dual-speed transmission.**

7. Technician A says the first-gen Prius was all gear-to-gear design inside the transaxle.
Technician B says the first-gen Prius used a chain and sprocket design inside the transaxle.
A. only.
B. only.
C. A & B are both correct.
D. Neither A nor B is correct.
**Answer: B. Technician B is correct.**

8. Technician A says a Honda dual motor powers the vehicle at low speeds with the ICE.
Technician B says a Honda dual motor powers the vehicle at low speeds with the small motor (Generator).
A. only.
B. only.
C. A & B are both correct.
D. Neither A nor B is correct.
**Answer: D is correct. Honda dual motor powers the vehicle with the large electric traction motor at low speeds.**

9. Technician A says a Honda dual motor combines the large traction motor and ICE under most driving conditions.
Technician B says the Honda dual motor only uses a large traction motor.
A. only.
B. only.
C. A & B are both correct.
D. Neither A nor B is correct.
**Answer: D is correct. The Honda dual motor uses a traction motor at low to medium speeds and switches to engine mode for highway speeds.**

## COMPLETE CHAPTER TEST QUESTIONS WITH ANSWERS

10. Technician A says a DVOM is adequate for testing stator windings.
Technician B says you need a milliohm meter for testing stator windings.
A. only.
B. only.
C. A & B are both correct.
D. Neither A nor B is correct.
**Answer: B. A DVOM is not accurate at taking readings below one ohm.**

11. True or false? An isolation test is used to test the insulation integrity of the high voltage side.
True.
False.
**Answer: True.**

12. True or false? A megaohm meter outputs 50-1000 volts into a circuit and measures leakage to ground.
True.
False.
**Answer: True.**

**Notes**

13. True or false? The Chevy Bolt EV has a 3.89:1 total gear ratio.
True.
False.
**Answer: False. The Chevy Bolt EV has a 7.05:1 total gear ratio.**

14. True or false? The Chevy Volt second gen 5ET50 has four modes of operation.
True.
False.
**Answer: False. The Chevy Volt second gen 5ET50 has five modes of operation.**

15. True or false? AWD electric vehicles must have the exact tire size front and back.
True.
False.
**Answer: False. Some Tesla AWD vehicles use a different gear ratio from the front motor to the rear motor; therefore, they can use two different size tires front to back.**

**Notes**

## XXXXXXXXXX

# MAINTENANCE OPPORTUNITIES

## Contents

# AVI'S MISSION

The Mission of Automotive Video Innovations (AVI) is to produce automotive repair training courses and information for the automotive aftermarket, providing current and future repair technicians with the highest level of technical training. AVI produces automotive technician training through instructor-led courses, technical training manuals, and other media, with a commitment to continually update this training to stay in step with ever-changing automotive technology. AVI's goal for its course participants is to acquire the necessary skill set they seek and apply those skills competently due to their training.


# COURSE OBJECTIVES

Upon successful completion of this course, you should be able to:

- ✓ Identify the safety equipment and tools necessary for servicing Hybrid Electric Vehicles (HEVs) and Battery Electric Vehicles (BEVs), including meters, high voltage gloves, high voltage tools, and all Personal Protection Equipment (PPE)
- ✓ Identify common HEV/BEV components
- ✓ Identify the HEV/BEV systems that require maintenance
- ✓ Describe the function and maintenance requirements of the HEV/BEVs cooling systems
- ✓ Explain the maintenance requirements of the 12-volt auxiliary battery system
- ✓ Understand the importance of oils and coolants
- ✓ Identify the issues associated with the high-voltage battery maintenance
- ✓ Describe the special service requirements associated with HEV/BEV air conditioning systems
- ✓ Determine common mistakes Technicians may make
- ✓ Determine correct power-down procedures based on repair

# INTRODUCTION

With over 6 million HEVs/BEVs on US roads today, maintenance services for these vehicles have become a viable market for those shops that have the foresight to see the potential revenues. It is obvious the market is only going to continue to grow. HEV and BEV owners are searching for service facilities with the knowledge and equipment to service their vehicles. Offering maintenance services opens the door for customers to return to your shop for other services.

This course thoroughly examines the maintenance procedures associated with servicing the HEV and BEV. Throughout the course, emphasis on safety is a central theme by reinforcing the use of the proper tools, equipment, and PPE as various service procedures are introduced.

General service concerns covered in the course include:

- Lifting - Jacking
- Oil changes
- Cooling system services
- Transmissions
- HVAC system service

Although Customer Service Teammates (CST) are not typically performing maintenance work on an HEV or BEV, they also can benefit from this course as it makes them aware of the following:

- Maintenance requirements of HEVs and BEVs
- Special tool needs
- Common technician mistakes
- Correct maintenance procedures
- Pitfalls of performing service incorrectly
- Safety concerns

AVI ON DEMAND
ONLINE TRAINING FOR THE AUTOMOTIVE PROFESSIONAL

# ACRONYM LIST

| | |
|---|---|
| ABS | ANTILOCK BRAKE SYSTEM |
| AC | ALTERNATING CURRENT |
| A/C | AIR CONDITIONING |
| API | AMERICAN PETROLEUM INSTITUTE |
| BAS | BELT ALTERNATOR STARTER |
| BEV | BATTERY ELECTRIC VEHICLE |
| CST | CUSTOMER SERVICE TEAMMATE |
| DC | DIRECT CURRENT |
| DOT | DEPARTMENT OF TRANSPORTATION |
| DVOM | DIGITAL VOLT/OHM METER |
| ECU | ELECTRONIC CONTROL UNIT |
| EPB | ELECTRIC PARKING BRAKE |
| EREV | EXTENDED-RANGE ELECTRIC VEHICLE |
| EWP | ELECTRIC WATER PUMP |
| FWD | FRONT-WHEEL DRIVE |
| GMLAN | GENERAL MOTORS LOCAL AREA NETWORK |
| HCU | HYDRAULIC CONTROL UNIT |
| HEV | HYBRID ELECTRIC VEHICLE |
| HV | HIGH VOLTAGE |
| HVAC | HEATING/VENTILATION/AIR CONDITIONING |
| ICE | INTERNAL COMBUSTION ENGINE |
| IEC | INTERNATIONAL ELECTROTECHNICAL COMMISSION |
| IMA | HONDA INTEGRATED MOTOR ASSIST |
| ISO | INTERNATIONAL STANDARDS ORGANIZATION |
| KM/H | KILOMETERS PER HOUR |
| KPA | KILOPASCALS |
| LiPB | LITHIUM-ION POLYMER BATTERY |
| MG | MOTOR/GENERATOR |
| MPH | MILES PER HOUR |
| MSMS | MANUFACTURER SUGGESTED MAINTENANCE SERVICE |
| NIMH | NICKEL METAL HYDRIDE |
| OEM | ORIGINAL EQUIPMENT MANUFACTURER |
| OSHA | OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION) |
| PAG | POLYALKYLENE GLYCOL |
| PHEV | PLUG-IN HYBRID ELECTRIC VEHICLE |
| PID | PARAMETER IDENTIFIER |
| PM | PERMANENT MAGNET |
| POE | POLYOL ESTER |
| PPM | PARTS PER MILLION |
| RESS | RESERVE ENERGY STORAGE SYSTEM |
| RPM | REVOLUTIONS PER MINUTE |
| RWD | REAR-WHEEL DRIVE |
| SOP | STANDARD OPERATING PROCEDURE |
| TSB | TECHNICAL SERVICE BULLETINS |
| VST | VEHICLE SERVICE TEAMMATE |

# HIGH VOLTAGE SAFETY


It is possible to be severely injured or even killed by the high voltage (HV) systems of the HEV and BEV. However, you can also be severely injured or killed doing almost any type of work on the automobile. The risk is 100% correlated with safety practices and proper training. In reality, the HV system is as safe to work around as any other system on a car. As with all automotive systems, HV systems need to be respected.

Switching the vehicle "off" opens the main contacts of the relays, isolates the HV battery, powers down the inverter, and drains the capacitors contained within it. The power-down process can take as few as 15 seconds to several minutes. That is the normal shutdown process, but what if the contact relay system fails to isolate the HV voltage battery properly?

When a vehicle comes into the service facility with a customer concern other than for scheduled maintenance, is there a chance an onboard system is malfunctioning? Certainly, there is. Something has stopped operating as designed and caused the customer to seek help from you to repair the situation. This could mean the HV system has failed to power down into a safe mode without alerting you.

An important safety rule is always treating a high-voltage component or circuit as live until you have proven otherwise through testing.

Notes:

## SAFE LIFT PLACEMENT

It is common for the HV cables of the HEV/BEV and the Plug-in Hybrid Electric Vehicle (PHEV) to run under the vehicle's body. The location of the hoist and jack pads while lifting the vehicle is of concern. Damage to an HV cable can cause a short to the vehicle's chassis. In most cases this will shut down the vehicle and prevent its operation. Cables that are damaged are not repairable and will necessitate replacement.

# WHAT IS THE DANGER?

| mA | Effect on Human Body |
|---|---|
| 0.5-3 | Tingling sensations |
| 3 - 10 | Muscle contractions and pain |
| 10 - 40 | "Let-go" threshold |
| 30 - 75 | Respiratory paralysis |
| 100 - 200 | Ventricular fibrillation |
| 200 - 500 | Heart clamps tight |
| 1500 + | Tissue and Organs start to burn |

HEVs can use over 600 volts AC. Consider that the common outlet in your home is 120 volts AC; it should be apparent that working around high voltage can be very dangerous. Although it is true that voltage is not what will kill you (it's the amperage), as a technician servicing an HEV/PHEV/BEV, you need to take precautions when high voltage may be present. This chart indicates how amperage levels affect the human body. It only takes 3-10 milliamps to cause muscle contractions and only 30-75 milliamps to cause respiratory paralysis.

# PERSONAL PROTECTION EQUIPMENT


How you view safety while working within the shop environment says a lot about your professionalism. Safety encompasses more than watching out for yourself but also embraces the well-being of others. Most workplace accidents and injuries are avoidable. You reduce the risk of injury by assuring you are properly equipped to enter the shop area.

When servicing an HEV, PHEV, or BEV, you need access to various types of Personal Protection Equipment (PPE).

## SAFETY GLASSES

Most eye injuries are preventable. Wearing Occupational Safety and Health Administration (OSHA) approved safety glasses substantially reduces your risk of an eye injury. However, there will be some tasks that you need to undertake that safety glasses may not provide the level of protection needed. Safety glasses work well to prevent impact to the eye but do not prevent foreign material from falling into the eye. Performing maintenance services exposes you to dirt and dust that can easily enter your eyes. Also, you may be working with compressed air, solvents, grease, and chemicals. There will be times when safety goggles will be necessary to provide the required level of protection. It may also be necessary to wear a face shield over the safety glasses or goggles.

## CLASS 0 RUBBER GLOVES


When servicing an HEV, PHEV, or BEV and you need to power down the vehicle (or service the high voltage systems), you must wear Class 0 isolation gloves rated at 1000 volts AC and 1500 volts DC.

The glove will have a tested date stamped on it. The gloves have a one-year shelf life. However, once opened, the gloves must be professionally tested and certified (or replaced) every six months. Prior to each use, the glove *must* be leak tested.


Wearing insulating gloves will likely cause your hands to sweat some. To control this, you can wear disposable lightweight cotton gloves under the rubber gloves. Another option is to use a specially formulated non-conductive glove powder. Do not use standard talcum or baby powders since these may contain metal.


Several companies offer special air testers that fill the glove with air to test for leaks. If using an air tester, do not expand the gloves more than 1.5 times their original size. If a leak is detected, notify your manager and dispose of them. NEVER use a pair of leaking isolation gloves. Wear the outer leather gloves over the insolation gloves to protect them against snags and cuts. If the outer leather gloves are not worn, the isolation gloves cannot be reused.

The isolation gloves only need to be worn when high voltage is present. After confirmation that the high-voltage system is powered down, you can remove the gloves and service the vehicle without the gloves. An exception to this rule is if you are working on the high-voltage battery. There is always high voltage in the battery, even with the vehicle powered down.

It is a good practice to wear safety glasses or a face shield anytime you wear insulating gloves. Metal can splatter if a high-voltage arc jumps to it.

Notes:

# MISCELLANEOUS HIGH-VOLTAGE EQUIPMENT

When working on high-voltage components, the use of insulated tools helps isolate the technician from harmful high-voltage. Insulated tools are rated at 1000 volts but tested to 10,000 volts. Use these tools any time you are working inside the HV battery. There are two basic types of insulated tools: those with insulation added to them and those made of composites. Both types are sufficient for isolating the technician from high voltage.

Other equipment the shop should have available include Caution Tape and/or safety cones, and “High Voltage Warning” placards. While the vehicle is in the bay for service, the cones and placard alert others to the potential damage. Also, they indicate that the assigned technician is the only one allowed to enter the work area unless they provide permission for someone to enter.

Notes:

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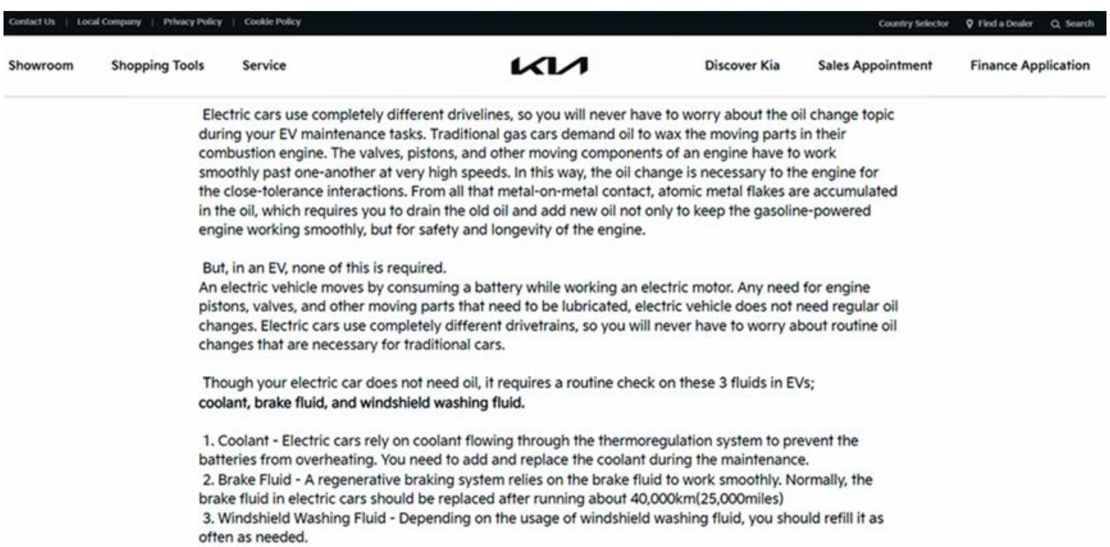

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Showroom | Shopping Tools | Service | KIA | Discover Kia | Sales Appointment | Finance Application

Electric cars use completely different drivelines, so you will never have to worry about the oil change topic during your EV maintenance tasks. Traditional gas cars demand oil to wax the moving parts in their combustion engine. The valves, pistons, and other moving components of an engine have to work smoothly past one-another at very high speeds. In this way, the oil change is necessary to the engine for the close-tolerance interactions. From all that metal-on-metal contact, atomic metal flakes are accumulated in the oil, which requires you to drain the old oil and add new oil not only to keep the gasoline-powered engine working smoothly, but for safety and longevity of the engine.

But, in an EV, none of this is required.
An electric vehicle moves by consuming a battery while working an electric motor. Any need for engine pistons, valves, and other moving parts that need to be lubricated, electric vehicle does not need regular oil changes. Electric cars use completely different drivetrains, so you will never have to worry about routine oil changes that are necessary for traditional cars.

Though your electric car does not need oil, it requires a routine check on these 3 fluids in EVs;
**coolant, brake fluid, and windshield washing fluid.**

1. Coolant - Electric cars rely on coolant flowing through the thermoregulation system to prevent the batteries from overheating. You need to add and replace the coolant during the maintenance.
2. Brake Fluid - A regenerative braking system relies on the brake fluid to work smoothly. Normally, the brake fluid in electric cars should be replaced after running about 40,000km(25,000miles)
3. Windshield Washing Fluid - Depending on the usage of windshield washing fluid, you should refill it as often as needed.

Hybrid and Electric owners fall into different categories. Many are very tech-savvy, while others may not completely understand that their vehicle still requires routine maintenance. It is also possible that they have misperceptions of what services are required. When discussing maintenance services with the customer, always refer to the manufacturer’s suggested maintenance schedule for the proper information. You may need to help the customer understand this information.

**Maintenance under severe usage conditions**

I: Inspect and if necessary, adjust, correct, clean or replace.

R: Replace or change.

| Maintenance item | Maintenance operation | Maintenance intervals | Driving condition |
|---|---|---|---|
| Reduction gear fluid | R | Every 72,000 miles (117,000 km) | A, B, E, F, H, J |
| Drive shaft and boots | I | More frequently | B, C, D, E, F, G, H, I |
| Climate control air filter | R | More frequently | B, D, F |
| Brake discs, pads and calipers | I | More frequently | B, C, D, F, G, H, I, J |
| Steering gear rack, linkage and boots | I | More frequently | C, D, E, F, G |
| Suspension ball joints | I | More frequently | B, C, D, E, F |

Severe driving conditions

A. Repeated driving short distance of less than 5 miles (8 km) in normal temperature or less than 10 miles (16 km) in freezing temperature

B. Driving on rough, dusty, muddy, unpaved, graveled or salt spread roads

C. Driving in areas using salt or other corrosive materials or in very cold weather

D. Driving in heavy dust condition

E. Driving in heavy traffic area with the ambient temperature higher than 90 °F (32 °C) while consuming more than 50% of electric energy.

F. Driving on uphill, downhill, or mountain roads repeatedly

G. Towing a trailer, or using a camper or roof rack

H. Driving as a patrol car, taxi, other commercial use or vehicle towing

I. Frequently driving under high speed or rapid acceleration/deceleration

J. Frequently driving in stop-and-go conditions

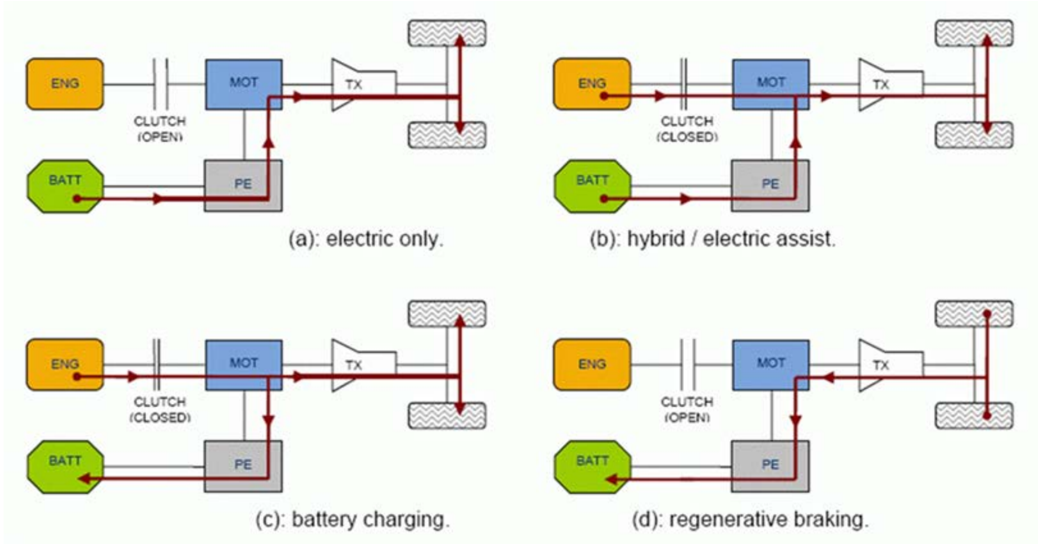
This Kia EC6 severe usage conditions maintenance guide shows that the reduction gear oil requires changing every 72,000 miles (117,000 km). Other components require inspections based on driving conditions.

Your instructor will present several customer conversation scenarios. Follow along and note how to incorporate them into your customer interactions.

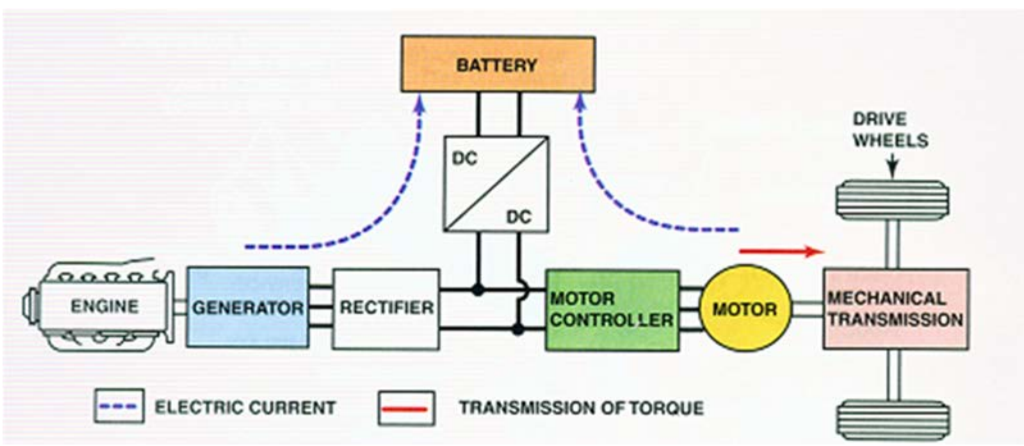
**Notes:**

**Notes:**

# CONFIGURATIONS

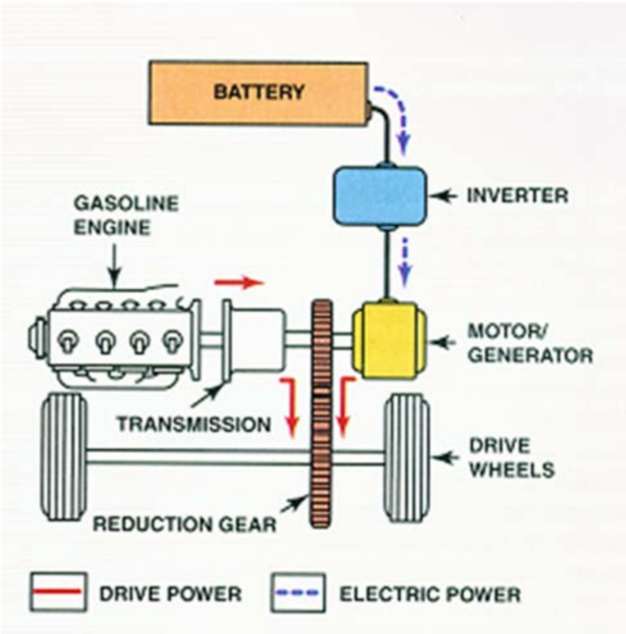


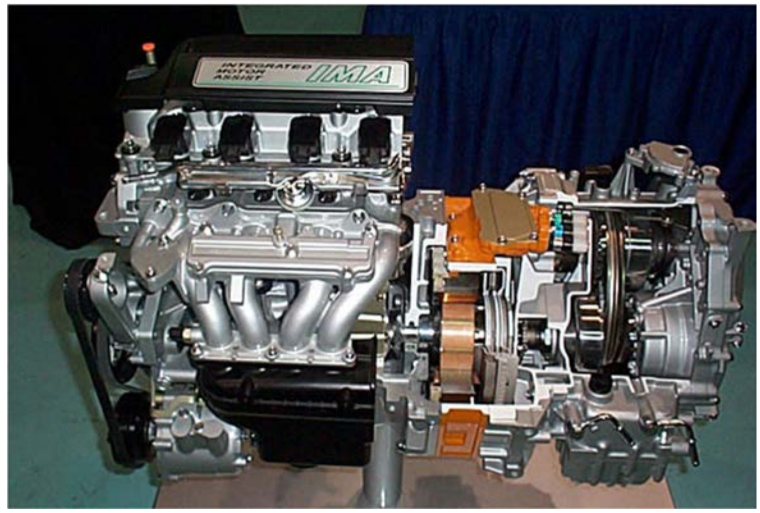

There are three major configurations of the HEV: series, parallel, and series-parallel. Other classifications include *strong (full)* and *mild*.




The series HEV uses a single electric motor (traction motor) between an internal combustion engine (ICE) and a traditional transaxle. The electric motor can drive the wheels via the transmission or be engaged with the ICE to start it. When started, the ICE powers the generator to charge the HV battery. The ICE does not propel or assist in moving the vehicle. In a series hybrid, the electric motor is the only means of providing power to the wheels. When a large power demand is needed, the electric motor receives electrical energy from both the HV battery and the generator. Extended Range EVs (EREVs) use this drivetrain type.

**Notes:**




The parallel HEV uses the ICE and the motor/generator (MG) in tandem to propel the vehicle. During periods of low power demands, the MG can be used as a generator to charge the HV battery. The MG is also used to start the ICE.

The vehicle can never be propelled in pure electric mode in a mild parallel hybrid. The electric motor turns on only when additional power assist is needed.

Strong parallel HEVs have the ability to propel the vehicle solely off the electric motor.

**Notes:**

The series-parallel drivetrain is the most common HEV design. This drivetrain has a power splitter instead of a typical transmission. The vehicle can be propelled by the ICE working alone, the electric motor alone, or by both working together.

**Notes:**

# IDENTIFYING HIGH-VOLTAGE COMPONENTS

Warning stickers identify high-voltage components. Yellow, blue, or orange conduit and connectors identify high-voltage cables. Yellow and blue identify circuits that are higher than the typical 12 volts but less than 60 volts. Orange identifies the circuit as greater than 60 volts.

Remember to follow your shop's SOP concerning who and when service to these components is allowable. Many services will make you decide if the HV system must be powered down or not. However, if you are going to be moving or handling the orange cable or any HV cable, you MUST power down the HV system by removing the HV disconnect. If you are uncertain about the need to power down the HV system or not, lean to the side of safety and power it down.

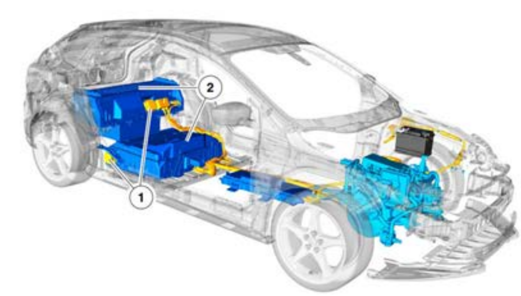
## MANUAL DISCONNECT

Separating the HV battery is necessary anytime you service an HV system or component serviced. The manual disconnect provides the means for disconnecting the HV battery from the rest of the HV system. The manual service disconnect is located at the HV battery and essentially splits the HV battery in two. Removing the service disconnect disables the battery from delivering any current.

Some manual disconnects have two sets of terminal connectors. The larger terminals are for the HV circuit and may have a fuse. The smaller terminals are for the safety interlock circuit. The interlock circuit is a safety system that, when opened, causes the HV system to power down. When reinstalling the manual disconnect, if the interlock is not properly engaged prior to attempting to power up the system can trigger setting fault codes and warning indicators.

It is important to remember the battery itself can still be dangerous if handled without proper gloves. The battery cannot deliver any power out of the negative and positive posts, but the battery is still full of energy. Touching across two terminals is approximately 7.2 volts which is not dangerous, but moving hands and contacting across 10 modules would be 72 volts which could be hazardous. Always wear insulating gloves when servicing the HV battery. After removing the service disconnect, wait the vehicle manufacturer's specified time to allow the capacitors to discharge. Before working on the system, confirm there is no voltage.

Another example of a manual disconnect is the rotation type. Ford uses this design. In the Lock position, normal vehicle operations are allowed. Placing the knob in the Unlock position disconnects the battery and powers down the HV system. The Service Shipping position is a secured disconnect. To place the dial in Service Shipping, lift the dial slightly to disengage the pins from the connector cavities and rotate the dial. When aligned with "Service Shipping," lower the dial so the connectors drop into empty cavities. This eliminates any possibility of an accidental power-up connection.


Ford Focus EVs may have two service disconnects. One disconnect is behind a cover behind the rear seat back. The other is in the right wheel well, behind the park brake cable bracket.


Honda uses a switch, which is very similar to a typical household circuit breaker. Some will have a red plastic tab that needs to be removed to operate the switch. Reversing the tab and reinstalling it ensures the switch cannot be accidentally turned on.

Because there are several different methods of removing the service disconnect, always refer to the proper service procedures for the specific method for the vehicle you are servicing. In some instances, the manufacturer may also require disconnecting the auxiliary 12-volt battery.

Notes:

# DETERMINE PROPER DVOM


After the service disconnect plug has been removed and the capacitors have discharged, you must confirm that there is no longer any voltage in the HV system. Do not remove the insulating gloves until the completion of this process.

Due to the potential that high voltage is still present and transient voltages can occur, you must use a Digital Volt/Ohm Meter (DVOM) that can safely handle the voltage. The DVOM must have a CAT 3 1,000 volts rating at the least. Be aware that not all CAT 3 DVOMs have a 1,000 volts rating. Meters are designed to the International Electrotechnical Commission (IEC) standard. The IEC develops international safety standards for electrical equipment.

Transient voltage spikes are momentary high voltage spikes. These spikes can damage the meter and put the user at high risk. Consider the following example. An engineer was monitoring the supply circuit of an electric train that ran a 600-volt supply. During the analysis, the engineer found that when the train started and stopped, transient voltages of over 10,000 volts were present. Transient voltages like this can create an arc inside your meter and blow your meter up in your hand, possibly causing injury or death.

Like most DVOMs, CAT 3 meters have a 10 megaohm (10,000,000-ohms) impedance. The high impedance isolates the meter from becoming part of the circuit. However, when measuring low amperage in a circuit by installing the meter in series with the circuit, the meter has an extremely low (.01 ohms) impedance. This is necessary so current can flow through the meter and obtain precise amperage flow measurements. When testing high voltage circuits while the meter leads are in the amperage jacks, the low impedance would cause a short circuit between the two leads allowing large amounts of current to flow through the meter. This event could cause immediate failure and possibly user injury. To avoid this issue, the meter employs a fast burn fuse to protect the meter and the user.

Don’t forget about the test leads. They too must be CAT 3, 1,000-volt rated. Some DVOM manufacturers use twist guards to interchange the lead from CAT 2 to CAT 3. With the guards installed, the leads are CAT 3. Removing the guards exposes more of the tip and drops the rating from CAT 3 to CAT 2.

Notes:

# TIRE DESIGN

HEVs and BEVs benefit from tires designed with low rolling resistance. However, low rolling resistance is not the only characteristic to consider when recommending a new set of tires for an HEV or BEV. In some instances, the wrong tire type can lower fuel economy by 5% or more. On a car averaging 50 miles per gallon, incorrect tires can cause a drop of over 2 mpg. A customer is very likely to notice this and be dissatisfied. It is always best practice to advise the customer of the availability of tires best suited to the needs of the vehicle.

HEVs and BEVs may weigh more than their conventional gas counterparts. For this reason, you need to be sure the recommended tire has an appropriate weight rating. Another attribute to consider is the ability of the tire to roll more quietly, especially on a BEV. If you think about how quiet a vehicle is without an engine running, it is easy to see why we need to recommend a tire that is known to be as quiet as possible.

Torque with electric motors is immediate and sustained. The recommended tires should meet the traction qualities that will ensure tire contact during acceleration and braking is not compromised.

We can now see how quickly a tire sale can become problematic if the customer is not made aware of the differences in the tires available. Buying the cheapest possible tire is common, but in the case of the HEV and BEV, that choice may negatively impact fuel economy, ride noise, and safety.

## HYBRID AND EV TIRE SERVICE

There are no special requirements to follow when an HEV or BEV requires tire service. Tire services (such as flat repairs, balancing, and alignments) do not involve the HV systems. Perform these services in the same manner as tire services on conventional vehicles.

Notes:

# WHAT SYSTEMS NEED SERVICE?

HEV and BEV systems that may require service include:

- Intake
- Lubricating fluids
- Injectors
- Cooling system(s)
- Air conditioning
- Battery temperature control
- Brakes

The procedures for performing many of the services on an HEV and BEV are not that different from conventional vehicles. Also, most HEV and BEV maintenance services do not involve the HV system's manual disconnect, so you do not need to wear the HV insulation gloves. However, you do need to power down the 12-volt system properly. In addition, it is a best practice to remove the key from the vehicle.

## ENGINE OIL CHANGE


Although an oil change is a simple task for most technicians, there are some safety concerns due to the nature of push-button start and how the ICE works in conjunction with the hybrid portion of the HEV.

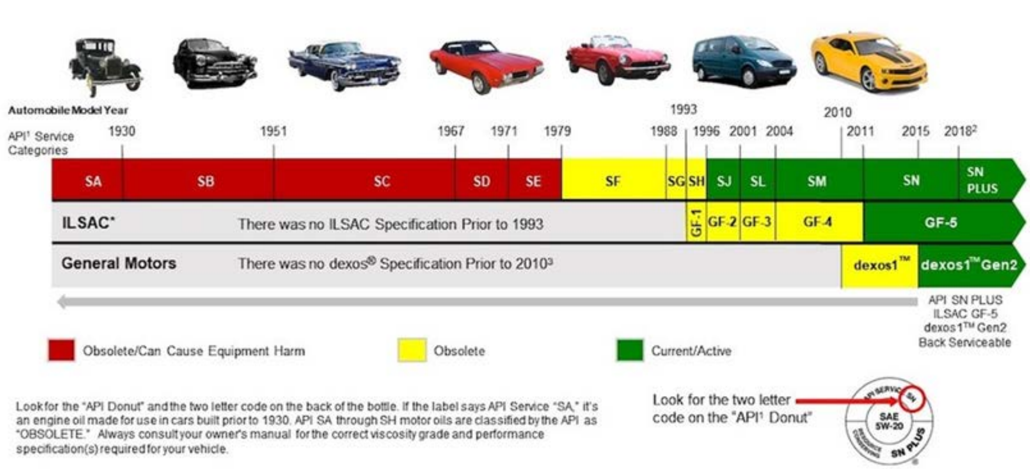
To prevent the engine from starting while performing an oil change, ensure the vehicle is turned off. If a READY or RUN or some other indicator is illuminated, the vehicle is not off. If unsure, reference the proper service information or the owner's manual.

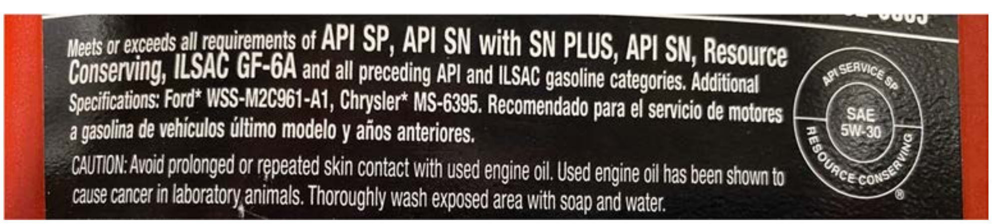
After powering off the vehicle, place the keys or FOB at least 20 feet from the vehicle.

Notes:

Although the ICE used in an HEV does not operate for as long or work as hard as a conventional vehicle's ICE, they do crank at a higher engine speed (1,000 rpm) and may run at a high speed during cold weather to warm the coolant faster. These conditions put high demands upon the engine oil.

With all the choices in engine oil, selecting the wrong one can damage the ICE. Other issues that can arise from using the incorrect oil include reduced fuel economy and excessive engine noises. When selecting an oil, make sure the oil meets the requirements of the Original Equipment Manufacturer (OEM) requirements. This includes American Petroleum Institute (API) service category and viscosity.



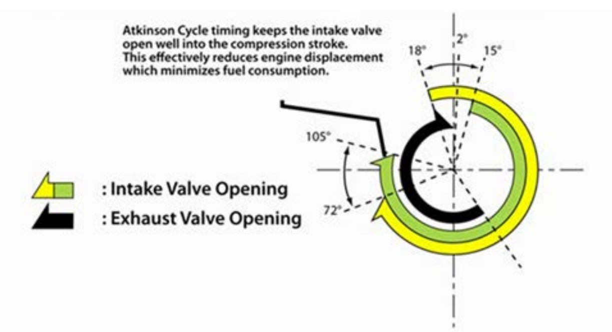




The label on the oil container may indicate that the oil meets the requirements of certain automotive manufacturers. If this is the case, the label should also state the manufacturer's specifications that it meets. In the label above it indicates this oil meets Ford and Chrysler specifications. However, this does not mean it meets the specifications for all Ford and Chrysler engines.

Oil change intervals are not just time and mileage based. The interval also takes into consideration the type of driving, climate, and the type of oil. Conventional oil will not deliver the same mileage as long-distance synthetic oil. Some Chevy Volt engines may not start for months at a time, depending on driving habits. The oil may need changing on these vehicles due to time rather than mileage. Oil provides lubrication, a cushion between parts, helps seal piston rings, cleans and cools internal parts, and prevents corrosion. The oil in today's engines also must work as hydraulic fluid acting on cam phasers. Oil becomes contaminated with blowby gasses and fuel. Oil may become oxidized, which leads to a viscosity change. The oil may also become acidic and start attacking components and seals. An oil analysis can determine the total base number, viscosity, fuel, antifreeze, and water content. A spectral analysis identifies wear metals.


The crankcase may accumulate some sludge and varnish depending on when and how the ICE operates. Carbon may cause piston rings and cam phasers to stick. Adding a carbon cleaner before performing the oil change may remove the carbon. It is also a good practice to perform carbon cleaning on a routine basis.

**Notes:**




Engine design can also influence the need for performing an intake system service along with the oil change service. For example, Toyota ICEs use the Atkinson cycle that holds the intake valve open longer. Holding the valve open into the compression stroke pushes some of the air/fuel mixture out of the cylinder and back into the intake manifold. This effectively decreases the compression stroke and reduces the resistance of the compression stroke, improving fuel economy.

Holding the intake valve open can lead to oil being pushed back into the intake manifold along with the air/fuel mixture. The oil residue may thicken and turn to a varnish that affects airflow, may cause components to become sticky, and may coat sensors.

Another side-effect is that fuel vapors can become trapped in the intake manifold after shutting the engine down. To prevent raw fuel vapors from exiting the intake manifold into the atmosphere, the air filter housing is fitted with a charcoal filter to hold the vapors. When the engine restarts, the airflow will carry the vapors from the filter into the combustion chamber to be burned.

**Notes:**

# INJECTOR CLEANING


The QMI Fuel and Induction Decarbonization kit is a 3-Step process to clean the entire fuel system. The injector cleaner is added to the fuel tank to clean the fuel injectors, intake valves, and the combustion chamber. The Throttle Body Cleaner removes varnish and carbon buildup on the throttle body valve and shaft. The Induction Cleaner is drip-fed into the intake manifold to dissolve carbon deposits and improve airflow.

Notes:

# MAINTENANCE MODE

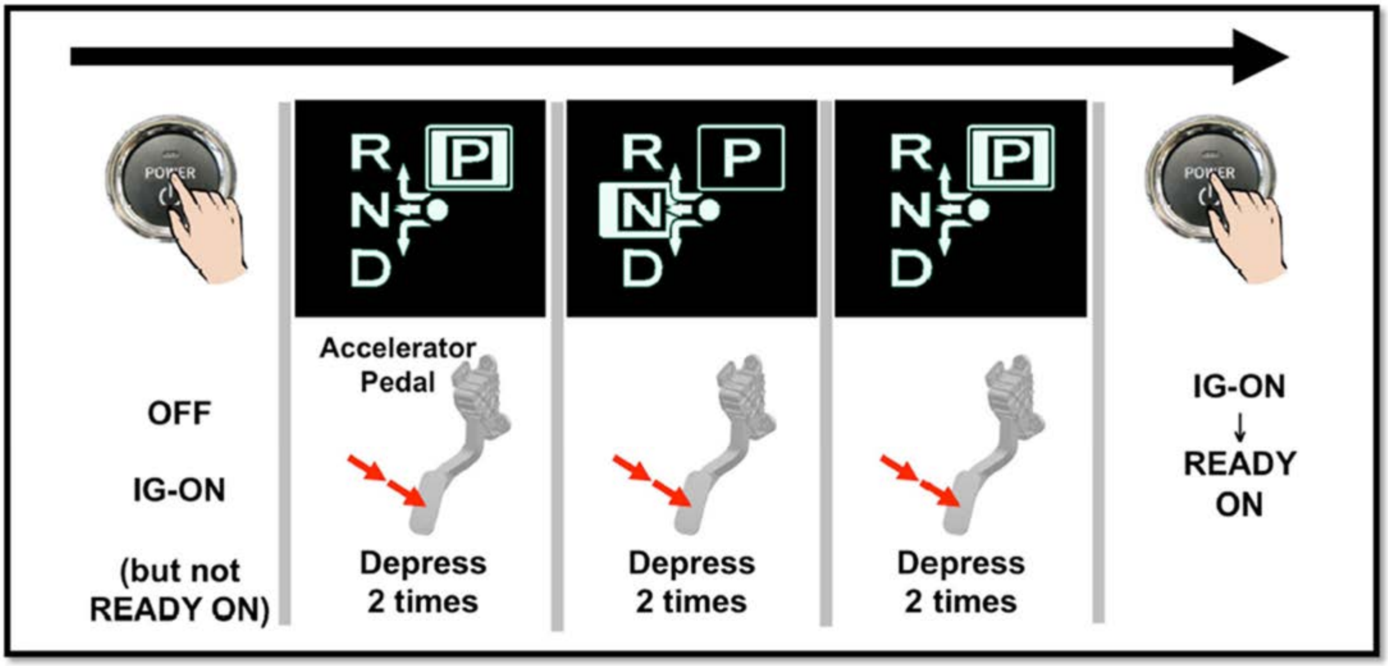
Most HEVs have a form of “Service Mode” that will allow the ICE to start, idle, and for raising the RPM during some service and diagnostic procedures. In some instances, this may be a simple hood switch. The ICE is allowed to start when the hood is open, and the vehicle is in the READY mode. This is why it is always important to be aware of what mode the vehicle is in.

For most Honda HEVs, entering maintenance mode by performing the following procedure listed:

1. Ignition ON
2. Depress the throttle pedal 2 times
3. Depress the brake pedal and shift to N
4. Depress the throttle pedal 2 times
5. Depress the brake pedal and shift to P
6. Depress the throttle pedal 2 times
7. Depress the brake pedal and press the start button

It may be necessary to manually exit Maintenance Mode. This usually occurs by cycling the ignition. If cycling the ignition fails to exit Maintenance Mode, then do the following:

1. Turn the ignition OFF, then back ON
2. Depress the throttle pedal 6 times
3. Turn the ignition OFF




Shown is a typical process for activating Toyota Hybrid Maintenance Mode. However, this may not work on all Toyota Hybrid models.

In most instances, if the scan tool has the ability to initiate the Maintenance Mode it is best to use it to enter the appropriate mode for the service you are carrying out. Using the scan tool will help ensure the proper procedure is followed.

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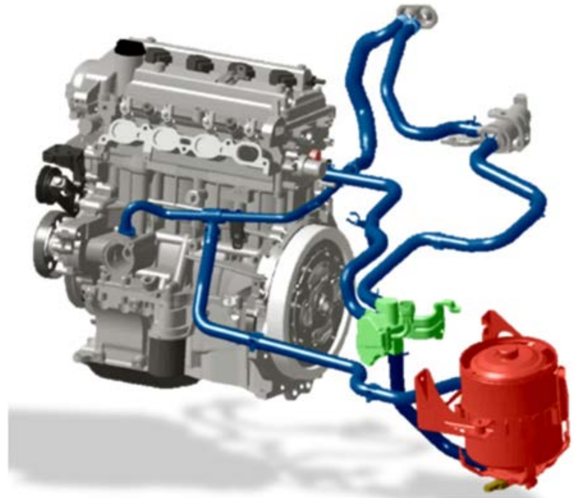
# COOLING SYSTEM MAINTENANCE

The evolution of the HEV has brought about changes to the cooling systems. Most HEVs have at least two separate cooling systems: one for the ICE and one for the high-voltage system. Some HEVs have a separate third cooling system for the HV battery. Each cooling system can have its own coolant pump, radiator, and surge tank. Some systems may have three-way valves, heaters, and chillers in the coolant system.

A challenge to the HEV is how to provide cabin heating when the ICE does not run at all times. The BEV has a larger challenge since it does not even have an ICE. The HEV also needs to be able to control emissions associated with starting, shutting off, and restarting a cold ICE.

The Gen 2 Prius (2004-09) used a Coolant Heat Retention System to preheat the cylinder head on cold starts to reduce emissions. Located in the left front fender well, the retention tank stores approximately 1.5 gallons (5.7 liters) of coolant at up to 150°F (65°C) for up to 3 days.



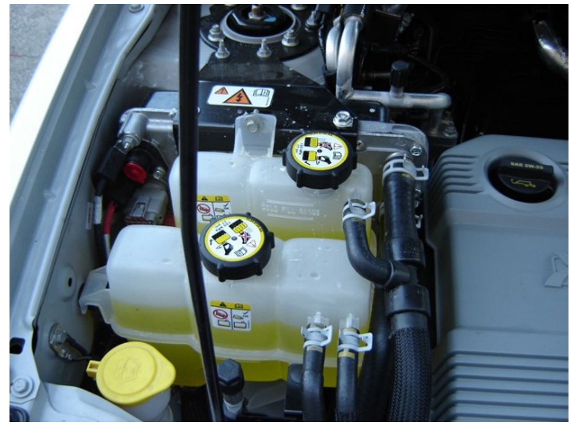
When placed into Ready Mode on a cold start, a switching valve (green in this illustration) moves to block the passenger cabin heater core, and the pump (inside the tank) circulates coolant from the tank directly to the cylinder head. Once the head warms slightly, the engine starts, and the switching valve moves to open the heater core path. When powered down after operation, the system waits a few minutes for the engine temperature to rise, then moves the switching valve to circulate hot coolant from the engine into the tank, and then closes the passages to the storage mode for the next cold start.

When servicing the ICE cooling system on these models, drain the radiator, the engine block, and the retention tank. Remember, the tank coolant can still be hot days after the last engine run cycle.

**Notes:**

The Gen 3 Prius (2010-2015) discontinued using the retention tank. Coolant heating is accomplished by flowing it through a section of the exhaust. Control of coolant heating is by a themo-wax device that opens or closes an exhaust restriction. When the coolant is cold, the thermo-wax control moves the rod to close the restrictor valve. The restricted exhaust flow creates back pressure and generates heat quickly. The coolant circulates around the section of exhaust and will transfer heat to the coolant and, thus, to the engine. When the wax pellet warms, it opens the valve to allow for free-flowing exhaust.

As mentioned, there may be more than one cooling system. Typically, each system will have its own electric coolant pump. However, some ICEs still have a belt-driven pump. Some systems may have three-way valves, heaters, and chillers. Inspection of the cooling system will involve additional hoses and connections than most conventional vehicles. It is also possible that each cooling system has unique coolant type requirements.



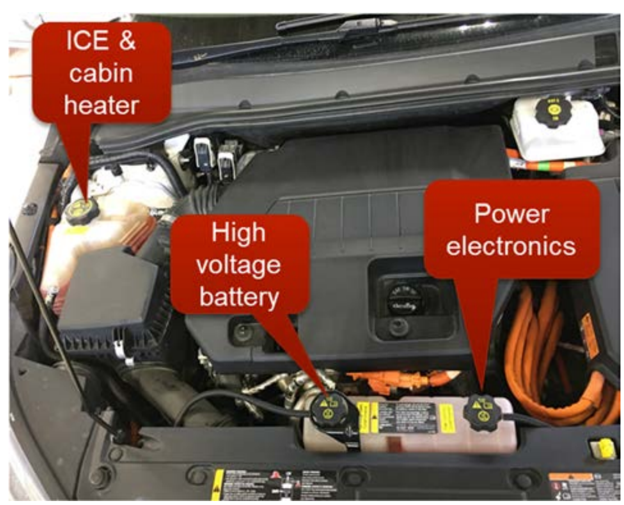
Even EVs have cooling systems. Cooling systems are necessary to prevent overheating of the high-voltage components. The HV battery, inverter, DC-to-DC converter, and electric motors all create a lot of heat and require cooling.

**Notes:**

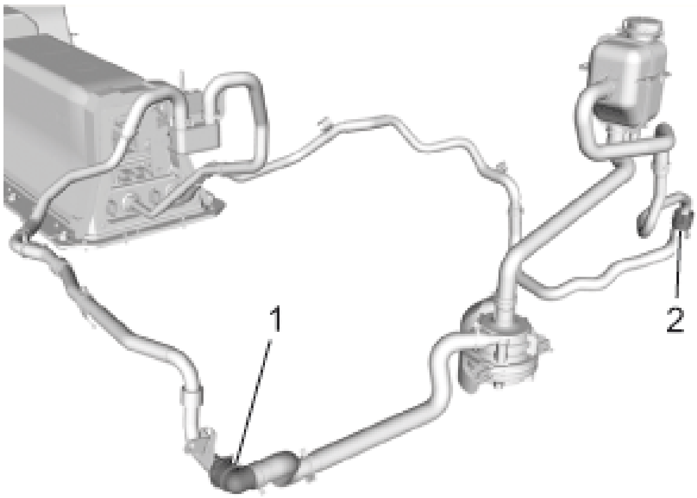
Customers may forget about the cooling systems and neglect the proper maintenance of these systems. In addition, they may not know that their vehicle may have multiple cooling systems or their purpose.

During a maintenance service, the technician should ensure the coolant systems are full of the correct type of coolant. Like any engine, a low ICE coolant level can damage the engine. Low coolant levels in the HV cooling systems can cause damage to the inverter, DC-to-DC converter, and HV battery.

The Gen 1 Chevy Volt is an example of a vehicle with three fully independent cooling loops. Each loop employs its own heat exchanger at the front of the vehicle. The power electronics cooling system is dedicated to the battery charger and inverter. The HV battery cooling system is dedicated to cooling and heating the HV battery. The engine cooling system is dedicated to cooling the ICE and heating the passenger compartment.




**Notes:**

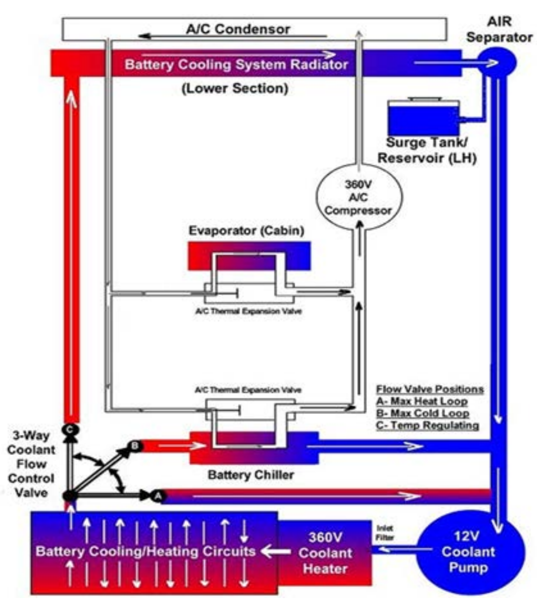



This illustration of a 2017 Volt cooling system shows that service on the HV battery assembly requires disconnecting four hose connections to drain the system fully. Refilling the cooling systems on HEVs and BEVs generally involves activating a bleed pump and/or switching valves. Before you drain these systems, ensure you fully understand the drain and refill procedure and that you have a scan tool capable of initiating the appropriate procedure.

Be aware that each cooling system on the HEV or BEV will have different servicing labor times. Be sure to charge the correct time for the system you are servicing.

Notes:

## BATTERY COOLING




The Hybrid Powertrain Control Module 2 (HPCM2) monitors battery cooling or heating requirements. This battery cooling loop of a Chevy Volt utilizes a 360-volt coolant heater to warm the coolant in cold weather and uses a battery chiller to help cool the coolant flowing through the loop. The battery chiller is located in the vehicle's A/C system but has its own thermal expansion valve. A three-way coolant flow control valve routes coolant either through the heat exchanger, or through the battery chiller, or bypasses the heat exchanger and chiller and flows through the coolant heater. A 12-volt electric coolant pump creates flow through the coolant loop. The HPCM2 activates the coolant pump, positions the three-way valve, turns on the cooling fans, requests A/C system operation, and activates the 360-volt heater or the chiller as needed.

Notes:

## COOLANT SYSTEM CARE


Cooling system maintenance includes:

- Coolant testing
- Coolant flushing
- Air Bleeding
- Coolant pump inspection
- Coolant cap inspecting/testing

Be cautious about using chemical cooling system cleaners or additives. Many manufacturers expressly state not to use these chemicals in their systems. The different cooling systems may have small orifices located in various parts. Using chemical cleaners or sealers can clog these orifices. If blockages occur, DTCs will typically set due to high temperatures in the system affected by the blockage. The blockage may be permanent and may require the replacement of expensive parts to restore proper coolant flow. Be sure to read the appropriate service information prior to servicing with chemical additives. It is important to reference Technical Service Bulletins (TSBs) for updates concerning cooling system service.


It is also important to use the correct coolant. The formulation of the antifreeze must be compatible with the metals used in the system. It is a best practice to use premixed 50/50 coolants. If the coolant needs to be mixed, use only deionized water. Using ordinary tap, well, or spring water may result in the formation of scaling.

Notes:

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## PROPER TESTING TOOLS

During the maintenance service, test the concentration and freeze point of the antifreeze. Accurate test results require the use of the proper tool. For example, these hydrometers will only work on Ethylene Glycol type coolants and not on Propylene Glycol.


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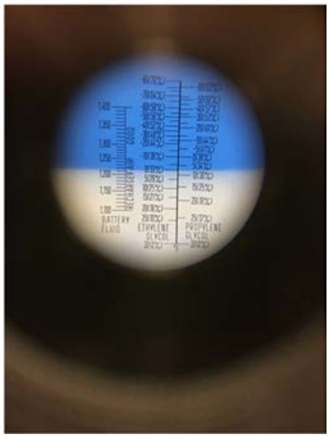

A refractometer can work on either type of coolant. The reading can indicate the concentration of the coolant along with its freeze point.

Special coolant test strips can determine the strength of the coolant. They can also indicate the reserve alkalinity of the coolant. Confirm that the test strip is compatible with the coolant you are testing.



Be aware that the different cooling systems may have very different pressure cap ratings. Typically, the ISE cooling system will have a much higher pressure rating than the electronics or HV battery cooling systems. When testing the caps, be sure to use the proper specifications.

**Notes:**

## COOLANT AIR BLEEDING

Most HEVs and all BEVs use an Electric Water Pump (EWP) to circulate the coolant throughout the system. It is easy to overlook the EWP during the inspection process. If servicing the cooling system, confirm the operation of the EWP first. You do not want to find out after the service that there is an issue with the EWP. Usually, the scan tool provides an EWP activation test.

After performing a cooling system service, it is imperative to remove air from the system. Failure to do this may severely damage the ICE, inverter, converter, or HV battery. The air bleed procedure may require opening a bleed port. Some systems only require leaving the reservoir cap off during the process. Be sure to refer to the proper service information for the procedure.

A typical method of bleeding air from the cooling system with an EWP is to use a scan tool. With the scan tool connected to the DLC, take this opportunity to check for codes related to the system's coolant pump.


To start the air bleed process, activate the EWP and check for flow through the reservoir. Continue to run the EWP until air bubbles cease to appear. It may be necessary to add more coolant to correct the level after bleeding the air.

The cooling system may have air bleed ports if the reservoir is not the system's highest point. Open the port and, if possible, attach a clear hose to it that will direct any coolant into an approved container. Run the EWP until air-free coolant flows out of the port.

A "Coolant Pulsator" is a good tool for removing scale within a cooling system. The tool uses high-frequency pulses to develop kinetic energy in the liquid flow. The pulsing energy lifts and suspends scale particulates while also scrubbing the buildup from the surfaces.

Coolant vacuum refill tools help to fill the cooling system without introducing air. It is a good practice to retest the EWP after filling the system with this method.

Notes:

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# 12-VOLT BATTERY SYSTEM

Often forgotten is the fact that HEVs and BEVs still have a 12-volt system (some have a 36/42-volt system). This means there is a 12-volt auxiliary battery that also requires maintenance. The auxiliary battery needs to be tested on a routine schedule to ensure its ability to perform its duties.


Some vehicles (2015 Subaru Hybrid, for example) have two 12-volt batteries and two separate charging systems. In this case, a DC-to-DC converter charges one of the batteries while a belt-driven alternator charges the other. Both batteries and both charging systems need to be checked and maintained.

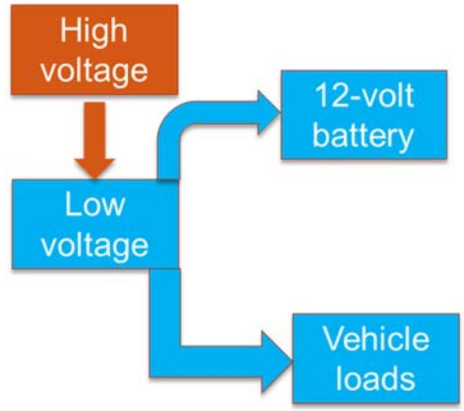
Most auxiliary batteries are typically AGM. However, that will not always be the case. For example, Hyundai uses a 12v battery Lithium-Ion Polymer Battery (LiPB) located under the rear seat next to the HV battery. This battery has 8 cells and an open circuit voltage of 12.8 volts. Since it is used for auxiliary purposes only, it has a low rating of 30-amp hour.

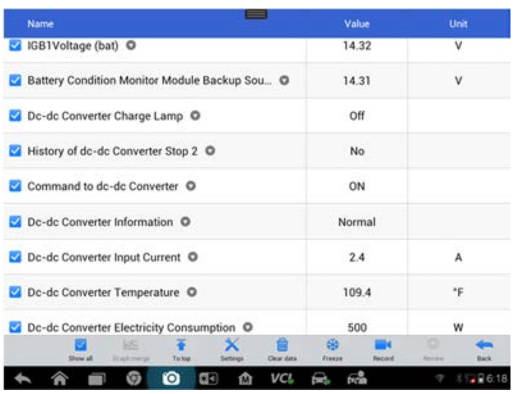
The testing of this battery is very different. In addition, these applications have many DTCs available regarding the 12-volt system. A scan tool that can read these codes and perform bi-directional controls will be required to diagnose these batteries.

**Notes:**

# DC-DC CONVERTER

The 12-volt system used in HEVs and BEVs has the same requirements as a conventional vehicle. The 12-volt battery supplies the vehicle's electrical system with the required voltage and reserve energy. It is usually the responsibility of the DC-to-DC converter to charge the 12-volt battery as it receives voltage from the HV battery and reduces it to between 13.8- and 14.5-volts DC to charge the 12-volt battery. In addition, the reduced voltage provides the energy to operate all the 12-volt loads in the vehicle. The voltage reduction is known as bucking the voltage down. Some DC-DC converters also boost the voltage from the 12-volt side to the high-voltage side to offer a jump-start feature.




A scan tool may be able to access DC-DC data PIDS. Check that the output voltage is in the normal range. With the system on, without any accessories commanded on, the voltage may be around 12.8 volts. This voltage is typical for a fully charged AGM battery. Placing the vehicle in the READY mode, or commanding accessories on, should increase the voltage to about 14 volts. The Charge Lamp should be off if the system is working properly. DC-DC Command should be on indicating the 12-volt battery is being charged and the 12-volt system is supplied electrical energy. DC-DC Temperature can be monitored for overheating conditions. Electricity Consumption indicates the current watt output of the DC-DC converter. Loading the 12-volt system with a carbon pile and slowly increasing the load should increase the wattage output until the maximum output is reached.

The DC-DC converter may operate under different modes. One example is the 2017 Chevy Volt which has six modes. Only five are used throughout the life of the vehicle. The battery controller only uses the 6th mode for the first 500 miles (805 kilometers) to ensure a full charge for the original purchasing customer. Before testing the 12-volt system, research the system to determine the procedures and normal operational characteristics. In this example, the 5 modes are:

1. Battery Sulfation Mode – When system voltage is below 13.2v for 30 minutes, the system will enter this mode and increase the voltage to 13.9 – 15.5 for 5 minutes and recheck the battery state of charge.
2. Normal Mode – will occur if any of the following conditions are met:
   - Wipers are on for more than 3 seconds
   - GMLAN Climate Control Voltage Boost is requested, High-speed fan, rear defog are active
   - Estimated battery temp is less than 32 deg F
   - Vehicle speed greater than 90mph
   - Current sensor fault is set
   - System voltage below 12.56v
   - Tow/Haul mode selected

3. Fuel Econ Mode – Ambient temp between +32 and 176 deg F, battery current between -8A and 5A, battery state of charge 85% or better, open circuit voltage 12.6 – 13.2
4. Headlamp Mode – When headlamps are on, High or Low beam, the voltage is set to hold between 13.9 – 14.5v
5. Voltage Reduction Mode – Ambient temp over +32 deg F, and load is -7A to 1A

Test the DC-to-DC converter output and ripple to make sure it's capable of maintaining the 12-volt battery and providing enough energy to operate the vehicle's 12-volt electrical system. Testing the DC-DC converter is much like testing the output of a conventional alternator. The main difference is that the ICE does not need to be running. Output voltages can be tested at the battery or the DC-DC output terminals. With the vehicle in READY mode (or any other mode that allows the DC-DC converter to charge), the voltmeter should read approximately 14.0 to 14.5 volts. Turn on 12-volt accessories to provide a load while monitoring the voltmeter. The voltage should not fall as the load increases. Additional testing procedures include using a carbon pile, a scope, and amp probes.

**Notes:**

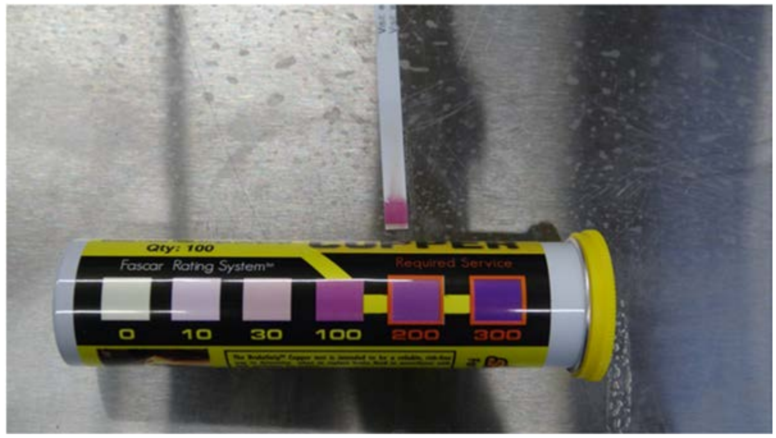
# BRAKE SERVICE

HEVs and BEVs can use a blended braking system. This means they can use a combination of electric motors and hydraulics to slow and/or stop the vehicle.

HEVs and BEVs use regenerative braking to recharge the HV battery and to slow or stop the vehicle. However, regenerative braking will only occur if the HV battery can store the energy. If the battery is full, the vehicle uses only the hydraulic brakes. During regenerative braking, the electric motors operate as a generator. The process of generating current creates an induced voltage that will slow the electric motor.

In a typical Front Wheel Drive (FWD) HEV or BEV, the front brake pads may not experience much brake wear. Since the electric motors are driving the front wheels, regenerative braking is only available to the front wheels. The rear brakes operate by a hydraulic system. Thus, the rear pads may wear out before the front. Depending on vehicle usage, it is possible for the front brakes not to be operating properly and for the driver to be unaware of the issue. This is why it is important to inspect the brakes. In some cases, the removal of the pads is necessary to inspect, clean, and lubricate the slides and pins. It is also possible for the rotors to develop a layer of rust.

Test the brake fluid for copper content. Copper is an indicator of the fluid's condition. One method is to use brake fluid test strips. The strip is dipped into the fluid, removed, and allowed to sit for a minute to stabilize and turn color. Compare the strip color to the chart on the bottle. A reading of more than 200 parts per million (PPM) cooper indicates the need to flush and replace the fluid.





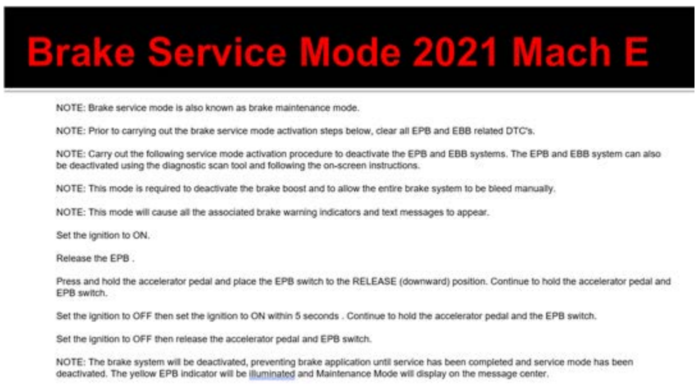
Brake fluid is hygroscopic, meaning it takes on moisture. Moisture lowers the boiling point of the fluid. Over time, the boiling point may drop so low that the brake fluid may become dangerous. A Brake Fluid Safety Meter tests the fluid to determine its boiling point. The meter works on DOT 3, DOT 4, DOT 5.1 brake fluids.

**Notes:**

Brake system services that require bleeding the fluid of air may necessitate using a scan tool. Since the hydraulic portion of the braking system is typically a "brake by wire" system, normal brake bleeding procedures may not be effective. In addition, since the antilock braking system's Hydraulic Control Unit (HCU) and pump activate the brakes, the valves require cycling while the pump operates to remove the air. This requires activation by the scan tool. In most cases, the scan provides directions for the bleeding procedure.

Be sure you follow all service information brake bleed procedures. Consider the 2017 Chevy Volt. To bleed the brakes on this vehicle you must activate the Service Only Mode. In this mode, only the 12-volt battery powers up the 12-volt systems. The engine and HV system are not powered up and will not activate, preventing the vehicle's operation.

The caliper may be electrically activated. The integrated caliper has a gear reduction motor that extends and retracts the piston.



Brake Service Mode 2021 Mach E

NOTE: Brake service mode is also known as brake maintenance mode.

NOTE: Prior to carrying out the brake service mode activation steps below, clear all EPB and EBB related DTC's.

NOTE: Carry out the following service mode activation procedure to deactivate the EPB and EBB systems. The EPB and EBB system can also be deactivated using the diagnostic scan tool and following the on-screen instructions.

NOTE: This mode is required to deactivate the brake boost and to allow the entire brake system to be bleed manually.

NOTE: This mode will cause all the associated brake warning indicators and text messages to appear.

Set the ignition to ON.

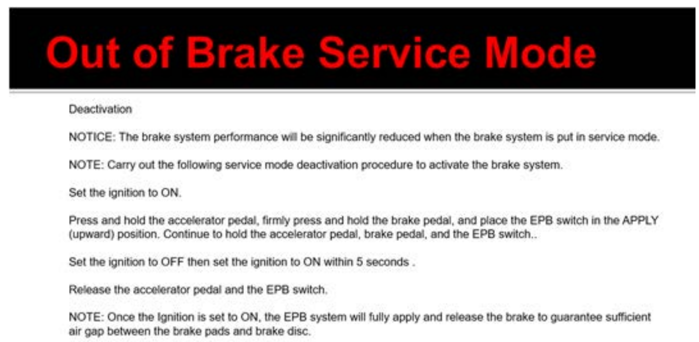
Release the EPB .

Press and hold the accelerator pedal and place the EPB switch to the RELEASE (downward) position. Continue to hold the accelerator pedal and EPB switch.

Set the ignition to OFF then set the ignition to ON within 5 seconds . Continue to hold the accelerator pedal and the EPB switch.

Set the ignition to OFF then release the accelerator pedal and EPB switch.

NOTE: The brake system will be deactivated, preventing brake application until service has been completed and service mode has been deactivated. The yellow EPB indicator will be illuminated and Maintenance Mode will display on the message center.



Out of Brake Service Mode

Deactivation

NOTICE: The brake system performance will be significantly reduced when the brake system is put in service mode.

NOTE: Carry out the following service mode deactivation procedure to activate the brake system.

Set the ignition to ON.

Press and hold the accelerator pedal, firmly press and hold the brake pedal, and place the EPB switch in the APPLY (upward) position. Continue to hold the accelerator pedal, brake pedal, and the EPB switch..

Set the ignition to OFF then set the ignition to ON within 5 seconds .

Release the accelerator pedal and the EPB switch.

NOTE: Once the Ignition is set to ON, the EPB system will fully apply and release the brake to guarantee sufficient air gap between the brake pads and brake disc.

Not all HEVs and EVs have a service mode, and those that do have very different methods of activating and deactivating it. Typically, vehicles with an Electric Parking Brake (EPB) system and/or electric brakes will have a service mode. Refer to the proper service information regarding how to place the system into and out of service mode.

**Notes:**

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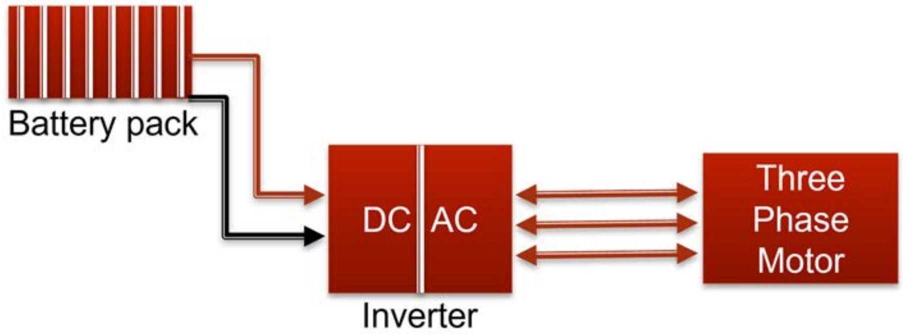
## HIGH-VOLTAGE BATTERY MAINTENANCE

HEVs use the HV battery to propel the vehicle during normal starts from a stop and during most in-city driving. The ICE starts to assist the battery during high load demands. On BEVs, the battery is the only source of energy used to propel the vehicle.

Although a scan tool can provide data that assists in diagnosing the condition of the HV battery, there will be times when removing the battery case to perform additional testing or service is necessary. Do not perform these procedures unless you have received the proper training and have met all of your shop's requirements.

The HV battery pack connects to the inverter with one positive high-voltage cable and one negative high-voltage cable. The battery provides DC voltage to the inverter, which converts the DC voltage into AC voltage to power the electric motor(s). DC power is necessary to recharge the HV battery pack.

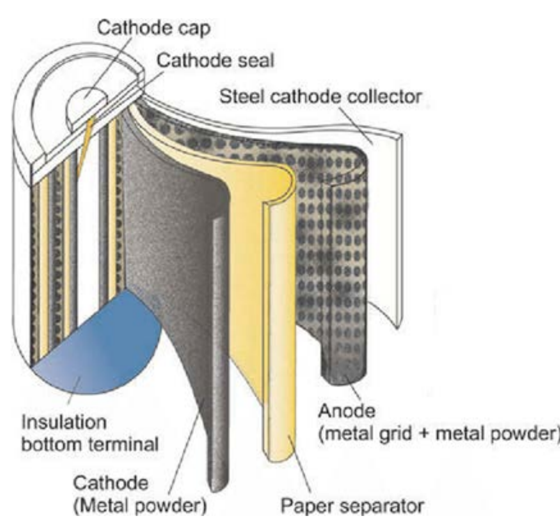


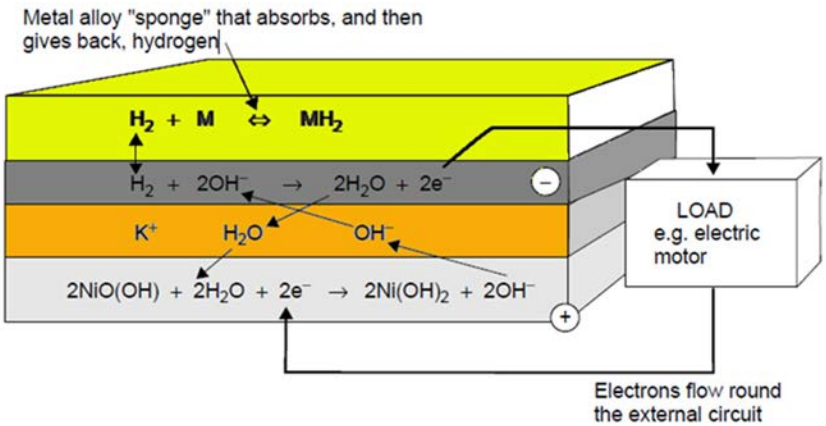

The HV battery can be located anywhere in the vehicle that has the space. Common locations include under the body, in the trunk, behind the rear seat, or under a seat. The vehicle manufacturer determines the voltage requirements the HV battery must supply. The HV battery can provide from 100 to over 400 volts, based on the size of the unit. Higher voltage allows for greater horsepower and torque motors, quicker acceleration, higher top speeds, and increased vehicle range.

Nickel Metal Hydride (NIMH) batteries usually come in two cell shapes: cylindrical or prismatic. Cylindrical cells look much like a standard D-Cell battery. The cells are stacked and shrink-wrapped together to form a module and then connected to other modules. The cylindrical cell design tends to operate at a higher core temperature than the prismatic design; therefore, it requires a more robust cooling system. Some manufacturers that use cylindrical cell batteries will use the vehicle's A/C system to cool the batteries.

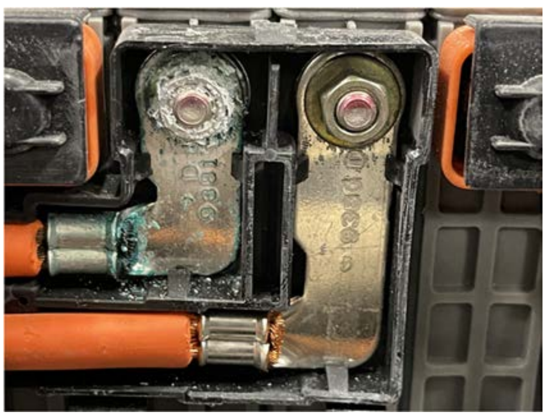
Regardless of the cell design, the cells are connected in series to make up a module. The modules are also wired in series to make up battery sections. Finally, the sections are wired in series to make the total battery.

NIMH batteries were prevalent in early HEVs and are still in use today. Most BEVs use a lithium-based battery. The electrode plates of the NIMH battery are porous nickel and metal hydride alloy. The positive electrode has more nickel, and the negative electrode is formed using hydrides. Rare earth materials like lanthanum, cobalt, neodymium, and cerium are used along with other hydride compounds to make up the negative electrode. The electrolyte used is a potassium and sodium hydroxide, high alkaline mixture.






The electrolyte is more of a paste held in the separator plates with a very small amount of liquid electrolyte. The electrolyte material is highly conductive. Hydrogen molecules are constantly moving through the electrolyte during charge and discharge cycles. The battery cases are under slight pressure and rated up to 40 psi. Pressure builds during high rates of discharge and recharge.



Due to the highly corrosive nature of the electrolyte, follow all applicable safety procedures. The electrolyte can cause skin burns, breathing issues, and blindness.

**Notes:**

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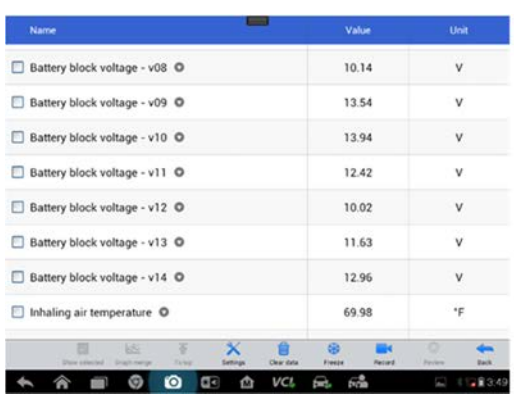
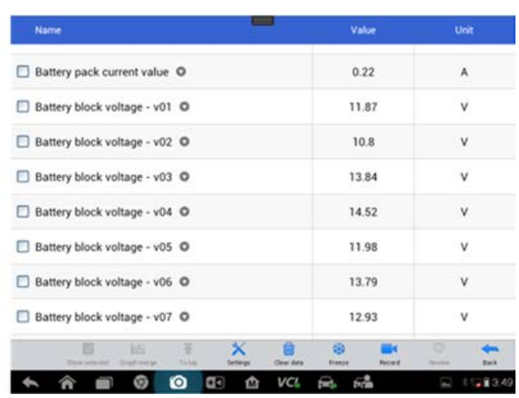
Always remove the service disconnect plug when working on or around the HV battery. The battery stores energy and can still produce a shock even with the service plug removed. Wear high-voltage gloves when working around the terminals of the HV battery.

## BATTERY DEGRADATION

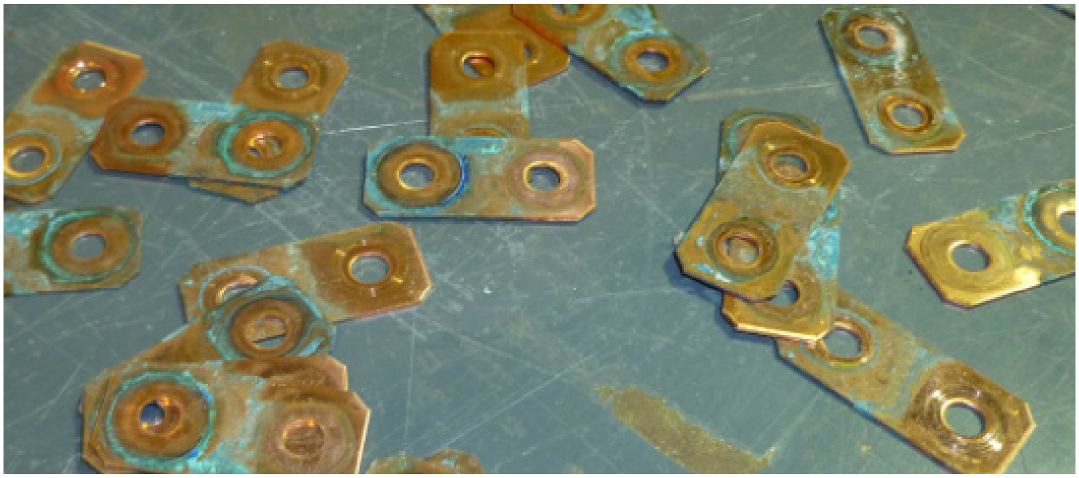



A common failure in NIMH batteries is cell impedance increases due to electrolyte dry-out that occurs during natural degradation. In an HEV battery, degradation can result in a drastic reduction in fuel economy and poor acceleration. The scan tool can provide data PIDs that will indicate if the battery is failing. The difference between block voltages needs to be within the vehicle manufacturer's specifications.

## TERMINAL CORROSION

Like any battery, terminal corrosion reduces its effectiveness. If there is terminal corrosion, confirm it is not caused by a leaking module case. Also, capillary action may pull the corrosion a great distance up the cable. Perform a voltage drop test of the terminal to cable connection and at both ends of the cable to confirm they are good.



The Buss bars connecting the modules can be removed and cleaned. Use a solution of ¼ cup white vinegar and 1 teaspoon salt. Allow the bars to sit in the solution for at least 5 minutes. Wash the bars with clean water to remove all of the solution. Failure to completely rinse the bars will cause them to oxidize.

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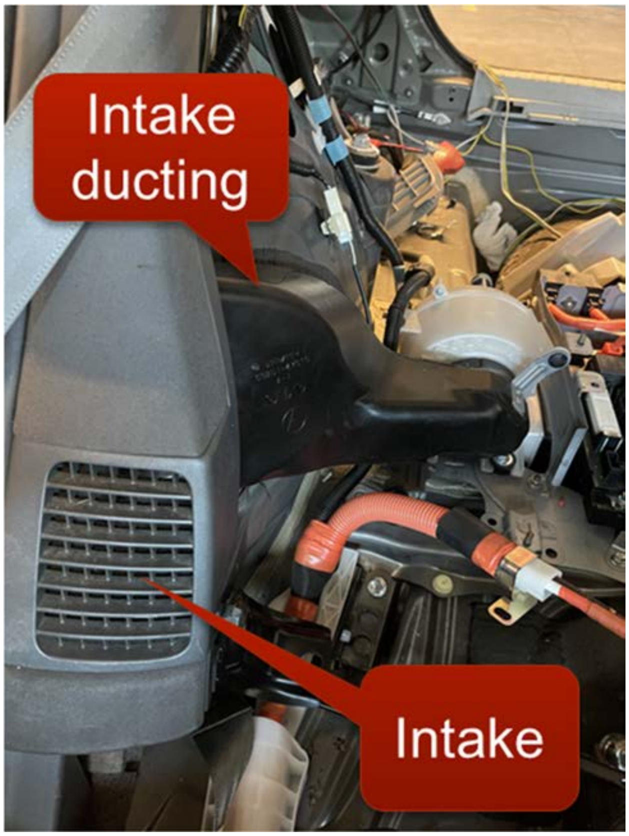
## HIGH-VOLTAGE BATTERY COOLING

The HV battery may have a thermal management system that includes a cooling and a heating system. The manufacturer may design the cooling system to be air-cooled, coolant-cooled, or a combination of both. The air-cooled version may simply pull air from the cabin and circulate it through the battery, or it may use the AC system to cool the air before circulating it through the battery. The coolant system provides a separate cooling system with an electric coolant pump to circulate coolant through the battery to cool the battery. The coolant system may add a chiller to help cool the coolant more effectively.

Lithium-based batteries do not function well when cold, so they normally incorporate a heater in their thermal management system. Adding a coolant heater to the coolant system warms the coolant to get the battery up to operating range faster.

Driving the vehicle in areas where regenerative braking occurs often can result in the HV battery overheating if the cooling system is not functioning correctly. When the vehicle enters regenerative braking mode, the HV battery tends to get hotter as it receives large amounts of current. Battery overheating causes terminal corrosion and cell dry-out.

| Parameter | Value | Unit |
|---|---|---|
| Cooling Fan Mode1 | 4 | |
| Temp of Batt TB1 | 115.0 | F |
| Temp of Batt TB2 | 117.7 | F |
| Temp of Batt TB3 | 113.4 | F |
| Batt Block Minimum Vol | 16.01 | V |
| Batt Block Max Vol | 16.14 | V |
| Battery Block Vol -V01 | 16.04 | V |
| Battery Block Vol -V02 | 16.04 | V |
| Battery Block Vol -V03 | 16.09 | V |
| Battery Block Vol -V04 | 16.11 | V |
| Battery Block Vol -V05 | 16.02 | V |
| Battery Block Vol -V06 | 16.04 | V |
| Battery Block Vol -V07 | 16.04 | V |
| Battery Block Vol -V08 | 16.06 | V |
| Battery Block Vol -V09 | 16.06 | V |
| Battery Block Vol -V10 | 16.09 | V |
| Battery Block Vol -V11 | 16.06 | V |
| Battery Block Vol -V12 | 16.11 | V |
| Battery Block Vol -V13 | 16.04 | V |
| Battery Block Vol -V14 | 16.04 | V |
| Pattern Switch (PWR/M) | OFF | |

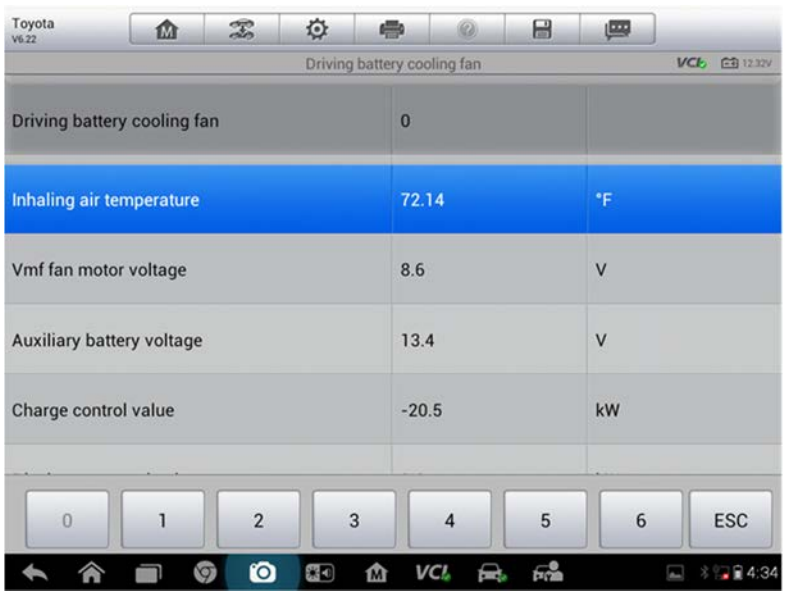



Vehicles that use air to cool the HV battery pack typically locate the air intake inside the cabin. They utilize a blower motor that pulls air from the cabin and directs it into the battery. Vents allow the heated air to escape from the HV battery case.

If the HV battery is experiencing overheating, ensure no items are blocking the intake. Also, check the intake ducting for proper assembly from the air inlet to the blower.

The fans can become clogged and unbalanced due to lint, pet hair, and mouse nests. A DTC will set if the fan cannot provide sufficient airflow to cool the HV battery. If the fan is clogged, remove and clean it to restore proper airflow and balance. Check the ducting and the battery for lint and debris. If the HV battery pack has lint and debris between the cells, use air to blow it out.

Some manufacturers have added filters to the air intake to trap the lint and debris. The filter requires replacement on a regular basis. Most manufacturers recommend inspecting the filter at every oil change. Some vehicles have two air inlet grills and two filters. The aftermarket offers some filters to add to the air inlet to help fight against lint and debris plugging the system.

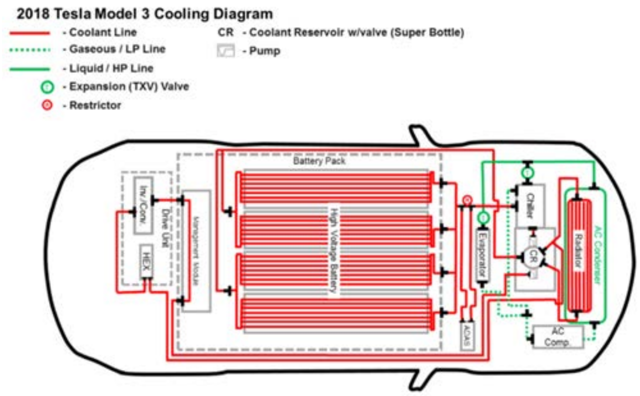


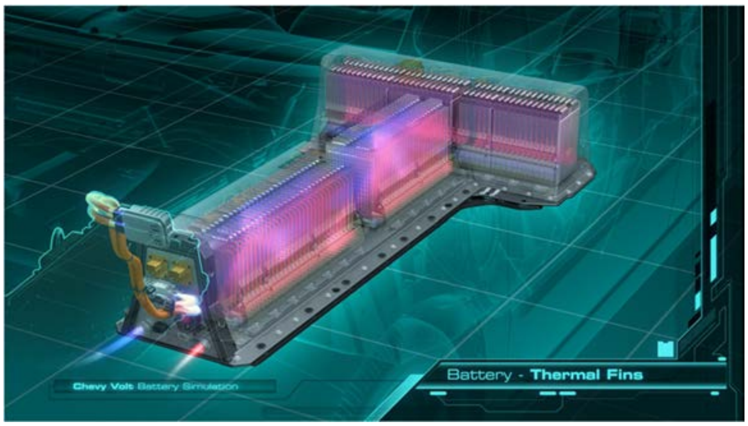

Use a scan tool to test fan motor operation. Command the HV battery cooling fan motor on. With the fan running at different speeds, listen for unusual noise. Test that the fan is pulling in air using a piece of paper. The paper should be pulled to the inlet grill.

Some manufacturers will use the cabin air conditioning system to cool the HV battery and electronics. Ford uses an A/C compressor that is both belt and HV-operated. Solenoid valves shut off refrigerant flow to the battery or cabin evaporator as needed. When diagnosing air conditioning faults on these applications, keep in mind there is a rear assembly with an evaporator, blend door, fan assembly, and a cabin air filter which requires regular maintenance.

Notes:

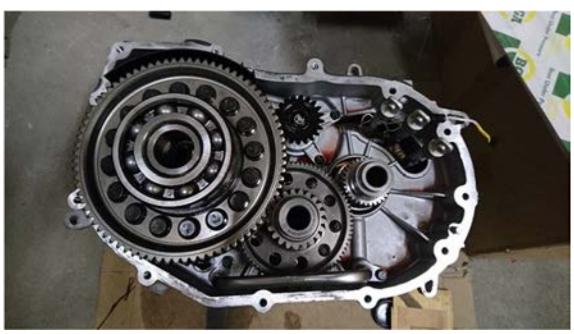
This is the HV battery coolant path on a Tesla Model 3




This thermal image shows the coolant flow through the plates between the battery modules of the HV battery of a Chevy Volt.

# GEAR OIL MAINTENANCE

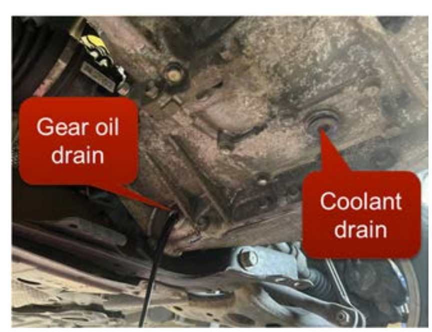


Most HEVs and BEVs have some form of a gearbox that requires oil. Reduction gears are needed to convert the high speed of the motor shaft rotation to a lower speed for use by the drivetrain.

Gear oil becomes contaminated with moisture. In addition, oil may become acidic over time. In the case of HEVs and BEVs, this can lead to contamination of electrical windings. Also, the acids can attack bearings and cause excessive wear. The gearbox oil should be drained and refilled according to the manufacturer’s maintenance schedule. The oil must meet the OEM specifications.

Many drive assemblies will have an external filter.

The gear oil drain plug is located at the bottom of the gearbox. Some gearboxes may also have a coolant drain in the same area. Make sure you select the correct drain plug.



# A/C SERVICE

Another often overlooked system is the A/C system. This system is no longer a seasonal service. Due to the A/C system's role in cooling the high-voltage electronics and/or the HV battery, this system must be in proper operating condition year-round.


If the A/C system requires recharging, pay attention to the type of refrigerant and oil used. Although the service fittings of the different freon systems make it difficult to use the incorrect freon, there is nothing to prevent using the incorrect oil. The oil used in a system that operates by a high-voltage A/C compressor requires high insulating properties.

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## OIL PROPERTIES

The oil used in an A/C system that operates by a high-voltage A/C compressor requires high insulating properties. PAG oils have exhibited higher levels of electrical conductivity than the industry considers acceptable. PAG oil is not refined enough to use in electric compressors. POE oil used in electric compressors has specific properties that give it high insulating properties. Do not mix PAG and polyol ester (POE) oils.


There are a variety of POE oil types and grades, and it is important to know which POE oil is in the system you are servicing. Mixing incompatible POE oils may create A/C performance issues and lead to compressor failure. Always reference the manufacturer's service information for the proper oil to use.

Lack of oil can cause catastrophic failure of the compressor. Some compressors incorporate an oil separator inside the compressor to trap most of the oil, giving the compressor a wet sump. However, many compressors allow the oil to flow with the refrigerant through the system. Refrigerant undercharge allows oil to fall out of the refrigerant and become trapped in areas like the accumulator. If the oil does not make it back to the compressor, severe damage can result.

Also, traditional dyes usually mixed with PAG oil are incompatible with electric compressors. Special dyes are available for EV vehicles. The dye used is typically POE based. EV dyes must have high-dielectric properties.

Using non-compatible oil or dye may cause an insulation fault. On an HEV, this may lead to a no-crank situation. Mixing non-compatible oil or dye may necessitate the replacement of all the major A/C components.

OEMs may have added dye during the manufacturing of the vehicle. An indicator that the OEM added dye during production is the presence of dye under the service fitting caps. If dye is already in the system, there is no reason to add more dye.

**Notes:**

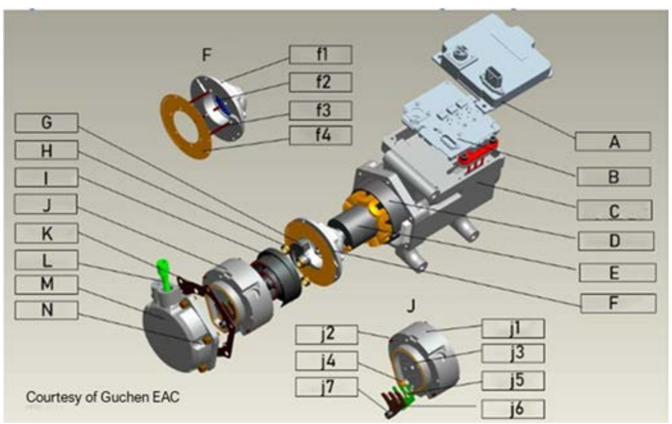
## ELECTRIC COMPRESSORS AND OIL

Most HEVs and all current BEVs use electric A/C compressors. The electric compressor allows the A/C system to continue operation even with the ICE shutdown. Another advantage is the electric compressor doesn't have a protruding shaft to allow refrigerant to leak out.

Disadvantages include that an A/C system failure may prevent the vehicle from operating or reduce its performance. Also, if the A/C system fails, the HV battery and/or high-voltage electronics may overheat and become damaged. To most, the biggest disadvantage is the drop in the BEV's range the more the A/C is used.

**Notes:**


An electric compressor consists of an electric motor containing a rotor, a stator, an inverter, an oil separator, and two scrolls. The wiring at the compressor consists of two large terminals from the HV battery (A & B). The small connector contains 12-volt positive, 12-volt negative, Start/Stop signal, PWM speed control signal, CAN-H, and CAN-L.




The oil and gas separator (L) removes the oil from the refrigerant and drops it in the compressor. The oil provides for compressor cooling and lubrication. The refrigerant is much more efficient without having to carry the oil through the system with it.

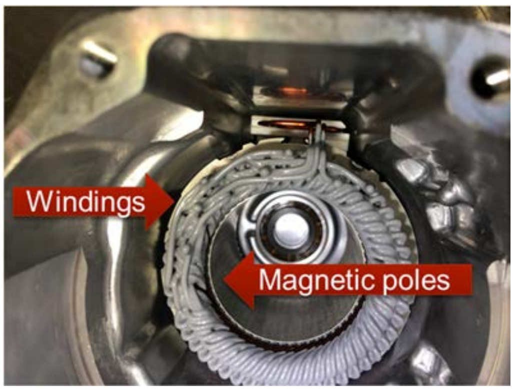
**Notes:**


Compressors may have a kilowatt rating. Kilowatt requirements depend on HV battery capacity and voltage, the size of the cabin, and any thermal requirements for the HV battery. Early models with low capacity and lower voltage batteries may only have a 1.8 to 2.4-kilowatt compressor. BEV models with large batteries and higher voltage may use 4 to 6-kilowatt compressors. Compressors may also have a swept volume rating in CCs to indicate the size of the compressor.

# HONDA THREE-PHASE OPERATION

We will explore the operation of the electric A/C compressor used on the Honda Civic. The inverter provides the high voltage used to operate the compressor.

In this vehicle, the inverter is located in the back of the rear seat with the other high-voltage controllers.




The electric motor's stator is stationary in the compressor's case. The stator is three-phase, so it has three wires attached to the wye windings. A heavy layer of epoxy insulates the windings. Energizing the windings in a certain sequence creates the magnetic poles.

The magnetic poles interact with the rotor to cause rotation of the rotor and the compressor drive shaft. The rotation of the rotor and the compressor driveshaft causes the scroll to move and compress the gas as well as circulate the refrigerant through the system.

Oil lubricates the bearings that support each end of the rotor. The low-pressure gas entering the compressor is cold, so the refrigerant helps reduce the heat inside the compressor.

The scroll is two pieces; one is movable, and one is stationary. The gas is pressurized and circulated as the movable scroll orbits around the stationary scroll.

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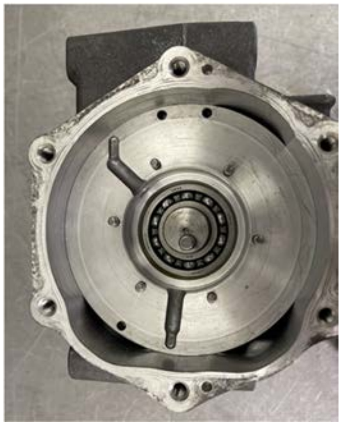

The scroll must move in an orbital rotation. This movement is created by offsetting the drive pin.

The speed of an electric motor is determined by the frequency from the inverter and the number of poles in the motor. Controlling the compressor's speed varies the output of the compressor. Controlling the speed controls not only the output but also controls energy consumption. To calculate the speed of an electric motor, multiply the frequency by 60 and divide by the number of poles in the motor.

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## HONDA BELT & ELECTRIC COMPRESSOR

The early Honda compressors were a dual scroll type. The compressor had two sides; one side ran by mechanical means of a belt and traditional pulley. The other side of the compressor operates via an electric motor. The compressor is provided power from a 144-volt battery. The electric motor compressor is a three-phase motor requiring an inverter to convert the DC from the battery to three-phase AC delivered to the compressor.

The Honda dual scroll compressor operates in three distinct modes. Electric mode for low-demand situations. Mechanical mode for medium-demand situations. High-demand situations initiate the Combined mode. When the engine is off during a vehicle stop, the electric side continues cooling the cabin. The mechanical side of the compressor has a rated 75cc output. The electrical side output is 15 cc. The two sides of the compressor share the inlet and the outlet ports.

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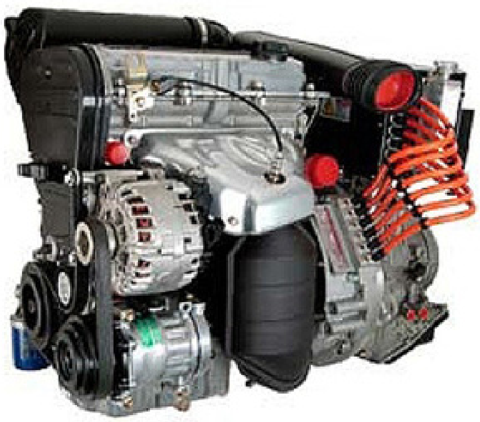
# ENGINE SERVICE



Under normal operating conditions, the HV system cranks the engine to start it. These motor units can spin the engine up to about 1,000 RPMs. Exercise caution when working around an HEV ICE when the vehicle is in the READY mode. The ICE can start at any time and without warning. Some early Ford and Honda HEVs had a 12-volt starting system as a backup starter in the event the HV system failed.

**Notes:**

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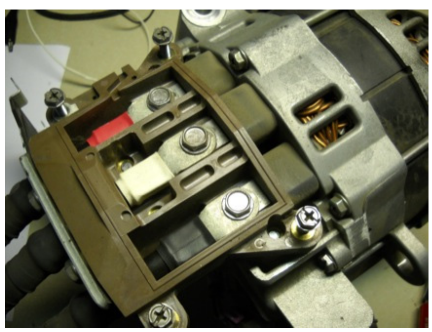
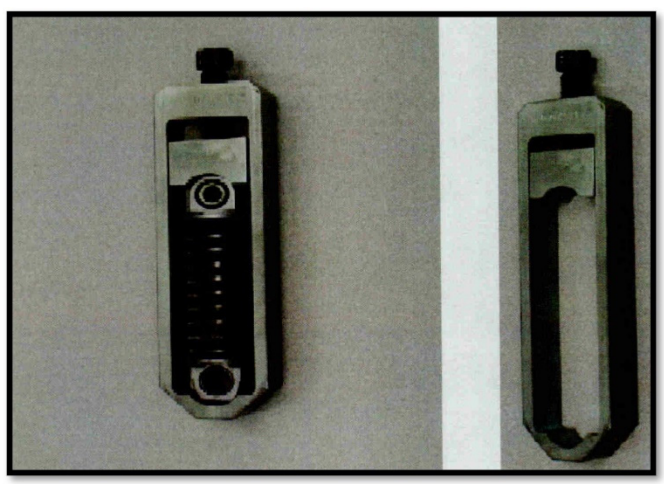
A special service mode may be provided that allows mechanical cylinder compression testing and other diagnostic routines that require slower engine cranking speeds. A properly equipped scan tool can initiate the cranking test mode.



A common example of the Belt Alternator Starter (BAS) system is that of the GM truck and SUV lines. These are considered mild HEVs that use a 36-volt battery with a 42-volt charging system. Although the BAS unit looks like a conventional alternator, it is unique in the fact that they have three HV wires going to it.

Belt service to the BAS requires a special tool. The tool compresses the belt tensioner, allowing the removal of the tensioner's spring bolts. The tool holds the tensioner's spring while installing the new belt and the tensioner.



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