# Hybrid vehicle measurement safety basics:
## Taking high-voltage readings

**Application Note**

**By Jack Rosebro, for Fluke**

Hybrid vehicle technology may be in its infancy, but the field is growing rapidly. Every major auto and truck manufacturer is developing hybrids, and hybrid technology is a stepping-stone to advanced electric-drive components that will be used in both hydrogen fuel cell vehicles and pure electric vehicles. The complexity and sophistication of today's hybrids are well above that of a normal car or truck.

Nowhere is this more evident than in a comparison of hybrid and non-hybrid electrical circuits. While a conventional vehicle's electrical system is almost entirely driven by voltages of 12 to 14 volts, today's hybrid vehicle may produce five or more different circuit voltages, ranging from 12 to 650 volts. Both ac and dc currents are employed, and variable voltages are common.

Hybrids are designed to minimize the need to directly measure live high-voltage circuits. However, there will be times when the experienced hybrid vehicle technician will need to do just that. Although articles such as this can only supplement OEM service information, there are some general precautions that a professional technician should take when approaching a high-voltage circuit.

After turning the vehicle off, the technician disconnects the vehicle's auxiliary 12 V battery to ensure that the HV battery pack is mechanically isolated. The battery of this Toyota Prius can be disconnected from inside the main fuse/relay box.

For the purpose of this article, **high voltage** is defined as circuit voltage of more than 50 volts. Although the high voltage (HV) systems of most hybrids do not normally need to be disabled when performing routine maintenance, HV systems must be shut down before HV cables or components are disconnected or removed. For example, disconnecting HV components can be useful when diagnosing a hybrid vehicle's ground fault. Such work requires the use of a milliohmmeter or insulation tester, which will be covered in a future article.

Potentially dangerous electrical currents can be produced or carried by any of four different types of hybrid components: (1) the **high-voltage battery pack**, (2) the **capacitors** inside the vehicle's inverter-rectifier assembly, (3) the electric motor or motors, also known as **motor-generators**, and (4) the **high-voltage** cables, usually orange in color, that connect these essentials together.

One of the most common measurements of a hybrid vehicle's HV system is the voltage reading that is taken after disabling the system to verify that it has been properly shut down. Let's walk through the generic steps that are normally required to establish that a hybrid's HV system has been safely disabled.

### Getting ready

Direct measurements of potentially live HV, high-current circuits require planning and focus. Although it is **expected** that little to no voltage will be encountered during the following procedure if the system has been properly shut down and is free of faults, **always assume that the circuit is live**. Let others know that you will be working on high-voltage circuitry. Remove all jewelry as well as anything metallic that can fall out of any pocket. Wear flame-resistant clothing with long sleeves rolled all the way down.

Turn the vehicle's ignition key to OFF and remove the key. If the vehicle is equipped with a "keyless start" feature, disable it and ensure that the key fob is out of range of the vehicle. Disconnect the vehicle's conventional 12 V lead-acid battery. Before proceeding further, wait for the prescribed amount of time—which can be as much as ten minutes, depending on OEM requirements—to allow the system's HV capacitors to discharge.

To safely disable or isolate a hybrid's HV circuits, you will need to have:

1. An understanding of the vehicle manufacturer's approved HV system shut-down procedures for the specific vehicle that is being serviced.
2. A pair of rubber or synthetic rubber insulating gloves, rated to at least 1000 V ac (Class 0), that are free of faults.
3. Wear both safety glasses and an arc-rated face shield over top, per NFPA 70E.
4. A digital multimeter (DMM) that is rated to at least 1000 V, CAT III or CAT IV.
5. Electrical leads that are rated to at least 1000 V, CAT III or CAT IV, and which are equipped with at least one insulated alligator clip.

The Fluke 88 and 1587 automotive meters and leads are rated to 1000 V, CAT III and CAT IV. Gloves, meter, and leads must all have a voltage rating that is greater than the highest voltage you plan to measure. Rubber insulating gloves must be inspected prior to each use according to the glove manufacturer's specifications, and tested periodically. Most glove manufacturers also recommend or require that leather overprotectors be worn over insulating gloves to protect them.

As all hybrid shutdown mechanisms are directly connected to high-voltage cables, insulating glove, safety glasses and an arc-rated face shield must be worn when removing a hybrid vehicle's HV service plug (Ford, Toyota, Lexus) or turning off its HV safety switch (Honda).

Required equipment for high-voltage measurements include a properly rated meter and leads, a properly rated pair of insulating gloves, and—if sharp edges are present—a pair of leather overprotectors. Always wear safety glasses. The 2009 National Fire Protection Association 70E electrical safety standard now also requires wearing an arc-rated face shield when working with live voltage.

After verifying that the vehicle's ignition key has been removed, its keyless start function (if equipped) disabled, and its 12 V battery disconnected, you will typically put on a pair of rubber insulating gloves, then disconnect the vehicle's HV system by either removing a service plug or turning a safety switch to OFF, according to the manufacturer's recommendations. By disconnecting the vehicle's 12 V battery, you are ensuring that a properly operating system will mechanically isolate the HV battery pack until the 12 V battery is re-connected.

If the vehicle has been shut down correctly, **and** if no faults are present in its electrical system:

- No current will be produced by its motor-generators, as they will not be mechanically turning, and will have no access to external current sources.
- No current will be available at its capacitors, which will have been discharged during the prescribed time interval.
- No current will be present in the vehicle's HV cables, BUT the vehicle's HV battery WILL remain charged, and is thus a potential current source, although it will be isolated from the rest of the system.

Once all required safety precautions have been carried out, manufacturers' service information may direct you to take a voltage reading with an appropriate meter to verify that all sources of high voltage have been isolated or discharged.

## Taking a reading

Assuming that the vehicle's high-voltage system has been properly shut down, and you are wearing your insulating gloves, safety glasses, and face shield, the voltage reading can be taken. Before doing so, turn on the meter, select "volts dc", and verify that the meter is working by measuring a known low-voltage current source such as the vehicle's 12 V battery. Faulty meters or leads can produce a false "zero voltage" reading!

After putting on insulating gloves, the technician disconnects and removes the battery service plug. 2007 Toyota Prius hybrid shown.

Because a hybrid vehicle's HV circuits are isolated from chassis ground, readings are taken directly at the HV connections. OEM service information will provide instructions on what and where to measure. This reading is usually taken at the "normally off" HV safety relays that link the HV battery pack to the rest of the system. However, if service work requires exposure or disconnecting of HV cables, you'll need to verify that no voltage is present by taking a reading between HV cable ends as well as between each HV cable end and vehicle ground.

Veterans of HV work traditionally use the "one-hand rule" when working on a HV circuit. This means that only one hand at a time can be used to work on a HV circuit. The purpose of this rule is to reduce the risk of electrical shock—which has the potential to cause heart arrest—from current passing through the technician. Such discipline adds a layer of safety to the protection already afforded by the rubber insulating gloves.

To adhere to the "one-hand rule" when taking a direct reading of a HV circuit, it is essential that you have at least one electrical lead that is equipped with an insulated alligator clip. Using one hand, connect the lead with the alligator clip to one of the circuit's terminals, then place the other lead in contact with another terminal to make the reading. No more than one hand should be holding a lead or touching vehicle ground at any time.

Do **not** back-probe HV connectors, as this will damage them. Do not use any sprays, including cleaning sprays, around HV circuits, as this may energize the air surrounding the circuit, making it conductive. Remember that a 600 V circuit has a far greater capacity to produce an electrical arc than a 12 V circuit. Use electrical tape to immediately insulate any exposed HV terminals that have been disconnected.

## Putting it back together

Any HV connection that is secured with a threaded bolt or nut must be torqued to manufacturers' specification. The quality of the electrical connection, as well as its resistance to corrosion, is dependent on proper torque.

Check to make sure that you have not left a part or a tool in the area you are working on. If the vehicle's HV system has a removable service plug, make sure that it has seated firmly and correctly when you reinstall it. Do not re-connect the 12 V battery until the vehicle's HV service plug or switch has been returned to its original position, and any access covers that had been removed have been reinstalled.

Once the vehicle has been reassembled and its 12 V battery connected, start it up and check for codes and/or READY status. Some hybrid systems will set codes whenever the system has been disturbed or shut down, so codes may have to be cleared and then checked to see if they return. Initialize electrical systems such as power windows, if needed. Test drive the vehicle to verify normal operation. Finally, check your insulating gloves for defects before putting them away.

## Things to remember

Safe measurement of HV, high-current circuits requires discipline and awareness. There are no short cuts: Proper procedures and equipment are essential. Remember that once the vehicle has been turned off, disconnecting the 12 V battery is the first step in a HV measurement procedure, and re-connecting it is the last step before turning the vehicle back on.

Take time to develop safe HV measurement practices **before** hybrid technology becomes commonplace, and you will be laying the foundation for a competitive and profitable skill set that will serve you well in the future.

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