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Performance Tuning & Carburation Specialists

ELECTRIC VEHICLE
HIGH VOLTAGE SYSTEM TESTING
INFORMATION SHEET

This document is to illustrate some of the tests that are appropriate for testing the ‘high voltage’ systems used in electric and hybrid vehicles. The high voltage system is said to be an ‘isolated’ system, that is to say that it is not connected, or referenced to, either earth or other electrical systems.

The definition of ‘high voltage’ with respect to electric cars differs from that used in other industries. With electric and hybrid vehicles DC voltages between 60 and 1500 Volts are said to be 'high voltage’. Electric vehicles also have high voltage 3 phase AC systems.

As mistakes at these voltages can be fatal, these tests should only be undertaken by trained and experienced automotive technicians with sufficient knowledge and suitable equipment to perform the work without causing danger to themselves or others.

The law has quite a lot to say about working with electricity, specifically the Electricity at Work Regulations 1989. Regulations 13, 14 &16 are particularly pertinent to the matter in hand.

For those involved in electrical testing the Health and Safety Executive (HSE) provides detailed guidance on the matter in GS38.

The tests described below fall in to one of two categories:

- Live tests – Where the circuit is energised
- Dead tests – Where the circuit is safely isolated from all sources of power, and is locked off.

Phase conductor labelling

On electric vehicles the phases are usually labelled as U, V and W

Other alternative phase labels are possible as shown in the table below:

Phase 1	L1	R		U
Phase 2	L2	Y		V
Phase 3	L3	B		W

Insulation resistance test

This is a dead test – it is performed with the power isolated and locked off.

This test uses an **insulation resistance tester**. The test is conducted at a voltage higher than the normal operating voltage of the system. For electric vehicles the test is usually performed at 1000Volts DC.

Remember that as the test instrument itself is providing a high voltage, then all the precautions stated in GS38 will apply.

The test measures the resistance between:

- All conductors e.g. Battery+ & Battery– ,U&V, V&W, W&U
- Between all the conductors and the vehicle body.

We need an insulation resistance reading of over 1MΩ, but the higher the reading the better. The insulation resistance reduces over time; thus, we would expect a new car to have a significantly higher insulation resistance than a car that is five years old for example.

Before performing the test, the meter is checked to verify that it is operating correctly. First the resistance is measured with the test probes apart, the reading should be 'over range'. Next the resistance is measured with the test probe tips pressed firmly together, the reading should be 0MΩ.

The reason we test the meter is verify the test leads are not damaged and that they are making a proper connection. I have seen at least one person try to perform this test with one test lead not fully inserted in the meter, they thought they were getting very good readings, when in fact they were not testing anything at all.

Low insulation resistance between a high voltage cable and the vehicle body creates a fault known as 'loss of isolation'. This is not immediately dangerous as although this causes the vehicle body to be at several hundred volts there is no return path and thus no immediate risk, unless a second fault occurs. The electric vehicle has several systems that can detect a loss of isolation and shut off the power. One way this is done, is for the high voltage battery module to test for a connection between the negative output and the vehicle body and then the positive output and the vehicle body. Provided no low resistance connection is detected, the output relays are engaged. This test is performed at vehicle start up. This is backed up by voltage monitoring, often in the inverter assembly. An unequal voltage drop indicates a loss of isolation and the vehicle will shut off the power at a suitable moment. This monitoring is carried out continuously whilst the vehicle is powered up.

Common causes of deterioration in the insulation are physical damage to the cable sheath, either due to mechanical damage or being too close to hot parts. Water ingress and age will also lower the insulation resistance.

Conductor resistance test (also known as a 'continuity' test)

This is a dead test – it is performed with the power isolated and locked off.

This test uses either a four wire **milliohm meter** or if one is not available a 'low reading Ohm meter'. The technician is going to need to measure very small resistances with sufficient accuracy to identify if there is a problem. A multimeter is usually <u>not</u> suitable for this task.

As the resistance measurements we are taking are so low, it is important to null (zero) the instrument, to remove the resistance of the leads and probes from the final reading. Alternatively for instruments not so equipped, manually subtract the resistance of the leads, probes etc from the final reading.

If using a milliohm meter, the technician must ensure that it is correctly set to compensate for temperature. A temperature probe is usually connected to the milliohm meter for this purpose.

1mΩ is 0.001Ω

The amount of heat dissipated by a conductor is proportional to its resistance. Therefore, a high resistance joint or connector, can cause overheating and damage.

Common causes of high resistance are:

- Corrosion of the terminals
- Loose connections

This is why all high voltage connections must be clean, free from corrosion, and tightened using a torque wrench / torque screwdriver to the torque figure specified by the vehicle manufacturer. Too tight and you risk over stressing the connection, this can lead to premature failure. Not tight enough, and the connection might vibrate loose as the vehicle is driven, this can lead to very significant danger from arcing.

Equipotential bonding test

This is a dead test – it is performed with the power isolated and locked off.

This test is applicable to some system designs. It tests the continuity between two metal parts that might be touched simultaneously. The equipotential bonding conductor prevents a dangerous potential difference (voltage) from occurring, for example between the metal case of the high voltage inverter and the car body.

This test uses either a four wire **milliohm meter** or if one is not available a 'low reading Ohm meter'. The technician is going to need to measure very small resistances with sufficient accuracy to identify if there is a problem. The lower the resistance reading of the equipotential bonding the better!

If using a milliohm meter, the technician must ensure that it is correctly set to compensate for temperature. A temperature probe is usually connected to the milliohm meter for this purpose.

It should be noted that many metal components will already be bonded together as part of the 12 volt system as this uses the vehicle body as the return path to the negative battery terminal.

Motor Stator resistance test

This is a dead test – it is performed with the power isolated and locked off.

This test uses a four wire **milliohm meter**. A multimeter is usually <u>not</u> suitable for this task.

As the resistance measurements we are taking are so low, it is important to null (zero) the instrument, to remove the resistance of the leads and probes from the final reading. Alternatively for instruments not so equipped, manually subtract the resistance of the leads, probes etc from the final reading.

The technician must ensure that it is correctly set to compensate for temperature. A temperature probe is usually connected to the milliohm meter for this purpose.

The motor stator is removed from the vehicle and place on a workbench, once it has acclimatised to ambient temperature the technician takes a resistance reading between:

- U and V
- U and W
- V and W

All three reading should be the same, within the tolerances specified by the vehicle manufacture.

Phase sequence test (also known as a Phase rotation test)

This is a live test – It is performed with the power on. The technician must take all relevant precautions and great care.

This test uses a dedicated **phase sequence tester**.

The phase rotation function on a 2 pole voltage tester, is not suitable for use on electric vehicles as the tester utilises capacitive coupling through the operators hand to gain a neutral reference via the earth return path.

The purpose of this test is to ensure that 3 phase motors have been connected in the correct sequence and that wires have not been accidently crossed over.

Incorrect phase sequence is caused by technician error when installing a 3 phase component.

Voltage measurement

This is a live test – It is performed with the power on. The technician must take all relevant precautions and great care.

This test is performed using either the voltage setting on an automotive insulation resistance tester or the voltage setting on a suitably rated multimeter i.e. CAT III 1000V or better.

Direct current (DC) voltage measurements are often taken at the battery output and again at the input of the inverter to check for voltage drop. Measurement of the battery voltage is also useful for comparing to the serial data from the vehicle's computer.

Alternating current (AC) voltage measurements are taken at the output of the inverter to check all 3 phases are functioning correctly.

Oscilloscope

This is a live test – It is performed with the power on. The technician must take all relevant precautions and great care.

A suitable oscilloscope, used in conjunction with a **differential voltage probe** rated to at least 1000V Cat III, can be used to verify the Pulse Width Modulation (PWM) at the inverter, or motor.

It should be noted that the inverter 3 phase output is not actually a sine wave.

Thermal imaging

This is a live test – It is performed with the power on. The technician must take all relevant precautions and great care; however, this is a non-contact test.

Before use the technician must ensure the 'emissivity correction value' is set correctly to ensure an accurate spot temperature measurement. The emissivity correction values for common materials are shown in reference tables supplied with the thermal imaging tool.

The colour palette will change how the thermal data is expressed. Selecting the most appropriate thermal palette will help identify different heat sources in the in the areas of interest.

The technician uses a thermal imaging camera to identify hot spots. This can identify loose or corroded connections, or damaged conductors.

A thermal imaging camera can also identify faults in the thermal management systems (the 'cooling' system)

Safe isolation procedure

Before any work can be undertaken on, or in close proximity to, the high voltage system the power must be disconnected to make it safe.

The safe isolation procedure is as follows:

- The technician puts the vehicle keys in a secure metal lock box
- The technician puts up relevant barriers and safety signage around the vehicle to alert those in the vicinity to the potential danger.
- The technician puts on the relevant Personal Protective Equipment (PPE) e.g. class 0 insulated gloves and eye protection, and wears either insulated boots or stands on a rubber insulating mat
- The technician disconnects the negative terminal of the vehicle's 12 volt battery, then covers the terminal with a plastic cap to prevent accidental reconnection
- The technician removes the 'Manual Service Disconnect' (MSD) from the high voltage battery pack.
- The technician puts the MSD in the secure metal lock box
- The technician uses a lock off device and an insulated padlock lock to secure the MDS receptacle. Only the technician working on the vehicle should have the key to ensure it is under their control and their control only.
- The technician now waits for 10 minutes (or whatever the vehicle manufacture specifies) for the capacitors to discharge.
- The technician will then remove a high voltage access cover, using insulated tools, and being very careful not to drop any fastenings as they can cause danger from arcing
- The technician will now inspect the probes and leads of their 2 pole voltage detector, there must be no damage and the 'GS38' caps must be on the probes to limit the amount of exposed metal at the tip.
- The technician will then use a 'proving unit', or a mains test socket adaptor & the vehicle's 12 volt battery to verify that the 2 pole voltage detector is working. It should be beeping, buzzing and light up like a Christmas tree; they should be in no doubt that voltage had been detected.

- The technician will now test between:
    - The high voltage battery + & - cables
    - The high voltage battery + & the vehicle body
    - The high voltage battery - & the vehicle body
- The above readings should all be zero (or as close to zero as makes no difference)
- If the technician is testing at the inverter, they will verify there is no voltage between any of the phases, and between any of the phases and the vehicle body
- The technician will then test the 2 pole voltage detector again to make sure it is still working. They will then use a 'proving unit', or a mains test socket adaptor & the vehicle's 12 volt battery to verify that the 2 pole voltage detector is working. It should be beeping, buzzing and light up like a Christmas tree; they should be in no doubt that voltage had been detected.

A multimeter should not be used for this purpose as the HSE have stated in GS38 – "*The use of incorrectly set multimeters (or makeshift devices) for voltage detection has often caused accidents*."

The lock box (or small metal cash box) should be one per vehicle, so that there is no requirement to open it whilst work is in progress. The Faraday cage effect will block radio transmissions from the key fob and prevent danger from 'keyless' entry systems inadvertently activating the vehicle.
