**U.S. Proposal for BMS Functionality**

**Sequential Fault Testing Requirements**

**Background:** The test methods in the draft GTR are component level tests and the U.S. believes that the currently specified test procedures are insufficient to conduct at the vehicle level. To fully evaluate the functioning of the BMS under external inputs that can be expected in real world conditions, the U.S. intends to conduct BMS functionality tests at the vehicle level. The following proposed test procedures are built on research conducted by the U.S. While the U.S. intends to conduct these tests at the vehicle level, it understands that some contracting parties that utilize type approval certification may want to maintain the currently proposed component level tests. At this time, the U.S. can accept the inclusion of the type approval tests as a contracting party option only.

**Purpose:** The purpose of this sequential testing program is to test the response of the Battery Management System (BMS) and/or vehicle controls at the safety boundary limits of the REESS during operation. The test evaluates the ability of the vehicle to safely monitor and control the REESS under external inputs in such a way that the REESS is able to withstand the proscribed abuse and failure conditions without posing a hazard to the vehicle occupant or the surrounding environment.

**Safety Need:** In hybrid and electric vehicles, the BMS and other vehicle controls are critical components as they are involved in monitoring and controlling REESS operations. Failure Modes Effects Analysis identified five safety boundary limits of REESS operations beyond which hazardous conditions could arise. These are listed below.

1. Charging and discharging at low temperature: Some battery cell chemistries can be significantly negatively affected if charging/discharging is done at low temperatures. For example, lithium-ion cells are prone to lithium metal plating when charged at high rates at low temperatures, which can damage the cells. In addition, variability in impedance between lithium-ion cells can be increased at low temperatures leading to temperature or voltage imbalance during operation at low temperatures. Many REESS employ heating systems to ensure that the cells of the REESS are maintained at an optimal temperature range during cold weather. The vehicle should limit or prevent operation at REESS temperatures below its capabilities, even when a heating system for the REESS fails.
2. Charging and discharging at high temperature: Some battery cell chemistries can be negatively affected if charging/discharging operations are attempted at high temperatures. For example, a failed cooling system can lead to higher REESS temperature during discharging and may also allow “hot spots” to develop within the REESS, particularly if pockets of high impedance cells exist within the REESS (a potential effect of aging). A temperature imbalance may grow during operation, and, if appropriate steps are not taken by the vehicle, can ultimately lead to the thermal runaway of cells. Many REESS have cooling systems to ensure that the cells of the REESS are maintained within an optimal temperature range during hot weather and/or under extended operation. The vehicle should limit or prevent operation of the REESS at temperatures above its capabilities, even when a cooling system for the REESS fails.
3. Over-discharge: Many battery chemistries can experience undesirable aging, electrolyte leakage, swelling, or even violent failure if over-discharged. Even though over-discharge of lithium-ion cells generally appears benign, it can cause damage to cell electrodes that can compromise cell stability and safety on subsequent recharge. Cell aging and the development of capacity imbalance can increase susceptibility to over-discharge, particularly if voltage sensing is not robust. The vehicle should prevent the cells in the REESS from over-discharge.
4. Overcharge, overcurrent, and overvoltage during charging: Overcharge of an REESS can occur as a result of a failure of the charging system, such as a fault in an external charger or in a regenerative braking charge system. It may also occur as a result of sensor failure or voltage reference drift. Significant overcharge of an REESS can result in thermal runaway of lithium-ion cells. Overcurrent and overvoltage during charging can also damage the REESS. The vehicle controls should monitor for such abnormal external inputs and take appropriate action to prevent hazardous conditions.
5. *Overcharge* – Overcharge occurs when the REESS is charged at its maximum allowable charging rate (AC charging) with current and voltage within normal operating conditions, until charging is terminated. If an automatic interrupt function to terminate charging at maximum SOC is not available or fails to operate, charging is continued until the actual SOC of the cells in the REESS reaches 130% (determined from manufacturer input). Charging beyond this level may create unsafe conditions for the test personnel.
6. *Overcurrent During Charging* – Overcurrent input during charging occurs when charge voltage remains within boundary limits of REESS operation but excessive current- significantly beyond safety boundary limits of REESS operation- is delivered.
7. *Overvoltage Overcharge* – During an over-voltage overcharge, charge voltage exceeds the safety boundary limits of the REESS, but charge current remains within the REESS safety boundary limits.
8. External short circuit: An external short circuit can result in overheating or arcing and therefore result in dangerous conditions. Vehicle controls should terminate operation and bring the REESS to a safe state in the event of a short circuit.

**Application:**  This test applies to all electric vehicles (EVs), hybrid EVs (HEVs), and plug-in hybrid EVs (PEVs) with lithium-ion batteries.

**Test Procedure:**

1. Test condition: The proposed test procedure applies to a complete vehicle. The reasons for selecting to test a complete vehicle as opposed to a component are:
2. It is a test to evaluate the performance of the BMS and/or vehicle controls under external inputs.
3. For vehicles with BMS and controls distributed across the vehicle, this is a simpler test to assess the complete functioning of the BMS.
4. Sequential test: The test is a sequential series of subtests, with each subtest (based on a Failure Modes Effects Analysis) placed in a sequence that not only reduces the number of required test articles, but is also intended to reveal and exacerbate a range of potential failure modes by approaching safety limit boundaries of REESS operating conditions.
   1. The order of testing is as follows:
      1. high temperature charging/discharging,
      2. over-discharge test in drive/charge mode,
      3. overcurrent, overvoltage overcharge, and overcharge tests, and
      4. short circuit test (this test may be done in drive mode or charge mode).
   2. Charging/discharging at low temperature is not included in this sequence of testing because it may be difficult to maintain the low temperature of the REESS and therefore cause a test burden. Instead, the proposal requires manufacturers to provide documentation indicating that the BMS monitors and appropriately controls REESS operations at the low temperature boundary limit for safe operation of the REESS.
   3. In cases where a protection measure does not allow normal vehicle operation until expert evaluation of the vehicle after a high temperature, over-discharge, overcurrent, or overvoltage overcharge test, that test would be conducted individually outside the sequence of tests.
   4. The concept of sequential testing for cells and battery packs is derived from the approach used in the UN Manual of Tests and Criteria for testing lithium-ion cells and battery packs. In the UN Manual, a series of five tests for lithium-ion systems (T1-T5) are conducted in a specified order so that conditions that may damage cells or battery packs, but that may not provide clear indication of damage (altitude simulation, thermal cycling, vibration, and mechanical shock), are followed by an external short circuit test. This not only tests the article’s robustness to external short circuit, but is likely to indicate whether the article accrued serious damage in previous tests. As with the UN Tests, the final test in Sequential Testing is an external short circuit test.
5. DC link: The fault conditions (safety boundary limits of REESS) in the over-discharge, overcharge, and short circuit tests are applied using Direct Current equipment (DC link). A DC link may contain a switchboard with a short circuit box, a discharge resistor unit, and a power supply. The DC link is connected to the REESS on the traction side of the automatic disconnect for those REESS with an automatic disconnect physically contained within the REESS, and is connected to the battery side of the automatic disconnect if the automatic disconnect is located outside the REESS. Specification for the use of such a device would improve the repeatability and reproducibility of the test, as well as improving safety for the test lab personnel.
6. Safety while conducting sequential tests: In the overcurrent, overvoltage, and overcharge tests, the SOC of cells in the REESS should never be more than 130% of cell SOC. Note that cell SOC is the actual SOC of cells, and is not the same as the SOC of REESS set by the manufacturer. The fire/explosion during the testing of a REESS in General Motors laboratory was a result of SOC of cells reaching levels beyond 130% of cell SOC. If SOC of a cell or group of cells during the overcharge, overcurrent, or overvoltage tests reaches 130% cell SOC, the test should be terminated immediately.

**Details of the Subtests in the Sequential Tests:**

1. High temperature test: The REESS cooling system is disabled if the REESS remains functional without a cooling system being operational. The manufacturer shall provide the temperature at which the cooling system (if available) will normally initialize and the maximum operating temperature of the REESS without a cooling system or with a disabled cooling system. The vehicle is charged to highest SOC as specified by TF6 (6.2.1.2.). The vehicle is placed in a temperature-controlled chamber at the manufacturer’s specified maximum operating temperature of the REESS or at 45oC (if the maximum operating temperature of REESS is greater than 45oC) for 10 hours or until the REESS temperature is at its maximum operating temperature, whichever occurs first. If REESS temperature has not reached the manufacturer specified maximum operating temperature within this time, the REESS is charged and discharged to raise its temperature. When the REESS temperature reaches the maximum REESS operating temperature, either the cooling function should operate or the charge and/or discharge of the REESS should be inhibited and/or limited to prevent further increase in REESS temperature.
2. Over-discharge test (drive mode): This test is conducted at ambient conditions (20±100C). Discharge the vehicle REESS until it reaches 10% SOC (measured in accordance with manufacturer’s recommendation) and remove fuel from the fuel tank (for HEVs and PHEVs) until it is less than 5% full. Install the DC link appropriately to the REESS. Put the vehicle in drive mode and discharge the vehicle through the overcharge resistor in the DC link at a power load determined through information from the manufacturer so as to get the battery under over-discharge conditions within 8 hours. If no manufacturer information is available, the vehicle is discharged at a power load of 1kW. A load of 1kW was selected since this is comparable to many of the 12V system loads in a vehicle, and likely to be allowed by the BMS of the REESS. Continue over-discharge until the DC link voltage reaches 0 volts (this would happen when the REESS stops discharging) or 8 hours elapse.
3. Over-discharge test (charge mode): The “charge mode over-discharge” test is only applicable to vehicles with separate driving and charging modes (EVs, PHEVs). This test is intended to simulate a condition where the charge connector is damaged and discharges the vehicle instead of charging it. The “charge mode over-discharge” test may also apply to a scenario wherein a vehicle undergoes over-discharge conditions when simply parked. For EVs and PHEVs, connect the vehicle to a 120V AC charger and recharge the REESS just enough that it will be able to enter drive mode. Disconnect the charger at the AC supply and then install the over-discharge resistor through the DC link. Discharge at a power load determined through information from the manufacturer so as to get the battery under over-discharge conditions within 8 hours. If no manufacturer information is available, the vehicle is discharged at a power load of 1kW (1kW load) until the DC link voltage reaches 0 volts or 5 hours elapse. This test is conducted at ambient conditions (20 ± 10 0C).
4. Overcurrent test: For EVs and PHEVs, charge the REESS normally until it is at 50% SOC. For HEVs, charge the REESS to 50% SOC using a driving pattern recommended by the manufacturer. For HEVs and PHEVs, fill the fuel tanks to maximum capacity allowed. Connect the DC link to the vehicle. Put the vehicle REESS in charging mode by connecting EVs or PHEVs with an AC charger. For HEVs, place the vehicle into operational mode. Determine the maximum overcurrent to be applied and the maximum operational voltage using information from the manufacturer. Apply the overcurrent during charging at any SOC between 50% SOC and 95% SOC through the DC link. This is done by increasing the current through the DC link from zero to the maximum overcurrent level (determined from manufacturer’s information) at a linear rate in 1,000 seconds. Stop the test if charging is terminated or at 24 hours after charging was initiated. This test is conducted at ambient conditions (20 ± 100C)
5. Overvoltage overcharge test: Since overcharge may also occur during charging, due to voltage exceeding the safety boundary limits of the REESS, the BMS should be able to respond to this overvoltage input during charging and control the REESS operation appropriately. For this reason, the overvoltage overcharge is conducted as part of the BMS sequential test. Charge or discharge the REESS normally until it is at 95% SOC. Connect the DC link to the vehicle. Put the REESS of the EV or PHEV in charging mode by connecting it to an AC charger. For HEVs, place the vehicle into driving or operational mode. Apply the overvoltage (maximum voltage determined from manufacturer’s information) with a current limit within operating range. Stop the test if charging is terminated or at 24 hours after charging was initiated. This test is conducted at ambient conditions (20 ± 100C).
6. Overcharge Test: An overcharge test similar to that in the draft GTR is added to this proposal for completeness. The REESS is charged with voltage and current within the normal operating range specified by the manufacturer. The charging is continued until the tested device terminates charging when maximum SOC (set by the manufacturer) is reached.
7. Charge/Discharge Cycle: A discharge/charge cycle is conducted at ambient conditions (20 ± 100C) after the overcharge tests in order to evaluate whether normal operation of the REESS is possible after subjecting the vehicle to the sequential testing program thus far (high temperature charge/discharge, over-discharge tests and overvoltage tests). This charge/discharge cycle could have been conducted after the short circuit test, however since some automatic disconnects may require maintenance/repair after activating and before the vehicle can resume normal operation (a feature that a manufacturer may include since a short circuit is a significant safety hazard), this charge/discharge cycle is conducted just before the short circuit test. In cases where a protection measure does not allow normal vehicle operation until expert evaluation of the vehicle after a high temperature, over-discharge, overcurrent, or overvoltage overcharge test, that test would be conducted individually outside the sequence of tests. The discharge/charge cycle is as follows:
   * 1. Discharge Operation: For a vehicle with only a charge-depleting operational mode (EV), adjust the vehicle speed and the dynamometer rolling resistance to induce the maximum sustained discharge power load for the vehicle REESS (information obtained from the manufacturer). Continue the discharge until the vehicle will no longer provide motive power. For a vehicle with charge-sustaining operation modes (HEV or PHEV), apply one UDDS discharge cycle followed by one US06 discharge cycle. Repeat the alternating UDDS and US06 discharge cycles in rapid succession, with no more than 5 minutes between the end of one discharge cycle and the beginning of the next cycle. Continue to discharge until the vehicle will no longer provide motive power or when 12 hours has passed, whichever occurs first.
     2. Charge Operation: For an EV or PHEV, immediately after the discharge cycle is completed (within 10 minutes), charge the vehicle by connecting the vehicle to a charging system capable of supplying the maximum allowable charge rate for the vehicle, and charge at the maximum allowable charge rate until charging terminates normally.
8. Short circuit test: Connect the DC link to the REESS. For EVs and PHEVs, place the vehicle in drive mode or charge mode. Place HEVs in drive mode. Introduce the short circuit in the DC link (total impedance less than 5 milliohms). Stop the test when charging or discharging is terminated and temperature has remained within ±20C for 60 minutes. This test is conducted at ambient conditions (20 ± 100C).

**Performance Criteria:**

1. Since this series of tests evaluates BMS functionality and/or the capability of the vehicle controls to maintain the vehicle in safe operating mode, we believe that the REESS should continue to perform normally after completion of the sequential testing. In cases where a protection measure does not allow normal vehicle operation until expert evaluation of the vehicle, that test would be conducted individually outside the sequence of tests and performance criterion 2(d) will not apply.
2. The proposed performance criteria for the sequential tests are as follows:
   1. Over-discharge Test (drive mode and charge mode): The REESS terminates discharge during the test if SOC level goes below the minimum SOC limit (set by the manufacturer) for safe REESS operation.
   2. Overcurrent Test: Charging is terminated after the current level exceeds the maximum current limit (set by the manufacturer) for safe REESS operation.
   3. Overcharge and Overvoltage Overcharge Test: Charging is terminated when the maximum SOC of the REESS (set by the manufacturer) is reached.
   4. Normal Charge/Discharge Operation: The vehicle charges and discharges as it would under normal operating conditions in the discharge/charge cycle conducted after the overcharge tests.
   5. Short Circuit Test (charging and driving mode): The charging or discharging operation (whichever operation is being conducted at the time the short circuit is introduced) is terminated after the short circuit is introduced.
3. During the sequential test and up to 24 hours after completion of the short circuit test, there is no evidence of fire, smoke, venting, or explosion. This post-test criterion is needed to ensure that the BMS response to the fault conditions introduced in the sequential tests were within adequate time (were not delayed) to not cause any damage to the REESS.

**Regulatory Text:**

**5.3.5 Sequential Fault Testing**

This sequential test shall be conducted under in-use operating conditions with a complete vehicle.

Contracting Parties may choose to adopt a test procedure using a complete REESS with related REESS subsystems.

For the safety of testing personnel, the SOC of the cells in the REESS (manufacturer information) shall not exceed 130% during the sequential tests.

**5.3.5.1 High-temperature, over-discharge, overcharge, and short circuit protection**

The sequential test shall be performed according to 6.3.5. The high temperature test is conducted in accordance with 6.3.5.1, the over-discharge (drive-mode and charge-mode) test is conducted in accordance with 6.3.5.2, the overcurrent test is conducted in accordance with 6.3.5.3, the over-voltage overcharge test is conducted in accordance with 6.3.5.4, the overcharge test is conducted in accordance with 6.3.5.5, a discharge/charge cycle is conducted in accordance with 6.3.5.6, and the short-circuit test is conducted in accordance with 6.3.5.7. If a protection measure does not allow normal vehicle operation until expert evaluation of the vehicle in the high temperature, over-discharge, overcurrent, or overvoltage overcharge test, that test is conducted separately outside the sequence of tests with a different vehicle and performance criterion 2(e) shall not apply.

* + - 1. During the over-temperature test, when the maximum operating temperature of the REESS is reached, protective measures shall operate to terminate or limit charge/discharge operation and/or initiate a cooling system.
      2. During the over-discharge test (drive mode and charge mode), discharge shall be terminated if SOC level goes below the minimum SOC limit (set by the manufacturer) for safe REESS operation.
      3. In the overcurrent tests, charging shall be terminated after the current level exceeds the maximum current limit (set by the manufacturer) for safe REESS operation.
      4. In the overcharge and overvoltage overcharge tests, charging shall be terminated when the maximum SOC level specified by the manufacturer is reached.
      5. In the discharge/charge cycle, conducted after the overvoltage overcharge test, the vehicle charges and discharges as it would under normal operating conditions.
      6. The charging or discharging operation (whichever operation is being conducted at the time the short circuit is introduced) shall be terminated after the short circuit is introduced.
      7. During the sequential test and for 24 hours after completion of the short circuit test, there shall be no evidence of fire, smoke, venting, or explosion. For a test conducted outside the sequence of tests because a protection measure does not allow normal vehicle operation until expert evaluation of the vehicle, there shall be no evidence of fire, smoke, venting, or explosion during the test or the 24 hours after the test is completed.

**5.3.5.2 Low Temperature Protection**

To ensure that the vehicle monitors and appropriately controls REESS operations at low temperatures at the safety boundary limits of the REESS, vehicle manufacturers must make available a system diagram and a written explanation on the lower bound temperature for safe operation of REESS, the method of detecting REESS temperature, and the action taken when the REESS temperature reaches this lower bound for safe operation.

**6.3.5 Sequential Fault Test Procedure**

**Definition:**

**UDDS:** EPA Light-DutyUrban Dynamometer Driving Schedule **-** An urban operation simulated discharge cycle described in Appendix 1 to Title 40, part 86, “Control of emissions from new and un-used highway vehicles and engines,” of the CFR, whose required operational precision is specified in Title 40 part 86.115-78, “EPA dynamometer driving schedules.” For the purpose of this document only the speed and time requirements of this cycle will be applied**.** <http://www.ecfr.gov/cgi-bin/text-idx?SID=86a71a41c6af14166a31d1f074d61291&mc=true&node=pt40.19.86&rgn=div5#ap40.19.86_11931_686_11999.i>

**US06:** EPA US06 Driving Schedule for Light-Duty Vehicles and Light-Duty Trucks - A high acceleration and high speed simulated discharge cycle described in Appendix 1 to Title 40 Part 86, “Control of emissions from new and un-use highway vehicles and engines,” of the CFR, whose required operational precision is specified in Title 40 Part 86.159-08, “Exhaust emission test procedures for US06 emissions.” For the purpose of this document only the speed and time requirements of this cycle will be applied. <http://www.ecfr.gov/cgi-bin/text-idx?SID=86a71a41c6af14166a31d1f074d61291&mc=true&node=pt40.19.86&rgn=div5#ap40.19.86_11931_686_11999.i>

**DC Link:** A DC link is a break-out box that consists of a switchboard, a discharge resistor unit, and a power supply that can be connected to the positive and negative terminal of the REESS. The DC Link is used for the REESS over-discharge, overcurrent overcharge, overvoltage overcharge, and external short circuit tests. The switchboard contains a short circuit box to allow for shorting of the REESS, as well as two Tap boxes. The Tap boxes allow for a switched connection to the positive and negative terminal of the DC Link. All switches are rated for voltages up to 600V and the entire switchboard is touch-safe. See Appendix ( )

1. **Vehicle Charge and Discharge during High Temperature Conditions:** 
   * + - 1. If a REESS is thermally coupled to an active cooling system, and if the REESS will remain functional without cooling function being operational, the cooling system will be deactivated for the test.
         2. For a vehicle with only a charge-depleting operational mode (EV), determine the REESS maximum sustained discharge power load at different temperature levels. This information may be obtained for the vehicle manufacturer. Define a speed and grade combination that can be applied on a dynamometer to produce the maximum sustained discharge power load on the vehicle REESS.
         3. The vehicle shall be charged to the highest SOC in accordance with 6.2.1.2.
         4. For a vehicle with charge-sustaining operations modes (for example, an HEV or PHEV), add sufficient fuel to fill the fuel tank to 100% of its total volume.
         5. Place the vehicle in a temperature-controlled chamber at the manufacturer’s specified maximum REESS operating temperature or at 45°C if the maximum REESS operating temperature is greater than 45oC. Chamber temperature shall be controlled to ±2°C of the target temperature. The vehicle shall be placed in the chamber for 10 hours or until the vehicle and REESS equalize to ambient temperature, whichever occurs first. If REESS temperature does not reach the manufacturer’s specified maximum operating temperature threshold in 10 hours, the REESS shall be charged and discharged at manufacturer-specified maximum charge and discharge rates until the specified REESS temperature is attained.
         6. For a vehicle with only a charge-depleting operational mode (EVs), a dynamometer may be used for discharging the REESS. For a vehicle with charge-sustaining operational modes (HEVs or PHEVs), a UDDS discharge cycle followed by a US06 discharge cycle may be applied on a dynamometer for charging and discharging operation. If the vehicle is not capable of operation at the requested speeds or the discharge rate at the described temperature, maintain the achieved speed or discharge rate of the vehicle for sufficient time to cover the distance that would have been covered during the described test cycle before continuing to the next required speed.
2. Charging of EVs or PHEVs may be conducted by connecting the vehicle to a charging system capable of supplying the maximum allowable charge rate for that vehicle. Allow normal charge termination, or terminate charging one hour after the vehicle reaches a “steady state”: either a battery temperature remaining within ±2°C for 30 minutes and an SOC remaining within ±1% for 60 minutes, or a rate of change of SOC over the previous hour indicating that charging will require more than 10 hours to complete.
3. Regardless of the point in testing that has been reached, terminate the test after 24 hours have elapsed since the start of step 6.3.5.1.5.
4. Return the vehicle to ambient temperature and restore cooling system functionality (if it was disabled).

**6.3.5.2 REESS Over-Discharge Test Procedure**

1. Make the connection to the DC Link. Installation may require that the REESS be removed from the vehicle and subsequently re-installed.
2. Discharge the vehicle REESS to approximately 10% SOC. For an HEV or PHEV, remove fuel from the fuel tank so that the tank is less than 5% full.
3. Chock the vehicle to prevent rolling or creep. Conduct the test at ambient temperature (20 ± 100C).
4. Drive Mode Over-Discharge Attempt

Place the vehicle into drive mode but do not request any acceleration.

Install the ‘over-discharge resistor’ into the terminals of the DC Link connection box, and close the positive and negative terminal switches to create a circuit across the DC Link with a resistive load.

Allow the REESS to discharge at a power load determined through information from the manufacturer so as to get the battery under over-discharge conditions within 8 hours. If no information is provided by the manufacturer, a discharge power load of 1kW is used.

Continue to discharge the REESS via this method until one of the following happens: either the DC Link Voltage reaches 0V (this may occur if the REESS terminates discharge) or 8 hours elapse.

Isolate the discharge resistor in the DC Link (open the discharge circuit).

1. Should the vehicle not have separate driving and charging modes (e.g. an HEV), continue to step 6.3.5.2.9.
2. Charge Mode Over-Discharge Attempt

For a vehicle with separate driving and charging modes (an EV or PHEV), connect the vehicle to an AC charger and recharge the REESS to the lowest operational SOC at which vehicle will enter Drive Mode using energy from the REESS only.

Disconnect the charger at the AC supply side, but allow the cable to remain connected to the vehicle.

Install the ‘over-discharge resistor’ into the terminals of the DC Link connection box, and close the positive and negative terminal switches to create a circuit across the DC Link with a resistive load. Allow the REESS to discharge at a power load determined through information from the manufacturer so as to get the battery under over-discharge conditions within 8 hours. If no information is provided by the manufacturer, a discharge power load of 1kW is used.

Continue to discharge the REESS via this method until one of the following happens: either the DC Link voltage reaches 0V (this may occur if the REESS terminates discharge) or 5 hours elapse.

1. Isolate the discharge resistor in the DC Link (open the discharge circuit).
   * + 1. **REESS Over-Current Test Procedure**
          1. Charge the REESS until it is at 50%±5% SOC. This may be accomplished by connecting the vehicle to a charger (EV or PHEV) and allowing it to charge normally.
          2. For an HEV, the REESS should be charged fully using a driving pattern recommended by the manufacturer.
          3. Confirm the DC Link connection is properly installed and that all switches are open within the switchboard.
          4. Determine the maximum over-current that will be applied to the REESS using relevant information provided by the manufacturer. This value may be based upon the maximum current that can be supplied by regenerative braking or a faulting charger. The vehicle manufacturer may be consulted.
          5. Determine the maximum voltage that can be applied to the REESS by the on-board charger or a faulting compatible charger based on information provided by the manufacturer. The vehicle manufacturer may be consulted. Multiply the maximum voltage by the maximum over-current to obtain the maximum charging power for power supply selection.
          6. Connect the Over-Current Supply to the DC Link. Set the current limit and voltage limit on the Overcurrent Supply based on steps 6.3.5.3.5 and 6.3.5.3.6.
          7. Conduct the test at ambient temperature (20 ± 100C).

* + - * 1. Place the vehicle into charging mode. For an EV or PHEV, connect an AC charger to the vehicle and initiate charging. If the vehicle is a HEV with no separate charging and discharging mode, place the vehicle into an operational mode. Initiate charging and allow charging currents to stabilize.
        2. Turn on the Overcurrent Supply connected to the DC Link and linearly increase the charging current over 1000 seconds from zero current until it reaches the maximum charging current determined in step 6.3.5.3.6 or until the REESS isolates itself from the power supply. The overcurrent supply is initiated at any SOC between 50% and 95%.
        3. Continue to attempt to charge at the final charging current reached in step 6.3.5.3.11 until one of the following occurs: charging is terminated, 24 hours elapse from the time charging was initiated in 6.3.5.3.10, or a failure occurs (smoke, fire, or explosion).
      1. **REESS Over-Voltage Overcharge**
         1. Discharge or charge the REESS, until it is at 95% ± 2% SOC. This may be accomplished by using the vehicle cabin heater, using the AC system, or through driving.
         2. For an HEV or PHEV, fill the fuel tank to 100% of capacity.

6.3.5.4.3 Confirm the DC Link connection is properly installed on the REESS and that all terminal switches are open within the DC Link.

* + - * 1. Determine the maximum voltage that can be applied to the REESS by the on-board charger or a faulting compatible charger using information provided by the manufacturer. The vehicle manufacturer may be consulted.
        2. Determine the appropriate current limit: divide 1.4kW (AC charging power) by the maximum voltage determined in step 6.3.5.4.4.
        3. Connect an Overvoltage Supply to the DC Link. Set its voltage limit to the maximum voltage determined in step 6.3.5.4.4. Set the current limit to the maximum current determined in step 6.3.5.4.5.
        4. The test is conducted at ambient temperature (20 ± 100C).
        5. Place the vehicle into charge mode. If the vehicle is an HEV with no separate charging and discharging mode, place the vehicle into its driving or operational mode.
        6. For an EV or PHEV, attach a charging cable to the vehicle at its charge inlet and begin charging at AC charging levels. In an HEV, move to the next step without taking any action.
        7. Once charging has begun, turn on the Overvoltage Supply connected to the DC Link. Close the positive and negative terminal switches on the DC Link and allow the Overvoltage Supply to begin charging the vehicle.
        8. Continue to attempt to charge until one of the following occurs: charging is terminated, 24 hours elapse, or a failure occurs (smoke, fire, or explosion).
        9. Once the test has concluded, disconnect the overvoltage supply and the charging cable (if present).
      1. **REESS Overcharge Test**
         1. Discharge or charge the REESS until it is at 95% ± 2% SOC.
         2. This test is conducted at ambient temperature (20 ± 100C).
         3. Place the vehicle into charging mode. For an EV or PHEV, connect an AC charger to the vehicle and initiate charging. If the vehicle is an HEV with no separate charging and discharging mode, place the vehicle into an operational mode.
         4. Continue charging until the charging is automatically interrupted or limited. If no automatic interrupt function operates, continue charging but do not exceed 130% cell SOC.

* + - 1. **Discharge and Charge Cycle**

6.3.5.6.1 The discharge and charge cycle is conducted at ambient temperature (20 ± 100C). The vehicle REESS shall be charged to its highest SOC for EVs and PHEVs and the fuel tank shall be filled to 100% capacity for HEVs and PHEVs.

6.3.5.6.2 Discharging: For a vehicle with only a charge-depleting operational mode (EV), adjust the vehicle speed and the dynamometer rolling resistance to induce the maximum sustained discharge power load for the vehicle REESS (information obtained from the manufacturer). Continue the discharge until the vehicle will no longer provide motive power. For a vehicle with charge-sustaining operation modes (HEV or PHEV), apply one UDDS discharge cycle followed by one US06 discharge cycle. Repeat the alternating UDDS and US06 discharge cycles in rapid succession, with no more than 5 minutes between the end of one discharge cycle and the beginning of the next cycle. Continue to discharge until the vehicle will no longer provide motive power or until 12 hours have passed, whichever occurs first.

Charging: For an EV or PHEV, immediately after the discharge cycle is completed (within 10 minutes), connect the vehicle to a charging system capable of supplying the maximum allowable charge rate for the vehicle and charge until charging terminates normally.

* + - 1. **REESS External Short Circuit**

6.3.5.7.1 Confirm the DC Link connection is properly installed on the REESS and that all terminal switches are open within the DC Link.

* + - * 1. If an HEV or PHEV is being tested, fill the fuel tank to 100% capacity.
        2. Chock the vehicle to prevent rolling or creep.

6.3.5.7.4 Conduct the test at ambient temperature (20 ± 100C).

* + - * 1. Place the vehicle into Drive Mode or Charge Mode.
        2. Connect the short circuit device to the DC Link.
        3. Create the short circuit across the DC Link, causing a short circuit of the REESS and vehicle high voltage system. The total impedance of the short circuit shall be less than 5mΩ.
        4. Continue to monitor the REESS, and terminate the test when the REESS temperature has remained stable for 60 minutes (within ±2°C).

**APPENDIX ( )**

**DC Link Function and Installation**

A DC Link is required for the REESS over-discharge, overcurrent overcharge, overvoltage overcharge, and external short circuit tests. A variety of devices can be connected to the DC Link to achieve the required electrical conditions for the test. One possible configuration of electrical test equipment is diagrammed in Figure 1 to Figure 4 with images of example equipment in Figure 5 and Figure 6.

Figure 1 shows the connection method of the DC Link to the REESS via a junction box that may exist in a vehicle. Requirements for a DC Link include:

* The vehicle OEM should provide the testing agency with documentation detailing how a DC Link can be installed with minimum disruption to the vehicle systems. Generally, vehicle high voltage cables should be accessible adjacent to the REESS-to-vehicle high voltage connection.
* The DC Link should be electrically connected as closely as possible to the outside of the REESS enclosure. There should be no active or passive protection components between the DC Link connection and the REESS unless they are contained within the REESS. This includes devices such as fuses, thermally activated switches, and relays.
* The vehicle OEM should provide information regarding expected short circuit current, maximum operational pack voltage, and a pack charge capacity vs. voltage curve in order to allow construction of an appropriate DC Link including cable gauge.
* The DC Link shall be sufficiently isolated from all other parts of the vehicle. This isolation shall be capable of withstanding a voltage difference equal to U + 1695V.
* If the Overvoltage Supply is of the type which features both a current/voltage limit and a trip current/voltage setting, the trip values should be set 10% higher than the current/voltage limit of the REESS.
* Joints or terminals shall be of a design capable of secure and low resistance connection, such as a bolt-secured lug.
* Cables used in the DC Link shall be rated to safely conduct the currents levels expected in all test procedures such that they do not become failure points.
* Exposed high voltage should be minimized as part of the DC Link.
* Many functionally equivalent circuits are possible, but care should be taken to select components that are rated for the appropriate currents and voltages.
* Vehicle shall be able to charge and discharge normally with the DC Link connection installed.

An example of the electrical equipment used for Sequential Testing is shown in Figure 5 and Figure 6. It is composed of three key components: a switchboard, a discharge resistor unit, and a power supply. As shown in Figure 2, the switchboard contains a short circuit box to allow for shorting of the pack, as well as two Tap boxes. The Tap boxes allow for a switched connection to the positive and negative terminal of the DC Link. All switches are rated for voltages up to 600V and the entire switchboard is touch-safe.

To perform the Short Circuit Test, only the switchboard is required and the Tap boxes are open circuit with nothing connected.

* Appropriate information regarding sizing of the fuses in the vehicle and REESS should be provided by the vehicle OEM.
* The switch shall be capable of withstanding the short circuit discharge current of the REESS.
* The short circuit box shall be fused to protect the DC link cables, connections, and shorting switch. The short circuit device should be sized such that it does not interrupt the test. After the short circuit test, the fuses should be checked and, if still intact, then the test is valid. Otherwise, the short circuit device needs to be scaled up such that the vehicle or REESS interrupts the short circuit test.

The example shown in Figure 6 contains two 630A fuses in parallel and at least 2/0 AWG cable or equivalent bus bar size.

Figure 3 illustrates an example configuration for performing the Over-Discharge Test. For this test, the short circuit box shall remain open circuit and a discharge resistor is connected to the Tap boxes.

* The over-discharge resistor may represent a significant hazard during operation, and should be physically isolated from other circuit components and flammable material.
* This unit should be sufficiently cooled, for example, with air blowing fans, to allow it to maintain a safe operating temperature.

The example shown in Figure 5 is constructed from ten separate 20Ω resistors. The discharge resistor unit construction allows for resistors to be placed in parallel or in series, so that the discharge resistor unit can be configured to produce a 1kW discharge for REESS of a variety of operational voltages.

Figure 4 shows an example configuration of the setup for both the Over-Current Overcharge and Over-Voltage Overcharge Tests. The short circuit box is open circuit and both Tap boxes are used to make a connection to a power supply.



**Figure 1: Diagram of DC link for as tested for Manufacturer A.**



**Figure 2: Diagram of DC Link with switchboard configured for the Short Circuit Test.**

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**Figure 3: Diagram of DC Link with switchboard and discharge resistor configured for the Over-Discharge Test.**



**Figure 4: Diagram of DC Link with switchboard and power supply configured for the Overcharge Tests.**

 

**Figure 5: The switchboard (left) and discharge resistor (right). The discharge resistor is protected beneath a mesh cage to prevent inadvertent contact by an operator. During use a fan provided cooling air across the resistors to maintain their temperature.**

 

**Figure 6: The interior of a Tap box (left) and the fused short circuit box (right). The fused shorting switch connects directly to the copper bus-bar seen inside the Tap box and to the same component on the other Tap box.**