FORMULA® HYBRID — SAE INTERNATIONAL

PART EV - ELECTRICAL POWERTRAINS AND SYSTEMS

ARTICLE EV1 ELECTRIC SYSTEM DEFINITIONS

EV1.1 Basic Definitions

EV1.1.1 The **Accumulator** is defined as all the batteries or capacitors that store the electrical energy to be used by the tractive system.

EV1.1.2 **Accumulator Segments** are sub-divisions of the accumulator and must respect either a maximum voltage or energy limit. (See **EV3.4.3**). Splitting the accumulator into segments is intended to reduce the risks associated with working on the accumulator.

EV1.1.3 The **Tractive System** of the car is defined as every part that is electrically connected to the motor(s) and accumulators.

EV1.1.4 The **Grounded Low Voltage (GLV)** system of the car is defined as every electrical part that is not part of the tractive system.

EV1.2 Grounded Low Voltage and Tractive System Voltage

EV1.2.1 The maximum permitted operating voltage for Formula Hybrid is 300 V. (See **Table 9.)** The maximum operating voltage is defined as the maximum measured accumulator voltage during normal charging conditions.

Note 1: The Tractive System Voltage limit may be exceeded within the motor/controller system as a result of transient inductive effects, but may not be intentionally increased through the use of DC/DC converters, transformers, etc.

Note 2: Commercially available motor controllers containing boost converters that have internal voltages greater than 300 VDC may be used provided the unit is approved in advance by the electrical rules committee.

EV1.2.2 The GLV system may not have a voltage greater than 30 VDC or 25 VAC[5]. (See **Table 9**).

Formula Hybrid Maximum Voltages	
Maximum operating voltage	300 V
Maximum GLV	30 VDC or 25 VAC

Table 9 – Maximum Voltages

EV1.2.3 The GLV system must be grounded to the chassis. See **EV3.8.5**

EV1.2.4 The tractive and GLV system must be galvanically isolated from one another.

Note: The border between tractive and GLV systems is the galvanic isolation between both systems. Therefore, some components, such as the motor controller, may be part of both systems.

EV1.2.5 The tractive system must be electrically isolated from the chassis and any other conductive parts of the car.

[5] GLV system voltages up to 60 VDC may be allowed with prior review and approval of the rules committee.

EV1.2.6 The tractive system motor(s) must be connected to the accumulator through a motor controller. Bypassing the control system and connecting the tractive system accumulator directly to the motor(s) is prohibited.

EV1.2.7 The GLV system must be powered up before it is possible to activate the tractive system. (See **EV4.7**). Furthermore, a failure causing the GLV system to shut down must immediately deactivate the tractive system as well.

EV1.3 Electrical Insulating Materials

EV1.3.1 All Electrical insulating materials used must:

(a) be UL recognized (i.e., have an Underwriters Laboratories (http://www.ul.com) or equivalent rating and certification).

(b) be rated for the maximum expected operating temperatures at the location of use or

(c) have a minimum temperature rating of 90 °C. (Whichever is greater)

EV1.3.2 Electrical insulating barriers used to meet the requirements of **EV4.1.4** for separation of tractive system and GLV wiring must be rated for 150 °C.

EV1.3.3 Vinyl electrical insulating tape and rubber-like paints and coatings are not acceptable electrical insulating materials.

ARTICLE EV2 ELECTRIC POWERTRAIN

EV2.1 Accelerator Pedal

EV2.1.1 The accelerator pedal must be a right-foot-operated foot pedal.

EV2.1.2 The foot pedal must return to its original, rearward position when released. The foot pedal must have positive stops at both ends of its travel, preventing its sensors from being damaged or overstressed.

EV2.2 Accelerator Signal Limits Check

EV2.2.1 All analog acceleration control signals (between accelerator pedal and motor controller) must have error checking which can detect open circuit, short to ground and short to sensor power and will shut down the torque production in less than one (1) second if a fault is detected.

Note: If these capabilities are built into the motor controller, then no additional error-checking circuitry is required.

EV2.2.2 The accelerator signal limit shutoff may be tested during electrical tech inspection by replicating any of the fault conditions listed in **EV2.2.1**

EV2.3 Accelerator Signal Isolation

EV2.3.1 The accelerator signal and similar electric motor controller input circuits must be galvanically isolated from the Tractive System.

EV2.3.2 These circuits must be positively bonded to GLV ground.

Note: This is typically accomplished by connecting the negative or common accelerator input conductor to GLV ground.

ARTICLE EV3 TRACTIVE SYSTEM - ENERGY STORAGE

EV3.1 Allowed Tractive System Accumulators

EV3.1.1 The following accumulators are acceptable; batteries (e.g. lithium-ion batteries, NiMH batteries, lead acid batteries and many other rechargeable battery chemistries) and capacitors, such as super caps or ultracaps. JY 5/10/16

The following accumulators are not permitted; molten salt batteries, thermal batteries, fuel cell, atomic and flywheel mechanical batteries.

EV3.1.2 Manufacturer's data sheets showing the rated specification of the accumulator cell(s) which are used must be provided in the ESF along with their number and configurations.

EV3.2 Tractive System Accumulator Container – General Requirements

EV3.2.1 All batteries or capacitors which store the tractive system energy must be enclosed in (an) accumulator container(s) JY 5/10/16

EV3.2.2 If spare accumulators are to be used then they all must be of the same size, weight and type as those that are replaced. Spare accumulator packs must be presented at Electrical Tech Inspection.

EV3.2.3 If the accumulator container(s) is not easily accessible during Electrical Tech Inspection, detailed pictures of the internals taken during assembly must be provided. If the pictures do not adequately depict the accumulator, it may be necessary to disassemble the accumulator to pass Electrical Tech Inspection.

EV3.3 Virtual Accumulator Housing.

Teams may interconnect multiple (non-removable) accumulator housings such that the grouping will be considered one container provided the following conditions are met:

EV3.3.1 The interconnect conduit(s) (See **Figure 26** below) must be flexible METALLIC liquid-tight steel electrical conduit (NEC type LFMC) securely fastened at each end with fittings rated for metallic LFMC).

EV3.3.2 The conduit must be red, or painted red[6].

EV3.3.3 The maximum unsupported length of the interconnect conduit is 150 mm. i.e. it must be physically supported at least every 150 mm to ensure that it cannot droop or be snagged by something on the track.

EV3.3.4 Separate conduits must be provided between housings for:

(a) Individual tractive System conductors (Only one high-current TSV conductor may pass through any one conduit.)

(b) GLV-level wiring.

(c) AMS wiring such as cell voltage sense wires that are at TS potential.

EV3.3.5 The accumulator housings may not be removable (as referenced in **EV3.4.7** and **EV8.3.1**)

EV3.3.6 All rules relating to accumulator housings (including, but not limited to firewalls, location etc.) also apply to the interconnect conduit.

EV3.3.7 If the interconnect conduit is the lowest point in the virtual housing it must have a 3-5 mm drain hole in its lowest point to allow accumulated fluids to drain.

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[6] LFMC conduit is available with a red jacket - see for example: http://www.afcweb.com/liquid-tuff-conduit/ul-liquidtight-flexible-steel-conduit-type-lfmc/

EV3.3.8 Segmentation requirements must be met considering the housings individually, and as an interconnected system

EV3.3.9 Each housing must comply individually with TS fusing requirements (**EV3.4.2**) JY 5/10/16

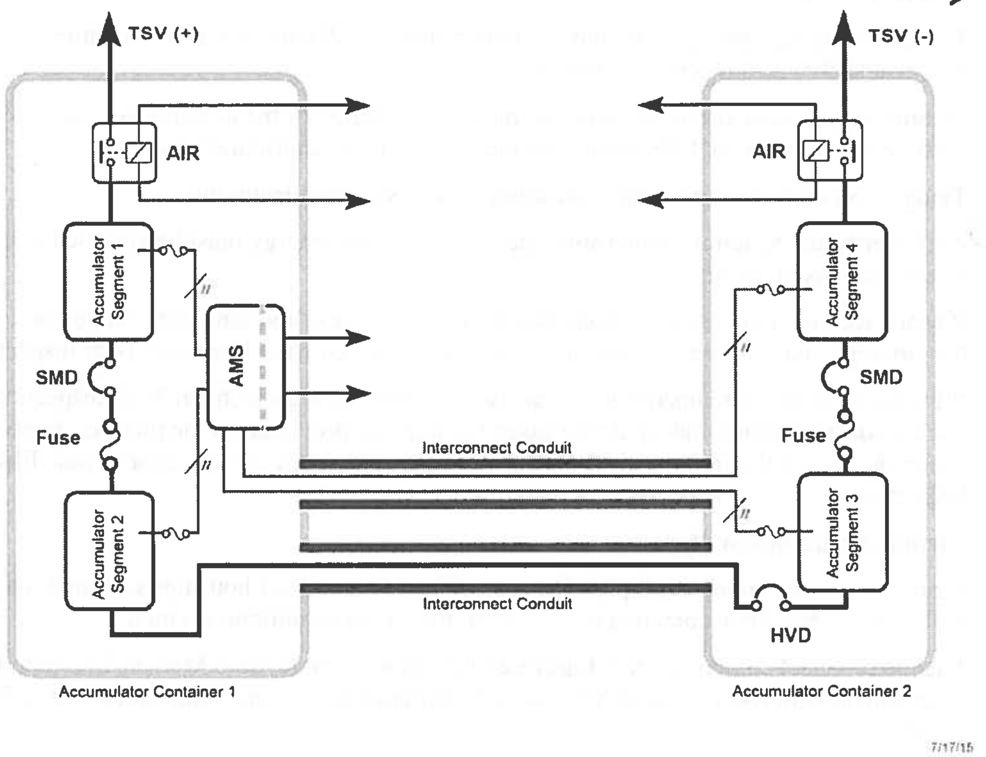

Figure 26 - Virtual Accumulator Housing Example

EV3.4 Tractive System Accumulator Container - Electrical Configuration

EV3.4.1 If the container is made of electrically conductive material, the poles of the accumulator stack(s) and/or cells must be electrically insulated from the inside wall of the accumulator container by insulating material rated for the maximum voltage of the tractive system.

All conductive surfaces on the outside of the container must have a low-resistance connection to the GLV system ground. All conductive penetrations (mounting hardware, etc.) must be located outside of the insulation and configured such that there is no possibility that they could penetrate the insulating barrier.

EV3.4.2 Every accumulator container must contain at least one fuse See **EV3.6**. JY 5/10/16

EV3.4.3 All batteries or capacitors that make up the accumulator must be divided into accumulator segments. A Segment Maintenance Disconnect (SMD) must be installed between each segment, to allow electrical separation such that the separated segments contain a maximum voltage of less than 120 VDC (fully charged) and a maximum energy of 6 MJ[7].

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[7] Commercial packs with larger segment energy may be permitted upon approval by the rules committee.

Note: If the high-voltage disconnect (HVD, section **EV4.7**) is located between segments, it satisfies the requirement for an SMD between these segments. (See **Figure 27**)

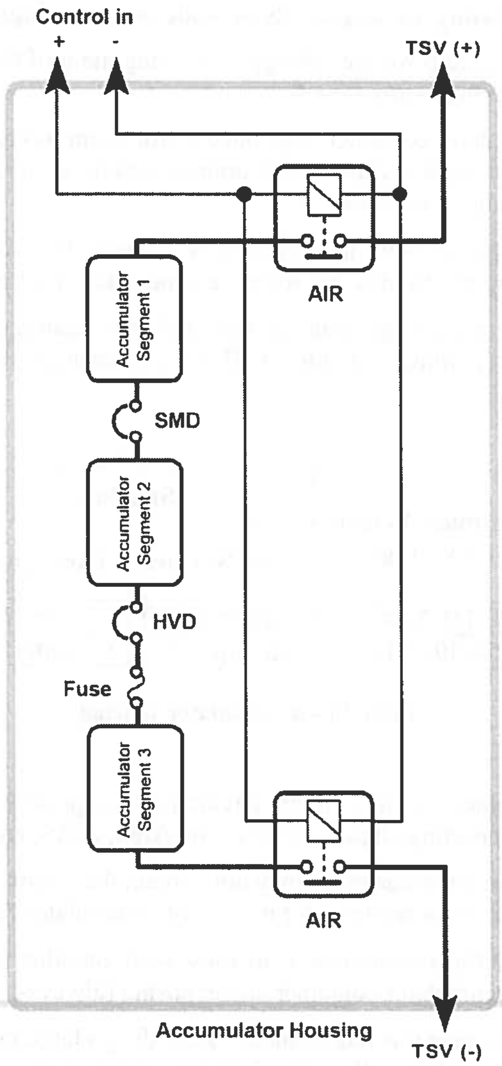

Figure 27 - Example Accumulator Segmenting

The SMD must be used whenever the accumulator containers are opened for maintenance and whenever accumulator segments are removed from the container.

EV3.4.4 The SMD may be implemented with a switch or a removable maintenance plug. There must be a positive means of securing the SMD in the disconnected state; for example, a lockable switch can be secured with a zip-tie or simply a clip.

Note: A removable plug meets this requirement if the plug is secured or fully removed such that it cannot accidentally reconnect.

EV3.4.5 SMD methods requiring tools to isolate the segments are not permitted. If the SMD is operated with the accumulator container open, any removable part used with the SMD (e.g., a clip or zip-tie used to secure the SMD off, or a plug that is removed) must be non-conductive on surfaces that are not used to make electrical connections.

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EV3.4.6 Contacting / interconnecting the single cells by soldering in the high current path is prohibited.

Note: Soldering wires to cells for the voltage monitoring input of the AMS is allowed since these wires are not part of the high current path.

EV3.4.7 Any removable accumulator container must have a prominent indicator, such as an LED, that is visible through a closed container that will illuminate whenever a voltage greater than 30 VDC is present at the vehicle side of the AIRs.

EV3.4.8 The accumulator voltage indicator must be directly controlled by voltage present at the container connectors using analog electronics. No software control is permitted.

EV3.4.9 The minimum spacing or creepage distance[8] for conductive materials at different voltages in the Accumulator shall be according to **Table 10**. This requirement applies to all conductors including cell-to-cell connections.

Maximum Vehicle TS Voltage	Spacing	
	Over Surface	Through Air
0-150 VDC	6.4 mm (1/4")	3.2 mm (1/8")
150-300 VDC	9.5 mm (3/8")	6.4 mm (1/4")

Table 10 - Accumulator spacing

EV3.4.10 The accumulator container may not contain circuitry or components other than the accumulator itself and necessary supporting circuitry such as the AIRs, AMS, and pre-charge circuitry.

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For example, the accumulator container may not contain the motor controller, IMD, TSVP or any GLV circuits other than those required for necessary accumulator functions.

Note 1: The purpose of this requirement is to allow work on other parts of the tractive system without opening the accumulator container and exposing (always-live) high voltage.

Note 2: It is possible to meet this requirement by dividing a large box into an accumulator section and a non-accumulator section, with an insulating barrier between them. In this case, it must be possible to open the non-accumulator section while keeping the accumulator section closed, meeting the requirements of the "finger probe" test. See: **EV4.5.1** . When the tractive system is not energized, there must be no tractive system voltage present in the non-accumulator section. The AIRs must therefore be located in the accumulator section.

EV3.5 Tractive System Accumulator Container - Mechanical Configuration

EV3.5.1 All accumulator containers must be rugged and rigidly mounted to the chassis to prevent the containers from loosening during the dynamic events or possible accidents.

[8] Creepage distance is the shortest distance measured along the surface of the insulating material between two conductors.

EV3.5.2 The mounting system for the accumulator container must be designed to withstand forces from a 40g deceleration in the horizontal plane and 20 g deceleration in the vertical plane. The calculations/tests proving this must be part of the SES.

(a) For tube frame cars, each accumulator container must be attached to the Frame by a minimum of four (4) 8 mm Metric Grade 8.8 or 5/16 inch Grade 5 bolts.

(b) For monocoques:

(i) Each accumulator container must be attached to the Frame at a minimum of four (4) points, each capable of carrying a load in any direction of 400 Newtons x the mass of the accumulator in kgs, i.e. if the accumulator has a mass of 50 kgs, each attachment point must be able to carry a load of 20kN in any direction.

(ii) The laminate, mounting plates, backing plates and inserts must have sufficient shear area, weld area and strength to carry the specified load in any direction. Data obtained from the laminate perimeter shear strength test (**T3.30**) should be used to prove adequate shear area is provided

(iii) Each attachment point requires a minimum of one (1) 8 mm Metric Grade 8.8 or 5/16 inch SAE Grade 5 bolt.

(iv) Each attachment point requires steel backing plates with a minimum thickness of 2 mm. Alternate materials may be used for backing plates if equivalency is approved.

(v) The calculations/tests must be included in the SES.

EV3.5.3 All accumulator containers must lie within the surface envelope as defined by **IC1.5.1**

EV3.5.4 The accumulator container(s) must be built of mechanically robust material; See **EV3.5.1**.

EV3.5.5 The container material must be fire resistant according to UL94-V0, FAR25 or equivalent.

EV3.5.6 The cells and/or segments must be appropriately secured against loosening inside the container. All accumulator segments must be attached to the accumulator container(s) with mechanical fasteners. The fasteners must comply with **ARTICLE T11**.

EV3.5.7 The accumulator segments contained within the accumulator must be separated by an electrically insulating barrier such that the limits of **EV3.4.3** are met. For all lithium based cell chemistries, these barriers must also be fire resistant (according to UL94-V0, FAR25 or equivalent).

EV3.5.8 Holes in the container are only allowed for the wiring-harness, ventilation, cooling or fasteners. These holes must be sealed according to **EV4.5**. Openings for ventilation should be of a reasonable size, e.g. completely open side pods containing accumulators are not allowed.

EV3.5.9 A sticker with an area of at least 750mm² and a red or black lightning bolt on yellow background or red lightning bolt on white background must be applied on every accumulator container. The sticker must also contain the text "High Voltage" or something similar if the accumulator voltage is greater than 30 VDC. DF 5/10/16

EV3.5.10 Any accumulator that may vent an explosive gas must have a ventilation system or pressure relief valve to prevent the vented gas from reaching an explosive concentration.

EV3.5.11 Every accumulator container which is completely sealed must have a pressure relief valve to prevent high-pressure in the container.

EV3.6 Accumulator Isolation Relay(s) (AIR)

EV3.6.1 At least two isolation relays must be installed in every accumulator container. JY 5/10/16

EV3.6.2 The accumulator isolation relays must open both poles of the accumulator. JY 5/10/16

EV3.6.3 If these relays are open, no TSV may be present outside of the accumulator container. (Including to the AMS and/or IMD) JVC 5/10/16 Joseph Cerinch

EV3.6.4 The isolation relays must be of a "normally open" type. JVC 5/10/16 Joseph Cerinch

EV3.6.5 The fuse protecting the accumulator circuit must have a rating lower than the voltage and current ratings of the isolation relays. JY 5/10/16

Note: The AIR contacts must be protected by Pre-Charge and Discharge circuitry, See **EV4.9**

EV3.6.6 Accumulator isolation relays containing mercury are not permitted. JVC 5/10/16 Joseph Cerinch

EV3.7 Accumulator Management System (AMS)

EV3.7.1 Each accumulator must be monitored by an accumulator management system whenever the tractive system is active or the accumulator is connected to a charger. JVC 5/10/16 Joseph Cerinch

EV3.7.2 The AMS must continuously measure cell voltages in order to keep those voltages inside the allowed minimum and maximums stated in the cell data sheet. If single cells are directly connected in parallel, only one voltage measurement is needed. (See **Table 11**) JVC 5/10/16 Joseph Cerinch

Chemistry	Maximum number of cells per voltage measurement
PbAcid	6
NiMh	6
Lithium based	1

Table 11 - AMS Voltage Monitoring

EV3.7.3 The AMS must continuously measure the temperatures of critical points of the accumulator to keep the cells below the allowed maximum cell temperature bound stated in the cell data sheet. JY 5/10/16

EV3.7.4 All voltage sense wires to the AMS must be either protected by fuses as defined in **ARTICLE EV6** or must be protected by resistors so that they cannot exceed their current carrying capacity in the event of a short circuit. Any fuse or resistor must be located as close as possible to the energy source. If any of these fuses are blown or if the connection to measure the cell voltage is interrupted in any other way then this must be detected by the AMS and must be reported as a critical voltage problem. If the AMS monitoring board is directly connected to the cell, it is acceptable to have a fuse integrated into the monitoring board.

EV3.7.5 Any GLV connection to the AMS must be galvanically isolated from the TSV. This isolation must be documented in the ESF.

Note: Per **EV3.6.3**, AMS connections that are not isolated, such as cell sense wires, cannot exit the accumulator container, unless they are isolated by additional relays when the AIRs are off. This requirement should be considered in the selection of an AMS system for a vehicle that uses more than one accumulator container.

EV3.7.6 All connections from external devices such as laptops to a tractive system component must include galvanic isolation, and include a connection to frame ground. These connections must be documented in the ESF.

EV3.7.7 The AMS must monitor the temperature of the minimum number of cells in the accumulator as specified in **Table 12** below. The monitored cells must be equally distributed over the accumulator container(s). JY 5/10/16

Chemistry	Cells monitored
PbAcid	5%
NiMh	10%
Li-Ion	30%

Table 12 – AMS Temperature Monitoring

NOTE: It is acceptable to monitor multiple cells with one sensor if this sensor has direct contact to all monitored cells.

NOTE: It is strongly recommended to monitor the temperature of all cells.

EV3.7.7 The AMS must shut down all the electrical systems, open the AIRs and shut down the I.C. drive system if critical voltage or temperature values are detected. (Some GLV systems may remain energized - See **Table 16**) The tractive system must remain disabled until manually reset by a person other than the driver. It must not be possible for the driver to re-activate the tractive system from within the car in case of an AMS fault.

EV3.7.9 Team-Designed Accumulator Management Systems

Teams may design and build their own Accumulator Management Systems. However, microprocessor-based accumulator management systems are subject to the following restrictions:

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(a) The processor must be dedicated to the AMS function only. However it may communicate with other systems through shared peripherals or other physical links.

(b) The AMS circuit board must include a watchdog timer. It is strongly recommended that teams include the ability to test the watchdog function in their designs.

EV3.7.10 AMS Test Port.

A break-out test connector must be provided inside the accumulator enclosure for AMS voltage testing. This port allows testing of the AMS by substituting a test box voltage for a measured cell voltage. See **Figure 28.**

The connector must be located where it can be readily accessed during technical testing.

Note: This may require opening the accumulator container. It does not need to be accessible during dynamic events.

The test connector must be either:

(a) Four (4) 4 mm shrouded banana jacks arranged in a 0.75 inch square pattern, meeting the requirements of **EV4.4** or

(b) A four conductor Molex Minifit junior 1 x 4 pin housing, PN 39-01-4040 (**Figure 29 A**) with PN 39-00-0039 female receptacles which Mates with Molex Minifit Jr housing, PN 39-01-4046 (**Figure 29 B**) with PN 39-00-0041 male pins[9].

[9] A set of Molex Minifit Jr. connectors will be provided to teams on request. Contact the organizers at info@formula-hybrid.org

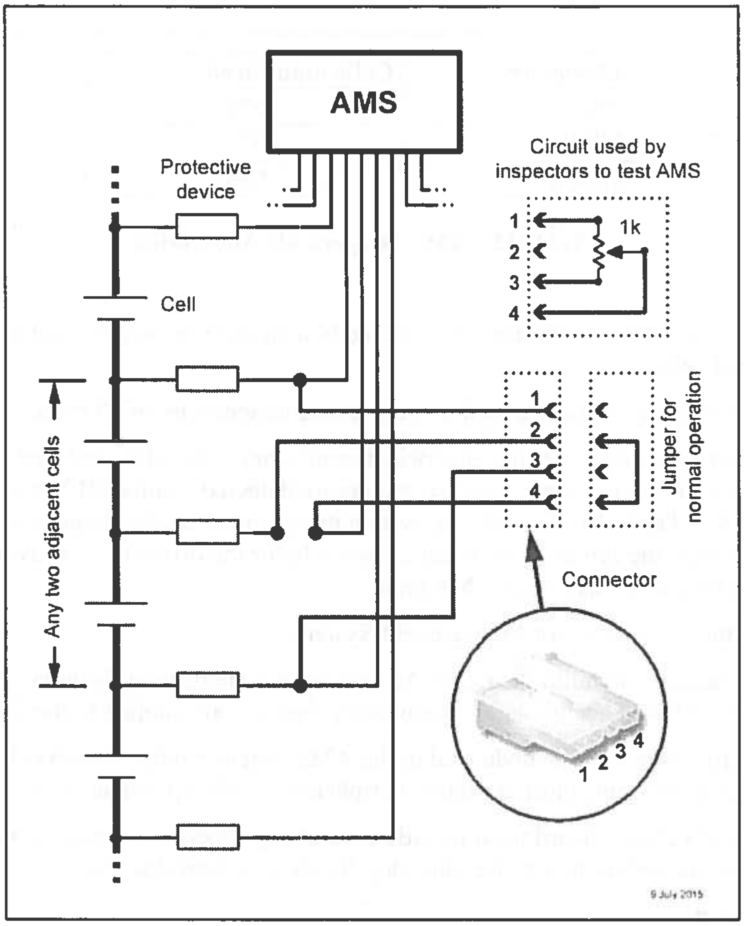

Figure 28 - AMS Test Connector Wiring

Notes:

1. The test connector makes three adjacent cell connections and an AMS input available for testing.
2. During testing, inspectors will connect a test circuit, energize the tractive system, and vary the cell voltage sense using the potentiometer in the test circuit. Cell voltage will be measured and compared to ESF values for AMS trip points.
3. For normal operation, a jumper that connects pins 2 & 4 is used.
4. It is recommended that teams construct their own test circuit to confirm proper wiring and operation prior to the competition. (<u>Use extreme caution, since TSV will be present at the potentiometer connections</u>.)

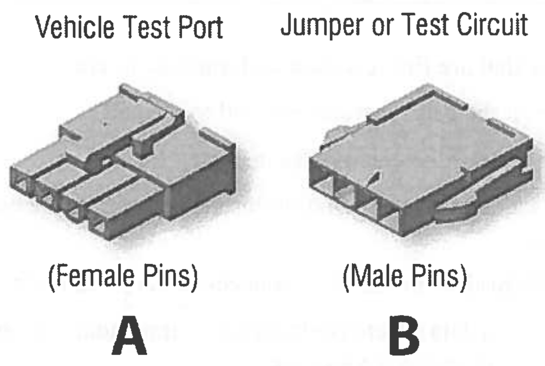

Figure 29 - Molex Minifit Connectors

EV3.8 Grounded Low Voltage System

EV3.8.1 All GLV batteries must be attached securely to the frame.

EV3.8.2 Any wet-cell battery located in the driver compartment must be enclosed in a nonconductive marine-type container or equivalent and include a layer of 1.5 mm of aluminum or equivalent between the container and driver.

EV3.8.3 The hot (ungrounded) terminal must be insulated.

EV3.8.4 Battery packs based on Lithium Chemistry (other than commercially assembled packs) must have over-voltage, under-voltage, short circuit and over-temperature cell protection. Details on how the required protection is achieved must be included as part of the ESF submission.

EV3.8.5 One terminal of the GLV battery or other GLV power source must be connected to the chassis by a ground wire. The ground wire must be sized adequately for the GLV system fusing. The ground wire must be robustly secured and protected from mechanical damage. Note that minimizing the length of the ground wire is also recommended.

Note: The ungrounded conductor of the GLV system must be fused as close as possible to the battery terminal in accordance with **EV6.1.5**

EV3.9 Pouch type Lithium Ion cells

Batteries constructed using pouch type lithium ion cells are subject to the following design constraints:

Note: Teams are responsible for documenting compliance with all of the following requirements. This documentation must be submitted as part of the ESF.

Designing an accumulator system utilizing pouch cells is a substantial engineering undertaking which may be avoided by using prismatic or cylindrical cells.

EV3.9.1 Stack arrangement

Cells in a stack (a group of pouch cells) must be arranged face-to-face not edge-to-edge.

EV3.9.2 Expansion Limiter

A mechanical restraining system (the expansion limiter) must limit volumetric expansion. The expansion limiter must:

(a) Be capable of applying ≥10 psi without yielding at temperatures up to 150 °C.

(b) allow the stack to expand by at least 8% and not more than 12% in volume before reaching 10 psi.

(c) use materials that are fire retardant and immune to creep.

(d) not impinge on the cell separator internal to the cell.

Conductive materials must be electrically insulated from cells.

Expansion limiter calculations (simulation results or appropriate mechanical analysis) must be included in the ESF.

NOTE: Formula Hybrid will consider variances to **EV3.9.2** if the request includes:

1. Manufacturer's data sheets containing recommendations and/or requirements for assembling a stack of the intended devices, **or**

   a letter from the cell manufacturer with the same information.

2. Drawings and a mechanical analysis of the team's proposed cell mounting structures.

EV3.9.3 Filler

Soft elastic material (filler) is required between cells.

The filler must:

(a) be evenly distributed through the stack, between every cell.

(b) apply pressure evenly to each cell surface.

(c) be non-conductive and fire resistant with a rating of UL94-V0 or compliant with FAR25.

EV3.9.4 Pouch Cell tabs

Pouch cell tabs must be:

(a) Mechanically restrained so they cannot move in relation to the cell due to vibration or physical handling.

(b) connected above the level of the tab insulator. No metallic parts of battery assembly may bridge the insulation gap provided by the tab insulator.

(c) insulated such that it is not possible to short circuit adjacent cells by accident.

EV3.9.5 Repeating Frame

Each cell in a stack must be held in position using a repeating frame or equivalent method. A repeating frame must not:

(a) change the natural shape of the cell.

(b) impinge on the cell separator internal to the cell.

(c) allow the edges of the cell to move in relation to the cell due to vibration or physical handling.

No cell may be in contact with or be likely to contact sharp corners or metal/plastic burrs.

A repeating frame or similar component, if conductive, must be resistively grounded such that an insulation failure will trip the IMD. The grounding resistance should be less than 250 ohms per volt (based on nominal system voltage) and be rated for the power it would dissipate at full system voltage.

EV3.9.6 General Construction

(a) Pouch cells must be handled with care before, during, and after assembly. They must be protected from being dented or deformed, or contaminated with debris such as shavings or filings. Evidence of pouch cell damage or debris will require removal of the damaged or contaminated cells.

(b) Each stack must be firmly anchored in the accumulator enclosure. See **EV3.5**. Construction must be robust and mechanically sound. Accumulator electrical spacing requirements must be observed, including paths through tension rods etc.

ARTICLE EV4 TRACTIVE SYSTEM – GENERAL REQUIREMENTS

Minimum Conductor/Conductor Spacing			
Location		**GLV/TS**	**TS/TS**
Inside Accumulator	PCB	**Table 15**	**Table 10**
	Non-PCB	**Table 14**	**Table 10**
Outside Accumulator	PCB	**Table 15**	Not specified
	Non-PCB	**Table 14**	Not specified

Table 13 - Applicability of different spacing rules

EV4.1 Separation of Tractive System and Grounded Low Voltage System

EV4.1.1 The layout of electrical devices designed by the team must be documented accurately in the ESF.

EV4.1.2 There must be no electrical connection between the frame of the vehicle (or any other conductive surface that might be inadvertently touched by a crew member or spectator), and any part of any tractive system circuits.

EV4.1.3 Tractive system and GLV circuits must be physically segregated. I.e. they may not run through the same conduit or connector, except for interlock circuit connections.

EV4.1.4 Where both tractive system circuits and GLV circuits are present within an enclosure, they must be:

(a) separated by electrical insulating barriers meeting the requirements of **EV4.1.6** or

(b) separated by the spacings shown in **Table 14** through air, or over a surface (similar to those defined in UL1741)

Voltage	**Spacing**
V < 100 VDC	1 cm
100 VDC < V < 200 VDC	2 cm
V > 200 VDC	3 cm

Table 14 - Enclosure Conductor Spacing

EV4.1.5 Insulating barriers used to meet the requirements of **EV4.1.4** Must be:

(a) UL recognized as electrical insulating materials for a temperature of 150 °C or higher.

(b) Must be adequately robust for the application and in no case thinner than 0.25 mm.

(c) Must be in addition to wire insulation.

(d) Must extend far enough at the edges to block any path between uninsulated GLV and tractive-system conductors shorter than the distances specified in **Table 14**.

EV4.1.6 Spacing must be clearly defined. Components and cables capable of movement must be positively restrained to maintain spacing.

EV4.1.7 If tractive system circuits and GLV circuits are on the same circuit board they must be on separate, clearly defined areas of the board. Furthermore, the tractive system and GLV areas must be clearly marked on the PCB.

EV4.1.8 Required spacing between GLV and TS circuits are as shown in **Table 15**. If a cut or hole in the board is used to allow the "through air" spacing, the cut must not be plated with metal, and the distance around the cut must satisfy the "over surface" spacing requirement.

Maximum Vehicle TS Voltage	**Spacing**	
	Over Surface	**Through Air (Cut in board)**
0-50 VDC	1.6 mm	1.6 mm
50-150 VDC	6.4 mm	3.2 mm
150-300 VDC	9.5 mm	6.4 mm

Table 15 - PCB Conductor Spacing

EV4.1.9 Teams must be prepared to demonstrate spacings on team-built equipment. Information on this must be included in the ESF (**EV9.1**). Spare boards and photographs must be available for inspection. Teams should also be prepared to remove boards for direct inspection if asked to do so during the technical inspection.

EV4.1.10 Plated prototyping boards having plated holes and/or generic conductor patterns may not be used for applications where both GLV and TS circuits are present on the same board. Bare perforated board may be used, if the spacing and marking requirements (**EV4.1.7** and **EV4.1.9**) are met, and if the board is easily removable for inspection.

EV4.2 Positioning of tractive system parts

(See also: Section **T4.5.1**)

EV4.2.1 All parts belonging to the tractive system including conduit, cables and wiring must be contained within the Surface Envelope of the vehicle (See **Figure 24**) such that they are protected against being damaged in case of a crash or roll-over situation or being caught (snagged) by road hazards.

EV4.2.2 If tractive system parts are mounted in a position where damage will occur from a side or rear impact, for example motors at the rear of the car, they must be protected by a structure meeting the requirements of **T3.3**

EV4.2.3 Outboard wheel motors are allowed where the motor is outside of the frame but only if an interlock is added such that the Shutdown Circuit, **EV5.1**, is opened if the wheel assembly is damaged or separates from the car.

EV4.2.4 In side or front view no part of the tractive-system can project below the lower surface of the frame or the monocoque, whichever is applicable.

EV4.2.5 There must be a layer of an electrically insulating material between any tractive terminal or connection and the firewall or frame if they are within 50 mm of one another.

NOTE: If the enclosure of the tractive system component is electrically insulating it can be used to meet this requirement.

EV4.3 Grounding

EV4.3.1 All accessible metal parts of the vehicle, except conductors and components of the GLV system, must have a resistance below 300 mΩ (measured with a 4-point technique at a current of 100 mA) to GLV system ground.

NOTE: Accessible parts include that those that are exposed in the normal driving configuration or when the vehicle is partially disassembled for maintenance or charging.

EV4.3.2 All accessible parts of the vehicle containing conductive material (e.g. coated metal parts, carbon fiber parts, etc.) which might contact a damaged wire or electrical part, no matter if tractive system or GLV, must have a resistance below 100 ohms to GLV system ground. (Measured using a 4-point technique.)

EV4.3.3 Electrical conductivity of any part may be tested by checking any point which is likely to be conductive, for example the driver's harness attachment bolts. Where no convenient conductive point is available then an area of coating may be removed.

NOTE: Carbon fiber parts may need special measures such as using copper mesh or similar modifications to keep the ground resistance below 100 ohms.

NOTE: Conductors used for grounding shall be stranded and 16 AWG minimum.

Make a Note of this

EV4.4 Tractive System Measuring Points (TSMP)

EV4.4.1 Two tractive system voltage measuring points must be installed in an easily accessible well marked location. Access must not require the removal of body panels.

EV4.4.2 The TSMPs must be protected by a non-conductive housing that can be opened without tools.

EV4.4.3 The TSMP must be protected from being touched with the bare hand / fingers, even when the housing is opened.

EV4.4.4 4 mm safety banana jacks that accept shrouded (sheathed) banana plugs with non-retractable shrouds must be used for the TSMPs.

See **Figure 30** for examples of the correct jacks and of jacks that are not permitted because they do not accept the required plugs (also shown).

EV4.4.5 The TSMPs must be connected to the positive and negative motor controller/inverter supply lines.

EV4.4.6 Each TSMP must be secured with an appropriately rated current limiting resistor. (Fuses are not permitted)

EV4.4.7 The TSMPs will be used to check during Electrical Tech Inspection that the tractive system is shut down properly in the given time; see **EV5.1.3**. They are also needed to ensure the isolation of the tractive system of the vehicle for possible rescue operations after an accident or when work on the vehicle is to be done.

EV4.4.8 Next to the TSMP a GLV system ground measuring point must be installed. This measuring point must be connected to the GLV system ground.

EV4.4.9 A 4 mm safety banana jack that accepts shrouded (sheathed) banana plugs with non-retractable shrouds must be used for the GLV ground measuring point. See **Figure 30** for examples of the correct jacks and of jacks that are not permitted because they do not accept the required plugs (also shown).

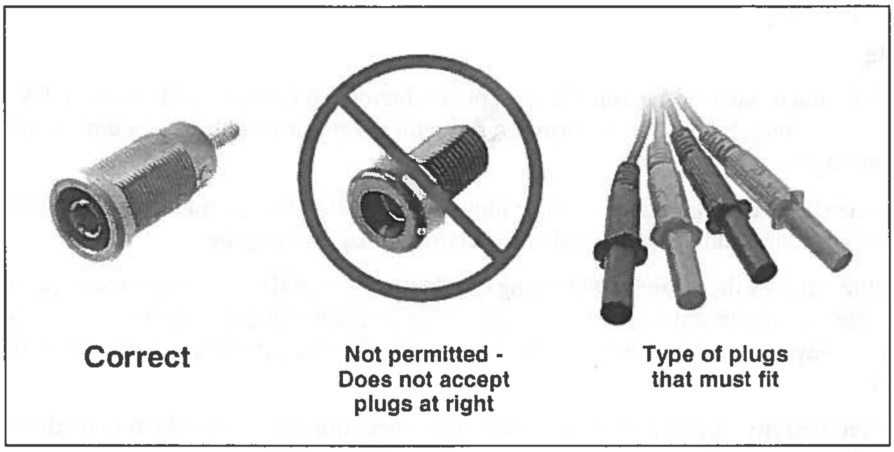

Figure 30 - Shrouded 4mm Banana Jack

EV4.5 TSV Insulation, wiring and conduit

EV4.5.1 All parts especially live wires, contacts, etc. of the tractive system need to be isolated by non-conductive material or covers to be protected from being touched. In order to achieve this, it must not be possible to touch any tractive system connections with a 10 cm long, 0.6 cm diameter insulated test probe when the tractive system enclosures are in place. (The "finger probe" test.)

EV4.5.2 Non-conductive covers must prevent inadvertent human contact with any tractive system circuit. This must include crew members working on or inside the vehicle. Covers must be secure and adequately rigid. Body panels that must be removed to access other components, etc. are not a substitute for enclosing tractive system connections.

EV4.5.3 Tractive systems and containers must be protected from moisture in the form of rain or puddles.

EV4.5.4 All controls, indicators and data acquisition connections or similar must be galvanically isolated from the tractive system.

EV4.5.5 All electrical insulating material must be appropriate for the application in which it is used. See: **EV1.3**

EV4.5.6 All wires and terminals and other conductors used in the tractive system must be sized appropriately for the continuous rating of the fuse which protects them. Wires must be marked with wire gauge, temperature rating and insulation voltage rating. Alternatively a manufacturers part number printed on the wire is sufficient if this can be referenced to a manufacturers data sheet.

The minimum acceptable temperature rating for TSV cables is 90°C.

Note: Many high current fuses can allow significant overcurrent conditions which may be adequate to cover the peak power requirements and allow sizing of fusing and wiring according to continuous or RMS needs.

EV4.5.7 All tractive system wiring must be done to professional standards with appropriately sized conductors and terminals and with adequate strain relief and protection from loosening due to vibration etc. Conductors and terminals cannot be modified from their original size/shape and must be appropriate for the connection being made.

EV4.5.8 All tractive system wiring that runs outside of electrical enclosures must be either:

(a) Shielded, dual-insulated cable (in accordance with ISO 6722 / ISO 14572 or approved equivalent) with a minimum cross section of 25 mm^2 (0.039 in^2) **or**

(b) Enclosed in separate orange non-conductive conduit.

EV4.5.9 Tractive system wiring run without conduit per Formula Hybrid rule **EV4.5.8** must be 25 mm^2 or larger and must be shielded.

EV4.5.10 If conduit is used, it must be non-metallic and UL Listed as "Conduit".

Note 1: "Sleeving" does not qualify as conduit.

Note 2: "UL Recognized" is not the same as "UL Listed" and will not be automatically accepted by the technical inspectors.

Note 3: UL Listed Conduit of other colors may be painted orange or wrapped with orange tape provided it is done in a professional manner. I.e. it will not chip or fall off.

EV4.5.11 Teams must receive rules committee approval before using any non-UL Listed conduit.

EV4.5.12 Cable or conduit exiting or entering a tractive system enclosure must use a liquid-tight fitting proving strain relief to the cable or conduit such that it will withstand a force of 200N without straining the cable[10].

The fitting must be one of the following:

(a) A conduit fitting rated for use with the conduit used **or**

(b) A cable gland rated for use with the cable used **or**

(c) A connector rated for use with the cable used. The connector must provide termination of the shield to ground (per **EV4.5.16**) and latch in place securely enough to meet the strain-relief requirements listed above. Both portions of the connector must meet or exceed IEC standards IP53 (mated) and IP20 (unmated).

EV4.5.13 Tractive system wiring outside of the frame must be in conduit, with the exception of connections to wheel motors.

Note: Shielded, dual insulated cables without conduit are only permitted inside the frame.

EV4.5.14 Wiring to outboard wheel motors may be in conduit or shielded dual insulated cable, meeting the specifications of **EV4.5.8**. In either case, at least one wire of the interlock system must accompany each conduit or cable.

EV4.5.15 All tractive system connections must be designed so that they use intentional current paths through conductors such as copper or aluminum and should not rely on steel bolts to be the primary conductor. The connections must not include compressible material such as plastic in the stack-up.

EV4.5.16 If shielded, dual-insulated cable is used, (per **EV4.5.8(a)**) the shield must be terminated and connected to chassis ground at both ends of the cable.

EV4.5.17 Tractive system wiring must be mechanically shielded against damage by rotating and / or moving parts.

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[10] This will be tested during the electrical tech inspection by pulling on the conduit using a spring scale.

EV4.6 Tractive System Enclosures

EV4.6.1 Every housing or enclosure containing parts of the tractive system except motor housings must be labeled with sticker(s) (minimum 4 x 4 cm) with a red or black lightning bolt on yellow background or red lightning bolt on white background. The sticker must also contain the text "High Voltage" or something similar if the voltage is more than 30 VDC or 25 VAC.

EV4.6.2 If the housing material is electrically conductive, it must have a minimum-resistance connection to GLV system ground; see **EV4.3**.

EV4.6.3 If external, un-insulated heat sinks are used, they must be properly grounded to the GLV system ground; see **EV4.3**.

EV4.7 High Voltage Disconnect (HVD)

EV4.7.1 It must be possible to positively break the current path of the tractive system accumulator quickly by turning off a disconnect switch or removing an accessible element, fuse or connector.

EV4.7.2 It must be possible to disconnect the HVD within 10 seconds in ready-to-race condition.

Note: Ready-to-race means that the car is fully assembled, including having all body panels in position, with a driver seated in the vehicle and without the car jacked up.

The team must demonstrate this during Electrical Tech Inspection. Being able to quickly disconnect the accumulator(s) from the rest of the tractive system by its connector(s) will satisfy this rule.

EV4.7.3 The disconnect must be clearly marked with "HVD".

EV4.7.4 There must be a positive means of securing the HVD in the disconnected state; for example, a lockable switch can be secured with a zip-tie or simply a clip.

Note: A removable plug will meet this requirement if the plug is secured or fully removed such that it cannot accidentally reconnect.

EV4.7.5 Teams must establish a formal lockout/tagout procedure that is documented in the ESF, and that all team members know and follow.

EV4.7.6 The recommended electrical location for the HVD is near the middle of the accumulator string. In this case, it can serve as one of the SMDs (**EV3.4.3** and **Figure 27**)

EV4.7.7 The HVD must be operable without the use of tools.

EV4.8 Activating the Tractive System

EV4.8.1 The driver must be able to re-activate or reset the tractive system from within the cockpit without the assistance of any other person except for situations in which the AMS or IMD have shut down the tractive system; see **EV5.1.5**.

Note: Resetting or re-activating the tractive system by operating controls which cannot be reached by the driver is considered to be working on the car.

EV4.8.2 At least one action in addition to enabling the shutdown circuits is required to set the car to ready-to-drive mode. (The car is ready to drive as soon as the motor(s) will respond to the input of the torque control sensor / acceleration pedal.)

For example, the additional action could be pressing a dedicated "start" button. However this must be configured such that it cannot inadvertently be left in the "on" position after system shutdown.

Note: This action may also be used to trigger the required "Ready to drive" sound. (**See EV4.11**)

EV4.9 Pre-Charge and Discharge Circuits

EV4.9.1 The AIR contacts must be protected by a circuit that is able to pre-charge the intermediate circuit to at least 90% of the rated accumulator voltage before closing the second AIR. This circuit must be disabled by a de-activated shutdown circuit; see **EV5.1**. Therefore, the pre-charge circuit must not be able to pre-charge the system if the shutdown circuit is open.

EV4.9.2 It is allowed to pre-charge the intermediate circuit for a conservatively calculated time before closing the second AIR. A feedback via monitoring the intermediate circuit voltage is not required.

EV4.9.3 If a discharge circuit is needed to meet the requirements of **EV5.1.3**, it must be designed to handle the maximum discharge current for at least 15 seconds. The calculation proving this must be part of the ESF.

EV4.9.4 The discharge circuit must be fail-safe. I.e. wired in a way that it is always active whenever the shutdown circuit is open or de-energized.

EV4.9.5 The pre-charge circuit must operate regardless of the sequence of operations used to energize the vehicle, including, for example, restarting after being automatically shut down by a safety circuit.

EV4.9.6 All components and insulating materials used in and near the pre-charge circuits must be rated for the maximum expected operating temperature. (See also **EV1.3.1(b)).**

Note: For always-on discharge circuits and other circuits that dissipate significant power for extended time periods, measurements of the maximum operating temperature of the power dissipating components (e.g., resistors) must be included in the ESF. If the resistor operating temperature exceeds the rating of nearby insulating or structural materials, their temperatures must also be measured.

EV4.10 Tractive System Energized Light (TSEL)

EV4.10.1 The car must be equipped with a TSEL mounted under the highest point of the main roll hoop which must be lit and clearly visible any time the AIR coils are energized.

EV4.10.2 The TSEL must be amber.

EV4.10.3 The TSEL must flash continuously with a frequency between 2 Hz and 5 Hz.

EV4.10.4 It must not be possible for the driver's helmet to contact the TSEL.

EV4.10.5 The TSEL must be clearly visible from every horizontal direction, (except for the small angles which are covered by the main roll hoop) even in very bright sunlight.

EV4.10.6 The TSEL must be visible from a person standing up to 3 m away from the TSEL itself. The person's minimum eye height is 1.6 m.

NOTE: If any official e.g. track marshal, scrutineer, etc. considers the TSEL to not be easily visible during track operations the team may not be allowed to compete in any dynamic event before the problem is solved.

EV4.10.7 It is prohibited to mount other lights in proximity to the TSEL.

EV4.11 Ready-To-Drive-Sound

EV4.11.1 The car must make a characteristic sound, for a minimum of 1 second and a maximum of 3 seconds, when it is ready to drive. **(See EV4.8.2)**

(The car is ready to drive as soon as the motor(s) will respond to the input of the torque control sensor / accelerator pedal.)

EV4.11.2 The emitting device must produce a tone of approximately 2500 to 3500 Hz with a minimum loudness of 68 dB(A) at 2 ft. One device that meets this requirement is the Mallory Sonalert SC648AJR[11].

The emitting device must be located and oriented so as to be easily audible from in front of the vehicle in noisy environments.

EV4.12 Tractive System Voltage Present (TSVP) indicators

There must be two TSVP lamps. One mounted on each side of the roll bar in the vicinity of the side-mounted shutdown buttons (**EV5.6**) that can easily be seen from the sides of the vehicle.

EV4.12.1 They must be Red, complying with DOT FMVSS 108 for trailer clearance lamps[12]. See **Figure 31**

EV4.12.2 They must be lit and clearly visible any time the voltage outside the accumulator containers exceeds 32 V or 1/3 the maximum bus voltage, whichever is higher.

EV4.12.3 The TSVP system must be powered entirely by the tractive system and must be directly controlled by voltage being present at the output of the accumulator (no software control is permitted). TS wiring and/or voltages must not be present at the lamps themselves.

Note: This requirement may be met by locating an isolated dc-dc converter inside a TS enclosure, and connecting the output of the dc-dc converter to the lamps. Although the wiring from the dc-dc converter to the TSVP lamps must not be connected to the main GLV system, it must be ground-referenced by connecting one side of it to the frame or GLV ground in order to comply with **EV1.1.4** and **EV1.2.3.**

Figure 31 - TSVP Lamp

ARTICLE EV5 SHUTDOWN CIRCUIT AND SYSTEMS

EV5.1 Shutdown Circuit

EV5.1.1 The shutdown circuit must directly carry the current driving the accumulator isolation relays (AIRs).

EV5.1.2 The shutdown circuit (See: **Figure 35**) must consist of at least:

(a) GLVMS See: **EV5.3**

(b) TSMS See: **EV5.4.1**

[11] http://www.mallory-sonalert.com/specifications/SC648AJR.PDF
[12] http://www.superbrightleds.com - Part Number M9-x4 or equivalent

(c) 2 Side mounted shutdown buttons See: **EV5.6**

(d) Cockpit-mounted shutdown button See: **EV5.7**

(e) Brake over-travel switch. See: **EV5.8**

(f) Insulation monitoring device (IMD) See: **EV5.9**

(g) Accumulator management system (AMS) See: **EV3.7**

(h) Plus all required interlocks.

EV5.1.3 If the shutdown circuit is opened/interrupted the tractive system must be shut down by opening all accumulator isolation relay(s). The voltage in the tractive system must drop to under 30 VDC or 25 VAC RMS in less than five seconds after opening the shutdown circuit. BM 5/10/16

EV5.1.4 An example schematic of the required shutdown circuit, excluding possibly needed interlock circuitry, is shown in **Figure 35**.

EV5.1.5 It must not be possible for the driver to re-activate the tractive system from within the car in case of an AMS or IMD fault. Remote reset, for example via WLAN or use of the three shutdown buttons or TSMS to reset the AMS or IMD is not permitted. BM 5/10/16

Note: Applying an IMD test resistor between tractive system positive and GLV system ground must deactivate the system. Disconnecting the test resistor must not re-activate the system. The tractive system must remain inactive until it is manually reset.

EV5.1.6 If the tractive system is de-activated while driving, the motor(s) must spin free, e.g. no braking torque may be derived from the motor(s).

EV5.1.7 The recommended sequence of operation of the shutdown circuit and related systems is shown in the form of a state diagram in **Figure 32**.

Teams are required to either:

(a) Demonstrate that their vehicle operates according to this state diagram, or,

(b) Obtain approval for an alternative state diagram by submitting an electrical rules query on or before the ESF submission deadline, and demonstrate that the vehicle operates according to the approved alternative state diagram.

EV5.1.8 If the shutdown circuit operates differently from the standard or approved alternative state diagram during inspection, the car will be considered to have failed inspection, regardless of whether the way it operates meets other rules requirements.

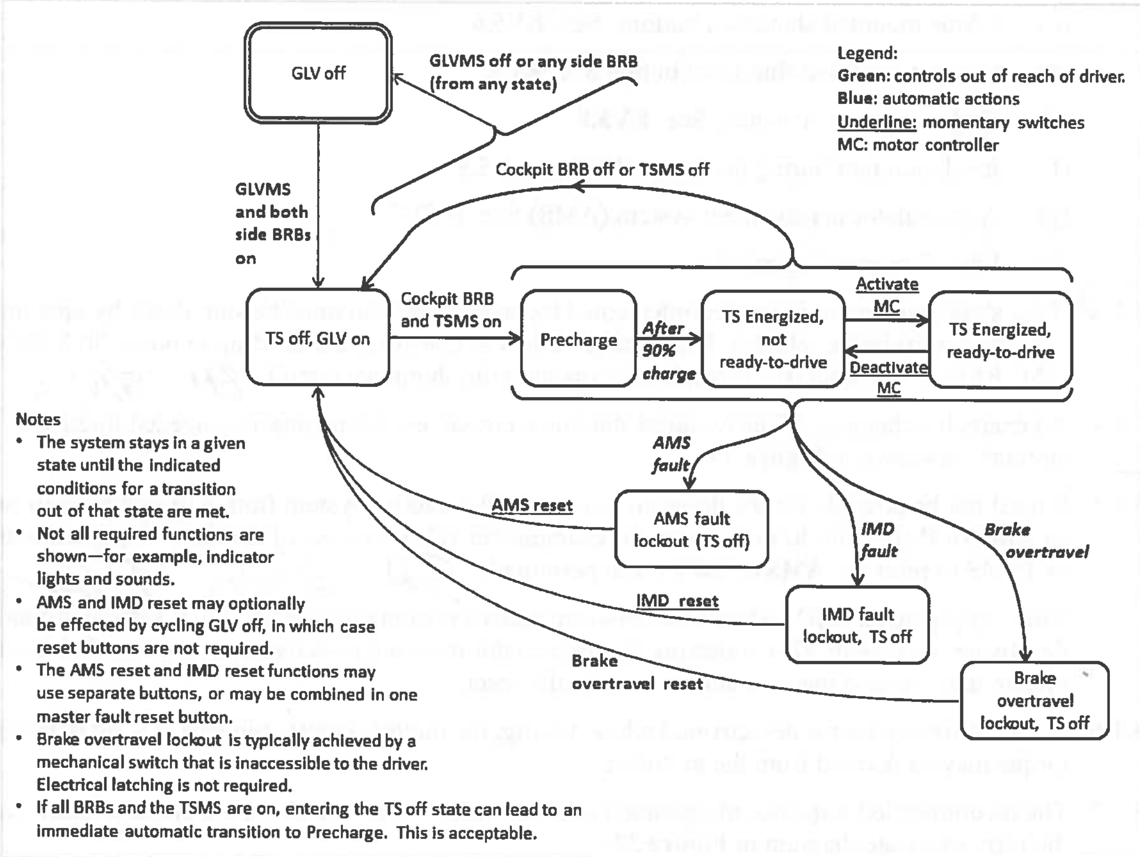

Figure 32 - Example Shutdown State Diagram

EV5.2 Master Switches

EV5.2.1 Each vehicle must have two Master Switches:

(a) Grounded Low Voltage Master Switch (**GLVMS**)

(b) Tractive System Master Switch (**TSMS**).

EV5.2.2 Both master switches must be located on the right side of the vehicle, in proximity to the Main Hoop, at the driver's shoulder height and be easily actuated from outside the car.

EV5.2.3 Both master switches must be of the rotary type, with a red, removable key, similar to the one shown in **Figure 33**.

EV5.2.4 Both master switches must be direct acting. I.e. they may not operate through a relay.

EV5.2.5 The master switches are not allowed to be easily removable, e.g. mounted onto removable body work.

EV5.2.6 The function of both switches must be clearly marked with "**GLV**" and "**TSV**".

EV5.2.7 The "ON" position of both switches must be parallel to the fore-aft axis of the vehicle

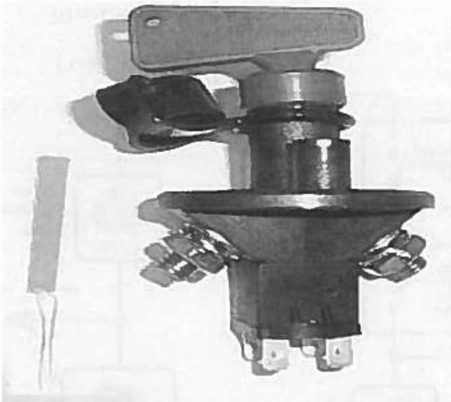

Figure 33 - Typical Master Switch

EV5.3 Grounded Low Voltage Master Switch (GLVMS)

EV5.3.1 The GLVMS must disable power to <u>ALL</u> electrical circuits, including the alternator, lights, fuel pump(s), ignition and electrical controls. See **Table 16.** BM 5/10/16

EV5.3.2 All GLV current must flow through the GLVMS. BM 5/10/16

EV5.4 Tractive System Master Switch (TSMS)

EV5.4.1 The TSMS must open the Tractive System shutdown circuit.

EV5.4.2 The TSMS must be identified with a sticker with a red lightning bolt in a blue triangle. (See **Figure 34.)**

EV5.4.3 The TSMS must be the last switch in the loop carrying the holding current to the AIRs. (See **Figure 35.)**

Figure 34 - International Kill Switch Symbol

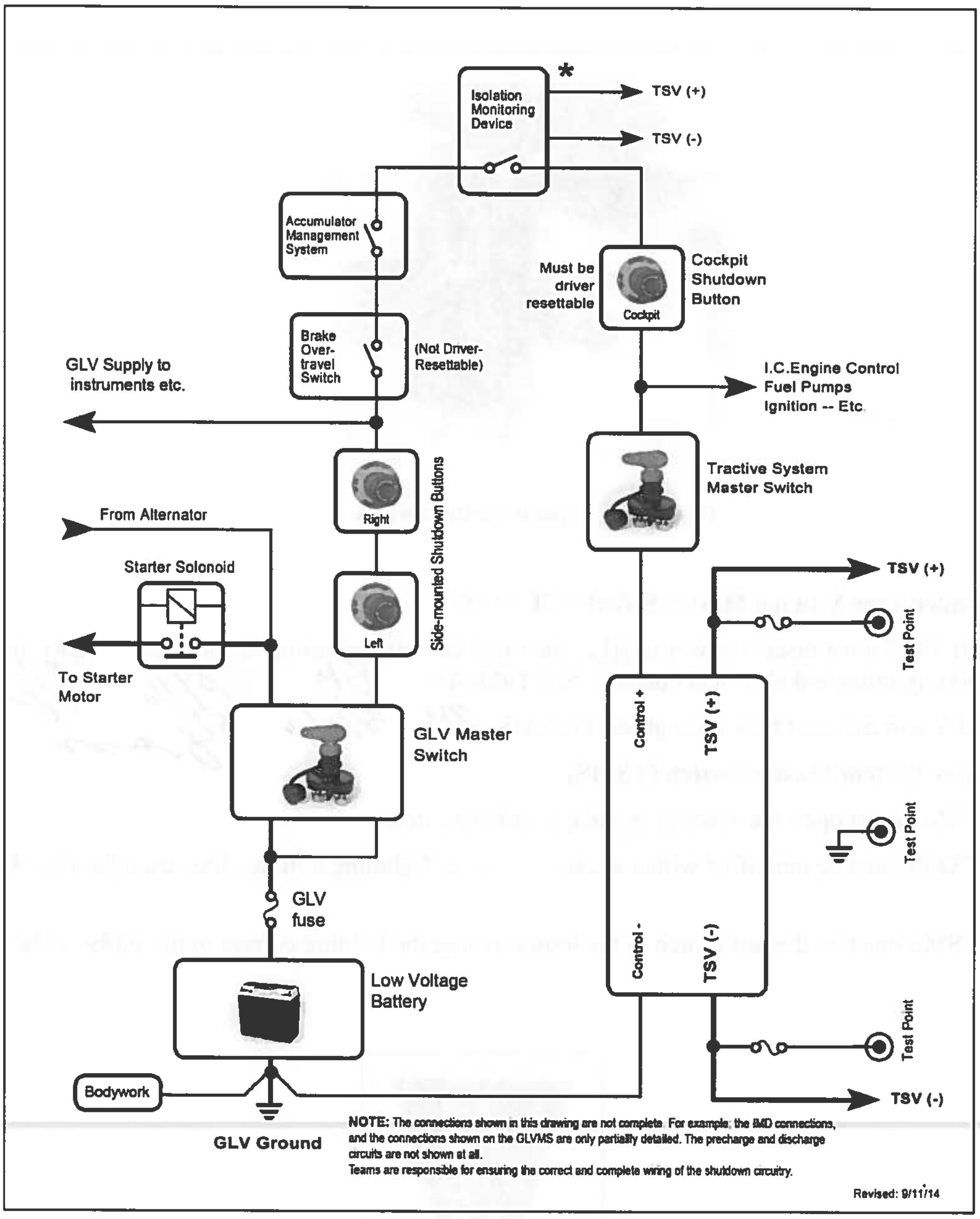

Figure 35 – Example Master Switch and Shutdown Circuit Configuration

EV5.5 Shutdown Buttons

EV5.5.1 A system of three shut-down buttons ("Big Red Buttons" or BRBs) must be installed on the vehicle.

EV5.5.2 The shut-down buttons must all be normally-closed, push-pull or push-rotate where pushing the button opens the circuit.

EV5.5.3 Pressing any of the shut-down buttons must isolate the accumulator from the rest of the vehicle by opening the shutdown circuit. This must also kill the engine and fuel pumps; see **EV5.1**.

EV5.5.4 The shut-down buttons may not act through logic such as a micro-controller or relays.

EV5.5.5 The shutdown buttons may not be easily removable, e.g. they may not be mounted onto removable body work.

EV5.5.6 Electronic systems that contain internal energy storage to allow an orderly shutdown of operations upon the loss of GLV, must be prevented from feeding power back into the GLV.

EV5.6 Side Mounted Shutdown Buttons

EV5.6.1 One button must be located on each side of the vehicle behind the driver's compartment at approximately the level of the driver's head. They must be installed facing outward and be easily visible from the sides of the car. The minimum allowed diameter of the side-mounted shutdown buttons is 40 mm.

EV5.6.2 The side-mounted shutdown buttons must shut down all electrical systems. (See: **Table 16**) BM 5/10/16

EV5.7 Cockpit Shutdown Button

EV5.7.1 One shutdown button is mounted in the cockpit and must be easily accessible by the driver with the steering wheel in any position.

EV5.7.2 The cockpit mounted button must shut down all electrical systems except for those listed in **EV5.7.3** (below).

EV5.7.3 Control, Telemetry, and Instrumentation systems may remained energized if the cockpit BRB is depressed. (See: **Table 16**)

EV5.7.4 The cockpit shutdown button must be driver resettable. I.e. if the driver disables the system by pressing the cockpit-mounted shutdown button, the driver must then be able to restore system operation by pulling the button back out. BM 5/10/16

Note: There must still be one additional action by the driver after pulling the button back out to reactivate the motor controller. (See: **EV4.8.2**)

EV5.7.5 The cockpit shutdown button must be at least 24 mm in diameter.

EV5.8 Brake Over-Travel Switch

EV5.8.1 The brake over-travel switch, as defined in **T7.3**, must shut down:

(a) The tractive system by opening the shutdown circuit (See: **EV5.1**) **and**

(b) the engine and fuel pumps, as illustrated in **Table 16**.

EV5.8.2 The Brake over-travel switch may not be driver resettable. See: **T7.3.2**.

EV5.9 Insulation Monitoring Device (IMD)

EV5.9.1 Every car must have an insulation monitoring device (IMD) installed in the tractive system.

EV5.9.2 The IMD must be a Bender A-ISOMETER ® iso-F1 IR155-3203 or IR155-3204 or equivalent IMD approved for automotive use. Equivalency may be approved by the rules committee based on the following criteria: robustness to vibration, operating temperature range, availability of a direct output, a self-test facility and must not be powered by the system which is monitored.

EV5.9.3 The response value of the IMD needs to be set to no less than 500 ohm/volt, related to the maximum tractive system operation voltage.

EV5.9.4 In case of an insulation failure or an IMD failure, the IMD must shut down all the electrical systems, open the AIRs and shut down the I.C. drive system. (Some GLV systems may remain energized – See: **Table 16**). This must be done without the use of any logic (e.g., a micro-controller).

BM 5/10/16

EV5.9.5 The tractive system must remain disabled until manually reset by a person other than the driver. It must not be possible for the driver to re-activate the tractive system from within the car in case of an IMD-related fault. (See **Appendix H** – Example Relay Latch Circuits.)

Note: The electrical inspectors may test the IMD by applying a test resistor between tractive system positive (or negative) and GLV system ground. This must deactivate the system. Disconnecting the test resistor must not re-activate the system.

EV5.9.6 The status of the IMD must be shown to the driver by a red indicator light in the cockpit that is easily visible even in bright sunlight. This indicator must light up if the IMD detects an insulation failure or if the IMD detects a failure in its own operation e.g. when it loses reference ground.

EV5.9.7 The IMD indicator light must be clearly marked with the lettering "IMD" or "GFD" (Ground Fault Detector).

EV5.9.8 The IMD ground connection must be wired according to the manufacturer's instructions so that the reference ground detector is functional.

		Controlled Systems			
		Engine Starter (High Current)	GLV Supply to: Instrumentation Data acquisition Computers Telemetry Etc.	I.C. Engine Ignition Fuel pumps Starter solenoid Etc.	AIRs (TS Voltage)
Shutdown Sources	TSMS				OFF
	Cockpit BRB			OFF	OFF
	AMS			OFF	OFF
	IMD			OFF	OFF
	Brake Over-travel			OFF	OFF
	Side-mounted BRBs		OFF	OFF	OFF
	GLVMS	OFF	OFF	OFF	OFF

Table 16 - Shutdown Priority Table

ARTICLE EV6 FUSING

EV6.1 Fusing

EV6.1.1 All electrical systems (including tractive system, grounded low voltage system and charging system) must be appropriately fused.

Note: For further guidance of fusing, see the Fusing Tutorial on the Formula Hybrid Web site.

EV6.1.2 The continuous current rating of a fuse must not be greater than the continuous current rating of any electrical component that it protects. This includes wires, busbars, battery cells or other conductors. See **Appendix E** for ampacity rating of copper wires.

EV6.1.3 All fuses and fuse holders must be rated for the highest voltage in the systems they protect. Fuses used for DC must be rated for DC, and must carry a DC rating equal to or greater than the system voltage of the system in which they are used.

EV6.1.4 All fuses must have an interrupt current rating which is higher than the theoretical short circuit current of the system that it protects.

EV6.1.5 The fuse protecting a circuit or must be physically located at the end of the wiring closest to an uncontrolled energy source (e.g., a battery).

TK 05/10

Note: For this rule, a battery is considered an energy source even for wiring intended to charge the battery, because current could flow in the opposite direction in a fault scenario.

EV6.1.6 Circuits with branches using smaller wire than the main circuit require fuses located at the branching point, if the branch wire is too small to be protected by the main fuse for the circuit.

EV6.1.7 If more than one battery cell or capacitor is used to form a set of single cells in parallel such that groups of parallel cells are then combined in series, then either each cell must be appropriately fused or the cell manufacturer must certify that it is acceptable to use this number of single cells in parallel. Any certification must be included in the ESF.

EV6.1.8 If multiple parallel strings of batteries or capacitors are used then each string must be individually fused. If individual fuses are used this must provide a total fusing equal to the number of fuses multiplied by the fuses rating. Any conductors, for example wires, bus bars, cells etc. conducting the entire pack current must be appropriately sized to this total fusing or an additional fuse must be used to protect the conductors.

EV6.1.9 Battery packs with low or non-voltage rated fusible links for cell connections may be used provided that:

(a) A fuse rated at a current three times lower than the sum of the parallel fusible links and complying with **EV6.1** is connected in series.

(b) The accumulator monitoring system can detect an open fusible link, and will shut down the electrical system by opening the AIRs if a fault is detected.

(c) Fusible link current rating is specified in manufacturer's data or suitable test data is provided.

EV6.1.10 Cells with internal over-current protection may be used without external fusing or fusible-links if suitably rated.

Note: Most cell internal over-current protection devices are low or non-voltage rated and conditions of **EV6.1.9** will apply.

EV6.1.11 The ESF must include all details of fuse and fusible link and internal over current protection including documentation from manufacturer for the particular series and parallel configuration, and string voltage.

ARTICLE EV7 ELECTRICAL SYSTEM TESTS

Note: The following three tests must be done in order, and each test passed before the next can be performed. i.e. (IMDT) then (IMT) then the rain test.

EV7.1 Insulation Monitoring Device Test (IMDT)

EV7.1.1 The insulation monitoring device will be tested during Electrical Tech Inspection. This is done by connecting a resistor between the TSMP (see **EV4.4**) and several electrically conductive vehicle parts while the tractive system is active, as shown in the example below.

EV7.1.2 The test is passed if the IMD shuts down the tractive system within 30 seconds at a fault resistance of 250 ohm/volt (50% below the response value).

EV7.1.3 The IMDT may be repeated at any time during the event. After the car passes the test for the first time, critical parts of the tractive system will be sealed. The vehicle is not allowed to take part in any dynamic event if any of the seals are broken until the IMDT is successfully passed again.

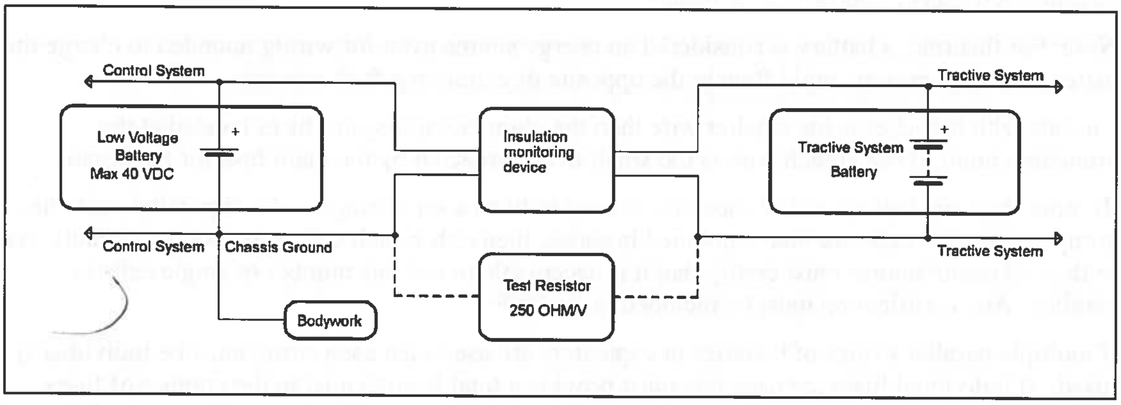

Figure 36 – Insulation Monitoring Device Test

EV7.2 Insulation Measurement Test (IMT)

EV7.2.1 The insulation resistance between the tractive system and control system ground will be measured during Electrical Tech Inspection. The available measurement voltages are 250 V and 500 V. All cars with a maximum nominal operation voltage below 300 V will be measured with the next available voltage level. For example, a 175 V system will be measured with 250 V; a 300 V system will be measured with 500 V etc.

EV7.2.2 To pass the IMT the measured insulation resistance must be at least 500 ohm/volt related to the maximum nominal tractive system operation voltage.

EV7.3 Rain test

EV7.3.1 Upon passing the rain test a vehicle will receive a "Rain Certified" sticker and may be operated in damp or wet conditions. See: **ARTICLE D3**

If the vehicle does not pass the rain test, or if the team chooses to forego the rain test, then the vehicle is not rain certified and will not be allowed to operate in damp or wet conditions.

EV7.3.2 During the rain test the tractive system must be active and none of the driven wheels may touch the ground. It is not allowed to have a driver seated in the car during the rain test.

EV7.3.3 Water will then be sprayed at the car from any possible direction for 120 seconds. The water spray will be rain like. Therefore there will be no direct high-pressure water jet shot at the car.

EV7.3.4 The test is passed if the insulation monitoring device does not react while water is sprayed at the car and 120 seconds after the water spray has stopped. Therefore the total time of the rain test is 240 seconds, 120 seconds with water-spray and 120 seconds without.

EV7.3.5 Teams must make sure that water cannot aggregate anywhere in the chassis.

ARTICLE EV8 HIGH VOLTAGE PROCEDURES & TOOLS

EV8.1 Working on Tractive System Accumulator Containers

EV8.1.1 If the organizers have provided a "Designated Charging Area", then opening of or working on accumulator containers is only allowed in that charging area, see **EV8.2**, and during Electrical Tech Inspection.

EV8.1.2 Whenever the accumulator containers are opened the accumulator segments must be separated by using the maintenance plugs; see **EV3.4.3**.

EV8.1.3 Whenever the accumulator or tractive system is being worked on, only appropriate insulated tools may be used.

EV8.1.4 Whenever the accumulator or tractive system is open or being worked on, a "Danger High Voltage" sign (or other warning device provided by the organizers) must be displayed.

Note: Be sure to remove the warning sign or indicator once the hazards are no longer present.

EV8.2 Charging

EV8.2.1 If the organizers have provided a "Designated Charging Area", then charging tractive system accumulators is only allowed inside this area.

EV8.2.2 The chassis or frame of the vehicle must be securely connected to earth ground using a (minimum) 16 AWG green wire during charging.

Note: Earth ground can be a water pipe or metal electrical conduit permanently installed at the competition site.

EV8.2.3 If the organizers have provided "High Voltage" signs and/or beacons these must be displayed prominently while charging.

EV8.2.4 The accumulators may be charged inside the vehicle or outside, if fitted with a removable accumulator container.

EV8.2.5 In addition to the requirement in **EV8.2.9**, the accumulator containers or the car itself, depending on whether the accumulators are charged externally or internally, must have a label with the following data during charging:

(a) Team name

(b) RSO Name with cell phone number(s).

EV8.2.6 Only chargers presented and sealed at Electrical Tech Inspection are allowed. All connections of the charger(s) must be isolated and covered. No open connections are allowed.

EV8.2.7 No work is allowed on any of the car's systems during charging if the accumulators are charging inside of or connected to the car.

EV8.2.8 No grinding, drilling, or any other activity that could produce either sparks or conductive debris. is allowed in the charging area.

EV8.2.9 At least one team member who has knowledge of the charging process must stay with the accumulator(s) / car during charging.

EV8.2.10 Moving accumulator cells and/or stack(s) around at the event site is only allowed inside a completely closed accumulator container.

EV8.2.11 High Voltage wiring in an off board charger does not require conduit; however it must be a UL listed flexible cable that complies with NEC Article 400; jacketed.

EV8.2.12 All chargers must be UL (Underwriters Laboratories) listed. Any waivers of this requirement require approval in advance, based on documentation of the safe design and construction of the system, including galvanic isolation between the input and output of the charger. Waivers for chargers must be submitted at least 30 days prior to the start of the competition.

EV8.2.13 The vehicle charging connection must be appropriately fused for the rating of its connector and cabling in accordance with **EV6.1.1**.

EV8.2.14 The charging port shall only be energized when the tractive system is energized and the TSEL is flashing.

There shall be no voltage present on the charging port when the tractive system is de-energized.

The external charging system shall be disconnected if there is an AMS or IMD fault, or if one of the shutdown buttons (See **EV5.5**) is pressed.

EV8.3 Accumulator Container Hand Cart

EV8.3.1 In case removable accumulator containers are used in order to accommodate charging, a hand cart to transport the accumulators must be presented at Electrical Tech Inspection.

EV8.3.2 The hand cart must have a brake such that it can only be released using a dead man's switch, i.e. the brake is always on except when someone releases it by pushing a handle for example.

EV8.3.3 The brake must be capable to stop the fully loaded accumulator container hand cart.

EV8.3.4 The hand cart must be able to carry the load of the accumulator container(s).

EV8.3.5 The hand cart(s) must be used whenever the accumulator container(s) are transported on the event site.

EV8.4 Required Equipment

Each team must have the following equipment accessible at all times during the event. The equipment must be in good condition, and must be presented during technical inspection. (See also **Appendix F**)

(a) Multimeter rated for CAT III use with UL approval. (Must accept shrouded banana leads.)

(b) Multimeter leads with shrouded banana leads at one end and probes at the other end. The probes must have finger guards and no more than 3 mm of exposed metal. (Heat shrink tubing may be used to cover additional exposed metal on probes.)

(c) At least one pair of leads with shrouded banana plugs at both ends.

(d) Insulated tools. (I.e. screwdrivers, wrenches etc. compatible with all fasteners used inside the accumulator housing or on other TSV connections.)

(e) Face shield which meets ANSI Z87.1-2003

(f) HV insulating gloves (tested within the last14 Months) plus protective outer gloves.

(g) HV insulating blankets of sufficient size and quantity to cover the vehicle's accumulator(s).

(h) Safety glasses with side shields (ANSI Z87.1-2003 compliant) for all team members.

Note: All electrical safety items must be rated for at least the maximum tractive system voltage.

ARTICLE EV9 ELECTRICAL SYSTEM FORM AND FMEA

EV9.1 Electrical System Form (ESF)

EV9.1.1 All teams must submit clearly structured documentation, prior to the posted deadline, of their entire electrical system (including control and tractive system) called the Electrical System Form (ESF).

EV9.1.2 The ESF must illustrate the interconnection of all electric components including the voltage level, the topology, the wiring in the car and the construction and build of the accumulator(s).

EV9.1.3 Teams must present data pages with rated specifications for all tractive system parts used and show that none of these ratings are exceeded (including wiring components). This includes stress caused by the environment e.g. high temperatures, vibration, etc.

EV9.1.4 MSDS Sheets must be included for the accumulator cells.

EV9.1.5 A template containing the required structure for the ESF will be made available online.

EV9.1.6 The ESF must be submitted as an Adobe PDF file.

EV9.2 Failure Modes and Effects Analysis (FMEA)

EV9.2.1 Teams must submit a complete failure modes and effects analysis (FMEA) of the tractive system prior to the event.

EV9.2.2 A template including required failures to be described will be made available online.

Note: Do not change the format of the template. Pictures, schematics and data sheets to be referenced in the FMEA must be included in the ESF.