CV Internal Combustion Engine Vehicles

CV 1 Internal Combustion Engine Powertrains

CV 1.1 Engine Limitation

CV 1.1.1 The engine(s) used to power the vehicle must be piston engine(s) using a four-stroke primary heat cycle with a displacement not exceeding 710 cm^3 per cycle. Hybrid powertrains must use a purely electrical energy storage.

CV 1.2 Starter

CV 1.2.1 Each vehicle must be equipped with an on-board starter, which must be used to start the vehicle.

CV 1.2.2 For autonomous operation, the vehicle must be equipped with an additional engine start button next to the LVMS, see T 11.3, that can be easily actuated from outside the vehicle. Using the external engine start button, the engine may only start if

- the ASMS, see T 14.5, is switched on and
- the gearbox is in neutral.

CV 1.2.3 If CV 1.2.2 requires an additional engine start button, there must be a green light next to it, that indicates that the gearbox is in neutral. It must be marked with the letter "N". This letter must have a minimum height of 25 mm.

CV 1.2.4 The AS must not be able to (re-)start the engine.

CV 1.3 Air Intake System

CV 1.3.1 All parts of the engine air and fuel control systems (including the throttle and the complete air intake system, including the air filter and any air boxes) must lie within the surface envelope, see T 1.1.18.

CV 1.3.2 Any portion of the air intake system that is less than 350 mm above the ground must be protected from impacts, see T 3.14. Impact protection must follow T 3.15 when having bolted attachments.

CV 1.3.3 The intake manifold must be securely attached to the engine block or cylinder head with brackets and mechanical fasteners. The threaded fasteners used to secure the intake manifold are considered critical fasteners and must comply with T 10. Rubber bushings or hoses are not considered as securely attached.

CV 1.3.4 Intake systems with significant mass or cantilever from the cylinder head must be supported to prevent stress to the intake system resulting from engine movement and chassis torsion.

CV 1.4 Throttle

CV 1.4.1 The vehicle must be equipped with a throttle body. The throttle body may be of any size or design.

CV 1.4.2 The throttle must be actuated mechanically by a foot pedal, i.e. via a cable or a rod system, see CV 1.5, or by an Electronic Throttle Control (ETC) system, see CV 1.6.

CV 1.4.3 Throttle position is defined as percentage of travel from fully closed to fully open where 0 % is fully closed and 100 % is fully open. The idle position is the average position of the throttle body while the engine is idling.

CV 1.4.4 The throttle system mechanism must be protected from debris ingress to prevent jamming.

CV 1.5 Mechanical Throttle Actuation

CV 1.5.1 CV 1.5 can only be used if no AS is used.

CV 1.5.2 The throttle actuation system must use at least two return springs located at the throttle body, so that the failure of any one of the two springs will not prevent the throttle returning to the idle position.

CV 1.5.3 Each return spring must be capable of returning the throttle to the idle position with the other disconnected.

CV 1.5.4 Springs in the Throttle Position Sensor (TPS) are not allowed as return springs.

CV 1.5.5 Throttle cables must be located at least 50 mm from any exhaust system component and out of the exhaust stream.

CV 1.5.6 Throttle cables or rods must have smooth operation and must not have the possibility of binding or sticking. They must be protected from being bent or kinked by the driver's foot during operation or when entering the vehicle.

CV 1.5.7 A positive pedal stop must be incorporated on the accelerator pedal to prevent over-stressing the throttle cable or actuation system.

CV 1.6 Electronic Throttle Control

CV 1.6.1 CV 1.6 only applies if ETC is used.

CV 1.6.2 The team must be able to demonstrate the functionality of all safety features and error detections of the ETC system at technical inspection, see IN.

CV 1.6.3 The ETC system must be equipped with at least the following sensors:

- Accelerator Pedal Position Sensors (APPSs) as defined in T 11.8.
- Two Throttle Position Sensors (TPSs) to measure the throttle position.

CV 1.6.4 All ETC signals are SCS, see T 11.9.

CV 1.6.5 When power is removed, the electronic throttle must immediately close at least to idle position ±5 %. An interval of one second is allowed for the throttle to close to idle, failure to achieve this within the required interval must result in immediate disabling of power to ignition, fuel injectors and fuel pump. This action must remain active until the TPS signals indicate the throttle has returned to idle position ±5 % for at least one second.

CV 1.6.6 If plausibility does not occur between the values of at least two TPSs and this persists for more than 100 ms, the power to the electronic throttle must be immediately shut down. Plausibility is defined as a deviation of less than ten percentage points between the sensor values as defined in CV 1.4.3 and no detected failures as defined in T 11.9.

AS must check this signal consistency on a low level itself.

CV 1.6.7 The electronic throttle must use at least two sources of energy capable of returning the throttle to the closed position. One of the sources may be the device that normally actuates the throttle, e.g. a DC motor, but the other device(s) must be a return spring that can return the throttle to the idle position in the event of a loss of actuator power.

CV 1.6.8 Springs in the TPSs are not acceptable as return springs.

CV 1.6.9 The power to the electronic throttle must be immediately shut down, as defined in CV 1.6.5, if the throttle position differs by more than 10 % from the expected target TPS position for more than 500 ms.

CV 1.7 Intake System Restrictor

CV 1.7.1 In order to limit the power capability from the engine(s), a single circular restrictor must be placed in the intake system and all engine(s) airflow must pass through this restrictor. The only allowed sequence of components are the following:

- For naturally aspirated engines, the sequence must be: throttle body, restrictor, and engine, see figure 16
- For turbocharged or supercharged engines, the sequence must be: restrictor, compressor, throttle body, engine, see figure 17

CV 1.7.2 The maximum restrictor diameters which must be respected at all times during the competition are:

- Gasoline fueled vehicles - 20 mm
- E 85 fueled vehicles - 19 mm

CV 1.7.3 The restrictor must be located to facilitate measurement during the inspection process.

CV 1.7.4 The circular restricting cross section must not be movable or flexible in any way, e.g. the restrictor must not be part of the movable portion of a barrel throttle body.

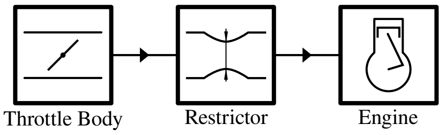

Figure 16: Intake configuration for naturally aspirated engines.

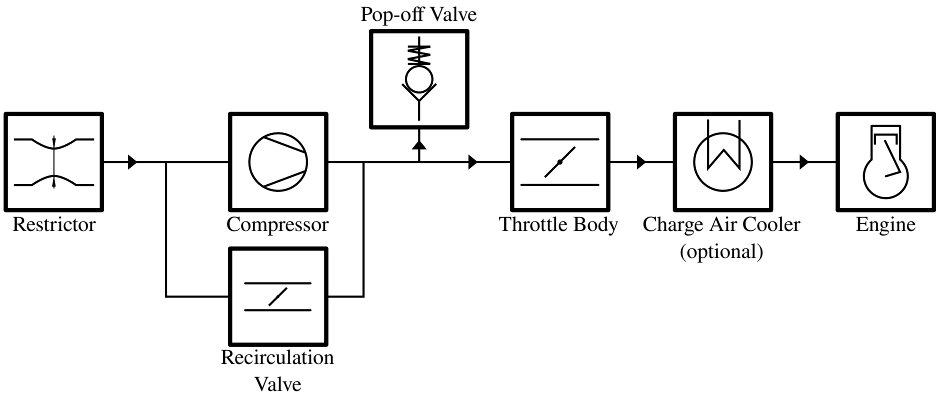

Figure 17: Intake configuration for turbocharged or supercharged engines.

CV 1.8 Turbochargers and Superchargers

CV 1.8.1 The intake air may be cooled with an intercooler. Only ambient air may be used to remove heat from the intercooler system. Air-to-air and water-to air intercoolers are allowed. The coolant of a water-to-air intercooler system must be plain water without any additives.

CV 1.8.2 If pop-off valves, recirculation valves, or heat exchangers (intercoolers) are used, they may only be positioned in the intake system as shown in Figure 17.

CV 1.8.3 Plenums anywhere upstream of the throttle body are prohibited. A “plenum” is any tank or volume that is a significant enlargement of the normal intake runner system.

CV 1.8.4 The maximum allowable internal diameter of the intake runner system between the restrictor and throttle body is 60 mm diameter, or the equivalent area of 2827 mm^2 if non-circular.

CV 1.9 Crankcase / Engine Lubrication Venting

CV 1.9.1 Any crankcase or engine lubrication vent lines routed to the intake system must be connected upstream of the intake system restrictor.

CV 1.9.2 Crankcase breathers that pass through the oil catch tank(s) to exhaust systems, or vacuum devices that connect directly to the exhaust system, are prohibited.

CV 2 FUEL AND FUEL SYSTEM

CV 2.1 Fuel

CV 2.1.1 The available fuel types will be unleaded gasoline 98RON and E 85.

CV 2.1.2 The vehicles must be operated with the fuel provided at the competition.

CV 2.1.3 No agents other than fuel and air may be induced into the combustion chamber.

CV 2.1.4 The temperature of fuel introduced into the fuel system must not be changed with the intent to improve calculated efficiency.

CV 2.2 Fuel System Location Requirements

CV 2.2.1 The fuel tank must be located within the rollover protection envelope, see T 1.1.16, except the fuel filler neck if it is 350mm above the ground.

CV 2.2.2 All parts of the fuel storage and supply system must lie within the surface envelope, see T 1.1.18.

CV 2.2.3 All parts of the fuel storage and supply system must be adequately protected against any heat sources and located at least 50 mm from any exhaust system component.

CV 2.2.4 All parts of the fuel system which can come in contact with the fuel must be rated for permanent contact with fuel.

CV 2.3 Fuel Tank

CV 2.3.1 The fuel tank is defined as the part of the fuel containment device that is in contact with the fuel. It may be made of a rigid material or a flexible material.

CV 2.3.2 The fuel tank must be securely attached to the vehicle structure with mountings that allow some flexibility such that chassis flex cannot unintentionally load the fuel tank.

CV 2.3.3 The fuel tank must not touch any part of the vehicle other than its mounting and parts of the fuel system at any time.

CV 2.3.4 Any fuel tank that is made from a flexible material, for example a bladder fuel cell or a bag tank, must be enclosed within a rigid fuel tank container which is securely attached to the vehicle structure. Fuel tank containers (containing a bladder fuel cell or bag tank) may be load carrying.

CV 2.3.5 The fuel system must have a provision for emptying the fuel tank if required.

CV 2.3.6 The fuel tank, by design, must not have a variable capacity.

CV 2.4 Fuel Lines for Low Pressure Systems

CV 2.4.1 Fuel lines between fuel tank and fuel rail and return lines must:

- have reinforced rubber fuel lines with an abrasion protection with a fuel hose clamp which has a full 360° wrap, a nut and bolt system for tightening and rolled edges to prevent the clamp cutting into the hose, or
- have metal braided hoses with crimped-on or reusable, threaded fittings.
- be rated for temperatures of at least 120 °C.

CV 2.4.2 The use of unmodified OEM fuel lines and connectors, including those manufactured from plastic, is acceptable.

CV 2.4.3 For reinforced rubber fuel lines with hose & clamp style connections beaded or barbed hose fittings must be used.

CV 2.4.4 Fuel lines must be securely attached to the vehicle and/or engine.

CV 2.4.5 All fuel lines must be shielded from possible rotating equipment failure or collision damage.

CV 2.4.6 All fuel lines must be fitted in such a way that any leakage cannot result in the accumulation of fuel in the cockpit.

CV 2.5 Fuel Injection System Requirements

Low Pressure Injection (LPI) fuel systems are those functioning at a pressure below 10 bar and High Pressure Injection (HPI) fuel systems are those functioning at 10 bar pressure or above. Direct Injection (DI) fuel systems are those where the injection occurs directly into the combustion chamber.

CV 2.5.1 The following requirements apply to LPI fuel systems:

- The fuel lines must comply with CV 2.4.
- The fuel rail must be securely attached to the engine cylinder block, cylinder head, or intake manifold with mechanical fasteners. The threaded fasteners used to secure the fuel rail are considered critical fasteners and must comply with T 10.
- The use of fuel rails made from plastic, carbon fiber or rapid prototyping flammable materials is prohibited. However, the use of unmodified OEM Fuel Rails manufactured from these materials is acceptable.

CV 2.5.2 The following requirements apply to HPI and DI fuel systems:

- All high pressure fuel lines must be stainless steel rigid line or Aeroquip FC807 smooth bore PTFE hose with stainless steel reinforcement and visible Nomex tracer yarn. Use of elastomeric seals is prohibited. Lines must be rigidly connected every 100 mm by mechanical fasteners to structural engine components.
- The fuel rail must be securely attached to the engine cylinder head with mechanical fasteners. The fastening method must be sufficient to hold the fuel rail in place with the maximum regulated pressure acting on the injector internals and neglecting any assistance from in-cylinder pressure acting on the injector tip. The threaded fasteners used to secure the fuel rail are considered critical fasteners and must comply with T 10.
- The fuel pump must be rigidly mounted to structural engine components.
- A fuel pressure regulator must be fitted between the high and low pressure sides of the fuel system in parallel with the DI boost pump. The external regulator must be used even if the DI boost pump comes equipped with an internal regulator.
- Before the tilt test specified in IN 7, engines fitted with mechanically actuated fuel pumps must be run to fill and pressure the system downstream of the high pressure pump.

CV 2.6 Fuel Tank Filler Neck and Sight Tube

CV 2.6.1 The fuel tank must have a filler neck which:

- has at least an inner diameter of 35 mm at any point between the fuel tank and the top of the fuel filler cap.
- is accompanied by a clear fuel resistant sight tube above the top of the fuel tank with a length of at least 125 mm vertical height for reading the fuel level, see figure 18.
- is made of material that is permanently rated for temperatures of at least 120 °C.

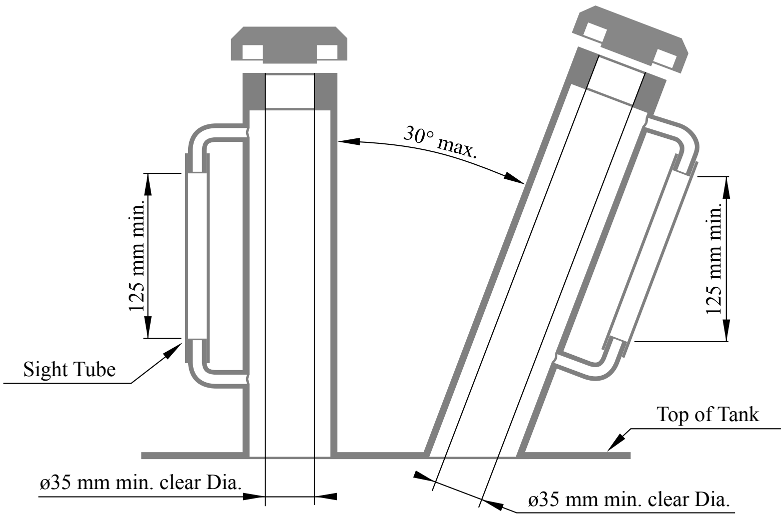

Figure 18: Minimum requirements fuel tank filler neck.

CV 2.6.2 A clear filler neck tube may be used as a sight tube.

CV 2.6.3 Above the lowest point of the sight tube, the filler neck must not be angled more than 30° from the vertical.

CV 2.6.4 A permanent, non-movable, clear and easily visible fuel level line must be located between 12 mm and 25 mm below the top of the visible portion of the sight tube. This line will be used as the fill line for the tilt test, see IN 7.1, and before and after the endurance test to measure the amount of fuel used during the endurance event.

CV 2.6.5 The filler neck opening must be directly accessible without removing any parts of the vehicle except for the fuel filler cap.

CV 2.6.6 The filler neck must have a fuel filler cap that can withstand severe vibrations or high pressures such as could occur during a vehicle rollover event.

CV 2.7 Tank Filling Requirement

CV 2.7.1 The fuel tank must be capable of being filled to capacity without manipulating the tank or the vehicle in any manner. The fuel system must be designed in a way that during refueling of the vehicle on a level surface, the formation of air cavities or other effects that cause the fuel level observed at the sight tube to drop after movement or operation of the vehicle (other than due to consumption) is prevented.

CV 2.7.2 The fuel system must be designed such that the spillage during refueling cannot contact the driver position, exhaust system, hot engine parts, or the ignition system.

CV 2.8 Venting Systems

CV 2.8.1 The fuel tank venting systems must be designed such that fuel cannot spill during hard cornering or acceleration.

CV 2.8.2 All fuel vent lines must be equipped with a check valve to prevent fuel leakage when the tank is inverted. All fuel vent lines must exit outside the bodywork.

CV 3 EXHAUST SYSTEM AND NOISE CONTROL

CV 3.1 Exhaust System General

CV 3.1.1 The exhaust outlet must be routed to the side or rear of the vehicle and so that the driver is not subjected to fumes at any speed considering the draft of the vehicle.

CV 3.1.2 The exhaust outlet(s) must not extend more than 450 mm behind the centerline of the rear axle and must be no more than 600 mm above the ground.

CV 3.1.3 Any exhaust components (headers, mufflers, etc.) that protrude from the side of the chassis in front of the rear axle must be shielded to prevent contact by persons approaching the vehicle or a driver exiting the vehicle. The temperature of the outer surface must not be harmful to a person touching it.

CV 3.1.4 The application of fibrous/absorbent material, e.g. “headerwrap”, to the outside of an exhaust manifold or exhaust system is prohibited.

CV 3.2 Maximum Sound Level

CV 3.2.1 The maximum sound level test speed for a given engine will be the engine speed that corresponds to an average piston speed of 15.25 m/s. The calculated speed will be rounded to the nearest 500 rpm. The maximum allowed sound level up to this calculated speed is 110 dB(C), fast weighting.

CV 3.2.2 The idle test speed for a given engine will be up to the team and determined by their calibrated idle speed. If the idle speed varies then the vehicle will be tested across the range of idle speeds determined by the team. At idle the maximum allowed sound level is 103 dB(C), fast weighting.

CV 4 SHUTDOWN SYSTEM

CV 4.1 Shutdown Circuit

CV 4.1.1 The Shutdown Circuit (SDC) directly controls all electric power to the ignition, fuel injectors and all fuel pumps. It must act through a minimum of two mechanical relays. One relay for the fuel pump and at least one relay for injection and ignition.

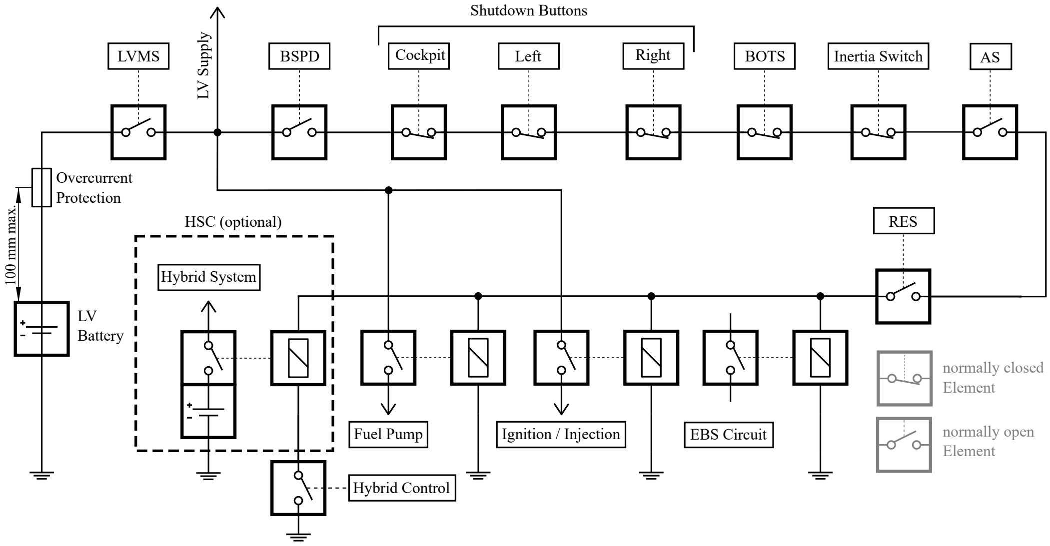

Figure 19: Explanatory example schematic of the required Shutdown Circuit (SDC)

An explanatory schematic of the required SDC, is shown in Figure 19.

CV 4.1.2 The SDC is defined as a series connection of at least the LVMS, see T 11.3, the BSPD, see T 11.6, three shutdown buttons, see T 11.4, the BOTS, see T 6.2 and the inertia switch, see T 11.5.

CV 4.1.3 All circuits that are part of the SDC must be designed in a way, that in the de-energized/disconnected state they open the SDC.

CV 4.1.4 [HY ONLY] The HSC AIR as per CV 5.2.2 must be part of the SDC in such a way that one side of the relay coil is directly incorporated into the SDC and the other side is controlled by the hybrid control system.

CV 5 HYBRID SYSTEM

CV 5.1 Hybrid System General

CV 5.1.1 Hybrid System – the hybrid storage container, motors and every part that is electrically connected to them.

CV 5.1.2 The hybrid system must be a LVS, T 11.1 and T 11.7 are applied for all hybrid system components.

CV 5.1.3 All electrical parts of the hybrid system except for ground terminals must be covered at least according to IPxxB when energized.

CV 5.1.4 Hybrid Storage Container (HSC) – the electric energy storage system, including the AIR and overcurrent protection, that is used in the hybrid system.

CV 5.1.5 Moving energy into the Hybrid Storage Container (HSC) from a different electric storage system is prohibited during any dynamic event.

CV 5.1.6 A firewall, see T 4.8, must be present between the HSC and the fuel tank.

CV 5.1.7 The HSC must be positioned according to T 11.7.2, all other hybrid system components must be positioned within the surface envelope, see T 1.1.18.

CV 5.1.8 The high current path, see EV 1.2.2, of the hybrid system must meet EV 4.5.15.

CV 5.1.9 Motors must meet EV 2.1.

CV 5.1.10 The hybrid system may only be activated when the combustion engine is running or during engine start.

CV 5.2 Hybrid Storage Container

CV 5.2.1 The HSC must be attached to the primary structure, see T 1.1.12, according to T 9.3.1.

CV 5.2.2 A disconnection mechanism, designed as an AIR must be integrated inside of the HSC, disconnecting the positive pole of the HSC. The AIR must be compliant with EV 5.6.3.

CV 5.2.3 The maximum total weight of all elements in the hybrid system that store the electric energy, e.g. battery cells or supercapacitors, including all casings and tabs that are integral to them, is 3 kg.

CV 5.2.4 Holes, both internal and external, in the HSC, are only allowed for the wiring harness, ventilation, cooling, or fasteners. The total cutout area must be below 25 % of the area of the respective single wall.

CV 5.2.5 The HSC must be removable to be inspected at the mechanical inspection and it must be possible to easily check the weight limit.

CV 5.3 Hybrid System Form

CV 5.3.1 A Hybrid System Form (HSF) has to be submitted using the HSF template.

CV 5.3.2 The HSF template will be available on the competition website.

CV 5.3.3 If no HSF is submitted, the team must not use the hybrid system at the competition. A 5.4.2 will not be applied for the HSF.

EV ELECTRIC VEHICLES

EV 1 DEFINITIONS

EV 1.1 Tractive System

EV 1.1.1 Tractive System (TS) – every part that is electrically connected to the motors and TS accumulators. The LVS may be supplied by the TS if a galvanic isolation between both systems is ensured.

EV 1.1.2 TS enclosures – every housing or enclosure that contains parts of the TS.

EV 1.2 Electrical

EV 1.2.1 Galvanic Isolation – two electric circuits are defined as galvanically isolated if all of the following conditions are true:

- The resistance between both circuits is $\geq 500\,\Omega/\mathrm{V}$, related to the maximum TS voltage of the vehicle, at a test voltage of maximum TS voltage or 250 V, whichever is higher.
- The isolation test voltage RMS, AC for 1 min, between both circuits is higher than three times the maximum TS voltage or 750 V, whichever is higher.
- The working voltage of the isolation barrier, if specified in the datasheet, is higher than the maximum TS voltage.

Capacitors that bridge galvanic isolation must be class-Y capacitors.

EV 1.2.2 High Current Path – any path of a circuitry that, during normal operation, carries more than 1 A.

EV 2 ELECTRIC POWERTRAIN

EV 2.1 Motors

EV 2.1.1 Only electric motors are allowed.

EV 2.1.2 Motor attachments must follow T 10.

EV 2.1.3 Motor casings must follow T 7.3.

EV 2.1.4 The motor(s) must be connected to the TS accumulator through a motor controller.

EV 2.2 Power Limitation

EV 2.2.1 The TS power at the outlet of the TSAC must not exceed 80 kW.

EV 2.2.2 Regenerating energy is allowed and unrestricted.

EV 2.2.3 Wheels must not be spun in reverse.

EV 3 GENERAL REQUIREMENTS

EV 3.1 Grounding

EV 3.1.1 TS enclosures, see EV 1.1.2, must consist of either

- a grounded solid layer made of at least 0.5 mm thick electrically conductive material, aluminium or better, see EV 3.1.3 or
- be fully made out of electrically insulating materials having an isolation resistance of at least 2 MΩ, measured with a voltage of 500 V. The TS enclosure must be rigid and must prevent possible mechanical penetrations. Protruding electrically conductive parts, such as fasteners or connectors, must follow EV 3.1.2

The TSAC might use at least 0.9 mm thick steel layer as the grounded layer.

EV 3.1.2 Electrically conductive seat, driver harness, and firewall mounting points as well as the aluminium layer of the TS firewall, see T 4.8, and the LVS ground measuring point, see EV 4.7.8, must be grounded, see EV 3.1.3.

EV 3.1.3 An electrically conductive part is grounded if its resistance to LVS ground is below 100 mΩ, measured with a current of 1 A, and the grounding wire is able to continuously carry at least 10 % of the TS accumulator main fuse current rating.

EV 3.1.4 Parts of the vehicle which are or may become electrically conductive within 100 mm of any TS component must have a resistance below 100 Ω to LVS ground.

EV 3.1.5 The rotating part of the wheels does not need to be grounded.

EV 3.2 Overcurrent Protection

EV 3.2.1 All electric systems must have appropriate overcurrent protection.

EV 3.2.2 The continuous current rating of the overcurrent protection must not be greater than the continuous current rating of any electric component, for example, wire, busbar, or other conductors that it protects. I.e. if multiple pins of a connector are used to carry currents in parallel, each pin must be appropriately protected.

EV 3.2.3 All used fuses must have an interrupt current rating that is higher than the theoretical short circuit current of the system that it protects.

EV 3.2.4 All overcurrent protection devices must be rated for the highest voltage in the systems they protect. All devices used must be rated for DC.

EV 3.2.5 All overcurrent protection devices that are part of the TS must not rely on programmable logic. The overcurrent protection function of motor controllers/inverters for the motor outputs may rely on programmable logic.

EV 3.2.6 The overcurrent protection must be designed for the expected surrounding temperature range but at least for 0 °C to 85 °C

EV 3.2.7 The TS high current path, see EV 1.2.2, through the TS accumulator(s) must be fused.

EV 4 TRACTIVE SYSTEM

EV 4.1 General Requirements

EV 4.1.1 The maximum allowed voltage that may occur between any two electric connections is 600 V DC and for motor controller and Accumulator Management System (AMS) internal low power control signals 630 V DC.

EV 4.1.2 All components in the TS must be rated for the maximum TS voltage.

The TS area of a PCB, see EV 4.3.6, is considered as one component. Every input connected to the TS must be rated to the maximum TS voltage.

EV 4.1.3 All components must be rated for the maximum possible temperature that may occur during usage.

EV 4.2 Tractive System Enclosures

EV 4.2.1 TS enclosures, see EV 1.1.2, must be labeled with reasonably sized stickers according to "ISO 7010-W012" (triangle with a black lightning bolt on a yellow background). The sticker must also contain the text "High Voltage" if the voltage is more than 60 V DC or 50 V AC RMS.

EV 4.3 Separation of Traction System and Grounded Low Voltage System

EV 4.3.1 The entire TS and LVS must be galvanically isolated, see EV 1.2.1 and IN 4.1.1.

EV 4.3.2 All connections from a TS component to external devices, such as laptops must include galvanic isolation, see EV 1.2.1.

EV 4.3.3 TS and LVS circuits must be physically segregated such that they are not running through the same conduit or connector, except for interlock circuit connections.

EV 4.3.4 Where both TS and LVS are present within an TS enclosure, they must be separated by barriers made of moisture-resistant insulating materials or maintain 20 mm spacing through air, or over a surface.

EV 4.3.5 Components and cables capable of movement must be positively restrained to maintain spacing.

EV 4.3.6 If TS and LVS are on the same PCB, they must be on separate well-defined areas of the board, meeting the spacing requirements in table 5, each area clearly marked with "TS" or "LV". The outline of the area required for spacing must be marked.

Groves and cut-outs must have a minimum width of 1.5 mm to influence the creepage path. "Conformal coating" refers to a coating insulator on a PCB. Solder resist is not a coating.

EV 4.3.7 Teams must be prepared to demonstrate spacing on team-built equipment. For inaccessible circuitry, fully assembled spare boards must be available.

Voltage	Clearance Distance	Creepage Distance	
		General	conformal coating
0 V DC to 50 V DC	1.0 mm	4 mm	1.0 mm
50 V DC to 150 V DC	1.0 mm	5 mm	1.0 mm
150 V DC to 300 V DC	1.5 mm	10 mm	2.0 mm
300 V DC to 600 V DC	3.0 mm	20 mm	4.0 mm

Table 5: Spacing required between TS and LV.

EV 4.4 Positioning of Tractive System Parts

EV 4.4.1 Except what is allowed according to EV 4.4.3, all parts belonging to the TS including cables and wiring must be located within the rollover protection envelope, see T 1.1.16. “Part” is the whole device such as the complete HVD.

EV 4.4.2 Any part of the TS that is less than 350 mm above the ground, except what is allowed according to EV 4.4.3, must be protected from impacts, see T 3.14. Impact protection must follow T 3.15 when having bolted attachments. TS wiring in front of the front hoop may alternatively be shielded by the front bulkhead support structure according to T 3.13.

EV 4.4.3 Outboard wheel motors are allowed only if

- an interlock is routed along the TS wiring such that the SDC, see EV 6, is opened before the TS wiring or its clamping fails
- an interlock is routed along a suspension member such that the SDC, see EV 6, is opened if the suspension fails
- TS wiring is not able to reach the cockpit opening or the driver regardless of where it breaks
- wiring outside of the rollover protection envelope, see T 1.1.16 is minimum length
- wiring outside of an impact structure or front bulkhead support structure, see EV 4.4.2, is minimum length
- Minimum length is the shortest distance plus extra wiring caused by bending radius.

EV 4.5 Tractive System Insulation, Wiring, and Conduit

EV 4.5.1 All live parts of the TS must be protected from being touched. This must include team members working on or inside the vehicle. This is tested with a 100 mm long, 6 mm diameter insulated test probe when the TS enclosures are in place.

EV 4.5.2 Insulation material that is rated for the maximum TS voltage must be used. Using only insulating tape or rubber-like paint for insulation is prohibited.

EV 4.5.3 The temperature rating for TS wiring, connections, and insulation must be appropriate for the expected surrounding temperatures but at least 85 °C.

EV 4.5.4 TS components and TS enclosures must be protected from moisture in the form of rain or puddles, see IN 9.

EV 4.5.5 It must be possible to clearly assign and prove the wire gauge, temperature rating, and insulation voltage to each used TS wire.

EV 4.5.6 All TS wiring must be completed to professional standards with appropriately sized conductors and terminals and with adequate strain relief and protection from loosening due to vibration etc.

EV 4.5.7 TS wiring must be located out of the way of possible snagging or damage.

EV 4.5.8 All TS wiring that runs outside of TS enclosures must:

- Be enclosed in separate orange non-conductive conduit or use an orange shielded cable. The conduit must be securely anchored to the vehicle, but not to the wire, at least at each end.
- Be securely anchored at least at each end so that it can withstand a force of 200 N without straining the cable end crimp.

Bodywork is not sufficient to meet this enclosure requirement.

EV 4.5.9 Any shielded TS cable must have the shield grounded.

EV 4.5.10 Every TS connector outside TS enclosures must include a pilot contact/interlock line which is part of the SDC. TS enclosures only used to avoid interlocks are prohibited.

EV 4.5.11 All TS connections must be designed so that they use intentional current paths through conductors such as copper or aluminium and must not rely on steel bolts to be the primary conductor.

EV 4.5.12 All TS connections must not include compressible material such as plastic in the stack-up or as a fastener.

EV 4.5.13 All electric connections, including bolts, nuts, and other fasteners, in the high current path, see EV 1.2.2, of the TS must be secured from unintentional loosening. Fasteners must use positive locking mechanisms, see T 10.2, that are suitable for high temperatures, see EV 4.5.3.

Components, e.g. inverters, certified for automotive use might be allowed without a positive locking feature if connections are completed as recommended by the manufacturers' datasheet and no positive locking is possible.

EV 4.5.14 Teams must be prepared to demonstrate positive locking. For inaccessible connections, appropriate photographs must be available.

EV 4.5.15 Soldered connections in the TS high current path, see EV 1.2.2, are only allowed if all of the following are true:

- connections on PCBs
- the connected devices are not cells or wires
- the devices are additionally mechanically secured against loosening

EV 4.6 Data Logger

EV 4.6.1 A data logger will be provided by the officials and must be inserted during the competition. The data logger measures TS voltage and TS current.

EV 4.6.2 The data logger must be in an easily accessible location so that it is possible to insert, remove, or replace it within 15 min in ready-to-race condition.

EV 4.6.3 The data logger must not be placed within the TSAC.

EV 4.6.4 All current supplying the TS must run through the data logger. The data logger must be inserted in the negative TS supply between the most negative AIR and the inverters.

EV 4.6.5 The TS voltage sense connection of the data logger must be directly connected, see T 1.3.1, to the most positive AIR on the vehicle side.

EV 4.6.6 The specification of the data logger will be available in the competition handbook.

EV 4.7 Tractive System Measuring Point

EV 4.7.1 Two TSMPs must be installed directly next to the master switches, see T 11.2.

EV 4.7.2 The TSMPs must be directly connected, see T 1.3.1, to the intermediate circuit capacitors even if the HVD has been removed or the TS accumulator is disconnected.

EV 4.7.3 4 mm shrouded banana jacks rated for 600 V CAT III or better must be used.

EV 4.7.4 The TSMPs must be marked "TS+" and "TS-" and exclusively mounted on an orange background.

EV 4.7.5 The TSMPs must be protected by a non-conductive cover that can be opened without tools. The cover must always be mechanically linked to the vehicle.

EV 4.7.6 Each TSMP must be secured with a current limiting resistor according to the following table. Fusing the TSMPs is prohibited. The resistor's power rating must be chosen such that they can continuously carry the current if both TSMPs are short-circuited.

Maximum TS Voltage	Resistor Value
Umax $<$200 V DC	5 kΩ
200 V DC <Umax $\leq$400 V DC	10 kΩ
400 V DC <Umax $\leq$600 V DC	15 kΩ

EV 4.7.7 All electric connections needed to connect the TSMP to the intermediate circuit capacitors, including bolts, nuts, and other fasteners, must be secured from unintentional loosening by the use of positive locking mechanisms. Bolted connections must follow T 10.2, soldered connections EV 4.5.15.

EV 4.7.8 Next to the TSMPs an LVS ground measuring point must be installed. A 4 mm black shrouded banana jack must be connected to LVS ground and must be marked "GND".

EV 4.8 High Voltage Disconnect

EV 4.8.1 It must be possible to disconnect at least one pole of the TS accumulator by quickly removing an unobstructed and directly accessible element, fuse, or connector. It must be possible to remove the HVD without removing any bodywork. The HVD must be above 350 mm from the ground. Remote actuation of the HVD through a long handle, rope, or wire is not allowed.

EV 4.8.2 Any ESO must be able to remove the HVD within 10 s when the vehicle is in ready-to-race condition.

EV 4.8.3 A dummy connector or similar may be required to restore the system's isolation, see EV 4.5. The dummy connector must be attached to the push bar, see T 13.1, if not in use.

EV 4.8.4 The HVD must be clearly marked with "HVD".

EV 4.8.5 No tools must be necessary to remove the HVD. An interlock is required, see EV 4.5.10.

EV 4.9 Discharge Circuit

EV 4.9.1 If a discharge circuit is required to meet EV 6.1.5, it must be designed to handle the maximum TS voltage permanently. After three subsequent discharges within 15 s in total, the discharge time specified in EV 6.1.5 may be exceeded. Full discharging functionality must be given after a reasonable time with a deactivated discharge circuit.

EV 4.9.2 The discharge circuit must be wired in a way that it is always active whenever the SDC is open. Furthermore, the discharge circuit must be fail-safe such that it still discharges the intermediate circuit capacitors if the HVD has been removed or the TS accumulator is disconnected.

EV 4.9.3 Fusing of the discharge main current path is prohibited.

EV 4.10 Tractive System Active Light

EV 4.10.1 The vehicles must include a single TSAL that must indicate the TS status. The TSAL must not perform any other functions. A TSAL with multiple LEDs in one housing is allowed.

EV 4.10.2 The TSAL itself must have a red light, flashing continuously with a frequency between 2 Hz and 5 Hz and a duty cycle of 50 %, active if and only if the LVS is active and the voltage across any DC-link capacitor exceeds

- 60 V DC or 50 V AC RMS
- Half the nominal TS voltage

whichever is lower.

EV 4.10.3 The TSAL itself must have a green light, continuously on, active if and only if the LVS is active and ALL of the following conditions are true:

- All AIRs are opened.
- The pre-charge relay, see EV 5.7.2, is opened.
- The voltage at the vehicle side of the AIRs inside the TSAC does not exceed 60 V DC or 50 V AC RMS.

EV 4.10.4 The mentioned voltage detection must be performed inside the respective TS enclosure.

EV 4.10.5 The mentioned states of the relays (opened/closed) are the actual mechanical states. The mechanical state can differ from the intentional state, i.e. if a relay is stuck. Any circuitry detecting the mechanical state must meet EV 5.6.2.

EV 4.10.6 The voltage detection circuit of the red light and the relay state and voltage detection circuit of the green light must be independent. Any plausibility check between both lights is not allowed. A TSAL state with both lights simultaneously active might occur and must not be prevented.

EV 4.10.7 The TSAL must:

- Be located lower than the highest point of the main hoop and including the mounting within the rollover protection envelope, see T 1.1.16.
- Be no lower than 75 mm from the highest point of the main hoop.
- Not be able to contact the driver's helmet in any circumstances.

EV 4.10.8 The entire illuminated surface of the TSAL must be clearly visible:

- Except for angles less than 10° on each side which are blocked by the main hoop.
- From a point 1.60 m vertically from ground level, within 3 m horizontal radius from the TSAL.
- In direct sunlight.

EV 4.10.9 The TSAL and all needed circuitry must be hard-wired electronics. Software control is not allowed.

EV 4.10.10 A green indicator light in the cockpit that is easily visible even in bright sunlight and clearly marked with "TS off" must light up if TSAL green light is on, see EV 4.10.3.

EV 4.10.11 Signals influencing the TSAL and the indicator according to EV 4.10.10 are SCS, see T 11.9. The individual safe state of each of the TSAL lights is off. The TSAL's red light must not be illuminated for a visible check, see T 11.9.6.

EV 4.10.12 The TSAL's red light voltage detection circuit, see EV 4.10.2, does not need to detect an open circuit, as required by T 11.9. A plausibility check must not be implemented.

EV 4.10.13 The TSAL's green light relay state detection circuit, see EV 4.10.3, does not need to detect an open circuit, as required by T 11.9, when the intentional state of the used (auxiliary) contact is opened. A plausibility check against the intentional relay state must be implemented in a way that the TSAL's green light stays off after the open circuit is detectable.

EV 4.10.14 The TSAL's green light voltage detection circuit, see EV 4.10.3, does not need to detect an open circuit, as required by T 11.9, when no voltage is present. A plausibility check against the intentional relay states must be implemented in a way that the TSAL's green light stays off after the open circuit of the TS accumulator voltage detection circuit is detectable.

EV 4.10.15 The latching required by EV 4.10.13 and EV 4.10.14 must not be triggered during normal operation conditions and must only be reset by power cycling the LVS.

EV 4.11 Activating the Tractive System

EV 4.11.1 The TS is active if any of the AIRs or the pre-charge relay is closed.

EV 4.11.2 The driver must be able to activate and deactivate the TS from within the cockpit without the assistance of any other person.

EV 4.11.3 The ASR must be able to activate the TS from outside the vehicle with an external TS activation button in proximity to the TSMS if and only if the ASMS is in “On” position.

EV 4.11.4 Closing the SDC by any part defined in EV 6.1.2 must not (re-)activate the TS. Additional action must be required.

EV 4.11.5 The AS must not be able to (re-)activate the TS.

EV 4.11.6 The vehicle is in Ready-to-drive (R2D) mode as soon as the motors will respond to the input of the APPS.

EV 4.11.7 After the TS has been activated, additional actions must be required by the driver to set the vehicle to R2D mode, e.g. pressing a dedicated start button. The transition to R2D mode must only be possible during the actuation of the mechanical brakes and a simultaneous dedicated additional action.

EV 4.11.8 The R2D mode must be left immediately when the SDC is opened.

EV 4.12 Ready-To-Drive Sound

EV 4.12.1 The vehicle must make a characteristic sound, continuously for at least 1 s and a maximum of 3 s while entering R2D mode.

EV 4.12.2 The sound level must be a minimum of 80 dBA and a maximum of 90 dBA, fast weighting in a radius of 2 m around the vehicle.

EV 4.12.3 The used sound must be easily recognizable. No animal voices, song parts, or sounds that could be interpreted as offensive are allowed.

EV 4.12.4 The vehicle must not make any other sounds similar to the R2D sound.

EV 5 TRACTIVE SYSTEM ENERGY STORAGE

EV 5.1 Definitions

EV 5.1.1 Cell – a battery cell or super-capacitor.

EV 5.1.2 Cell Energy – the maximum cell voltage times the nominal capacity of the used cell.

EV 5.1.3 TS Accumulator – all cells that store the electric energy to be used by the TS as a whole.

EV 5.1.4 Tractive System Accumulator Container (TSAC) – the container itself, which contains the TS accumulator.

EV 5.1.5 TS Accumulator Segments – sub-divisions of the TS accumulator.

EV 5.2 Allowed Tractive System Cells

EV 5.2.1 Molten salt and thermal batteries are prohibited.

EV 5.2.2 Fuel cells are prohibited.

EV 5.3 Tractive System Energy Storage – General Requirements

EV 5.3.1 All cells that store the TS energy must be enclosed in TSACs.

EV 5.3.2 Each TS accumulator segment must not exceed a maximum static voltage of 120 V DC, a maximum energy of 6 MJ, see EV 5.1.2, and a maximum mass of 12 kg.

EV 5.3.3 Spare cells must be stored in an electrically insulated container made of fire retardant material, see T 1.2.1. The container must be labeled according to EV 5.3.7.

EV 5.3.4 Spare accumulators and spare cells must be presented at technical inspection.

EV 5.3.5 It must be possible to open the TSAC for technical inspection.

EV 5.3.6 Each TSAC must be removable from the vehicle while still remaining rules compliant without the need to install extra components. A dummy connector or similar may be used to restore the system's isolation, see EV 4.5.

EV 5.3.7 The vehicle number, the university name, and the ESO phone numbers must be displayed and written in Roman Sans-Serif characters of at least 20 mm high on the lid of each TSAC. The characters must be clearly visible and placed on a high-contrast background.

EV 5.4 Tractive System Energy Storage – Electrical Configuration

EV 5.4.1 If the TSAC is made from an electrically conductive material, the insulation barrier must be adequately protected against conductive penetrations.

EV 5.4.2 Every TSAC must contain at least one fuse and at least two AIRs, see EV 5.6 and EV 3.2.7.

EV 5.4.3 LVS must not be included in the TSAC except where inherently required. Exceptions include the AIRs, TS DC/DC converters, the AMS, the Insulation Monitoring Device (IMD), the TSAL's green light circuitry, and cooling fans.

EV 5.4.4 Maintenance plugs must allow electrical separation of all TS accumulator segments, see EV 5.3.2. The separation must affect both poles of all segments including the first and last segment.

EV 5.4.5 Maintenance plugs must:

- Not require tools to separate the TS accumulator segments.
- Be non-conductive on surfaces that do not provide any electric connection.
- Be designed in a way, that it is physically impossible to electrically connect them in any way other than the design intent configuration.
- Be protected against accidental reconnection.
- Be designed such that it is clearly visible whether the connection is open or closed. Electrically controlled switches must not be used.

EV 5.4.6 Each TS accumulator segment must be electrically insulated by the use of suitable rigid and fire retardant material, see T 1.2.1, on top of the segment to prevent arc flashes caused by inter-segment contact or by parts/tools accidentally falling into the TSAC during maintenance.

EV 5.4.7 Every wire used in a TSAC, regardless of whether it is part of the LVS or TS, must follow EV 4.5.2, EV 4.5.3, and EV 4.5.5.

EV 5.4.8 Each TSAC must have a prominent indicator, a voltmeter, or a red LED visible even in bright sunlight that will continuously illuminate whenever a voltage greater than 60 V DC or half the maximum TS voltage, whichever is lower, is present at the vehicle side of the AIRs.

EV 5.4.9 The indicator must be clearly visible while disconnecting the TSAC from the vehicles. The indicator must be clearly marked with "Voltage Indicator"

EV 5.4.10 The indicator must be hard-wired electronics without software control, directly and only supplied by the TS from the vehicle side of the AIRs, and always working, even if the TS accumulator is disconnected from the LVS or removed from the vehicle.

EV 5.5 Tractive System Energy Storage – Mechanical Configuration

EV 5.5.1 All TSACs must lie within and be attached to the primary structure or any additional structures fixed to the primary structure that meet the minimum specification for impact structures, see T 3.2, no higher than the top of the impact structure, see T 3.14.

EV 5.5.2 TSACs must be protected from impacts, see T 3.14. Impact protection must follow T 3.15 when having bolted attachments. The TSAC must not be part of this structure.

EV 5.5.3 All TSAC materials as well as all structural parts used to comply with EV 5.5.8 must be fire retardant, see T 1.2.1. All calculations must be conducted for an ambient temperature of 60 °C except for metallic materials and continuous fiber-reinforced laminates.

EV 5.5.4 The design of the TSAC and its contents, calculations and/or tests must be documented in the ASES. This includes materials used, drawings, images, fastener locations, segment weight, cell, and segment position.

EV 5.5.5 TSACs must be constructed of steel or aluminium. With the following requirements:

- The bottom of the TSAC must be at least 1.25 mm thick if made from steel or 3.2 mm if made from aluminium.
- The internal and external vertical walls, covers, and lids must be at least 0.9 mm thick if made from steel or 2.3 mm if made from aluminium.

Alternative materials are allowed with proof of equivalency per T 3.3 or for composite materials per EV 5.5.6. When alternative materials are used, test samples must be presented at technical inspection.

EV 5.5.6 Composite TSACs must satisfy the following requirements:

- Data obtained from the laminate perimeter shear strength test and three-point bending test, see T 3.5, should be used to prove adequate strength is provided.
- 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.
- The calculations and physical test results must be included in the ASES.

EV 5.5.7 TS accumulator segments, see EV 5.3.2, must be separated by internal vertical walls which extend upwards until the lid. Openings must follow EV 5.5.14.

EV 5.5.8 The TSAC itself, the mounting of the TSAC to the chassis, and the mounting of each cell to the TSAC must be designed to withstand the accelerations according to T 9.3.1. All considered TSAC attachment points must follow EV 5.5.13. TSACs made of materials as stated in EV 5.5.5 or EV 5.5.6 may need further reinforcement to comply with this rule.

EV 5.5.9 Pouch cells must be fixed using one or both of the large surfaces only. Each used surface must be fixed on at least 80 %. Tabs of pouch cells must not carry mechanical loads and must not press into the pouch.

EV 5.5.10 Friction-based cell mounting requires physical testing. Mechanically representative test cells or cell mockups can be used for testing.

EV 5.5.11 All fasteners used within or to mount the TSAC must comply with T 10. Fasteners within the TSAC used for non-structural parts, e.g. PCBs, do not have to follow T 10.1.2. Fasteners made of electrically non-conductive material within the TSAC used for non-structural parts do not have to follow T 10.

EV 5.5.12 The AIRs and the main fuse, see EV 3.2.7, must be separated with an electrically insulated and fire retardant material, see T 1.2.1, from the TS accumulator, see EV 5.1.3. Air is not considered to be a suitable insulation material in this case.

EV 5.5.13 The mounting of the TSAC requires a minimum of 2 attachment points. Any brackets used to mount the TSAC must be made of steel 1.6 mm thick or aluminium 4 mm thick and must have gussets to carry bending loads.

EV 5.5.14 Holes, both internal and external, in the TSAC, are only allowed for the wiring harness, ventilation, cooling, or fasteners. The TSAC must still be compliant with all other rules, especially the ones concerning its structural requirements. The total cutout area must be below 25 % of the area of the respective single wall. External holes must be sealed according to EV 4.5.

EV 5.5.15 External openings in the TSAC or mounted ducts must not point toward the driver or the operator of the TS accumulator hand cart even though there is a firewall, see T 4.8, in between. Ducts and their mounting must be fire retardant, see T 1.2.1, and properly sealed.

EV 5.5.16 A sticker according to “ISO 7010-W012” (triangle with a black lightning bolt on a yellow background) with the triangle side length of at least 100 mm and the text “Always Energized” must be applied on every TSAC. The sticker must also contain the text “High Voltage” if the voltage is more than 60 V DC or 50 V AC RMS.

EV 5.5.17 Any TS accumulators that may vent an explosive gas must have a ventilation system to prevent the vented gas from reaching an explosive concentration.

EV 5.5.18 Every TSAC which is completely sealed must also have a pressure relief valve to prevent high pressure in the TSAC.

EV 5.6 Accumulator Isolation Relays

EV 5.6.1 At least two AIRs must be fitted inside each TSAC.

EV 5.6.2 The AIRs must open both poles of the TS accumulator. If the AIRs are open, no TS voltage may be present outside of the TSAC and the vehicle side of the AIRs must be galvanically isolated from the TS accumulator side, see EV 1.2.1.

EV 5.6.3 The AIRs must be mechanical relays of a “normally open” type.

EV 5.7 Pre-Charge Circuit

EV 5.7.1 A circuit that ensures that the voltage at the vehicle side of the AIRs is pre-charged to at least 95 % of the actual TS accumulator voltage before closing the second AIR must be implemented.

EV 5.7.2 The pre-charge circuit must use a mechanical, normally open relay. All pre-charge current must pass through this relay.

EV 5.8 Accumulator Management System

EV 5.8.1 Each TS accumulator must be monitored by an AMS whenever the LVS is active or the TS accumulator is connected to a charger.

EV 5.8.2 Every TSAC must contain its full AMS including its own and AMS exclusive SDC power stage, see EV 6.1

EV 5.8.3 The AMS must continuously measure

- all cell voltages
- the TS current
- the temperature of thermally critical cells
- for lithium-based cells: the temperature of at least 30 % of the cells equally distributed within the TSAC

EV 5.8.4 Cell temperature must be measured at the negative terminal of the respective cell. The sensor used must be in direct contact with the electrically exposed negative terminal or less than 10 mm along the high current path, see EV 1.2.2, away from the terminal in direct contact with the respective busbar. It is acceptable to monitor multiple cells with one sensor if this requirement is met for all cells sensed by the sensor.

EV 5.8.5 The maximum cell temperature is 60 °C or the limit stated in the cell data sheet, whichever is lower.

EV 5.8.6 An independent cell temperature monitoring device may be provided by the officials during accumulator inspection and must be installed, see IN 3.

The device must be placed on the warmest negative cell terminal of the TSAC and in direct contact with the terminal or less than 30 mm away from it on the busbar.

EV 5.8.7 The AMS must open the SDC, if a critical voltage, temperature, or current value according to the cell manufacturer's datasheet or these rules persistently occurs for more than:

- 500 ms for voltage and current values
- 1 s for temperature values

The accuracy, noise, and sample rate of the measurement must be taken into account.

EV 5.8.8 AMS cell voltage measurement inputs, temperature measurement inputs, and supply voltage of decentralized AMS slaves may be rated below the maximum TS voltage.

EV 5.8.9 A red indicator light in the cockpit that is easily visible from inside and outside the cockpit even in bright sunlight and clearly marked with the lettering "AMS" must light up if and only if the AMS opens the SDC. It must stay illuminated until the error state has been manually reset, see EV 6.1.6. Signals controlling this indicator are SCS, see T 11.9.

EV 5.8.10 AMS signals are System Critical Signals, see T 11.9. The loss of any measurement connection, see EV 5.8.3, must result in an open SDC.

EV 5.8.11 It must be possible to individually disconnect the current sensor, one temperature sensor, and one cell voltage measurement wire during technical inspection if any wire is used.

EV 5.8.12 The AMS must be able to read and display all measured values according to EV 5.8.3 in a single overview e.g. by connecting a laptop to the AMS at any place and any time e.g. inside the dynamic area.

EV 6 SHUTDOWN CIRCUIT AND SYSTEMS

EV 6.1 Shutdown Circuit

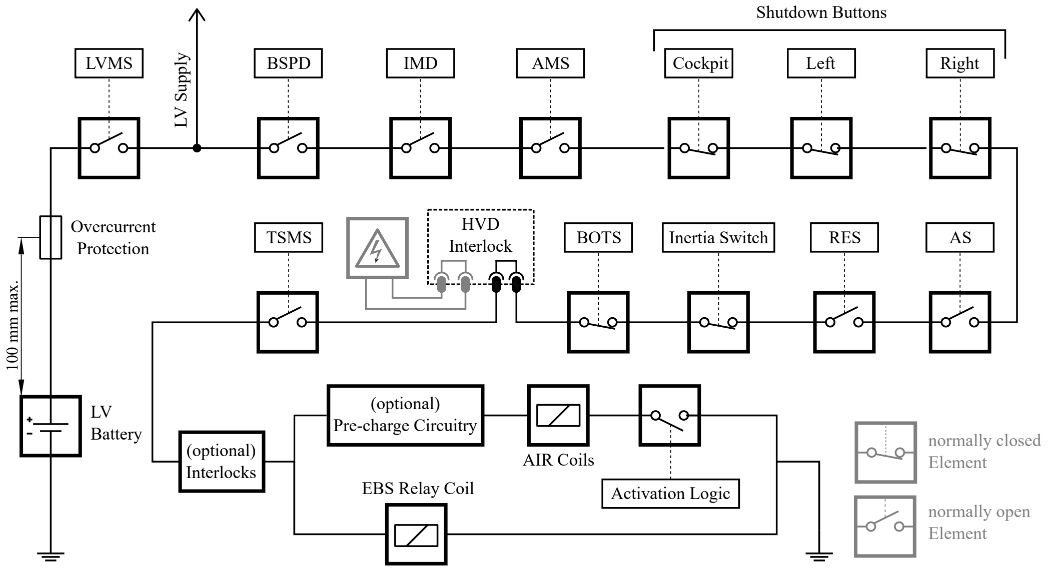

Figure 20: Explanatory example schematic of the required Shutdown Circuit (SDC)

EV 6.1.1 The Shutdown Circuit (SDC) directly carries the power driving the AIRs, see EV 5.6, and the pre-charge circuitry, see EV 5.7.

EV 6.1.2 The SDC is defined as a series connection of at least two master switches, three shutdown buttons, the BOTS, see T 6.2, the IMD, the inertia switch, see T 11.5, the BSPD, see T 11.6, all required interlocks, and the AMS.

An explanatory schematic of the required SDC, excluding any possible interlock circuitry, is shown in Figure 20.

EV 6.1.3 All parts of the SDC defined in EV 6.1.2 must be on the high-side connection of the AIR coils and the pre-charge circuitry.

EV 6.1.4 The Tractive System Master Switch (TSMS), see EV 6.2, must be the last switch before the AIRs except for pre-charge circuitry and hardwired interlocks.

EV 6.1.5 If the SDC is opened the TS must be shut down by opening all AIRs as well as the pre-charge relay and the voltage in the TS must drop to below 60 V DC and 50 V AC RMS in less than 5 s. All TS accumulator current flow must stop immediately.

The action of opening the AIRs may be delayed by ≤250 ms to signal the action to the motor controllers and reduce the TS current before the AIRs are opened. The AIR supply must be abruptly switched off before reaching the minimum AIR supply voltage.

EV 6.1.6 If the SDC is opened by the AMS or the IMD, it has to be latched open by a non-programmable logic that can only be manually reset by a person at the vehicle who is not the driver.

EV 6.1.7 All circuits that are part of the SDC must be designed in a way, that in the de-energized/disconnected state, they open the SDC.

EV 6.1.8 It must be possible to demonstrate that all features of the SDC function correctly. This includes all interlocks.

EV 6.1.9 Every system that is required to or can open the SDC must have its own, non-programmable, power stage to achieve this. The respective power stages must be designed to be able to carry the SDC current, e.g. AIR inrush currents, and such that a failure cannot result in electric power being fed back into the electric SDC.

EV 6.1.10 The shutdown buttons, the BOTS, the TSMS, and all interlocks must not act through any power stage.

EV 6.1.11 All signals influencing the SDC are SCSs, see T 11.9.

EV 6.2 Tractive System Master Switch

EV 6.2.1 An TSMS according to T 11.2 must be part of the SDC, see EV 6.1.2.

EV 6.2.2 The TSMS must be fitted with a "lockout/tagout" capability to prevent accidental activation of the TS. The ESO must ensure that it is locked in the off position whenever work is done on the vehicle or no ESO is present.

EV 6.2.3 The TSMS must be mounted in the middle of a completely orange circular area of ≥50 mm diameter placed on a high contrast background.

EV 6.2.4 The TSMS must be marked with "TS" and a symbol according to "ISO 7010-W012" (triangle with a black lightning bolt on a yellow background).

EV 6.3 Insulation Monitoring Device

EV 6.3.1 Every vehicle must have an IMD installed in the TS system.

EV 6.3.2 The IMD must be a Bender A-ISOMETER® iso-F1 IR155-3203, -3204, -4203, or -4204, or a Bender ISOMETER® iso165C-1, iso175, or equivalent IMD approved for automotive use. Equivalency may be approved by the officials based on the following criteria: robustness to vibration, operating temperature range, IP rating, availability of a direct output, a self-test facility, and must not be powered by the system that is monitored.

EV 6.3.3 The response value of the IMD must be set to ≥500 Ω/V, related to the maximum TS voltage.

EV 6.3.4 The response value must not be changed after electrical inspection.

EV 6.3.5 The IMD must be connected on the vehicle side of the AIRs.

EV 6.3.6 One IMD chassis ground measurement line must be connected to the grounded TSAC or the respective grounded TS enclosure of the IMD. The other chassis ground measurement line must be connected to the main hoop. Each connection must use a separate conductor, rated for at least maximum TS voltage. An open circuit in any of these ground measurement connections must result in an opened SDC.

EV 6.3.7 In case of an insulation failure or an IMD failure, the IMD must open the SDC. This must be done without the influence of any programmable logic. See also EV 6.1.6 regarding the re-activation of the TS after an insulation fault.

EV 6.3.8 A red indicator light in the cockpit that is easily visible from inside and outside the cockpit even in bright sunlight and clearly marked with the lettering “IMD” must light up if and only if the IMD opens the SDC. It must stay illuminated until the error state has been manually reset, see EV 6.1.6. Signals controlling this indicator are SCS, see T 11.9.

EV 7 CHARGERS

EV 7.1 Chargers General Requirements

EV 7.1.1 Only chargers presented at technical inspection are allowed. All connections of the chargers must be insulated and covered. No open connections are allowed.

EV 7.1.2 Exposed conductive parts and the TSAC must be connected to protective earth (PE).

EV 7.1.3 All components interfacing with mains must be accredited to a recognized standard e.g. CE. All remaining parts must comply with all electrical requirements for the vehicle TS, e.g. EV 4.3, EV 3.1, and EV 4.2.

EV 7.1.4 TS charging leads must be orange.

EV 7.1.5 When charging, the AMS must be active and must be able to open the SDC, see EV 7.2.

EV 7.1.6 The charger must include a push-type emergency stop button which has a minimum diameter of 24 mm.

EV 7.1.7 When charging, an IMD as described in EV 6.3 must be active and must be able to open the SDC, see EV 7.2, The second chassis ground measurement line must be connected to the casing of the charger.

EV 7.1.8 An IMD indicator light as defined in EV 6.3.8 must be available.

EV 7.1.9 TSAL’s green light, see EV 4.10.3, must be available as an easily visible green indicator.

EV 7.1.10 The charger must include TSMPs as described in EV 4.7. The TSMPs must be connected to the TS output of the charger.

EV 7.1.11 All indicators, switches, buttons, and connectors of the charger must be labeled.

EV 7.2 Charging Shutdown Circuit

EV 7.2.1 The charging Shutdown Circuit (SDC) consists of at least the charger shutdown button, see EV 7.1.6, the IMD, the AMS, and the charging leads' interlocks.

EV 7.2.2 If the SDC is opened the charging system must remain disabled and the SDC opened until it is manually reset. Closing the SDC by any part defined in EV 7.2.1 must not (re-)activate charging.

EV 7.2.3 The charging shutdown systems must comply with EV 6.1.1, EV 6.1.5, EV 6.1.7, EV 6.1.8 and EV 6.1.9.

EV 7.2.4 All signals influencing the charger SDC are SCS, see T 11.9.

EV 8 TRACTIVE SYSTEM ACCUMULATOR CONTAINER HAND CART

EV 8.1 Tractive System Accumulator Container Hand Cart

EV 8.1.1 A hand cart must be used for transporting the TSACs around the competition site.

EV 8.1.2 The hand cart must have at least four wheels.

EV 8.1.3 The hand cart must have a brake that is always on and only released if someone pushes the handle, or similar.

EV 8.1.4 The brake must be capable of safely stopping the fully loaded hand cart.

EV 8.1.5 The hand cart must be easily moved when the brake is released.

EV 8.1.6 The hand cart must be able to carry the load of the TSACs.

EV 8.1.7 The hand cart must provide a firewall to protect the person while moving the hand cart. The firewall must have the same width as the hand cart, appropriately protect the legs and body, and be at least 30 cm higher than the hand cart handle and the TSAC. The firewall must be made from a rigid, fire retardant material, see T 1.2.1, and be transparent from 1.3 m above the ground.

EV 8.1.8 The TSACs must be mechanically fixed to the hand cart to enable safe transportation.

EV 8.1.9 The TSACs must not protrude the hand cart.

EV 8.1.10 The TSACs must be protected from vibrations and shocks during normal operation of the cart, e.g. by the use of air tires.

EV 8.1.11 The hand cart itself must have a label according to EV 5.3.7 on its firewall maximum 1.3 m above the ground.

EV 8.1.12 The overall floor space used by the fully loaded hand cart must not exceed 1200 mm x 800 mm. If the TSAC is larger than the allowed floor space, exceptions may be approved by the officials before the competition.

EV 9 ELECTRICAL SYSTEM FORM

EV 9.1 Electrical System Form

EV 9.1.1 Before the competition, all teams must submit structured documentation of their entire electrical system (including control and TS) called the ESF.