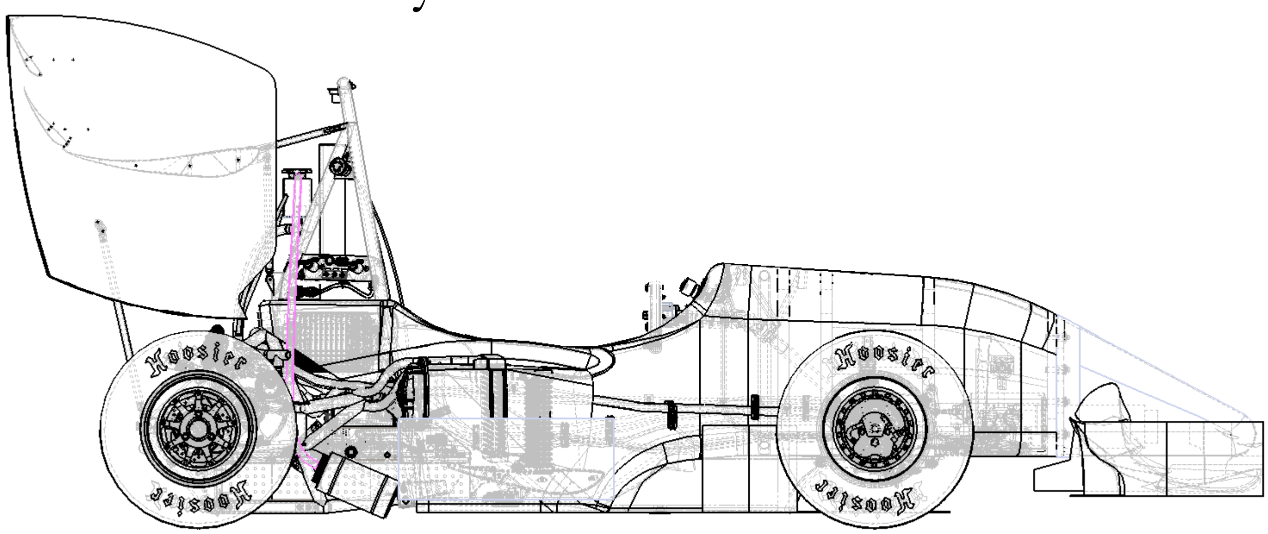
Electrical System Form FSAE-E2018

University of Wisconsin-Madison



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Abbreviations

AIR – Accumulator Insulation Relay
BMS- Battery Monitoring System
BOTS – Brake-Over-Travel-Switch
BSPD – Brake System Plausibility Device
GLV – Grounded Low Voltage
GLVMP – Ground Low Voltage Measurement Point
HV – High Voltage
IC – Integrated Circuit
IMD – Insulation Monitoring Device
SDC – Shutdown Circuit
TS – Tractive System
TSAL – Tractive System Active Light
TSMP – Tractive System Measurement Point

1 System Overview

This electric vehicle is designed for a race environment where it must have high acceleration, good stability, and the ability to run for 30 minutes continuously with safety as the highest priority. The vehicle is driven by 4 in hub synchronous permanent magnet motors where each wheel is controlled independently through a torque vectoring algorithm run on our ECU. Our battery pack is in 60s10p configuration with total available energy of 6.70 kWh and nominal voltage of 216 VDC.

Maximum Tractive System Voltage:	252VDC
Nominal Tractive System Voltage:	216VDC
Grounded Low Voltage System Voltage:	3.3VDC, 5VDC, 12VDC
Number of Accumulator Containers:	1
Total Accumulator Capacity:	31Ah, 6.70kWhr
Motor Type:	Synchronous Permanent Magnet
Number of Motors:	Total 4, one per wheel (hub motors)
Maximum Combined Motor Power:	160kW

Table 1-1 - High Level Specifications

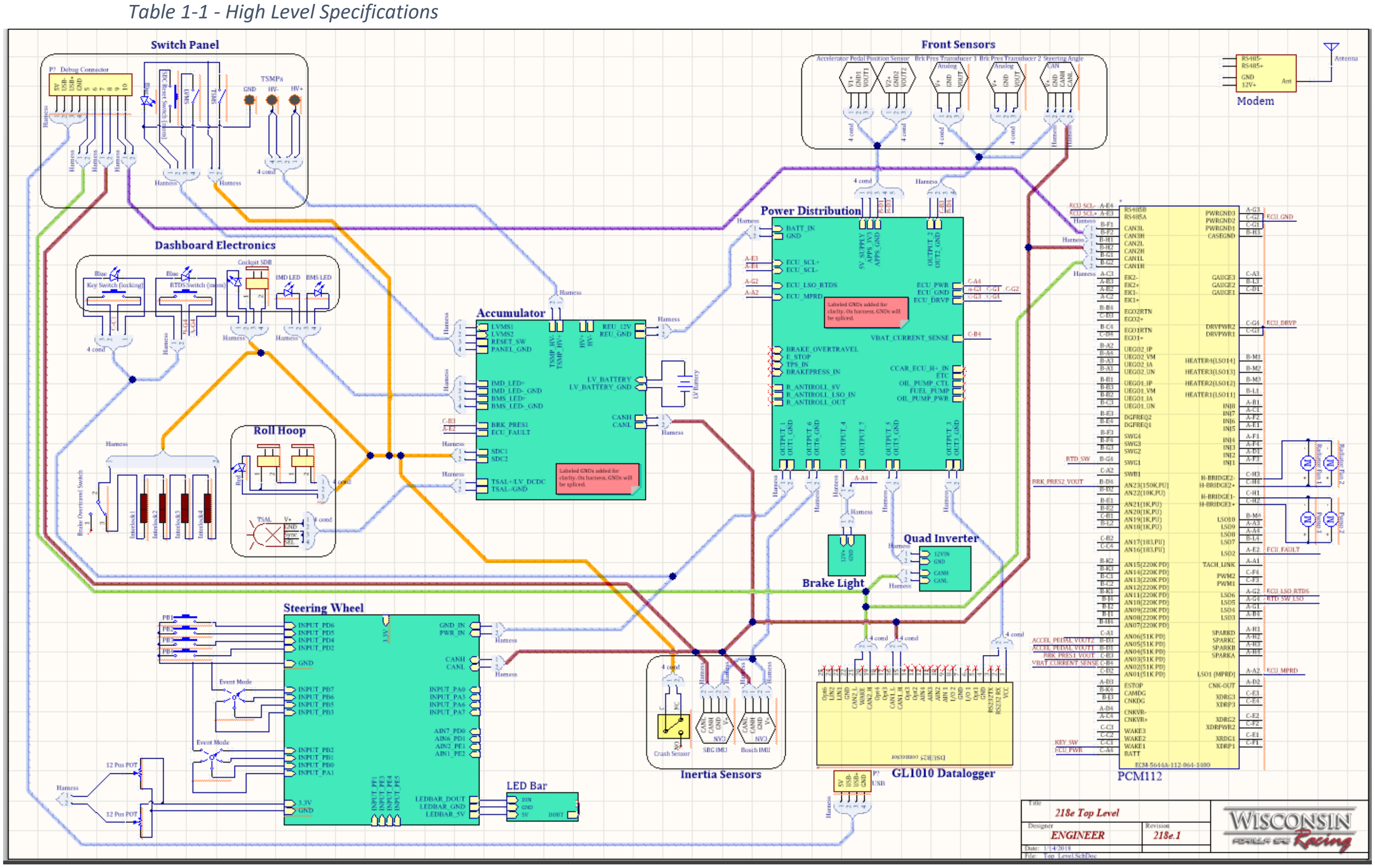


Figure 1-1 - System Block Diagram

2 Tractive System Schematics

2.1 Tractive System Schematic (Power Electronics ONLY)

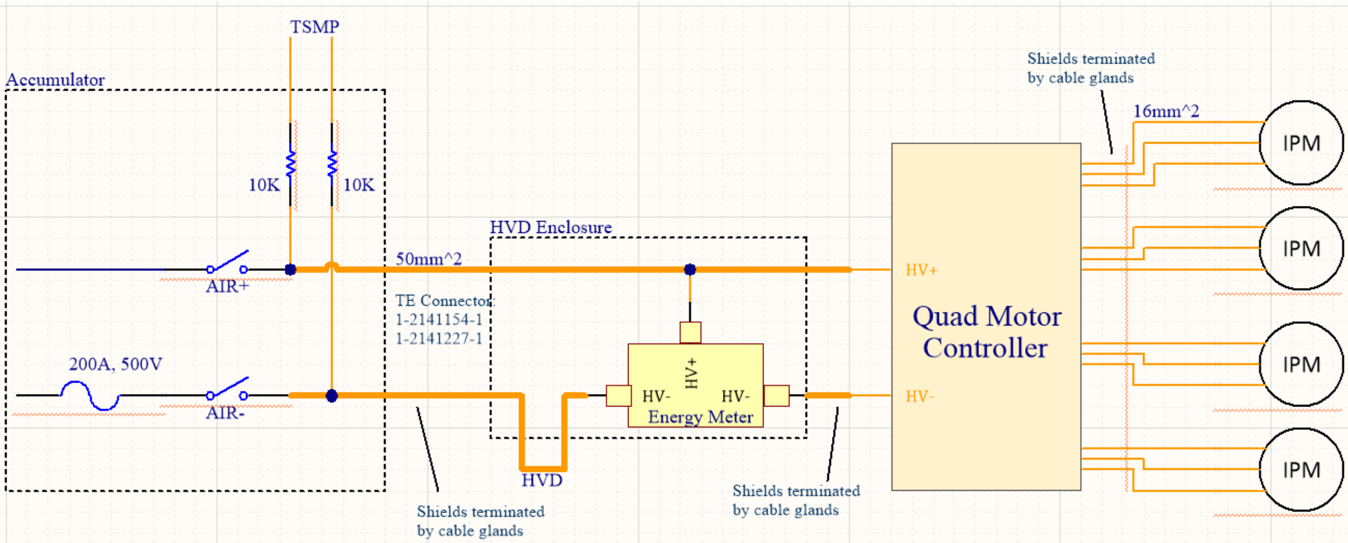


Figure 2-1 - HV System Schematic

2.2 Fusing Diagram

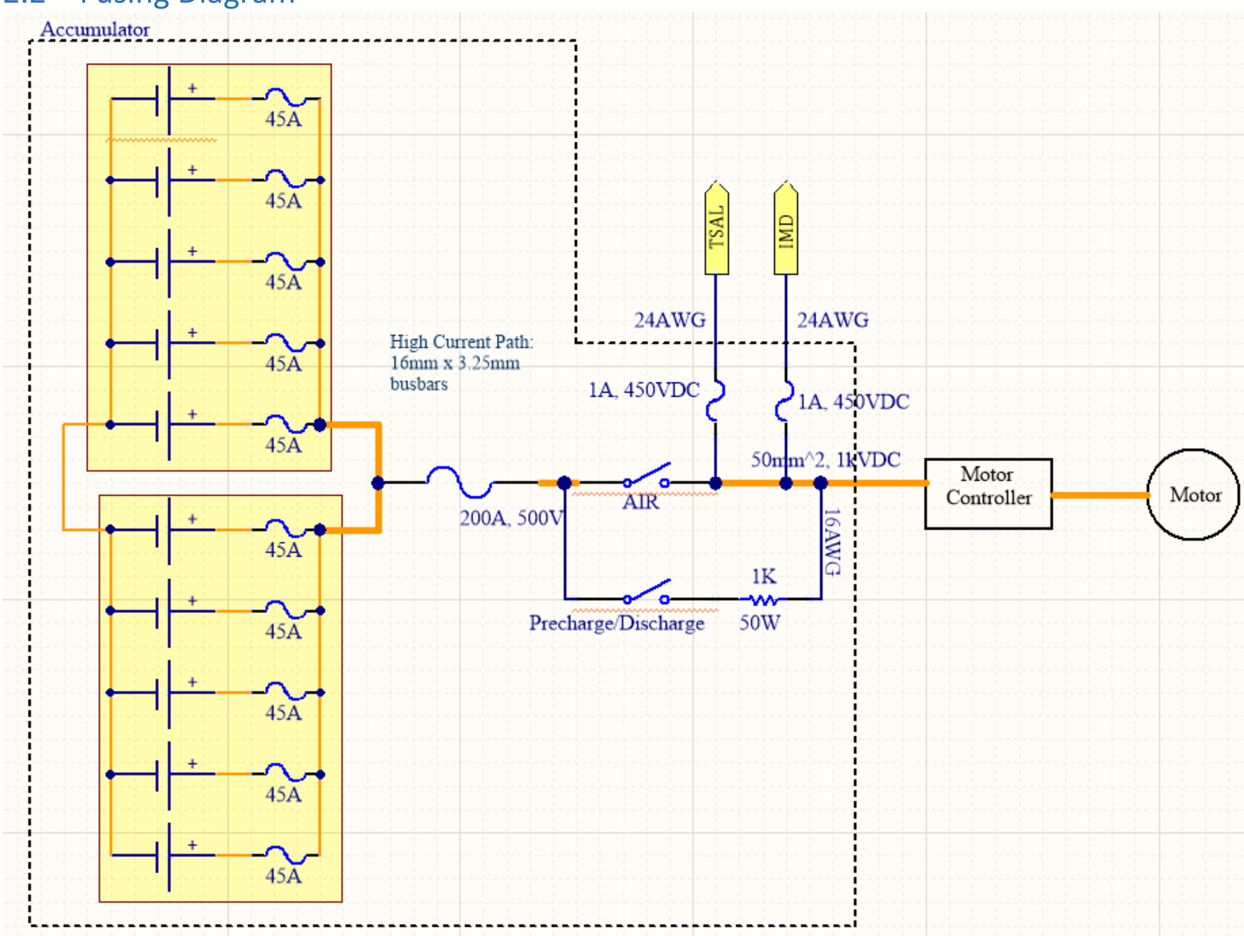


Table 2-1- Fuse Tree Diagram

2.2.1 Fuse Specifications

Fuse Location	Current Rating	Voltage Rating	Interrupt Rating	Datasheet
Cell fuse - Cell to busbar within module	45A	N/A	N/A	Link
Main path fuse - Inside pack on + pole	200A	500V	20kA	Link
TSAL fuse – on battery master board PCB	1A	600V	100A	Link
IMD fuse – on battery master board PCB	1A	600V	100A	Link

Table 2-2 - Fuse Specifications

2.2.2 Conductor Specifications

Conductor Location	Size	Voltage Rating	Ampacity	Rating of fuse providing protection	Datasheet
Busbars- connected to cell modules	$50mm^2$	N/A	N/A	200A	N/A
DC cable going to HVD and quad inverter	$50mm^2$	600VAC/1kVDC	400A @40C	200A	Link
Phase cables	$16mm^2$	600VAC/1kVDC	200A @40C	None	Link

Table 2-3 - Conductor Specifications

2.2.3 Connector Specifications

Connector Location	Ampacity	Voltage Rating	Includes Interlock	Accepted wire gauge	Wire gauge connected
HVD connector male	250A @40C	650VDC	Y	$25mm^2$ – $50mm^2$	$50mm^2$
HVD connector female	250A @40C	650VDC	Y	$25mm^2$ – $50mm^2$	$50mm^2$

Table 2-4- Connector Specifications

Note: The HVD is the only connector in the HV path. All other connections are done with ring terminals and cable glands for strain relief

3 Shutdown Circuit

3.1 Shutdown Circuit Schematic

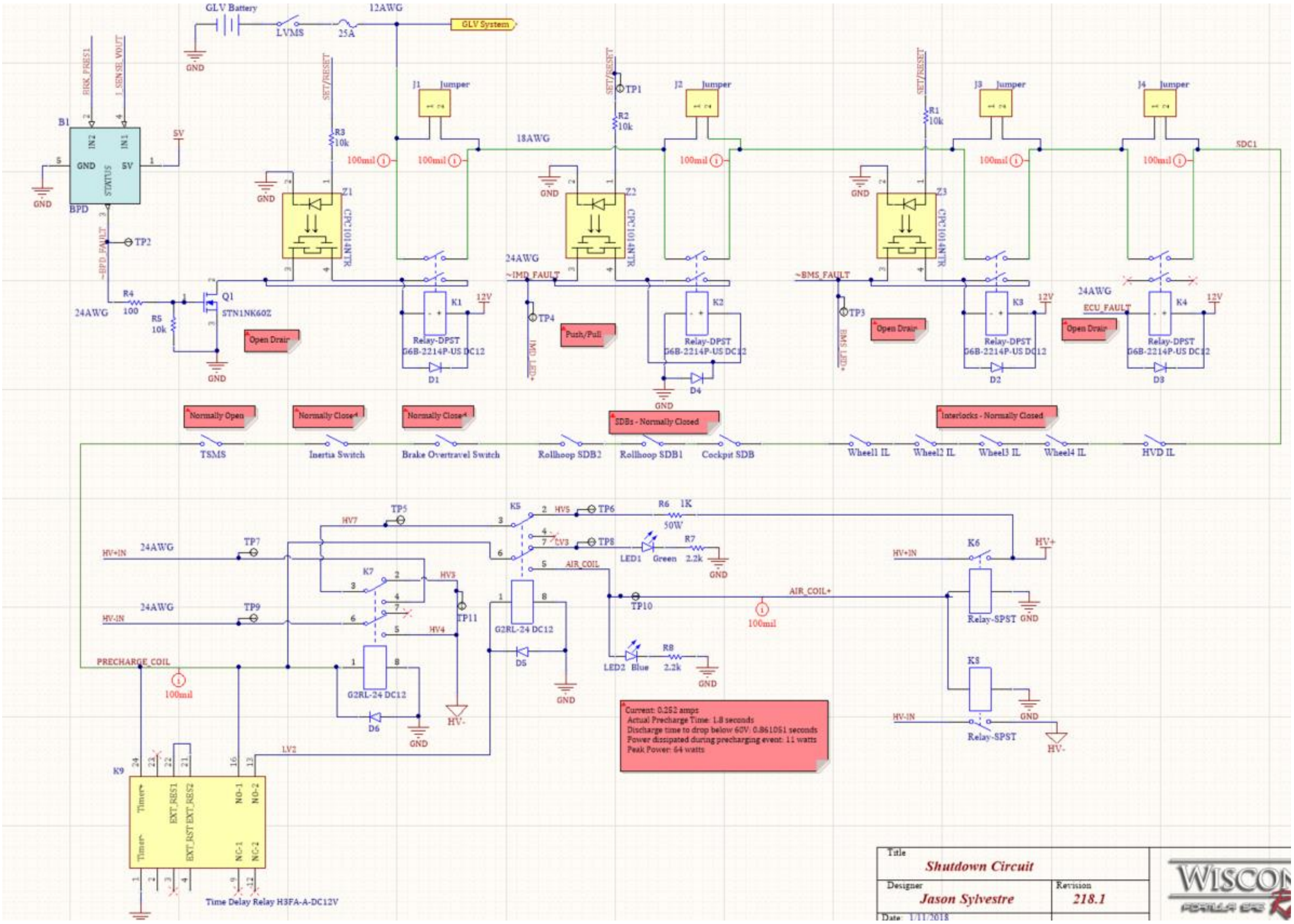


Figure 3-1 - Shutdown Circuit Schematic

3.1.1 Switch Locations

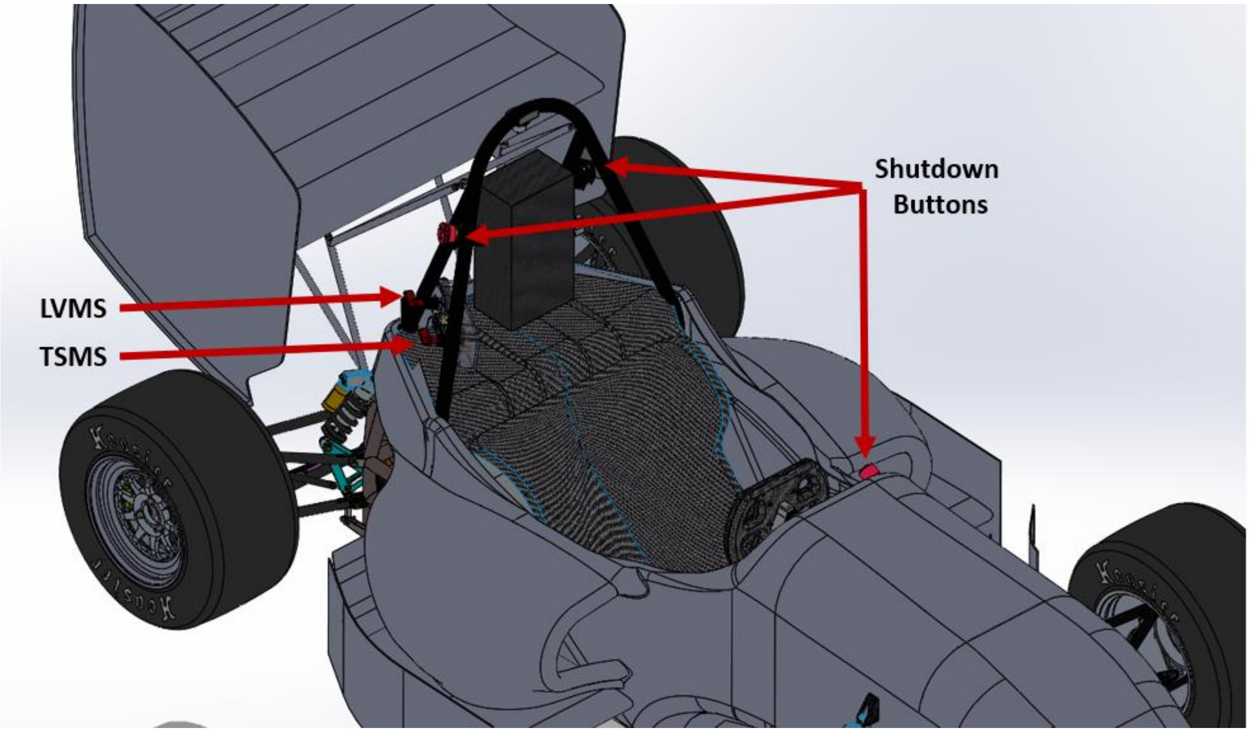


Figure 3-2 - Shutdown Circuit Switch Locations

3.2 Wiring

3.2.1 Shutdown Circuit Current

Total Number of AIRs:	2
Current per AIR:	0.5A
Additional parts consumption within the shutdown circuit:	0.155A (4 Powerstages + 3 Solid State Relays for reset functionality)
Total current:	1.155A
AIR Coil Resistance:	33Ω ± 10%
Max AIR Coil Voltage:	16V

Table 3-1 - Shutdown Circuit Loads

3.3 IMD

3.3.1 IMD Specifications

Make / Model	Bender ISOMETER IR155-3204
Supply voltage	12VDC
Environmental temperature range:	-40..105°C
Self-test interval:	Always at startup, then every 5 minutes
High voltage range:	DC 0..1000V
Set response value:	126kΩ (500Ω/Volt)

Max. operation current:	150mA
Approximate time to shut down at 50% of the response value:	10s
Datasheet	[Datasheet]()

Table 3-2 - IMD Specifications

3.3.2 IMD Fault Latching

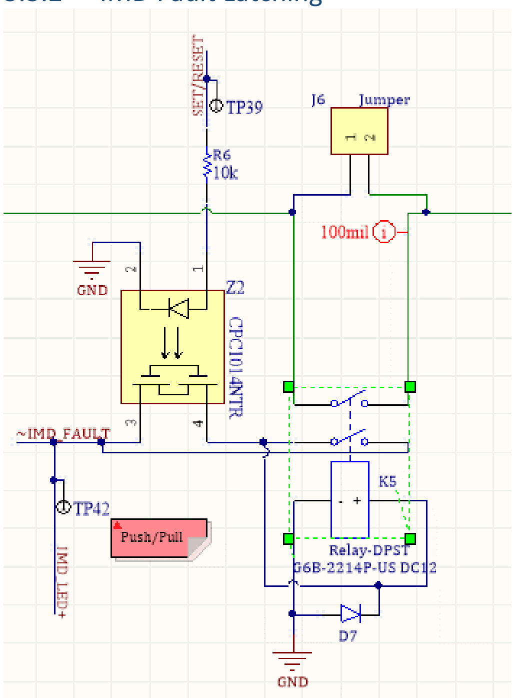


Figure 3-3 - IMD Latch Circuit Schematic

3.3.3 IMD Location

The IMD is located inside the accumulator so the device will be active when we pull the accumulator out for charging.

The IMD indicator is mounted on monocoque to the right of our steering wheel so the driver will be able to clearly see if there is an IMD fault

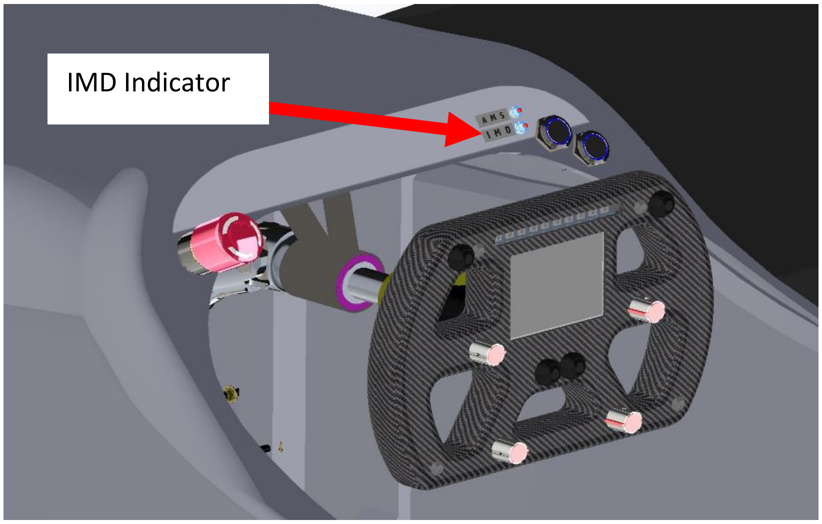


Figure 3-4 IMD Indicator

The reset button is on the side of our vehicle, mounted to the roll hoop. The driver cannot activate this from within the cockpit.

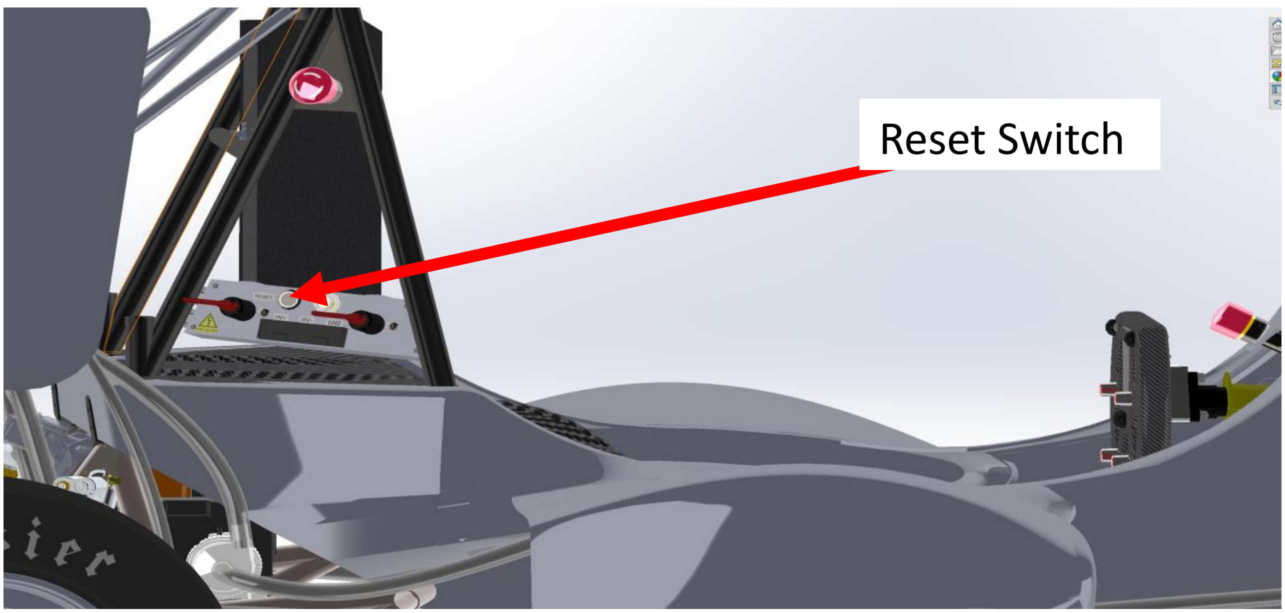


Figure 3-5 Reset Switch Location

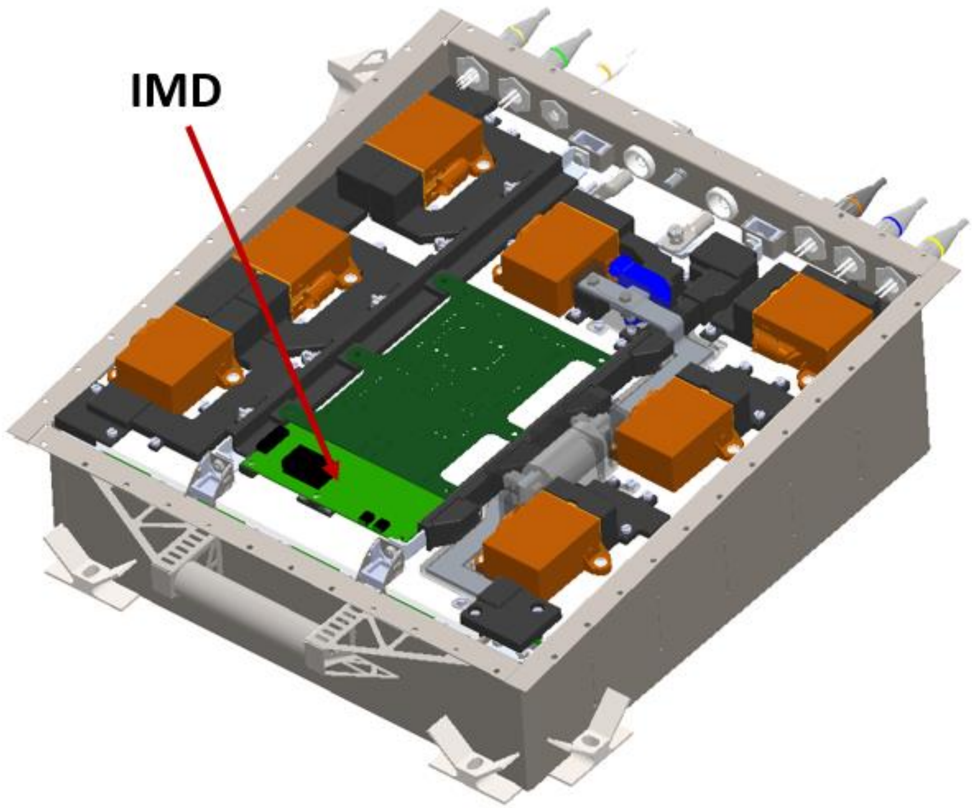


Figure 3-6 IMD Location in the Accumulator Container

3.3.4 IMD Demonstration

Describe numbered steps of how to demonstrate that the IMD can detect a fault at competition.

1. Activate tractive system – turn LVMS and TSMS to ON, press the set/reset button, and press the key switch.
2. Connect a resistor of value 63kOhm (50% of the set between HV- at the TSMPs and various locations on GLV)
3. The Shutdown circuit will open and the IMD LED on the dashboard will illuminate
4. Ensure tractive system is latched off until fault clears and reset button is pressed

Reference: EV7.1.1, EV7.1.2, EV7.1.3

3.4 Brake System Plausibility Device

3.4.1 BSPD Current Sensor

Make / Model:	LEM HO 200-S
Current input range:	+/- 500A
Output range:	0-5V
Datasheet:	Datasheet

Table 3-3 - BSPD Current Sensor Specifications

3.4.2 BSPD Setpoint

Trip Current	23A
Current sensor output @Trip Current	2.592V
Delay time	500ms

Table 3-4 - BSPD Operation Details

3.4.3 BSPD Schematic

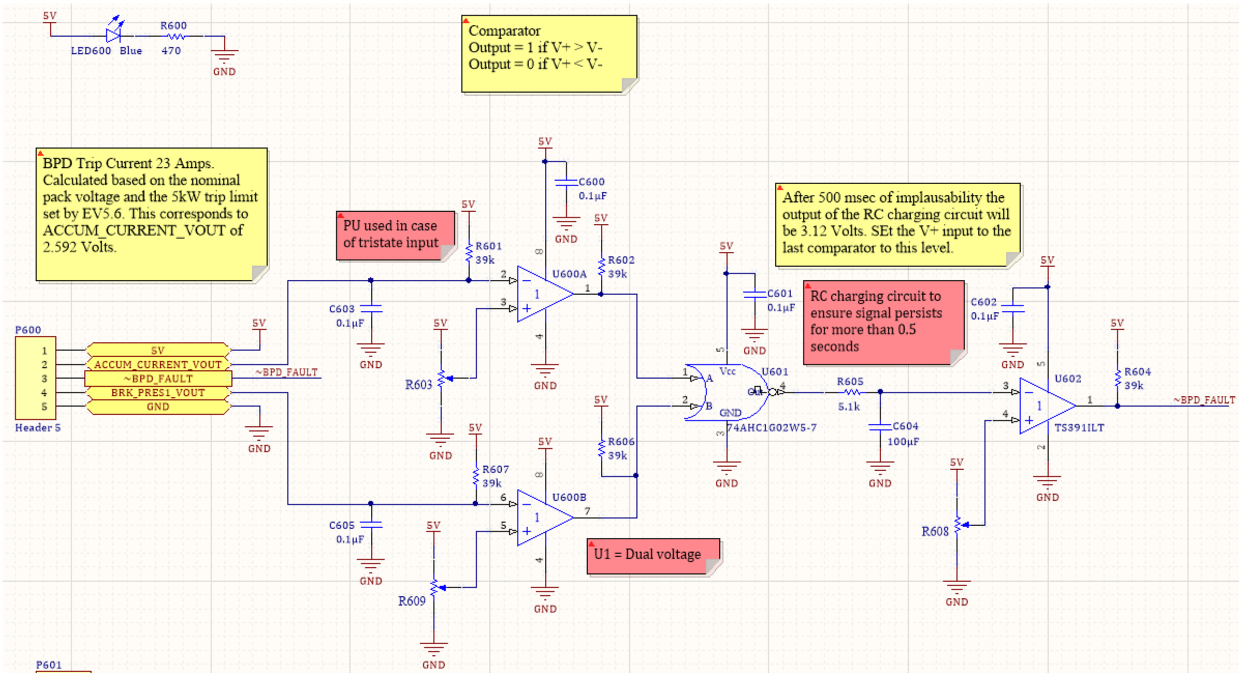


Figure 3-7 - BSPD Schematic

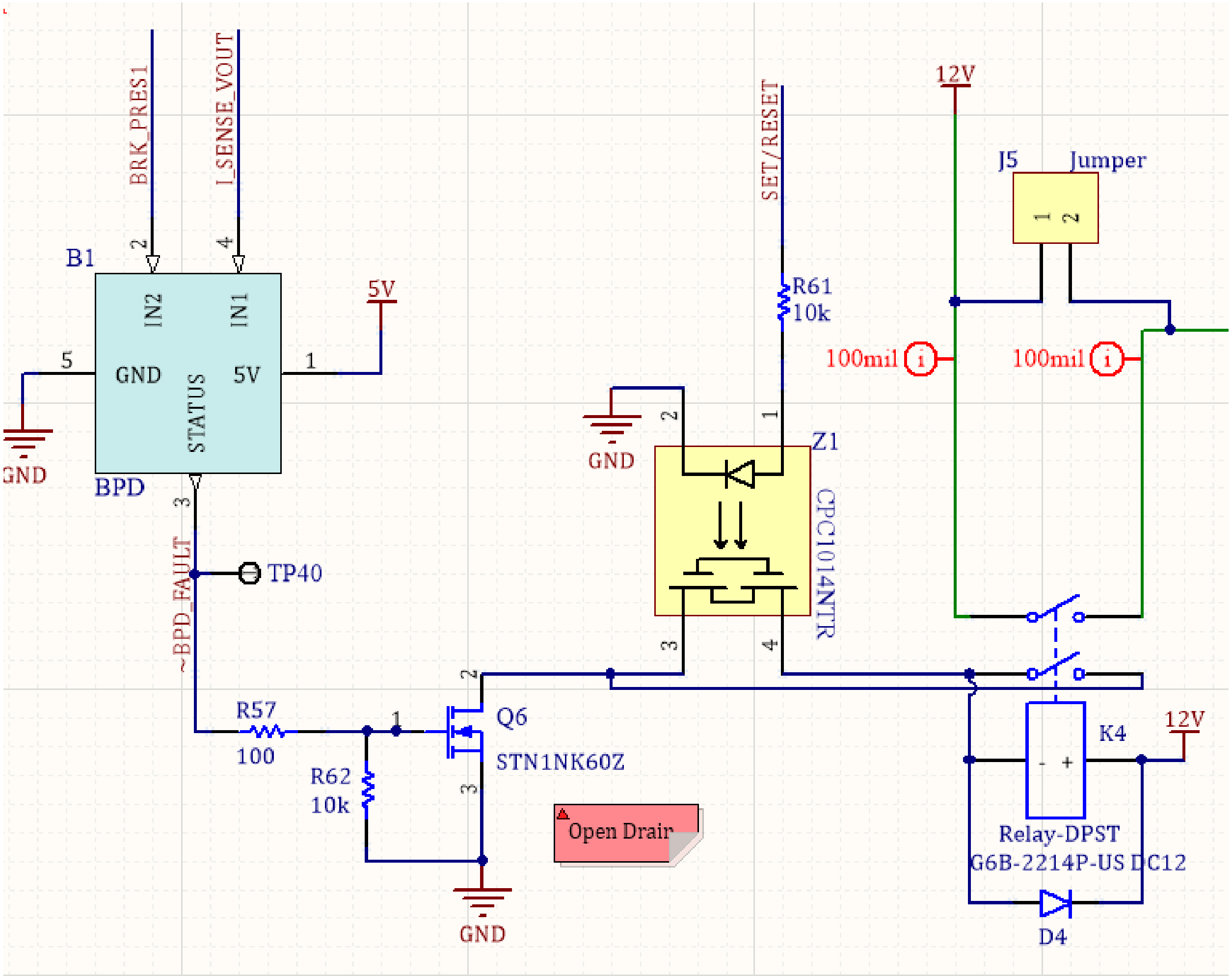


Figure 3-8 BSPD Powerstage being driven by a NMOS transistor controlled by the BSPD

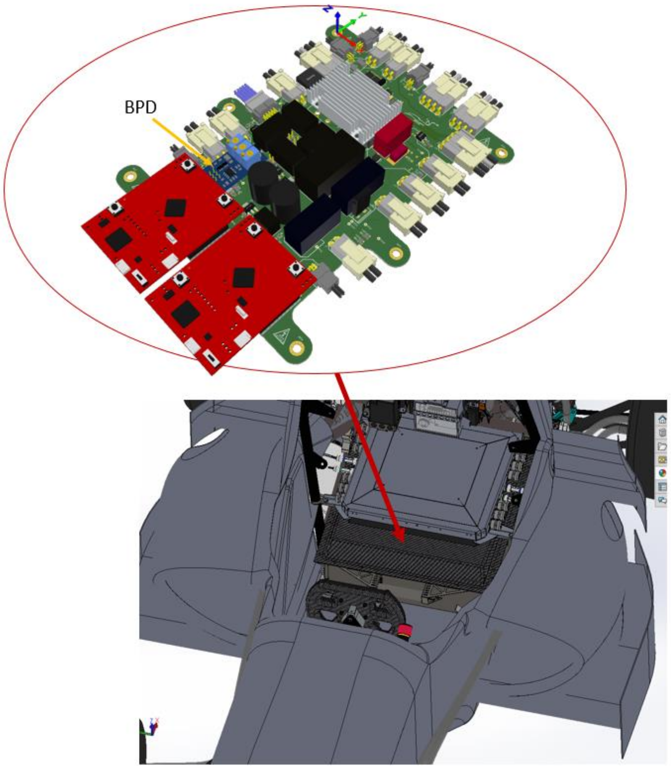


Figure 3-9 - BSPD Component Location

3.4.4 BSPD Demonstration

1. Connect BSPD test unit to battery pack. This will drive the current sensor output node to 2.592V, which corresponds to a 5kW draw.
2. Depress the brake pedal
3. Observe accumulator indicator or TSAL to see if contactors were opened by the implausibility event (indicator should be OFF)
4. Release the brake pedal
5. Observe accumulator indicator or TSAL to see if contactors remain open (indicator should be OFF)
6. Remove the BSPD test unit
7. Observe accumulator indicator or TSAL to see if contactors remain open (indicator should be OFF)
8. Press the set/reset SDC button on the switch panel
9. Observe accumulator indicator or TSAL to see if contactors close ((indicator should be ON)

3.5 Battery Management System

3.5.1 BMS Faults

The BMS will cause the shutdown circuit to open under the following conditions:

1. Cell overvoltage (above 4.2V) or undervoltage (below 2.5V)
2. Cell overtemperature (above 60C) or cell under temperature (below -20C)
3. If the current drawn from the HV Battery is greater than the limit calculated by the BMS for the current cell conditions
4. If the charger determines a fault condition and requests the contactors to be opened
5. If the BMS detects an open circuit in a voltage tap
6. If the BMS detects it is reading less than 30% of the cell temperatures

3.5.2 BMS Fault Latching

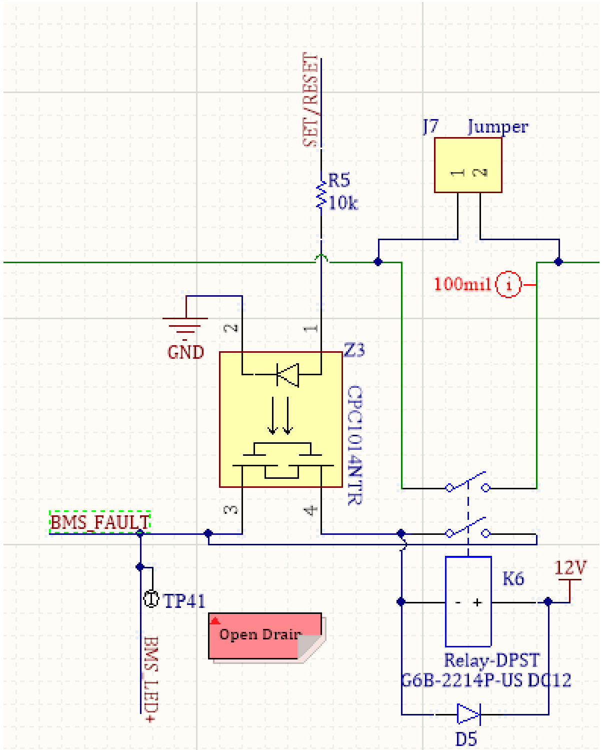


Figure 3-10 BMS SDC Powerstage and reset circuitry

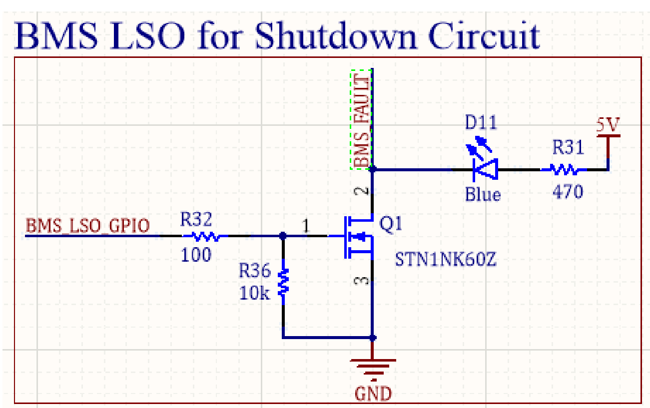


Figure 3-11 BMS MCU control of the BMS powerstage in the shutdown circuit

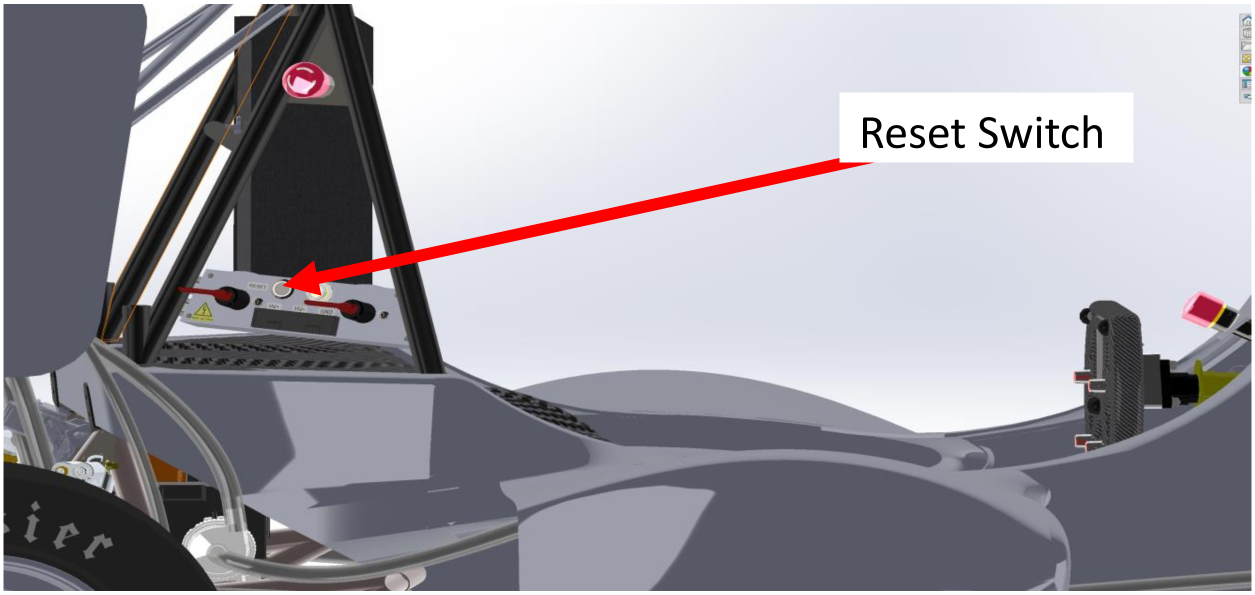


Figure 3-12 Reset Switch Location

The BMS MCU drives BMS_LSO_GPIO high during normal operation (no faults detected). This provides the Ground signal for its powerstage in the shutdown circuit. For the powerstage to be closed, the BMS must be ON and the SET/RESET signal is asserted for the powerstage to close. IF the BMS detects a fault, the BMS MCU will open its FET by setting BMS_LSO_GPIO low. This will open the powerstage, and the powerstage will be unable to close again until the BMS fault condition clears, and the SET/RESET button is pressed again.

3.5.3 BMS Demonstration

1. Turn the GLV System ON
2. Connect to the Sensor CAN Bus (BMS is on this bus) at 1000 kbit/s
3. Send CAN request to broadcast all cell voltages and temperatures
4. Display CAN Bus traffic with symbols database to show the voltages and temperatures of all the cells
5. Display code snippets for conditions to open the AIRS

4 Safety Systems

4.1 TSAL

4.1.1 TSAL Specifications

Make/Model:	MSTRB Series Mini-Strobe LED Lights
Color:	Red
Flash Rate:	5Hz
Powered By:	GLV
Controlled By:	TS
TS Turn On Voltage:	120VDC
TS Turn Off Voltage:	114VDC

Table 4-1 - TSAL Specifications

4.1.2 TSAL Schematic

TSAL is driven directly off the DC-DC converter which takes the tractive system voltage and converts it to a voltage that can be used by the GLV system. This turns on at a minimum of 120VDC. Our BMS will not allow the AIRs to close if the total pack voltage is less than 150V (2.5V/cell). Thus, there is no condition where the AIRs will be closed and the DCDC converter will not be active. When the shutdown circuit is closed, this will enable the DC-DC converter and the TSAL will flash as soon as the contactors close.

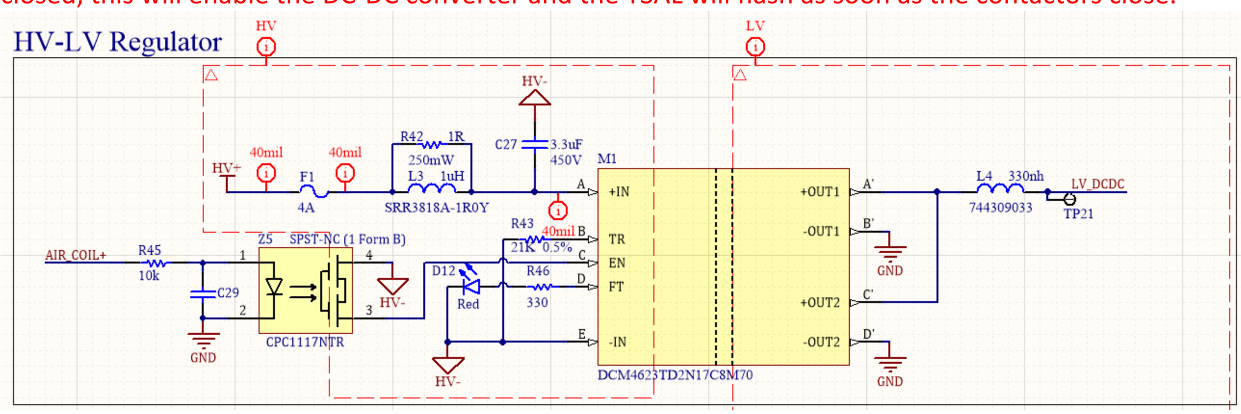


Figure 4-1 - TSAL Circuit Schematic

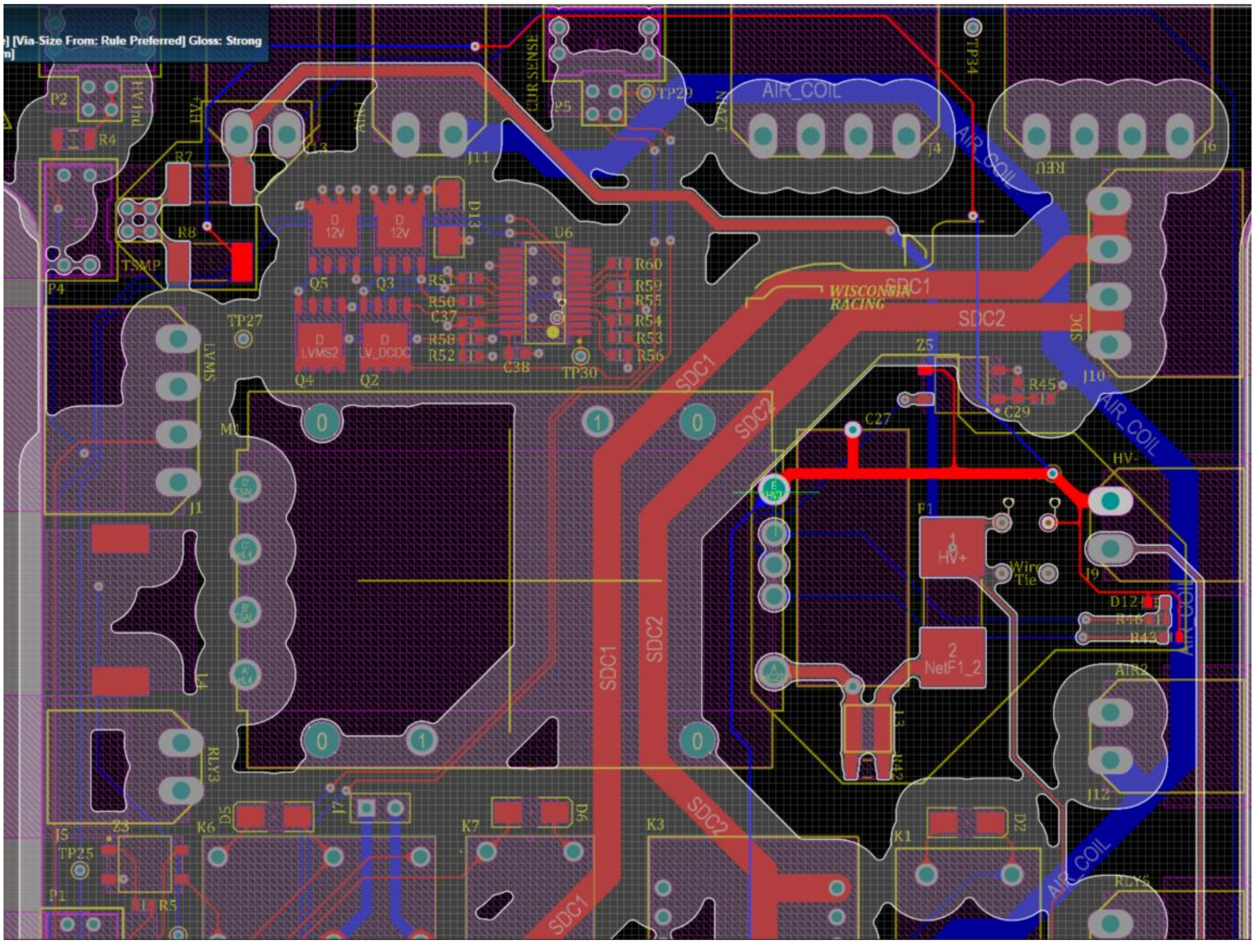


Figure 4-2-1 – Isolation Zones on battery master board – Clearance between HV and LV circuits = 3.2mm

4.1.3 TSAL Location

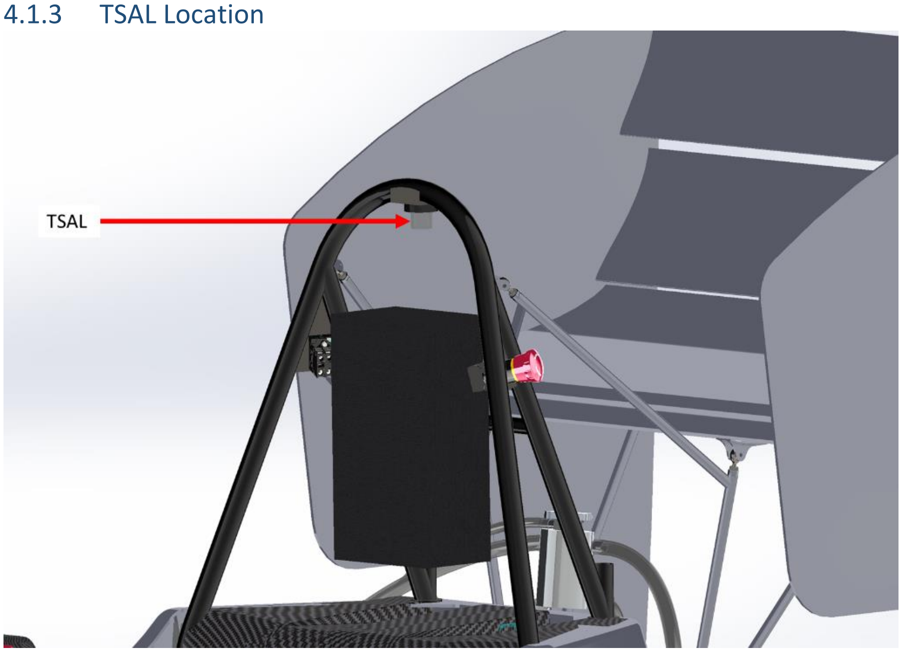


Figure 4-3 - TSAL Component Locations

4.2 Measurement Points

4.2.1 Measurement Point Specifications

Make / Model:	Pomona Electronics / Model 72930
Voltage Rating:	1000V
Datasheet:	Datasheet

Table 4-2 - Measurement Point Specifications

4.2.2 Measurement Point Location

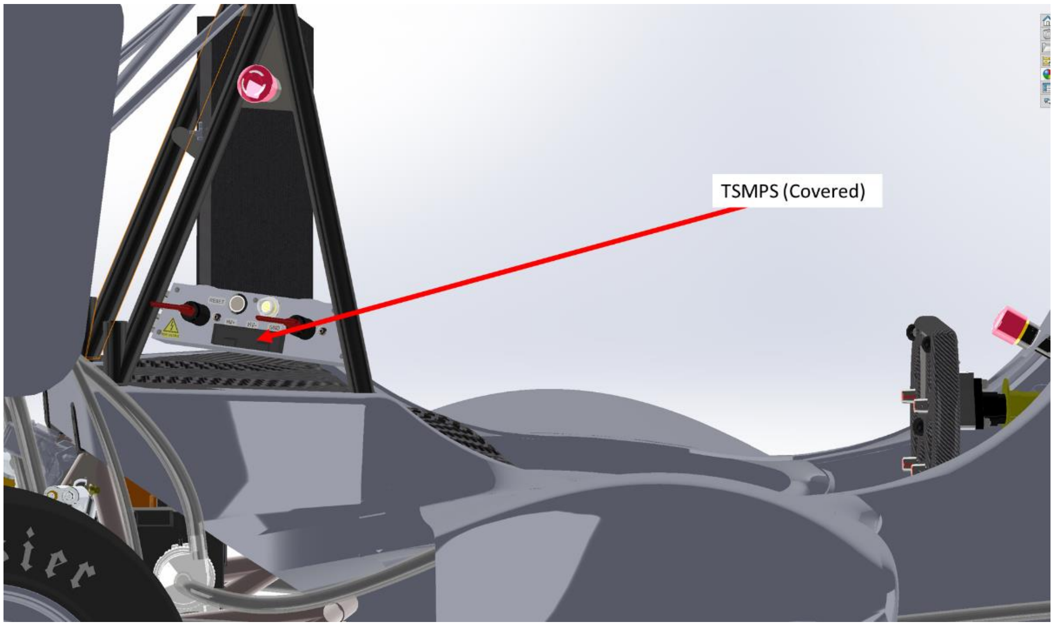


Figure 4-4 - Measurement Point Location

4.2.3 Measurement Point Protection

As shown in Figure 4-4, we have a plastic housing on the backside of TSMPs that prevents anyone from touching the HV. A slide piece with a rubber gasket is used to cover the TSMPs and prevent water ingress.

4.2.4 TSMP Protection Resistor

Make / Model:	TE Connectivity/ 352210KFT
Resistance:	10,000Ω
Voltage Rating:	250V
Power Rating:	3W
Datasheet:	Datasheet

Table 4-3 - TSMP Protection Resistor Specifications

4.2.5 TSMP Protection Resistor Location

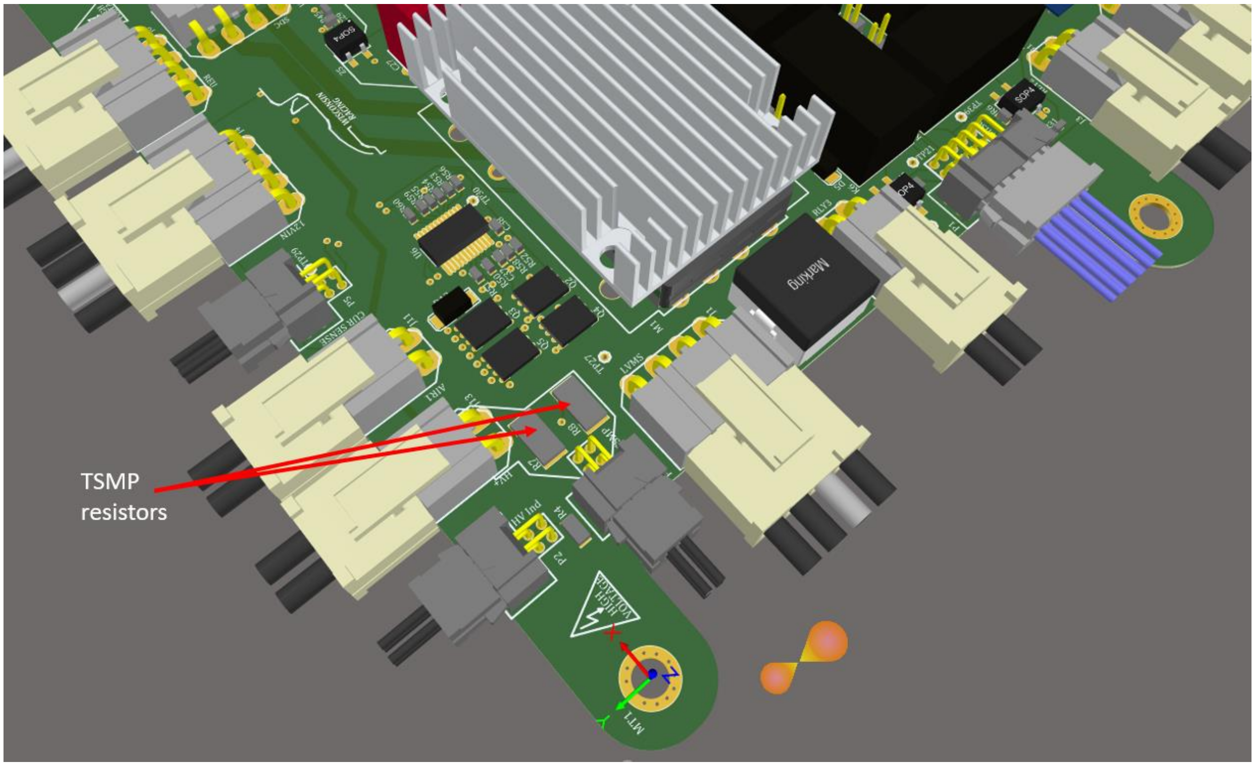


Figure 4-5 - TSMP Protection Resistor Location

4.2.6 TSMP Demonstration

<u>Discharge/Charge Resistor Measurement</u>

1. Remove the tractive system master switch
2. Observe the TSAL or accumulator indicator to confirm the contactors are open (indicator should be OFF)
3. Measure the resistance across the 'HV+' and 'HV-' measuring points located at the switch panel with a resistance measurement device
4. Subtract 20k from the measurement to get the discharge/charge resistance

<u>TS Voltage</u>

1. Insert the HVD, TSMS, and GLVMS
2. Press the key switch
3. Observe the TSAL or accumulator indicator to confirm the contactors closed (indicator should be ON)
4. Measure the voltage across the 'HV+' and 'HV-' measuring points located at the switch panel with a voltmeter.

4.3 HVD

4.3.1 HVD Specifications

Make / Model:	TE Connectivity
Ampacity:	250A @40C
Voltage rating:	650V
Datasheet:	Datasheet

Table 4-4 - HVD Specifications

The HVD is a service and safety disconnect located at the rear off the car. It contains an interlock so that either terminals of the connection will not become energized when disconnected. The HVD has a locking feature so that it does not come lose during normal operation, but it is able to be quickly disconnected in the case of an emergency.

4.3.2 HVD Location

The bottom of the HVD is 35.2 cm off the ground.

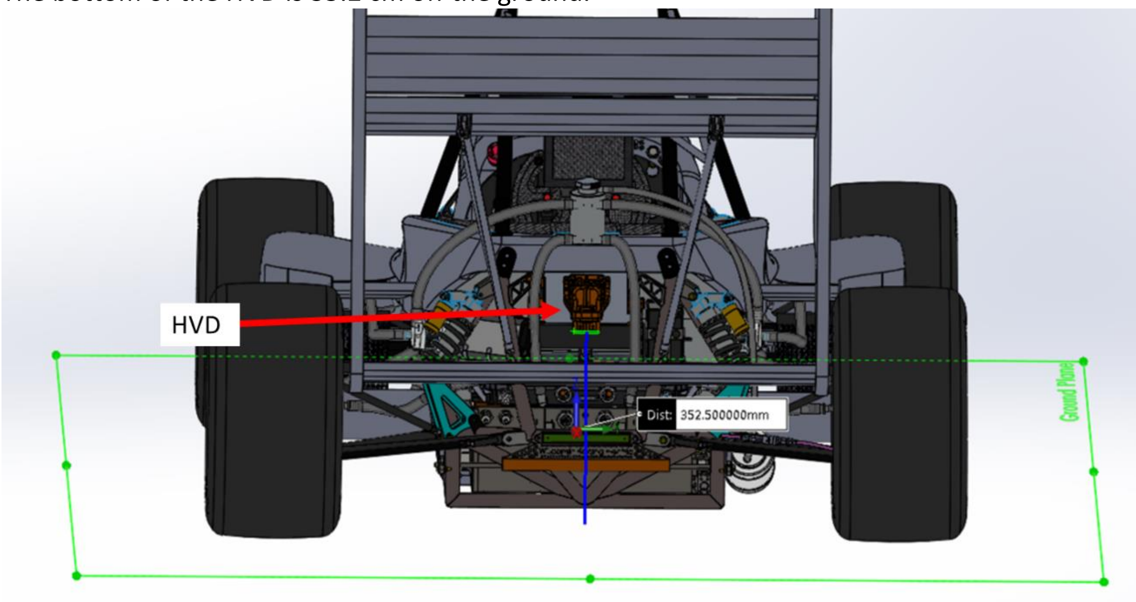


Figure 4-6 - HVD Location

4.3.3 HVD Connections

Ring terminals and hex bolts are used to connect to the female receptacle. A 3D printed plastic enclosure is bolted on the backside of the receptacle to prevent touching the HV terminals and water ingress. The male connectors came preassembled with $50mm^2$ cable. The connector is sealed to prevent touch and water ingress. The HVD connector will have an interlock in the plug side that is a series element of the SDC when it is inserted into the HVD receptacle on the car. This ensures that high voltage will never be present at the HVD terminals when it is unplugged from the car.

4.3.4 HVD Demonstration

To remove HVD, pull red latch down. While depressing the grey latch, lift up on the black handle. Rotate until it latches into removal position and then pull it out. Then, insert dummy connector to prevent exposure of HV terminals.

Situations where HVD must be removed

- Performing maintenance on battery pack, inverter, or anything that contains HV while it’s still in the car
- Manually pushing the vehicle
- At competition until we pass technical inspection
- During charging

4.4 Ready to Drive Sound

4.4.1 RTDS Device and Control

The RTDS is controlled by a low side driver on the PCM112. The software on the PCM112 will operate the RTDS for 3 seconds when the car is put into drive mode.

Make / Model:	PUI Audio, Inc. X-2629-TWT-R
Control Voltage:	14V
SPL at 2m:	81 dB
Datasheet:	Datasheet

Table 4-5 - RTDS Specifications

4.4.2 Ready to Drive Mode Demonstration

1. Turn LVMS and TSMS to the ON position to give the car power
2. Press the key switch to turn the ECU ON
3. Press the set/reset button to set the shutdown circuit
4. Press the Ready-To-Drive button while pressing the brake pedal

4.5 Discharge Circuit

4.5.1 Discharge Circuit Component Specifications

Make / Model:	Caddock / MP850-1.00K-1%
Resistance:	1000Ω
Voltage:	300V
Power:	50W
Power @15sec:	N/A (Datasheet says 2X for 5sec)
Datasheet	Datasheet

Table 4-6 - Discharge Resistor Specifications

energy_precharge_event = (1/2) *C * V^2 = 19.18 J
precharge_time = 3 * R * C = 1.8123 secs
power = energy_precharge_event / precharge_time = 11W
peak_power = V^2 / R = 64W

The peak power seen during a precharge/discharge event will be 64W and the power dissipation will then decay exponentially as the DC bus link capacitors are charged/discharged. The capacitors will be charge to 90% of their bus voltage in 1.81 seconds and the capacitors will discharge to less than 60V in 0.867 seconds. Thus, selecting a resistor rated at 100W for 5 seconds satisfies these requirements.

Make / Model:	Omron / G2RL-24 DC12
Contact Current Rating:	8A
Contact Voltage Rating:	440 VAC, 300 VDC
Datasheet:	Datasheet

Table 4-7 - Discharge Relay Specifications

Capacitance of the TS bus
DCDC Converter: 4.1uF
Inverter DC Link: 600uF
TS bus: 604.1uF

Time to discharge to <60V
Discharge time = R * C * log(V/60) = 1KΩ * 604.1uF * log(252V/60V = **0.867 seconds**

4.5.2 Discharge Circuit Location

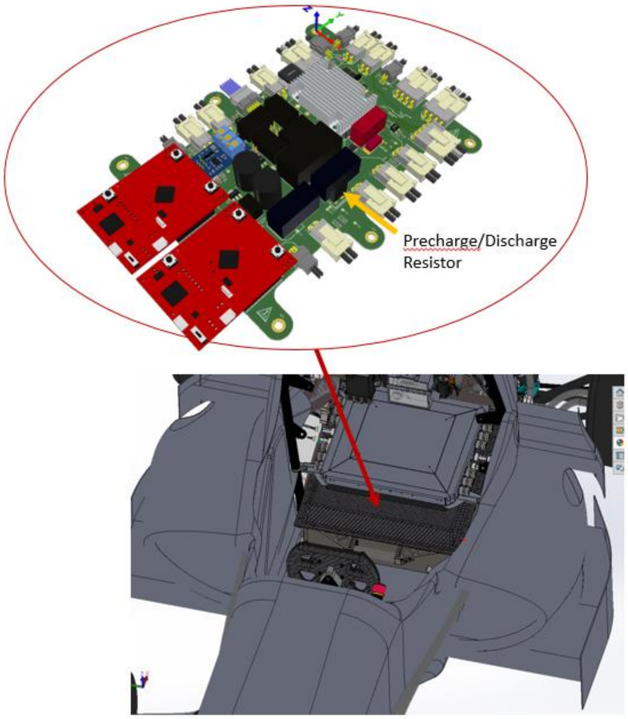


Figure 4-7 - Discharge Circuit Component Locations

4.5.3 Discharge Circuit Control

The normal position of the relays in our precharge/discharge circuit result HV+ being connected to HV- across the precharge/discharge resistor when everything is powered off.

4.5.4 Discharge Circuit Demonstration

1. Activate the tractive system
2. Measure HV at TSMPs to ensure contactors closed
3. Hit shutdown button to open shutdown circuit
4. Measure HV at TSMPs to check if capacitors discharged across resistor (should read 0V)

5 Accumulator

5.1 Accumulator Schematic

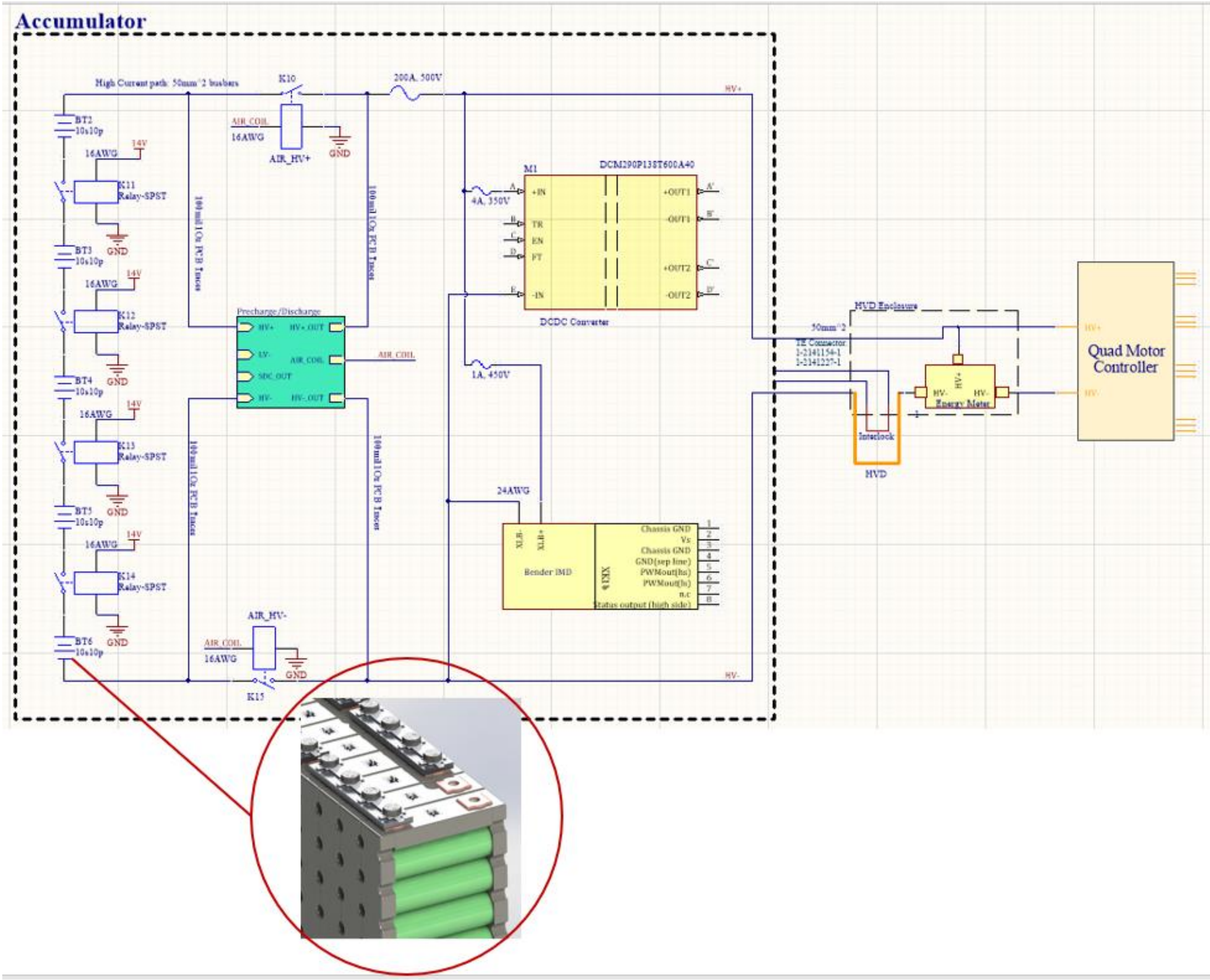


Figure 5-1 - Accumulator Schematic

5.2 Cells

5.2.1 Cell Specifications

Cell Make / Model / Style:	SONY US18650VTC6 Cylindrical
Cell nominal capacity:	3120 mAh
Maximum Voltage:	4.20 V
Nominal Voltage:	3.60V
Minimum Voltage:	2.50 V
Maximum output current:	15C
Maximum continuous output current:	10C
Maximum charging current:	0.96C
Maximum Cell Temperature (discharging)	60°C

Maximum Cell Temperature (charging)	45°C
Cell chemistry:	Lithium Ion

Table 5-1 - Cell Specifications

5.2.2 Cell Electrical Configuration

Our battery pack is a 60s2p configuration of modules developed by Energus Power Solutions. Each module contains 5 cells in parallel. Thus, in terms of individual cylindrical cells, the battery pack is a 60s10p configuration.

5.2.3 Cell Connections

The individual cells are packaged into modules by Energus Power Solutions. A rendering is provided how the cells are connected. The modules are then connected using busbars with a cross sectional area of 50mm^2 and ampacity of 350A. Positive locking is achieved using tab washers. Once all four bolts on each busbar are torqued down, the tabs are bent up around the bolt head to prevent rotation.

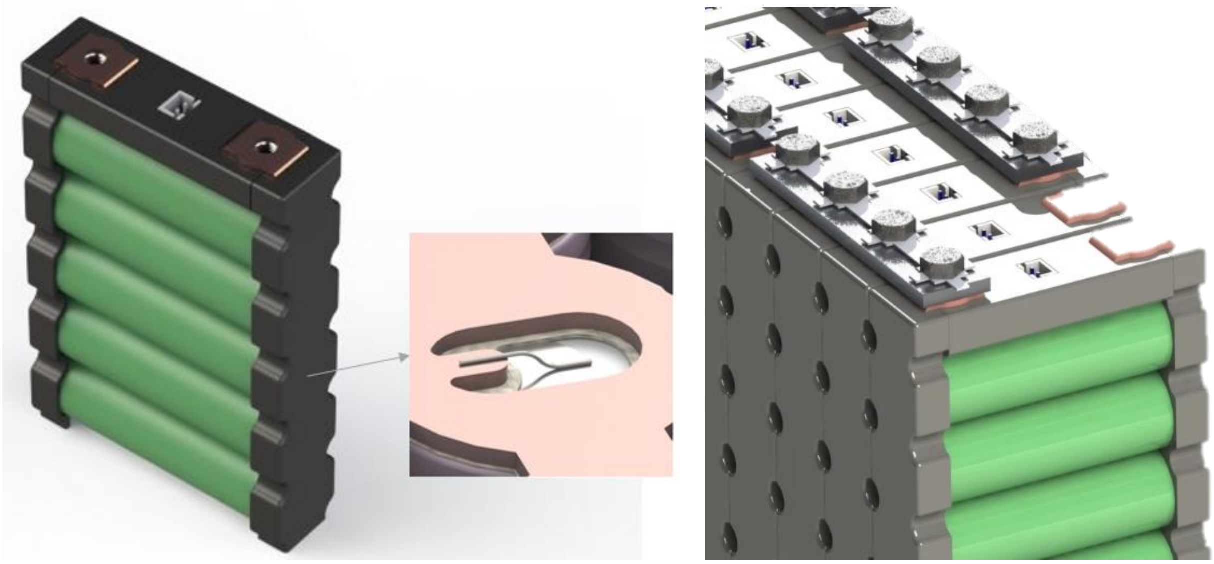


Figure 5-2 - Cell Connection Detail

5.2.4 Parallel Cell Overcurrent Protection

Each cell is connected to the module busbar with a 45A fusible link as shown above. Thus, the fuse rating is 225A per module and 450A for two modules in parallel. The main fuse in the high current path is rated for 200A and is "fast acting." In the event of an overcurrent condition, this main fuse will blow long before the cell level fuses blow.

5.2.5 Cell Mounting

The cell modules are placed vertically in the accumulator container and connected by the busbars. A 0.25 inch sheet of polycarbonate is placed on top of the busbars to insulate the cells from the other low voltage components within the pack. Two L straps are placed across the polycarbonate sheet to retain the cells.

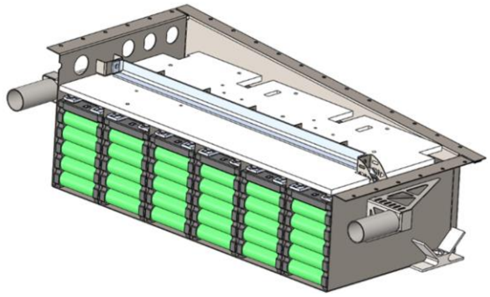


Figure 5-3 - Cell Mounting in Accumulator

5.3 Segments

5.3.1 Segment Specifications

# of Segments:	6
Cells per segment:	100
Cell configuration in segment:	10S10P
Energy in segment:	4.03MJ / 1.12kWhr

Table 5-2 - Segment Specifications

5.3.2 Segment Physical Isolation

The Energus battery modules come as a set of five 18650 cells encased on the top and on the sides by a structural UL94-V0 plastic. This layer of structural plastic ensures that the cells do not come into contact with the accumulator container. The modules are packaged into 6 rows of 20 bricks, separated by walls of 4130 steel. When packaged into their sections, the only visible surface of the battery brick is the top. The top plastic layer on the battery would prevent dropped tools from damaging the cells. The segments themselves are also physically isolated from other low voltage components by means of a 0.25" sheet of polycarbonate, which rests on top of the busbars connected to the cells. This sheet (as well as 3D printed busbar covers) ensure that there is no way of dropping a tool onto the batteries or any other part of the high-voltage path.

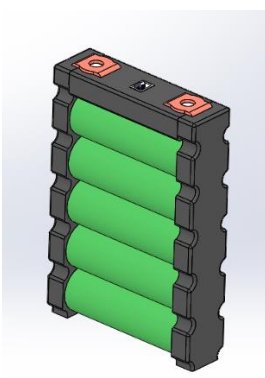


Figure 5-4 Energus Cell Module

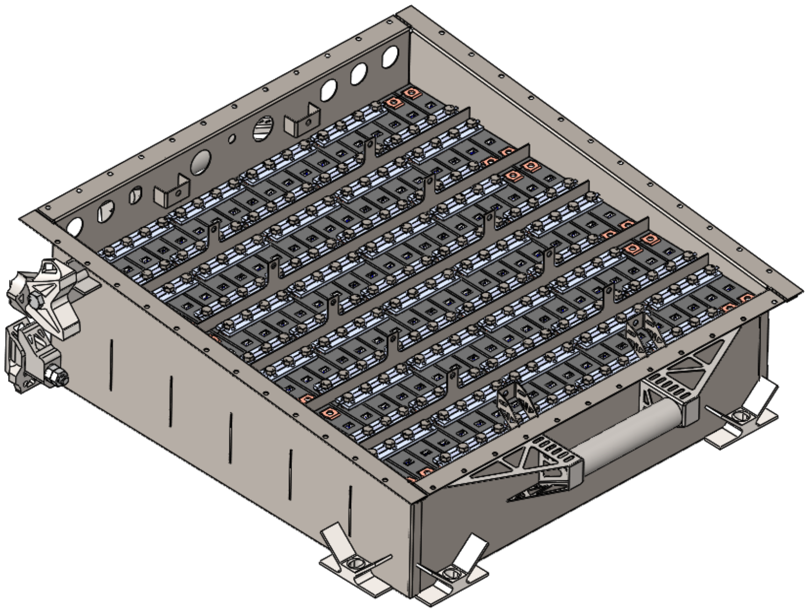


Figure 5-5 Cells packaged into the accumulator container

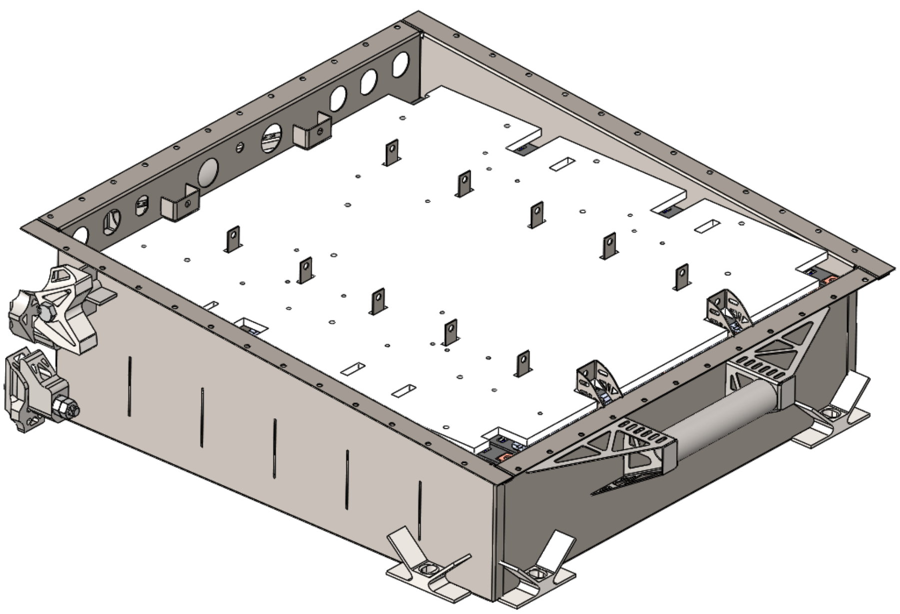


Figure 5-6 Polycarbonate cover on the cell modules and bus bars

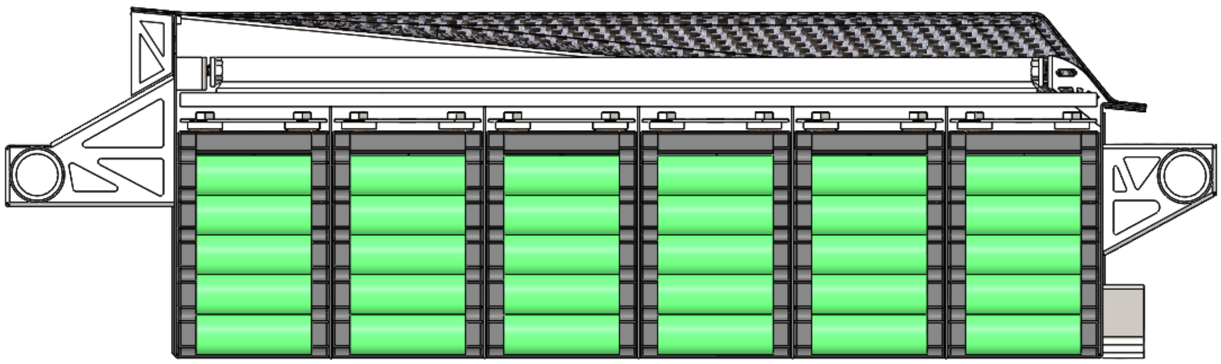


Figure 5-7 Cross section showing the polycarbonate on top of the cell modules and bus bars

5.3.3 Maintenance Plugs

Contactors are used to separate segments (10s2p) of the pack. Thus, when separated, the max voltage present in the accumulator segment is 42 volts. The contactors close when GLV is turned on.

Make / Model:	TE EVC 250
Ampacity:	250A
Voltage:	500V
Datasheet:	Datasheet

Table 5-3 - Maintenance Plug Connector Specification

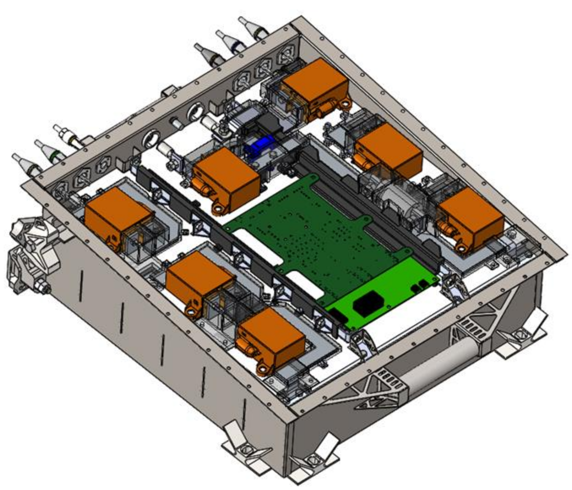


Figure 5-8 – Segment Separator Locations, Contactors Shown in Orange

5.3.4 Maintenance Plug Positive Locking

The segment separators are connected to the bus bars using tab washers so the cannot unintentionally come loose.

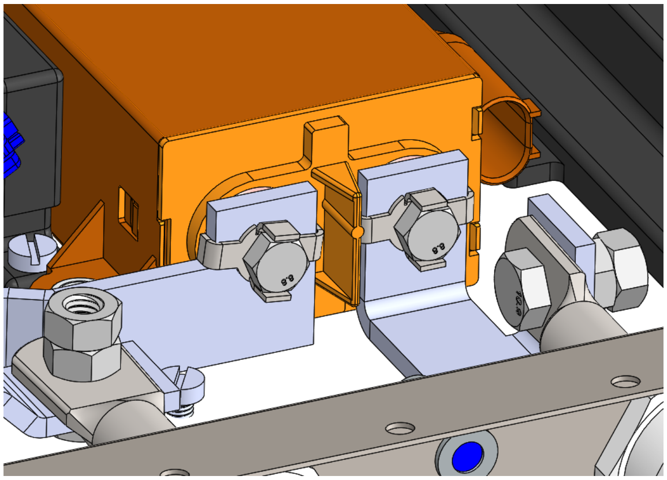


Figure 5-9 Segment separator showing the tab washer

5.3.5 Maintenance Plug Unique Configuration

Not applicable. We are using contactors to separate accumulator segments. The contactors are all the same and can be used interchangeably.

5.3.6 Maintenance Plug Demonstration

The segment separators are installed such that only one terminal of the contactor is exposed at one time. High voltage gloves, safety glasses, and insulated tools shall be used.

1. Install the first busbar
2. Attach segment separator to the first busbar
3. Cover the first terminal and busbar of the segment separator with plastic housing
4. Install the second busbar and attach it to the segment separator relay
5. Cover the second terminal and busbar of the segment separator with plastic housing
6. Connect segment separator relay control signal to the Battery Master Board

5.4 Precharge Circuit

5.4.1 Precharge Circuit Component Specifications

Make / Model:	Caddock / MP850-1.00K-1%
Resistance:	1000Ω
Voltage:	300V
Power:	50W
Power @15sec:	N/A (Datasheet says 2X for 5sec)
Datasheet	Datasheet

Table 5-4 - Precharge Resistor Specifications

The precharge resistor is the same as the discharge resistor. Precharge/discharge resistor power is dissipated with this heatsink.

Make / Model:	Omron / G2RL-24 DC12
Contact Current Rating:	8A
Contact Voltage Rating:	440 VAC, 300 VDC
Datasheet:	Datasheet

Table 5-5 - Precharge Relay Specifications

5.4.2 Precharge Circuit Location

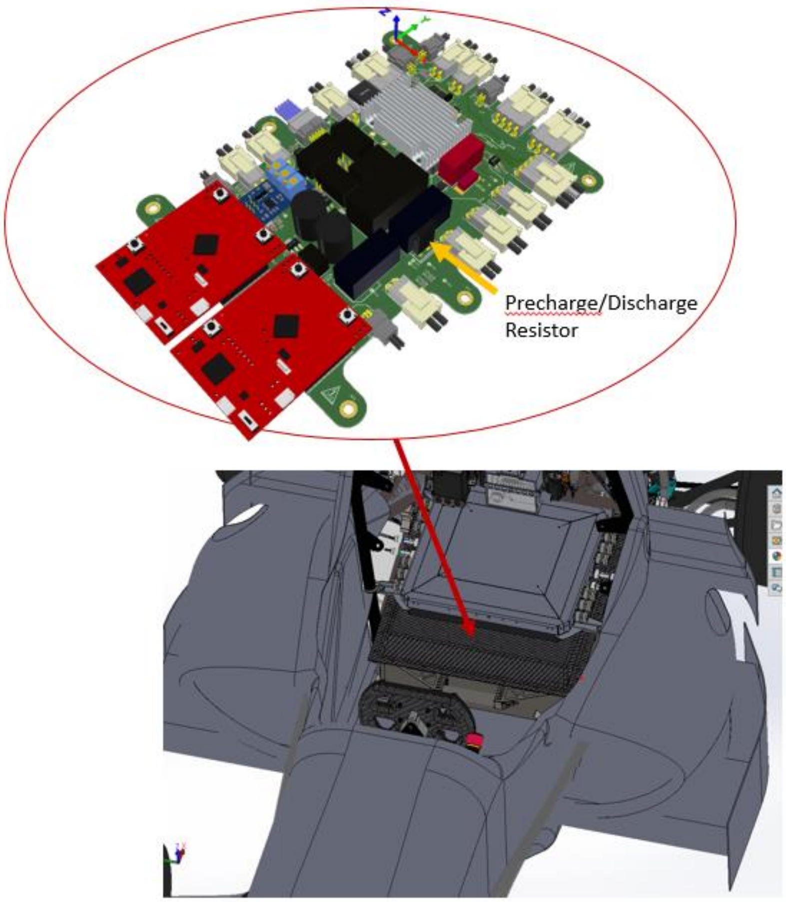


Figure 5-10 - Precharge Circuit Location

5.4.3 Precharge Circuit Controls

The output of the shutdown circuit is connected to the input of the precharge/discharge circuit. Once all devices in the shutdown circuit close, the K2 relay closes and HV_IN is connected to HV_OUT across the precharge resistor. At this point in time, the timer relay (K3) begins. This timer determines the precharging time and is set with a potentiometer on the relay. Once the timer is up, the SDC output will be connected to the AIR coil and the AIRs will close.

To calculate the value needed, we created a MATLAB script. We have 600uF of capacitance inside our motor controllers and 4.1uF of capacitance on our DC-DC converter

```
% User inputs
C = 604.1*10^-6;  % capacitance [Farads]
V = 252;          % bus voltage [Volts]
R = 1000;         % precharge resistor [Ohms]
fprintf('\n Actual Resistor: %i ohms', R);
```

```
actual_I = V / R;
fprintf('\n Current: %g amps', actual_I);

actual_precharge_time = 3 * R * C;
fprintf('\n Actual Precharge Time: %g seconds', actual_precharge_time);

% time to discharge to 60V
% make sure less than 5 seconds as per EV5.1.3
discharge_time = R * C * log(V/60);
fprintf('\n Discharge time to drop below 60V: %g seconds', discharge_time);

% actual energy dissipated over the precharging event
E = (1/2) *C * V^2;
power = E / actual_precharge_time;
fprintf('\n Power dissipated during precharging event: %g watts', ceil(power));

% maximum power dissipated by resistor
max_power = V^2 / R;
fprintf('\n Peak Power: %g watts', ceil(max_power));
```

Based on the calculations above, we get the following results

Actual Resistor: 1000 ohms
Current: 0.252 amps
Actual Precharge Time: 1.8123 seconds
Discharge time to drop below 60V: 0.866935 seconds
Power dissipated during precharging event: 11 watts
Peak Power: 64 watts

5.5 BMS

5.5.1 BMS Specifications

We are developing a custom BMS this year with a distributed architecture where there is a slave board directly connected to each battery segment and that communicates with a master board over an isoSPI protocol. This protocol is the only interface between the master and slave board and is isolated using pulse transformers.

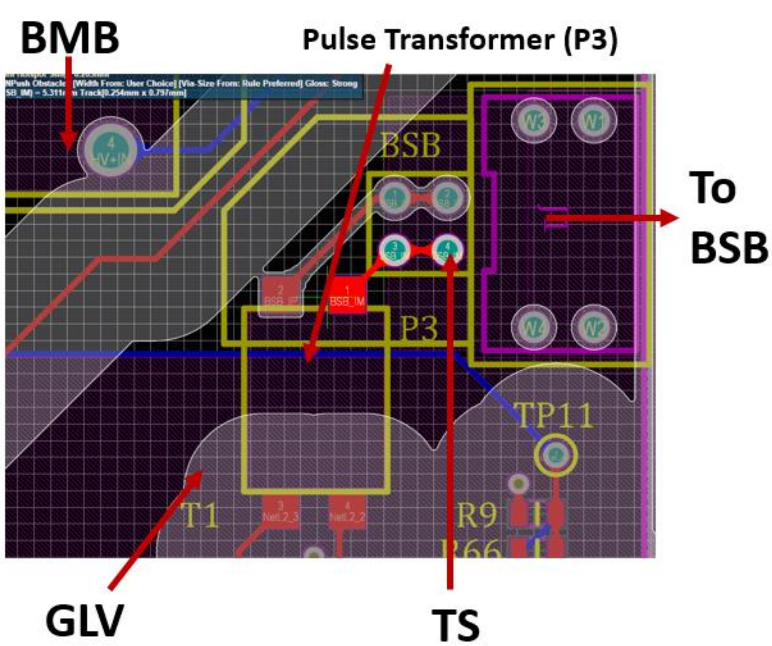
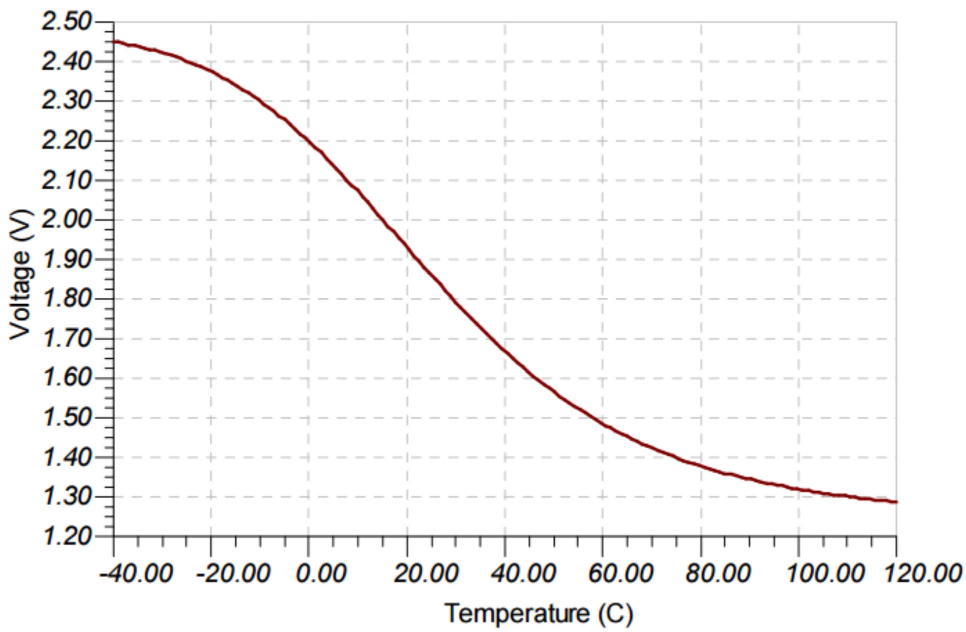


Figure 5-11 –Isolation between TS and GLV on battery master board

5.5.2 Temperature Sensors

Make / Model:	Texas Instruments LM 135
Accuracy of sensor:	Max: 1 deg C in operating range -20 to 60 C
Datasheet:	[Datasheet]
# of sensors:	5
% of cells sensed:	100%

Table 5-6 - Temperature Sensor Specifications



The temperature sensors are read by a LTC6811 BMS IC. In the 7kHz cutoff frequency filter mode, the total measurement error is maximum +/-2.2mV over the IC temperature range of -40 to 125 degrees C.

Figure 5-12 Temperature Voltage Curve

5.5.3 Temperature Sensor Location

The temperature sensors are built into the cell module and attached to the negative pole of the cells. There are 5 sensors per module and they are OR'd together such that the highest temperature will be read.

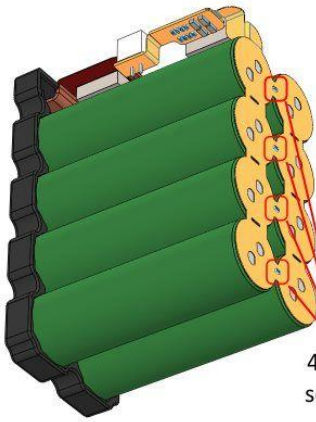


Figure 5-13 - Location of Temperature Sensors

5.5.4 BMS Voltage Sense Leads

The cell modules are directly bolted connected to the Battery Slave Board. A trace runs from the mount hole to the cell monitoring IC.

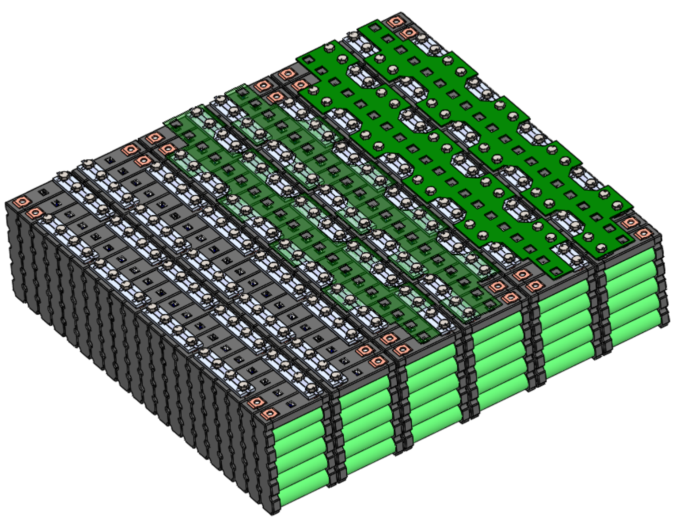


Figure 5-14 The cell modules on the right show the connection to the battery slave board pictured in green. The cell modules on the left are shown without the battery slave board

5.5.5 BMS Voltage Sense Lead Overcurrent Protection

Max Voltage	125V
Datasheet	Datasheet
Current Rating	250 mA
Breaking Capacity at 125V	50A

The traces in the PCB that connect to the cell modules are 30 mil. The Battery Slave Board is a 1 oz board so these traces can carry 0.7 A.

5.5.6 BMS Limits

Max Cell Voltage:	4.25V – 2.2mV
Min Cell Voltage:	2.00V + 2.2mV
Max Temperature:	59°C
Min Temperature:	-9°C

Table 5-7 - BMS Setpoints

The BMS IC that reads the cell voltages has a maximum total measurement error of 2.2mV in the 7kHz cutoff frequency filter mode over the temperature operating range of the IC of -40 to 120 degrees C. This same IC is used to measure the temperature sensor. The temperature sensor has a maximum 1 degree C error over the operating range of the battery -10 to 60 degrees C.

5.5.7 BMS Location

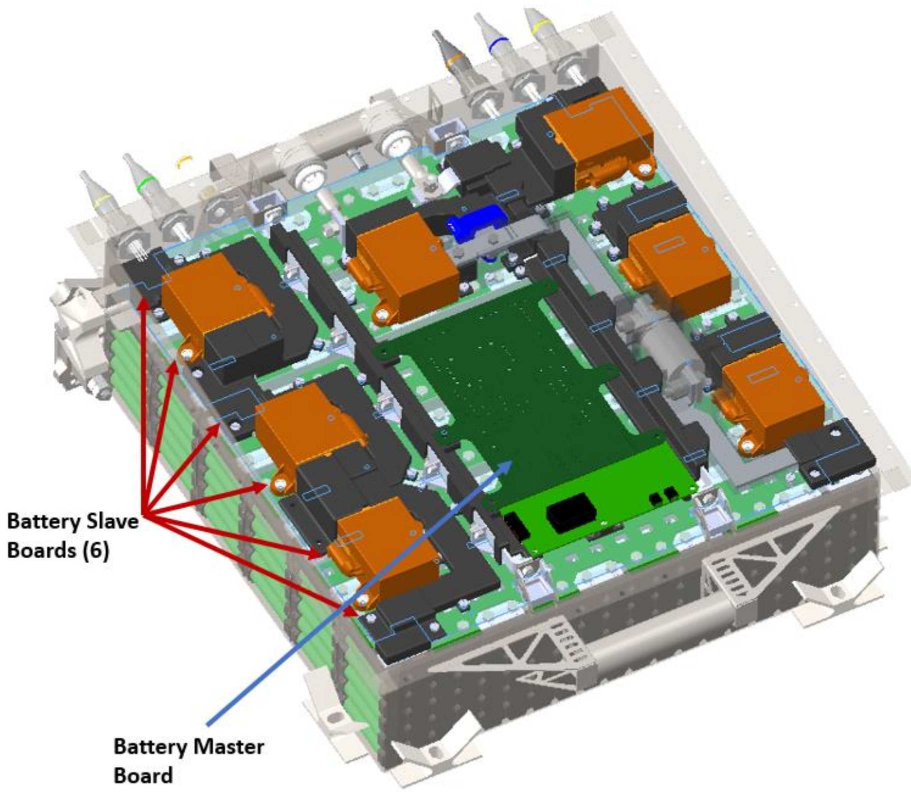


Figure 5-15 - BMS Location

5.6 AIR

5.6.1 AIR Specifications

Make / Model:	TE EVC250
Contact Current:	250A
Contact Voltage:	500V
Datasheet:	Datasheet

Table 5-8- AIR Specifications

5.7 Accumulator Indicator

5.7.1 Accumulator Indicator Schematic

Make/Model	APEM Q Series Panel Mount LED Indicator
Color	Blue
Operating Current	40 mA
Operating Voltage	10.8 to 13.2VDC
Datasheet	Datasheet

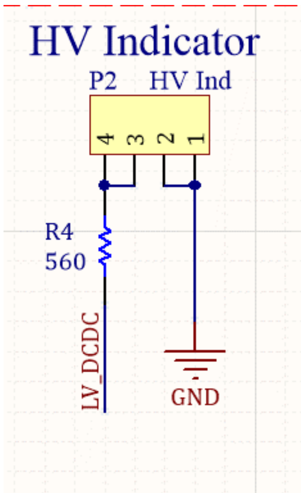


Figure 5-16 - Schematic of Accumulator Indication

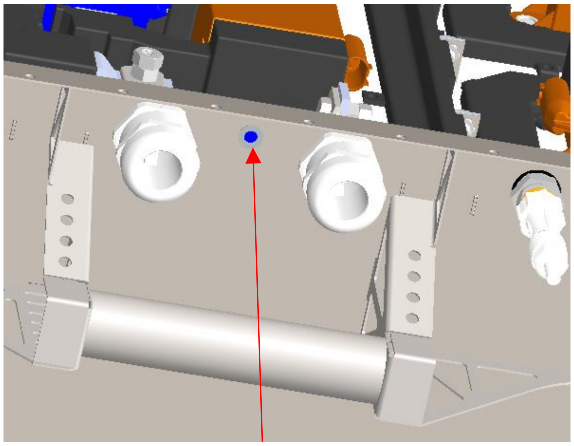


Figure 5-17 Accumulator Indicator

The accumulator Indicator is powered off the DC-DC Converter in the accumulator container, which is directly driven off the HV bus. Whenever the AIRs are closed, the DCDC will be on and the accumulator indicator will be illuminated.

5.8 Mechanical

5.8.1 Accumulator Enclosure

The chassis of the accumulator container is created from 4130 sheet steel. This sheet is laser cut, bent, and welded together with internal vertical walls, which separate the accumulator into 6 sections, each containing a maximum voltage of 42 V and a maximum energy of 4.03 MJ. The cell modules are electrically isolated from the 4130 chassis by means of a structural UL94 V-0 plastic that encases the cells. The segments have a 0.25” polycarbonate sheet above them which is retained by two L-shaped straps. This sheet, in addition to 3D printed busbar covers, will cover all portions of the high voltage path and separate it from both the accumulator container and all low voltage components above the polycarbonate isolation sheet including the main pack fuse, contactors, Battery Master board, and LV wiring.

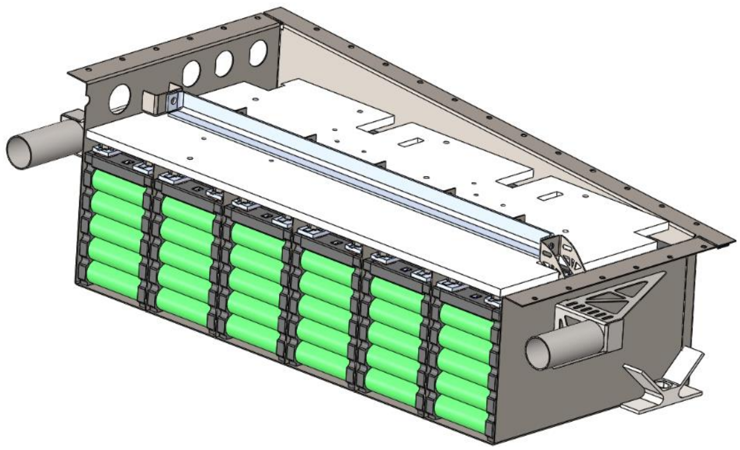


Figure 5-18 Cross section of accumulator container showing polycarbonate sheet isolation

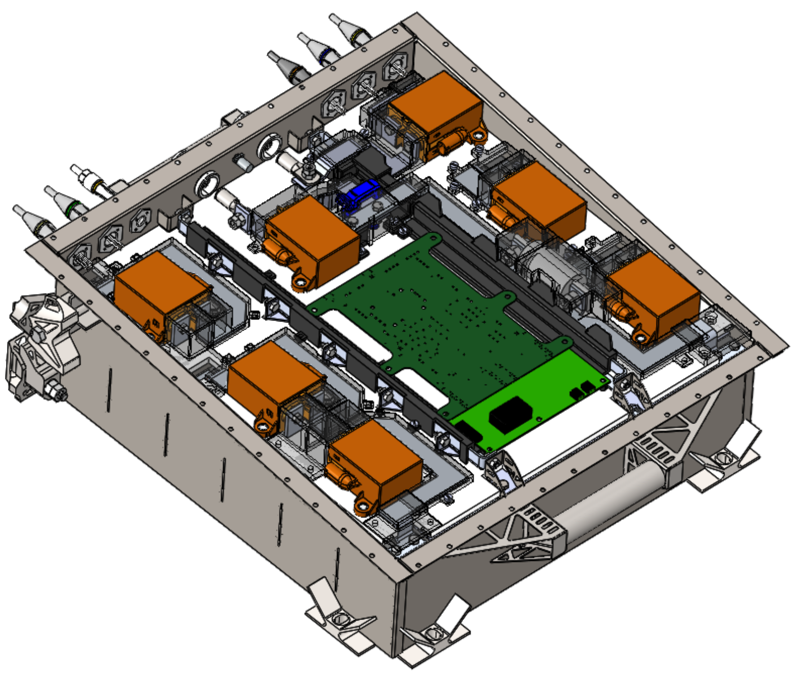


Figure 5-19 Accumulator container with plastic covers shown transparent to show HV fuse

5.8.2 AIR and Fuse Separation

The fuse and AIRs are separated from the cells by means of a 0.25” polycarbonate isolation sheet. The fuse is additionally encased by a UL94 V-0 3D printed plastic.

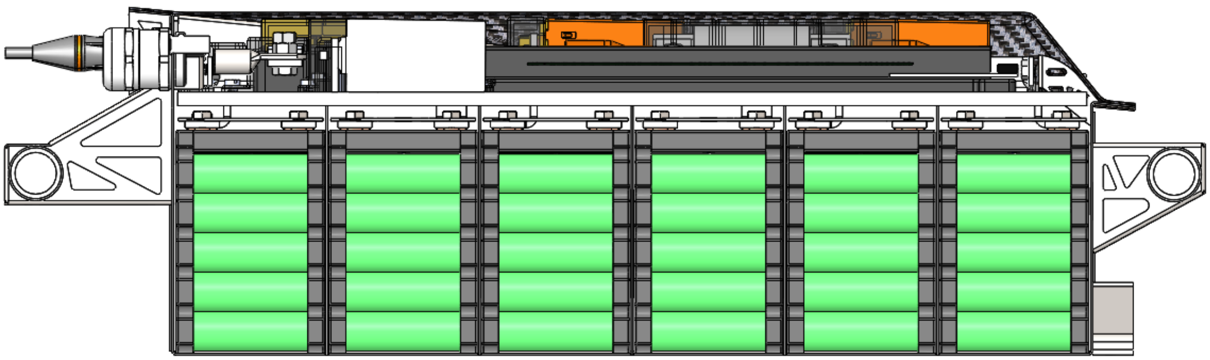


Figure 5-20 - AIR and Fuse Separation

5.9 Charging

5.9.1 Charger Specifications

Make / Model:	Eaton Vehicle Mounted Hybrid Battery Charger P/N 4307212
Power:	5kW
Output Voltage:	428VDC (Max)
Output Current:	16A (Max)
Input Voltage:	120/240VAC
Input Current:	30A (Max)
Datasheet:	Datasheet

Table 5-9 - Charger Specifications

5.9.2 Charging Shutdown Circuit

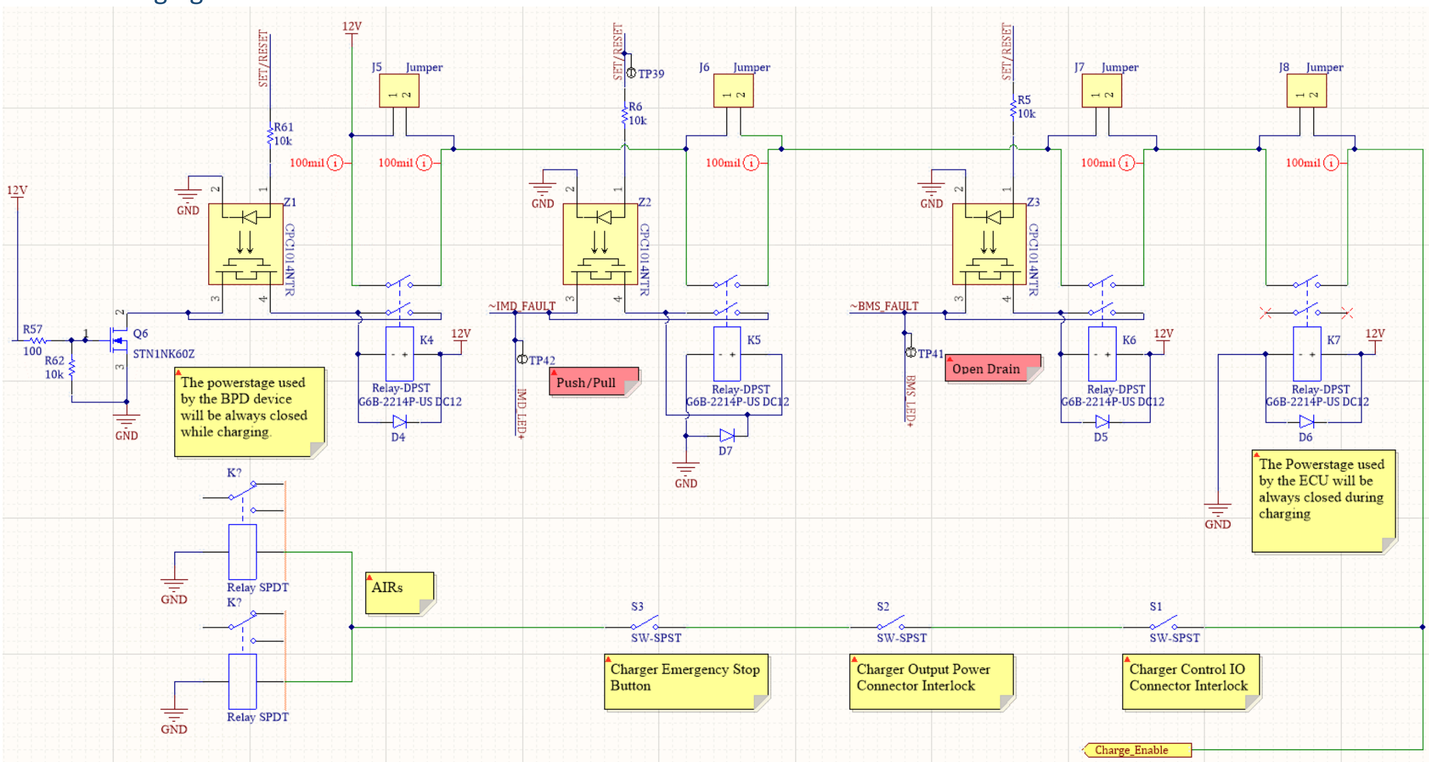


Figure 5-21 - Charging Shutdown Circuit Schematic

5.9.3 Charging TS Circuit

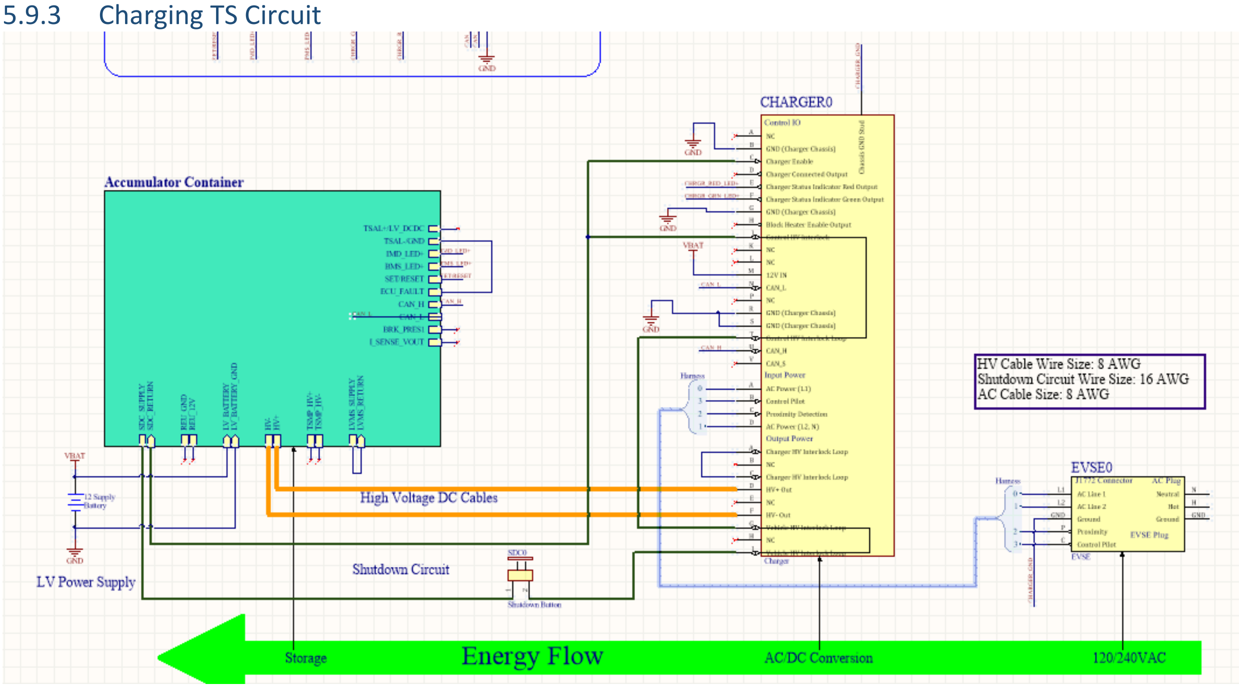


Figure 5-22 - Charging TS Schematic

The Charger is controlled by the BMS over CAN. The BMS can stop charging two ways, sending the CAN message to stop charging and open the shutdown circuit which will isolate the HV battery and de-assert the charge enable input on the charger. Charging will not be allowed if any of the interlocks are not present that are listed in 5.9.4. 8 AWG cable will be used to connect the HV and AC connections to the Charger to the Accumulator and to the J1772 Plug. 16 AWG wire will be used for the charger shutdown circuit and low voltage power to the charger. 22 AWG wire will be used for the charger communication and indicators. The charger uses MIL C 5015 Connectors of service rating A (voltages up to 700 VDC).

5.9.4 Charger TS Connection Interlock

The charger has 3 connectors: Input Power, Output Power, and Control IO. The input power connector follows the SAEJ1772 standard and will not be energized unless connected. The output power and control IO connectors contain interlocks that are a part of the shutdown circuit. The output power connector also contains an interlock in the harness, so it must be connected before the charger will output power. The high voltage connector from the accumulator container to the charger contains an interlock that is a part of the shutdown circuit, so it must be connected to become energized.

5.9.5 Charger Control

The BMS controls the charger using a CAN message. It can stop the charger by setting *Charge Enable* to 0. If the charger does not receive this CAN message for more than 1 second, it will disable itself. The charger has a hardware enable signal that will be connected to the output of the shutdown circuit from the accumulator container. If the BMS or any other device opens the shutdown circuit, the charger will be disabled.

3.3.2 Command

Message Name	Command
Transmission Rate	100ms
Data Length	8 Bytes
Default Priority	0x6
PGN	0xFF4A
Source Address	0xEF

Start Bit	Length (bits)	Signal	Reference
0	2	Charge Enable	3.3.2.1
2	2	Charge Complete	3.3.2.2
4	2	Charge System Fault	3.3.2.3
8	12	Voltage Limit	3.3.2.4
20	12	Current Limit	3.3.2.5
56	4	Message Counter	3.3.1.10
60	4	Message Checksum	3.3.1.11

Figure 5-23 BMS Charger Control CAN Message

5.9.6 Charger Demonstration

Describe numbered steps you would use to demonstrate the safe operation of charging, include how to connect, and how to disconnect. Include any safe use practices, as well as what to look for proper operation vs. a faulted condition.

1. Ensure the charger is unplugged from AC Power.
2. Make the 3 connections to the charger – Control IO Connector, Input Power Connector, and the Output Power Connector.
3. Connect the HVD HV Connector coming from the accumulator container to the Output Power Connector on the Charger.
4. Connect the MISC Connector to the accumulator container
5. Connect the TSMP, LVMS, REU Power covers to the accumulator container
6. Connect the LV Input power connector to the accumulator container

7. Connect the SDC Connector to the accumulator container

All the connectors are circular and have a twist lock. Ensure the connector is locked when connected, and twist again to disconnect. In proper operation the accumulator indicator should be on indicating the AIRs are closed for charging. The charger has two indicators, red and green.

Red Indicator	Green Indicator	Charger State
OFF	OFF	No charge connector is present, or the charger is in sleep mode.
Blinking	OFF	Charge connector detected
OFF	Blinking	Charging
Solid	OFF	Fault
OFF	Solid	Charging Completed

After all connections are made, the BMS will handle all charging control automatically unless a fault occurs which requires team intervention.

6 Motor Controller

6.1 Controls Architecture/Torque Security

A dual output APPS supplied with two different voltages (5V and 3.3V) is used to generate two signal outputs. A microcontroller is used to read the signals. The two signals go through a signal plausibility check to determine if the two signals deviation is less than 5%. If greater than 5%, zero torque will be requested to motor controller. The signals are also checked to make sure they are not out of range. If signals are out of range, zero torque will be requested to motor controller. Based on the APPS signal a percent max torque is determined, known as the pedal requested torque. The pedal requested torque signal is limited based on the power limit of the accumulator, vehicle speed, and traction. A final torque request is created, and the signal is sent to the motor controller. If there is no new torque command received by the motor controller (loss of communication) the motor controller will stop operation.

Figure 6-1 - Torque Control Signal Path

6.1.1 Galvanic Isolation

Inside the inverter, GLV and TS are galvanically isolated up to 600V. All boards that have both TS and GLV on the same board have spacing of 3mm or more and are conformally coated. The physical isolation zones on the PCB were accomplished by implementing clearance rules between HV and LV classes. Any net part of the HV class cannot be within 3mm of an LV net. The components where the GLV and TS interface all have isolation barriers. Phase voltage measurements are isolated using isolation amplifiers, gate signals are isolated using an isolated gate driver, and Hall effect current sensors inherently have a galvanically isolated output.

7 Other Items

7.1 Energy Meter

7.1.1 Energy Meter Location

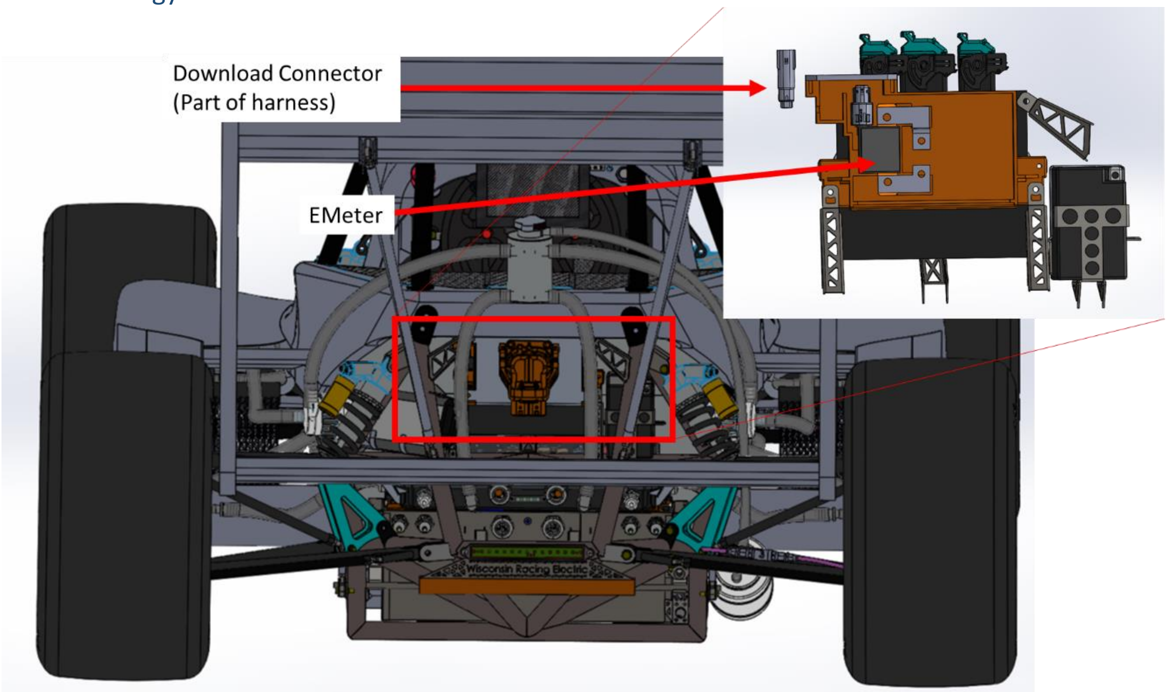


Figure 7-1 - Energy Meter Location

7.1.2 Energy Meter GLV Supply

The energy meter will be supplied with GLV power distributed from the Rear Electronics Unit.

7.1.3 Energy Meter HV Sense

The energy meter is connected to HV+ to measure voltage through a 3 Amp Fuse, and in-line with HV- to measure current. The energy meter is provided at competition.

Datasheet	Datasheet
Interrupt Rating	1500A@400VDC
Voltage Rating	400VDC
Current Rating	3.15A

7.2 Firewall

7.2.1 Firewall Layer Specifications

Aluminum layer thickness:	1mm
Insulating layer thickness:	0.6mm
Insulating Material Make / Model:	DuPont Nomex 410
Insulating Material Datasheet:	Datasheet
Insulating layer side:	Driver

Table 7-1 - Firewall Specifications

7.2.2 Firewall Location

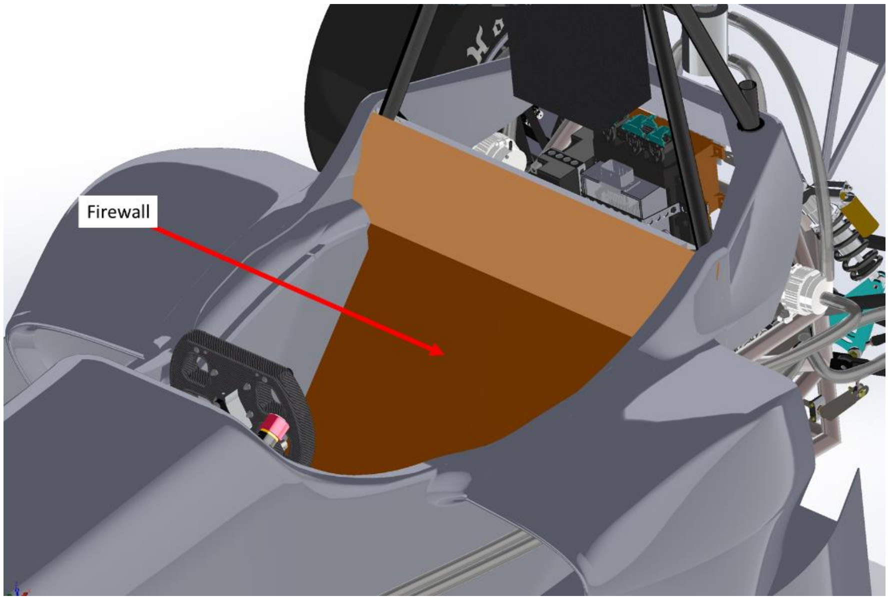


Figure 7-2 - Firewall Location

7.3 Grounding

7.3.1 Composite Grounding

All areas of the monocoque within 100 mm of any tractive system or GLV component will have 0.5 mm aluminum sheeting placed between it and the monocoque ensuring resistance of 300 mOhm (measured with a current of 1A) to GLV system ground. The rear half of the vehicle is a fully conductive steel space frame.

7.4 Other Components

7.4.1 Low Voltage Battery

A Shorai 12V lithium iron phosphate battery is used as the power source for the low voltage system when the tractive system is not active. The 18Ah size was chosen such that it could be used for an entire competition event without recharging and have sufficient capacity to power the fans and pumps as necessary when the tractive system is disabled.

Battery Model:	Shorai LFX18L1-BS12
Supply voltage:	12V
Maximum supply current:	270A
Capacity:	18Ah
Link:	Link

7.4.2 DCDC Converter

Make/Model:	Vicor DCM 290 P 138 T 600 A40
Datasheet	Link
Voltage Output	14.4V
Input Voltage Range:	160 – 420 VDC
Maximum Output Power:	600 Watts

Temperature Range:	-40 to 125 ° C

8 Appendix

8.1 SDS (MSDS) of accumulator cell

Link