2017 Formula Hybrid Electrical System Form (ESF)

INTRODUCTION

The goal of the ESF is to ensure that vehicles are as safe as possible, and that they comply with the Formula-Hybrid completion rules. The ESF is divided seven main sections:

1 – Overview
2 – Cables, Fusing & Grounding
3 – Isolation & Insulation
4 – Electric Tractive System
5 – Accumulator System
6 – Safety Controls and Indicators
7 – GLV System

The *Cables and Fusing,* and *Insulation and Isolation* sections are at the beginning of the ESF as these are the areas where teams most often have trouble in complying with FH rules.

A clear, concise ESF will help you to build a better car. It will also help you to pass tech testing as most common tech problems can be addressed before the car reaches the track.

IMPORTANT INSTRUCTIONS AND REQUIREMENTS

1. Every part of this ESF must be filled with content. If a section is not relevant to your vehicle, mark it as "N/A" and describe briefly why not.
2. Please leave the written instructions in place and add your responses below them.
3. All figures and tables must be included. An ESF with incomplete tables or figures will be rejected.
4. The maximum length of a complete ESF is 100 pages.
5. Note that many fields ask for information that was submitted in your ESF-1. This information must be reentered – in some cases will be different than what was entered in ESF-1, which is OK.
6. When completed, this document must be converted to a pdf and submitted to: http://formula-hybrid.com/uploads/

Please submit any questions, corrections and suggestions for improvement to: http://www.formula-hybrid.org/level2/support

REVIEW PROCESS

Once submitted, your ESF will be reviewed by at least two FH reviewers. One will be the designated *primary reviewer* for your team.

Feedback on your ESF occurs through the Formula Hybrid upload system. You will receive emails via this system from your reviewers offering guidance and feedback. You will also submit revised versions of your ESF in this system. When you submit a revised ESF, please indicate the REVISION DATE AND LETTER (starting with Letter A) and which sections have been updated in the following table:

REVISION DATE:	2/24/17
REVISION: (A, B, C, etc.)	A
Section	Revised (Yes / No)
1 – Overview	Yes
2 – Cables and Fusing	Yes
3 – Insulation and Isolation	Yes
4 – Electric Tractive System	Yes
5 – Accumulator System	Yes
6 – GLV System	Yes
7 – Safety Controls and Indicators	Yes
8 – Appendices / Datasheets	Yes

TITLE PAGE

Please include team logo, car picture, etc..

LAFAYETTE
MOTORSPORTS

University Name: Lafayette College

Team Name: Lafayette Motorsports

Car Number: 217

Main Team Contact for ESF related questions:

Name: Graham Thomas

e-mail: thomasg@lafayette.edu

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III List of Abbreviations

AIR	Accumulator Isolation Relay
AMS	Accumulator Management System
FH Rules	Formula Hybrid Rule
GLV	Grounded Low-Voltage
IMD	Insulation Monitoring Device
PacMAN	Pack manager
SMD	Segment Maintenance Disconnect
TS	Tractive System
TSEL	Tractive System Energized Light
TSMP	Tractive System Measurement Point
TSV	Tractive System Voltage
TSVP	Tractive System Voltage Present

Section 1 Vehicle Overview

Person primarily responsible for this section:

Name: Graham Thomas

e-mail: thomasg@lafayette.edu

Check the appropriate boxes:

Vehicle is

- ☒ New (built on an entirely new frame)
- ☐ New, but built on a pre-existing frame (FSAE, FS, FH-HIP, FH electric-only, etc.)
- ☐ Updated from a previous year vehicle

Architecture

- ☐ Hybrid
  - ☐ Series
  - ☐ Parallel
- ☐ Hybrid in Progress (HIP)
- ☒ Electric-only

Drive

- ☐ Front wheel
- ☒ Rear wheel
- ☐ All-wheel

Regenerative braking

- ☐ Front wheels
- ☐ Rear wheels
- ☐ All wheels
- ☒ None

NARRATIVE OVERVIEW

The accumulator system consists of four containers each producing ~24 V and each monitored by an AMS consisting of our PackMAN and AMS boards. Each of the seven cells within the accumulator container communicates via the AMS boards to the PackMAN, which monitors state of charge, cell voltage, cell temperature, overall voltage, and safety loop status. The high voltage will be entering the TSI System from the accumulator and pass through the IMD to ensure that there are no ground connections to the chassis. This will then be passed onto the motor controller that will determine the voltage to apply to the motor itself.

Include the following figures:

- **Figure 1** – an electrical system block diagram showing all major parts associated with the tractive-system. (Not detailed wiring).
- **Figure 2** – Drawings or photographs showing the vehicle from the front, top, and side
- **Figure 3** – A wiring diagram superimposed on a top view of the vehicle showing the locations of all major TS components and the routing of TS wiring.
- **Figure 4** -- Include a complete TSV wiring schematic per FH Rule EV13.2.1showing connections between all TS components. This should include accumulator cells, AIRs, SMDs, motor controller, motor, pre-charge and discharge circuits, AMD, IMD, charging port and any other TS connections. **NOTE:** Figure 4 is the most important diagram in the ESF

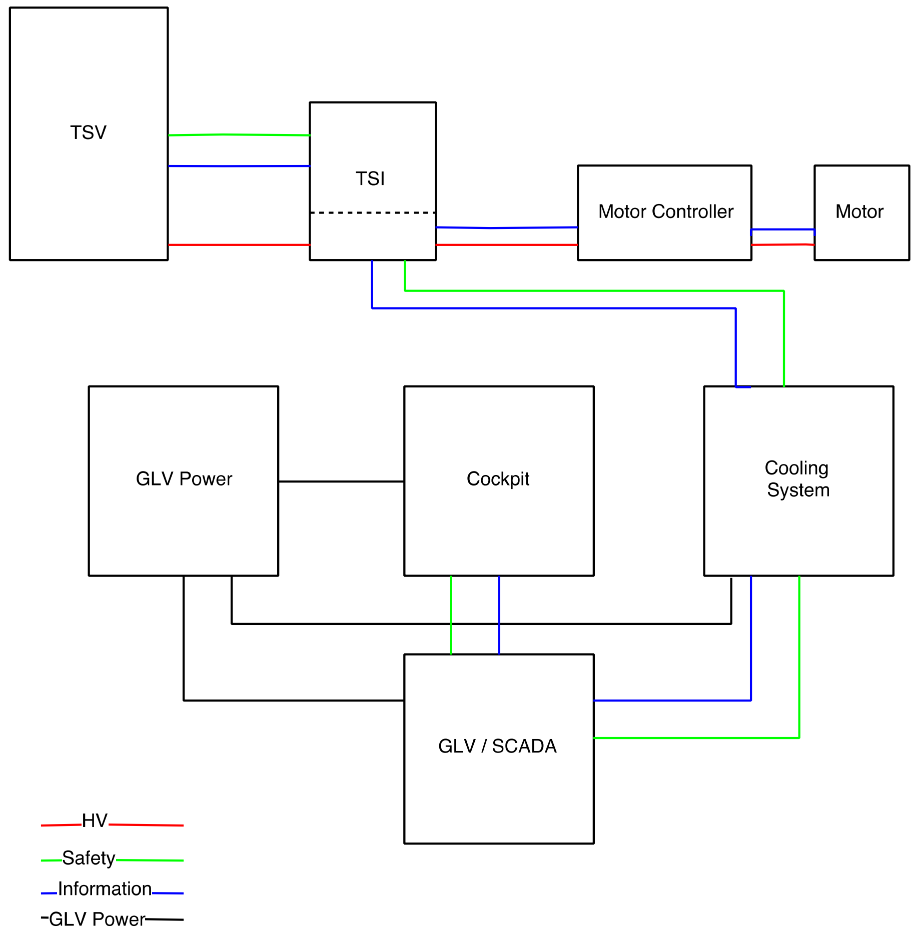

Figure 1 - Electrical System Block Diagram

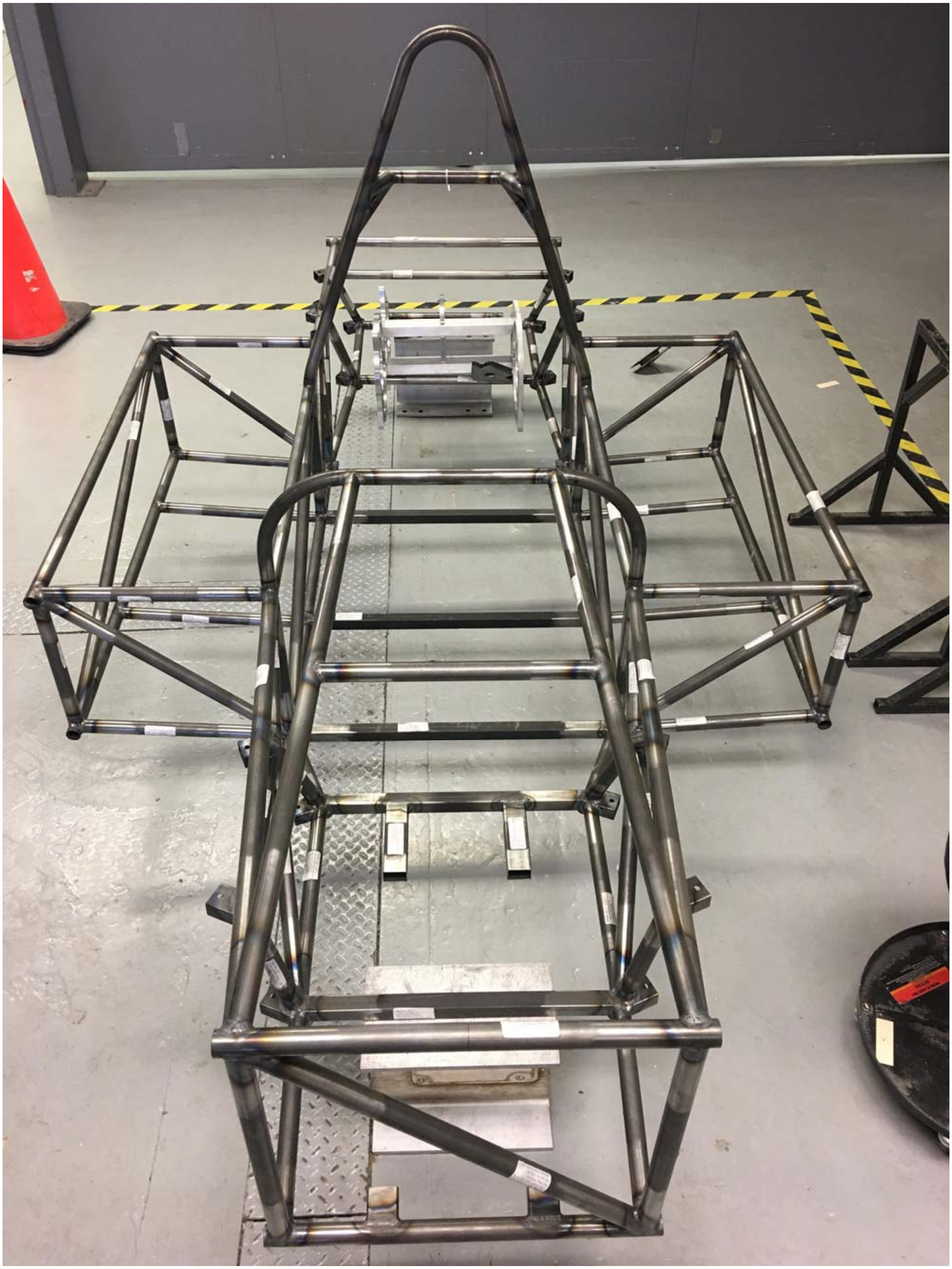

Figure 2 - Drawings showing the vehicle from the front, top, and side

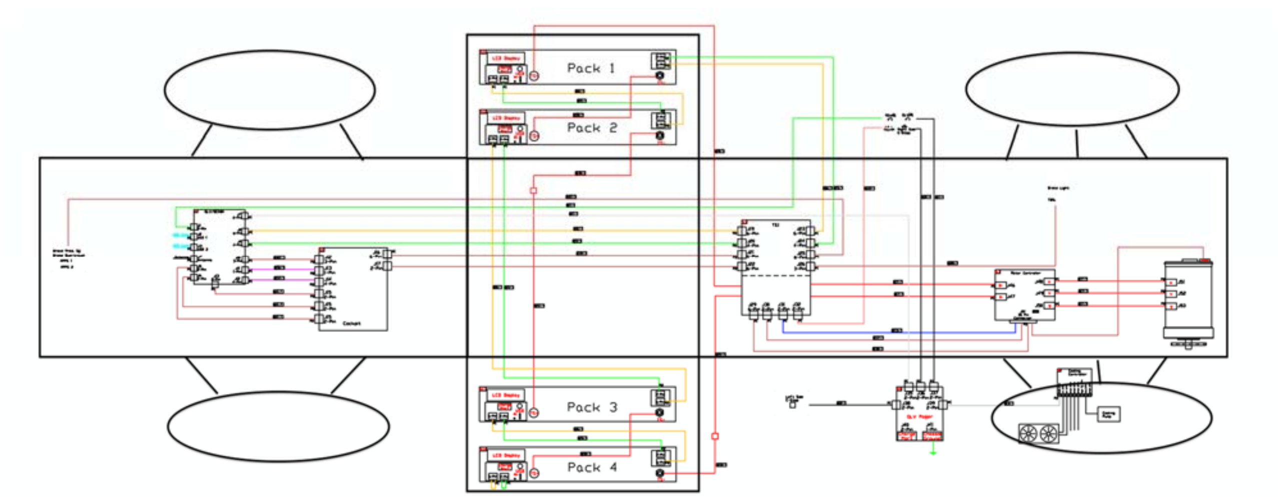

Figure 3 - Locations of all major TS components

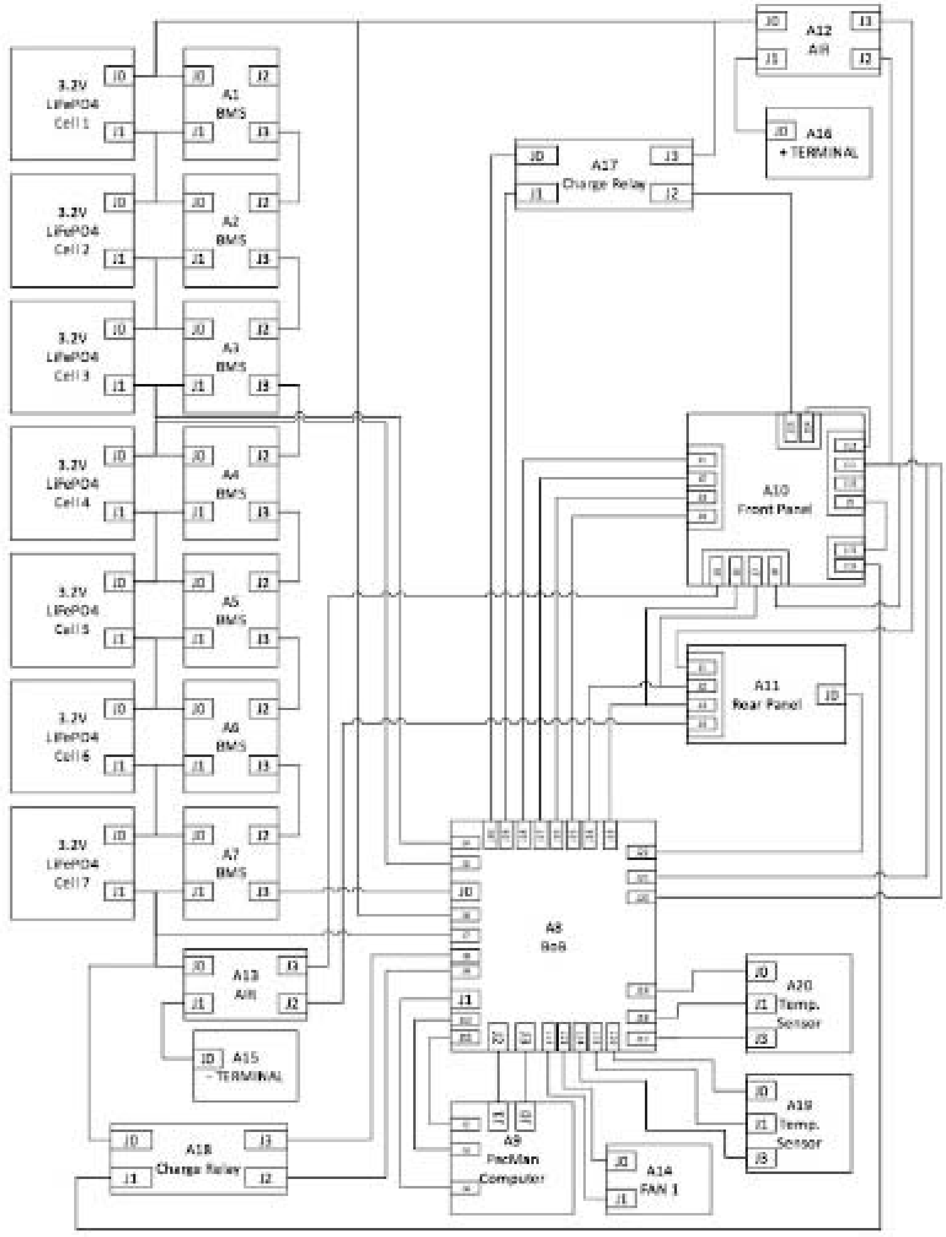

Figure 4 - AMS and PacMAN board wiring

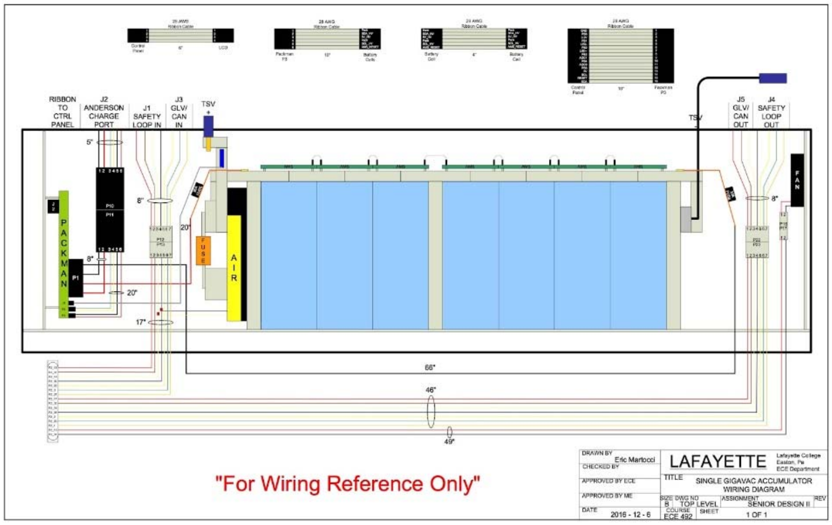

Figure 5 - First pack (with 2 AIRs)

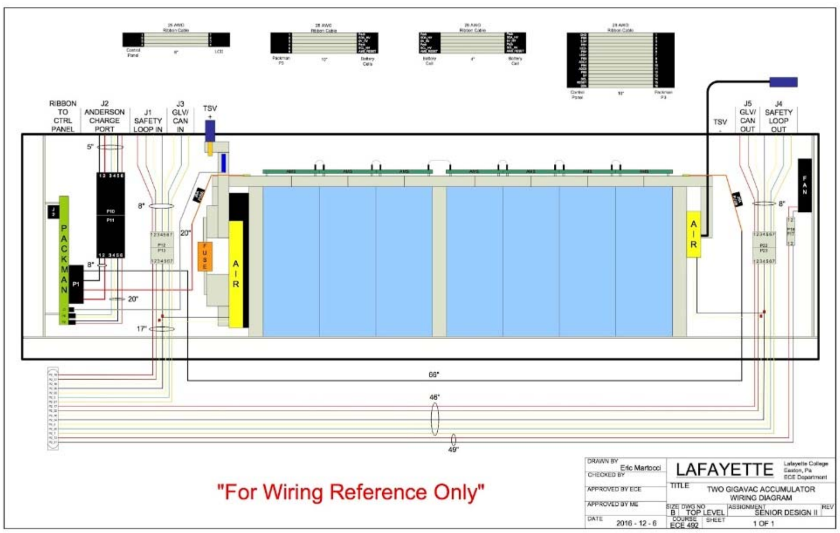

Figure 6 - Packs 2-4 (with 1 AIR)

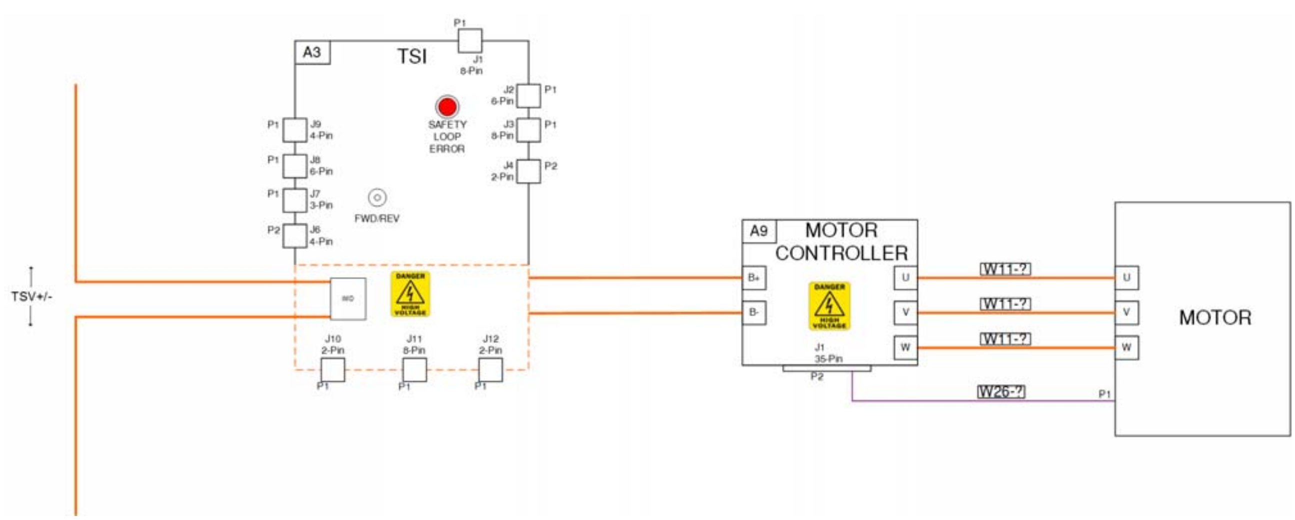

Figure 7 - HV interfaces

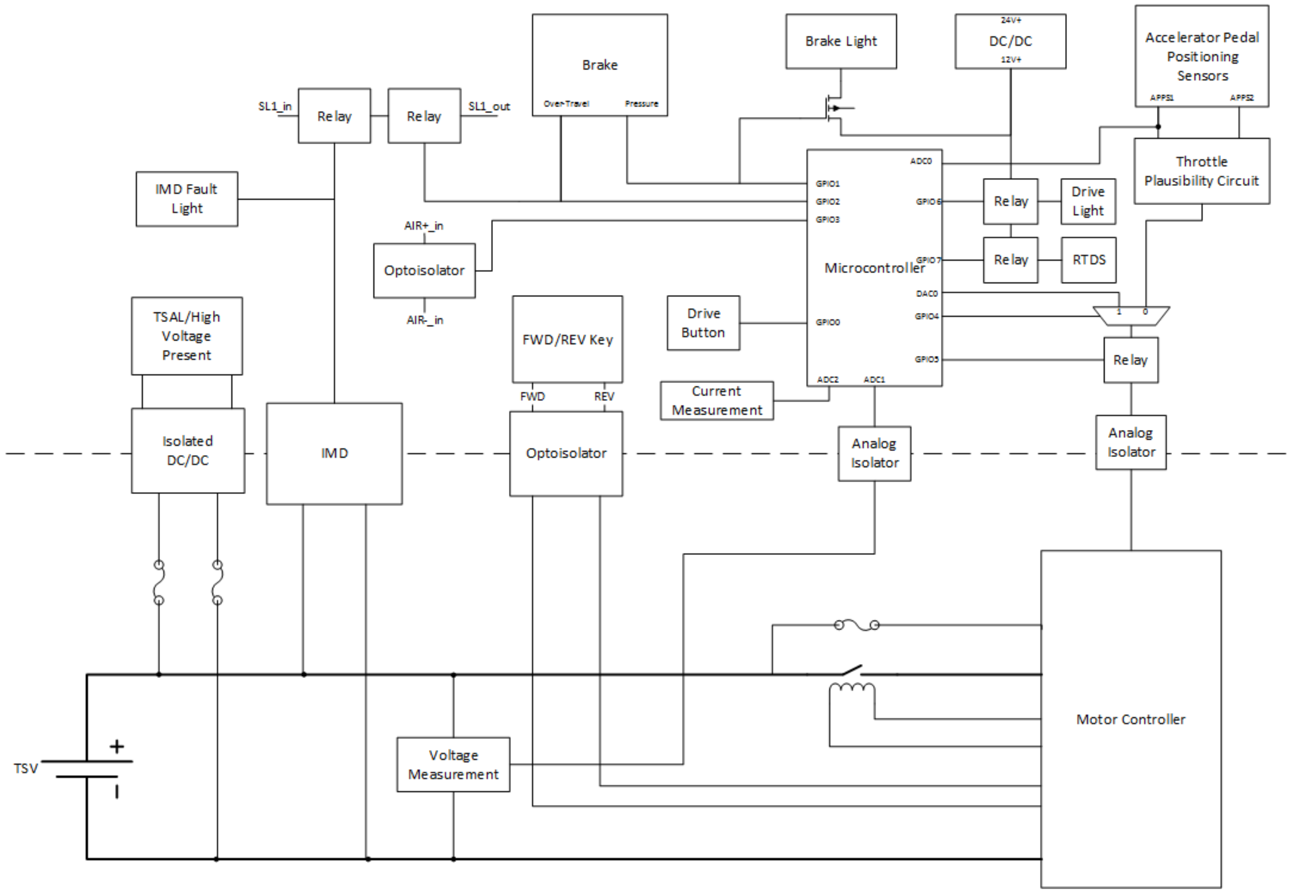

Figure 8 - TSV Wiring Schematic

Fill in the following table:

Item	Data
Nominal Tractive System Voltage (TSV)	89.6VDC
Max. TSV (typically this is during charging)	106.4 VDC
Control System voltage (GLV)	24 VDC
Total Accumulator capacity (Wh)[1]	5.375 kWh
Accumulator type (Lead-acid, Li-Ion, NiMH, Ultracap..)	LiFePO4
Number of electric motors, total	1
Are wheel motors used?	☐Yes / ☒ No

Table 1- General Electrical System Parameters

[1] Calculate accumulator capacity per 2017 FH Rules Appendix A. Be sure to use the 2C (0.5 hour) discharge rate for the Ah value.

Section 2 Cables, Fusing & Grounding

Person primarily responsible for this section:

Name: Greg Flynn

e-mail: flynng@lafayette.edu

2.1 Fusing & Overcurrent Protection

List TS and GLV fuse (or circuit breaker) data, and where used

Mfg.	Fuse Part Number	Cont. Rating (A)	DC Voltage Rating	DC Interrupt Rating (A)	Where Used
Mersen/Ferraz Shawmut	A3T200	200 A	160 V	50,000 AIC	Accumulator container; between the positive input terminal of the first cell and the AIRS.
Littelfuse	0287005.PXCN	5 A	32 V	1 kA at 32 VDC	PacMAN board; separates the incoming high voltage from the accumulator from the 5V in the high voltage section of the PacMAN board.
Littelfuse	0287025.PXCN	25 A	32 V	1kA @ 32 VDC	Accumulator container; one between positive input terminal of the first cell and PacMAN board. One between the negative input terminal of the last cell and the PacMAN board.
Qualtek	QLB-103-11B3N-3BA	10A	32	10A	Safety Loop and GLV power

Table 2 - Fuse Table

2.2 Component Fusing

List major components (e.g., motor controller, dc-dc converter) and data sheet max fuse rating. Ensure that the rating of the fuse used is less than the maximum value for the component

Component	Fuse Part Number	Max Fuse Rating A	Installed Fuse Rating A	Notes

DC-DC Converter (Murata Power Solutions, NCS6S1205C)	0287005.PXCN (LittelFuse)	5 A	5A	On PacMAN board.
Microcontroller (Microchip Technology, AT90CAN128-16AUR)	0287005.PXCN (LittelFuse)	200mA	5A	On PacMAN board.
AMS - PacMAN board	0287025.PXCN (LittelFuse)	25A	25A	In accumulator container; two fuses from positive input terminal of the first cell and the negative input terminal of the last cell both to the PacMAN board.
DC-DC	VYC30W-Q24-S12	2.5A	2.5A	
DC-DC	VYB20W-Q24-S5	4A	4A	
Curtis 1238 Motor Controller KSI	Internal to Motor Controller	1.0A	1.0A	
Curtis 1238 Motor Controller Coil Return	Internal to Motor Controller	12A	12A	

Table 3 - Component Fuse Ratings

2.3 System Wire Tables

*List wires and cables used in the Tractive System and the GLV system - wires protected by a fuse of 1 A or less may be omitted. Cable capacity is the value from FH Rules **Appendix E** (Wire Current Capacity). A revised version of **Appendix E** that includes metric wire sizes is available at the FH web site. Show available fault current and how calculated. Available fault current can be calculated from*

$Fault\ Current = Vsource\ /\ (Rsource\ +\ Rwiring)$

Mfg.	Part Number	Size AWG / mm2	Insul-ation Type	Voltage Rating	Temp. Rating C	Cable Capacity A	Fuse Part #	Fuse Cont. A	Fuse Interr-upting Rating Adc	Avail. Fault Current A	Where Used & How fault current is calculated
CCI	10416	00	EPDM	600 V	-50 to 105	400 A	3203 1T	200 A	-	200 A	Input into container 1
CCI	10416	00	EPDM	600 V	-50 to 105	400 A	3203 1T	200 A	-	200 A	Between containers 1 and 2
CCI	10416	00	EPDM	600 V	-50 to 105	400 A	3203 1T	200 A	-	200 A	Between containers 2 and 3
CCI	10416	00	EPDM	600 V	-50 to 105	400 A	3203 1T	200 A	-	200 A	Between containers 2 and 3
CCI	10416	00	EPDM	600 V	-50 to 105	400 A	3203 1T	200 A	-	200 A	Between containers 3 and 4
CCI	10416	00	EPDM	600 V	-50 to 105	400 A	3203 1T	200 A	-	200 A	Between containers 4 and output
CCI	10416	00	EPDM	600 V	-50 to 105	400 A	3203 1T	200 A	-	200 A	Between containers 4 and output
CCI	10416	00	EPDM	600 V	-50 to 105	400 A	-	-	-	400 A	Between TSI and Motor Controller
CCI	10416	00	EPDM	600 V	-50 to 105	400 A	-	-	-	400 A	Between TSI and Motor Controller
CCI	10416	00	EPDM	600 V	-50 to 105	400 A	-	-	-	400 A	Between TSI and Right Side Control

CCI	10416	00	EPDM	600 V	-50 to 105	400 A	-	-	-	400 A	Between Motor Controller and Motor
CCI	10416	00	EPDM	600 V	-50 to 105	400 A	-	-	-	400 A	Between Motor Controller and Motor
CCI	10416	00	EPDM	600 V	-50 to 105	400 A	-	-	-	400 A	Between Motor Controller and Motor
WTW	WT16-4	16	PVC	60 V	-55 to 80	3.7 A	QLB-103-11B3N-3BA	10 A	10 A	3.7 A	Input into container 1
WTW	WT16-4	16	PVC	60 V	-55 to 80	3.7 A	QLB-103-11B3N-3BA	10 A	10 A	3.7 A	Between containers 1 and 2
WTW	WT16-4	16	PVC	60 V	-55 to 80	3.7 A	QLB-103-11B3N-3BA	10 A	10 A	3.7 A	Between containers 2 and 3
WTW	WT16-4	16	PVC	60 V	-55 to 80	3.7 A	QLB-103-11B3N-3BA	10 A	10 A	3.7 A	Between containers 3 and 4
WTW	WT16-4	16	PVC	60 V	-55 to 80	3.7 A	QLB-103-11B3N-3BA	10 A	10 A	3.7 A	TSI to Cooling Controller

WTW	WT16-4	16	PVC	60 V	-55 to 80	3.7 A	QLB-103-11B3N-3BA	10 A	10 A	3.7 A	GLV/SCADA to Cooling Controller
Prestolite Wire	152077	20	HDPE	-	-60 to 125	1.5 A	-	-	-	1.5 A	Input into container 1
Prestolite Wire	152077	20	HDPE	-	-60 to 125	1.5 A	-	-	-	1.5 A	Between containers 1 and 2
Prestolite Wire	152077	20	HDPE	-	-60 to 125	1.5 A	-	-	-	1.5 A	Between containers 2 and 3
Prestolite Wire	152077	20	HDPE	-	-60 to 125	1.5 A	-	-	-	1.5 A	Between containers 3 and 4
Prestolite Wire	152077	20	HDPE	-	-60 to 125	1.5 A	-	-	-	1.5 A	TSI to Cooling Controller
Prestolite Wire	152077	20	HDPE	-	-60 to 125	1.5 A	-	-	-	1.5 A	TSI to Motor Controller
Prestolite Wire	152077	20	HDPE	-	-60 to 125	1.5 A	-	-	-	1.5 A	GLV/SCADA
Prestolite Wire	152077	20	HDPE	-	-60 to 125	1.5 A	-	-	-	1.5 A	GLV/SCADA to Cooling Controller
General Cable/	C2410A.41.10	12	PVC	300 V	-20 to 80	9.3 A	-	-	-	9.3 A	GLV Power to Right Side Control

Carol Brand											
General Cable/ Carol Brand	C2410A.41.10	12	PVC	300 V	-20 to 80	9.3 A	-	-	-	9.3 A	GLV Power to Right Side Control
General Cable/ Carol Brand	C2410A.41.10	12	PVC	300 V	-20 to 80	9.3 A	-	-	-	9.3 A	GLV Power to Left Side Control
General Cable/ Carol Brand	C2410A.41.10	12	PVC	300 V	-20 to 80	9.3 A	-	-	-	9.3 A	GLV/SCADA to Right Side Control
General Cable/ Carol Brand	C2410A.41.10	12	PVC	300 V	-20 to 80	9.3 A	-	-	-	9.3 A	GLV Power Supply
General Cable/ Carol Brand	C2410A.41.10	12	PVC	300 V	-20 to 80	9.3 A	-	-	-	9.3 A	GLV Battery
General Cable/ Carol Brand	C2410A.41.10	12	PVC	300 V	-20 to 80	9.3 A	-	-	-	9.3 A	GLV Charger

General Cable/ Carol Brand	C2410A.41.10	12	PVC	300 V	-20 to 80	9.3 A	-	-	-	9.3 A	GLV Power to GLV/SCADA
General Cable/ Carol Brand	C2410A.41.10	12	PVC	300 V	-20 to 80	9.3 A	-	-	-	9.3 A	GLV Power to Cooling Controller
General Cable/ Carol Brand	C2410A.41.10	12	PVC	300 V	-20 to 80	9.3 A	-	-	-	9.3 A	TSI to GLV/SCADA
General Cable/ Carol Brand	C2405A.46.10	16	PVC	300 V	-20 to 90	3.7 A	-	-	-	3.7 A	GLV/SCADA to Right Side Control
General Cable/ Carol Brand	C2405A.46.10	16	PVC	300 V	-20 to 90	3.7 A	-	-	-	3.7 A	TSI to Right Side Control
CCC	2.3.1.1.1	26	PVC	30 V	<70	0.361 A	-	-	-	0.361 A	GLV/SCADA to Cockpit

Alpha Wire	5178C SL001	16	PVC	300 V	-35 to 105	3.7 A	-	-	-	3.7 A	TSI to Motor Controller
Alpha Wire	5178C SL001	16	PVC	300 V	-35 to 105	3.7 A	-	-	-	3.7 A	TSI to Foot Pedals
Alpha Wire	5178C SL001	16	PVC	300 V	-35 to 105	3.7 A	-	-	-	3.7 A	TSI to Cockpit
Alpha Wire	5440/12 SL002	16	PVC	600 V	-30 to 105	3.7 A	-	-	-	3.7 A	GLV/SCADA to Cockpit
Alpha Wire	5176C SL005	16	PVC	300 V	-35 to 105	3.7 A	-	-	-	3.7 A	TSI to TSAL Left
Alpha Wire	5176C SL005	16	PVC	300 V	-35 to 105	3.7 A	-	-	-	3.7 A	TSI to Brake Light
Alpha Wire	5176C SL005	16	PVC	300 V	-35 to 105	3.7 A	-	-	-	3.7 A	TSI to TSAL Right
Alpha Wire	5176C SL005	16	PVC	300 V	-35 to 105	3.7 A	-	-	-	3.7 A	GLV/SCADA to TS Energized Light
General Cable/ Carol Brand	C4066 A.12.10	22	PVC	300 V	-20 to 80	0.92 A	-	-	-	0.92 A	Motor Controller to Motor

Table 4 - System Wire Table

2.4 Grounding System

*Describe how you keep the resistances between accessible components below the required levels as defined in FH Rules **EV8.1**. If wire is used for ground bonding, state the AWG or mm^2 of the wire*

To ensure that we will have proper grounding to the chassis, we will be using 12AWG wire for distributing the chassis ground.

2.5 Conductive Panel Grounding

*If carbon fiber or coated conductive panels are used in your design, describe the fabrication methods used to ensure point to point resistances that comply with **EV8.1.2**. Describe results of measurements made per **EV8.1.5**.*

We are not using any carbon fiber or coated conductive panels on our vehicle.

Section 3 Isolation & Insulation

Person primarily responsible for this section:

Name: Greg Flynn

e-mail: flynng@lafayette.edu

3.1 Separation of Tractive System and Grounded Low Voltage System

*Describe how the TS and GLV systems are physically separated (**EV5.3**). Add CAD drawings or photographs of how TS and GLV are segregated in key areas of the electrical system.*

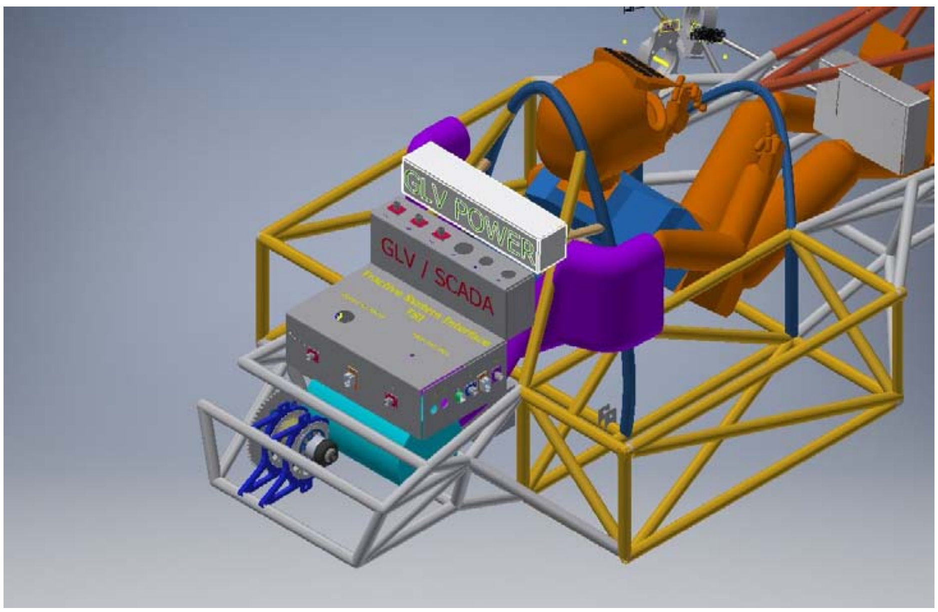

Figure 9 - TS and GLV separation

List all electrical circuit boards designed by team that contain TS and GLV voltage in the following table.

Device / PCB	TS Voltage Present (V)	Minimum Spacing mm	Thru Air of Over Surface	Notes
TSI-PCB-HV-LV	96	6.4	Over Surface	

Table 5 - PCB Spacings

List all purchased components with both TS and GLV connections (at min motor controller and AMS)

Our AMS boards are powered from the TSV system so they do not have a GLV connection. To ensure isolation there is a DC to DC converter between the cell and the AMS board.

Component	Isolation Method	Link to Document Describing Isolation	Notes
Bender ISOMETER IR155-3203	Galvanic Isolation	http://www.bender-es.com/fileadmin/products/doc/IR155-32xx-V004_D00115_D_XXEN.pdfhttp://www.bender-es.com/fileadmin/products/doc/IR155-32xx-V004_D00115_D_XXEN.pdf http://www.bender-es.com/fileadmin/products/doc/IR155-32xx-V004_D00115_D_XXEN.pdf	Recommended by rules.
Curtis 1238 Motor Controller	Only High Voltage	http://www.thunderstruck-ev.com/Manuals/1234_36_38%20Manual%20Rev%20Feb%2009.pdf	

3.2 Isolation & Insulation

Provide a list of containers that have TS and GLV wiring in them. If a barrier is used rather than spacing, identify barrier material used (reference Table 7- Insulating Materials).

Container Name	Segregation by Spacing (Y or N)	How is Spacing maintained	Actual Measured Spacing mm	Alt – Barrier Material P/N	Notes

Accumulator Container	N	Containers being bolted down	N/A	Steel	Can bus isolation description.
Accumulator Container	N	Isolators	N/A	Steel	Safety Loop Isolation, Galvanically isolated
TSI System Box	Y	PCB Designed with spacing guidelines. All wires entering/exiting box will be fastened to structure of box.		N/A	

Table 6 – List of Containers with TS and GLV wiring

*List all insulating barrier materials used to meet the requirements of **EV2.4** or **EV5.4***

Insulating Material / Part Number	UL Recog-nized ?	Rated Temper-ature ºC	Thickness mm	Notes
Al/8975K111	TBD	TBD	1.65	We will use aluminum sheet

Table 7- Insulating Materials

3.3 Conduit

*List different types of conduit used in the design. Specify location and if manufacturer's standard fittings are used. Note Virtual Accumulator Housing FH Rules **EV2.12** requires METALLIC type LFMC.*

NO conduit is being used

Describe how the conduit is anchored if standard fittings are not used.

Conduit Type	MFR	Part Number	Diameter Inch or mm	Standard Fittings (Y or N)	Location / Use

Table 8 - Conduit Data

*Is all conduit contained within the vehicle Surface Envelope per **EV3.1.6**? (**Y or N**).*
*Does all conduit comply with **EV3.2**? (**Y or N**).*

3.4 Shielded dual-insulated cable

If Shielded, dual-insulated cable per EV3.2.5 used in the vehicle, provide specifications and where used:

MFR	Part Number	Cross Section mm2	Shield grounded at both ends (Y or N)	Location / Use
TBD	TBD	TBD	TBD	Used between Accumulators and TSI container

Table 9 - Shielded Dual Insulated Cable Data

3.5 Firewall(s)

Description/materials

*Describe the concept, layer structure and the materials used for the firewalls. Describe how all firewall requirements in FH Rules **T4.5** are satisfied. Show how the low resistance connection to chassis ground is achieved.*

The firewall will consist of 1/16” thick aluminum sheet that will separate the driver from the accumulators and motor.

Position in car

Provide CAD-rendering or photographs showing the location of the firewall(s).

Section 4 **Electric Tractive System**

Person primarily responsible for this section:

Name: Greg Flynn

e-mail: flynng@lafayette.edu

4.1 Motor(s)

Describe the motor(s) used and reason for this particular choice. Add additional tables if multiple motor types are used

Manufacturer and Model:	HPEVS AC 50
Motor type (PM, Induction, DC Brush)	Induction
Number of motors of this type used	1
Nominal motor voltage (Vrms l-l or Vdc)	96V
Nominal / Peak motor current (A or A/phase)	Nom: 200A / Peak: 600A
Nominal / Peak motor power	Nom: 18HP / Peak: 71 HP
Motor wiring – conductor size and type	3/8” Ring Connectors w/ 00 Gauge Copper Wire

Table 10 - Motor Data

Provide calculations for currents and voltages. State how this relates to the choice of cables and connectors used.

4.2 Motor Controller

Describe the motor controller(s) used and reason for this particular choice. Add additional tables if multiple motor controller types are used.

We are using the Curtis 1238 due to its voltage rating allowing for 96V input and 24V isolation as 24V is used for our GLV power.

Manufacturer and Model:	Curtis 1238
Number of controllers of this type used:	1
Maximum Input voltage:	96V

Nominal Input Current (A)	200A
Max Input Fuse (A) per Mfr.	650A
Output voltage (Vac l-l or Vdc)	96Vac
Isolation voltage rating between GLV (power supply or control inputs) and TS connections	24-96V
Is the accelerator galvanically isolated from the Tractive System per **EV3.5 & EV5**?	☒Yes / ☐ No

Table 11 - Motor Controller Data

*If the answer to the last question is NO, how to you intend to comply with **EV3.5** (an external isolator is acceptable).*

Provide calculations for currents and voltages. State how this relates to the choice of cables and connectors used.

4.3 Tractive System Measurement Points (TSMP)

*The TSMP must comply with FH Rule **EV10.3**. Describe the TSMP housing and location. Describe TSMP electrical connection point.*

The TSMP will be mounted to the face of the TSI system box. This will be attached behind the driver and covered with a plastic case on a hinge. The measuring points themselves will be the specified 4mm shrouded banana jacks.

TSMP Output Protection Resistor Value	10 kΩ
Resistor Voltage Rating	460 V
Resistor Power Rating	5 W

Table 12 – TSMP Resistor Data

4.4 Pre-Charge circuitry

Describe your design for the pre-charge circuitry. Describe wiring, connectors and cables used.

- *Include a schematic of the pre-charge circuit*
- *Include a plot of calculated TS Voltage vs. time*
- *Include a plot of calculated Current vs. time*
- *Include a plot of resistor power vs time.*

The pre-charge circuit we are using is included in the motor controller.

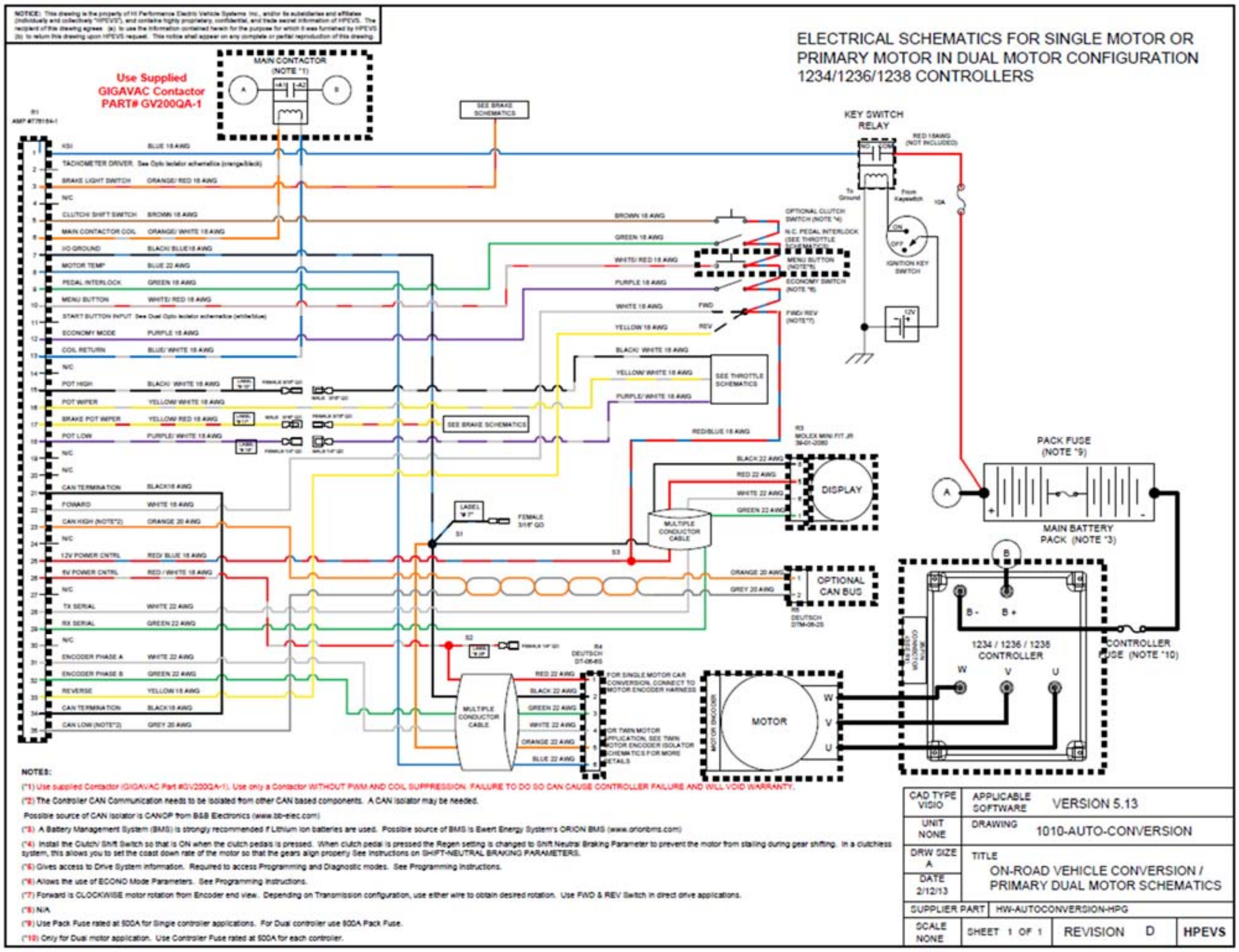

Figure 10 - Wiring Schematic for Curtis 1238.
Source: http://evwest.com/support/auto1234-1236-1238_500-512_Reva.pdf

Provide the following information:

Resistor Type:	Blade Fuse
Resistance:	6.80mΩ
Continuous power rating:	1.045 W
Overload power rating:	1.9 W for 5 sec
Voltage rating:	58V

Table 13 - Data for the pre-charge resistor

Relay MFR & Type:	GIGAVAC GV200QA
Contact arrangement (e.g. SPDT)	SPST-NO
Continuous DC contact current (A):	500+ A
Contact voltage rating (Vdc).	800 V

Table 14 - Data of the pre-charge relay

4.5 Discharge circuitry

Describe your concept for the discharge circuitry. Describe wiring, connectors and cables used.

- *Include a schematic of the pre-charge circuit*
- *Include a plot of calculated TS Voltage vs. time*
- *Include a plot of calculated "Discharge current" vs. time*
- *Include a plot of resistor power vs time.*

None of the student designed parts have capacitors in them so a discharge circuit is not required. The motor controller does have internal capacitance but has its own discharge circuit designed by Curtis.

Provide the following information:

Resistor Type:	
Resistance:	Ω
Continuous power rating:	W
Overload power rating:	W for _____ sec
Voltage rating:	V
Maximum expected current:	A
Average current:	A

Table 15 - Data of the discharge circuit.

4.6 HV Disconnect (HVD)

Describe your design for the HVD and how it is operated, wiring, and location. Describe how your design meets all requirements for ***EV2.9.***

The HVD is the TSMS shown in the safety shutdown circuit schematic in section 6.1 of this document. This tractive system master switch will cut the power from the accumulator's AIRs upon being toggled, and this will quickly cut power to high voltage. The HVD is a key lock switch which is accessible on the interior of the vehicle without the use of tools. The key can be removed from the vehicle to follow the Lockout/Tagout procedure.

4.7 Accelerator Actuator / Throttle Position Sensor

Describe the accelerator actuator and throttle position sensor(s) used, describe additional circuitry used to check or condition the signal going to the motor controller. Describe wiring, cables and connectors used. Provide schematics and a description of the method of operation of any team-built signal conditioning electronics. Explain how your design meets all of the requirements of FH Rules ***IC1.6*** *and* ***EV3.5.***

The position sensors we are using are two 5K piston potentiometers. They will be offset by 5 volts and mounted next to each other so the pedal will compress them evenly under normal use. The outputs from the potentiometers used for throttle position are first passed through window comparators that will ensure there is not open or short circuit. The unbiased signals will then be passed through a differential op-amp and compared against a 0.5 volt signal to determine their plausibility to each other. If all of these tests pass, one of the potentiometer signals will be fed to the throttle input of the motor controller.

Actuator / Encoder manufacturer and model:	LPPS Linear Potentiometer – LPPS-050
Encoder principle (e.g.Potentiometer):	Potentiometer
Output:	5V range of signals (max 5-10V)
Is motor controller accelerator signal isolated from TSV?	☒Yes / ☐ No
If no, how will you satisfy rule **EV3.5**?	

Table 16 - Throttle Position encoder data

4.8 Accelerator / throttle position encoder error check

Describe how the system reacts if an error (e.g. short circuit or open circuit or equivalent) is detected. Describe circuitry used to check or condition the signal going to the motor controller. Describe how failures (e.g. Implausibility, short circuit, open circuit etc.) are detected and how the system reacts if an error is detected. State how you comply with ***EV3.5.4.***

If either a short or open circuit occurs, the signal closing a power MOSFET switch is opened preventing voltage from reaching the motor controller throttle input. If there is an implausibility detected by a differential op-amp circuit fed into a window comparator, the same situation will occur as a short or open circuit where voltage to the motor controller throttle input is driven to zero.

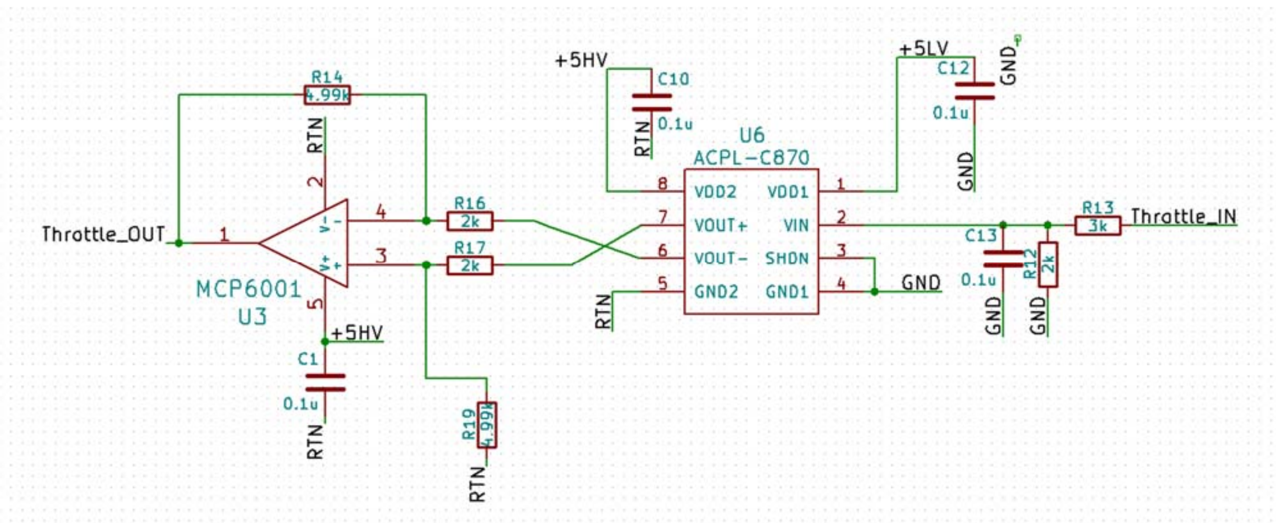

Figure 11 - Throttle isolation

Section 5 Accumulator System

Person primarily responsible for this section:

Name: Greg Flynn

e-mail: flynng@lafayette.edu

5.1 Accumulator Pack

Provide a narrative design of the accumulator system and complete the following table.

The Tractive System Voltage is provided by four accumulator containers placed in series to provide the power necessary to operate the motor. An accumulator segment, housed within each container, is comprised of a battery of 7 LiFeP04 cells (3.2 V nominal) connected in series. Each cell is monitored for temperature and voltage by an AMS (accumulator), which communicates this information to the Pack Management Computer (PacMAN). The PackMAN utilizes an AT90CAN128 Atmel microcontroller. The AMS, comprised of these AMS boards and the PackMAN, is further described in section 5.8.

The accumulator high current output is available through ITT Cannon connectors. Accumulator voltage is present only while the safety loop is closed. A low current output is also available through an Anderson Power connector. This output is limited to 20 A. Charging is also accomplished through this connector, and is similarly limited to 20 A and 30 V, and implements “plug and forget” charging. The functioning of both ports is controlled by the PackMAN board.

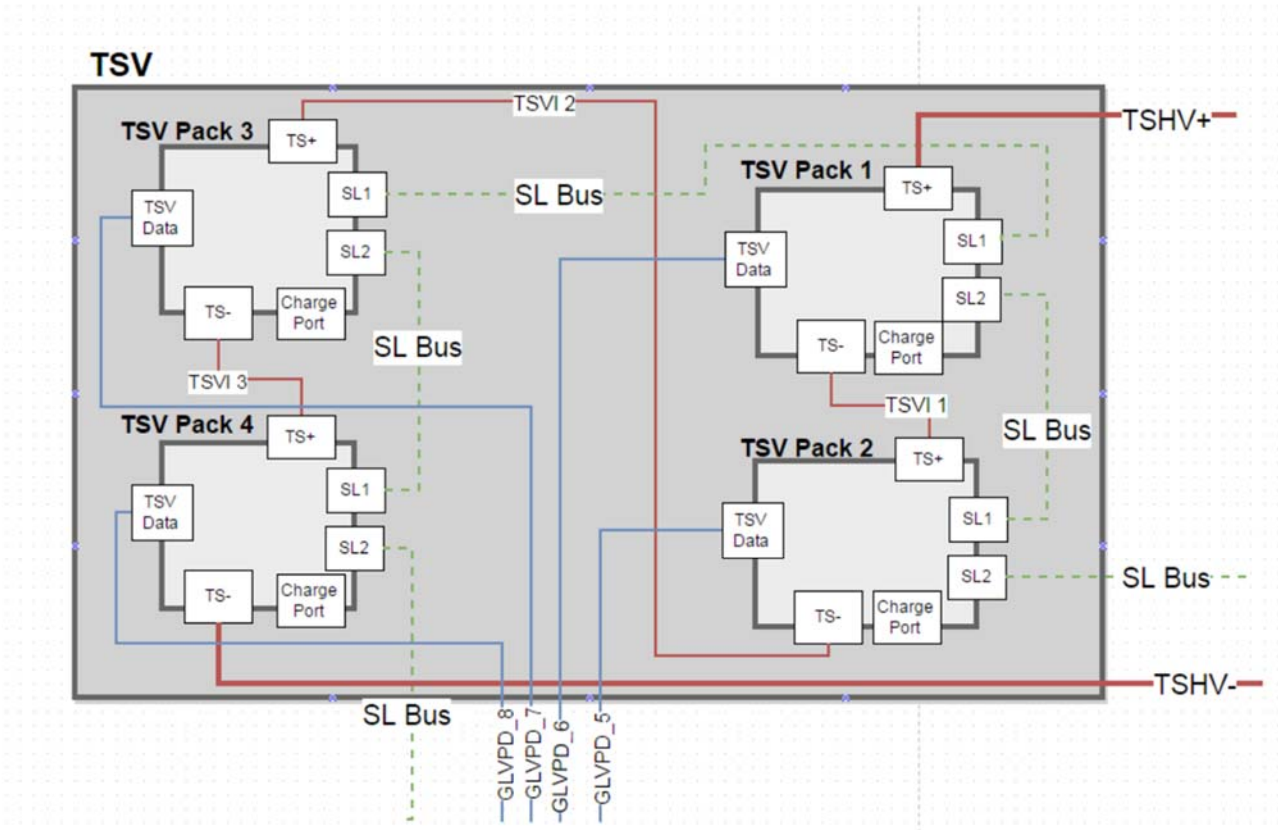

Figure 12 - Safety loop

Maximum Voltage (during charging):	26.6 VDC
Nominal Voltage:	22.4 VDC
Total number of cells:	28
Cell arrangement (x in series / y in parallel):	28 in series
Are packs commercial or team constructed?	☐Commercial / ☒ Team
Total Capacity (per FH Rules **Appendix A**[2]):	4.3 kWh
Maximum Segment Capacity	1.5 MJ
Number of Accumulator Segments	4

Table 17 - Main accumulator parameters

Cp = (I^k)*t = (3^1.05)*0.5 = 63.4 AH
63.4 = (I^1.05)*0.5

[2] This includes an 80% derating for available traction energy

I = 100.686 (half hour discharge)
2C = 50.3 AH

*Describe how pack capacity is calculated. Provide calculation at 2C (0.5 hour) rate? How is capacity derived from manufacturer's data? If so, include discharge data or graph here. Include Peukert calculation if used (See FH Rules **Appendix A**)*

Show your segment energy calculations. The segment energy is calculated as

$$Vnom\ x\ Cell\ AH\ (2C\ rate)\ x\ Number\ of\ Cells\ x\ 3.6\ (kJ)$$

(The 80% factor is not applied for this calculation.)

5.2 Cell description

Describe the cell type used and the chemistry and complete the following table.

Cell Manufacturer and Model	AA Portable Power Corp, LFP-G60
Cell type (prismatic, cylindrical, pouch, etc.)	Prismatic
Are these pouch cells	☐Yes / ☒ No
Cell nominal capacity at 2C (0.5 hour) rate:	50.3 AH
Data sheet nominal capacity	60 Ah at 20 hour rate
Maximum Voltage (during charging):	3.9 V
Nominal Voltage (data sheet value):	3.2 V
Minimum Voltage (AMS setting):	2.0V
Maximum Cell Temperature (charging - AMS setting)	60 C
Maximum Cell Temperature (discharging - AMS setting)	60 C
Cell chemistry:	LiFePO4 in prismatic case

Table 18 - Main cell specification

Cp = (I^k)*t = (3^1.05)*0.5 = 63.4 AH
63.4 = (I^1.05)*0.5
I = 100.686 (half hour discharge)

2C = 50.3 AH

*IMPORTANT: Show your calculations here for 2C nominal AH capacity if the data sheet uses a different discharge rate. Refer to FH rules **Appendix A***

5.3 Cell configuration

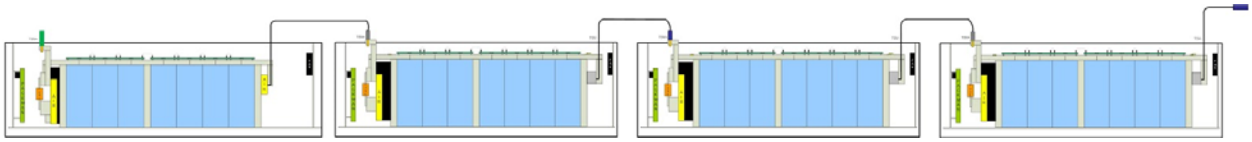

Figure 13 - Cell configuration

In each accumulator segment, seven cells are placed in series. Each segment is within an accumulator container. There are four containers, each of which is placed in series. In total, seven cells in four containers are all in series.

Does the accumulator combine individual cells in parallel without cell fuses? ☐Yes / ☒ No

*If Yes, explain how **EV2.6** is satisfied.*

5.4 Segment Maintenance Disconnect

Describe segment maintenance disconnect (SMD) device, locations, ratings etc.

Is HVD used as an SMD?	☒Yes / ☐ No
Number of SMD Devices / Number of Segments	[10] / [4]
SMD MFR and Model	ITT Cannon, NLS-3-GY-S120-M40A and NPS-N-BL-T4 Gigavac, GX14CB
SMD Rated Voltage (if applicable)	3kV 24 V
SMD Rated Current (if applicable)	400 A 350 A
Segment Energy (6 MJ max[3])	6 MJ
Segment Energy Discharge Rate (Ref FH Rules **Appendix A**)	10 C

Table 19 - SMD Data

[3] Note Segment energy = rated AH x nominal voltage. The 80% derating is NOT applied for this calculation.

5.5 Lithium-Ion Pouch Cells

The vehicle accumulator uses individual pouch cells. Yes ☐ No ☒

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

*If your team has designed your accumulator system using individual Lithium-Ion pouch cells, include drawings, photographs and calculations demonstrating compliance with all sections of rule **EV11.** If your system has been issued a variance to **EV11** by the Formula Hybrid rules committee, include the required documentation from the cell manufacturer.*

5.6 Cell temperature monitoring

Each cell within each accumulator segment is monitored by an AMS board. Each AMS board contains a linear active thermistor (MCP9700, Microchip) that measures the temperature of each cell. The AMS boards communicate this information via I2C to the PacMAN board within their respective accumulator containers, which determines if any cell has exceeded 60°C. If this is the case, a fault case is asserted and the safety loop is opened.

Number of Cells with Temperature Monitoring (#1)	28
Total Number of Cells (#2)	28
Percentage Monitored (#1 / #2)	100%
Percentage Required by FH Rules **Table 11**	30%
If each sensor monitors multiple cells, state how many:	N/A

Table 20 - Cell Temperature Monitoring

5.7 Accumulator Isolation Relays (AIR)

Within the accumulator system, we utilize five AIRs. Our design places the four accumulator containers in series. The first in this series contains two AIRs. The three subsequent containers contain one AIR; we justify this design decision as the one AIR sufficiently separates each HV segment from each other.

MFR & Model	Gigavac GX14CB
Contact arraignment:	Single Pole Single Throw Normally Open
Continuous DC current rating:	350 A
Overload DC current rating:	1000 A for 85 sec
Maximum operation voltage:	32 VDC

Nominal coil voltage:	24 VDC
Normal Load switching:	Make and break up to 600 A

Table 21 AIR data

5.8 Accumulator Management System (AMS)

The AMS within each accumulator consists of one PacMAN board and seven AMS boards. The PacMAN board is comprised of a microcontroller (Microchip Technology, AT90CAN128-16AUR) which monitors overall pack current and voltage directly and receives individual cell information from the AMS boards. Each AMS board monitors a single cell for temperature and voltage and communicates this to the PacMAN via I2C. If the PacMAN detects a fault, defined as cell temperature exceeding 60°C, cell voltage exceeding 4 V, accumulator segment voltage exceeds 26 V, or an AMS board is unresponsive, the PacMAN board opens the safety loop relay. Accumulator voltage is only present when the safety loop is closed.

PacMAN also keeps track of accumulator state, state of charge, and the state of the safety loop relay on PacMAN. All of these data are regularly sent via CAN frames to the VSCADA computer. The microcontroller communicates on the CAN bus through a Microchip MCP2551 CAN interface IC. This information is also displayed on the top of each accumulator container through the control panel. Managed by PacMAN, this LCD will be able to display pack voltage, pack current, cell voltage, cell temperature, state of charge, cell balancing state, charging state, charging history, discharge history and safety loop state. It will also have functionalities of going into sleep mode and choosing calibration factors where they are necessary.

When either the charging or low current output port (Anderson Power connector on the control panel that is limited to 20 A and 30 V), are in use, a relay on the PacMan computer closes allowing access to the positive and negative terminal of the accumulator. These connections are fused at the terminals with 25A blade fuses. Current flowing through the charge relay also flows through a 1 mOhm current sensing resistor that is monitored via a Kelvin connection by a Texas Instruments INA 226 current monitor. This IC also allows voltage sensing for the full accumulator voltage.

While charging, the voltage of each cell is monitored by the AMS boards, and communicated to PacMAN via I2C. A cell will be placed in bypass mode when its voltage reaches 3.6 V, allowing other cells to continue to charge without overcharging. This is accomplished allowing some current to pass through a resistor attached to a heat sink instead of the cell. A 5V fan is allowed to run at all times while charging to maintain the ambient temperature inside the accumulator. Once any cell reaches 3.9 V, charging is considered complete. Both bypassing and completion of a charge cycle trigger an entry in a charge history stored on the microcontroller. This data will be accessible in debug via USB, and an abbreviated history is available on the control panel LCD.

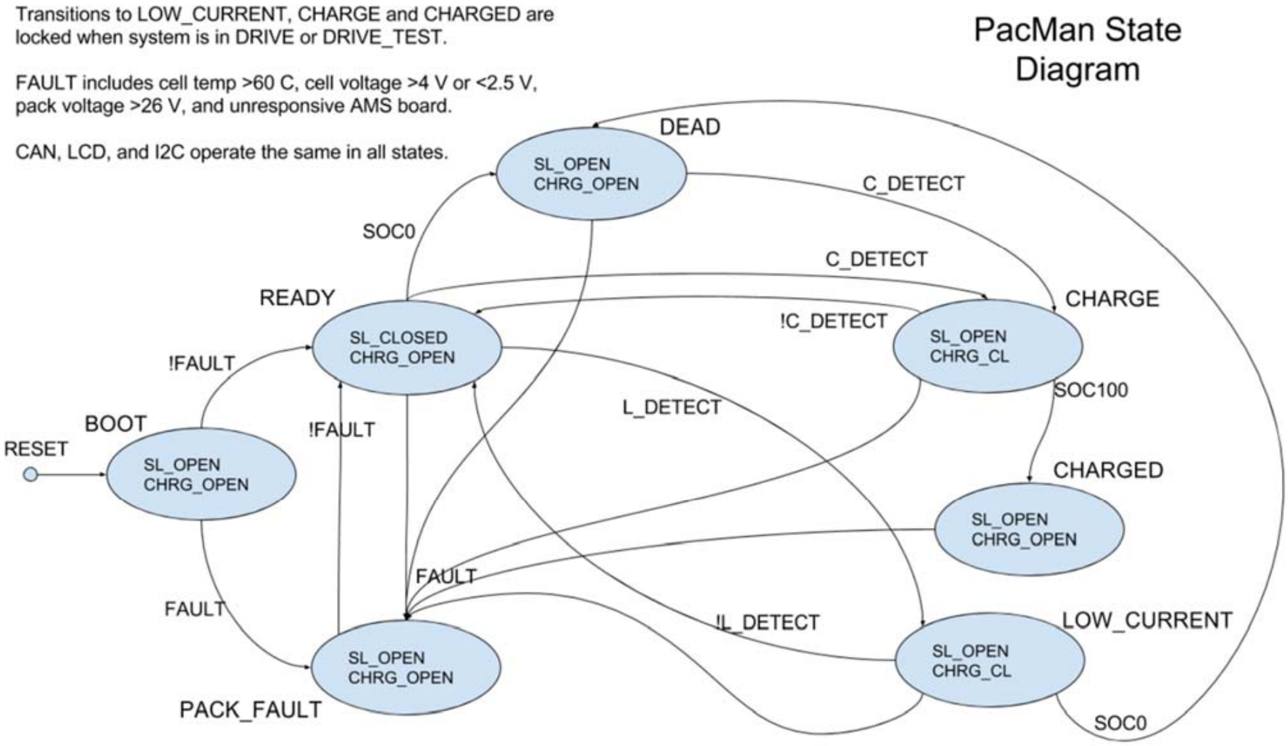

Figure 14 - PacMAN FSM

AMS MFR and Model	Manufactured/Designed in House
Number of AMSs	4
Upper cell voltage trip	4 V
Lower cell voltage trip	2 V
Temperature trip	60°C

Table 22 - AMS Data

5.9 Accumulator wiring, cables, current calculations

We expect no AC voltage. For an accumulator container we expect a thevenin voltage of 23.6 V with 14 mOhm thevenin resistance at 100% state of charge. With a fully charged accumulator container, we expect roughly 24 V with seven cells charged to 3.4 V. With a fully charged accumulator system we expect 96 V. From experimentation, it takes 53 minutes for full discharge for a single accumulator container. The low current output draws 20 A. Each cell has 60A-h.

Through a motor and controller characterization, the maximum RPM is 4500 RPM with a maximum possible torque of 92 ft-lbs. The maximum efficiency motor speed in the fully integrated car is 2500

RPM with steady state torque estimate of 15 ft-lbs based upon a constant power experiment showing the maximum efficiency for the motor reached at and above 2500 RPM. At this maximum efficiency, the motor will draw 71 A from the accumulator. This means the battery will dissipate from this analysis in 51 minutes or 0.85 hours.

The DC current from the accumulator is measured utilizing a current sensor from each accumulator container.

For the rate of charge and discharge of an accumulator container, assuming the slowest possible discharge current for an accumulator at 20A, the actual current is expected to be within the range of 20.366 and 19.634A. Given an accumulator capacity of 60 Ah, the capacity in Coulombs is equal to 216000. At 20 Coulombs per second, the pack will discharge in 10800 seconds, meaning a discharge rate of 1% every 108 seconds. For 20.366 and 19.634 A, the pack discharges 1.018% or 0.982% every 108 seconds respectively. .018 multiplied by 100 to account for the possible accumulation of error gives a confidence interval of +/ 1.8% between the measured and expected values for state of charge.

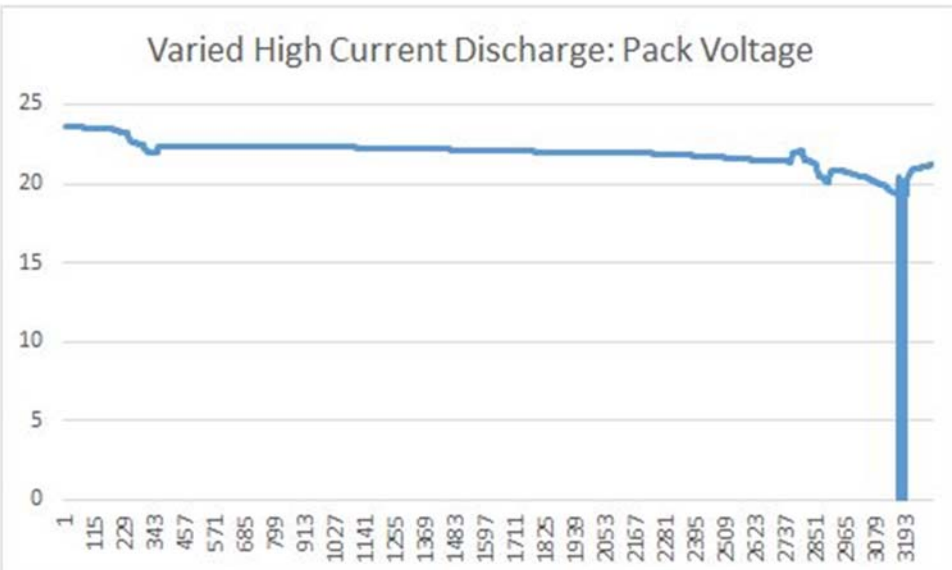

Figure 15 - High Current Discharge

5.10 Accumulator indicator

LCD display, controls and indicators are going to be provided on top of the pack.

As illustrated below, controls of the pack are four pushbuttons and an indicator is the red led. Four push buttons are integrated the LCD display. One is for navigating up through the options, one is for navigating down through the options, one is for choosing/selecting and one is for reset. The red LED is an indicator for when AIRs are closed (when the pack is alive).

Managed by the PacMAN board, the LCD will be able to display pack voltage, pack current, cell voltage, cell temperature, state of charge, cell balancing state, charging state, charging history, discharge history and safety loop state. It will also have functionalities of going into sleep mode and choosing calibration factors where they are necessary.

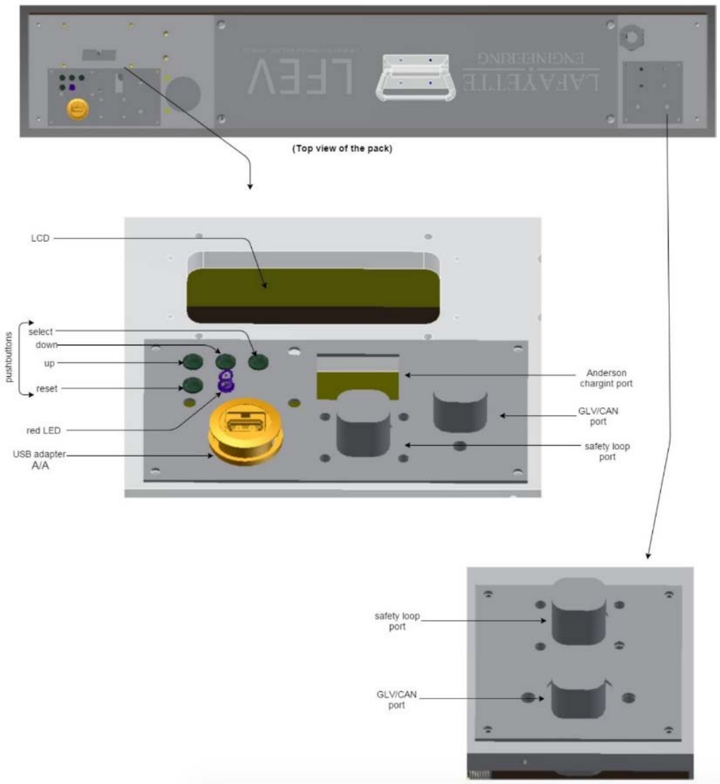

Figure 16 - Pack connections

5.11 Charging

This design utilizes coulomb counting, integrating the current flowing through the current sensing resistor to determine the increase in state of charge due to charging as well as the decrease in state of charge due to low current output and the operation of the PacMan computer.

To monitor current flowing through the high current output, a Ametes BBM01 current sensor is attached to the 0.5 in by 1 in aluminum bar wire that attaches the negative accumulator terminal to the negative terminal of battery of cells. This sensor provides a differential voltage output that is available to the microcontroller over I2C through a Texas Instruments ADS1115 analog to digital converter.

While charging, the voltage of each cell is monitored by the AMS boards, and communicated to PacMAN via I2C. A cell will be placed in bypass mode when its voltage reaches 3.6 V, allowing other cells to continue to charge without overcharging. This is accomplished allowing some current to pass through a resistor attached to a heat sink instead of the cell. A 5V fan is allowed to run at all times while charging to maintain the ambient temperature inside the accumulator. Once any cell reaches 3.9 V, charging is considered complete. This allows for plug-and-forget charging. Both bypassing and completion of a charge cycle trigger an entry in a charge history stored on the microcontroller. This data will be accessible in debug via USB, and an abbreviated history is available on the LCD.

Charger Manufacturer and model:	TDK-Lambda, GenH30-25
Maximum charging power:	750 W

Isolation	☒Yes / ☐ No
UL Certification (If “no”, fill in the line below)	☒Yes / ☐ No
Do you have a waiver from the FH rules committee?	☐Yes / ☐No
Maximum charging voltage:	30 V
Maximum charging current:	25 A
Interface with accumulator (e.g. CAN, relay etc)	Anderson Charging Port
Input voltage:	85-265 VAC continuous
Input current:	9.5 A

Table 23 - Charger data

5.12 Accumulator Container/Housing

The accumulator container will be made of 1/16” steel sheet/plate and each (2) will contain 2 battery packs. The container will have a latching cover that can be removed so that the accumulators can be removed from the vehicle. The cover will also have cutouts so that the high voltage 2/0 wires can go from pack to pack. The wires are connected to the poles of the accumulators and are encased in an insulated casing. That entire accumulator container will go in the side pods on the car, the area designated for the storage of the packs. There will also be cutouts for small amounts of air to help cool the accumulators, although the cells don’t end up reaching that high of a temperature during discharge. There will also be through-holes for the mounting method for the battery packs and accumulator containers.
Requirements for V-0

1. The specimens may not burn with flaming combustion for more than 10 seconds after either application of the test flame.
2. The total flaming combustion time may not exceed 50 seconds for the 10 flame applications for each set of 5 specimens.
3. The specimens may not burn with flaming or glowing combustion up to the holding clamp.
4. The specimens may not drip flaming particles that ignite the dry absorbent surgical cotton located 300 mm below the test specimen.
5. The specimens may not have glowing combustion that persists for more than 30 seconds after the second removal of the test flame.

1/16” steel sheet/plate will fulfill the requirements above

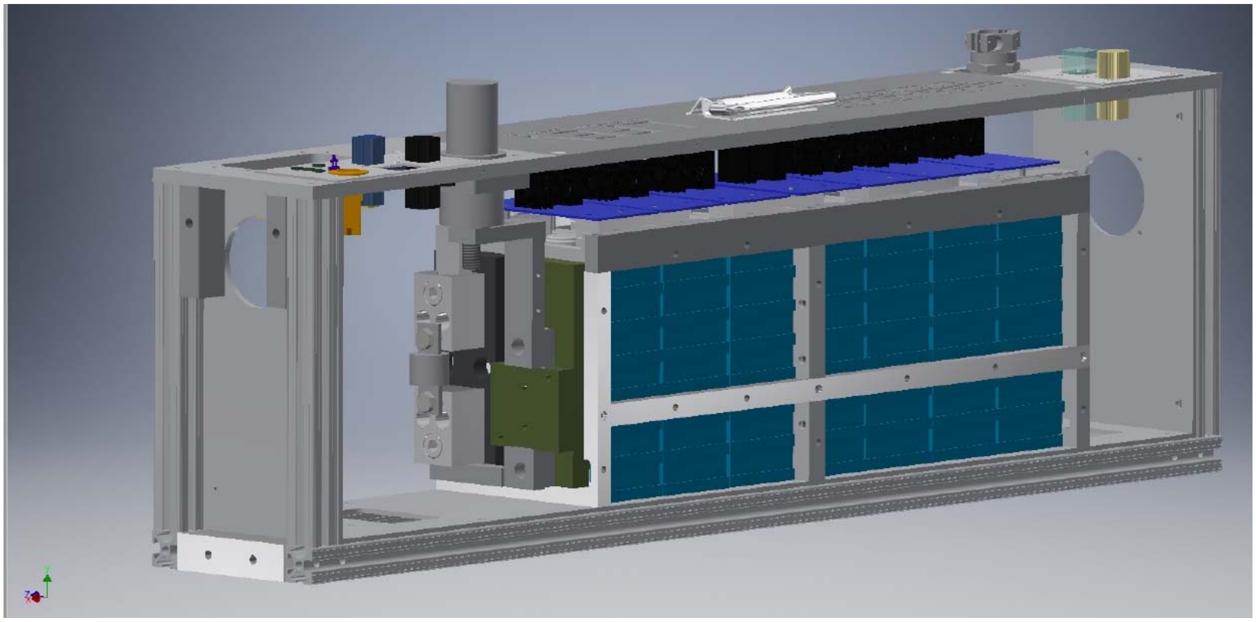

Figure 17 - Pack side

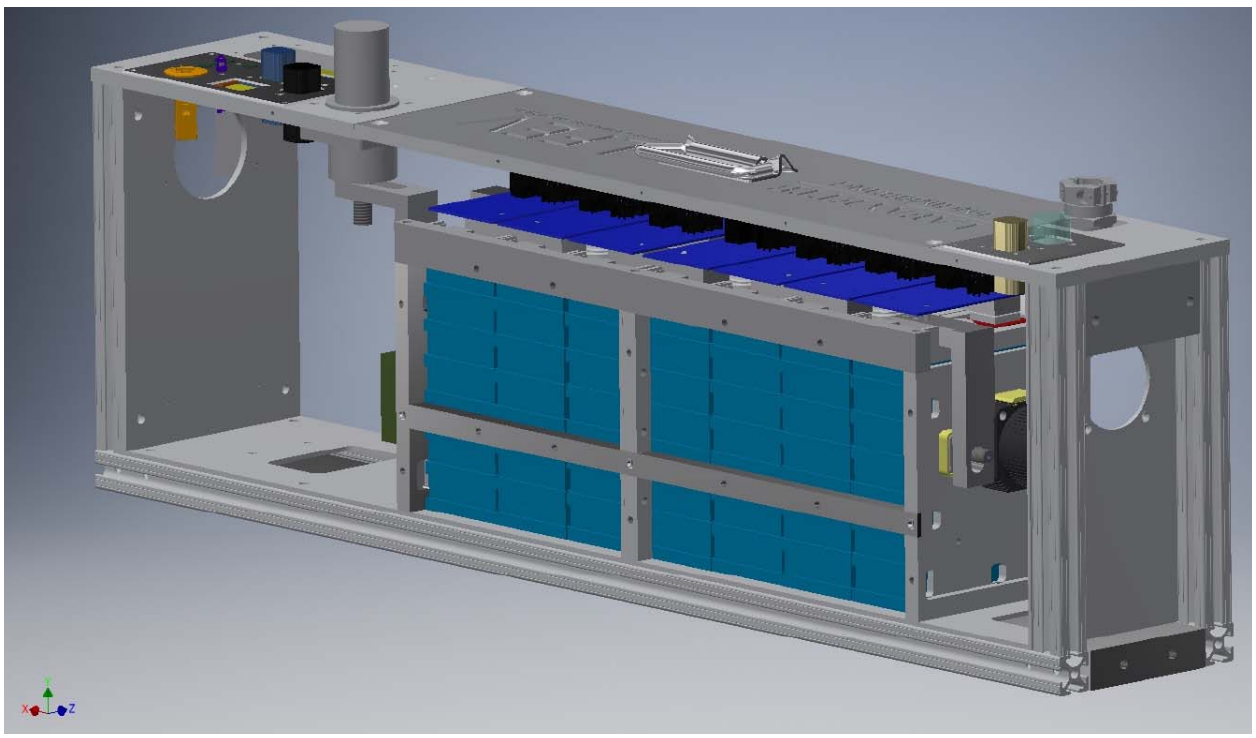

Figure 18 - Pack side

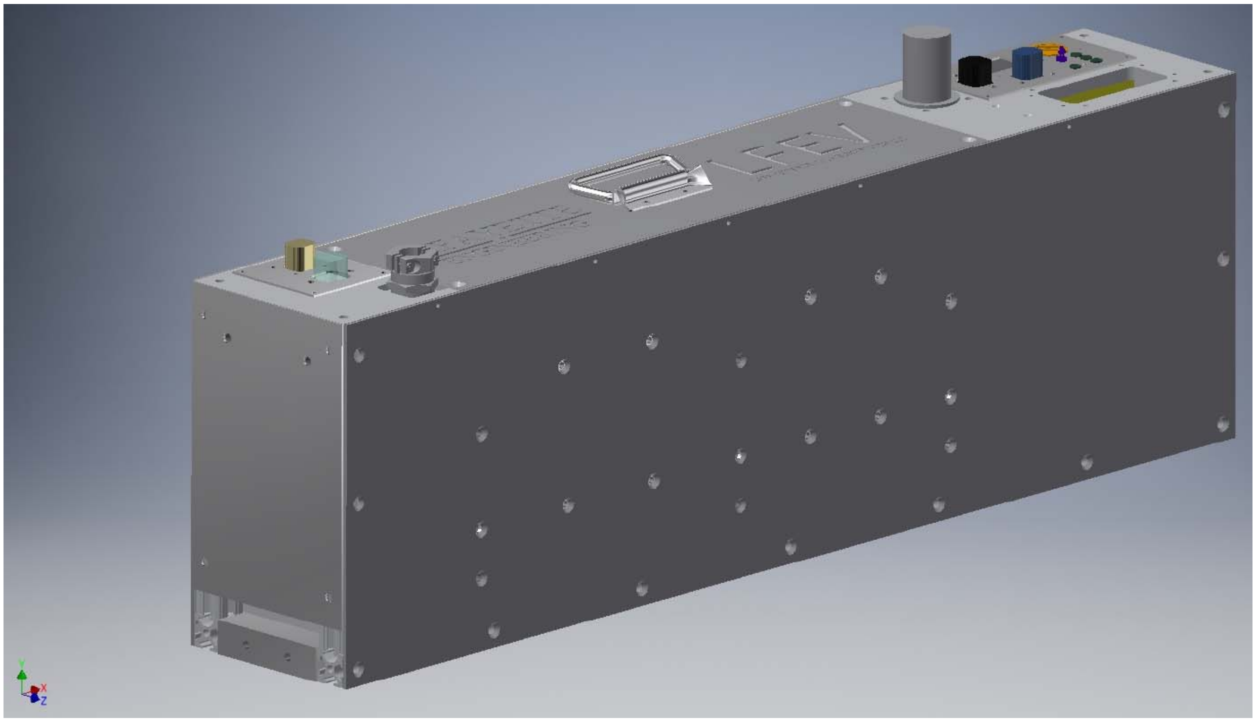

Figure 19 - Sealed Pack

Section 6 Safety Controls and Indicators

6.1 Shutdown Circuit

Include a schematic of the shutdown circuit for your vehicle including all major components in the loop

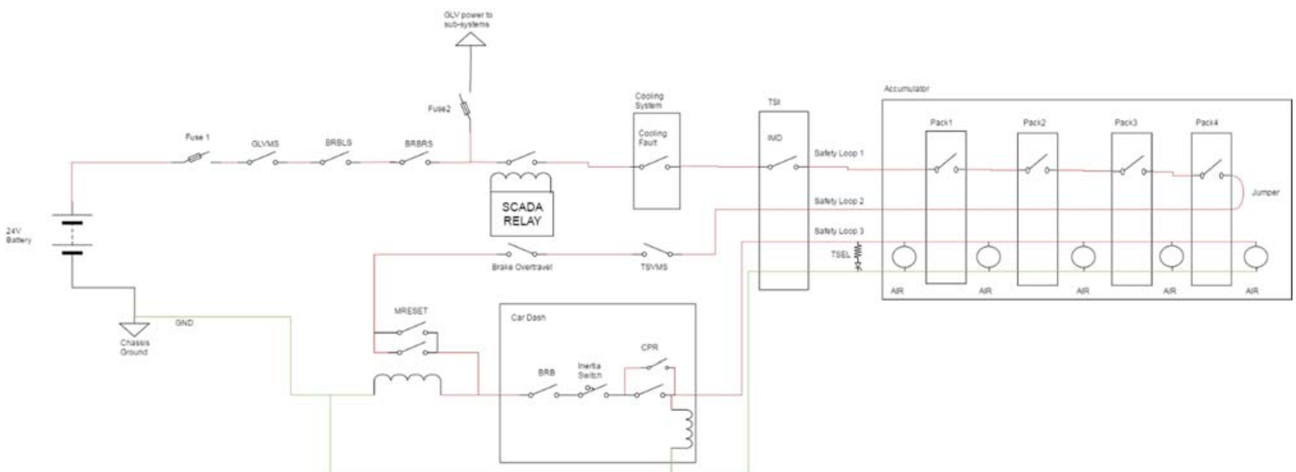

Figure 20 – Safety Shutdown Circuit Schematic

Describe the method of operation of your shutdown circuit, including the master switches, shut down buttons, brake over-travel switch, etc. Also complete the following table

Master switches and BRB's shut down entire system. SCADA monitoring, Cooling, AMS and IMD systems have the ability to shut down AIR's in TSV. Then post AMS the Brake overtravel switch and TSV master switch shut down the AIR's outside cockpit. The only Driver resettable switches are the BRB, inertia switch and CPR located directly before the AIR's.

Part	Function (Momentary, Normally Open or Normally Closed)
Main Switch (for control and tractive-system; GLVMS, TSMS)	Normally Closed
Brake over-travel switch (BOTS)	Push pull switch that will be pressed when the brake lines do not create enough pressure to stop the pedal. This will stop voltage from reaching the motor controller throttle input. Normally Closed.
Shutdown buttons (BRB)	Normally Closed
Insulation Monitoring Device (IMD)	Bender ISOMETER IR155-3203. Operating with normal specs stated on the datasheet. OK_{HS} will be used for monitoring ground

	faults. Normally outputs digital HIGH.
Battery Management System (AMS)	Normally Closed
Cooling system	Normally Closed
Scada Relay	Normally Open
Crash Protection Reset(CPR)	Normally Open
Master Reset	Normally Open
Interlocks (if used)	None

Table 24 - Switches& devices in the shutdown circuit

Each accumulator container houses one AIR between the HV positive input terminal of each container and the Mersen/Ferraz Shawmut A3T200 fuse, which then connects to the positive terminal of the first cell in the accumulator segment. Thus, simply, the AIR is in series with the HV input, fuse, and first cell. This AIR in each accumulator container is then connected to the PacMAN board and out the CAN output of the container. Only the first accumulator container in the series contains a second AIR which connects between the minus terminal of the last cell in series in the accumulator segment and the HV negative output terminal of the accumulator container.

If the PacMAN detects a fault, defined as cell temperature exceeding 60°C, cell voltage exceeding 4 V, accumulator segment voltage exceeds 26 V, or an AMS board is unresponsive, the PacMAN board opens the AIR. Accumulator voltage is only present when the safety loop is closed. Externally, the AIR can be opened or closed via the CAN connectors on each container from the safety loop.

Total Number of AIRs:	5
Coil holding current per AIR:	350 A
Current drawn by other components wired in parallel with the AIRs.	0 A
Total current:	350 A

Table 25 - Shutdown circuit Current Draw

Provide CAD-renderings showing the shutdown circuit parts. Mark the parts in the renderings

There will be one on the dashboard which is next to the steering wheel. The other will behind the driver on the main roll hoop supports.

Figure 21 – Location of Shutdown Circuit Components

6.2 IMD

Describe the IMD used and use a table for the common operation parameters, like supply voltage, temperature, etc. Describe how the IMD indicator light is wired. Complete the following table.

MFR / Model	Bender ISOMETER IR155-3203
Set response value:	100 kΩ (1 kΩ/Volt)

Table 26 Parameters of the IMD

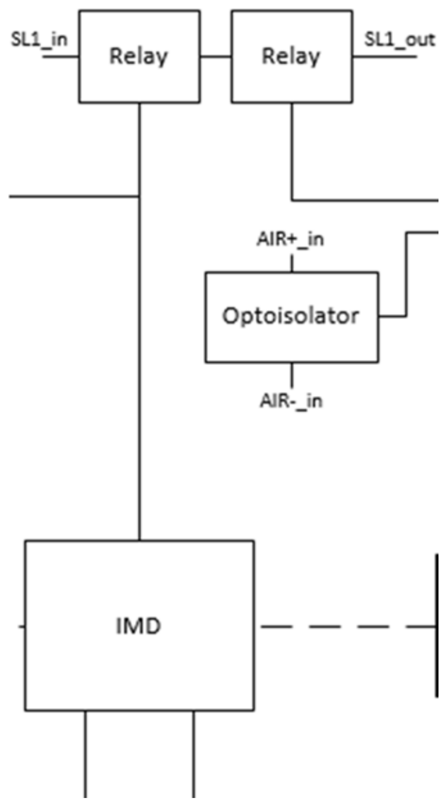

Figure 22 - IMD block diagram

6.3 Reset / Latching for IMD and AMS

Describe the functioning and circuitry of the latching/reset system for a tripped IMD or AMS. Describe wiring, provide schematics.

The IMD tripped circuit will open a relay that is use to complete the safety loop. When the OK_{HS} signal is not producing the normal 24V during safe usage, the relay will open and the override button that is not driver resettable will need to be pushed in order to close this relay again. Schematics for this can be found in the GLV safety loop.

When AMS or IMD breaks the safety loop two reset buttons must be pushed to reengage the AIR's. The Master reset on the outside of the car and the CPR in the cockpit of the car. Both are latching buttons. By pressing the reset it shorts the second switch and provides current through the inductor closing the bottom switch.

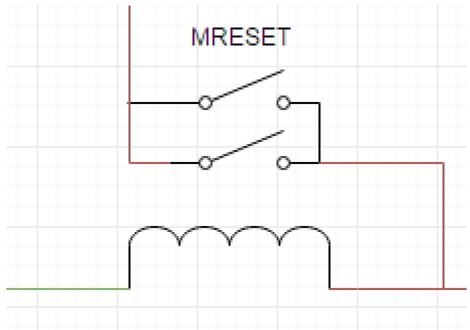

Figure 23 - Latching circuit

6.4 Shutdown System Interlocks

(If used) describe the functioning and circuitry of the Shutdown System Interlocks. Describe wiring, provide schematics.

N/A

6.5 Tractive System Energized Light (TSEL)

Describe the tractive system energized light components and method of operation. Describe location and wiring, provide schematics. See ***EV9.1.***

The TSEL light can be found on the schematic for the safety shutdown circuit shown in section 6.1. It will be wired in parallel with the AIRs on the accumulators to indicate when the tractive system is energized.

6.6 Tractive System Voltage Present light (TSVP)

Describe the tractive system voltage present light components and method of operation. Describe location and wiring, provide schematics. See ***EV9.3***

The TSVP will be made from a voltage divider network that is then passed through an optoisolator to the low voltage side of TSI. This signal will then go through an op-amp comparator set to the scaled down 30V from high voltage. This will be output from the board and power two trailer lights that will be mounted to the top of the chassis.

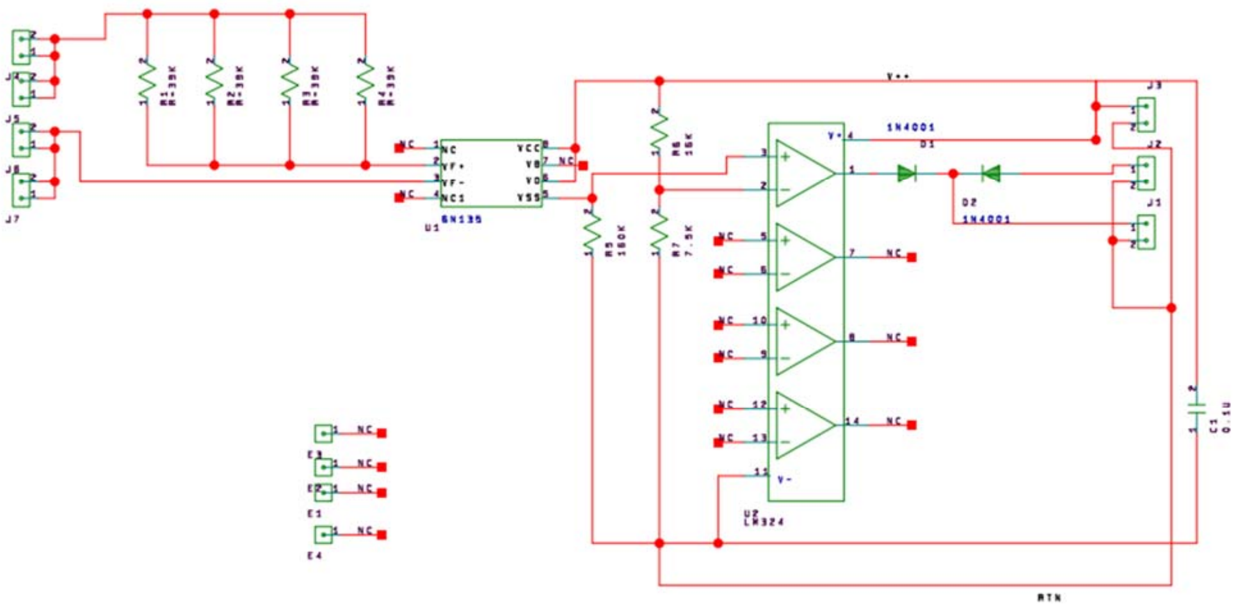

Figure 24 - TSVP circuit

6.7 Ready-To-Drive-Sound (RTDS)

*Describe your design for the RTDS system. See **EV9.2.***

The ready to drive sound will activate when the drive button is pressed assuming the correct startup sequence has been met up to that point. This information will be made available to us by the VSCADA system over CAN bus. If all conditions are met when the button is pressed, the microcontroller used in the TSI system will drive a sound maker similar to the provided sound clips for 2 seconds.

Section 7 GLV System

Person primarily responsible for this section:

Name: Chris Bennett

e-mail: bennettc@lafayette.edu

7.1 GLV System Data

Provide a brief description of the GLV system and complete the following table

The GLV system is comprised of the 24V LiFePo4 battery, vehicle computer interface(VCI), the vehicle user interface(VUI) and the safety loop. The battery provides 24V to all sub-systems. The VCI provides hardware for VSCADA interfacing. The VUI is the driver interface including buttons and dashboard display screen. The safety loop assures all systems are functioning properly before opening airs and allowing HV from the accumulators.

GLV System Voltage	24 V
GLV Main Fuse Rating	40 A(BMS)
Is a Li-Ion GLV battery used?	☐Yes / ☒ No
If Yes, is a firewall provided per **T4.5.1**?	☒Yes / ☐ No
Is a dc-dc converter used from TSV?	☐Yes / ☒ No
Is the GLV system grounded to chassis?	☒Yes / ☐ No
Does the design comply with **EV4**?	☒Yes / ☐ No

Table 27- GLV System Data

Section 8 Appendices

Include only highly-relevant data. A link to a web document in the ESF text is often more convenient for the reviewer.

The specification section of the accumulator data sheet, and sections used for determining accumulator capacity (FH Rules **Appendix A**) should be included here.

((50.3Ah calculated in section 5.2)* 96V (maximum from accumulator))/ 1000) = 4.82 kW hours