Lafayette College
Electrical and Computer Engineering

Critical Design Review Report

ECE 492 Spring 2018

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Abbreviations

TSV   Tractive System Voltage
TSI   Tractive System Interface
GLV   Grounded low Voltage
IMD   Isolation Monitoring Device
GLVMS   GLV master switch
TSVMS   TSV master switch
BRB(L/R S)   Big Red Button(Left/Right Side)
SSOK   Safety System OK
AIR   Accumulator Isolation Relay
TSAL   Tractive System Active Lamp
PackMAN   Pack (Accumulator Segment) Manager
HV   High Voltage
AMS   Accumulator Management System
AMSVU   AMS verification unit
TSMP   Tractive System Measuring Point

System Design

System Overview

The electrical system is designed to provide the power to the motor as well as host supporting subsystems. The major constituents of the overall system are:

1. TSV - Responsible for providing the power source for the high voltage required by the motor.
2. TSI - Responsible for providing a safe interface between the TSV and the motor controller, with inputs from the GLV and the pedals.
3. GLV - Responsible for providing a low voltage that operates the safety loop and any low voltage systems.
4. Motor Controller - Responsible for accepting inputs from the throttle and High Voltage and providing control signals to the motor.
5. Motor
6. VSCADA - Accumulation, monitoring and display of CAN data from TSV, TSI and motor controller.
7. Interconnect Cabling - Providing data transfer and power between each major subsystem
8. Cooling - Responsible for allowing the motor controller to operate at a safe temperature.

System States

State Diagram Compliant with Formula Hybrid Rules

Shutdown System State Machine
Jack Plumb
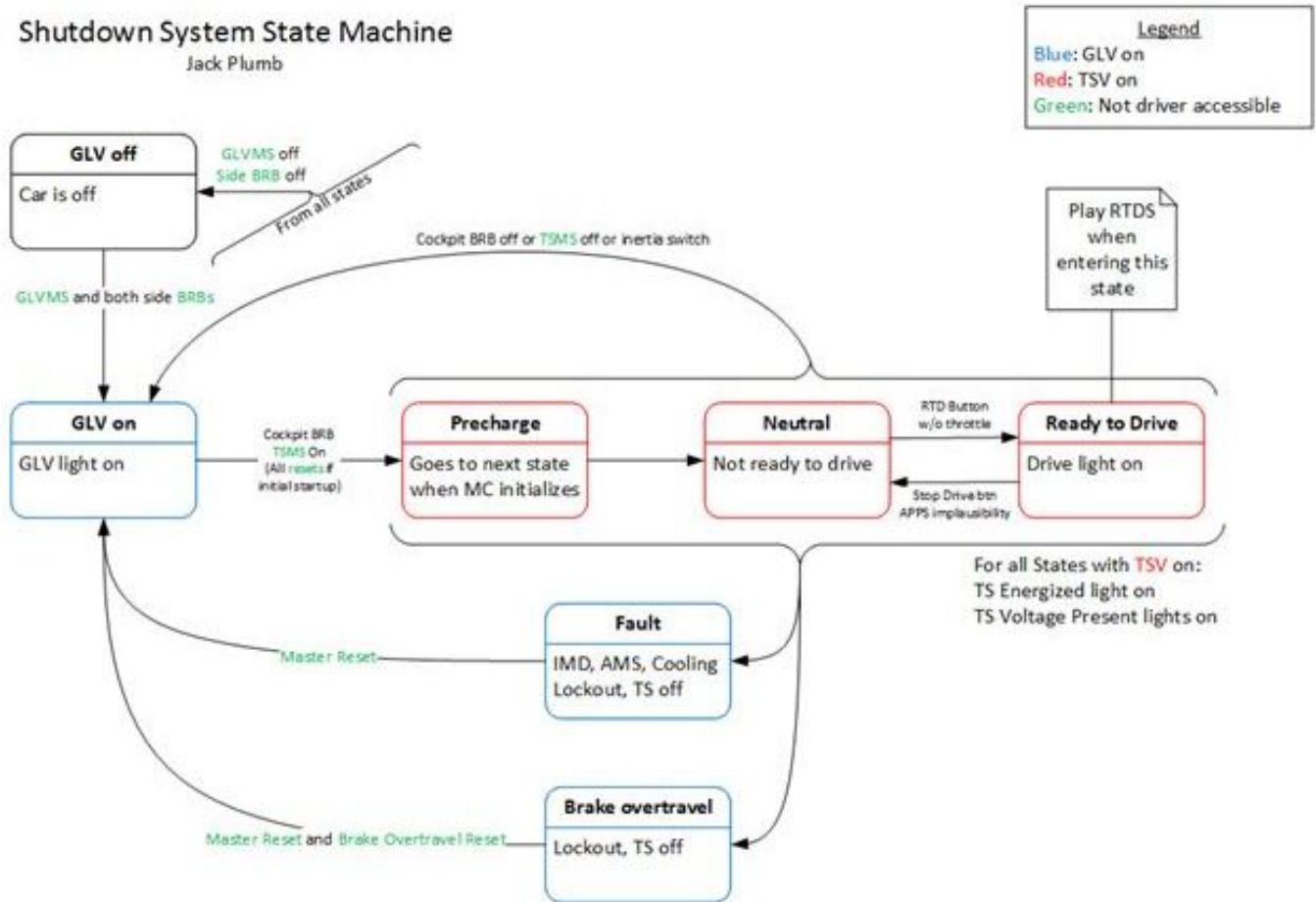
State Diagram for Electric Systems

The diagram above shows a depiction of the various states of the electrical system. The first state is off. While the car is in this state all electronics are turned off with the exception of the AMS and the PacMAN. These boards take power straight from the cells and do not have an off switch. How to enter:

- GLVMS to off
- BRBLS pushed
- BRBRS pushed
- GLV battery completely discharged

The only state that the car can enter after a full shutdown is GLV powered. In this mode low voltage power is provided to all subsystems. The safety loop is armed and the AIRs could be armed in this state. How to enter (AIRs off):

- BRBLS reset

- BRBRS reset
- Master Reset button on right side of car
- GLVMS on

At this point subsystems will be powered. Before drive mode can be entered the AIRs must be closed. How to close the AIRs:
- All subsystems must close the safety loop
- BRB Cockpit reset
- Cockpit reset
- Driver Reset
- TSVMS On

With the AIRs closed drive mode can be entered. To enter drive mode:
- Throttle must not be pressed
- Drive button pressed

Too exit drive mode and return to the AIRs closed state, push the drive button The throttle will disengage at this point and the car will come to a halt.
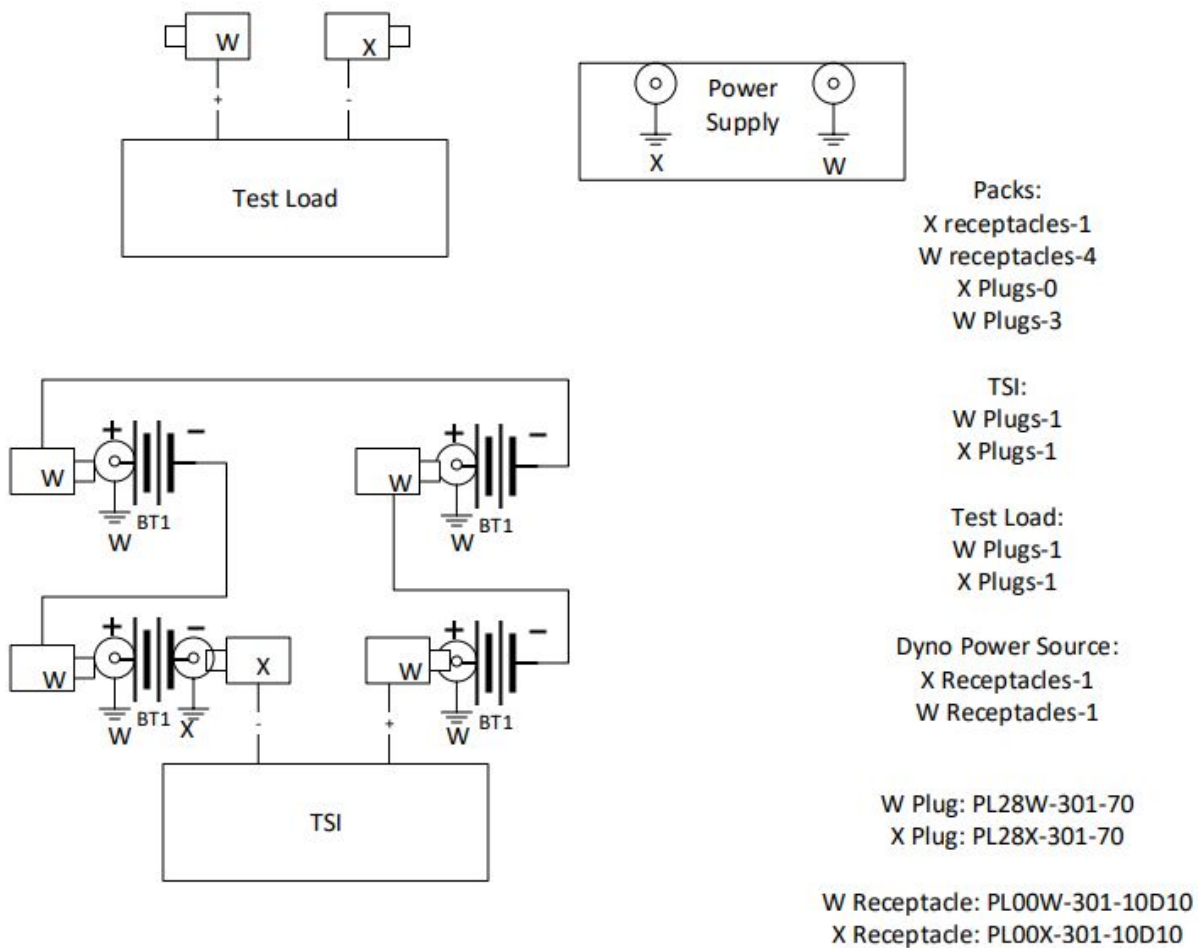
Overall Schematic

https://sites.lafayette.edu/ece492-sp18/files/2018/02/Overall_System_V1_5.pdf

TSV (Tractive System Voltage)

Accumulator

From previous years, the biggest change in the accumulators themselves is the replacement of the ITT Cannon connectors for HV+ and HV- with Amphenol PowerLok connectors. This is done in order to allow a fully shielded HV cable to be used as according to the rules. With the change in connectors, the bus bars within the accumulator containers will also be changed to accommodate the different terminals of the Amphenol connectors. The figure below shows the key-ing and the positions of the connectors.

Packs:
X receptacles-1
W receptacles-4
X Plugs-0
W Plugs-3

TSI:
W Plugs-1
X Plugs-1

Test Load:
W Plugs-1
X Plugs-1

Dyno Power Source:
X Receptacles-1
W Receptacles-1

W Plug: PL28W-301-70
X Plug: PL28X-301-70

W Receptacle: PL00W-301-10D10
X Receptacle: PL00X-301-10D10

Amphenol PowerLok Connection Layout

One segment will also now have two receptacles instead of one receptacle and one connector. As three of the segments have the same keyed connectors and receptacles, care must be taken to not self-plug.

Due to replacement of the connectors which now have a rating of 250 Amps, the main fuses attached to the HV current path must remain at or below 250 Amps.

PackMAN

The PackMAN has had minor changes since previous years. The majority of updates have been software related and are listed below:
1. Functional watchdog timer. If the microcontroller malfunctions, the watchdog timer will now reset it to ensure continuous operation.
2. Correcting interface with the LCD screen using buttons. This involved software debouncing of the buttons.
3. Configuration ability for different parameters as listed below currently:

| Config Add.	Config Param	EEPROM Addr	Size (bytes)	Default Value	Units
0x01	Pack Id	0x08	1	0x01	N/A
0x02	# Cells	0x09	1	0x07	Cells
0x03	Pack locked	0x02	1	0x00	bool
0x04	max Cell temp	0x03	1	0x3C	Degrees C
0x05	max cell voltage	0x04	1	0x24	tenth volts
0x06	screen reset time	0x05	1	0X0F	Seconds
0x07	screen sleep time	0x06	1	0x78	Seconds
0x08	min cell voltage	0x0A	1	0x1B	tenth volts
0x09	max cell charge voltage	0x0B	1	0x22	tenth volts
0x0A	min current	0x0C	1	0x01	Amperes

Currently, the PackMAN is capable of communicating (only transmission) with the VSCADA system using CAN bus.

In order to ensure that consistent reset of the packMAN do not cause the safety loop to open (unless a fault is detected), a time delay circuit will be added to the relay control signal. The circuit will be a basic RC circuit, providing an ~6 second delay. This will be tested to ensure ample time between relay opening and microcontroller reboot.

According the Formula Hybrid rules regarding fuses, the PackMAN fuses will also be altered to be rated for the entire TSV and 1 Amp.

AMS

From previous years, 28 functional AMS boards were tested and calibrated using the AMSVU. A test board was also developed to be able to test the trip voltages of the AMS and PackMAN.
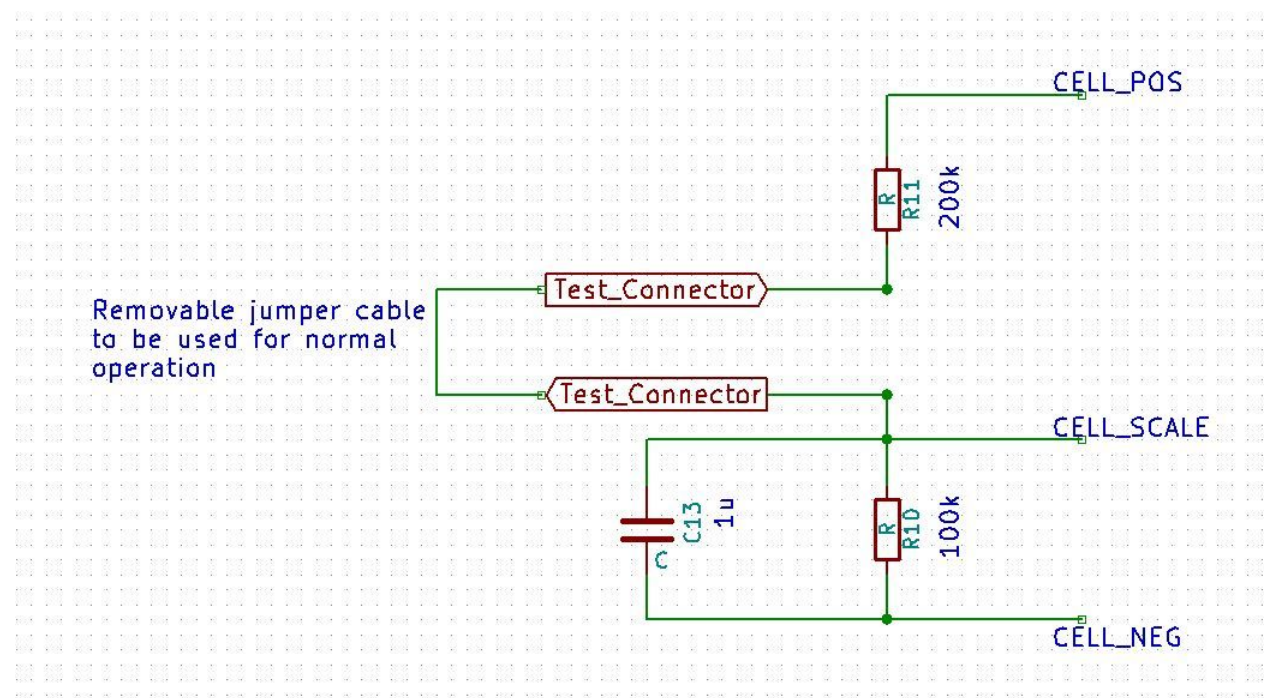
Schematic of the location of the test connectors

The figure above shows the location of the test connectors. The *cell_scale* input goes directly to the microcontroller via an ADC. This value is then sent to the PackMAN using I²C. The PackMAN then determines if this voltage is within range of the trip voltages. When testing, the jumper cable will be removed and replaced with a +/- 2 V source.

TSI (Tractive System Interface)

Hardware

The new internal wiring diagram can be found here:
https://sites.lafayette.edu/ece492-sp18/files/2018/02/tsi_box_wiring_diagram_1_1.pdf

Board

The board was redesigned this year to take care of throttle plausibility issues from the previous year as well as the TSAL requirement. Additionally, the board now contains new molex connectors to remove the need for the ribbon cable and din rail that seemed messy to assemble.

The board schematic can be found here:
https://sites.lafayette.edu/ece492-sp18/files/2017/11/Printing-Print-Schematic.pdf

The board layout can be found here:
https://sites.lafayette.edu/ece492-sp18/files/2018/02/tsi_circuit_layout_pcb.pdf

Brakes

The brake system is largely unchanged from last year. The brake overtravel switch relay was removed, and the brake overtravel switch will be wired directly into the safety loop to comply with rule T7.3.1.

Throttle

The same 5k throttle potentiometers from last year are still in use. They will be updated to be mechanically limited so they output 0.25V-4.75V, the acceptable range from throttle plausibility

IMD

We are still using the Bender ISOMETER IR155-3204 as it meets rule EV7.9.2. The IMD is hooked up directly to the safety loop with a relay so that when an IMD fault occurs the safety loop will open. The IMD is hooked up to the HV+ and HV- coming into the TSI but is also hooked up to the 24V of the GLV. The OKhs signal is put through the safety loop relay and the PWM output is an input into the TSI microcontroller.

TSAL

A new TSAL lamp was selected to comply with rule EV9.1. In order power this lamp, a higher power isolated DC/DC converter was selected to power it. The new converter has a maximum output of 1.25A at 24V, which is more than enough to power the lamp. The TSI PCB was updated to include this and supporting components

TSMP

There are three tractive system measuring points on the front of the TSI box. These are banana jacks that are hooked up with the HV+, HV- and chassis ground according to EV10.3. We have conducted a test on the IMD and verified that it can cut power to the tractive systems in about 10-15 seconds which meets the requirement of 30 seconds specified in EV10.1.2.

Firmware

Another big part of the TSI is the firmware that the microcontroller on the board will be running. This firmware is in charge of three major features of the TSI which are system measurements (current, voltage, temperature, and IMD status), CAN Bus communication to and from VSCADA, and the drive states implemented in the car. The microcontroller that is contained in the board is the Microchip AT90CAN128.

The current version of the firmware can be found at:
https://github.com/austinmam/TSI/tree/master/tsib

System Measurements

Voltage

The voltage is measured through use of an ADC. The signal V_measure is an input to the microcontroller which converts it to a digital signal. This signal is then sent to VSCDA over CAN.

Current

The Ametes Bus Bad DC Current Sensor BBM-01 is placed on both sides of the high voltage bus bar. This current sensor outputs measurements to an RJ11 which will connect to the RJ11 port on the TSI board and connect to the microcontroller. This is also measured through use of an ADC.

Temperature

An LM95071-Q1 Temperature Sensor interfaces with the microcontroller via SPI to provide temperature information from the TSI.

IMD Status

The Bender ISOMETER IR155-3204 outputs a PWM signal that will then be sent through a low pass filter and into the microcontroller. This signal is the measured resistance by the IMD and will be important especially when the safety loop opens as it will helps inform us whether it was because of the IMD or not.

The ISOMETER outputs a PWM signal that is sent through a low-pass filter. The output of the low-pass filter is then sent into the microcontroller as an analog voltage. This signal is then converted to a digital signal by an ADC that is then sent to VSCADA over CAN.

The analog voltage value of the PWM signal is equal to the amplitude of the PWM multiplied by its duty cycle. Per the data sheet of the ISOMETER, a duty cycle of 90% or greater is considered an IMD fault.

CAN Bus Communication

The TSI is able to send bytes of information to VSCADA. Currently it will be sending voltage measurements, current measurements, temperature measurements, IMD status (which is the PWM low filtered output of the IMD), and drive state (to tell which state the car is in.) These are all sent at a regular interval and was tested on a makeshift CAN network until it can be implemented in the car's CAN network.

The TSI is also receiving one signal from VSCADA which is the "throttle_control." This signal will be changed from a 0 to 1 and tells the TSI whether there is something wrong with the system and that the TSI should disable the throttle so the car cannot keep driving.

Drive States

The drive states are implemented in the car to control the various different states the car would be in. Currently, the states that are being implemented are the IDLE, SETUP_DRIVE, DRIVE, SETUP_IDLE. This will be further developed to accommodate the VSCADA throttle control signal.
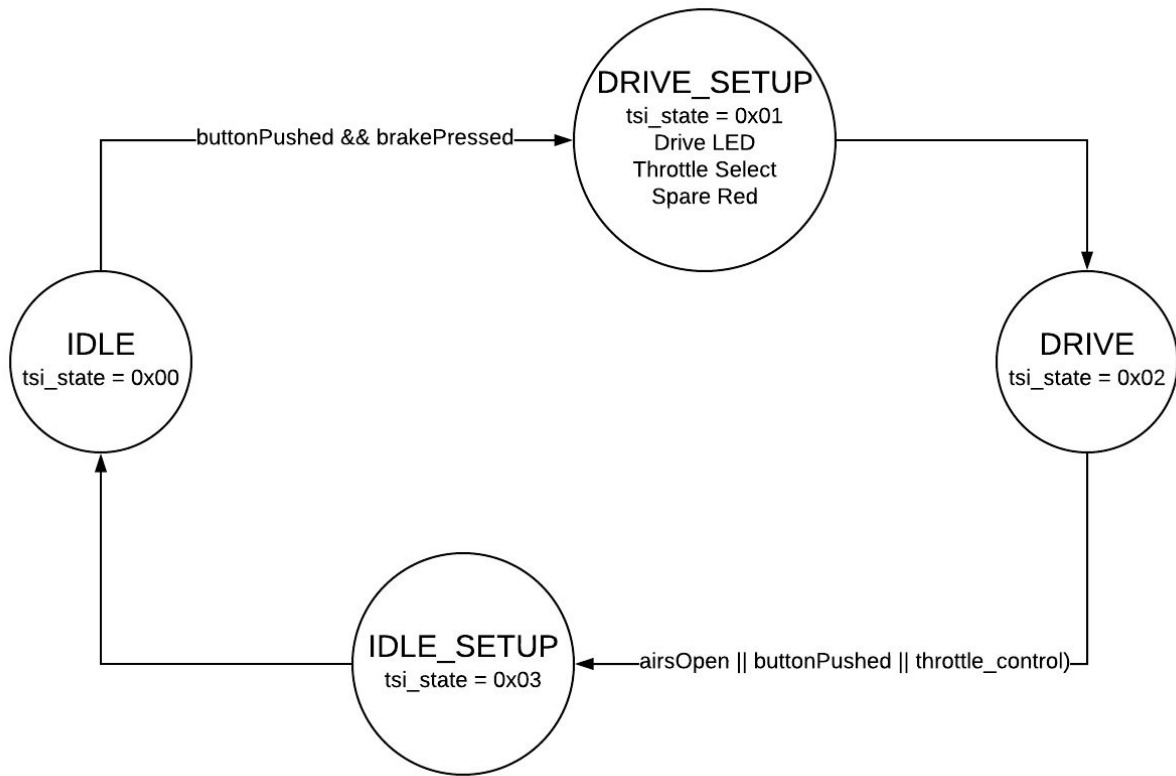
State Diagram of TSI Drive States

The car starts in the IDLE state, in this state the throttle is disabled and the car cannot move. In order to move to the SETUP_IDLE state, the driver must press down the brake and push the ready to drive button. The ready to drive button has been debounced so a press only registers once the button has been released. When the system goes into the SETUP_DRIVE state the throttle select is set high meaning throttle is enabled. Also the drive LED turns on as well as a Spare Red LED. The system goes from SETUP_DRIVE to DRIVE unconditionally. The car stays in this DRIVE state until one of three things: the AIRs open, the drive button is pushed again, or VSCADA sends the signal to drop out of drive mode. If one of those three conditions is seen then the car goes into SETUP_IDLE which sets throttle select back low, and turns off the drive LED and spare red LED. The system then goes to the SETUP state from the SETUP_IDLE unconditionally.

Grounded Low Voltage (GLV)

Overview

Grounded Low Voltage provides 24V power to low voltage subsystems on the vehicle, as well as control the safety loop, and monitoring Vehicle status through VSCADA system.

Design

The design of the GLV remains the same from last year. Major components on the GLV are functional and tested with the motor. The details of the design are shown in the link below: https://sites.lafayette.edu/ece492-sp17/subsystems/glv/

One of the major components that has been added is the SSOK lamps due to the rules requirement and shown on the high level GLV diagram below. (EV 9.3)
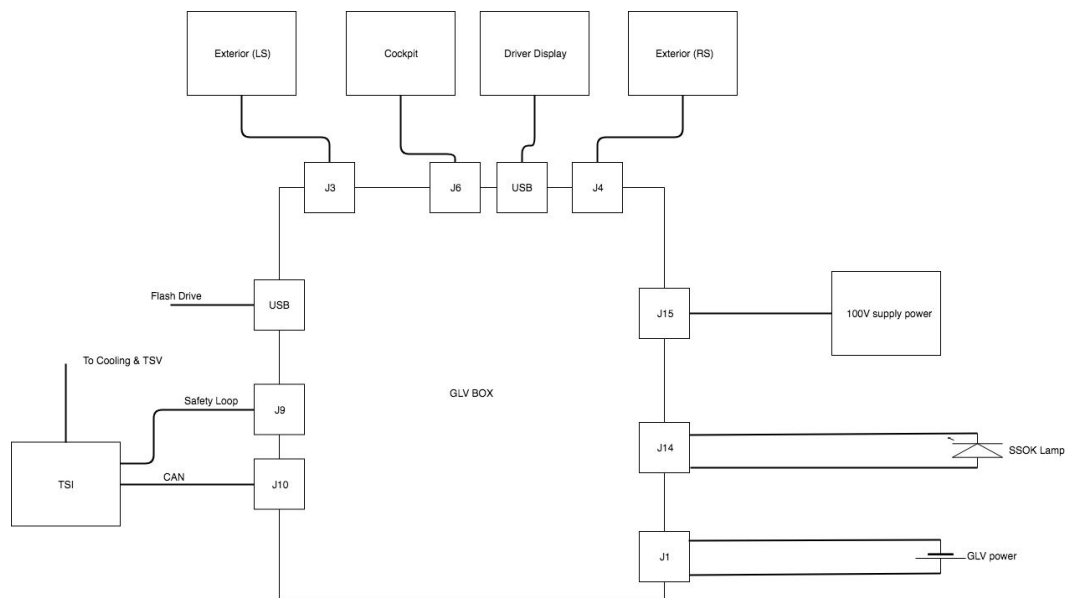
GLV Top Level Diagram

Besides adding functionality of the SSOK lamps, the VSCADA monitoring screen is also added on the right side of the GLV Enclosure. (A GLV enclosure picture is added below for reference

of the position of the VSCADA screen) The main functionality of the screen will be a monitoring device of the vehicle.
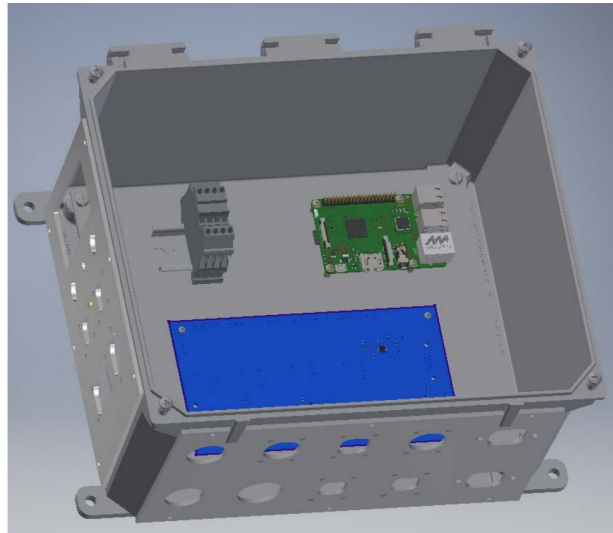
GLV Enclosure

Vehicle Supervisory Control and Data Acquisition (VSCADA)

Overview:

The SCADA software will be storing, monitoring, and displaying data from subsystems that is sent on the CAN bus channel. The packets received from the CAN bus will be parsed out into meaningful, human-readable information. That data is then checked against the thresholds set in the config file. If the data is outside of the allowed thresholds it is flagged and new entry is added to the log file. The system will also send a message over CAN bus to the TSI to drop out of drive mode if it is marked in the config file. The data is stored in the database with its flag status (true or false) if the "Start Recording" button as been pressed by the driver. Once the "Stop Recording" button has been pressed data will be exported to a CSV

Installation:

The target operating system is Linux, specifically Raspbian and Ubuntu. A link on the website will download the latest snapshot. Anyone will have the capability to either download a compressed file containing our code or will be able to clone the code down from our GIT repo. Upon download/uncompressing the files, a user will be able to 'cd' into the VSCADA directory and run the main file, getCANData.py. There will be a list of the requirements in the readme, that when installed, will allow the application to be launched properly.

CAN bus Interface:

To connect with the CAN network, we ditched the USB to CAN adapter they used last year and decided to use the PiCAN 2. It uses the GPIO pins to communicate with the Pi, making analysis of the network very easy. There is one command (listed in the repo's readme) that connects to the CAN network. Once connected, we use the python-can library to read and write to/from the network. Last year's team made a very helpful ICD which we used to interpret packets sent by different subsystems, including TSV, TSI, and the motor controller. In it, it relates a particular address and certain bytes that contain data for particular sensor (as shown below).

Description	Address	Offset	ByteLength	System	Units
Pack 1 state	0x100	0	1	TSV	

Above is an example entry in the ICD made last year

So in the example above, we know that the state of pack 1 is stored in the first byte of the packet with address 0x100. We only made small revisions to the previous year's ICD, and we made a list of dictionaries, acting as a lookup table (as shown below)

{"address": 0x100, "offset": 0, "byteLength": 1, "system": "TSV", "pack": 1, "sampleTime": 15, "updated": 0, "description": "State"}

The dictionary with the matching entry as the ICD entry above

We added some attributes, like sample time and updated, to keep track of our update frequency.

Database:

The database consists of only one table where all of the data is stored in its separate components. The columns of the table are: id(automatically assigned 0,1,2…), sensor name, pack number, system, time, flagged, session_id. If the data did not come from a TSV pack then it is marked with a pack number of 0. System is TSI, TSV, or MC (motor controller). Time is Hour:Minute:Second. The raspberry pi does not have a real time clock so dates are not currently being stored. The time will reset every time the pi reboots. The session_id is just an integer that increments every time the pi restarts or the driver stops recording. The session_id can be used to keep data relative and should be written down or noted when the car is started. The session_id is the only way to know what data corresponds to which driver/ what times. Data is sampled and stored once per second or once per 15 seconds depending on the sensor. When the "Stop Recording" button is pressed on the driver dashboard is pressed, two CSV files will be generated and placed onto the USB flash drive. One CSV will have all of the data from the entire database. This file will overwrite the old one each time so that after each export the file will always contain all of the data. The second CSV will on contain data from the current session. These files will be called car_data_{session_id}.csv. Again it is important to note the session number on the GLV display.

Displays:

The car will have two displays. One for the driver in the cockpit referred to as the "Dashboard Display" and one on the GLV box for troubleshooting referred to as the "GLV Display". The dashboard display will display only a few valuable data values for the drive (Motor temp, state of charge, current). It will also have LEDs for indicating status of car. A red LED means that the system is recording and a yellow LED means check engine. The dashboard display will also have a "Start Recording" button (check mark) and a "Stop Recording" button (X) to control the SCADA system.

The GLV display currently shows the voltage and current of each pack and overall. It also displays the session_id, motor rpm, and motor temperature. The SCADA team is working to add more information to this display. The display will also show a null value if data is not received from a system after a fixed amount of time. This will be valuable when troubleshooting issues on the vehicle.

Interconnect Cabling

Overview

Interconnect cabling is responsible for providing data transfer and power between each major subsystem. It is the job of interconnect cabling to integrate each system into the larger design. These cables must be safe, manageable, and durable so they will survive when the car is in motion or other forces or acting on them. This year's interconnect team focused on the organization and fixing of last year's cables. We are using the same cables used on last year's interconnectivity document listed here:
https://sites.lafayette.edu/ece492-sp17/files/2017/01/IC_ICD.pdf

The tasks of this year's team included gathering every cable and fixing cables that would not pass tech inspection. This included covering exposed wires and trimming any unnecessary wires in a cable. Another main task of interconnect was researching and purchasing new cables for the TSV battery packs to be used with the new Amphenol Powerlok connectors.

Shielded Cables

Currently the black cables that are being used on the TSV battery packs with the old ITT powerlock connectors violate the rules of the competition. They are not grounded, and the new rules call for orange shielded cables to be used in the tractive systems. The interconnect team purchased exrad xle 3/0 orange shielded cable from Champlain Cable. This cable is in accordance with the rules, and the diameter of the 3/0 cable fits best with our Amphenol Powerlok connectors on the TSV designed for 70mm^2 cable.

Cooling System

Overview

The cooling system is responsible for keeping the motor controller at a safe temperature. The system runs off of 24v from the GLV.

Design

The cooling system we are using this year is a different design than last year. We got rid of the Arduino Uno and replaced it with the Koolance fan and motor controller that is used in the DYNO room. The system receives 24v from the glv. The system has a 24v to 12v DC converter to power the cooling controller with 12v. The controller powers the fans and pumps. It also displays the temperature readings and the flow rate. Last year they planned to send the flow rate and temperature data over the CAN network. Since we are not using the Arduino anymore, we are not connected to the CAN network. The system is not part of the safety loop anymore as well.
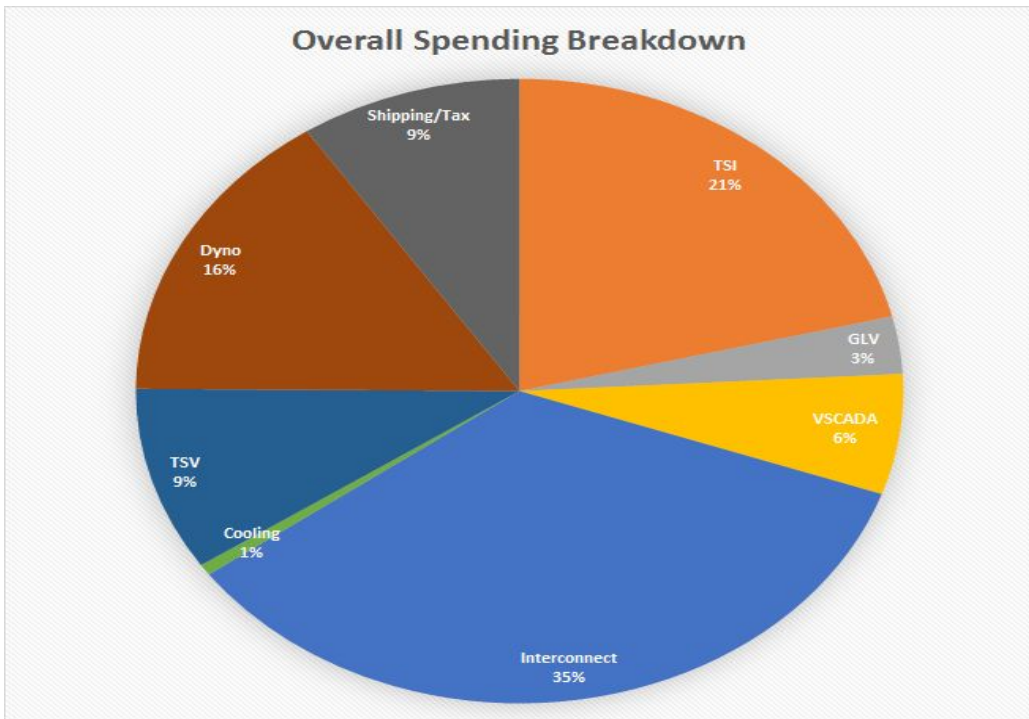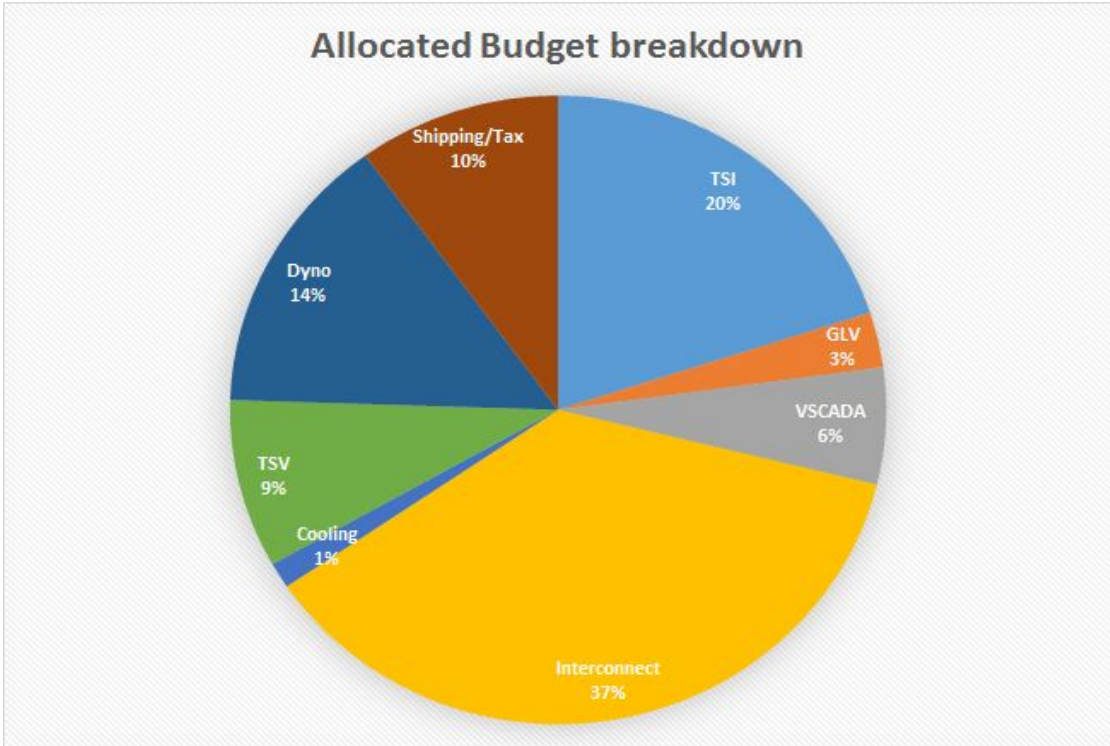
Budget

The table below shows that we have already spent 92.34% of our original Allocated Budget of $3000. The Allocated Budget on each sub-system was re-adjusted on week 5 and week 6 as the purchases on Subsystems Dyno,TSI and VSCADA were higher than initially anticipated. The spending in Dyno was higher as we bought new screen which could be used outside of the Danger area within the dyno room. Similarly, as we made new box for the TSI subsystem, we had to spend more money than anticipated in the PDR.

Considering we only have $229.86 budget remaining and anticipate more purchases in Interconnect (strain reliefs, materials for new W-21), TSI, TSV and Shipping/Tax, we anticipate we will go $300-$400 above the total budget of $3000 (as per our anticipation of March 2).

Note: The purchases report below is different from the one during the CDR presentation as some purchases were made on Thursday March 1 after the presentation was due. The Table below shows all the purchases made by March 2 5:00pm which is the end of week 6.

Subsystem	Spent this period	Spent to date	Budget Allocated	Budget Remaining	Percentage Spent
TSI	$223.37	$586.04	$600.00	$13.96	97.67%
GLV	$36	$82.22	$85.00	$2.78	96.73%
VSCADA	$0	$172.59	$180.00	$7.41	95.88%
Interconnect	$49.99	$960.01	$1,100.00	$139.99	87.27%
Cooling	$0	$15.99	$40.00	$24.01	39.98%
TSV	$65.81	$263.90	$260.00	$3.90	101.50%
Dyno	$78.53	$430.57	$435.00	$4.43	98.98%
Shipping/Tax	$151.86	$258.82	$300.00	$41.18	86.27%
Total	605.56	$2,770.14	$3,000.00	$229.86	92.34%

Allocated Budget breakdown

- Shipping/Tax 10%
- TSI 20%
- GLV 3%
- VSCADA 6%
- Interconnect 37%
- Cooling 1%
- TSV 9%
- Dyno 14%

Overall Spending Breakdown

- Shipping/Tax 9%
- TSI 21%
- GLV 3%
- VSCADA 6%
- Interconnect 35%
- Cooling 1%
- TSV 9%
- Dyno 16%

Note: The graph above shows how much of the total money spent till now has been spent in each subsystem.

Budget Spending Per Sub system

Percentage Spent of Total Budget
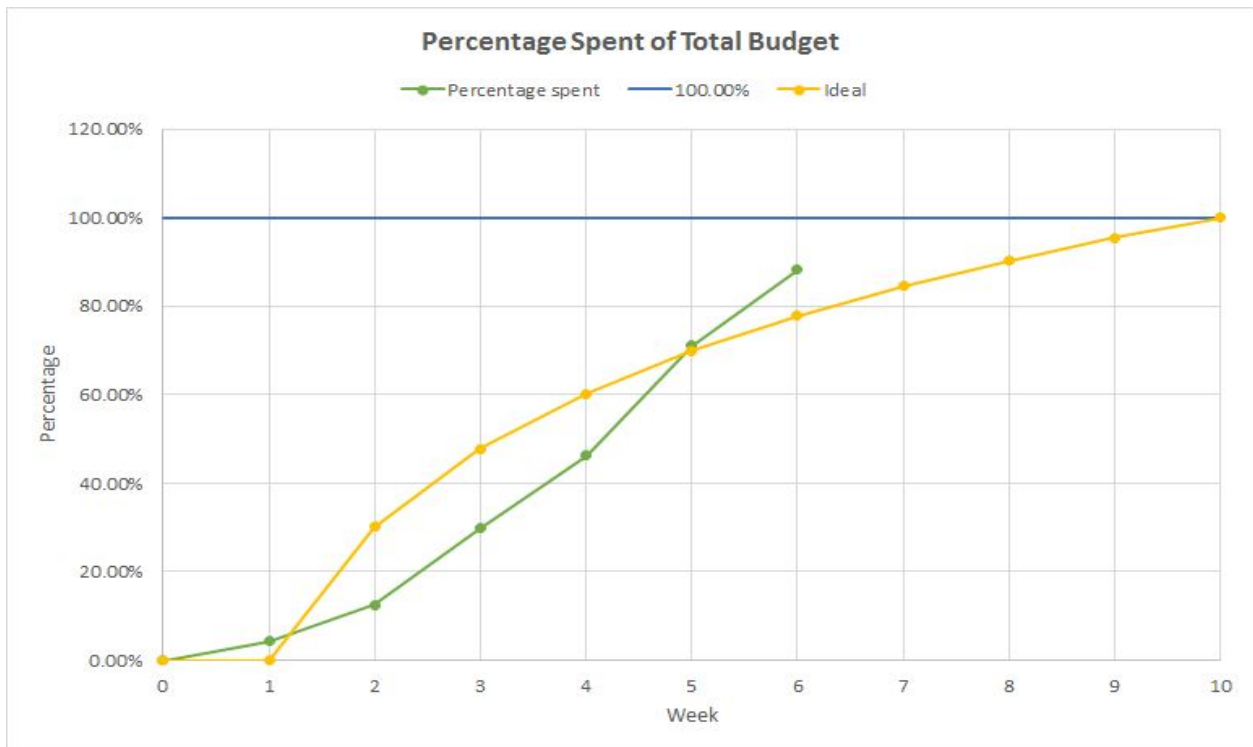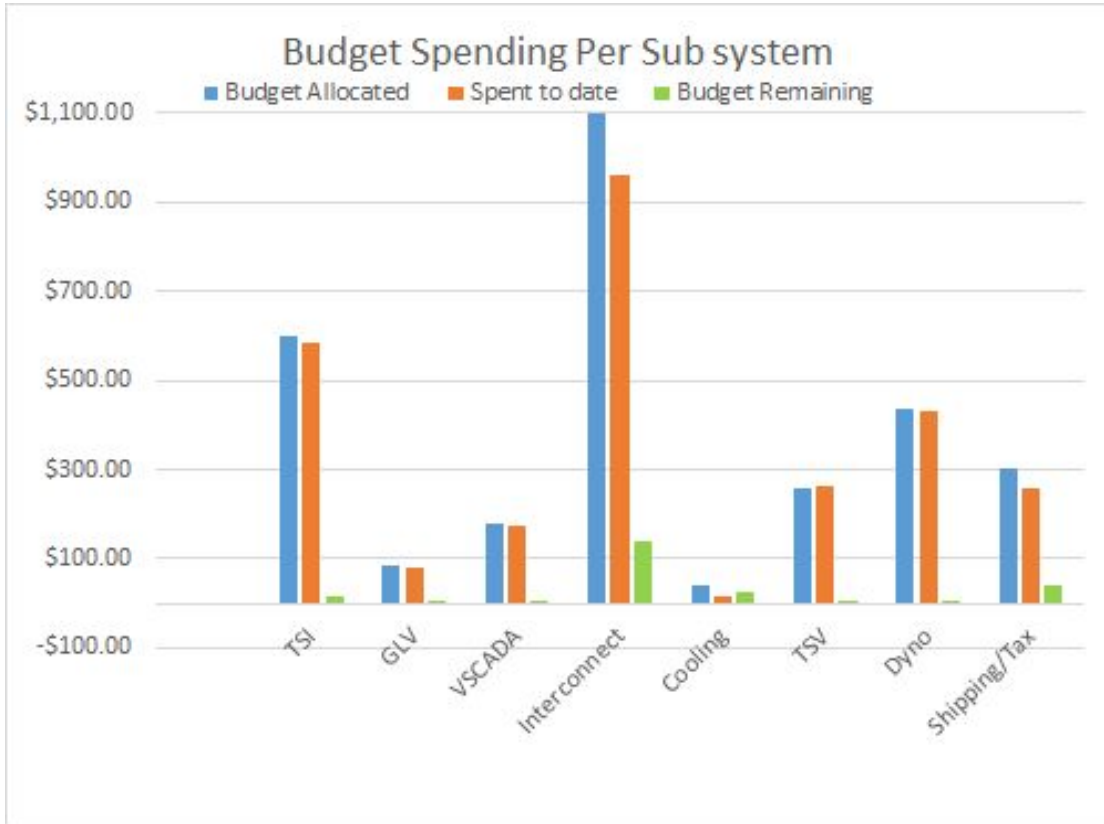
Work Breakdown Structure

Please access this year's work breakdown structure in the below link:
https://sites.lafayette.edu/ece492-sp18/work-breakdown-structure-wbs/