Dynamometer Test Plan

ECE 492 - Spring 2019

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Abstract

This document details the acceptance test plan for the dynamometer system being developed for the Lafayette Formula Electric Vehicle Design Project.

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List of Abbreviations

AIR	Accumulator Isolation Relay
AMS	Accumulator Management System
BRB	Big Red Button
CellMan	Cell Manager
Dyno	Dynamometer
FH Rules	Formula Hybrid Rule
GLV	Grounded Low-Voltage
GLVMS	Grounded Low Voltage Master Switch
HDPE	High Density Polyethaline
LFEV	Lafayette Formula Electric Vehicle
IMD	Insulation Monitoring Device
MCS	Motor Controller System
PackMan	Pack Manager
SegMan	Segment Manager
RTDS	Ready to Drive Sound
SMD	Segment Maintenance Disconnect
SSOK	Safety Systems OK
TS	Tractive System
TSI	Tractive System Interface
TSAL	Tractive System Active Light
TSMP	Tractive System Measuring Point
TSMS	Tractive System Master Switch
TSV	Tractive System Voltage
(V)SCADA	(Vehiclar) Supervisory Control and Data Acquisition

Summary

The dynamometer system being developed for testing the LFEV design project is intended to provide detailed characteristics of the Motor Controller System (MCS) over the entirety of its operating range. The tests to be run are to be performed in order to demonstrate compliance with the Formula Hybrid EV rules section as well as the requirements listed in GPR005 for ECE 492.

Testing Configurations

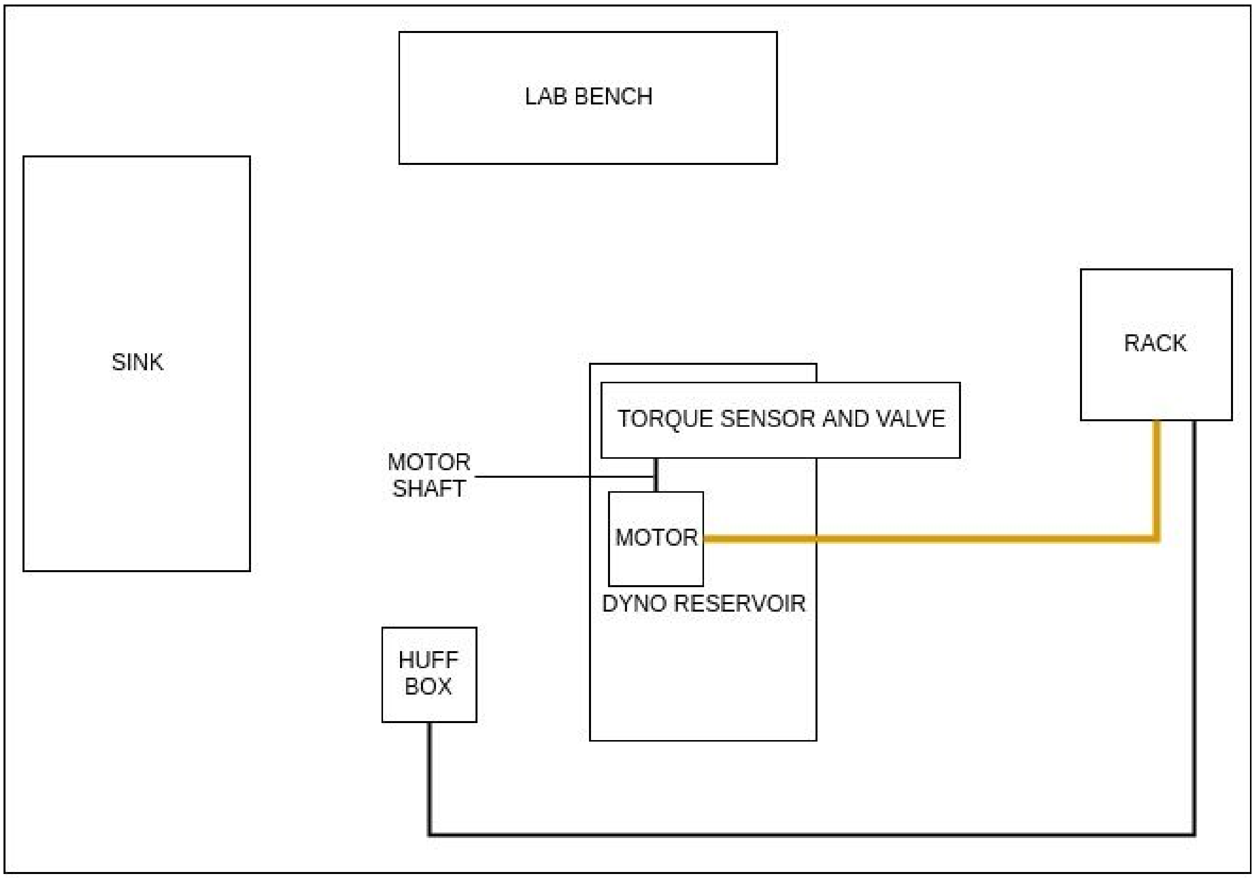

Figure 1. Dyno Room Overview

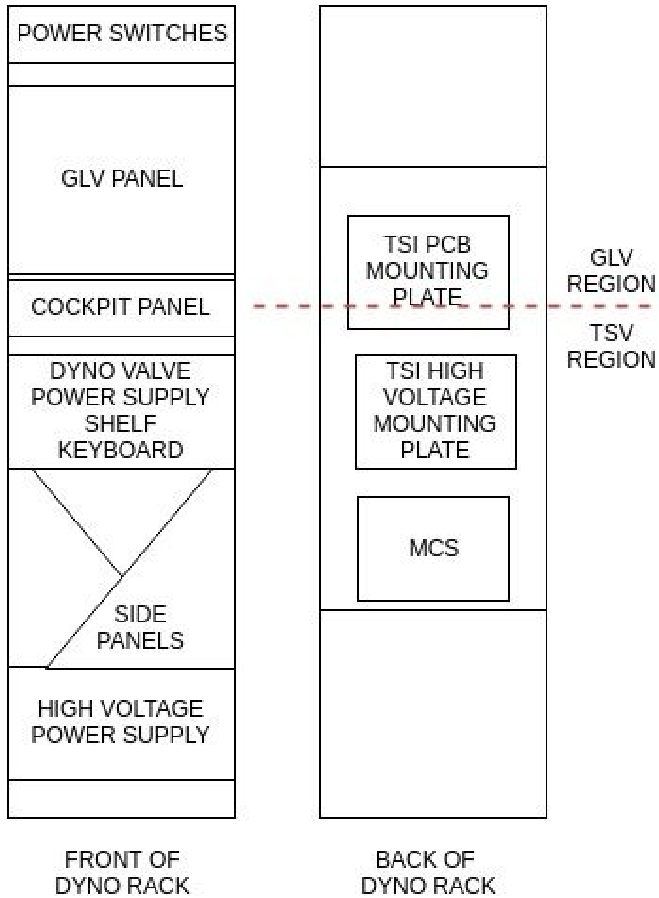

Figure 2. Rack Overview

Compliance Table

Rules to Waive	
Requirement	Reason for Waiving
EV2.1.2	Will not be using pouch type cells
EV2.4.10	Accumulator Containers will not be completely sealed
EV2.5.5	Will not be using a monocoque
EV2.6.3	Will not be using nPmS connections
EV2.6.4	Will not be using nSmP

EV2.6.5	Will not be reducing fuse ratings
EV2.6.6	Will not be reducing fuse ratings
EV2.10.2	Will not be using a timed circuit for the pre-charge
EV2.10.6	Will not be using an always-on discharge circuit
EV2.12	Will not be using Virtual Accumulators
EV3.1.8	Will not be using interlocks
EV3.1.10	Will not be meeting rain test requirements
EV3.2.6	Will not be using conduit
EV3.2.7	Will not be using conduit
EV3.2.8	Will not be using outboard wheel motors or TS cabling outside the roll hoop
EV3.5.2	Will not be producing a foot pedal
EV3.5.3	Will not be producing a foot pedal
EV4.1.5	Will not be using a battery, will be using Shore Power
EV4.1.6	Will not be using a wet-cell battery
EV5.2.1	Will not be using conduit
EV7.3.3	Will not be using GLV charging system such as alternators or DC/DC converters
EV7.9.6	Will not be using latching circuitry for the IMD
EV9.1.2	Will be using an amber TSAL
EV10.5	Will not be conducting rain test
EV11	Will not be using pouch type cells
EV12.3.2	Will not be using and hand cart with a brake
EV12.3.3	Will not be using a hand cart with a brake

Table 1. Waived Formula Hybrid Rules

All Formula Hybrid Competition Rules not listed in the above table will be met. We will demonstrate compliance by Inspection (Table 3), Analysis (Table 4) and/or Demonstrations.

Section	Related Test	Functional Requirement / Interface
R001	VSCADA	
R001-0	T001-1	Must interface sensors so that VSCADA can monitor the following sensors: ● Tractive System DC current and motor phase currents ● Temperature of motor system ● Data available from the Emsiso Motor Controller ● Data available from dyno sensors ● GLV Current Sensor ● TSI Current Sensor ● CellMan Voltage Sensors ● GLV Voltage Sensor ● TSI Voltage Sensors ● CellMan Temperature Sensors ● GLV Temperature Sensor ● TSI Temperature Sensor ● Cooling Temperature Sensor ● Cooling Flow Rate
R001-1	T001-1	The LFEV system shall use a commercial motor controller with a computer interface already installed. VSCADA shall use this interface to access, record, and display all available motor controller data in a form that is integrated with the overall LFEV data display.
R001-2	T001-1	The LFEV system shall use a commercial dynamometer with a data acquisition sensor hardware already installed. VSCADA shall use the data acquisition hardware interface to access, record, and display all available dynamometer data in a form that is integrated with the overall LFEV data display.
R001-3	T002-6	The system must be able to measure, collect, calibrate, display, and store data as specified in the configuration file. In the event that something goes wrong, it will be useful for VSCADA to display sensor data as well as log data for future reference. All code must be properly commented as required by GPR005 and all thresholds set in software should be easily accessible and able to alter. The VSCADA should be able to interface with other system firmware,

		such as in the TSI to be able to knock the system out of drive mode.

R002	TSV Packs	
R002-0 (EV1.2.1)	I001	Accumulator segments do not exceed 120 V or 6 MJ
R002-1 (EV2.2.1)	I004	Accumulator segments are separated by an electrically insulating barrier meeting the GLV/TS separation regulations ● Note: For Lithium based cell chemistries, barriers must also be fire resistant (according to UL94-V0, FAR25 or equivalent).
R002-2 (EV2.6.1)	I018	Every accumulator container must contain at least one fuse in the high-current TS path, located on the same side of the AIRs as the battery or capacitor
R002-3 (EV8.1)	T003-1	At least two isolation relays (AIRs) must be installed in every accumulator container, or in the accumulator section of a segmented container such that no TS voltage will be present outside the accumulator or accumulator section with the TS is shut down. ● Note: AIRs must be before TSMPs, such that TSMPs de-energize when AIRs are open.
R002-4 (EV8.2)	T003-1	The accumulator isolation relays must be of a normally open (N.O.) type which are held in the closed position by the current flowing through the shutdown loop. When this flow of current is interrupted, the AIRs must disconnect both poles of the accumulator such that no TS voltage is present outside of the accumulator container(s).
R002-5 (EV2.10.1)	T002-4	Intermediate circuitry must be charged to 90% of accumulator voltage before AIRs are closed
R002-6 (EV2.10.4)	A015	Discharge circuitry can handle maximum discharge current for a minimum of 15 seconds
R002-7 (EV2.11.2)	T003-3 T003-4	The AMS must monitor all critical voltages and temperatures in the accumulator as well the integrity of all its voltage and temperature inputs. If an out-of-range or a malfunction is detected, it must shut down the electrical systems and open the AIRs within 60 seconds

R002-8 (EV2.11.8)	A022	All GLV connections to the AMS must be galvanically isolated from the TSV.
R002-9 (EV5.1.1)	I052	All TS wiring and components must be galvanically isolated from GLV by separation and/or insulation. ● All interaction between TS and GLV must be by means of galvanically isolated devices such as opto-couplers, transformers, digital isolators or isolated dc-dc converters.
R002-10 (EV5.3.1)	I058	Tractive system wiring must be constructed using spacing, insulation, or both, in order to prevent short circuits between TS conductors. ● Minimum spacings: ○ Over Surface: 6.4 mm ○ Over Air: 3.2 mm
R002-11 (EV.5.5.5)	I068	All printed circuit boards located inside the accumulator container and having tractive system connections on them must be fused at 1 A or lower. ● Note: if fuses are located on the board, the spacing between tractive system conductors on the source side of the fuse must be at least 3.2 mm
R002-12 (EV9.5.1)	T003-6	Any removable accumulator container must have a prominent indicator, such as an LED, that is visible through a closed container that will illuminate whenever a voltage greater than 30 VDC is present at the vehicle side of the AIRs

R003	GLV / Safety Loop	
R003-0	T000-1	Safety Loop functions as described by Figure 3 in Appendix B
R003-1	T000-4	Safety Loop opens when unsafe sensor readings are detected
R003-2	T001-1	Must interface VSCADA with the following subsystem sensors: ● Cooling temperature and flow rate ● GLV current, temperature, and voltage ● TSI current, temperature, and voltage ● Motor current, temperature, throttle, torque, and voltage
R003-3	T000-1	Must interface with status lights on the car to indicate faults, safety loop closed, braking, and high voltage present. Must interface with buttons and switches to reset relays, turn on /

		off high and low voltage, and emergency stop.
R003-4 (EV4.1.1)	A031	GLV must have a voltage below 30 VDC
R003-5 (EV.4.1.8)	I051	Orange wiring/conduits may not be used in GLV wiring
R003-6 (EV7.1)	T000-1	If the flow of current through the safety loop is interrupted, the AIRs will open, disconnecting the vehicle's high voltage systems from the source of that voltage within the accumulator container.

R004	Motor / Motor Controller	
R004-0	I112, I115	A motor, motor controller, and dynamometer shall be assembled together along with all necessary mechanical parts, couplings, plumbing, fasteners, TSV and GLV cabling, cooling equipment, sensors, interlocks, safety shields, and cable strain relief per GPR005, and any other necessary items to create an integrated dynamometer room.
R004-1	I115	The dynamometer shall permit the safe testing and demonstration of motor and controller performance over the operational parameters (RPM and torque profiles) implied by the IEEE Formula EV competition rules.
R004-2 (EV3.5.1)	I045	The motor must be connected to the accumulator through a motor controller. Bypassing the control system and connecting the tractive system accumulator directly to the motor is prohibited.
R004-3 (EV3.5.4)	T002-1	Acceleration control signals between pedal and motor controller must have error checking. ● Must detect: open circuit, short to ground, short to sensor power
R004-4 (EV3.5.5)	T002-1	Torque production must be shut-down in under 1 second from time of fault detection in acceleration control

R005	TSI	
R005-1 (EV.5.1.1)	I052	All TS wiring and components must be galvanically isolated from GLV by speratation and/or isolation
R005-2 (EV.5.5.5)	I068	All printed circuit boards located inside the accumulator container and having tractive system connections on them must be fused at 1 A or lower. ● Note: if fuses are located on the board, the spacing between tractive system conductors on the source side of the fuse must be at least 3.2 mm
R005-3 (EV7.9.1)	T001-8	Vehicle must be outfitted with an insulation monitoring device installed in the tractive system ● IMD must be a Bender28 A-ISOMETER ® iso-F1 IR155-3203 or IR155-3204 or equivalent IMD approved for automotive use
R005-4	T002-2 T002-3	The system shall utilize a state machine to keep track of which state the system is in as well as ensuring certain conditions are met before moving onto the next state. The drive state FSM will also ensure that in the case of overcurrent, the system will shift out of drive mode.
R005-5 (EV9.1.8)	T003-1	The TSAL must be lit and clearly visible any time the voltage outside the accumulator container exceeds 60 V.
R005-6 (EV9.2.1)	T002-7	The car must make a characteristic sound, for a minimum of 1 second and a maximum of 3 seconds, when it is “ready to drive” ● The car is “ready to drive” as soon as the motor(s) will respond to the input of the torque encoder / accelerator pedal.
R005-7	T001-1	The system shall implement firmware to process data, communicate with SCADA, and manage the drive states.
R005-8 (EV.2.10.1)	T002-4	The AIR contacts must be protected by a circuit that will pre-charge the intermediate circuit to at least 90% of the rated accumulator voltage before completing the intermediate circuit by closing the second AIR.
R005-9 (EV.2.8.3)	A015	If a discharge circuit is needed to meet the requirements of EV2.8.3, it must be designed to handle the maximum discharge current for at least 15 seconds

Table 2. Compliance Matrix

T000 - Safety Loop

The MCS will have a safety system in place to minimize the risk of injury while operating the device. An emergency stop button will be clearly located, and the physical design will adhere to several safety standards.

T000-1 - Safety Loop

The Safety Loop will operate as described in Figure 3 of Appendix B.

Testing Procedure:

The system will begin in a powered up state with AIRs closed. A component of the Safety Loop will be toggled to an off or closed position and the system state will be observed and compared to the requirements. The system will then be returned to a fully powered up state before continuing to test each component of the Safety Loop.

Acceptance Threshold:

The system responds in the correct manner based on which piece of the Safety Loop has been tripped.

Requirements Met: R003-0, EV7.1, EV7.3.1, EV7.4.1, EV7.5.4, EV7.6.3, EV9.3.3, EV9.3.4

T000-2 - Safety Loop Resets

The two green reset buttons in the Safety Loop, the MReset and the Cockpit Reset, are able to turn on the SSOK lamps and the high voltage respectively when the Safety Loop is at the correct state.

Testing Procedure: The system begins in a powered off state. The GLVMS is turned to the on position and the MReset is pressed. Observe the SSOK lamps to see if they are ignited by the button press. Next the TSMS is turned to the on position. Next, the Cockpit Reset is pressed and observe if the AIRs are closed and the high voltage is connected to the system.

Acceptance Threshold: The system responds in the described manner based on the system state when the Reset Buttons are pressed.

Requirements Met: N/A

T000-3 - Faults and Resetting

The Safety Loop should visually notify when a fault has occurred and should be able to be reset by the Cockpit Reset Button in certain situations.The reset buttons should only be able to ignite the SSOK lamps or close the AIRs following certain types of faults.

Testing Procedure: A fault will be intentionally induced in the system before powering it on. The standard start up procedure would then be followed. Observe how far into the procedure the system is able to advance. Compare this to the expected progress for a given fault.

When an error is present in the system and displayed to the driver by an LED on the dashboard, the reset button will be pressed. Depending on the type of error, the reset button should either return the system to a functional state or should have no effect on the system. Both of these possible outcomes should be tested and observed for each of the possible faults.

Acceptance Threshold: The Safety Loop fault recognition will be considered functional if it is able to correctly notify an observer of a fault after it has occured and if it is able to be reset into a functional state after a fault if allowed by the system.

Requirements Met: N/A

T000-4 - SCADA Relay

Demonstrate the control the SCADA system has over the SCADA Relay in order to respond to an unsafe or out-of-range value measured by a sensor into the SCADA software to trigger a break in the Safety Loop.

Testing Procedure: The system will begin in a completely energized state with all of the sensors sending data to the SCADA software. A sensor's reading will be brought out-of-range to an unsafe level that the SCADA software recognizes. Observe if the SCADA relay is opened and the Safety Loop is broken as a result of this value.

Acceptance Threshold: The Safety Loop is broken if the SCADA detects a value out of the range of safety for any of the sensors connected to the software.

Requirements Met: R003-1

T000-5 - Shutdown System

Demonstrate that the system shutdown sequence operates in accordance with the shutdown state diagram provided in Figure 41 of the rules.

Testing Procedure: The system will begin in a completely de-energized state. The GLVMS and side BRBs will be turned on. Ensure that TS is off. Cockpit BRB and TSMS will be turned on. TSV should now be present. At any point, with TSV present in the system, turning TSMS off or hitting the Cockpit BRB should disable TSV. Additionally other faults such as AMS, IMD, or brake overtravel should disable TSV.

Acceptance Threshold: The system responds in the described manner based on the system state when the Reset Buttons are pressed.

Requirements Met: EV7.8.2

T001 - Sensors

T001-1 - SCADA Sensor Recording and Display

The SCADA software incorporated with the system is able to monitor and report the data acquired within the error ranges provided in Sensor Accuracy Document from all of the following sensors: Tractive System DC current and motor phase currents, temperature of motor system, data available from the Emsiso Motor Controller, data available from dyno sensors (RPM and Torque), GLV Current Sensor, TSI Current Sensor, CellMan Voltage Sensors, GLV Voltage Sensor, TSI Voltage Sensors, CellMan Temperature Sensors, GLV Temperature Sensor, TSI Temperature Sensor, Cooling Temperature Sensor, Cooling Flow Rate

Testing Procedure: The system is to be powered into the Drive state with all aspects energized and connected to the SCADA software. Observe if all of the included sensors are recording data. Compare the sensor acquired data to data obtained using an external meter for the same measurement, such as an oscilloscope, thermometer, tachometer, or ammeter.

Acceptance Threshold: All of the sensors are able to record information plausibly in the confidence range for the given sensor

Requirements Met: R001-0, R001-1, R001-2

T001-2 - Current Sensors

The system current will be measured continuously during operation. The Emsiso controller will limit the maximum amount of current able to be applied. The safety loop will be tested to prove that is will shut down the motor if unsafe amounts of current are detected by the motor optical encoder sensor. The safety loop will not shut down the system if the current values are within a safe operating range. If the system is in Drive Mode, the TSI firmware will also be able to shift the system out of the Drive Mode state if the current is too high. The firmware will not leave drive mode if the current values are within a safe operating range.

Testing Procedure: The system will begin in a fully energized state. Each of the current sensors will be monitored by the SCADA software under normal system function and compared to a reading from an external ammeter. Compare the measured current on both interfaces. The motor controller and motor current will be monitored by the SCADA software and the motor controller software supplied by Emsiso.

Acceptance Threshold: The current sensors of the system will be considered functional if they are able to produce measurements within a plausible error.

Requirements Met: N/A

T001-3 - Voltage Sensors

The high voltage of the system will be monitored during operation. If at any point the voltage reaches unsafe levels the safety loop will open and cut the system power. The safety loop will not shut down the system if the high voltage value is within the safe operating range.

The low voltage of the system will be monitored during operation to ensure that it stays within the voltage range for GLV power set by the Formula Hybrid rules. The system will not shut down if the low voltage is within the safe operating range.

Testing Procedure: The system will begin in a fully energized state. Each of the voltage sensors will be monitored by the SCADA software under normal system function and compared to a reading from an external voltmeter. Compare the measured voltage on both interfaces. The motor controller and motor voltage will be monitored by the SCADA software and the motor controller software supplied by Emsiso.

Acceptance Threshold: The voltage sensors of the system will be considered functional if they are able to measure voltages within a plausible error.

Requirements Met: N/A

T001-4 - Temperature Sensors

The temperature of the system will be monitored during operation. It is required for all subsystems to monitor and report temperatures to the VSCADA. If unsafe temperatures are recorded the safety loop will turn off power to the system and shut the system down. The safety loop will not shut down the system if temperature values are within a safe operating range.

Testing Procedure: The system will begin in a fully energized state. Each of the temperature sensors will be monitored by the SCADA software under normal system function and compared to a reading from an external thermometer. Compare the measured temperature on both interfaces. The motor controller and motor temperature will be monitored by the SCADA software and the motor controller software supplied by Emsiso.

Acceptance Threshold: The temperature sensors of the system will be considered functional if they are able to measure temperatures within a plausible error.

Requirements Met: N/A

T001-5 - RPM Sensor

The motor speed will be measured across all applicable ranges. The motor speed will be shown to correlate to the throttle drive for all valid ranges, and shown to idle through invalid ranges. This will be tested using the Emsiso controller, SCADA, and safety loop to ensure the unsafe RPMs cannot be reached. If they are reached, the safety loop will open and shut down the motor. The safety loop will not shut down the system if the RPM values are within a safe operating range.

Testing Procedure: The system will be begin in a fully energized and ready to drive state. Using the Emsiso motor controller software, set the motor to spin at a desired RPM. Using a handheld tachometer, measure the RPM of the motor. Compare this to the measured RPM on the motor controller software and the RPM reported on the SCADA software.

Acceptance Threshold: The RPM sensor of the system will be considered functional if the RPM is within a plausible margin of error between all of the RPM sensing methods.

Requirements Met: N/A

T001-6 - Torque Sensor

The torque of the motor will be measured across all RPM ranges and graphed. This torque curve will be compared to the curve provided by the manufacturer. The motor will be tested by using the Emsiso controller and the safety loop to ensure that the motor cannot apply unsafe levels of torque, either through tripping the safety loop or not allowing the controller to apply that much torque. The safety loop will not shutdown the system if the torque values are within a safe operating range.

Testing Procedure: The system will begin in an energized and ready to drive state. Using the Emsiso motor controller software, specific torques will be requested. The torque sensor in the dyno room will be displayed on the SCADA software and be compared to the measurement recorded by the Emsiso motor controller software.

Acceptance Threshold: The torque sensors on the system will be considered functional if it is able to

Requirements Met: N/A

T001-7 - Flow Rate Sensor

Coolant flow rate will be measured to ensure that the system is running and cooling the motor controller properly. The cooling pump will be turned on whenever the motor controller is running and the flow rate sensors ensures this will be the case. The system will not shut down if the cooling pump is operating.

Testing Procedure:

Acceptance Threshold:

Requirements Met: N/A

T001-8 - IMD

The resistance between TSV and GLV must be monitored to ensure that a short doesn't occur. In the event that the resistance between TSV and GLV is too low, the IMD should open the safety loop to prevent a short between HV and ground. The safety loop will not open if the TS/GLV isolation is above a safe threshold.

Testing Procedure: Connect a resistor between the TSMP and several electrically conductive dyno parts while the tractive system is active as shown in Figure XXX (Figure 43 from rules)

Acceptance Threshold: The test is passed if the IMD shuts down the tractive system within 30 seconds at a fault resistance of 250Ω/volt (50% below the response value)

Requirements Met: EV7.9.3, EV7.9.4, EV10.1

T002 - System Requirements

Status Lights

T002-1 - Throttle Plausibility: Pedal 1 Undervoltage Limit

The system will only consider a throttle signal to be plausible if the pedal 1 (or APPS1) voltage is at least 5.5 V. **We will write more tests here to cover all possible cases for throttle implausibility**

Testing Procedure: Attach a power supply to each throttle input. Set the power supply on APPs1 to 6 volts and the power supply on APPs 2 to 1 volt. Ensure that the drive light is still on. Decrease the voltage at each power supply in steps of 0.02 V until the system leaves drive mode. This will be indicated by the drive light turning off.

Acceptance Threshold: Throttle becomes implausible at an APPS1 Voltage between XXX V and XXX V.

Requirements Met: EV3.5.4, EV3.5.5, EV3.5.6

T002-2 - Drive States: Initialization

We will write more tests here to cover all possible drive state transitions

Testing Procedure: Begin with the system completely powered off. Follow the necessary start up steps.

Acceptance Threshold:

Requirements Met: R005-4

T002-3 - Drive States: Idle to Precharge

The system is required to remain in the Idle state until the Safety Loop has been closed. This is to ensure the safety loop is in place when high voltage is present and that the car can't shift into drive mode before the safety loop is closed (as per FH rule EV7.7.3)

Testing Procedure: Boot the TSI firmware and perform the necessary steps to reach "Idle" mode. The current drive state should be viewable on the SCADA display. Once in "Idle" mode, turn the GLVMS, ensure no emergency stops are pressed, press both the cockpit and master reset buttons, and turn the TSVMS.

Acceptance Threshold: The Safety Loop should be closed at this point and the SCADA display should indicated that the system is now in the "Precharge" state.

Requirements Met: R005-4

T002-4 - Precharge

A precharge circuit must be implemented to allow the motor controller capacitor to almost fully charge before turning on the motor controller. This circuit must be implemented to prevent large voltage and current spikes.

Testing Procedure: Supply high voltage to the circuit and use an oscilloscope to monitor the voltage across the capacitor of the precharge circuit and the output of the precharge circuit.

Acceptance Threshold: The precharge circuit will be considered operational if the output signal goes high after the the capacitor is 90% charged (*voltage threshold here*)

Requirements Met: R005-8, EV2.10.1

T002-5 - Discharge

A discharge circuit must be implemented to allow the high voltage present in the motor controller to safely discharge in a short amount of time after the motor controller is turned off.

Testing Procedure: Begin with a fully energized system. Turn off the high voltage power supply. Use an oscilloscope to monitor the voltage across the output of the discharge circuit.

Acceptance Threshold: The discharge circuit will be considered operational if the output signal is less than 30V within 5 seconds of high voltage being turned off.

Requirements Met: R005-9, EV2.8.3

T002-6 - Data Acquisition / Firmware

Demonstrate that the system is able to respond correctly with the Data Acquisition software receives out of range values.

Testing Procedure: The system will begin in a completely energized state with all of the sensors sending data to the SCADA software. A sensor’s reading will be brought out-of-range to an unsafe level that the SCADA software recognizes.

Acceptance Threshold: Observe that SCADA logs the correct out-of-range value. Additionally observe that SCADA displays errors by changing the color of the value displayed on the screen from yellow to red or by displaying an error message.

Requirements Met: R001-3

T002-7 - Drive States: Drive Mode

The system is able to enter and exit drive mode under the conditions described by the TSI drive state transition definitions.

Testing Procedure: The system will begin from the off state. It will follow the correct procedure to complete the Precharge process and be ready to enter the Drive state. To test the entry of the Drive state, a brake signal will be applied, the throttle must be in a plausible state, and the ready to drive button must be pressed. Observe if the system enters the drive state and a Ready-To-Drive sound happens. To test the exit conditions of the Drive state, the system will be placed into the Drive state. Then each of the exit conditions will be tested. These include: a break in the safety loop, an implausible throttle signal, an overcurrent error, the throttle and brake are pressed simultaneously, or the motor controller is deenergized.

Acceptance Threshold: The system enters and exits the Drive Mode under the correct stimulus.

Requirements Met: EV7.7.2, EV9.2.1, EV9.2.2

T003 - Tractive System Voltage

T003-1 - AIRs Open and Close

Demonstrate the functionality of the AIRs with a oscilloscope and timer that the tractive system drops to less than 30 volts in under 5 seconds when AIRs are opened. Use an oscilloscope to demonstrate that the precharge circuit must achieve 90% of the TSV voltage before closing the AIRs. Also demonstrate that there is no TSV present on the non-accumulator side of the AIRs until the AIRs are closed. The functionality of the TSAL will also be under inspection as a result of the AIRs state

Testing Procedure: The system will begin in a de-energized state. The startup procedure will be followed to the point before turning the TSMS and closing the AIRs. An oscilloscope will be setup to monitor the voltage present at precharge circuit and a voltmeter will be used to monitor the end of the AIRs away from the accumulator region. Check that the precharge voltage is above the correct 90% TSV threshold before the AIRs close. Observe that the high voltage is only present at the non-accumulator side of the AIRs after this event occurs. Close the TSMS in order to shut off the high voltage from the system. Using an oscilloscope across the AIRs contacts away from the accumulator region, observe that the voltage drops below 30 VDC in under 5 seconds from the time of opening.

Requirements Met: EV2.8.3, R002-3, R002-4, EV9.1.1, EV9.1.8,

T003-2 - High Voltage Disconnect (HVD)

Demonstrate that the Amphenol connectors can be removed without the use of tools and can disconnect TS within 10 seconds of “ready-to-race” conditions

Requirements Met: EV2.9.1, EV2.9.2, EV2.9.3

T003-3 - Accumulator Management System (AMS) - CellMan

Demonstrate CellMen monitoring voltages and temperatures, compare with thermometer or voltmeter

Testing Procedure: Use a single CellMan to measure the voltage and temperature of a single cell. Compare the CellMan measurements to measurements taken by a voltmeter and thermometer, respectively.

Acceptance Threshold: The values reported by the CellMan are within ±10% of measured values.

Requirements Met: EV2.11.2, EV10.4

T003-4 - Accumulator Management System - SegMan & PackMan

Demonstrate SegMan/PackMan turning off electrical systems, opening AIRS, and shutting down the I.C. drive within 60 of detecting a fault from CellMan

Testing Procedure: A CellMan will be connected to SegMan and PackMan. The CellMan will measure the voltage from a power supply. The power supply voltage will be adjusted to be too low and then too high.

Acceptance Threshold: Monitor the SegMan and PackMan responding to the under and over voltage limits being surpassed. The AMS will be considered compliant if the TS systems are turned off, AIRs are opened, and the TSI firmware is shifted out of drive mode within 60 seconds of creating the fault.

Requirements Met: EV2.11.2

T003-5 - Grounding

Demonstrate that all conductive parts of enclosure meeting minimum resistance grounding requirements

Requirements Met: EV3.1.4, EV8.1.1, EV8.1.2, EV8.1.5

T003-6 - High Voltage Indicator

Demonstrate that the High Voltage Indicator light is visible anytime that there is greater than 30 VDC present in the accumulator compartment.

Testing Procedure: With the accumulator packs in a normal operational state with the full pack voltage present, observe that the High Voltage Indicator is illuminated. Remove or disconnect cells from the pack in order to drop the accumulator voltage below 30 VDC. Observe that the High Voltage Indicator is no longer illuminated.

Acceptance Threshold: The High Voltage Indicator can be consider functional if it is illuminated at an accumulator voltage greater than 30 VDC and not illuminated at an accumulator voltage less than 30 VDC.

Requirements Met: R002-12, EV9.5.1

Inspections

Inspection Number	Requirement	Passed Inspection
I001	EV1.2.1	❏
I002	EV2.1.1	❏
I003	EV2.1.3	❏
I004	EV2.2.1	❏
I005	EV2.2.2	❏
I006	EV2.3.1	❏
I007	EV2.3.2	❏
I008	EV2.3.3	❏
I009	EV2.3.4	❏
I010	EV2.3.5	❏
I011	EV2.4.2	❏
I012	EV2.4.3	❏
I013	EV.2.4.4	❏
I014	EV2.4.5	❏
I015	EV2.4.7	❏
I016	EV2.4.8	❏

I017	EV2.4.9	❏
I018	EV2.6.1	❏
I019	EV2.6.2	❏
I020	EV2.7.1	❏
I021	EV2.7.2	❏
I022	EV2.7.4	❏
I023	EV2.8.1	❏
I024	EV2.8.5	❏
I025	EV2.8.6	❏
I026	EV2.9.5	❏
I027	EV2.9.6	❏
I028	EV2.10.7 -- Include TSI version 2 schematic	❏
I029	EV2.11.1	❏
I030	EV2.11.6	❏
I031	EV3.1.1	❏
I032	EV3.1.2	❏
I033	EV3.1.3	❏
I034	EV3.1.5	❏
I035	EV3.2.1	❏
I036	EV3.2.2	❏
I037	EV3.2.3	❏
I038	EV3.2.4	❏
I039	EV3.2.5	❏
I040	EV3.2.9	❏
I041	EV3.4.1	❏
I042	EV3.4.2	❏

I043	EV3.4.3	❏
I044	EV3.4.4	❏
I045	EV3.5.1	❏
I046	EV.3.5.8	❏
I047	EV3.5.9	❏
I048	EV4.1.3	❏
I049	EV4.1.4	❏
I050	EV4.1.7	❏
I051	EV4.1.8	❏
I052	EV5.1.1	❏
I053	EV5.1.2	❏
I054	EV5.1.3	❏
I055	EV5.1.4	❏
I056	EV5.2.2	❏
I057	EV5.2.4	❏
I058	EV5.3.1	❏
I059	EV5.3.2	❏
I060	EV5.3.3	❏
I061	EV5.4.2	❏
I062	EV5.4.3	❏
I063	EV5.4.4	❏
I064	EV5.5.1	❏
I065	EV5.5.2	❏
I066	EV5.5.3	❏
I067	EV5.5.4	❏
I068	EV5.5.5	❏

I069	EV6.1.6	❏
I070	EV6.1.7	❏
I071	EV7.1.1	❏
I072	EV7.1.3	❏
I073	EV7.2.1	❏
I074	EV7.2.4	❏
I075	EV7.2.6	❏
I076	EV7.2.7	❏
I077	EV7.3.4	❏
I078	EV7.5.2	❏
I079	EV7.5.3	❏
I080	EV7.5.5	❏
I081	EV7.5.7	❏
I082	EV7.6.2	❏
I083	EV7.6.5	❏
I084	EV7.8.1	❏
I085	EV7.9.1	❏
I086	EV7.9.2	❏
I087	EV7.9.7	❏
I089	EV8.1.3	❏
I090	EV8.1.4	❏
I091	EV9.1.3	❏
I092	EV9.1.10	❏
I093	EV9.3.1	❏
I094	EV9.3.2	❏
I095	EV9.4.1	❏

I096	EV9.4.2	❏
I097	EV9.5.1	❏
I098	EV9.6.1	❏
I099	EV9.6.2	❏
I100	EV10.3.1	❏
I101	EV10.3.2	❏
I102	EV10.3.3	❏
I103	EV10.3.4	❏
I104	EV10.3.6	❏
I105	EV12.3.1	❏
I106	EV12.3.4	❏
I107	EV12.3.5	❏
I108	EV12.4	❏
I109	EV13.1	❏
I110	EV13.2	❏
I111	GPR001	❏
I112	GPR005	❏
I113	GPR011	❏
I114	GPR012	❏
I115	R004-0, R004-1	❏

Table 3 -- FH and SOW Inspections

Analysis

Analysis Number	**Requirement Met**	**Justification**

A001	EV2.4.1	The battery packs will be manufactured with garolite and 80/20 bars. See Brian's calculations for strength analysis.
A002	EV2.4.6	The cells will be secured in place from the bottom by HDPE. There will also be pressure from the lid of the high voltage enclosure to secure the top of the cells.
A003	EV2.5.1	Side pods were designed on the frame to hold the battery packs within the surface envelope.
A004	EV2.5.2	The battery packs will be bolted into the side pods.
A005	EV2.5.3	See Brian's calculations.
A006	EV2.5.4	Holes have been designed into the containers and the frame for at least 4 bolts.
A007	EV2.7.3	**Need SMD design**
A008	EV2.7.5	**Need SMD design**
A009	EV2.8.2	The AIRs are located immediately before and after the Amphenol connectors to prevent TS from leaving the accumulator container.
A010	EV2.8.4	There are current limiting resistors in the precharge circuitry to protect the AIRs contacts
A011	EV2.9.4	When the 2020 team goes to competition they will be able to demonstrate that the Amphenol connectors satisfy all HVD rules.
A012	EV2.9.8	The Amphenol connectors will serve as our HVD. The HVD will disconnect the packs from the TSI enclosure where the TSMPs are so that when the HVD is open, the TSMPs are de-energized.
A013	EV2.10.3	Safety loop diagram
A014	EV2.10.4	See Hayden's analysis
A015	EV2.10.5	Safety loop diagram
A016	EV2.11.3	Shutdown diagram
A017	EV2.11.4	Rules require a voltage measurement for every Lithium based cell. We monitor every cell voltage with CellMan boards.
A018	EV.2.11.5	Rules require the temperature of 30% of Lithium based cells to be monitored. We monitor every cell temperature with CellMan boards.
A019	EV2.11.7	A garolite divider will be used to separate the segments. Cellmen connections will be isolated from the different segments with an

		SMD.
A020	EV2.11.8	See Yishak's analysis
A021	EV2.11.9	Each segman only performs AMS functions for its segment and communicates with other boards.
A022	EV3.1.6	All cables will be sized and cut to minimize extra length. Additionally, loose cables will be secured using mechanical strain relief.
A023	EV3.1.7	The frame was designed with triangulated side pods for the accumulators and a motor cover will be manufactured.
A024	EV3.1.9	The frame was designed to ensure all TS components will be above the lower surface of the frame.
A025	EV3.3.1	Se Drew's analysis
A026	EV3.3.2	See Drew's analysis
A027	EV3.4.5	See David's analysis
A028	EV3.5.7	The car wiring diagram plans to route TS cables from the side pods of the car to the rear. Firewalls will be fabricated to protect the driver and cockpit from the TS wiring.
A029	EV4.1.1	Shore power will not supply more than 24 V
A030	EV4.1.2	The GLV battery will be securely mounted in one of the side pods.
A031	EV5.2.3	Firewalls have been designed and will be fabricated to comply with this rule
A032	EV5.4.1	Garolite will be the primary insulating material.
A033	EV6.1.1	See Max, Jack, and Yishak's analysis
A034	EV6.1.2	See Max, Jack, and Yishak's analysis
A035	EV6.1.3	See Max, Jack, and Yishak's analysis
A036	EV6.1.4	See Max, Jack, and Yishak's analysis
A037	EV6.1.5	See Max, Jack, and Yishak's analysis
A038	EV7.1.2	See shutdown diagram
A039	EV7.1.4	See Max's analysis

A040	EV7.1.5	See shutdown diagram
A041	EV7.1.6	AIRs open when GLV is shutdown, so all battery pack energy will be contained in the battery packs. The discharge circuit is enabled when GLV is shutdown so the motor controller energy will be dissipated.
A042	EV7.2.2	Side panels for the car have been manufactured so that the master switches will be at the driver's shoulder height and mounted on the right side of the vehicle in proximity to the Main Hoop.
A043	EV7.2.5	Master switches will be mounted on non-removable side panels.
A044	EV7.3.2	See safety loop diagram
A045	EV7.4.3	See safety loop diagram
A046	EV7.5.1	Side panels for the car have been manufactured so that the emergency stops will be at the driver's head height and mounted on the sides of the vehicle in proximity to the Main Hoop.
A047	EV7.5.6	Emergency stops will be mounted on non-removable side panels.
A048	EV7.6.1	A cockpit panel for the car has been manufactured so that the emergency stop can be mounted. The length of the frame and cockpit has been designed so that the driver will be able to reach dashboard controls such as the emergency stop.
A049	EV7.6.4	Shutdown diagram
A050	EV7.7.1	Can't turn off a system that isn't powered on.
A051	EV7.7.3	Shutdown diagram
A052	EV7.9.5	Shutdown diagram
A053	EV9.1.1	The frame was designed so there will be space under the main roll hoop for the TSAL.
A054	EV9.1.4	The main roll hoop was designed to be tall enough for the TSAL to fit under it but tall and deep enough. This can be seen in the Inventor model of the frame.
A055	EV9.1.5	The TSAL will be mounted as high as possible on the frame while still under the main roll hoop. Nothing else should be mounted around or above it. This will ensure that the TSAL will be visible from all angles.
A056	EV9.1.6	

A057	EV9.1.7	All other lights on the car will not be mounted in enclosures, on the cockpit panel, or the brake light on the rear of the car so no other light swill be mounted in proximity to the TSAL
A058	EV9.1.8	As soon as TS is present in the TSI, a DC-DC converter is used to power the TSAL. HV+ and HV- are connected directly to the input of the DC-DC converter to ensure that this rule is met.
A059	EV9.2.3	
A060	EV9.2.4	The vehicle will only generate one sound (apart from other regular car noises) so there won't be any sounds similar to the Ready-to-Drive Sound
A061	EV9.5.2	
A062	EV10.3.5	See Jack's analysis
A063	GPR003	
A064	GPR004	
A065	GPR006	
A066	GPR007	
A067	GPR008	

Table 4. FH and SOW Analysis

Deliverables

D000: PDR

Completed in the Fall Semester.

D001: CDR

Waived. Team will instead complete two (2) weekly design reviews on individual components with detailed minutes recorded.

D002: User Manuals

Part	SCADA	GLV	TSI	TSV	Motor / Motor Controller / Dyno	Cooling	Interconnect
Annotated Drawing of Physical System							
Annotated Screenshots of all UI							
Annotated Drawings of any Physical Control Panels, Indicator Buttons, Power Switches, and other controls							
Simplified Block Diagram							
“Getting Started”							
“FAQ”							
Detailed Explanations of All Functions and Control							
User Level Troubleshooting, Calibration, and Maintenance							

D003: Final Report and Maintenance Manual

Final Report

Check	Completed
Maintenance Manual	
Static Copy of the Website	

Flash Drive Delivered in a Professional Quality Case	
Delivered to Advisors and Department Head on a Flash Drive	

Maintenance Manual

Part	SCADA	GLV	TSI	TSV	Motor / Motor Controller / Dyno	Cooling	Interconnect
Maintenance / Calibration							
Schematics / Layouts							
Connector Pinouts							
Cable Signal Assignment							
Interface Semantics							
Block Diagrams							
State Diagrams							
Source Code Trees							
Additional Low Level Information							

D004: Acceptance Test Plan

The ATP shall describe the inspections, analyses, and demonstrations that will be used to demonstrate the final project is compliant with the Statement of Work and FH Rules.

D005: Acceptance Test Report

The ATR shall document the results of the tests laid out by the ATP.

D007: Project Website

The project website shall be updated on a weekly basis with purchasing reports, project status letters, individual progress reports, source code, block diagrams, schematics, and layouts.

D008: Final Presentation and Delivery

Check	Completed
Project Posters Displayed	
Project Video Present	
Project Demonstrated	

D010: Project Posters

Part	SCADA	GLV	TSI	TSV	Motor / Motor Controller / Dyno	Cooling	Interconnect
Subsystem Summary							
47x35 inches							
High Resolution Text and Images							
Website URL Link							
Website QR Code							

D013: Purchasing Report

Robson
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D014: Project Management and Status Letters

Check	Completed
Project Status Letters Delivered	
ATP Delivered	
Individual Progress Reports Delivered	
Work Breakdown Structure Delivered	

Appendix A: Revision History

November 14, 2018 - Original
December 1, 2018 - Addressed concerns in Professor Nadovich comments
ATR in separate document
December 5, 2018 - Corrected required equipment for ATP006 and ATP007
Added specificity to pass criteria for ATP017
December 5, 2018 - Replaced N/A with valid passing criteria for tests with obvious results
Added specific measurements to tests that were lacking them
December 6, 2018 - Re-wrote test descriptions and passing criteria to be clear and specific
Added specific measurements to test descriptions
Removed some ATP items that were overlapping & Tests reindexed
February 2, 2019 - Original test plan for Spring 2019
Adapted format to model 2015 ATP

Appendix B: Supporting Documents

EV7.1 Shutdown Circuit

The shutdown circuit is the primary safety system within a Formula Hybrid vehicle. It consists of a current loop that holds the Accumulator Isolation Relays (AIRs) closed. If the flow of current through this loop is interrupted, the AIRs will open, disconnecting the vehicle's high voltage systems from the source of that voltage within the accumulator container.

Shutdown may be initiated by several devices having different priorities as shown in the following table.

		Controlled Systems				
		Engine Starter (High Current)	GLV Supply to: Instrumentation Data acquisition Computers Telemetry Etc.	I.C. Engine Ignition Fuel pumps Starter solenoid Brake light Etc.	AIRs (TS Voltage)	Shutdown source extinguishes SSOK lamps
Shutdown Sources	TSMS				OFF	NO
	Cockpit BRB			OFF		NO
	Interlocks*			OFF		YES
	AMS			OFF		YES
	IMD			OFF		YES
	Brake Over-travel			OFF		YES
	Side-mounted BRBs		OFF			YES
	GLVMS	OFF *(Vehicle is COMPLETELY de-energized)*				YES

*Optional interlocks as required. (such as wheel motors, etc.)

Figure 37 - Priority of shutdown sources

Figure 3. Table of Safety Loop Functionality For Shutdown Sources