GLV Preliminary Design Report

ECE 492 - Spring 2015

Abstract

This is the preliminary design report for the GLV project for the LFEV. Included are the materials required by D000 in the LFEV 2015 statement of work. This document will outline the plan of record of the semester project and specifically outline the design, test plan, requirements, system states, cost, and program schedule of the GLV portion of the LFEV-Y3-2015 project.

Revision 1.0.0
GLV Systems Group

Table of Contents

Summary

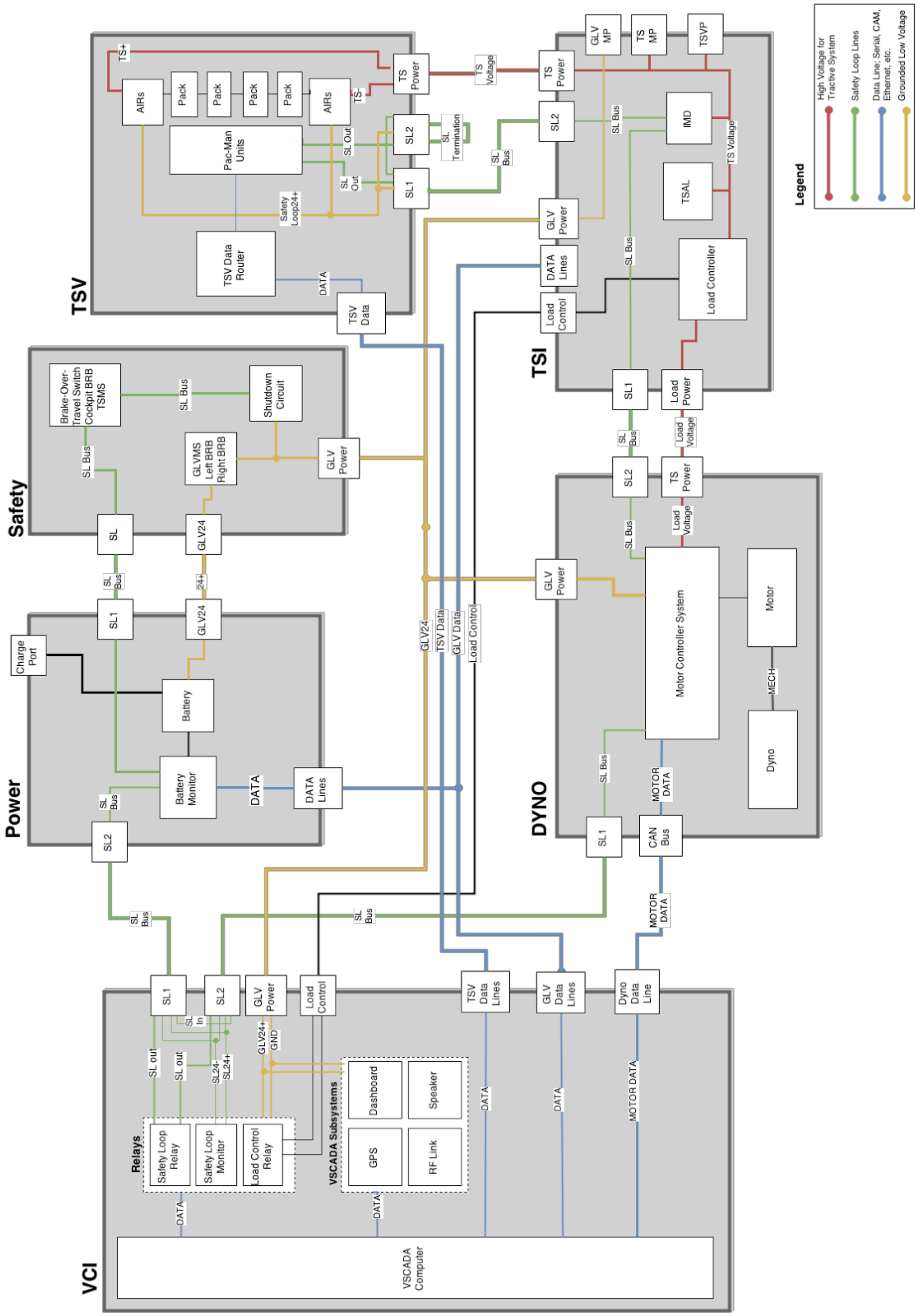
This document lays out the preliminary design for the GLV subsystem of the Lafayette Electric Vehicle Project. The GLV system is responsible for supplying power to all non-tractive devices on the vehicle, interfacing other subsystems together, developing the load controller, and operating the safety circuit in accordance to the EV requirements.

Previous years have already developed a safety loop system and load controller. The designs they used, while functional, are not prepared to be mounted to the vehicle, as they are too large and may not be reliable enough to sustain the wear and tear a car must endure.To update these designs, circuits must be redesigned and re-housed with emphasis on physical location of GLV parts, and how these parts will be mounted within the car chasis.

In previous years , the GLV power came from a power supply. This is not acceptable for use in a electric vehicle. The GLV system must include a rechargeable battery which can power all of the electric vehicle's components for a sufficient amount of time.

In this years electric car development, many of the systems must be able to be integrated together. Another one of the primary responsibilities for the GLV system is to ensure that this can happen smoothly. The GLV Load Controller will act as a buffer between the motor controller and the tractive system power source. The vehicle computer interface (VCI) will ensure that the VSCADA system can both collect system data and control the system state as needed.

System Design Baseline



GLV Requirement Matrix

Requirement	Description	Involved Sub-systems	Functional Requirement/Interface
R000	**Formula Hybrid Competition Rules**	**TSI, Power, VCI, Safety**	**The final LFEV shall meet all requirements given in the Formula Hybrid rules for 2015.** **The initial goal for competition entry shall be the pure electric vehicle (EV) category.**
EV1.2.2	GLV Max Voltage	Power	The GLV system may not have a voltage greater than 30 VDC or 25 VAC.
EV1.2.3	GLV Grounding	Power	The GLV system must be grounded to the chassis.
EV1.2.4	GLV/TSV Isolation	TSI	The tractive and GLV system must be galvanically isolated from one another.
EV1.2.7	GLV Powerup/ Shutdown	Power	The GLV system must be powered up before it is possible to activate the tractive system (see EV4.7). Furthermore, a failure causing the GLV system to shut down must immediately deactivate the tractive system as well.
EV1.3.1	Electrical Insulation	TSI, Power, VCI, Safety	All Electrical insulating materials used must: (a) be UL recognized (i.e, have an Underwriters Laboratories (www.UL.com) or equivalent rating and certification). (b) be rated for the maximum expected operating temperatures at the location of use or (c) have a minimum temperature rating of 90C. (Whichever is greater) Note: Electrical insulating barriers used to meet the requirements of EV4.1.5 for separation of tractive system and GLV wiring must be rated for 150 ºC.
EV1.3.2	Prohibited Insulators	TSI, Power, VCI, Safety	Vinyl electrical insulating tape and rubber-like paints and coatings are not acceptable electrical insulating materials.
EV2.2	Accelerator Signal Limits Check	**OUT OF SCOPE**	~~All analog acceleration control signals (between accelerator pedal and motor controller) must have error checking which can detect open circuit, short to ground and short to sensor power and will shut down the torque production in less than one (1) second if a fault is detected.~~ ~~The accelerator signal limit shutoff may be tested during electrical tech inspection~~

			~~by replicating any of the fault conditions listed in EV2.2.1~~
EV3.3.1	TSV Container Electrical Requiremen t	TSI	All conductive surfaces on the outside of the container must have a low-resistance connection to the GLV system ground. All conductive penetrations (mounting hardware, etc.) must be located outside of the insulation and configured such that there is no possibility that they could penetrate the insulating barrier.
EV3.6.5	GLV/TSV Isolation	TSI	Any GLV connection to the AMS must be galvanically isolated from the TSV. This isolation must be documented in the ESF.
EV3.7	GLV System specific	Power	EV3.7.1 All GLV batteries must be attached securely to the frame. EV3.7.2 Any wet-cell battery located in the driver compartment must be enclosed in a nonconductive marine-type container or equivalent and include a layer of 1.5mm of aluminum or equivalent between the container and driver. EV3.7.3 The hot (ungrounded) terminal must be insulated. EV3.7.4 Battery packs based on Lithium Chemistry other than LiFePO4 must have over-voltage, undervoltage, short circuit and over-temperature cell protection. EV3.7.5 A team built Lithium LV battery pack may be used, but details on how the required protection is achieved must be included as part of the ESF submission. EV3.7.6 One terminal of the GLV battery or other GLV power source must be connected to the chassis by a ground wire. The ground wire must be sized adequately for the GLV system fusing. The ground wire must be robustly secured and protected from mechanical damage. Note that minimizing the length of the ground wire is also recommended.
EV3.8	Pouch type Lithium Ion Cells	Power	Batteries constructed using pouch type lithium ion cells are subject to the following design constraints: Note: These rules do not apply to prismatic or cylindrical cells. EV3.8.1 Stack arrangement Cells in a stack (a group of pouch cells) must be arranged face-to-face not edge-to-edge. EV3.8.2 Expansion Limiter A mechanical restraining system (the expansion limiter) must limit volumetric expansion. The expansion limiter must: (a) Be capable of applying ≥10 psi without yielding at temperatures up to 150 C. (b) allow the stack to expand by at least 8% and not more than 12% in volume before reaching 10 psi. (c) use materials that are fire retardant and immune to creep. (d) not impinge on the cell separator internal to the cell. Conductive materials must be electrically insulated from cells. Expansion limiter calculations (simulation results or appropriate mechanical analysis) must be included in the ESF. EV3.8.3 Filler Soft elastic material (filler) is required between cells.

			The filler must: (a) be evenly distributed through the stack, between every cell. (b) apply pressure evenly to each cell surface. (c) be fire resistant and non-conductive. EV3.8.4 Pouch Cell tabs Pouch cell tabs must be: (a) Mechanically restrained so they cannot move in relation to the cell due to vibration or physical handling. (b) connected above the level of the tab insulator. No metallic parts of battery assembly may bridge the insulation gap provided by the tab insulator. (c) insulated such that it is not possible to short circuit adjacent cells by accident. EV3.8.5 Repeating Frame Each cell in a stack must be held in position using a repeating frame or equivalent method. A repeating frame must not: (a) change the natural shape of the cell. (b) impinge on the cell separator internal to the cell. (c) allow the edges of the cell to move in relation to the cell due to vibration or physical handling. No cell may be in contact with or be likely to contact sharp corners or metal/plastic burrs. EV3.8.6 General Construction Each stack must be firmly anchored in the accumulator enclosure. See EV3.4 Construction must be robust and mechanically sound. There must be no evidence of shavings or filings from battery manufacture in the stack. Accumulator electrical spacing requirements must be observed, including paths through tension rods etc.
EV4.1	Separation of Tractive System and Grounded Low Voltage System	TSI	EV4.1.1 The layout of electrical devices designed by the team must be documented accurately in the ESF. EV4.1.2 There must be no electrical connection between the frame of the vehicle (or any other conductive surface that might be inadvertently touched by a crew member or spectator), and any part of any tractive system circuits. EV4.1.3 Tractive system and GLV circuits must be physically segregated. I.e. they may not run through the same conduit or connector, except for interlock circuit connections. EV4.1.4 GLV circuits must not be present in the accumulator container except for required purposes, for example the AMS and AIR. This must be demonstrated in the ESF submission. EV4.1.5 Where both tractive system circuits and GLV circuits are present within an enclosure, they must be (a) separated by electrical insulating barriers meeting the requirements of EV4.1.6 or (b) separated by the spacings shown in Table 15 through air, or over a surface (similar to those defined in UL1741): Insulating barriers used to meet the requirements of EV4.1.5 (c) Must be UL recognized as electrical insulating materials for a temperature of 150 ºC or higher.

			(d) Must be adequately robust for the application and in no case thinner than 0.25 mm (0.010”). (e) Must be in addition to wire insulation. (f) Must extend far enough at the edges to block any path between uninsulated GLV and tractive-system conductors shorter than the distances specified in Table 15. EV4.1.6 Spacing must be clearly defined. Components and cables capable of movement must be positively restrained to maintain spacing. EV4.1.7 If tractive system circuits and GLV circuits are on the same circuit board they must be on separate, clearly defined areas of the board. Furthermore, the tractive system and GLV areas must be clearly marked on the PCB. Required spacing between GLV and TS circuits is as shown in the Table 16. If a cut or hole in the board is used to allow the “through air” spacing, the cut must not be plated with metal, and the distance around the cut must satisfy the “over surface” spacing requirement. EV4.1.8 Teams must be prepared to demonstrate spacings on team-built equipment. Information on this must be included in the ESF (EV9.1). Spare boards and photographs must be available for inspection. Teams should also be prepared to remove boards for direct inspection if asked to do so during the technical inspection. EV4.1.9 Plated prototyping boards having plated holes and/or generic conductor patterns may not be used for applications where both GLV and TS circuits are present on the same board. Bare perforated board may be used, if the spacing and marking requirements (EV4.1.7 and EV4.1.8) are met, and if the board is easily removable for inspection.
EV4.3	Grounding	Power (first not GLV)	EV4.3.1 All accessible metal parts of the vehicle, except conductors and components of the GLV system, must have a resistance below 300 mΩ (measured with a current of 1A) to GLV system ground. NOTE: Accessible parts include that those that are exposed in the normal driving configuration or when the vehicle is partially disassembled for maintenance or charging. EV4.3.2 All accessible parts of the vehicle containing conductive material (e.g. coated metal parts, carbon fiber parts, etc.) which might contact a damaged wire or electrical part, no matter if tractive system or GLV, must have a resistance below 5 ohm to GLV system ground. EV4.3.3 Electrical conductivity of any part may be tested by checking any point which is likely to be conductive, for example the driver's harness attachment bolts. Where no convenient conductive point is available then an area of coating may be removed. NOTE: Carbon fiber parts may need special measures such as using copper mesh or similar modifications to keep the ground resistance below 5 ohms. NOTE: Conductors used for grounding shall be stranded and 16 AWG minimum.
EV4.4	Tractive System Measuring Point	TSI	EV4.4.8 Next to the TSMP a GLV system ground measuring point must be installed. This measuring point must be connected to the GLV system ground. EV4.4.9 A 4 mm safety banana jack that accepts shrouded (sheathed) banana

			plugs with non-retractable shrouds must be used for the GLV ground measuring point. See Figure 29 for examples of the correct jacks and of jacks that are not permitted because they do not accept the required plugs (also shown).
EV4.6	Tractive System Enclosures	TSI	EV4.6.2 If the housing material is electrically conductive, it must have a minimum-resistance connection to GLV system ground. EV4.6.3 If external, un-insulated heat sinks are used, they must be properly grounded to the GLV system ground.
EV4.8	Activating the Tractive System	TSI	EV4.8.1 The driver must be able to re-activate or reset the tractive system from within the cockpit without the assistance of any other person except for situations in which the AMS or IMD have shut down the tractive system; see EV5.1.5. EV4.8.2 Resetting or re-activating the tractive system by operating controls which cannot be reached by the driver is considered to be working on the car. EV4.8.3 At least one action in addition to enabling the shutdown circuits is required to set the car to ready-to-drive mode. (The car is ready to drive as soon as the motor(s) will respond to the input of the torque control sensor / acceleration pedal.) For example, the additional action could be pressing a dedicated “start” button. However this must be configured such that it cannot inadvertently be left in the “on” position after system shutdown. Note: This action may also be used to trigger the required “Ready to drive” sound. (See EV4.11)
EV4.10	Tractive-system-active Light (TSAL)	TSI	EV4.10.1 The car must be equipped with a TSAL mounted under the highest point of the main roll hoop which must be lit and clearly visible any time the AIR coils are energized. EV4.10.2 The TSAL must be red or amber. EV4.10.3 The TSAL must flash continuously with a frequency between 2 Hz and 5 Hz. EV4.10.4 ~~It must not be possible for the driver's helmet to contact the TSAL~~ (OUT OF SCOPE). EV4.10.5 ~~The TSAL must be clearly visible from every horizontal direction, (except for the small angles which are covered by the main roll hoop) even in very bright sunlight~~ (OUT OF SCOPE). EV4.10.6 ~~The TSAL must be visible from a person standing up to 3m away from the TSAL itself. The person's minimum eye height is 1.6m.~~ ~~NOTE: If any official e.g. track marshal, scrutineer, etc. considers the TSAL to not be easily visible during track operations the team may not be allowed to compete in any dynamic event before the~~ ~~problem is solved~~ (OUT OF SCOPE). EV4.10.7 ~~It is prohibited to mount other lights in proximity to the TSAL~~ (OUT OF SCOPE).
EV4.11	Ready-To-Drive-Sound	VCI	EV4.11.1 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. (See EV4.8.3-At least one action in addition to enabling the shutdown circuits is required to set the car to

			ready to-drive mode, such as a dedicated "start" button) EV4.11.2 The emitting device must produce a tone of approximately 2500 to 3500 Hz with a minimum loudness of 68 dB(A) at 2 ft. One device that meets this requirement is the Mallory Sonalert SC648AJR11. The emitting device must be located and oriented so as to be easily audible from in front of the vehicle in noisy environments. Provide power to the speaker and modify the amplifier so the speaker meets the above requirements.
EV4.12	Tractive System Voltage Present (TSVP) Indicators	TSI	There must be two TSVP lamps. One mounted on each side of the roll bar in the vicinity of the side-mounted shutdown buttons (EV5.3.3) that can easily be seen from the sides of the vehicle. EV4.12.1 They must be red, complying with DOT FMVSS 108 for trailer clearance lamps. See Figure 30 EV4.12.2 They must be lit and clearly visible any time the voltage outside the accumulator containers exceeds 30 VDC or 25 VAC RMS. EV4.12.3 The TSVP system must be powered entirely by the tractive system and must be directly controlled by voltage being present at the output of the accumulator (no software control is permitted). TS wiring and/or voltages must not be present at the lamps themselves. Note: This requirement may be met by locating an isolated dc-dc converter inside a TS enclosure, and connecting the output of the dc-dc converter to the lamps. Although the wiring from the dc-dc converter to the TSVP lamps must not be connected to the main GLV system, it must be ground-referenced by connecting one side of it to the frame or GLV ground in order to comply with EV1.1.4 and EV1.2.3.
EV4.9.5	After Automatic Shutdown	Safety	Pre-charge circuit must operate regardless of the sequence of operations used to energize the vehicle, including after automatic safety shut down.
EV5.1	Shutdown Circuit	Safety	EV5.1.1 The shutdown circuit must directly carry the current driving the accumulator isolation relays (AIRs). EV5.1.2 The shutdown circuit consists of at least 2 master switches, 3 shut-down buttons, the brake-over-travel-switch, the insulation monitoring device (IMD), all required interlocks and the accumulator management system (AMS). EV5.1.3 If the shutdown circuit is opened/interrupted the tractive system must be shut down by opening all accumulator isolation relay(s). The voltage in the tractive system must drop to under 30 VDC or 25 VAC RMS in less than five seconds after opening the shutdown circuit. EV5.1.4 An example schematic of the required shutdown circuit, excluding possibly needed interlock circuitry, is shown in Figure 33. EV5.1.5 It must not be possible for the driver to re-activate the tractive system from within the car in case of an AMS or IMD fault. Remote reset, for example via WLAN

			or use of the three shutdown buttons or TSMS to reset the AMS or IMD is not permitted Note: Applying an IMD test resistor between tractive system positive and GLV system ground must deactivate the system. Disconnecting the test resistor must not re-activate the system. The tractive system must remain inactive until it is manually reset. EV5.1.6 ~~If the tractive system is deactivated while driving, the motor(s) must spin free, e.g. no braking torque may be derived from the motor(s).~~ (TSV) EV5.1.7 The recommended sequence of operation of the shutdown circuit and related systems is shown in the form of a state diagram in Figure 31. Teams are required to either: (a) Demonstrate that their vehicle operates according to this state diagram (b) Obtain approval for an alternative state diagram by submitting an electrical rules query on or before the ESF submission deadline, and demonstrate that the vehicle operates according to the approved alternative state diagram. EV5.1.8 If the shutdown circuit operates differently from the standard or approved alternative state diagram during inspection, the car will be considered to have failed inspection, regardless of whether the way it operates meets other rules requirements.
EV5.2	Master Switches	Safety	EV5.2.1 Each vehicle must have two Master Switches: (a) Grounded Low Voltage Master Switch (GLVMS) (b) Tractive System Master Switch (TSMS). EV5.2.2 The GLVMS must: (a) Disable power to ALL electrical circuits, including the alternator, lights, fuel pump(s), ignition and electrical controls. (b) All battery current must flow through this switch. (c) Be of a rotary type and must be direct acting, i.e. it cannot act through a relay. EV5.2.3 The GLVMS must be located on the right side of the vehicle, in proximity to the Main Hoop, at the driver's shoulder height and be easily actuated from outside the car. EV5.2.4 The TSMS must be located next to the GLVMS and must open the shutdown circuit. The TSMS must be direct acting, i.e. it cannot act through a relay or logic. EV5.2.5 Both master switches must be of the rotary type, with a red, removable key, similar to the one shown in the explanatory shutdown circuit and in Figure 32. EV5.2.6 The master switches are not allowed to be easily removable, e.g. mounted onto removable body work. EV5.2.7 The function of both switches must be clearly marked with "GLV" and "TSV". A sticker with a red or black lightning bolt on a yellow background or red lightning bolt on a white background must additionally mark the Tractive System Master Switch. EV5.2.8 The "ON" position of both switches must be parallel to the fore-aft axis of

			the vehicle.
EV5.3	Shutdown Buttons	Safety	EV5.3.1 A system of three shut-down buttons ("Big Red Buttons" or BRBs) must be installed on the vehicle. EV5.3.2 Each shut-down button must be a push-pull or push-rotate switch where pushing the button opens the shutdown circuit. The shut-down buttons must not act through logic, e.g. a micro-controller. EV5.3.3 Pressing any of the shut-down buttons must separate the tractive system from the accumulator by opening the shutdown circuit, and must also kill the engine and fuel pumps; see EV5.1. EV5.3.4 One button must be located on each side of the vehicle behind the driver's compartment at approximately the level of the driver's head. The minimum allowed diameter of the shutdown buttons on both sides of the car is 40 mm. EV5.3.5 In addition to the requirements in EV5.3.3, the side-mounted shutdown buttons must also shut down all electrical systems. (See Table 17) Note: Electronic systems may have local energy storage sufficient to allow an orderly shutdown of operations upon the loss of GLV, but must be prevented from feeding power back into the GLV. EV5.3.6 One shutdown button is mounted in the cockpit and must be easily accessible by the driver in any steering wheel position. The minimum allowed diameter of the shutdown button in the cockpit is 24 mm. The cockpit mounted button must comply with EV5.3.3, but is not required to de-energize control, instrumentation or telemetry. (See Table 17) EV5.3.7 If the shutdown circuit is opened by the cockpit-mounted shutdown button, it must be driver resettable. For example: If the driver disables the system by pressing the cockpit-mounted shutdown button, the driver must then be able to restore system operation by pulling the button back out. **Note**: There must be one additional action by the driver after pulling the button back out to reactivate the motor controller and make the vehicle ready-to-drive, per EV4.8.3. EV5.3.8 The shutdown buttons are not allowed to be easily removable, e.g. they must not be mounted onto removable body work.
EV5.4	Brake Over-Travel Switch	Safety	EV5.4.1 The brake over-travel switch, as defined in T7.3, must shut down: (a) The tractive system by opening the shutdown circuit (see EV5.1) and (b) the engine and fuel pumps, as illustrated in Table 17. EV5.4.2 The Brake over-travel switch may not be driver resettable. See T7.3.2.
EV5.5	Insulation Monitoring Device (IMD)	TSI, Safety	EV5.5.11 Every car must have an insulation monitoring device (IMD) installed in the tractive system. EV5.5.2 The IMD must be a Bender A-ISOMETER ® iso-F1 IR155-3203 or IR155-3204 or equivalent IMD approved for automotive use. Equivalency may be approved by the rules committee based on the following criteria: robustness to vibration, operating temperature range, availability of a direct output, a self-test

			facility and must not be powered by the system which is monitored. EV5.5.3 The response value of the IMD needs to be set to 500 ohm / volt, related to the maximum tractive system operation voltage. EV5.5.4 In case of an insulation failure or an IMD failure, the IMD must shut down all the electrical systems, open the AIRs and shut down the I.C. drive system. (See Table 17) This must be done without the influence of any logic (e.g., a micro-controller). EV5.5.5 The tractive system must remain disabled until manually reset by a person other than the driver. It must not be possible for the driver to re-activate the tractive system from within the car in case of an IMD-related fault. (See Appendix H – Example Relay Latch Circuits.) Note: The electrical inspectors may test the IMD by applying a test resistor between tractive system positive (or negative) and GLV system ground. This must deactivate the system. Disconnecting the test resistor must not re-activate the system. EV5.5.6 The status of the IMD must be shown to the driver by a red indicator light in the cockpit that is easily visible even in bright sunlight. This indicator must light up if the IMD detects an insulation failure or if the IMD detects a failure in its own operation e.g. when it loses reference ground. EV5.5.7 The IMD indicator light must be clearly marked with the lettering “IMD” or “GFD” (Ground Fault Detector). EV5.5.8 The IMD ground connection must be wired according to the manufacturer's instructions so that the reference ground detector is functional.
EV6.1	Fusing	Safety, TSI, VCI, Power	EV6.1.1 All electrical systems (including tractive system, grounded low voltage system and charging system) must be appropriately fused. Note: For further guidance of fusing, see the Fusing Tutorial on the Formula Hybrid Web site. EV6.1.2 The continuous current rating of a fuse must not be greater than the continuous current rating of any electrical component, for example wire, busbar, battery cell or other conductor that it protects. See Appendix E for ampacity rating of copper wires. EV6.1.3 All fuses and fuse holders must be rated for the highest voltage in the systems they protect. Fuses used for DC must be rated for DC, and must carry a DC rating equal to or greater than the system voltage of the system in which they are used. EV6.1.4 All fuses must have an interrupt current rating which is higher than the theoretical short circuit current of the system that it protects. EV6.1.5 The fuse protecting a circuit or must be physically located at the end of the wiring closest to an uncontrolled energy source (e.g., a battery). Note: For this rule, a battery is considered an energy source even for wiring intended to charge the battery, because current could flow in the opposite direction in a fault scenario.

			EV6.1.6 Circuits with branches using smaller wire than the main circuit require fuses located at the branching point, if the branch wire is too small to be protected by the main fuse for the circuit. EV6.1.7 If more than one battery cell or capacitor is used to form a set of single cells in parallel such that groups of parallel cells are then combined in series, then either each cell must be appropriately fused or the cell manufacturer must certify that it is acceptable to use this number of single cells in parallel. Any certification must be included in the ESF. EV6.1.8 If multiple parallel strings of batteries or capacitors are used then each string must be individually fused. If individual fuses are used this must provide a total fusing equal to the number of fuses multiplied by the fuses rating. Any conductors, for example wires, bus bars, cells etc. conducting the entire pack current must be appropriately sized to this total fusing or an additional fuse must be used to protect the conductors. EV6.1.9 Battery packs with low or non-voltage rated fusible links for cell connections may be used provided that: (a) A fuse rated at a current three times lower than the sum of the parallel fusible links and complying with EV6.1 is connected in series. (b) The accumulator monitoring system can detect an open fusible link, and will shut down the electrical system by opening the AIRs if a fault is detected. (c) Fusible link current rating is specified in manufacturer's data or suitable test data is provided. EV6.1.10 Cells with internal over-current protection may be used without external fusing or fusible-links if suitably rated. Note: Most cell internal over-current protection devices are low or non-voltage rated and conditions of EV6.1.9 will apply. EV6.1.11 The ESF must include all details of fuse and fusible link and internal over current protection including documentation from manufacturer for the particular series and parallel configuration, and string voltage.
EV7	Electrical Systems Tests	TSI	EV7.1 Insulation Monitoring Device Test (IMDT) EV7.1.1 The insulation monitoring device will be tested during Electrical Tech Inspection. This is done by connecting a resistor between the TSMP (see EV4.4) and several electrically conductive vehicle parts while the tractive system is active, as shown in the example below. EV7.1.2 The test is passed if the IMD shuts down the tractive system within 30 seconds at a fault resistance of 250 ohm / volt (50% below the response value). EV7.1.3 The IMDT may be repeated at any time during the event. After the car passes the test for the first time, critical parts of the tractive system will be sealed. The vehicle is not allowed to take part in any dynamic event if any of the seals are broken until the IMDT is successfully passed again. EV7.2 Insulation Measurement Test (IMT)

			EV7.2.1 The insulation resistance between the tractive system and control system ground will be measured during Electrical Tech Inspection. The available measurement voltages are 250 V and 500 V. All cars with a maximum nominal operating voltage below 300 V will be measured with the next available voltage level. For example, a 175 V system will be measured with 250 V; a 300 V system will be measured with 500 V etc. EV7.2.2 To pass the IMT the measured insulation resistance must be at least 500 ohm/volt related to the maximum nominal tractive system operation voltage.
EV8.2	Charging	Power	EV8.2.11 All chargers must be UL (Underwriters Laboratories) listed. Any waivers of this requirement require approval in advance, based on documentation of the safe design and construction of the system, including galvanic isolation between the input and output of the charger. Waivers for chargers must be submitted at least 30 days prior to the start of the competition. EV8.2.12 The vehicle charging connection must be appropriately fused for the rating of its connector and cabling in accordance with EV6.1.1.
EV8.3.6	Safety Ratings	Safety	All electrical safety items are rated for (at least) the maximum tractive system voltage.
EV9.1	Electrical System Form (ESF)	Safety, TSI, VCI, Power	EV9.1.1 All teams must submit clearly structured documentation, prior to the posted deadline, of their entire electrical system (including control and tractive system) called the Electrical System Form (ESF). EV9.1.2 The ESF must illustrate the interconnection of all electric components including the voltage level, the topology, the wiring in the car and the construction and build of the accumulator(s). EV9.1.3 Teams must present data pages with rated specifications for all tractive system parts used and show that none of these ratings are exceeded (including wiring components). This includes stress caused by the environment e.g. high temperatures, vibration, etc. EV9.1.4 A template including the required structure for the ESF will be made available online. EV9.1.5 The ESF must be submitted as an Adobe PDF file. Data pages and large schematics should be put in an appendix.
EV9.2	Failure Modes and Effects Analysis (FMEA)	Safety, TSI, VCI, Power	EV9.2.1 Teams must submit a complete failure modes and effects analysis (FMEA) of the tractive system prior to the event. EV9.2.2 A template including required failures to be described will be made available online. Note: Do not change the format of the template. Pictures, schematics and data sheets to be referenced in the FMEA must be included in the ESF.
R002	**VSCADA Sensor Integration**	**VCI**	**The VSCADA must be connected to all sensors**

R002-0	Required Sensors	VCI, TSI	Power, Current, and Voltage to Load Tractive System DC current and motor phase current Rate of charge/discharge of accumulator and individual cells System Temperatures Data from GPS / INS
R002-1	Uncertainty of measurements	VCI	R002-1.1 Uncertainty of all measurands shall be analyzed and specified in D011 and a Calibration and Error Analysis document required. R002-1.2 Each measurand shall have programmable sampling rates Plots of measurands vs time
R006	**GLV Power**	**Power**	**Supply power for all non-tractive systems**
R006-0	DC GLV Power	Power	The GLV system shall provide DC supply voltage with sufficient current to supply all the power needs of the GLV systems and other non-tractive systems.
R006-1	Rechargeable Battery	Power	The GLV system shall contain a rechargeable battery of sufficient capacity to run the car GLV systems for at least three hours.
R006-2	Charging Specifications	Power	i) The GLV system shall be rechargeable by means of a UL listed charging device that plugs into the 120 VAC mains. ii) The charging system shall be capable of powering the GLV system indefinitely as it simultaneously charges the GLV battery in a plug and forget functionality in a manner similar to typical laptop computers or cell phones. iii) It shall be possible to charge a fully discharged GLV battery without disassembly or special actions v) The GLV battery shall be protected from full discharge, overcharge, overcurrent, and overvoltage.
R006-3	Power Management	Power	Power management software and hardware should allow the GLV system to safely sit idle without fear of over-discharge and damage.
R006-4	GLV Data Measurement	Power	GLV voltage, current, temperature, and SOC shall be measured by VSCADA.
R007	**Safety Loop**	**Safety**	**Review the existing safety loop design and revised to improve electrical and mechanical performance, reliability, and maintainability.**
R007-0	Easy Integration (see R008 also)	Safety	The safety loop system shall be packaged so it is straightforward to integrate with the car. The safety loop system shall be packaged so as to be fully compliant with all Formula EV rules, including shock, vibration, temperature, and humidity (including rain).
R007-1	Cabling (see R008 also)	Safety	The cabling requirements for car installation shall be analyzed and a set of safety cables suitable for use on the car shall be designed, fabricated, and tested.

			Cables required to support the MCS Test Stand shall be designed, fabricated, and tested.
R007-2	Safety Loop Analysis Document	Safety	This document shall justify the design of the safety loop. Possible faults and risks shall be analyzed. Discussion and justification of the 4-wire loop versus 2-wire loop is required.
R007-3	Previous Years	Safety	Be familiar with, use, and improve upon the safety function and documentation from previous years.
R008	**TSV Load Controller**	**TSI**	**Review and revise existing design to improve electrical and mechanical performance, reliability, and maintainability**
R008-0	Easy Integration	TSI	The load controller system shall be packaged so it is straightforward to integrate with the car. The safety loop system shall be packaged so as to be fully compliant with all Formula EV rules, including shock, vibration, temperature, and humidity (including rain).
R008-1	Cabling	TSI	The cabling requirements for load controller shall be analyzed and a set of GLV and TSV suitable for use on the car shall be designed, fabricated, and tested. In addition, cables required to support the MCS Test Stand shall be designed, fabricated, and tested.

GLV Test Plan

Summary

The grounded low voltage system (GLV) being designed and developed in the LFEV project is intended to power all of the vehicle's elements, except for the tractive system. To verify the operation of the GLV system, the following subsystems must be designed and tested:

- Power: This system is responsible for powering all aspects of the vehicle except for the tractive system. The power system must run on a rechargeable battery and last for a specified amount of time.
- Safety: This system runs the shutdown circuit and safety loop. If any device detects a failure, or if a user engages a shutdown button, the system will shut down according to the procedure outlined in the EV.
- Tractive System Interface (TSI): This system acts as an interface between the tractive system voltage and the grounded low voltage. Specifically, it is responsible for requirements associated with galvanic isolation, the insulation monitoring device (IMD), the tractive system active light (TSAL), and the TSV load controller.
- Vehicle Computer Interface (VCI): This system acts as an interface between the VSCADA software and the rest of the vehicle. Specifically must interface vehicle sensors and the system computer.

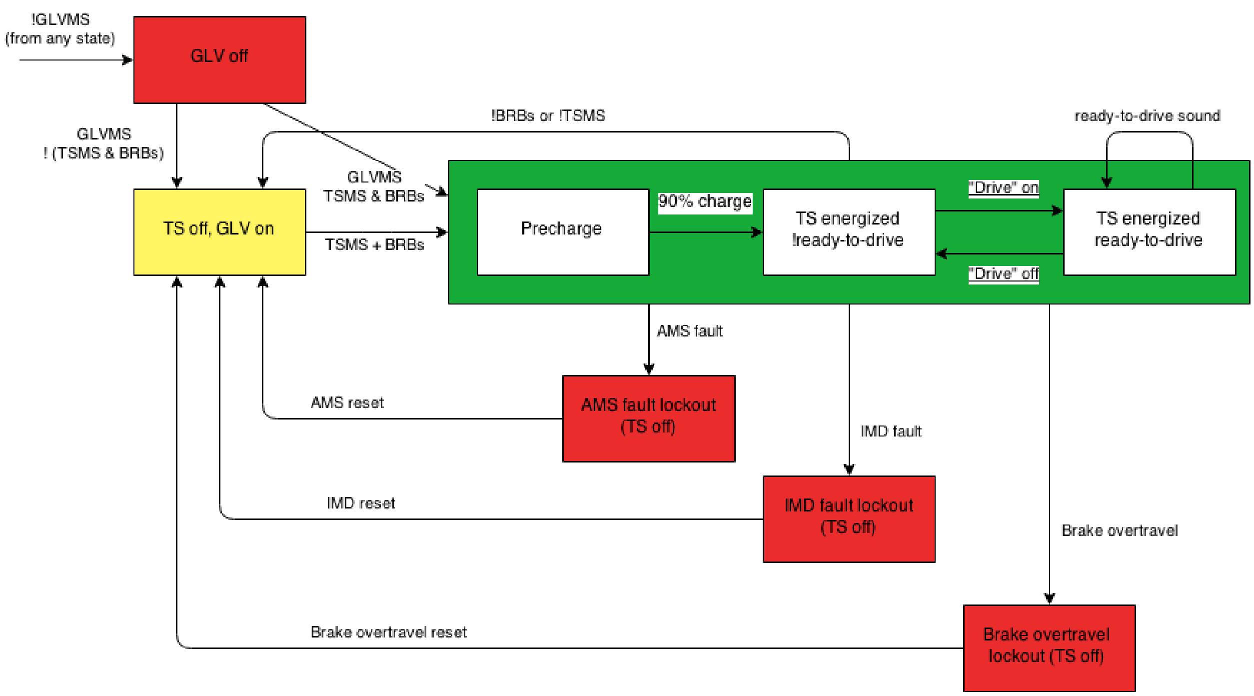
GLV System State Analysis

Summary

The grounded low voltage system (GLV) being designed and developed in the LFEV project is intended to power all of the vehicle's elements, except for the tractive system. The GLV system has been divided into the following subsystems: GLV Power, Safety, TSV Interface (TSI), and VSCADA Interface (VCI). The GLV group members determined that the GLV requirements do not necessitate the building of state transition diagrams. Much of what the GLV system provides is black-and-white. For instance, the VCI must implement sensors to take data, convert this data, and provide it to the VSCADA. This is a linear data path, which is not appropriate for a state analysis. As a result, much of the information given in this System State Analysis will be done in paragraph form, explaining what information the GLV collects, where the information comes from, and where it is stored.

Shutdown State Diagram

The following is almost identical to Figure 31 in the EV Spec. The following state transition diagram includes aspects from GLV Power (on a basic level), Safety, and TSI. There is also TSV information present, because it is relevant to the GLV states.



Shutdown Circuit State Analysis

The analysis begins with the topmost, red state. According to requirement EV4.1.2, it must not be possible to activate the tractive system unless the GLV system is powered. Thus, if the GLV system is not turned on, nothing else is important. If at any point the GLV system is turned off, this is the state that will be entered. GLV power is indicated on the diagram with the TSV Master Switch (TSVM). Once the GLV system is powered, the system enters one of two possible states. If the TS Master Switch (TSMS) and three safety switches are on, the system will enter the TSV On state, indicated in green. The two master switches and three safety switches are all part of the shutdown circuit, and they are all physical switches. The three safety switches are also known as Big Red Buttons (BRBs).

The three states within the TSV On green state are all TSV related, but it is important to note the GLV requirement for when the system enters the Ready-to-Drive state. At this point, the GLV system will make a Ready-to-Drive-sound according to requirement EV4.11. If at any point the TSMS or BRBs are deactivated, the system will enter the GLV On, TSV Off state. There are three other aspects of the shutdown circuit which would cause the TSV to turn off. AMS and Brake over-travel faults are not GLV controlled, but the IMD fault is. The IMD monitors electrical isolation between the GLV system and tractive system, and faults when there is a connection. The IMD is located within the load controller.

Safety State Analysis

The safety of the overall system can be defined in terms of the controlled system and the source of shutdown. As discussed in Table 17 (from the EV spec) below, when a certain switch is turned or button is pressed then certain processes need to either keep running or be killed within a set time to keep the driver and its surroundings safe. For example, if the IMD is automatically shut down due to something, the I.C Engine and AIRs need to be killed but leave the GLV and starter intact.

As discussed above, each fault will correspond to a state in the shutdown state transition diagram of Figure 31 and will prioritize shut down in such a way that the LFEV team is safe.

		Controlled Systems			
		Engine Starter (High Current)	GLV Supply to: Instrumentation Data acquisition Computers Telemetry Etc.	I.C. Engine Ignition Fuel pumps Starter solenoid Etc.	AIRs (TS Voltage)
Shutdown Sources	TSMS				OFF
	Cockpit BRB			OFF	OFF
	AMS			OFF	OFF
	IMD			OFF	OFF
	Brake Over-travel			OFF	OFF
	Side-mounted BRBs		OFF	OFF	OFF
	GLVMS	OFF	OFF	OFF	OFF

Table 17 - Shutdown Priority Table

Power State Analysis

The state analysis of the Power subsystem can be explained in the simple terms of the states of a batter running, dying, and being charged, while also having (safety) kill switches. Power management is one aspect that would have a lot more state transitions and different possibilities. At this point, the intention of the GLV team is to buy a battery and charger that already offer protections from overcharge, full discharge, overcurrent, and overvoltage as per requirement R006-2. The team is ready to be flexible in this regard, and limitations on the battery purchase make it a necessity, the team will have to create a more extensive power management system. As explained extensively in the Safety section and elsewhere, the GLV must cut power to other systems and shut down itself when appropriate. This is essentially equal to 0 and 1 states for the Power subsystem.

VCI State Analysis

One task of the VCI subsystem is to work with VSCADA to collect and implement data from sensors. The breakdown between VSCADA and GLV (VCI specifically) will be determined by the switch from analog to digital data. VCI will be in charge of buying the sensors, and this GLV subsystem will be in charge of converting that data and delivering it to VSCADA. Of course, GLV must coordinate with VSCADA to determine which sensors will be appropriate and what specific form the data should be delivered in.

Another responsibility of VCI that can be considered a change of state is the Ready-to-Drive Sound. This is another instance of interfacing with SCADA where the breakdown will be digital/analog or software/hardware. GLV will provide the speaker, power to the speaker, and any amplification before the speaker that is required.

TSI State Analysis

The main purpose of the TSI system is to control high voltage line between the Accumulator Isolation Relays (AIRS) of the TSV and the motor controller. The load controller must accomplish this task while keeping the TSV system galvanically isolated from the rest of the vehicle. When GLV power is present in the load controller, an LED will light up indicating that the load controller is on. The load controller is controlled directly from the VSCADA system. The load controller will also connect VSCADA to a voltage sensor that constantly measures the voltage of the high voltage line. The load controller also has a Tractive System Active Light (TSAL) the indicates when the TSV system is on. This light goes on when the AIRS are closed or when there is greater than 5 volts present at the high voltage line. There are two other lights, one connected to each of the load controller isolation relays (LCIR). These light are on when the respective LCIR is closed. The load controller is also an integral part of the safety loop because of the high voltage lines. The Isolation Monitoring Device constantly monitors the TSI system for an isolation failure. When a failure is detected, the AIRs are automatically opened, shutting down the high voltage power from the rest of the system.

GLV Risk Assessment

Summary

This portion of the PDR details the risk assessment for the Grounded Low Voltage system being developed for the LFEV design project. This document will identify the critical areas of risk and strategies for managing or ameliorating potential adverse consequences of that risk.

Power

The largest risk for the Power subsystem of the GLV team is buying a battery and/or charger that does not end up meeting the needs of the GLV team and the other three teams that are relying on this battery for low voltage power. These will be large expenses for our team, and for this year's project as a whole, so making either purchase twice would be seriously detrimental to the project's success. The danger is increased when the Power subsystem is relying on other groups to determine their needs for the battery. If a team vastly underestimates their need for power, then GLV Power could buy an inferior battery.

The best strategy for ameliorating this risk is to anticipate it and prevent it from happening. GLV Power needs to work with the other groups closely to determine and understand their needs before doing sufficient research before purchasing a battery and charging cable. If the mistake is, in fact, made, ameliorating it would be difficult. Another battery would need to be purchased (likely after the purchasing deadline). One possible amelioration would be to sell the incorrect purchases.

Safety

The most important elements of the GLV safety system is the safety loop and safety circuit. This two portions of the system must be functional before any system integration is performed. The safety system must remain on schedule or else the entire rest of the project will also fall behind.

Luckily for us, the electric vehicle team from 2013 designed and constructed a working safety loop that can be re-tooled and only slightly redesigned to fit our requirements. This means that we already have a design to work off of that we know works. Also, if anything were to put us behind on progress with the safety system, the 2013 design can be directly used as a safety loop and safety circuit.

Tractive System Interface

The main goal of the Tractive System Interface subsystem is to produce a competition acceptable Load Controller. The the Load Controller separates the high voltage TSV subsystem from the GLV subsystem and the rest of the vehicle. The 2013 LFEV team completed a Load Controller that meets most of the specs and safety requirements established in the EV rules, however there are a few components that must be added to the Load Controller. Specifically, high voltage Veam Powerlocks connectors, high voltage sensors, voltage present warning lights, and TSV active lights must be integrated and installed into the Load Controller. The fact that the Load Controller separates the driver and crew members from the TSV makes the Load Controller an extremely important safety component, therefore all of the tasks for the TSI subsystem have a high degree of risk and if any of them fail to be completed, the entire LFEV may not be deemed ready for competition.

One task that must be completed by the TSI subsystem is to design a new packaging layout so that the Load Controller can be easily installed onto the frame of the LFEV. This task will have the most risk involved because of the strict requirements outlined by the EV rules regarding the layout and separation of high voltage and low voltage systems. This packaging design will be no easy task because the Load Controller must be interfaced with TSV, GLV power, VSCADA, Dyno, and be small enough to fit on the frame of the LFEV. To address this risk we have dedicated over two weeks to the design of the packaging container and another week for the installation of the Load Controller into the container and to test to make sure the Load Controller meets the layout requirements. In a worst case scenario, the packaging container would be too small to fit the entire load controller without failing any layout tests, to prevent this from happening the TSI team will work closely with the mechanical team to ensure that the packaging container is designed to take advantage of any space that is available on the the frame of the LFEV.

Vehicle Computer Interface

The main responsibility of the Vehicle Computer Interface is to use sensors to collect data and then convert and deliver it to the VSCADA system. VSCADA will create an interface that will display the data which will be viewed by the car driver and the maintenance team. It is critical that these measurements are accurate and reliable at all times or the driver and teams working on the vehicle could be at risk. It will be important that the VCI team and the VSCADA team work together to determine the correct sensors to minimize risk. Also thorough testing of all sensors must be done to insure sensors are functioning properly and consistently collecting the appropriate data.

Another critical area of risk involves the Ready-to-Drive Sound, it is important that when the car is in ready to drive mode this alert is loud enough for everyone close to the car to hear it. We do not want any injuries because someone is not aware the car can now accelerate. It is important that we test this feature in various noisy environments to modify the amplifier as needed to meet the requirements and improve the overall safety of the vehicle.

GLV Cost Analysis

Power	Description	Cost	Quantity
Battery	A range for one 24V or two 12V batteries that would fit the needs of the GLV system.	$185	1 (or 2 12s)
Smart Charger	Tenergy Smart Universal Charger that includes either 12V or 24V in range.	$25	1
	Total	$210	

Safety	Description	Cost	Quantity
IMD	Bender A-ISOMETER iso-F1 IR155-3203 or IR155-3204	Owned	1
Master Switches	Master Switch	Owned	2
Big Red Buttons	Big Red Buttons	Owned	3
Brake Over-Travel	Brave Over-Travel Switch	Owned	1
Interlocks	Interlocks (EV5.1.2)		
Accumulator Management System	continuously measures cell voltages		
LEDs	visible in sunlight and waterproof, red, McMaster-Carr 2779K7	$9.62	2
LEDs	visible in sunlight and waterproof, green, McMaster-Carr 2779K2	$14.52	2
Wiring, Fuses, etc.	Based on 2013 Safety Controller BOM	$150	
	Total	$198.28	

TSI	Description	Cost	Quantity
Acrylic Frame	Electrical Insulating Barrier	$16.68	1
Toggle Switch	Tractive system reset button	$1.49	1
	Tractive system active light	$44.60	1
DC/DC Converter	dc-dc converter	$1.90	2
Voltage Sensor	Voltage sensors for HV terminals	$11.99	1
Veam Powerlocks	Surface mount drain and source connector	$55.00	4
TSAL	Tractive system voltage present lamp	$44.60	2
	Total	$387.76	

VCI	Description	Cost	Quantity
Speaker	BUZZ PIEZO CIRC 42.85MM PANEL (Sound Emitting Device)	$37.55	1
Amplifier	Audio amplifier for the speaker	$8.00	1
Sensors	Temperature Sensor	$6.00	4
	Current Sensor	$15.00	3
	Voltage Sensor	$19.00	3
	Rate of Charge Sensor	$15.00	2
	Rate of Discharge Sensor	$15.00	2
	State of Charge Sensor	$6.00	2
	Total	$243.55	

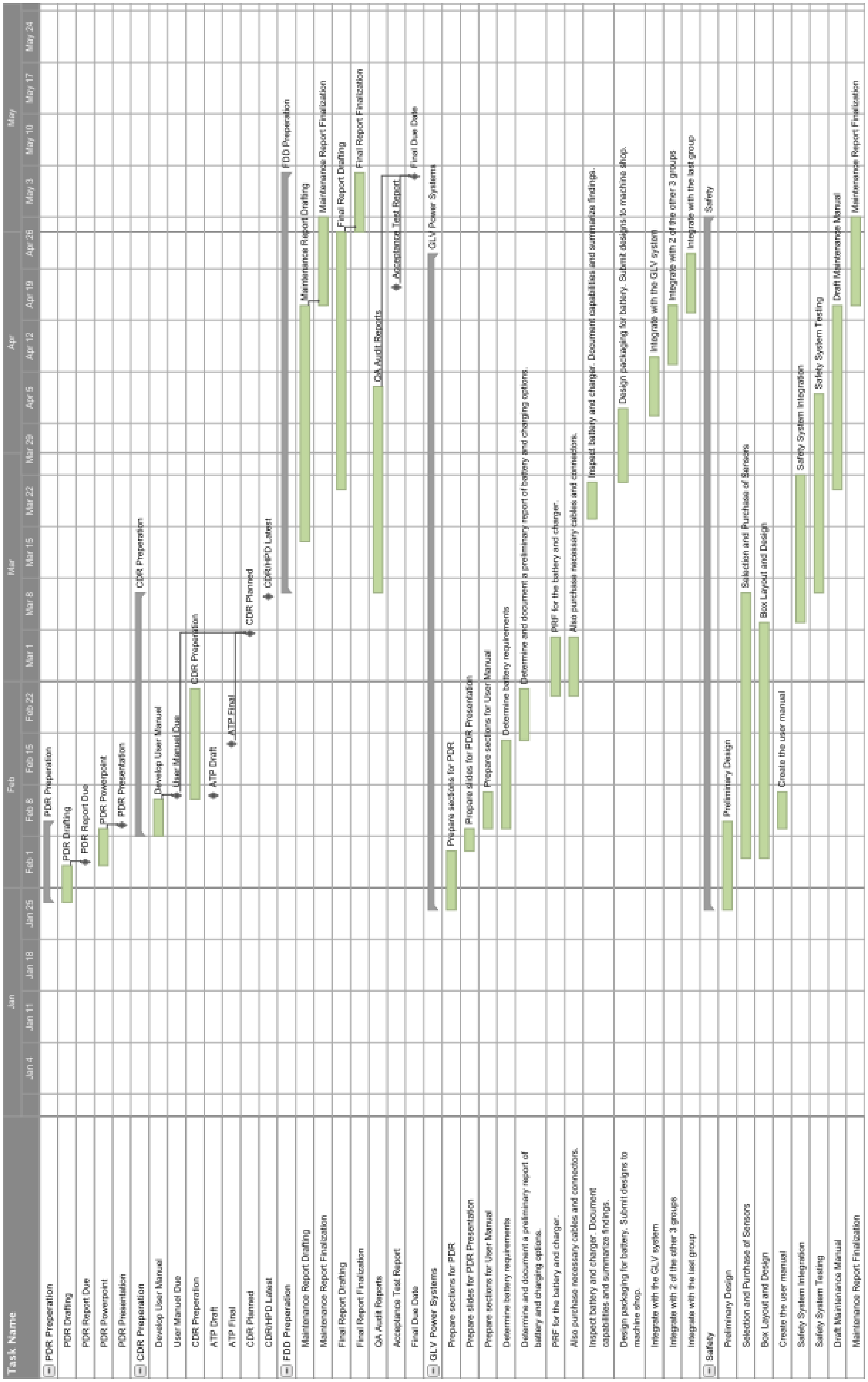
Total GLV		Cost
Power		$210
Safety		$198.28
TSV		$387.76
VCI		$243.55
	Total	$1,040

GLV Work Breakdown Structure

Summary

The GLV team is broken up into four sections: Power, Safety, Tractive System Interface (TSI), and Vehicle Computer Interface (VCI). Nicholas DiNino, Jordan Frank, Aloysius Posillico, and Zachary Helwig are assigned to these sections respectively. Daniel Zakzewski will be in charge of team management, intersystem interfacing, and assisting in any difficulties met.

The GLV team plans on having a CDR prepared by March 5th, a week before the latest allowed date. This is so that we can address any issues without being late on the hard deadline of March 12th.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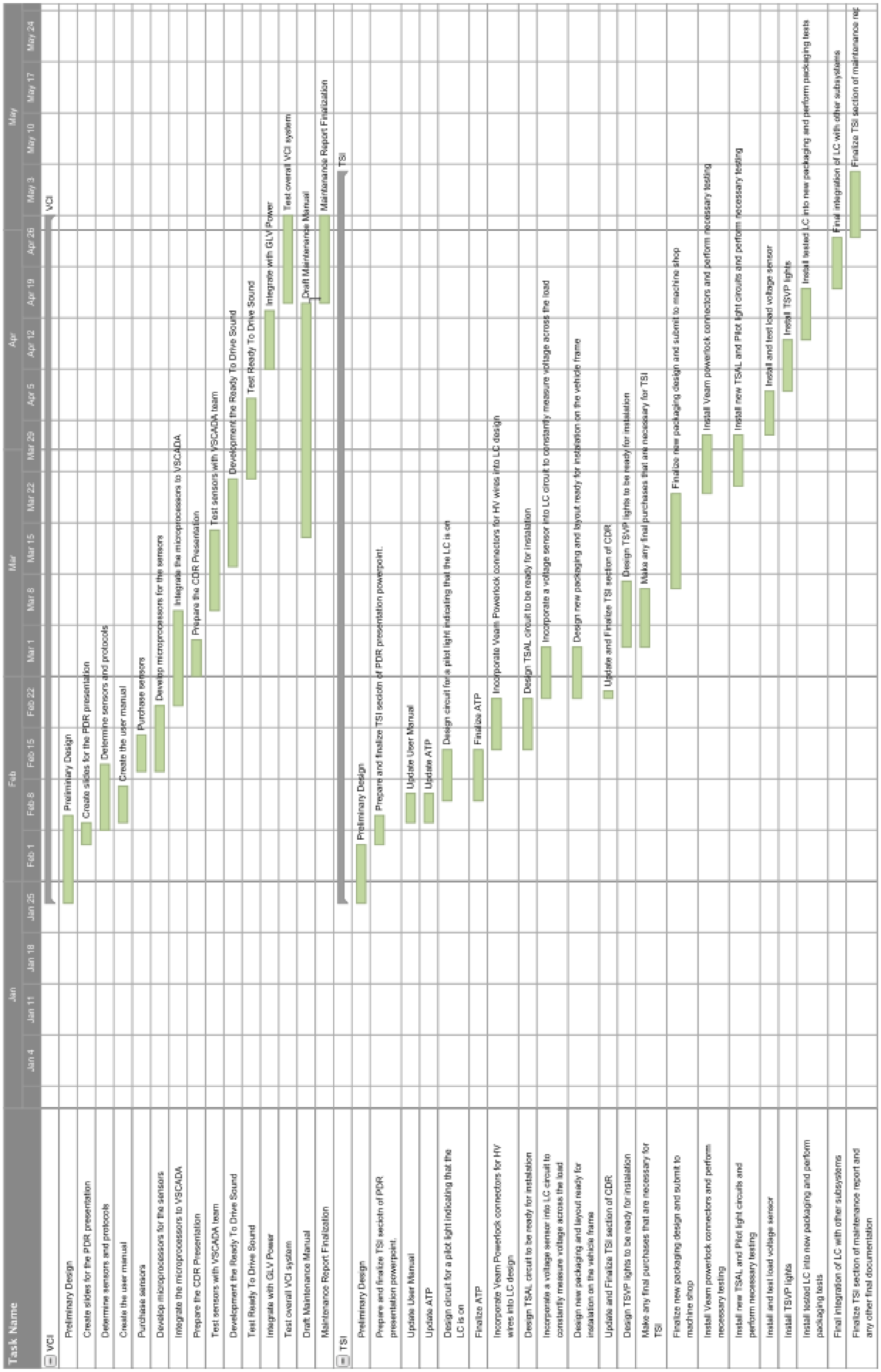
Mar 22
Mar 29
Apr 5
Apr 12
Apr 19
Apr 26
May 3
May 10
May 17
May 24
PDR Preparation
PDR Drafting
PDR Report Due
PDR Powerpoint
PDR Presentation
CDR Preparation
Develop User Manual
User Manual Due
CDR Preparation
ATP Draft
ATP Final
CDR Planned
CDR/HPD Latest
FDD Preparation
Maintenance Report Drafting
Maintenance Report Finalization
Final Report Drafting
Final Report Finalization
QA Audit Reports
Acceptance Test Report
Final Due Date
GLV Power Systems
Prepare sections for PDR
Prepare slides for PDR Presentation
Prepare sections for User Manual
Determine battery requirements
Determine and document a preliminary report of battery and charging options.
PRF for the battery and charger.
Also purchase necessary cables and connectors.
Inspect battery and charger. Document capabilities and summarize findings.
Design packaging for battery. Submit designs to machine shop.
Integrate with the GLV system
Integrate with 2 of the other 3 groups
Integrate with the last group
Safety
Preliminary Design
Selection and Purchase of Sensors
Box Layout and Design
Create the user manual
Safety System Integration
Safety System Testing
Draft Maintenance Manual
Maintenance Report Finalization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Mar 15
Mar 22
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Apr 5
Apr 12
Apr 19
Apr 26
May 3
May 10
May 17
May 24
VCI
Preliminary Design
Create slides for the PDR presentation
Determine sensors and protocols
Create the user manual
Purchase sensors
Develop microprocessors for the sensors
Integrate the microprocessors to VSCADA
Prepare the CDR Presentation
Test sensors with VSCADA team
Development the Ready To Drive Sound
Test Ready To Drive Sound
Integrate with GLV Power
Test overall VCI system
Draft Maintenance Manual
Maintenance Report Finalization
TSI
Preliminary Design
Prepare and finalize TSI seciotn of PDR presentation powerpoint.
Update User Manual
Update ATP
Design circuit for a pilot light indicating that the LC is on
Finalize ATP
Incorporate Veam Powerlock connectors for HV wires into LC design
Design TSAL circuit to be ready for instalation
Incorporate a voltage sensor into LC circuit to constantly measure voltage across the load
Design new packaging and layout ready for installation on the vehicle frame
Update and Finalize TSI section of CDR
Design TSVP lights to be ready for instalation
Make any final purchases that are necessary for TSI
Finalize new packaging design and submit to machine shop
Install Veam powerlock connectors and perform necessary testing
Install new TSAL and Pilot light circuits and perform necessary testing
Install and test load voltage sensor
Install TSVP lights
Install tested LC into new packaging and perform packaging tests
Final integration of LC with other subsystems
Finalize TSI section of maintenance report and any other final documentation