Requirements Analysis Matrix

LFEV-Y2-2014 Requirements

Requirement	Top Level Description	Related Subsystem(s)	Functional Requirement/Interface	ATP Test Confirmation
R000	**Formula Hybrid Competition Rules**	**Battery Pack, AMS, PMS, Charge, Load Controller, Motor, Motor Controller, Test Stand, Safety Loop**	**The Formula Hybrid Competition rule sections relating to electrical and power subsystems of the completed car will be analyzed to determine what rules are applicable to the scope of the proposed design. All rules determined to be within the proposed scope will become constraints and requirements within the design of the integrated system in order to produce a competition ready and compliant product at the completion of the project**	
R001	**VSCADA: Takes input from system's sensors and controls the system state**	**AMS, PMS, Safety Loop, Charger**	**A Pack Management System (PMS) will be introduced to each battery pack and will control the charging algorithm, open the safety loop in the case of out of bounds sensor readings, and supply pack information to the main VSCADA computer via a CAN bus**	
R001-1	VSCADA computer hardware shall be provided as required to handle the VSCADA user interface and processing requirements. This includes on-car and off-car functions	AMS, PMS	AMS includes a PIC processor to obtain data from on board voltage and temperature sensors. The PMS will utilize a microprocessor (Raspberry PI) to commicate with the AMS via I2C and the main VSCADA computer via CAN	
R001-2	VSCADA software shall be a suite of applications built to a unified API with common data formats, protocols, look and feel. To the greatest possible extent the same core system must run on various hardware platforms in and around the LFEV components	PMS	An API will be created to maintain communication with each PMS via CAN in order for the main VSCADA computer to obtain information about each battery pack for processing	
R001-3	VSCADA software must start automatically and reach a sane, operational state without human interaction	AMS, PMS	Both the AMS and PMS processors will contain software that will be loaded automatically and can run from bootup without human interaction	
R001-4	Sudden unexpected shutdown of the VSCADA software shall not cause failure or significant data corruption	AMS, PMS, Safety Loop	AMS and PMS software will be loaded in non-volitile media and will be written in a manner that it will recover from sudden power loss situations. The safety loop will be opened in the event of unexpected shutdown to prevent additional system failure	
R001-5	VSCADA shall communicate with AMS by means of the I2C protocol established in 2013	AMS, PMS	The PMS will utilize an I2C interface to communicate to each AMS and obtain readings from each individual cell	
R001-6	A backup system or recovery strategy must be developed to all the VSCADA system to be promptly repaired after a hardware failure in less time than the MTTR given in GPR007	AMS, PMS	AMS and PMS PCBs will contain accessible pin headers to quickly reprogram the flash memory of each processor chip in the pack. In the event of a damaged component or processor, the maintainability report will suggest the usage of spare completed AMS and PMS systems to quickly replace the damaged systems in the pack	
R001-7	VSCADA HW and SW are required to support these modes, interfaces, and displays: Dashboard (driver mode), Dashboard (maintainance and experimentation), Pit Station (monitoring and data acquisition), Charger (Plug and Forget), Discharger (Plug and Forget), Off-car Station (maintainance and experimentation), Driver Demo Mode (plug and forget)	AMS, PMS, Charger	The fully integrated system will support Charger (Plug and Forget) and Discharger (Plug and Forget). The PMS will use a microprocessor GPIO pin to switch a charging relay on to charge and off when charging is complete. An A/D pin on the PMS processor will be utilized to sense when the charger is plugged into it's battery pack's charge terminal and therefore when charging can begin	
R001-8	A suitable wireless link shall be provided for communication between the car and an off-car station	NOT IN SCOPE		
R001-9	All VSCADA application software must be written in conformance with a documented API using a delievered SDK	PMS	Software will be written for the PMS system and will thereby adhere to requirements including an API and SDK	

R001-10	The following analog measurands shall be monitored and stored by the VSCADA: Overall voltage, current, and power delievered to the load; Individual cell voltages; Rate of charge or discharge; estimate of battery state of charge; temperatures of ambient, all subsystems, and individual cells in the accumulator, data available from the motor controller, Vehicle speed and distance traveled; data available from a GPS or INS located on car or with pit station; data available from the MCS test stand	AMS, PMS, Motor Controller, Test Stand	AMS system will contain temperature sensors, a shunt voltage current sensor, and the ability to measure cell voltage. Raw data acquired by each AMS will be transmitted via I2C to the PMS. The PMS will collect all data, maintain an estimated battery state of charge, and present it to the main VSCADA computer via a CAN bus. Data from the motor controller can be accessed using the same CAN bus. GPS data will not be within the scope of this project	
R001-11	Measure individual parameters up to 60 times a minute or at slower rates. All parameters shall have their values logged electronically along with a time stamp. Sampling rates shall be individually programmable for each measurand	PMS	The PMS will poll each AMS in a battery pack as quickly as possible in order to obtain the most up to date information to present to the main VSCADA system via the CAN bus. The VSCADA main computer may poll each PMS at the 60 times per minute rate or slower.	
R001-12	Plots of measurands versus time shall be generated	NOT IN SCOPE		
R001-13	Fuel gauge displays of state of charge shall be generated	NOT IN SCOPE		
R001-14	VSCADA system shall log any events, exceptions, faults, or changes in operational state of the LFEV, including safety interface events	NOT IN SCOPE		
R001-15	VSCADA data storage shall have sufficient capacity for retaining data records over the lifetime of the system. If removable storage is used, system must be able to operate without media and to initialize blank media with sane configuration content	NOT IN SCOPE		
R001-16	VSCADA software must adapt automatically and safely to different numbers of cells and packs	PMS	The PMS software will commicate via I2C with each AMS in its battery pack in order to automatically determine how many cells are in its pack	
R001-17	VSCADA shall use the installed computer interface of a commercial motor controller to access, record, and display all available motor controller data in a form that is integrated with the overall LFEV data display	CAN Bus	The MCS that will be purchased contains a CAN interface which will allow us to access all necessary motor parameters	
R001-18	VSCADA system shall be expandable to allow the incorporation of additional measurands and control functions. Expansion shall be accomplished in a way that does not require recompiling software to make configuration changes	NOT IN SCOPE		
R001-19	Data storage shall be accumulated in a portable, non-proprietary format readily useale by commonly available data analysis tools	NOT IN SCOPE		
R001-20	All VSCADA software should automatically initialize when the VSCADA computer is powered up. It should not be necessary to manually run various programs and edit files to get the system going after a reboot or power outage	AMS, PMS	Both the AMS and PMS processor chips containing software are self-programming and the software loaded will be designed such that no human interaction is necessary for the system to operate normally after booting	
R001-21	VSCADA system shall have the capability to set alarms and shutdown rules should parameters extend beyond their predefined thresholds	PMS, Safety Loop	The PMS processor and its SW will be able to open the safety loop via a GPIO pin should acquired AMS readings go beyond their acceptable readings	
R002	**VSCADA API, SDK, and Applications**	**PMS**		
R002-1	Scope of the API must be sufficient to maintainably support both low level debugging applications and high-level automated applications on all hardware platforms in use. Same API must be used for all applications running on or off-car	PMS	Software written for the PMS microprocessor will include a documented API meeting these scope requirements	

R002-2	SDK must include a complete tool chain with compilers, linkers, libraries, include files, utilities, and developer level documentation. All tools shall be actively supported and mature	PMS	Software written for the PMS microprocessor will include the tools necessary for other developers to write new programs and software using our SDK	
R002-3	All sources must be maintained under configuration control	PMS	Software written for the PMS will use configuration control	
R002-4	The complete SDK, including API and application source under configuration control shall be delievered to or linked by the project website	PMS	All software tools will be linked to the course website upon their completion	
R002-5	API, SDK, and applications shall be copyrighted using open source practices. The team shall identify and GPL all software written by the team	PMS	Open source copyright practices shall be researched by the team and all software tools and software code written by the team will be copyrighted using a GPL.	
R002-6	Software written shall be maintainable as specified in GPR007	PMS	All software written by the team will follow the maintainability guidlines contained in GPR007	
R003	**Use of the 2013 Design**	**Battery Pack, AMS, Safety Loop, Load Controller**		
R003-1	Parts of the 2013 project that do adequately meet LFEV requirements may not be discarded and replaced with new parts that do not meet those requirements	Battery Pack, AMS, Safety Loop, Load Controller	Each component of the 2013 design will be analyzed and its use in the 2014 design will be decided. Currently, the Safety loop controller, AMS boards, battery pack, and load controller have been determined to meet most of their respective requirements and will be utilized in the 2014 integrated system	
R003-2	The pack design must not be altered significantly, except for AMS improvement required by R004	Battery Pack, AMS	AMS improvements as specified in R004 will be completed in the full system. The battery pack design will be altered in order to accomodate 7-cells and be mountable within the finished car, which may involve moving from an in-line to a U-configuration of the cells	
R004	**AMS Requirements: The basic design of the AMS developed in 2013 is acceptable for use in the car with the exception of a few critical shortfalls. The following requirements were not fully met and should be addressed specifically by the 2014 team**	**Battery Pack, AMS, PMS, Safety Loop**		
R004-1	Current Measurement - The AMS must measure the charge or discharge electrical current flow through each pack with accuracy sufficient for system state management, safety monitoring, and state of charge estimation	AMS, PMS, Battery Pack	Current measurement will be accomplished using a shunt voltage current sensor contained on one AMS board per battery pack. This will then be transmitted to the PMS via I2C	
R004-2	Voltage Measurement - The AMS shall measure the individual cell voltages as well as measuring the total pack voltage and the total battery voltage	AMS, PMS, Load Controller	Voltage measurement will be accomplished using A/D pins on the AMS PIC processor. Recorded cell voltage measurements will be sent to its PMS via I2C. The total pack voltage will be measured by taking voltage measurements at each pack terminal using a A/D pin contained on the PMS. The voltage will first be prescaled using an op-amp to put the range of pack voltages within the limits of the A/D in the PMS processor. Total battery voltage will be calculated at the load controller relays.	
R004-3	Charge Algorithm - An improved charging algorithm based on a more comprehensive set of cell measurements shall be developed.	PMS, AMS	The PMS processor will contain software which will communicate with it's set of AMS boards via I2C. It will receive sensor readings, calculate a state of charge of each cell, then control the bypass switch of each AMS board in order to balance the state of charge of each cell. After all cells have been fully charged, the PMS will use a GPIO pin to toggle a charging relay on and off.	

R004-4	Discharge limits shall consider all relevant cell measurements, not only crude cell voltage	PMS, AMS, Safety Loop	All measurements obtained from AMS boards will be available to the main VSCADA computer from each battery pack's PMS via CAN. VSCADA software functionality that will cause discharge can use all available measurements from the PMSs to determine when to break the safety loop or stop the discharge cycle when state of charge or voltage thresholds are passed.	
R004-5	AMS Power - The AMS must maintain regulated supply voltage to itself under all operation conditions, including high-current load and low SOC	PMS, AMS	The AMS boards operate at the battery cell voltage (3.3v) and will only fail to stay powered under extremely low SOC. The AMS Vcc and Vss junctions are connected to the battery's positive and negative terminals. The PMS voltage supply will come from the total voltage accross all 7 cells in a pack and be regulated down to 5V using a voltage regulator. The regulated supply voltage will be sent to its Vcc junction for use as a power supply. Since the PMS is powered by 7 cells, it will require each cell to drop below 1V before there is not enough voltage to power the PMS. This will only occur under extremely low SOC conditions.	
R004-6	Measurand Calibration and Accuracy - The AMS design must be analyzed by a Calibration and Error Analysis document (D011) that states the uncertainities associated with all AMS measurands	AMS, PMS	All measurements collected by both the AMS and PMS systems will be analyzed and included in a Calibration and Error Analysis document to be submitted with CDR materials	
R004-7	Cooling - The AMS requires a simple, small, manufacturable heat sink cooling system for the bypass switch. Performance of cooling system shall be proved by computer modeling and empirical measurements	AMS	The AMS heatsinks will be modeled and/or analyzed by hand to determine the performance of the current cooling system and propose and improvements to the design. Results will be published in a technical memo and posted to the course website	
R005	**MCS and Test Stand Requirements**	**Motor, Motor Controller, Test Stand**		
R005-1	Motor and Controller system shall be provided to meet the requirements of the IEEE FEV competition and should be sized suitably to achieve a reasonably competitive entry	Motor, Motor Controller	A proposal to purchase the motor (HPEVS AC-50) and motor controller (Curtis 1238R) recommended by the 2013 team will be submitted to the faculty. Once approved as a non-budget item, the motor and controller will be purchased	
R005-2	An MCS test stand shall be provided to permit the safe testing and demonstration of motor and controller performance over the operation parameters (RPM and torque profiles) implied by the IEEE FEV competition	Test Stand	A proposal to purchase a test stand which will fit the motor and motor controller performance standards will be submitted to the faculty. Once approved as a non-budget item, the test stand will be purchased.	
R005-3	The MCS test stand shall be instrumented with sensors that are interfaced to the VSCADA, reporting relevant performance parameters measured at the Test Stand	Motor, Motor Controller, Test Stand	The purchased test stand will contain sensors and an interface which can be connected to the VSCADA system during maintance and experimentation modes. The motor controller which will be purchased uses a CAN bus which will interface with the VSCADA system and allow the VSCADA to gather motor details from the controller	
R006	**Battery Pack Requirements: The basic design of the Battery Pack developed in 2013 is acceptable for use in the car with the exception of a few critical shortfalls. The following requirements were not fully met and should be addressed specifically by the 2014 team**	**Battery Pack, Charger**		
R006-1	Voltage - The system design requires a 7-cell pack, with nominal voltage of 24 VDC. The 3-cell pack design from 2013 should be extended to 7 cells	Battery Pack	The battery pack will be extended to 7 cells and requirement will be achieved through inspection of the completed pack	
R006-2	Resistance - An effort shall be made to lower the series resistance of the pack. The resistive connections in the 2013 design should be eliminated.	Battery Pack	The conduction path design will be evaluated. Each joint will undergo analysis to determine if it can be replaced with a solid conductor or resistance can be reduced through the use of conductive grease or other mediums. Requirement will be fulfilled through measurement of the resistance of the pack from terminal to terminal and compared with acceptable values from the Formula EV rules.	

R006-3	Charger Interface - The charging interface shall be reliable, maintainable, and contain safety features that meet requirements. This includes an improved fusing of the charger path from the 2013 design	Battery Pack, Charger	The battery pack charger will be redesigned to be simple to use and have plug and forget functionality. The charging path within the Battery pack will be refitted with properly rated fusing and contain sensors to determine when fuses need to be replaced.		
R006-4	Diagnostics - The 2013 pack did not meet requirements related to displays and diagnostics on the pack (voltage indicators, charge state, etc). These aspects shall be corrected	Battery Pack, PMS, AMS	The battery pack will contain a PCB with 2-seven segment displays to show pack voltage and current, a bargraph LED to display state of charge, and standalone LEDs to show state of the system (Charged, Charging, Safety Loop Fault, Voltage Fault, Temperature Fault). These LEDs will be driven by the PMS processor GPIO pins within each battery pack and the displayed values will be calculated by the PMS.		
R006-5	Delivery of four, fully integrated, 7 cell packs is required	NOT IN SCOPE	Delieverables will include one fully integrated 7 cell battery pack which can be copied and extended to 4 packs during next year		
GPR	**General Project Requirements**				
GPR001	Documentation	Battery Pack, AMS, PMS, Charge, Load Controller, Motor, Motor Controller, Test Stand, Safety Loop	Block Diagrams and schematics for all subsystems being designed will be completed using computer aided drawing programs and will be posted upon completion. Two members of the team have been designated as "Editors" and will review submitted technical memos, manuals, and drawings for accuracy, professionalism, and formatting.		
GPR003	EMI/EMC	Battery Pack, AMS, PMS, Charge, Load Controller, Motor, Motor Controller, Test Stand, Safety Loop	All designs being considered for production will undergo research to determine if any components or the completed system will breach the EMI/EMC limit as specified in US CFR Title 47 Part 15 subpart B regulations for Class A digital equipment. If infractions are found, an alternative design in compliance with this requirement will be proposed before proceeding with production		
GPR004	Hazmats	Battery Pack, AMS, PMS, Charge, Load Controller, Motor, Motor Controller, Test Stand, Safety Loop	System designs will be analyzed for the inclusion of hazardous material before production or procurement of the hazardous substances being used. If a design includes a hazardous material and no alternative design solution is feasible, the Safety officer will update the team's safety plan and system User Manual to include specific instructions for handling these materials both in the lab and in the integrated system.		
GPR005	Safety and Good Practice	Battery Pack, AMS, PMS, Charge, Load Controller, Motor, Motor Controller, Test Stand, Safety Loop			
GPR006	Reliability	Battery Pack, AMS, PMS, Charge, Load Controller, Motor, Motor Controller, Test Stand, Safety Loop	During subsystem design, all components involved will undergo testing and/or research to determine an accurate MTBF and therefore obtain an overal MTBF for the whole system. This report will be included on the website and in the set of delieverables for CDR and final system submission.		
GPR007	Maintainability	Battery Pack, AMS, PMS, Charge, Load Controller, Motor, Motor Controller, Test Stand, Safety Loop	Subsystem designs will be completed with the maintainability procedures in mind. A full maintaince manual for the system and MTTR reports will be submitted with the fully integrated system and to the website for reference purposes.		
GPR008	Manufacturability	Battery Pack, AMS, PMS, Charge, Load Controller, Motor, Motor Controller, Test Stand, Safety Loop	A BOM will be provided for each subsystem at PDR. Analysis of parts on the BOM will ensure they meet tolerance standards as outlined and are available from at least two manufacturers.		
GPR011	Project Demonstration	Battery Pack, AMS, PMS, Charge, Load Controller, Motor, Motor Controller, Test Stand, Safety Loop	Upon complete system integration, QA, and fulfillment of the Acceptance Test Plan, a live demonstration will be presented to the ECE faculty and students. The completed battery pack and related systems will be self contained and able to operate for at least a semester without the need of being charged, thus becoming a maintainance free display for ECE visitors.		

GPR012	Final Disposal of Projects	Battery Pack, AMS, PMS, Charge, Load Controller, Motor, Motor Controller, Test Stand, Safety Loop	Final disposal of project will take place the week of May 5th. System should be completed and demonstrated by this date, so final disposal is the final step to completion of the project. If adequete room is available, the battery pack can be displayed in the ECE hallway for vistors. Charger, MCS and test stand, and left over materials will be stored in AEC 402 or 400 in an orderly and inventoried fashion. All trash or disorder in AEC 400 which was a result of this project will be disposed over.	
Formula Hybrid Requirements (from Formula Hybrid 2014 Rules)				
Requirement	Documentation	Method	Met	Date
EV 1.2	**Grounded Low Voltage and Tractive System Voltage**			
EV 1.2.1	The maximum permitted operating voltage for Formula Hybrid is 300 V. (See Table 9). The maximum operating voltage is defined as the maximum measured accumulator voltage during normal charging conditions.	T		
EV 1.2.2	The GLV system may not have a voltage greater than 30 VDC or 25 VAC	T		
EV 1.2.4	The tractive and GLV system must be galvanically isolated from one another.	T		
EV 1.2.6	The tractive system motor(s) must be connected to the accumulator through a motor controller. Bypassing the control system and connecting the tractive system accumulator directly to the motor(s) is prohibited.	I		
EV 1.3.1	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)	I		
EV 1.3.2	Vinyl electrical insulating tape and rubber-like paints and coatings are not acceptable electrical insulating materials.	I		
EV 2.2	**Accelerator Signal Limits Check**			
EV 2.2.1	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.	T		
EV 2.2.2	The accelerator signal limit shutoff may be tested during electrical tech inspection by replicating any of the fault conditions listed in EV2.2.1	T		
EV 3.1	**Allowed Tractive Systems**			
EV 3.1.1	The following accumulators are acceptable; batteries (e.g. lithium-ion batteries, NiMH batteries, lead acid batteries and many other rechargeable battery chemistries) and capacitors, such as super caps or ultra caps. The following accumulators are not permitted; molten salt batteries, thermal batteries, fuel cell, atomic and flywheel mechanical batteries.	I		

EV 3.1.2	Manufacturer's data sheets showing the rated specification of the accumulator cell(s) which are used must be provided in the ESF along with their number and configurations.	I			
EV 3.2	**Tractive System Accumulator Container – General Requirements**				
EV 3.2.1	All batteries or capacitors which store the tractive system energy must be enclosed in (an) accumulator containers	I			
EV 3.2.2	If spare accumulators are to be used then they all must be of the same size, weight and type as those that are replaced. Spare accumulator packs must be presented at Electrical Tech Inspection.	I			
EV 3.2.3	If the accumulator container(s) is not easily accessible during Electrical Tech Inspection, detailed pictures of the internals taken during assembly must be provided. If the pictures do not adequately depict the accumulator, it may be necessary to disassemble the accumulator to pass Electrical Tech Inspection.	D			
EV 3.3	**Tractive System Accumulator Container - Electrical Configuration**				
EV 3.3.1	If the container is made of electrically conductive material, the poles of the accumulator stack(s) and/or cells must be electrically insulated from the inside wall of the accumulator container by insulating material rated for the maximum voltage of the tractive system. 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.	I			
EV 3.3.2	Every accumulator container must contain at least one fuse	I			
EV 3.3.3	All batteries or capacitors that make up the accumulator must be divided into accumulator segments. Maintenance plugs, additional contactors or similar measures must be taken to allow electrical separation of the internal accumulator segments such that the separated segments contain a maximum voltage of less than 120 VDC fully charged and a maximum energy as specified in Table. This separation method must be used whenever the accumulator containers are opened for maintenance and whenever accumulator segments are removed from the container. Maintenance separation requiring tools to isolate the segments will not be accepted.	D			
EV 3.3.4	If the TSV connectors of the accumulator containers can be removed without the use of tools, then a pilot contact/interlock line must be implemented which opens the shutdown circuit (see EV5.1) whenever the connector is removed.	T			
EV 3.3.5	Contacting / interconnecting the single cells by soldering in the high current path is prohibited.	I			

EV 3.3.6	Each accumulator container must have a prominent indicator, such as an LED, that will illuminate whenever a voltage greater than 30 VDC is present at the vehicle side of the AIRs. Alternatively, an analog voltmeter may be used.	T			
EV 3.3.7	The accumulator voltage indicator (see EV3.3.6) must be directly controlled by voltage being present at the connectors using hard-wired electronics. (No software control is permitted). Activating the indicator with the control signal which closes the Accumulator Isolation Relays (AIRs) is not sufficient.	D			
EV 3.3.8	The accumulator voltage indicator must always work, e.g. even if the container is removed from the car.	T			
EV 3.4	**Tractive System Accumulator Container - Mechanical Configuration**				
EV 3.4.3	All accumulator containers must lie within the surface envelope as defined by IC1.5.1	D			
EV 3.4.8	Holes in the container are only allowed for the wiring-harness, ventilation, cooling or fasteners. These holes must be sealed according to EV4.5.	I			
EV 3.4.10	A sticker with an area of at least 750mm² and a red or black lightning bolt on yellow background or red lightning bolt on white background must be applied on every accumulator container. The sticker must also contain the text “High Voltage” or something similar if the accumulator voltage is greater than 30 VDC.	I			
EV 3.5	**Accumulator Isolation Relay(s) (AIR)**				
EV 3.5.1	At least two isolation relays must be installed in every accumulator container.	I			
EV 3.5.2	The accumulator isolation relays must open both poles of the accumulator.	T			
EV 3.5.3	If these relays are open, no TSV may be present outside of the accumulator container. (Including to the AMS)	T			
EV 3.5.4	The isolation relays must be of a “normally open” type.	I			
EV 3.5.5	The fuse protecting the accumulator circuit must have a rating lower than the voltage and current ratings of the isolation relays.	D			
EV 3.5.6	Accumulator isolation relays containing mercury are not permitted.	I			
EV 3.6	**Accumulator Management System (AMS)**				
EV 3.6.1	Each accumulator must be monitored by an accumulator management system whenever the tractive system is active or the accumulator is connected to a charger.	I			
EV 3.6.2	The AMS must continuously measure cell voltages in order to keep those voltages inside the allowed minimum and maximums stated in the cell data sheet. If single cells are directly connected in parallel, only one voltage measurement is needed. (See Table 11)	T			

EV 3.6.3	The AMS must continuously measure the temperatures of critical points of the accumulator to keep the cells below the allowed maximum cell temperature bound stated in the cell data sheet.	T			
EV 3.6.4	All voltage sense wires to the AMS must be either protected by fuses as defined in ARTICLE EV6 or must be protected by resistors so that they cannot exceed their current carrying capacity in the event of a short circuit. Any fuse or resistor must be located as close as possible to the energy source. If any of these fuses are blown or if the connection to measure the cell voltage is interrupted in any other way then this must be detected by the AMS and must be reported as a critical voltage problem. If the AMS monitoring board is directly connected to the cell, it is acceptable to have a fuse integrated into the monitoring board.	T			
EV 3.6.5	Any GLV connection to the AMS must be galvanically isolated from the TSV, including any connections to external devices such as laptops. This isolation must be documented in the ESF.	D			
EV 3.6.6	The AMS must monitor the temperature of the minimum number of cells in the accumulator as specified in Table 12 below. The monitored cells must be equally distributed over the accumulator container(s).	T			
EV 3.6.7	The AMS must shut down the tractive system by opening the AIRs if critical voltage or temperature values are detected. 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 AMS fault.	T			

EV 3.6.8	Team-Designed Accumulator Management Systems: Teams may design and build their own Accumulator Management Systems. However, microprocessor-based accumulator management systems are subject to the following restrictions: (a) The processor must be dedicated to the AMS function only. However it may communicate with other systems through shared peripherals or other physical links. (b) The AMS circuit board must include a watchdog timer (Maxim MAX6373 or similar) which is physically separate from the CPU. (c) The external watchdog timer must be hardwired to the AIRs through an electro-mechanical relay such that a watchdog timeout or loss of power to the circuit board will result in the AIRs opening. (d) The watchdog “tickle” input must be driven high and low in separate routines (i.e. no “compliment port pin” code) At least one watchdog input transition must be driven inside a foreground routine, i.e. both transitions may not be contained in timer or externally-triggered interrupt routines. (e) The code that drives the watchdog input may not be located such that a malfunction resulting in continuous internal watchdog timeouts could prevent the external watchdog timer from timing out. (f) The external watchdog timer must be demonstrable.	I, T, D			
EV 4.1	**Separation of Traction System and Grounded Low Voltage System**				
EV 4.1.3	Traction 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.	D			
EV 4.1.4	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.	D			
EV 4.1.5	Where both tractive system circuits and GLV circuits are present within an enclosure, they must be (a) separated by electrical insulating barriers rated for 150 C or higher (e.g. Nomex based electrical insulation), or (b) separated by the spacings shown in Table 13 through air, or over a surface (similar to those defined in UL1741):	D			
EV 4.1.6	Spacing must be clearly defined. Components and cables capable of movement must be positively restrained to maintain spacing.	I			
EV 4.1.7	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.	I			
EV 4.1.8	Teams must be prepared to demonstrate spacings on team-built equipment. Information on this must be included in the ESF (EV9.1). For inaccessible circuitry, spare boards or appropriate photographs must be available for inspection.	I			

EV 4.2	**Positioning of tractive system parts**				
EV 4.2.5	There must be a layer of an electrically insulating material between any tractive terminal or connection and the firewall or frame if they are within 50 mm (2 inches) of one another.	I			
EV 4.3	**Grounding**				
EV 4.3.1	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.	T			
EV 4.3.2	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.	T			
EV 4.5	**TSV Insulation, wiring and conduit**				
EV 4.5.1	All parts especially live wires, contacts, etc. of the tractive system need to be isolated by non-conductive material or covers to be protected from being touched. In order to achieve this, it must not be possible to touch any tractive system connections with a 10 cm long, 0.6 cm diameter insulated test probe when the tractive system enclosures are in place.	T			
EV 4.5.2	Non-conductive covers must prevent inadvertent human contact with any tractive system circuit. This must include crew members working on or inside the vehicle. Covers must be secure and adequately rigid. Body panels that must be removed to access other components, etc. are not a substitute for enclosing tractive system connections.	T			
EV 4.5.4	All controls, indicators and data acquisition connections or similar must be galvanically isolated from the tractive system.	D			
EV 4.5.5	All electrical insulating material must be appropriate for the application in which it is used.	I			
EV 4.5.6	All wires and terminals and other conductors used in the tractive system must be sized appropriately for the continuous rating of the fuse which protects them. Wires must be marked with wire gauge, temperature rating and insulation voltage rating. Alternatively a manufacturers part number printed on the wire is sufficient if this can be referenced to a manufacturers data sheet. The minimum acceptable temperature rating for TSV cables is 90°C.	I			
EV 4.5.7	All tractive system wiring must be done to professional standards with appropriately sized conductors and terminals and with adequate strain relief and protection from loosening due to vibration etc. Conductors and terminals cannot be modified from their original size/shape and must be appropriate for the connection being made.	I			

EV 4.5.11	All tractive system connections must be designed so that they use intentional current paths through conductors such as copper or aluminum and should not rely on steel bolts to be the primary conductor. The connections must not include compressible material such as plastic in the stack-up.	D			
EV 4.5.13	If external, un-insulated heat sinks are used, they must be properly grounded to the GLV system ground	T			
EV 4.6	**Tractive System Enclosures**				
EV 4.6.1	Every housing or enclosure containing parts of the tractive system except motor housings must be labeled with (a) reasonably sized sticker(s) with a red or black lightning bolt on yellow background or red lightning bolt on white background. The sticker must also contain the text “High Voltage” or something similar if the voltage is more than 30 VDC or 25 VAC.	I			
EV 4.6.2	If the housing material is electrically conductive, it must have a minimum-resistance connection to GLV system ground	T			
EV 4.7	**High Voltage Disconnect (HVD)**				
EV 4.7.1	It must be possible to disconnect at least one pole of the tractive system accumulator by quickly removing an accessible element, fuse or connector.	T			
EV 4.7.2	It must be possible to remove the HVD within 10 seconds in ready-to-race condition.	T			
EV 4.7.3	The team must demonstrate this during Electrical Tech Inspection. Being able to quickly disconnect the accumulator(s) from the rest of the tractive system by its connector(s) will satisfy this rule.	T			
EV 4.7.4	The Disconnect must be clearly marked with "HVD".	I			
EV 4.7.5	If a tool is needed to open the HVD this tool must be attached to the push bar.	I			
EV 4.7.6	If no tools are needed to open the HVD, an interlock must open up the shutdown circuit when the HVD is removed.	I			
EV 4.9	**Pre-Charge and Discharge Circuits**				
EV 4.9.1	The AIR contacts must be protected by a circuit that is able to pre-charge the intermediate circuit to at least 90% of the rated accumulator voltage before closing the second AIR.. This circuit must be disabled by a de-activated shutdown circuit; see EV5. 1. Therefore, the pre-charge circuit must not be able to pre-charge the system if the shutdown circuit is open.	T			
EV 4.9.2	It is allowed to pre-charge the intermediate circuit for a conservatively calculated time before closing the second AIR. A feedback via measuring the current intermediate circuit voltage is not required.	D			
EV 4.9.3	If a discharge circuit is needed to meet the requirements of EV5.1.3, it must be designed to handle the maximum discharge current for at least 15 seconds. The calculation proving this must be part of the ESF.	T			

EV 4.9.4	The discharge circuit must be wired in a way that it is always active whenever the shutdown circuit is open. Furthermore, the discharge circuit must be fail-safe.	T			
EV 5.1	**Shutdown Circuit**				
EV 5.1.1	The shutdown circuit must directly carry the current driving the accumulator isolation relays (AIRs).	D			
EV 5.1.2	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).	I			
EV 5.1.3	If the shutdown circuit is opened/interrupted the tractive system must be shut down by opening all accumulator isolation relay(s) and 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.	T, D			
EV 5.1.5	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.	T			
EV 5.1.6	If the tractive system is de-activated while driving, the motor(s) must spin free, e.g. no brake torque must be applied to the motor(s).	D			
EV 6.1	**Fusing**				
EV 6.1.1	All electrical systems (both tractive system and grounded low voltage system) must be appropriately fused.	D			
EV 6.1.2	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.	D			
EV 6.1.3	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.	D			
EV 6.1.4	All fuses must have an interrupt current rating which is higher than the theoretical short circuit current of the system that it protects.	D			
EV 7.1	**Insulation Monitoring Device Test (IMDT)**				
EV 7.1.1	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.	T			
EV 7.1.2	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).	T			
EV 7.2	**Insulation Measurement Test (IMT)**				

EV 7.2.1	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 operation 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.	T			
EV 7.2.2	To pass the IMT the measured insulation resistance must be at least 500 ohm/volt related to the maximum nominal tractive system operation voltage.	T			
EV 8.2	**Charging**				
EV 8.2.3	It is also possible to charge the accumulators outside the car with a removable accumulator container.	T			
EV 8.2.4	The accumulator containers or the car itself, depending on whether the accumulators are charged externally or internally, must have a label with the following data during charging: Team name and Safety Responsible phone number(s).	I			
EV 8.2.5	Only chargers presented and sealed at Electrical Tech Inspection are allowed. All connections of the charger(s) must be isolated and covered. No open connections are allowed.	T			
EV 8.2.10	High Voltage wiring in an off board charger does not require conduit; however it must be a UL listed flexible cable that complies with NEC Article 400; double insulated.	D			
EV 8.2.11	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.	D			