Modules for Safe Power Distribution in an Electric Vehicle

ECE 445 Design Document

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1 Introduction

1.1 Objective

The objective of this project is to improve efficiency of the Illini Solar Car team's solar electric vehicles. It will allow the power distribution system (PDS) to individually monitor and control connections to the +12V bus of the solar cars. The current +12V bus, from which most of the vehicle's PCBs are powered, is just 12 connectors in parallel, with no protection circuitry, power monitoring, or switching. The idea is to significantly increase efficiency of the car by being able to switch each connection on the +12V bus on or off in response to signals from the driver or other PCBs on the car. The +12V bus module functionality extensions will also necessitate a revision to our PDS control board. These revisions include updated firmware and an updated PCB that will include connections for I2C and CAN processing.

1.2 Background

Solar electric vehicles are a growing sector in the vehicle market around the world. Companies around the world, like Sono Motors from Germany [2], are trying to break into the market with a sleek, fuel-efficient, and reliable alternative to the gas-based vehicle on the road. The project that we implement could have the potential to be applied to another product on the market.

For our purposes, we are focused on the solar car competition. The competition circuit is made up of mostly college teams who enter events around the world every one or two years. Our solar car must be able to drive for thousands of miles during week-long endurance races across United States (American Solar Challenge) and Australian highways (World Solar Challenge) in order to compete. The design and implementation of the PDS that we intend to complete would increase efficiency and security for the car. Implementing independent switching for the +12V bus will give us more freedom to control what parts of the car receive power and we also plan to monitor the current consumption for all the connections. By updating the PDS firmware and hardware, we will get better monitoring for the system, be able to identify power hungry low voltage systems, and optimize the low voltage power consumption based on the situation.

1.3 High level requirements:

- The control PCB must be able to communicate data from each +12V current sensing module over the CAN bus to the rest of the car's system.
- The control PCB must be able to decide which of eight +12V bus connections is on at any given time.

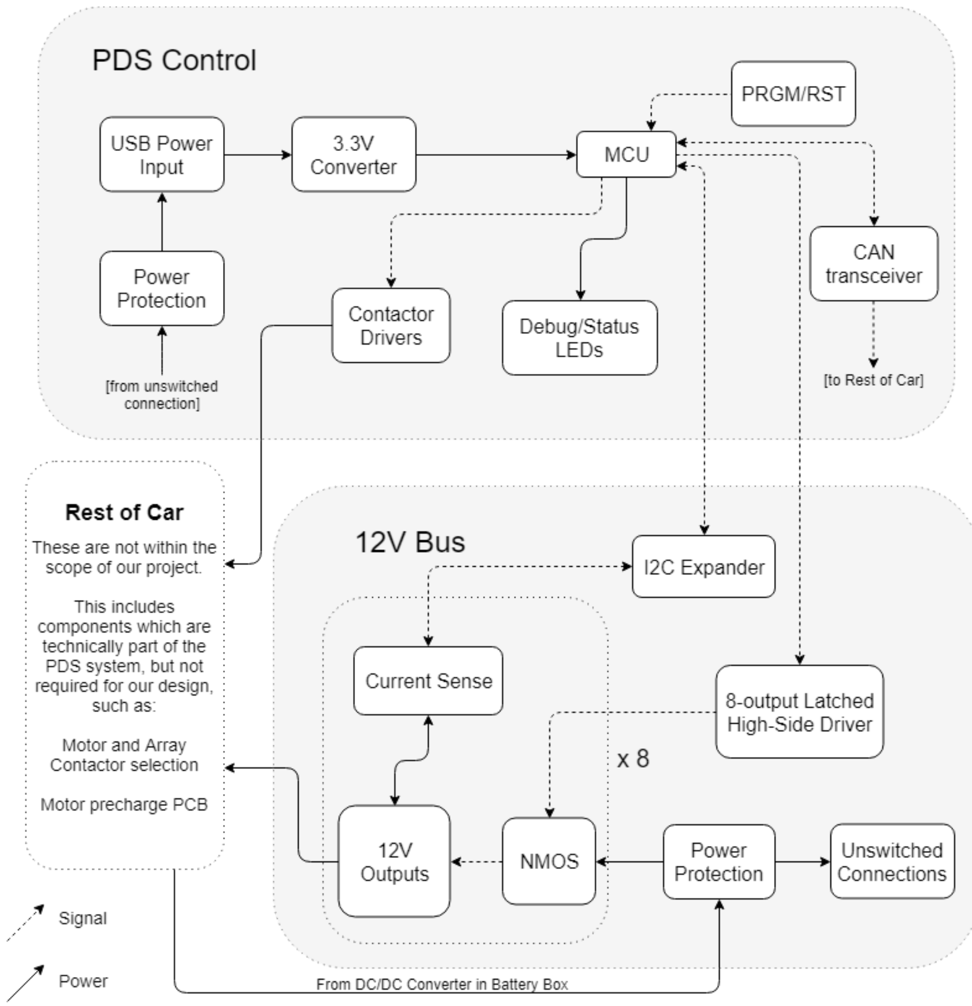
- Each of the +12V bus connections must be able to switch on and off independently of each other, and "on" must be the default or failure state.

2 Design

The power distribution system (PDS) in the scope of our project contains two PCBs: the PDS control board and the low voltage (+12V) bus board. The PDS control board interfaces with the rest of the car's systems over the CAN bus. This is crucial to this project because the car's telematics system and other systems must be able to collect information about the connections in the PDS. The PDS control board contains a microcontroller unit (MCU) which runs the control firmware, interpreting and sending messages as well as setting signals for the correct operation of connections. It includes components that facilitate debugging as well.

The PDS control board will communicate with the +12V bus PCB in order to switch the vehicle's low voltage boards on and off depending on the vehicle driver's commands. We will use a latching 1:8 MUX and FETs in order to develop independent switches. The purpose of this board is to control what parts of the car receive power in order to ration energy during tests and competitions, and to reveal what low voltage systems consume significant power. The PDS control board will communicate with the +12V bus board's current sensors via I2C, ideally with use of an expander that can allow different messages to be sent to the same slave address.

2.1 Block Diagram:



2.2 Block Requirements

2.1 PDS Control Board

2.1.1 Power Protection & Conversion

This module receives the high-voltage power delivered from the batteries (outside the scope of this class) to the converter which steps the voltage down to 3.3V. This will also protect the device to ensure that current is flowing properly in one direction and that the voltage that is received is manageable.

Requirement: Voltage after protection module should not exceed 14V for inputs from 9-18V.

2.1.2 Microcontroller Unit

The microcontroller takes in signals from the CAN bus transceiver and switches outputs based on those messages. It will be an ARM chip which can support I2C, SPI, and CAN communications.

Requirement 1: The microcontroller should be from the LPC 15xx family per ISC standard.
Requirement: The microcontroller will be able to use the CAN and I2C communication protocols.

2.1.3 Program/Reset

In case we want to restart the firmware, we will have the option to reset the device by pressing the Reset button. Pressing the program button will allow us to change the mode of in system programming (ISP), a functionality which the solar car team may use in the near future but which is out of the scope of our project.

Requirement: When pressed, the Reset button should restart the firmware on the MCU.

2.1.4 USB Power Input

This input provides power to the microcontroller when we wish to program the board through a JTAG connection. It is not able to power the full board, only the 3.3V bus, which provides power to the MCU.

Requirement: The current through this connection should be limited to 1A.

2.1.5 Precharge

The current precharge board does not need immediate revision. It is closely related to the system we are working on. The board controls the power delivered to the motor of the vehicle, and currently has a timed cycle from off to precharge to motor contactor, to prevent the inrush current to the motor controller capacitors from causing a fault or damage in the battery system.

Requirement: This is a reach goal. Instead of a timer, actually read voltage differential between high voltage bus and motor controller positive terminal to accurately switch motor contactor and bypass precharge resistor when voltage are within 10% of each other.

2.1.6 CAN transceiver

The CAN transceiver connects the PDS control to the vehicle's CAN bus. This allows the PDS control board to send to and receive messages from other boards. The IC for CAN transceiver converts 3.3V MCU logic to 5V logic, and it isolates the microcontroller from noise on the CAN bus.

Requirement: Should be able to withstand +/- 24V spikes on the CAN_HIGH and CAN_LOW pins.

2.1.7 Debug/Status LEDs

The PDS control board should have on-board LEDs for debugging and status indicating purposes during operation and fault states. Various conditions include: CAN connection status, I2C bus status, and a CAN heartbeat - completion of the function's main.

Requirement: PDS should have local signal, CAN receive signal, and CAN transmit LED that match the ISC guidelines

2.1.8 Contactor drivers

The PDS control board's main function is to switch contactors that are located in-line from major high voltage (HV) components to the HV bus board. The design on the current board is sufficient to reuse in our board revision.

Requirement: Continue working as normal, which is to switch contacts from high voltage components to high voltage bus board

2.1.9 Firmware

The firmware running on the microcontroller will process signals from the CAN transceiver and the 12V bus board and control the connections on the 12V bus board. It will be able to control each of the

Requirement: Firmware on the microcontroller should take signals from driver input & system input to turn on and off individual switched connections on +12V bus board.

2.2 Low-Voltage Bus Board

2.2.1 Input Protection

This is similar to 2.1.1, except instead of stepping down the voltage to 3.3V, it receives the full +12V supply.

Requirement	Verification	Passing
Voltage after protection should not exceed 14V for inputs from 9-18V.	Connect a bench power supply to the input connector of the protection circuitry, and a multimeter to the output of the protection circuitry	Verify that, while changing the power supply voltage between 9-18V, the output is below 14V

Requirement: Voltage after protection should not exceed 14V for inputs from 9-18V.

2.2.2 Latched Switching Chip

This switching IC will be able to switch 8 high-side outputs independently. It will receive commands from the microcontroller on our PDS PCB. It should ideally use the SPI or I2C standard for communication, but serial commands are acceptable.

Requirement: Switch the NMOS on each of 8 connections independently, and latch the switching state until a new signal is received or the board loses power.

2.2.3 Switching Module

Each of the connections from +12V bus to the rest low-voltage PCB in the electrical system should have a FET module built in. The FET module should fail short since we need power connection to all boards even if we sacrifice efficiency. Otherwise, crucial parts of information or road-legal requirements may fail unexpectedly, causing rule violations. The switching circuit should not introduce significant losses into the low voltage power flow and be rated for at least 50% above desired voltage level (+12V) for safety margin.

Requirement	Verification Tests	Passing
1. Connections should normally be closed	A. Connect LED test circuitry at each output connector B. CAN commands all connectors to disconnect C. Current limit for the LEDs is 100mA each	A. None of the LEDs should light up
2. FET in each module should be able to turn on and off individually in response to signals and driver input processed by PDS control board.	A. Cycle firmware through each possible combination of connections off and on	A. Connection should be enabled if the CAN message signals MOSFETs to. B. LED should light up if connections are enabled

Requirement 1: FET in each module should be able to turn on and off individually in response to signals and driver input processed by PDS control board.

Part requirement:
Requirement 2: FET in each module should fail short under fault condition.
Requirement 3: FET should at least rated for 50% above desired voltage level +12V.
Requirement 4: FET should at least rated for 2A continuous current draw (to accommodate with the for most power draining light board).

2.2.4 Current Sense

Each of the connections from the +12V bus to the PCBs it powers in the electrical system should have a current monitoring module connected to it and be able to report current information to the MCU whenever queried.

Requirement	Verification	Passing

Requirement: Current monitoring should be within +/- 10mA accuracy.

2.2.5 Connection

The new design of the board needs to have a sufficient number of connections on the +12V bus for all boards on the car, as well as extra ones for jump start and other debugging purposes. Two types of connections will be used: Molex KK396 and KK254, to match ISC standards. Ideally have four Molex KK254 and four Molex KK396 switched output connectors on the board, with additional 8 unswitched connectors.

Requirement	Verification	Passing
Have 4 Molex KK254 and 4 KK396 switched output connectors on the board to handle different currents and wire types on subsystem PCBs.	Check the PCB design and schematic	
One KK396 input connector (easily identifiable) and 8 unswitched connectors.	Check the PCB design and schematic	

Requirement 1: Have four Molex KK254 and four Molex KK396 switched output connectors on the board to handle different currents and wire types on subsystem PCBs.
Requirement 2: One KK396 input connector (easily identifiable) and 8 unswitched connectors.

2.2.6 I2C Expander

I2C expander will connect the MCU to each of the connections on the +12V bus to help read current sensors. It will also allow the MCU to communicate different messages with the same brand of slave chips to read current sensing values.

Requirement: MCU using I2C should be able to communicate with each current sensor on the +12V bus without interference. An expander should be used if necessary, e.g. if each current sensor has a hardcoded address.

2.3 Risk Analysis

The greatest risk to our project is the design and implementation of the PCBs themselves, specifically the +12V bus PCB. Should anything be designed on the boards incorrectly, it will be much harder to fix and take more time in comparison to connections between boards or firmware problems. We are completely redesigning the +12V bus board, which will not only take time but also a lot of careful planning. The board that we intend to design is significantly more complex than before, which has higher risk for errors. Realistically with the time that we have, we do not have many opportunities to redo our PCBs, so because of the time and complexity factor, production of the +12V bus PCB is the biggest risk we have.

3 Plots

4 Circuit Schematics

5 Calculations

6 Ethics and Safety

The IEEE Code of Ethics 7.8.1 [1] that lays out the rules regarding health, safety, and public welfare will be the code of ethics we intend to follow. Building a solar electric vehicle from scratch is a very challenging task that comes with a lot of safety risks. From designing the proper PCBs with correct connections to machining all of the parts that will come together to make the car, a lot of problems have, and will, occur. Should there be injuries, we intend to take them seriously. After the car is built and ready for testing, our priority is to ensure the safety of the driver. The driver should be able to control the car properly and the car should be reliable over long-periods of time, which will be the conditions for the races we compete in. Our goal is to make a quality, efficient, and reliable car while protecting the components as well as the drivers and crew that will take care of the car.

For our specific project, we will only be working with low voltages (+12V, logic levels) and nothing will require more than 50V. By working with low voltage modules, we will have an inherent level of safety. Within our project, will have current sensing on each of the connectors on our +12V bus in order to monitor the power that will be delivered. We also want to implement power protection for each power input to mitigate the chance of damage to sensitive components, like the microcontroller. This is to be proactive and prevent problems before they materialize.

Despite the relative safety in +12V power, we are implementing a switching system that is normally closed and fails closed instead of open.

Another part of our personal code of the ethics is to cite our sources properly to give credit where it is due. This goes for any outside research we do to expand our knowledge, and it includes for responsibilities among this team itself. There are a number of circuits which the solar car team has standardized across boards, and we will clearly indicate when that is where our design comes from and where we have improved on those or actually come up with a new design.

There are many challenges in designing an electric vehicle that will operate outdoors under various conditions. Overheating due to high temperatures (>50°C) and moisture from humidity or inclement weather could cause damage to the board and the connections, leading to fault states and short circuits. The redesign of our +12V bus and additional firmware, and CAN and I2C connections, should reduce the risk of damage to multiple components should the environment cause unavoidable risks.

7 Citations

1. Sono Motors: https://electrek.co/2017/07/28/sono-motors-unveils-its-solar-and-battery-powered-electric-car/
2. IEEE Code of Ethics: https://www.ieee.org/about/corporate/governance/p7-8.html
3. American Solar Car Challenge Regulations: http://americansolarchallenge.org/regulations/

4. [datasheets?]