ECE 445

Project Proposal

Custom MPPTs for Illini Solar Car

Team #25

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1. Introduction

Problem

Illini Solar Car is manufacturing their 3rd generation vehicle to race at the American Solar Challenge this coming summer. The team has recently installed their array and is looking for easy-to-use, configurable, and efficient solar MPPTs. The off-the-shelf models are very expensive and will take time to integrate into the vehicle's architecture. Also with off-the-shelf components if a part fails, we will not have access to the schematics to replace the component.

Solution

The idea is to create custom, efficient, and low cost MPPTs built for the team's electrical system. For some background, the vehicle has the array wired in three separate sections. The goal behind the 3 sections is better resilience to shading and redundancy built into the system. We would make an easy to move enclosure with three MPPTs inside that can be mounted in the vehicle. If one of the MPPTs fails we would still have 2/3 of the solar array producing power.

By making the MPPTs in house lots of problems could be solved. We could drastically reduce the cost, make it plug-and-play with our vehicle's electrical systems, and be able to debug issues quickly.

Visual Aid

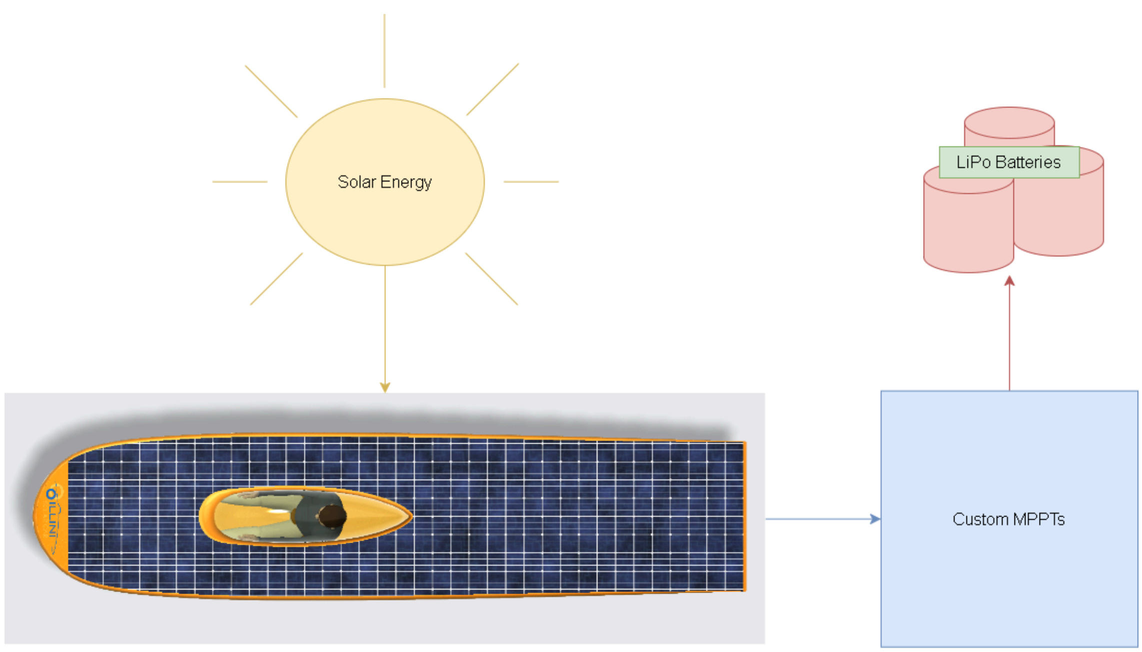

Figure 1: Visual Aid for MPPTs

High-Level Requirements

1. Logic Board is able to send information via CAN and control the power board using a perturb & observe algorithm
2. The power board is able to successfully boost input voltage from 5V - 90V a range of to a range of 77V-125V
3. The system is able to safely start-up and power down if potential faults are present

2. Design

Block Diagram

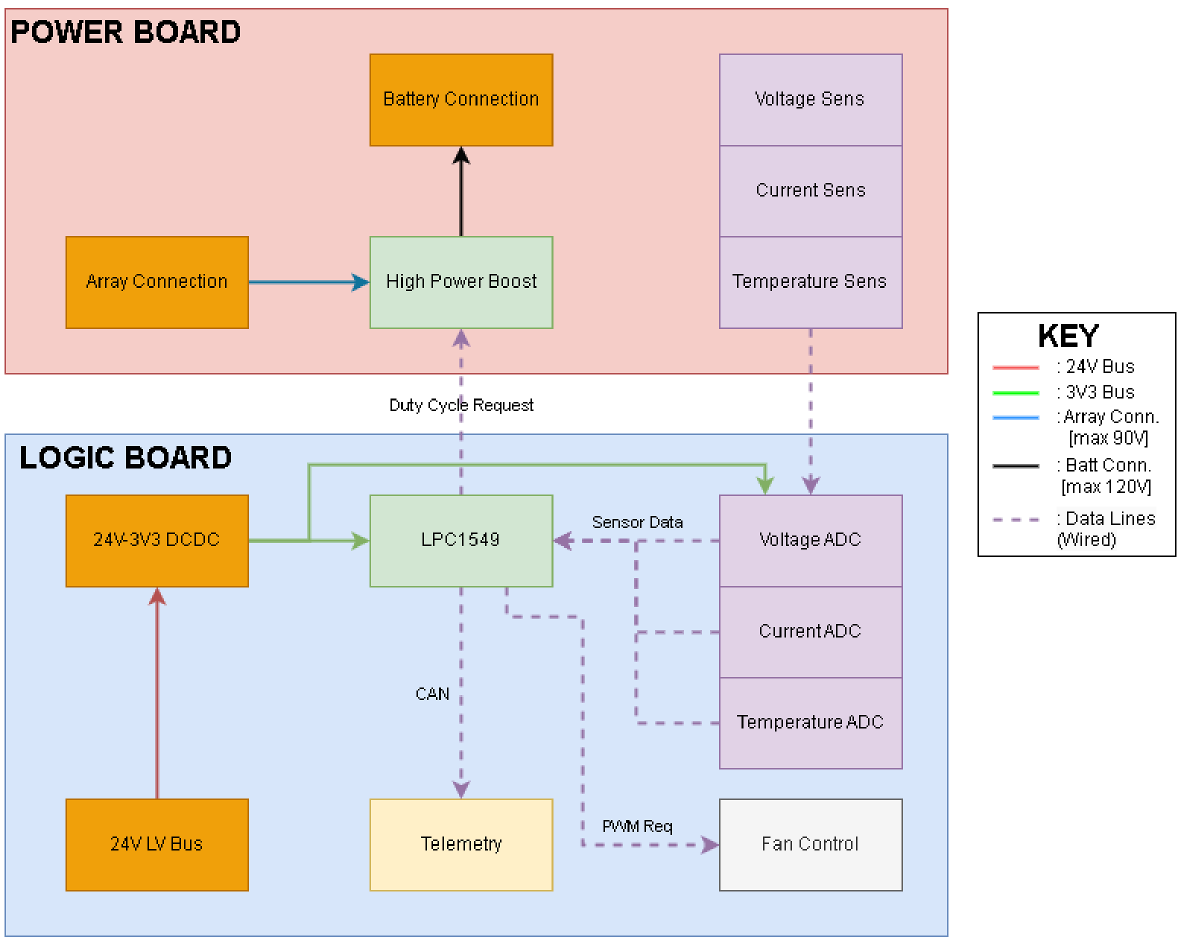

Figure 2: Block diagram of MPPTs

Subsystem Overview

1. Subsystem 1: Logic Board
    a. The logic board will be the main control board for our system. The logic board will collect I-V characteristics from the power board. Using this information It will be tasked with running a perturb and observe algorithm to vary the switching signals to a separate power board. The board will send data over a CAN bus to communicate with the rest of the car.
2. Subsystem 2: Power Board
    a. The power board will be a high power boost circuit controlled by the logic board to take in the input power and vary the output power to charge the battery. Each module should handle power up to 330W. MPPTs should be able to output in the range of 77V-125V. Max charge current is ~2.75A.

Subsystem Requirements

1. Subsystem 1: Logic Board
    a. MCU: MCU must be able to run code to control all other components of the logic board and power board. It will communicate with the relevant sensor ADCs through some digital communication protocol (SPI, I2C). It will also adjust PWM control for the fans. It will also have 3 PWM signals that can go to each individual power board to control duty cycle. It should also send and receive CAN from the rest of the car.
    b. Sensors: There will be 3 sensors for each power board. The voltage sensor should accurately report the voltage of that power board's solar array connection as well as the converted output voltage. The current sensor should accurately report the current of that power board's solar array connection as well as the output current. The temperature sensor should measure the temperature of each power board for safety.
    c. Fans Control: The fans will be controlled by a pwm signal from the MCU. The fans themselves will most likely be 24V pwm speed controlled noctua fans.
    d. CAN Data: A CAN transceiver circuit will exist to allow CAN data to be sent and received by the MCU. The data should include all voltage, current, and temperature measurements, as well as the state of the software control.
    e. Duty Cycle Request: The duty cycle request is the varying duty cycle pwm signal produced and sent by the MCU to the power electronics on the power board to adjust output voltage of the boost converter. THere will be one for each power board.
2. Subsystem 2: Power Board
    a. High Power Boost Circuit: The power board includes a boost converter that should be able to handle inputs up to 80V 330W, and be able to boost the voltage to an output range of 77-125V.

b. Duty Cycle Input: The duty cycle input is the varying duty cycle pwm signal produced and sent by the MCU to the power electronics on the power board to adjust output voltage of the boost converter.

Tolerance Analysis

High power MPPTs can have a few different tolerance challenges. One of the potential major issues would be thermal management of the power board. The highest risk components in this case would be the FETs. Using equation 1, we are able to approximate the switching losses of the FETs using common values. See [1] for a more detailed explanation.

$$P_{sw} = \frac{1}{2} * V_{in} * I_{out} * f_{sw} * (t_{rise} + t_{fall}) \approx 6.75W \quad (1)$$

The above equation assumes common values of FETs. These are $t_{rise} = t_{fall} = 25ns$, $f_{sw} = 20kHz$, $R_{on} = 10m\Omega$. With this knowledge, we know these switches will need to have a heatsink and fans to circulate air. We will be closely monitoring the temperature of the power board, using the temperature sensors that will be placed near the FETs.

3. Ethics and Safety

As MPPTs are high power devices, there are safety issues that may arise when working with high voltage electronics. For example when working with a solar array there will always be a voltage present, especially in strong light. This means that we should take caution when connecting the MPPTs to any solar array, or when handling solar array connections. When testing, we will also be using a high voltage power supply to test the power converter. When testing, care should be taken to ensure that there are no unwanted connections and everything is properly connected and covered so that there is no risk of accidental contact with the test setup.

The MPPTs should also have an enclosure that will prevent any accidental touches or any debris from getting inside and damaging the electronics or causing a short. Since these will be used inside our solar car, extra care will have to be taken with the construction of the enclosure to ensure there is no way for the driver or another person doing maintenance on the car to accidentally come into contact with the electronics. The enclosure should also be located in a safe place inside the car and built correctly so that any possible debris getting inside the car or other mechanical components becoming loose or damaged will not cause damage to the electronics. The enclosure should also comply with the American Solar Challenge regulations regarding labeling, mechanical structure, and wiring.

The MPPTs will be used to charge the car's batteries, which introduce additional safety concerns. We must ensure that the MPPTs are thoroughly tested with a load and power supply before actually connecting them to batteries to avoid any possible overvoltage or overcurrent issues. The battery itself already has a BMS with automatic monitoring and shut off, and the BMS should always be used and in working order whenever working with the batteries. Campus policy regarding batteries will be followed, which includes rules about battery storage, bringing batteries into buildings, and training for working with batteries. If any work is being done with batteries safety equipment such as fire extinguishers and sand will be present.

In terms of ethics, as this product is being built for a single specific application for our battery and solar array, there are minimal ethical issues with this product. This product will not be sold or used in any other situation and will remain with the team. There is little to no risk beyond the aforementioned high voltage safety concerns.

4. References

[1] Rohm Semiconductor. “Calculation of Power Loss (Synchronous).” https://fscdn.rohm.com/en/products/databook/applinote/ic/power/switching_regulator/power_loss_appli-e.pdf (accessed Feb. 8, 2024).