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 maximum power point trackers (MPPTs). MPPTs are used to control power output of a solar array. In this case, it will precisely control power into the vehicle's battery pack to charge the battery. 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 boost MPPTs built for the team's electrical system. These MPPTs will function by utilizing a boost converter to step the voltage of the array in order to charge the battery. It will use an algorithm to vary the switching duty ratio of the boost converter in order to control the power output. For context, as the battery charges the voltage will increase and therefore the requested duty ratio will vary as a result.

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

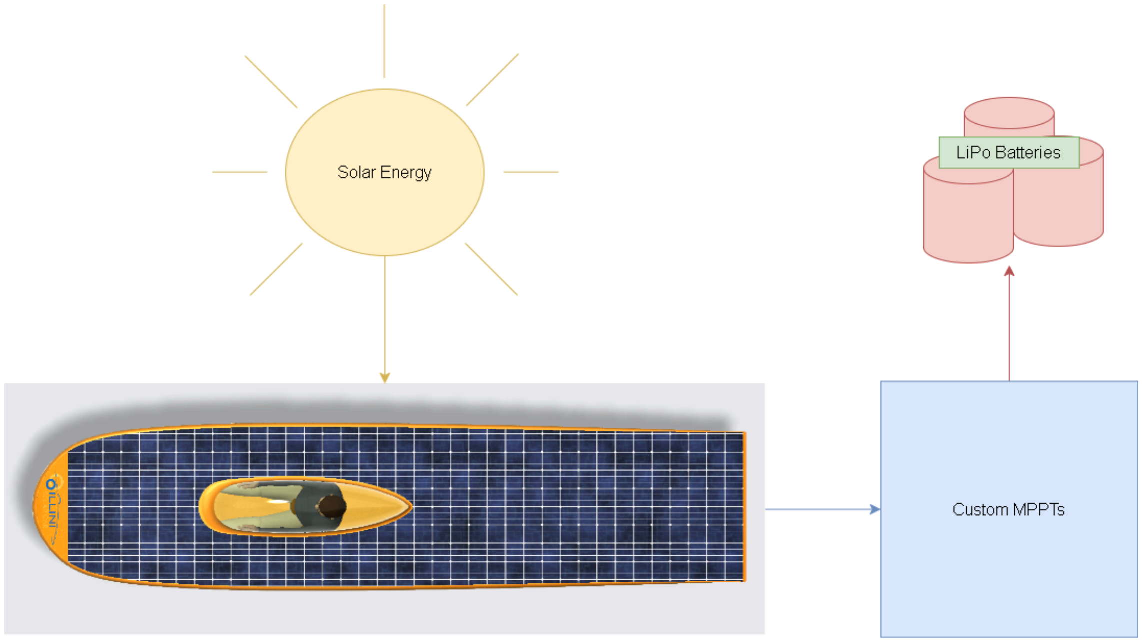


Figure 1: Visual Aid for MPPTs

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 20V - 90V a range of to a range of 77V-125V. It should have a tolerance of +/-10%.
3. The size of a single power board should be less that 272mm x 164mm in order to fit in the space allotted for the MPPTs in the vehicle.

2. Design

Block Diagram

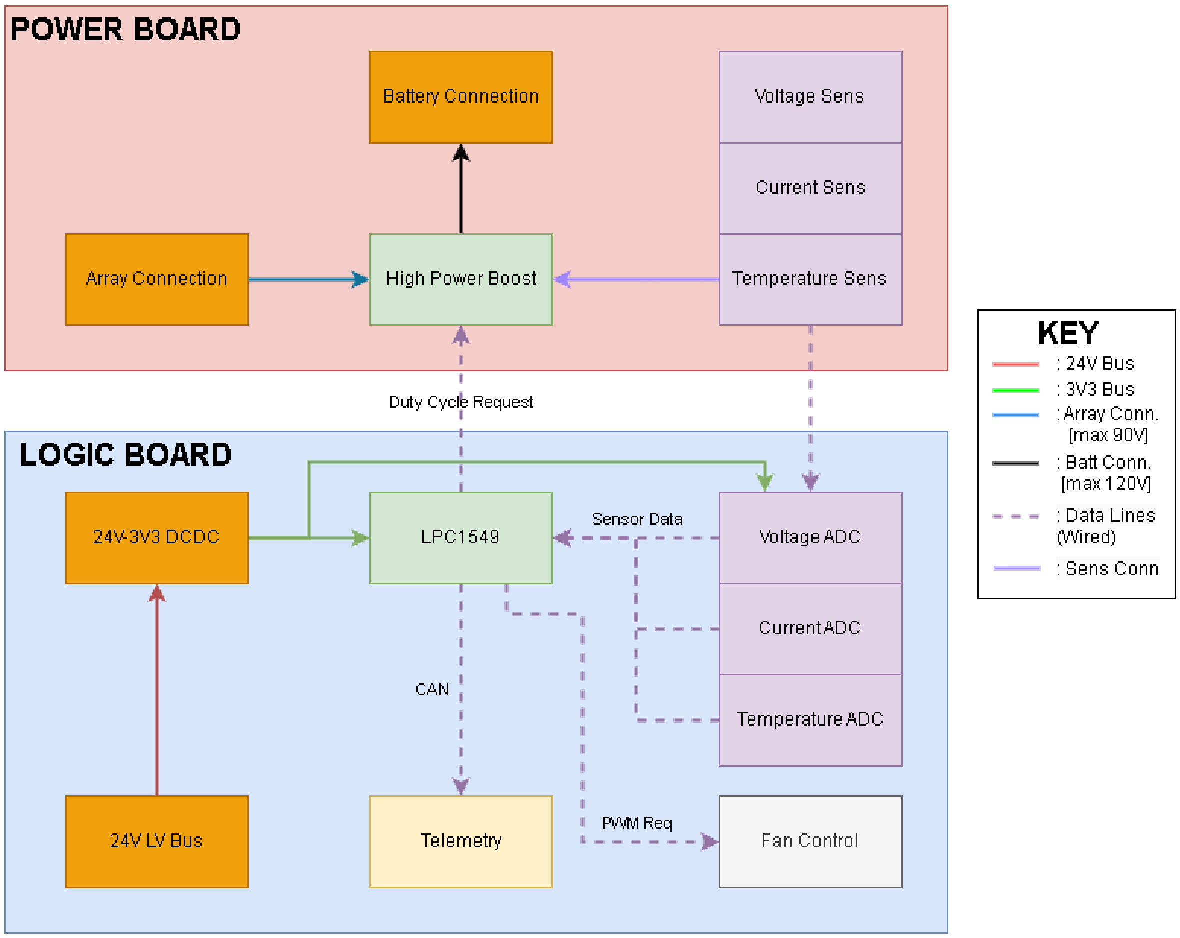


Figure 2: Block diagram of MPPTs

Subsystem Overview

1. Subsystem 1: Logic Board
    a. The logic board will be the main control board for our system. The board will collect I-V characteristics from the power board and use this information, to run 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. It will also be responsible for controlling the fans of the power board as temperature increases.

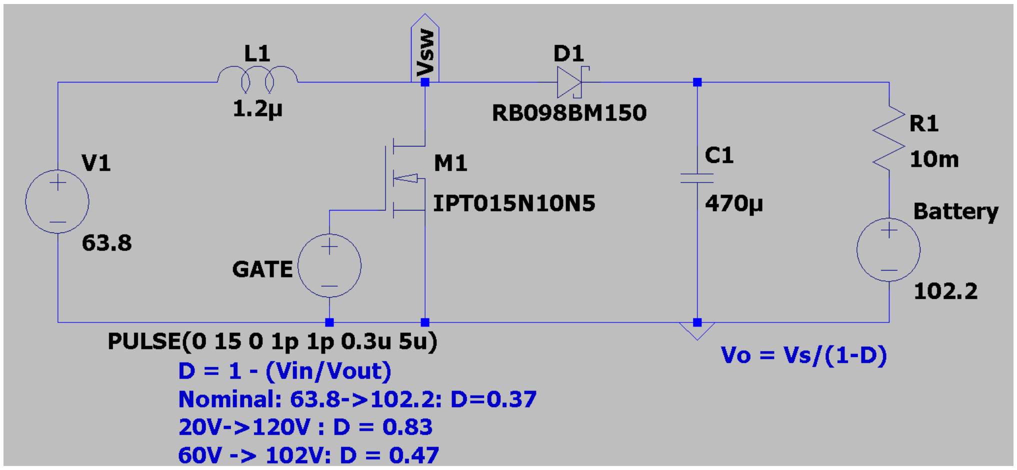
2. Subsystem 2: Power Board
    a. The power board will be a high power boost circuit controlled by the logic board to take in the input power from the array and vary the output power to charge the battery. Each module should handle power up to 400W. MPPTs should be able to output in the range of 77V-125V. Max charge current is ~2.75A. Because the array can only provide ~6A of max current we will not be introducing a current control loop into the system. If there is a noticeable issue on the amount of current drawn from the pack, a resistor will be placed in series to limit the charge current.

Subsystem Requirements

1. Subsystem 1: Logic Board
    a. MCU:
        i. MCU sends PWM gate signal requests to the power board.
        ii. MCU sends a fan request rpm message and spins the fan.
        iii.
    b. Power Protection
        i. The bus voltage(24V) is stepped down to 3V3 ± 5%
    c. Fans Control:
        i. Noctua fans are controlled by the MCU and vary their RPM based on temperature
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. Sensors:
    c. 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. To verify our design would meet specifications, we used a simulation to validate the operating conditions. The first simulation that was run was using our nominal case. If we vary the duty cycle, we are able to get the current down to an acceptable value. This simulation doesn't take into account the real characteristics of solar cells, which have an Isc of 6.46A. In this case, we are modeling the solar cells as a voltage source.



With the nominal simulation complete, we tried the worst case. This included the tolerance present in the inductor(±20%) and capacitor(±5%). With this addition, the current ripple increases by about 0.2A and the DC ripple increases by 0.4A. This is still within the specifications as we were charging at a very low current previously. This will need to be accounted for in the control loop when deciding acceptable duty ratio ranges.

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).