Small Satellite Power System Development

KISPE Space Systems

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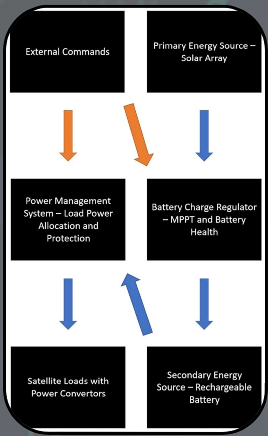
Abstract

A system capable of enabling Maximum Power Point Tracking (MPPT) was constructed to improve the efficiency of power conversion from Solar Array to Battery. The circuit exhibited efficiencies for conversion greater than 93%. A simulation was created in MATLAB showing the MPPT algorithm functioning in variable environmental conditions.

Power System Breakdown

The satellite power system has 4 key components:

- Primary Energy Source, a solar array.
- Secondary Energy Source, a rechargeable battery, required when the primary source is unavailable, such as during an eclipse.
- Battery Charge Regulator, regulates power conversion to the battery, controls charging/discharging cycles and protects against over/under charging and over/under heating.
- Power Management System, allocates power to loads within the satellite in response to power availability or external user commands.

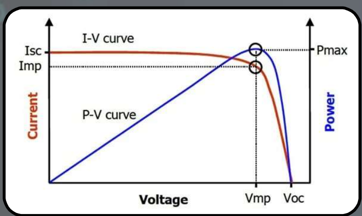


Maximum Power Point Tracking and How it can be Enabled

Unlike a conventional DC voltage supply, wherein the current supplied is solely dependent on the resistance of the load, a solar cell acts as a current source:

- Increasing the resistance of the load increases the voltage supplied by the cell.
- It behaves this way up to certain point at which the current then rapidly decays.

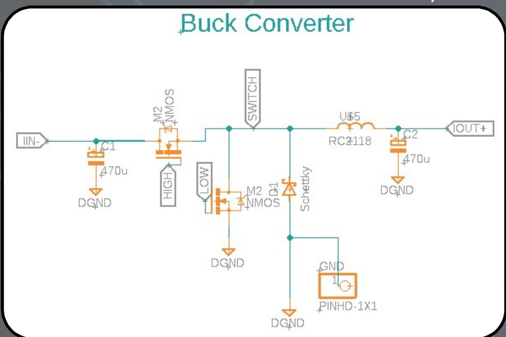
For an optimal resistive load, there is a specific point where the maximum power possible can be extracted from the solar cells under certain environmental conditions. This is the Maximum Power Point (MPP).



https://www.powerelectronics.com/technologies/solar/article/21863142/solar-system-efficiency-maximum-power-point-tracking-is-key

Using a MPPT algorithm, the circuit can adjust the impedance experienced by the solar array which allows the power extracted from the solar array to be maximised. This project made use of a buck converter, a type of non-isolated step-down DC-DC converter with theoretically no power loss. The DC input is converted into a pulse, by rapidly switching MOSFETs, which is rectified by an LC filter producing a DC output. The duty cycle, D, of the pulse drives the output voltage generated.

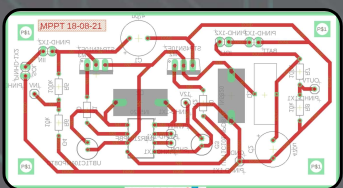
Vout = D x Vin   Iout = Iin / D

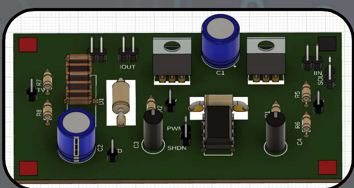


Circuit Design and Simulation

LTSpice was used to simulate the circuit design.

The most complex part of the design was deducing a way to amplify a low voltage PWM signal from an Arduino to a level able to operate the MOSFETs as switches along a higher voltage power rail. Initial designs used a Bipolar Junction Transistor (BJT) in a switching configuration to invert and amplify the signal to the voltage of the power rail, but a MOSFET driver IC was found to be the most effective method.

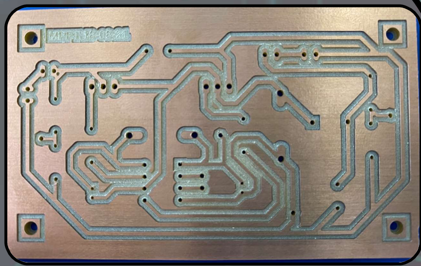




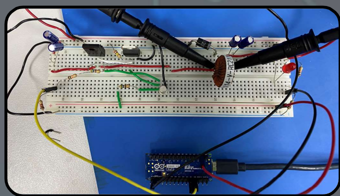
Once boards had been prototyped using breadboarding, Fusion 360 was used to design Printed Circuit Boards (PCBs) and Computer Aided Design (CAD) models for the boards.

MPPT Circuit Construction and Testing

Breadboarding allowed the generation of prototypes and inspection of the operation of the circuit using oscilloscopes and real loads. This allowed comparisons to the simulations in LTSpice and adjustments to be made. For example, adding an additional MOSFET to synchronously force the output pulse to ground to improve the accuracy of the DC output.



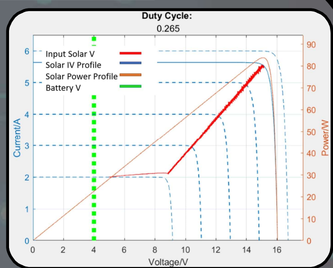
An Arduino (Nano IoT33 or MKR1000) was used to produce variable PWM signals (up to 100kHz) to control and operate the circuits. The high frequencies were required to allow optimal power conversion to occur.

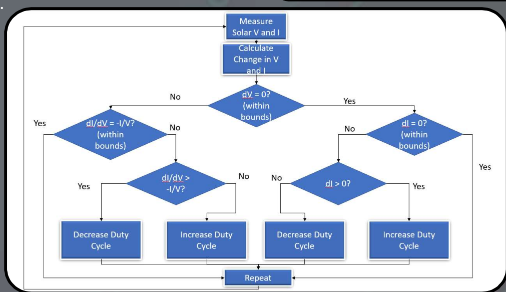


The Arduino was used to measure the input and output voltages as well as current (using ACS723 current modules). A battery was connected as a load and showed correct adjustment of the power supply voltage when in current limited mode and the efficiency of the conversion was no less than 0.93 in the final version of the circuit.
No solar cell large enough to drive the circuit could be sourced but the circuit exhibited all necessary properties for a MPPT system.

MPPT Algorithm and Simulations

MATLAB was used to visualise and test the functionality of the MPPT algorithm developed for changing and constant environmental conditions.
The algorithm approach used "Incremental Conductance" and used a comparison between the gradient of the IV profile of the solar cell and the ratio between the current and the voltage to deduce which side of the MPP the voltage currently lies, and so whether to increase or decrease the duty cycle.





Takeaways from Internship

During my internship I have improved upon several key skills including:

- Public speaking and presentation of my working due to weekly team meetings and midterm and final presentation.
- Coding in C++ for use with the Arduino.
- Using LTSpice for simulating and designing circuits, creating and importing new devices.

I have also learned multiple new skills such as:

- Using Fusion 360 to produce CAD models and PCBs and taking these through to hardware on the bench using a milling machine and soldering on components.
- Creating programs using MATLAB, in particular moving graphical simulations.

I have also gained a deeper understanding for satellite systems as a whole, and the industry that revolves around their creation and upkeep thanks to the weekly presentations made on varying topics from multiple members of the KISPE team.

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