

Solar Array Maximum Powerpoint Tracker

Michigan State University
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Project Sponsor

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1. Executive Summary/Introduction

1.1 Background

What is a Maximum Powerpoint Tracker?

A Maximum Power Point Tracker (MPPT) is a device which maximizes the power generated from photovoltaic (or solar) cells. It can also be recognized as an electronic circuit that links the solar array and the battery. MPPTs do this by finding the maximum power point located near the drop off of the I-V curve. According to basic circuit theory the optimum power is achieved when the derivative of the I-V curve (Figure 1-1) is equal and opposite to the I-V ratio. The MPPT is necessary because it matches the relatively low voltage of the solar array to the high voltage of the battery.

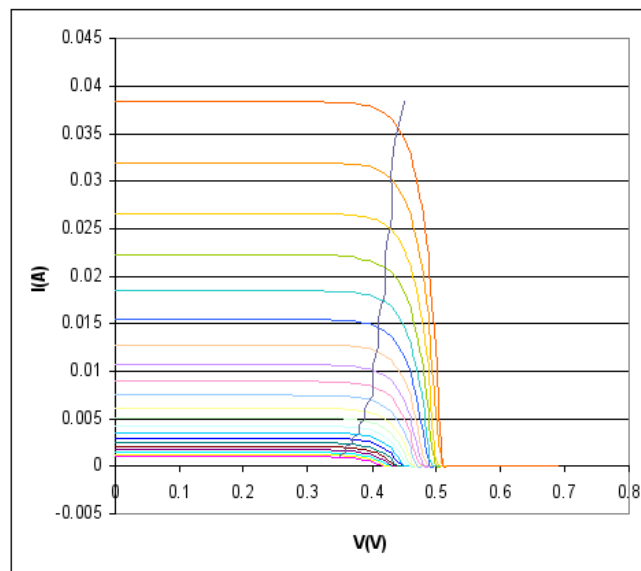


Figure 1-1: Solar Cell I-V Curve in Varying Sunlight [9]

There are eight methods that can be used to find the maximum power point. [4]

- Constant Voltage
 - A single predetermined voltage represents the maximum voltage point (V_{MP}). It has an estimated efficiency of 80%
- Open Circuit Voltage
 - The system finds the open circuit voltage (V_{OC}) and uses this to find the V_{MP} . This is calculated using the equation $V_{MP} = k * V_{OC}$, where k is between 0.7 and 0.8.
- Short Circuit Current

- The system uses a short load pulse to generate a short circuit condition. The short circuit current (I_{SC}) is used to estimate the maximum point current (I_{MP}) using the equation $I_{MP} = k * I_{SC}$.
- Current Sweep
 - The current sweep method uses a sweep waveform for the PV array current such that the I-V characteristic of the PV array is obtained and updated at fixed time intervals.
- Perturb and Observe
 - The system searches for the maximum power point by changing the PV voltage or current and detecting the change in the photovoltaic power output.
- Incremental Conductance
 - The system uses incremental conductance to locate the maximum power point when $\frac{dI_{PV}}{dV_{PV}} + \frac{I_{PV}}{V_{PV}} = 0$
- Temperature [3]
 - This method employs a sensor in order to obtain a sample of the photovoltaic surface temperature and then uses that temperature to find the optimal voltage that should be pushed across the device.
- Temperature Parametric [3]
 - The temperature parametric method uses the below equation to calculate the maximum power point voltage instantly by measuring

$$V_{MPP} \cong \left[(u + S \cdot v) - T \cdot (w + S \cdot y) \right] \cdot V_{MPP_STC}$$

time and solar irradiation.

1.2 Real World Applications

_____ Maximum Powerpoint Tracking is used in almost every product that contains a solar array. It has been used in cars, buses, golf carts, solar battery chargers, outdoor landscaping, pools, boats, and many other products.

Maximum Powerpoint Tracking can also be used in optical power transmission systems. Optical power transmission is a sufficient way of replacing copper wiring with fiber optic cables when a conventional power supply is challenging to implement. In optical power transmission power can be transmitted with light through an optical fiber. A light source, most likely a laser, generates light and then a photovoltaic cell converts the power back into electricity. [2] This is a very efficient way of converting monochromatic light into electricity.

1.3 Available Solutions

MSU's Solar Car Racing Team currently uses Dilithium Power Systems 'Photon Quad MPPT.' Dilithium is a supplier of MPPTs exclusively for solar car racing teams.

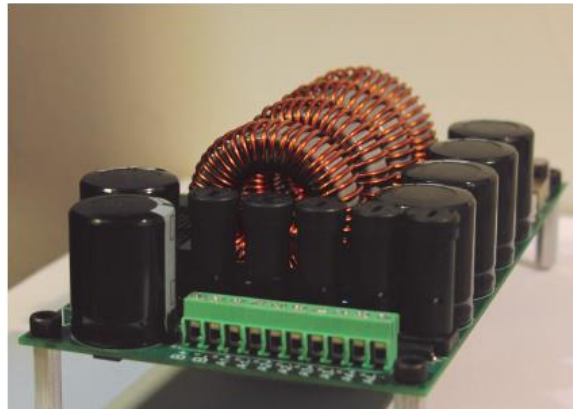


Figure 1-3: Current MPPT of MSU's Solar Car Racing Team [6]

It features four independent channels optimized for SunPower A300, C50, and C60 cell arrays. The Photon Quad has a boost ratio from 1 to 14 and contains a 160V battery. It has CAN based communication for remote telemetry monitoring. [6]

1.4 Design Approach

Figure 1-4 demonstrates the overall system diagram for the MPPT. One end of the voltage/current sensing modules connects to the input of the DC-DC boost converter. The other end is connected to the microcontroller that will utilize an Analog-to-Digital Converter (ADC) to measure the input voltage and current of the DC-DC boost converter. The microcontroller will then use the "Perturb and Observe Method" to force the input voltage up or down and calculate whether or not the change in voltage brought on a higher or lower power. The device will then control the duty cycles accordingly to ensure high efficiency during the converting process.

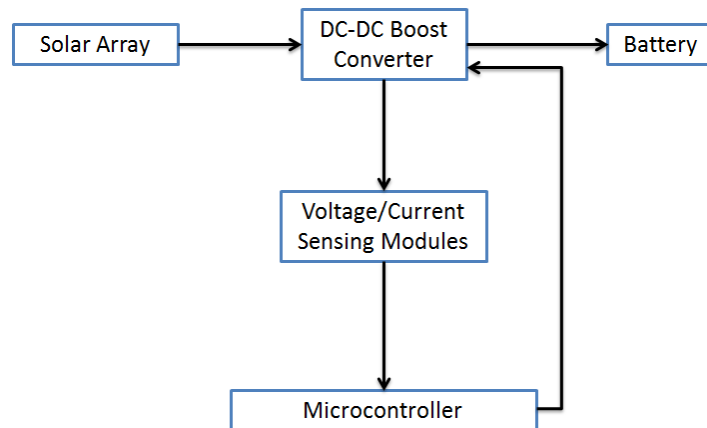


Figure 1-4: System Block Diagram

2. Technical Summary

2.1 Description of Customer Expectation

The Michigan State Solar Racing Team has a few requirements in the design of the MPPT. Efficiency greater than 95% is the main design consideration. Although the previous MPPT used by the solar car team had four channels, it is only required to design a MPPT with one. The input voltage will be between 20-60V and the maximum current is 6A, with an output voltage of 100-110V. [8] The size and weight of the MPPT is not a main consideration. A microcontroller or digital signal processor (DSP) should be utilized to do the necessary calculations. The final design should be on a printed circuit board (PCB).

2.2 Testing Strategies

The testing of the prototype will first be conducted using a small power supply due to the dangerous nature of dealing with large current and voltages. We will be using an Agilent E3611A power supply provided in the ECE lab.

2.3 Voltage/Current Sensing Implementation

The team has contemplated two ways to sense the voltage and current input from the solar cell: voltage sensing and resistive current sensing.

Voltage sensing requires a microcontroller to sense the voltage. However, the microcontroller can only handle small voltages so it also requires a voltage divider to bring the voltage down. The team has discarded this option given that a voltage divider generates power losses and the main requirement of the project is efficiency. [7]

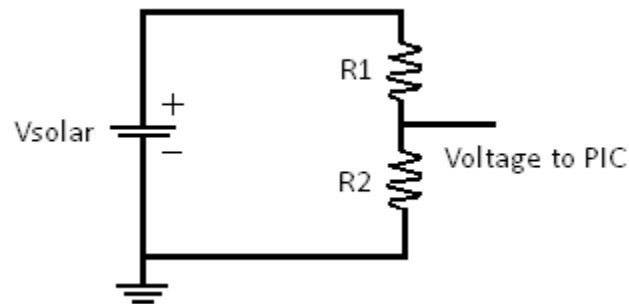


Figure 2-1: A voltage divider for voltage sensing [7]

Resistive current sensing is done by inserting a very low ohm resistor into the circuit. We can then measure the voltage across the resistor and therefore calculate the current using Ohm's law. The addition of the resistor does cause a small power loss but it is less than the loss that a voltage divider would generate. [7]

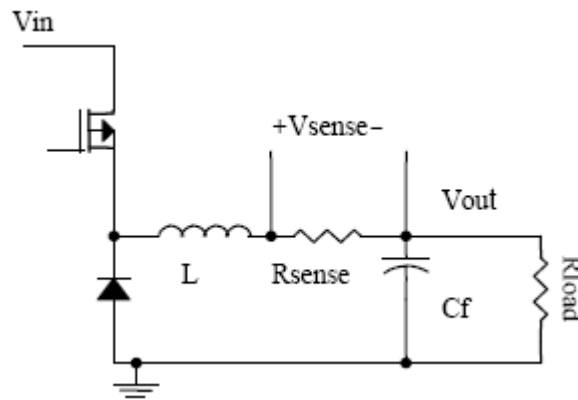


Figure 2-2: A Current Resistor Sensor [7]

3. Design Stages

3.1 DC-DC Boost Converter

The first stage of the project design is to prototype a DC-DC boost converter that operates under four specifications.

1. Input voltage in the range of 20-60V
2. Input current at max of 6A
3. Output voltage approximately of 100V
4. Efficiency greater than 95%

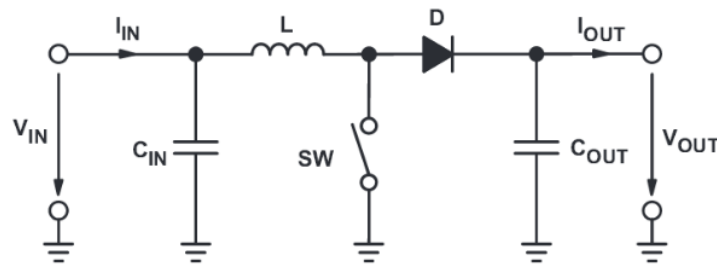


Figure 3-1: Schematic of Boost Converter [5]

Choosing the components for the DC-DC converter is a crucial part of achieving maximum efficiency. The component characteristics were selected to exceed their nominal capabilities by 25%. These characteristics can include, but are not limited to, their maximum voltage, current and temperature capabilities. The diode being used will be the CVFD20065A silicon carbide Schottky diode. The use of a Schottky diode is best because it will reduce losses. [5] The input capacitor is a KEMET ESG Series with a capacitance of $330\mu F$ but the output capacitor will be larger. The output capacitor selected is KEMET ESK Series and has a capacitance of approximately $22,000\mu F$. As for the inductor a 12 gauge copper wire will be wound around a magnetic core. The final component needed to be chosen was the transistor. A MOSFET will be used as a switch in the circuit. The C2M0025120D Silicon Carbide Power MOSFET will be used in the circuit because it supports high speed switching.

3.2 Microcontroller Tracking

The second stage of the project design is to program a microcontroller that will track and adjust the maximum powerpoint of the solar array. The microcontroller chosen has to be fast enough in order to perform computations involving multiplication and division in a short period of time.

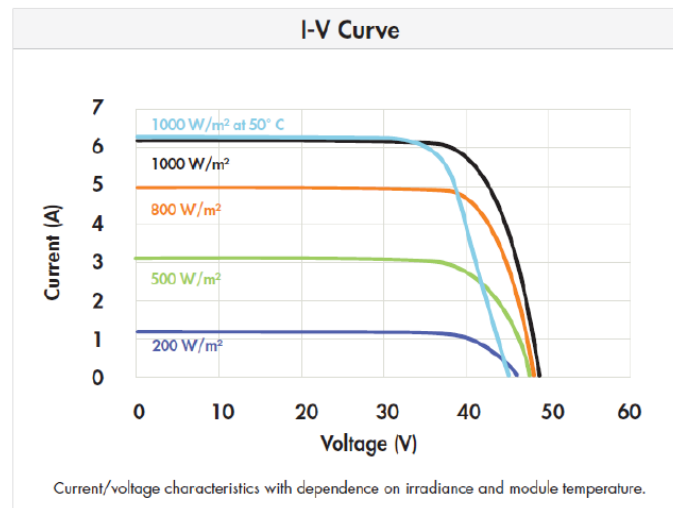


Figure 3-2 : I-V characteristic of solar array (Source: Sunpower)

According to figure 3-2, the current of a solar array and the drop off voltage vary based on the illumination and temperature the solar panel is operating under. The overall trend of the I-V curves is that the current will drop dramatically once the voltage is high enough. For instance, the current is steady at approximately 1A when the irradiance is about $200 \frac{W}{m^2}$ but when the voltage goes over 40V than the current drops. The input power of the DC-DC boost converter will depend on the output of the solar array. The output power from the array can be approximated by $P_{out} = I_{out} * V_{out}$. In order to get the maximum power from the solar array, the voltage must be increased until the current can no longer provide optimal power.

3.2.1 Perturb and Observe Method

The perturb and observe (P&O) method is used for its simplicity and high efficiency. By measuring the input voltage and current intermittently, the microcontroller can modify parameters to further increase the power efficiency. The microcontroller does this until it reaches the maximum power point(MPP) and will then oscillate around this point. When conditions change (which can be caused by shading, temperature, etc), the microcontroller will continue increasing or decreasing the voltage until the MPP is once again found. Figure 3.2.1 displays this perturb and observe algorithm. [1]

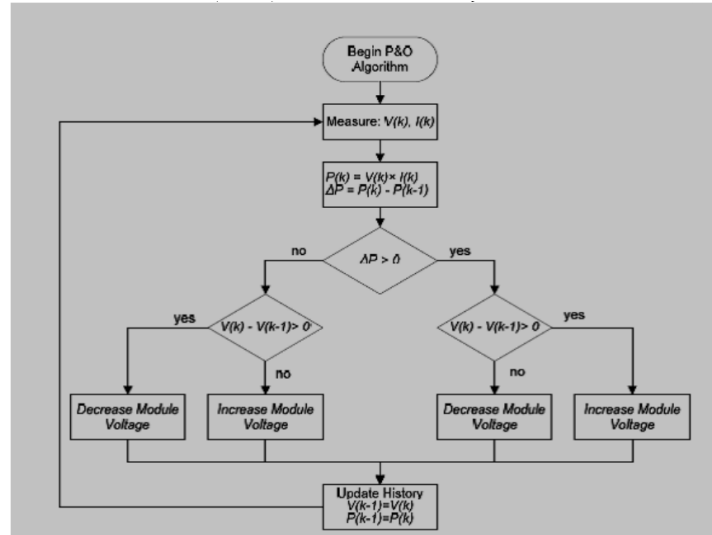


Figure 3.2.1 Perturb and Observe Algorithm [1]

3.3 PCB Layout

The last stage of the project design is to combine the DC-DC boost converter and the microcontroller on to a PCB board that is relatively compact and lightweight. The weight was required to be less than 100g; and the size was required to be less than that of a credit card. However, the team and the sponsor have agreed upon releasing these two constraints. Therefore, the main goal is to focus on the efficiency of the DC-DC boost converter and minimize the PCB layout.

3.4 Simulations

3.4.1 Buck-Boost Simulations

A PSpice simulation was made to simulate a buck-boost circuit using the values of the samples ordered. An input voltage of 20V was boosted to 110V using a period of 10μs and a pulse width of 5.6μs. V(3) (The green curve) is the output voltage and V(1) (The red curve) is the 20V input voltage. The circuit settles on 110V at around 14ms after a minimal overshoot of 113V.

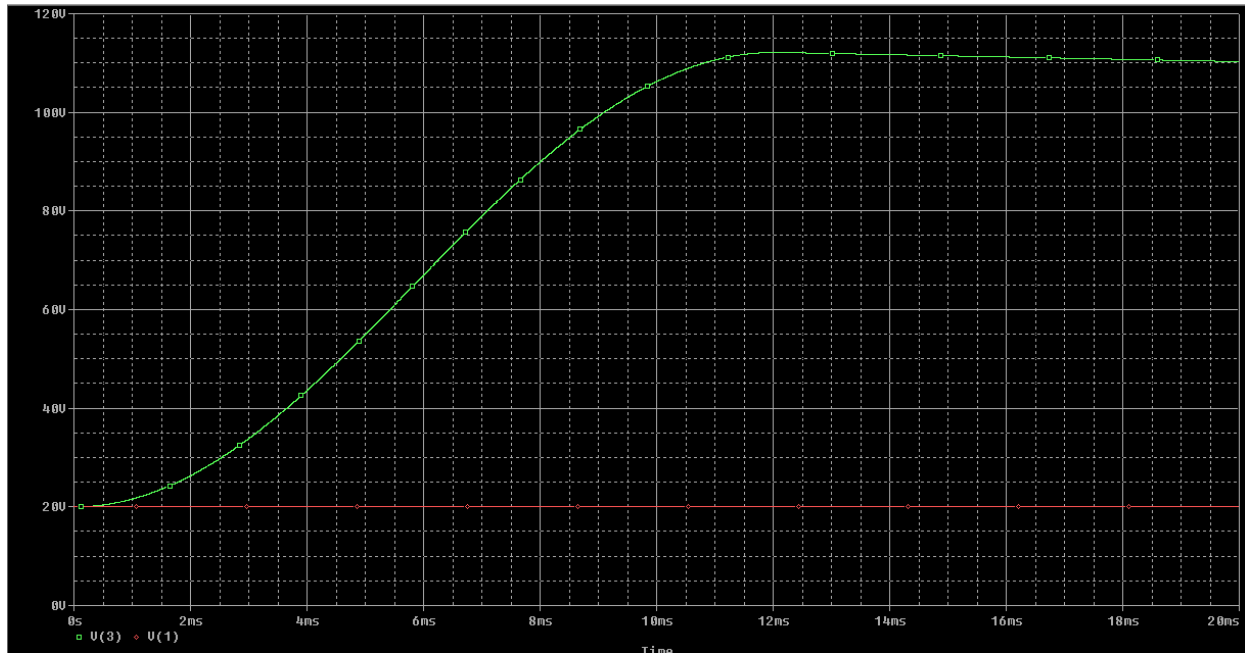
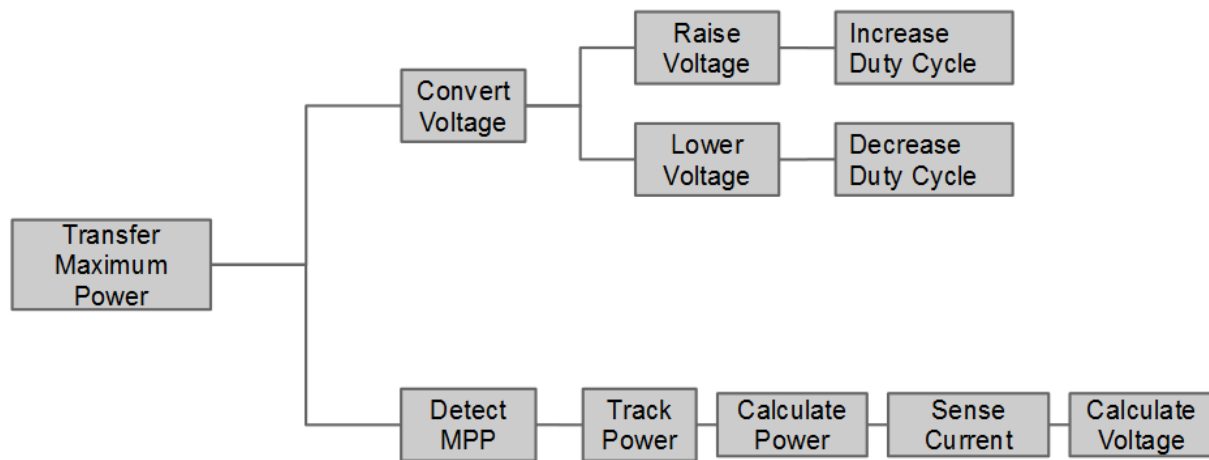


Figure 3.4.1 Buck Boost Simulation in PSpice

4. FAST Diagram

The following functional analysis system technique (FAST) diagram shows the relationships between the functions of a maximum power point tracker, which efficiently transfers the power from solar cells to a load. To accomplish this, manipulation and calculation of electrical characteristics are required.



5. Project Management

5.1 Technical Responsibilities

Name	Responsibility 1	Responsibility 2	Responsibility 3
	Selection & Ordering	Calculation & Simulations	Prototyping & Refinement
Daniel Chen	Resistor	Risk Analysis Data	Building/Testing Prototype
Yue Guo	Magnetic Core	PCB Layout	Building/Testing Prototype
Luis Kalaff	Microcontroller	Labview DC-DC Booster	Building/Testing Prototype
Jacob Mills	Diode	Inductor Core & Windings	Programming Microcontroller
Brenton Sirowatka	Capacitor	PSpice DC-DC Circuit	Programming Microcontroller

Table 4-1

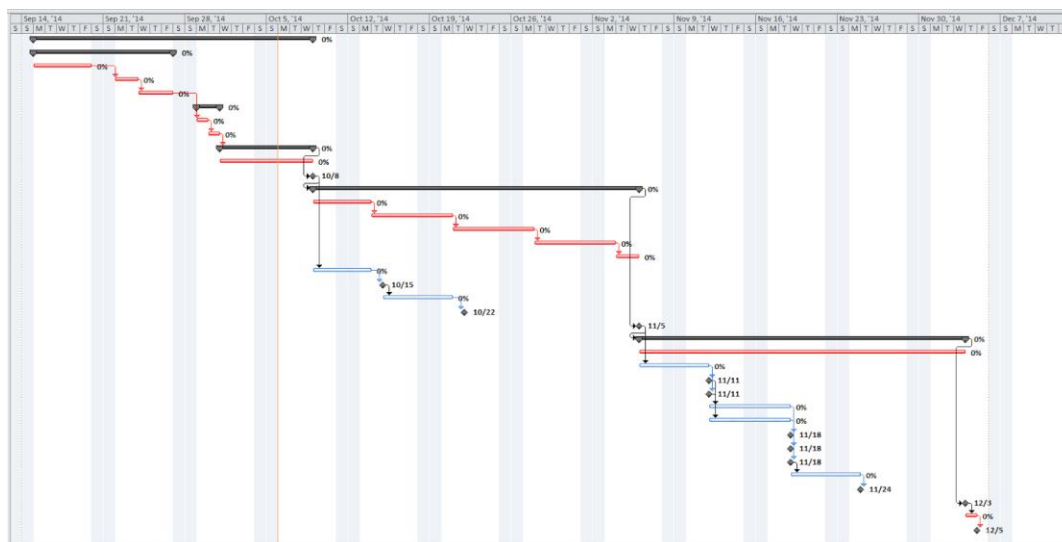
5.2 Non-Technical Responsibilities

Name	Responsibility
Daniel Chen	Presentation Preparation
Yue Guo	Lab Coordinator
Luis Kalaff	Project Management
Jacob Mills	Project Webmaster
Brenton Sirowatka	Documentation Preparation

Table 4-2

5.3 Gantt Chart/Schedule

	Task Mode	Task Name	Duration	Start	Finish	Predecessors
2		DC-DC boost converter	10 days	Mon 9/15/14	Fri 9/26/14	
3		Parameter Values Selection	5 days	Mon 9/15/14	Fri 9/19/14	
4		Procedure for Vdd of Microcontroller	2 days	Mon 9/22/14	Tue 9/23/14	3
5		Simulation for DC-DC Booster	3 days	Wed 9/24/14	Fri 9/26/14	4
6		Microcontroller	2 days	Mon 9/29/14	Tue 9/30/14	
7		Choose Microcontroller	1 day	Mon 9/29/14	Mon 9/29/14	5
8		Write MPPT Code	1 day	Tue 9/30/14	Tue 9/30/14	7
9		PCB layout	6 days	Wed 10/1/14	Wed 10/8/14	8
10		Cadence Simulation	6 days	Wed 10/1/14	Wed 10/8/14	
11		Final Proposal	0 days	Wed 10/8/14	Wed 10/8/14	9
12		Prototype	20 days	Thu 10/9/14	Wed 11/5/14	11
13		Visit ECE Shop for PCB Layout	3 days	Thu 10/9/14	Mon 10/13/14	
14		Low Voltage Testing	5 days	Tue 10/14/14	Mon 10/20/14	13
15		First Prototype	5 days	Tue 10/21/14	Mon 10/27/14	14
16		High Voltage Testing	5 days	Tue 10/28/14	Mon 11/3/14	15
17		Second Prototype	2 days	Tue 11/4/14	Wed 11/5/14	16
18		Prepare Oral Presentation	3 days	Thu 10/9/14	Mon 10/13/14	11
19		Oral Presentation	0 days	Wed 10/15/14	Wed 10/15/14	18
20		Prepare Progress Report	4 days	Wed 10/15/14	Mon 10/20/14	19
21		Progress report	0 days	Wed 10/22/14	Wed 10/22/14	20
22		First Demo	0 days	Wed 11/5/14	Wed 11/5/14	12
23		Refinement	20 days	Thu 11/6/14	Wed 12/3/14	22
24		Parameters Optimization	20 days	Thu 11/6/14	Wed 12/3/14	
25		Prepare Team Technical Lecture	4 days	Thu 11/6/14	Tue 11/11/14	22
26		Team Technical Lecture	0 days	Tue 11/11/14	Tue 11/11/14	25
27		Individual Application Notes	0 days	Tue 11/11/14	Tue 11/11/14	25
28		Prepare Design Issues Report	5 days	Wed 11/12/14	Tue 11/18/14	27
29		Prepare Progress Report	5 days	Wed 11/12/14	Tue 11/18/14	26
30		Design Issues	0 days	Tue 11/18/14	Tue 11/18/14	28
31		Progress report	0 days	Tue 11/18/14	Tue 11/18/14	29
32		Second Demo	0 days	Tue 11/18/14	Tue 11/18/14	29
33		Design for Poster	4 days	Wed 11/19/14	Mon 11/24/14	32
34		Finished Poster	0 days	Mon 11/24/14	Mon 11/24/14	33
35		Final Report	0 days	Wed 12/3/14	Wed 12/3/14	23
36		Project Revision	1 day	Thu 12/4/14	Thu 12/4/14	35
37		Design Day	0 days	Fri 12/5/14	Fri 12/5/14	36



6. Budget

Design Stages	Cost
DC-DC Boost Converter	\$40
Microcontroller	\$20
PCB layout	\$60
Miscellaneous	\$20

7. Conclusion/Recommendation

	Efficiency	Simplicity	Tracking ability	
Control Method				Feasibility
Perturb and Observe	5	5	4	14
Incremental Conductance	3	1	5	9
Current Sweep	3	2	3	8
Constant Voltage	2	3	1	6

Feasibility Matrix of Control Method

	TMS320F28027	MSP430G2553
Clock Speed	60MHz	16MHz
ADC	12 bits	10 bits
# of ADC Channels	7/13	8
Operate Temperature(C)	-40 to 105	-40 to 85
Interface	UART/I2C/SPI	UART
Cost	3.05/1ku	0.90/1ku
Rating	5	1

Selection Matrix of Microcontroller

The recommendation for the MSU solar car team is to utilize implement the perturb and observe method on the TMS320F28027. The final design will be on one single PCB.

8. References

- [1] Atallah, Ahmed M, Almoataz Y Abdelaziz, and Raihan S Jumaah.
"IMPLEMENTATION OF PERTURB AND OBSERVE MPPT OF PV

SYSTEM WITH DIRECT CONTROL METHOD USING BUCK AND BUCK-BOOST CONVERTERS."

- [2] Bishop, Todd. "LaserMotive lights up first product — transmitting power over fiber with lasers." *GeekWire*. N.p., 12 Feb. 2013. Web. 13 Sept. 2014. <<http://www.geekwire.com/2013/power-fiber-lasers/>>.
- [3] Coelho, Roberto F., Filipe M. Concer, and Denizar C. Martins. "A MPPT Approach Based on Temperature Measurements Applied in PV Systems ." *IEEE Xplore*. University of Santa Clara, 2010. Web. 2 Oct. 2014. <<http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5740006>>.
- [4] Freeman, Dave. "Introduction to Photovoltaic Systems Maximum Power Point Tracking." *Texas Instruments*. Texas Instruments, Nov. 2010. Web. 10 Sept. 2014. <<http://www.ti.com/lit/an/slva446/slva446.pdf>>.
- [5] Hauke, Brigitte. "Basic Calculation of a Boost Converter's Power Stage." *Texas Instruments*. Texas Instruments, Nov. 2009. Web. 13 Sept. 2014.
- [6] *Photon Quad MPPT*. Dilithium Power Systems LLC, Shakopee, MN. Web. 9 Oct. 2014.
- [7] Prevoo, Y. K. L. M., and M. G. P. Hovens. "Maximum Power Point Tracking Topology, sensor and switch design." Delft University of Technology, 26 June 2012. Web. 15 Sept. 2014.
- [8] "Project Descriptions." *ECE 480*. Michigan State University and Michigan State Solar Car, n.d. Web. 1 Sept. 2014. <<http://www.egr.msu.edu/classes/ece480/capstone/f14/Projects-F14.pdf>>.
- [9] *Solar Cell I-V Curve in Varying Sunlight*. 2006. Web. 13 Sept. 2014. <<http://commons.wikimedia.org/wiki/File:Solar-Cell-IV-curve-with-MPP.png>>.

9. Appendix

Definitions & Initialisms

- A - Amperes
- AWG - American Wire Gage
- DC - Direct Current

- DSP - Digital Signal Processor
- F - Farads
- g - Grams
- I - Current
- m - Milli (10^{-3})
- MPP - Maximum Power Point
- MPPT - Maximum Power Point Tracker
- PCB - Printed Circuit Board
- P&O - Perturb and Observe
- V - Voltages or Volts
- - Micro(10^{-6})