

# **Photovoltaic Power Converter**

**Senior Project Proposal**

**Date: 12/6/11**



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## **Advisors:**

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## 1. Project Summary

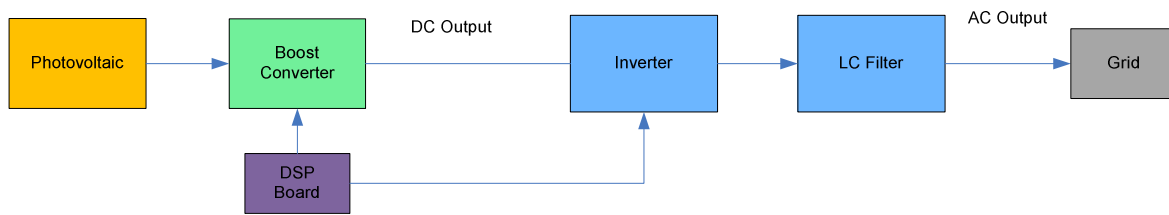
The Photovoltaic Power Converter system supplies both DC and AC power. The system utilizes Photovoltaic (PV) panels to generate DC power. Initially a boost converter steps up the DC voltage output from the PV panel. A Maximum Power Point Tracking (MPPT) algorithm is implemented to ensure maximum power from the solar panel is obtained. A current sensor, a voltage sensor, and a DSP board are used to control the MPPT algorithm. The boosted DC voltage is then inverted to 120 Vrms AC. The inverter contains four IGBTs controlled by the same DSP board. An LC filter is used to smooth out the output.

## 2. Detailed Project Description

The total system can be broken down into two groups of subsystems, DC and AC. The overall functional block diagram is shown in Figure 1. The DC subsystem is shown on the left side of the block diagram, and the AC subsystem is shown on the right side.

### 2.1 Functional Block Diagram

The following figure is a functional block diagram of our system.



**Figure 1 – Functional Block Diagram**

#### 2.1.1 DC Subsystem

The DC subsystem is composed of a step up converter and an MPPT system. The photovoltaic provides a voltage and current, which then goes through a DC-DC boost converter (step up). The DSP input to the DC subsystem controls the MOSFET in the boost converter with a PWM signal. The output from the boost converter is measured, and the duty-cycle of the PWM is altered by the MPPT system later discussed in the MPPT section.

#### 2.1.2 AC Subsystem

The AC subsystem inverts the DC output into 120 Vrms AC power for AC appliances. Additionally, excess AC power can be fed into the grid. This subsystem contains four IGBTs controlled by a DSP board, and an LC filter.

## 2.2 Over All Requirements

- The System shall take a voltage from photovoltaic cells.
- The System shall boost the input voltage.
- The stepped up voltage shall be converted to an AC voltage by means of an inverter.

### 2.2.1 DC Requirements

- The boost converter shall accept a voltage from the photovoltaic cells.

- The input voltage shall be 48 Volts.
- The average output shall be 200 Volts +/- 25 Volts.
  - The voltage ripple shall be less than 3 Volts.
- A MOSFET shall be used as a switch in the boost converter.
- The boost converter shall perform maximum power point tracking.
  - The PMW of the boost converter shall be regulated based on current and voltage from the PV array.
  - The efficiency of the MPPT system shall be above 85%.

### 2.2.2 AC Requirements

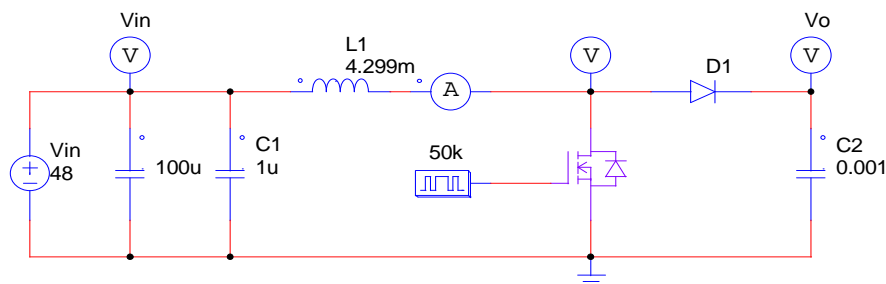
- The AC side of the system shall invert the output of the boost converter.
  - The output of the inverter shall be 120 Volts RMS.
  - The output shall be 60Hz +/- 0.1Hz.
  - Total harmonic distortion of the output shall be less than 15%.
  - Four IGBTs shall be the switches for the inverter.
- The inverter shall be filtered by a LC filter.
  - The filter shall remove high switching frequency harmonics.

### 2.2.3 Software Requirements

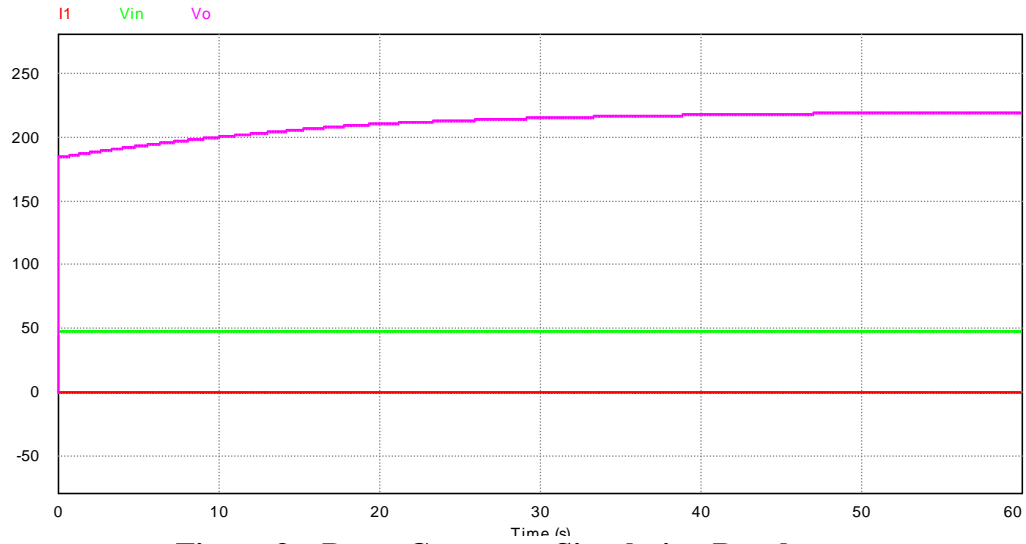
- A DSP board shall be used to control both the DC and AC subsystems.
- The DSP board shall control the MPPT.
  - The MPPT measurements shall be taken every 1 second.
- The PWM signals controlling the boost converter and inverter shall be generated by the DSP board.
- The test frequencies of the PWM signal shall be from 10kHz to 50kHz.

### 2.3 DC Subsystem

First calculations were done to find the size of the inductor and capacitors in the boost converter. Based on a 48V input voltage to the boost converter and a desired output voltage of 200V, a switching frequency of 50kHz requires an inductor value of 4.299mH. Calculations can be found in Luke's lab notebook. A PSIM schematic of the designed boost converter is shown in Figure 2. Figure 3 displays simulation results showing inductor current, input voltage, and output voltage. The output voltage is seen to be over 200V as designed.

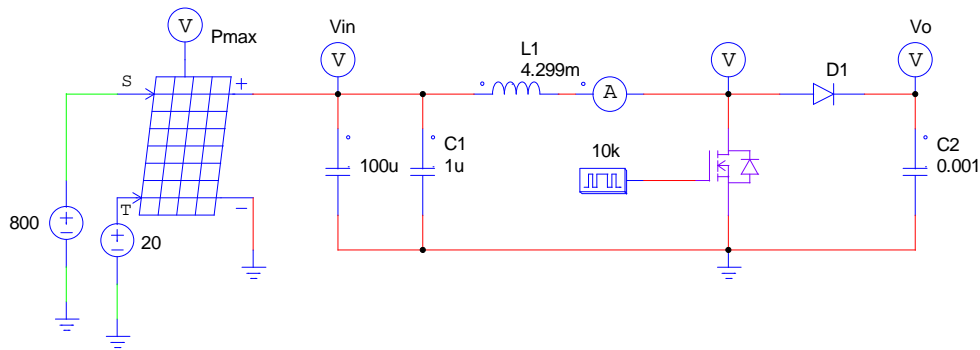


**Figure 2 – Boost Converter**

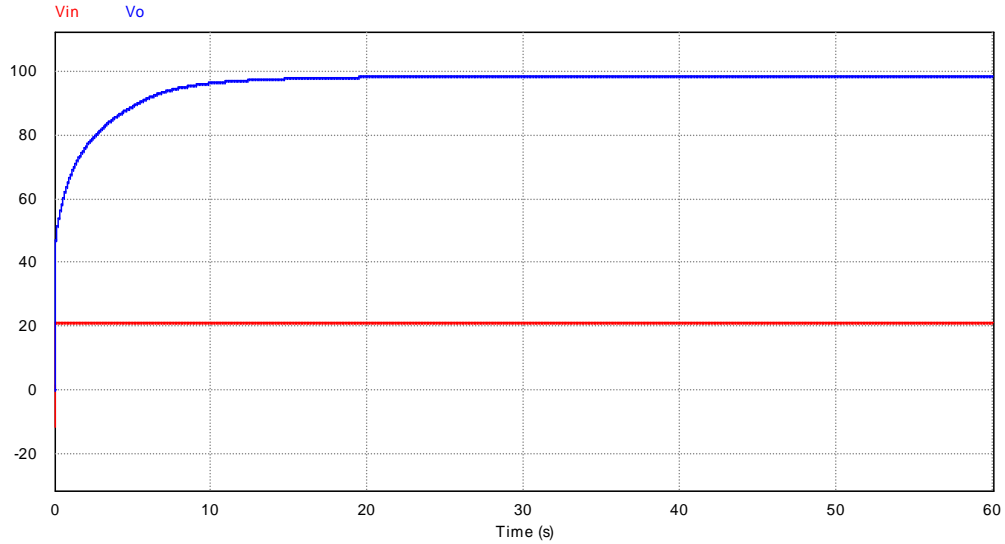


**Figure 3 – Boost Converter Simulation Results**

We used the physical model solar panel in PSIM to simulate a circuit with the parameters from the BP350J. This is a simulation of just one panel at an insolation level of  $800 \text{ W/m}^2$  and a temperature of 20 degrees Celsius. The schematic is shown in Figure 4 and the simulated input and output voltages are shown in Figure 5.



**Figure 4 – Boost Converter with PV**



**Figure 5 – Boost Converter with PV Simulation Results**

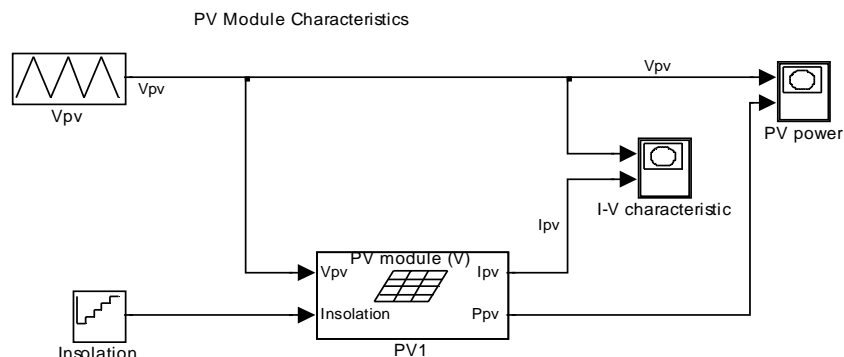
### 2.3.1 Photovoltaics

The PV array will consist of four 50Watt BP350J solar panels, each with a nominal voltage of 12Volts. With the four panels, an input voltage of 48Volts will be provided to the boost converter. Insolation is a measure of solar energy on a certain area over a given amount of time, and is usually expressed in units of watts per meters squared ( $W/m^2$ ). As shown in Table 1 below, units of  $kWh/(m^2\text{day})$  can also be used to express insolation values.

**Table 1 – Average Insolation in Peoria**

Solar Insolation Peoria, IL												
	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
$kWh/(m^2\text{ day})$	3.271	4.109	4.642	4.921	5.239	5.740	5.880	5.727	5.639	4.562	2.957	2.721
$W/m^2$	136.292	171.208	193.417	205.042	218.292	239.167	245.000	238.625	234.958	190.083	123.208	113.375

The above table shows the average insolation values for each month of the year in Peoria, IL. Figure 6 below is a Simulink model containing PV module with the BP350J parameters entered into it. The model inserts various insolation values (200, 400, 600, 800, 1000  $W/m^2$ ) to the PV module.



**Figure 6 – Matlab PV model**

In figures 7 and 8 the I-V and P-V characteristics of the PV module are shown for the changing insolation values. The higher peaks correspond to higher levels of insolation.

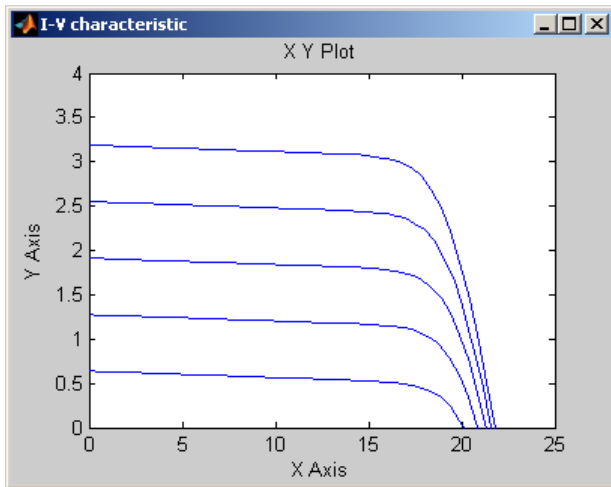


Figure 7 - PV Voltage (X) v. Current (Y)

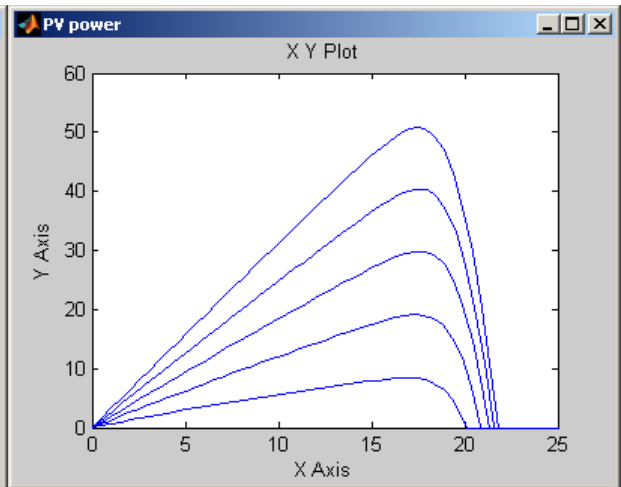


Figure 8 – PV Voltage (X) v. Power (Y)

### 2.3.2 Boost Converter Lab Testing

We currently do not have the parts that will be used with our actual boost converter, so to get some experience we built a boost converter to control using the DSP. We did this so that next semester we will be able to get to the testing phase of our project faster, since we will already have some experience building boost converters.

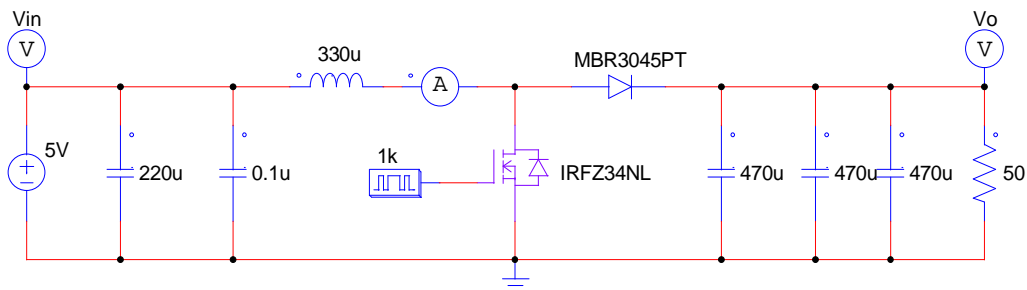


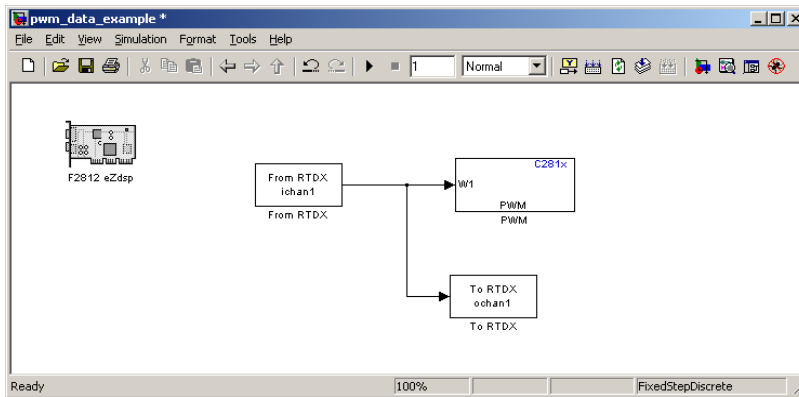
Figure 9 – Boost Converter Built and Tested in Lab

Figure 9 shows the boost converter circuit we tested. The MOSFET was controlled by the DSP board through a gate driver. We tested the boost converter at 10 KHz and varied the duty cycle of the PWM signal. At 50% duty cycle we got an output of 10V from an input of 5V. As we increased the duty cycle, the output voltage increased, and as we decreased the duty cycle, the output voltage decreased.

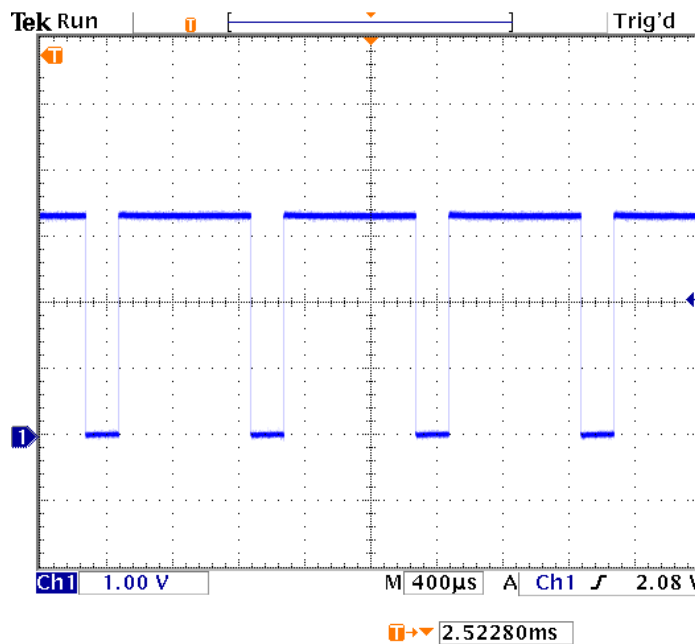
### 2.3.3 DSP

We have chosen the eZdsp F2812 board, which packages a Texas Instruments TMS320F2812 DSP chip with the peripherals needed to interface with the chip. The feedback control systems will be built in Simulink and we will use Simulink's automatic code generation to create software for the DSP chip. Our group has experimented with the chip enough to be able to read

in voltages with the DSP chip's A/D converters and generate PWM waveforms at user selected duty ratios. Figure 10 shows a Simulink block diagram that allows for a user-defined duty ratio to be sent to the DSP board. A PWM signal generated by this method is shown in Figure 11.



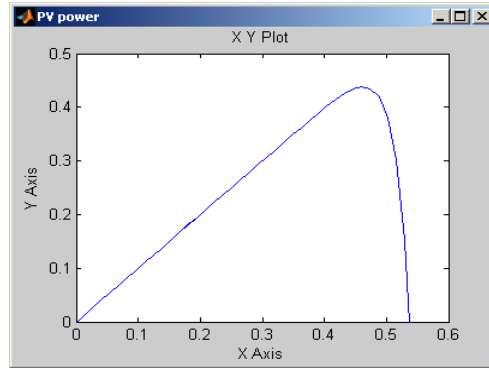
**Figure 10 – Sample Simulink block diagram**



**Figure 11 – PWM Signal Generation Output 80% Duty Ratio**

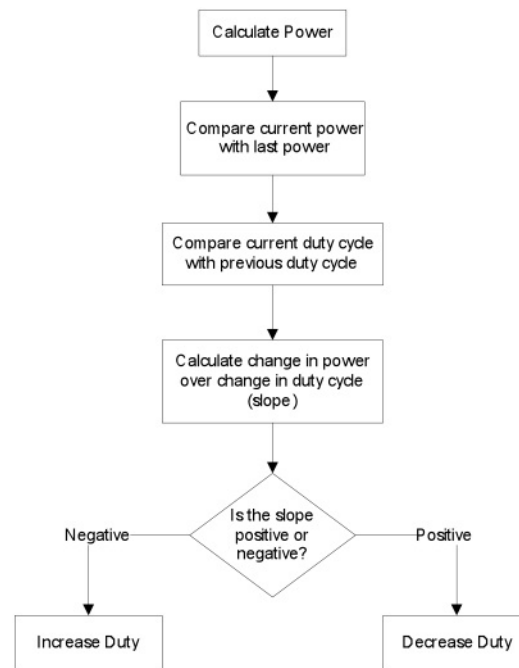
### 2.3.4 Maximum Power Point Tracking

Maximum Power Point Tracking (MPPT) is a method of ensuring that the Solar Panels are always delivering the maximum power that they are able to at any time. As insolation levels change, the photovoltaic will not be able to supply the same maximum power. The Figure 12 shows photovoltaic power versus voltage. The peak is where the panel is operating at max power. This is the point we want to be at all the time.



**Figure 12 – PV Voltage (X) v. Power (Y)**

If the duty cycle of the boost converter remains the same, we will not be getting maximum power from the solar panel. By measuring the input voltage and current from the photovoltaic, we can compare current power and past power to the current boost converter duty cycle and past boost converter duty cycle. The flowchart in Figure 13 explains the algorithm. This method of MPPT is called the “Perturb and Observe” method. By varying the duty cycle of the boost converter the current output of the photovoltaic changes and thus the input power to the system changes.

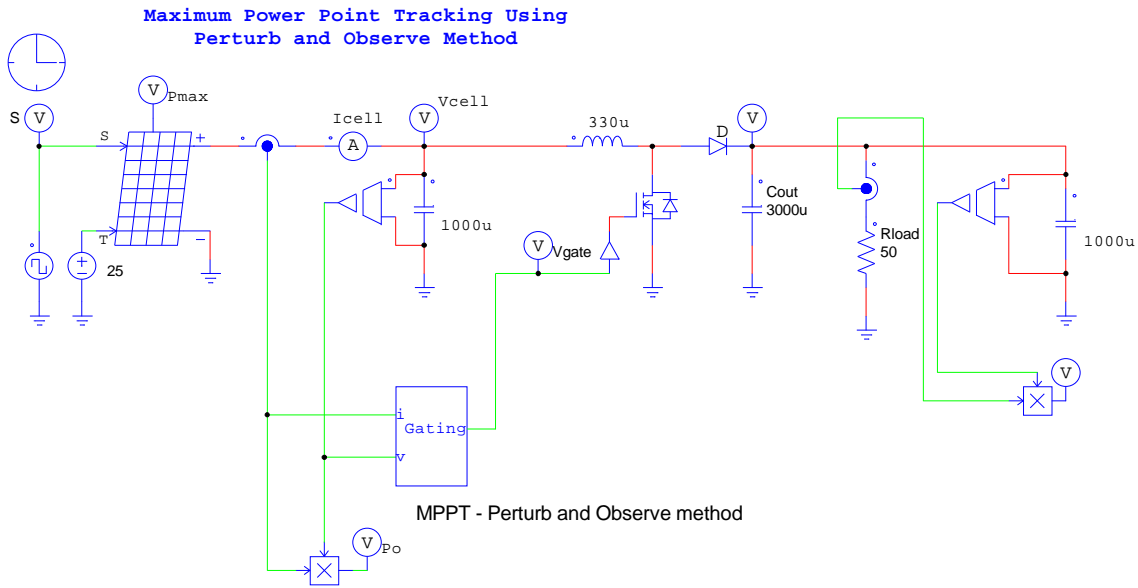


**Figure 13 – MPPT algorithm flowchart**

### 2.3.5 MPPT Simulation

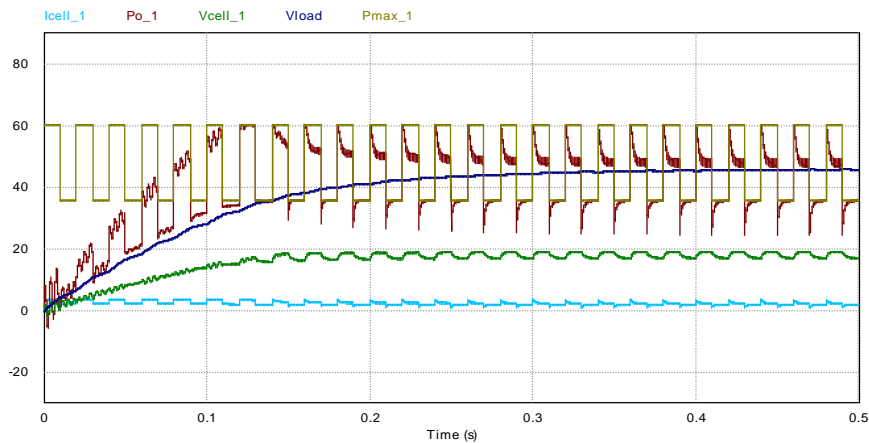
In order to better understand the effects of MPPT we ran some simulations of the algorithm.





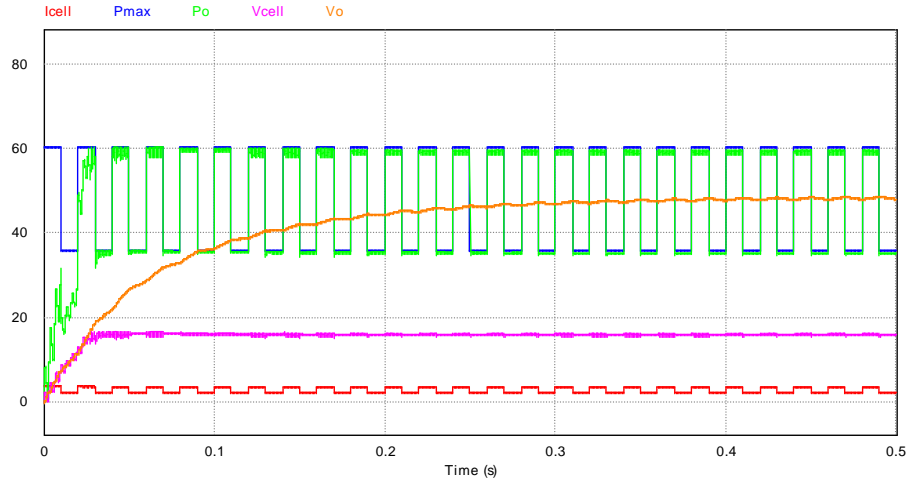
**Figure 14 – Boost converter with MPPT**

Figure 14 is a circuit of a simple boost converter with a photovoltaic as the input. The square wave input connected the solar panel varies the insolation level of the photovoltaic. In the simulation results the effects of doing this to a boost converter without MPPT are easily observed.



**Figure 15 – Boost converter output power and voltage without MPPT**

In Figure 15 the output power is not always operating at its peak point. This can be seen by comparing  $Po_1$  to  $Pmax_1$ .  $Pmax_1$  is the maximum power of the solar panel.

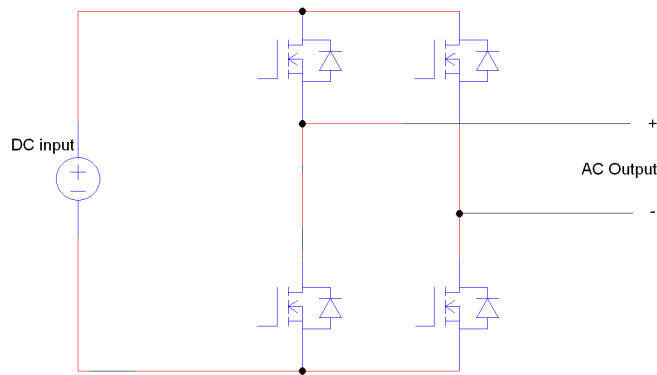


**Figure 16 - Boost converter output power and voltage with MPPT**

In Figure 16  $P_o$  is almost always at  $P_{max}$ . Additionally the photovoltaic current and current is kept at a more constant level.

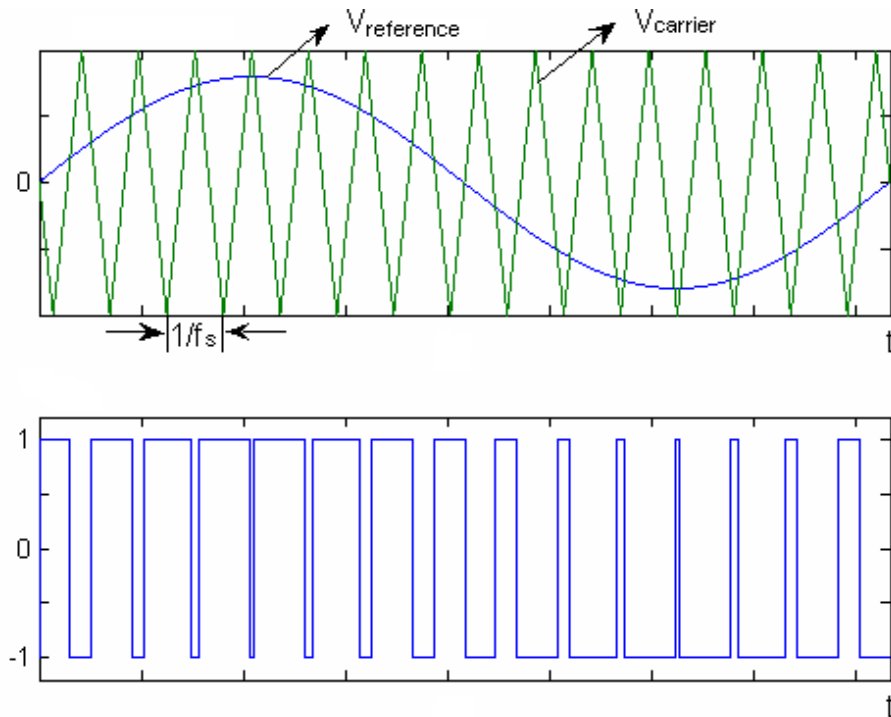
### 2.4 AC Subsystem

The AC subsystem’s purpose is to convert DC energy to AC power. The main components of the AC subsystem are the inverter and the output filter. The inverter uses four IGBTs in a standard H-bridge topology. This topology is shown in Figure 17. The switching action of the IGBTs is driven by the DSP board. The DSP board will regulate the output of the inverter to 120Vrms, 60Hz. Two switching methods have been explored, the bipolar method and the unipolar method.



**Figure 17 – Inverter H-Bridge Topology**

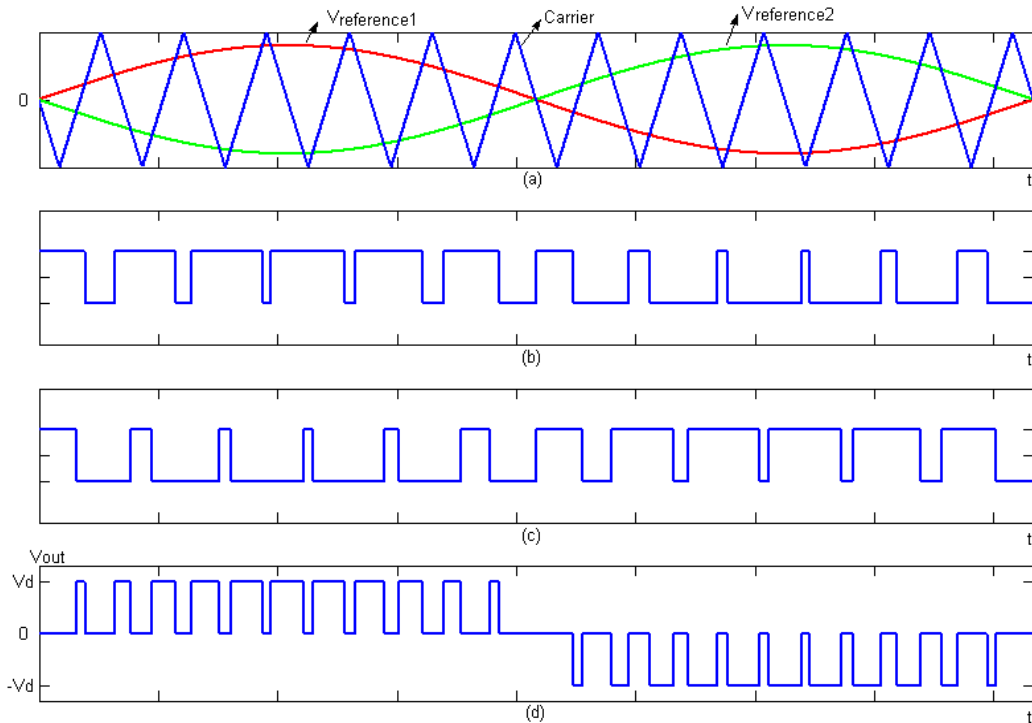
In the bipolar method a single sinusoid is used as a reference signal and is compared to a triangular waveform, called the carrier. The end result is one waveform which controls the IGBTs. When the reference waveform is greater than the carrier waveform, the switching signal is on and when the carrier waveform is greater than the reference waveform the switching signal is off. Figure 18 shows the carrier, reference, and generated switching signal. This switching signal drives one leg of the H-bridge. The signal is inverted and this drives the other leg.



**Figure 18 – Vreference and Vcarrier, Created switching signal**

The unipolar method uses two reference sinusoids, offset by 180 degrees phase difference. These two reference signals are compared to a triangular carrier waveform. When the reference waveform is greater than the carrier waveform, the switching signal is on and when the carrier waveform is greater than the reference waveform the switching signal is off. The end result is two switching signals, each driving one side of the H-bridge. The output waveform contains three voltage levels,  $+V_{input}$ , 0,  $-V_{input}$ .

The bipolar method is less complex to implement than the unipolar method, but the unipolar produces superior output characteristics when compared to the bipolar method. The frequency spectrum of the output of each method can be analyzed and the unipolar method will contain less distortion than the bipolar method.



**Figure 19 – Unipolar**

The output of both inverter switching methods will contain a large amount of harmonic distortion. In either case an output filter is necessary to remove this distortion. The filtering of the output will remove power spectra from the output, which is a source of system inefficiency. Total harmonic distortion of the system output is required to be less than 15%.

Key components to realize the inverter are the inverter switches (IGBTs), gate drives and power supplies, and PWM buffers. The PWM buffers are required to interface the DSP board to the gate drives, and the gate drives safely control the IGBTs. The gate drives require isolated power which is supplied by the power supplies.

### 3. Schedule

The table below shows the schedule our team will use for next semester.

**Table 2 – Spring 2012 Schedule**

	Brendan	Tom	Luke
Week 1	Build Boost	Build Inverter	Build Boost
Week 2	Voltage Sensing	DSP Programming	Current Sensing
Week 3	MPPT Code	DSP Programming	MPPT Code
Week 4	Interfacing	DSP Programming	Interfacing
Week 5	Interfacing	Interfacing	Interfacing
Week 6	Circuit + Software	Interfacing	Circuit + Software
Week 7	Testing	Testing	Testing
Week 8	DC-AC Integration	DC-AC Integration	DC-AC Integration
Week 9	DC-AC Integration	DC-AC Integration	DC-AC Integration
Week 10	Build Fullbridge+Boost	LC Filter	Build Fullbridge+Boost
Week 11	Circuit + Software	Testing	Circuit + Software
Week 12	DC-AC Integration	DC-AC Integration	DC-AC Integration
Week 13	DC-AC Integration	DC-AC Integration	DC-AC Integration
Week14	Presentation Prep	Presentation Prep	Presentation Prep
Week 15	Presentation Prep	Presentation Prep	Presentation Prep

## References

- “PV Module Simulink Models.” ECEN2060. University of Colorado Boulder.
- Rockett, Angus, Robert W. Scott. “Evaluation of the Potential for Photovoltaic Power Generation in Illinois” 22 Nov. 2011.  
<[www.isws.illinois.edu/pubdoc/IEM/ISWSIEM2006-05.pdf](http://www.isws.illinois.edu/pubdoc/IEM/ISWSIEM2006-05.pdf)>.
- Rozenblat, Lazar. "A Grid Tie Inverter for Solar Systems." Grid Tie Inverter Schematic and Principles of Operation. 6 Oct. 2011. <<http://solar.smps.us/grid-tie-inverter-schematic.html>>.
- Tafticht, T., K. Agbossou, M. Doumbia, and A. Cheriti. "An Improved Maximum Power Point Tracking Method for Photovoltaic Systems." Renewable Energy 33.7 (2008): 1508-516.
- Tian, Yi. ANALYSIS, SIMULATION AND DSP BASED IMPLEMENTATION OF ASYMMETRIC THREE-LEVEL SINGLE-PHASE INVERTER IN SOLAR POWER SYSTEM. Thesis. Florida State University, 2007.
- Zhou, Lining. EVALUATION AND DSP BASED IMPLEMENTATION OF PWM APPROACHES FOR SINGLE-PHASE DC-AC CONVERTERS. Thesis. Florida State University, 2005.

## Equipment List

PVC Parts List as of 12/06/11							
Part Type	Part #	Website	Digikey or Newark #	DESC	QTY	Unit Price	Price
MOSFET	IXTH110N25T	<a href="http://search.digikey.com">http://search.digikey.com</a>	IXTH110N25T-ND	Vds = 250V Id = 110A Pdiss = 694W	20	\$6.17	\$123.30
Capacitor	B43456	<a href="http://search.digikey.com">http://search.digikey.com</a>	495-4232-ND	1500uF 450V	8	\$38.09	\$304.72
Current Sensor	ACS712ELCTR-30A-T	<a href="http://search.digikey.com">http://search.digikey.com</a>	620-1191-1-ND	30A 63 to 69 mV/A	3	\$4.52	\$13.56
Ultrafast Diode	HFA50PA60C		N/A	If(av) = 25A Vf = 1.3C Vr = 600V	10	\$12.23	\$122.30
IGBT	IRG4PC30UD		N/A	Vce = 600v Ic = 23A Pdiss = 100W	20	\$2.50	\$50.00
Solar Panel	BP 350 J		N/A	50W 12V	3	\$279.00	\$837.00
Inductor	7448262510	<a href="http://www.newark.com">http://www.newark.com</a>	08P2917	1mH 25A	4	\$22.91	\$91.64
Inductor	7448263505	<a href="http://www.newark.com">http://www.newark.com</a>	08P2918	500uH 35A	2	\$22.91	\$45.82
Heat sink	WA-T247-101E	<a href="http://search.digikey.com">http://search.digikey.com</a>	WA-T247-101E-ND	Clip-on TO-247	6	\$1.80	\$10.80
Gate Driver	IR2110	<a href="http://search.digikey.com">http://search.digikey.com</a>	IR2110PBF-ND	MOSFET IGBT Driver 2.5A 500V	25	\$2.80	\$70.09
Op Amp	OP484FPZ	<a href="http://search.digikey.com">http://search.digikey.com</a>	OP484FPZ-ND	Sensing Op Amp	10	\$11.14	\$111.40
PWM Buffer	74LVC4245A	<a href="http://search.digikey.com">http://search.digikey.com</a>	568-5002-1-ND	IC Translator	10	\$0.91	\$9.12
PWM Buffer	74HCT541	<a href="http://search.digikey.com">http://search.digikey.com</a>	568-4592-1-ND	IC Buffer	10	\$0.50	\$5.02
Transformer	3FL20	<a href="http://search.digikey.com">http://search.digikey.com</a>	MT1113-ND		5	\$10.05	\$50.25
Capacitor	ECA-1VM101	<a href="http://search.digikey.com">http://search.digikey.com</a>	P5165-ND	35V 100uF	10	\$0.25	\$2.50
vtg regulator	LM7815	<a href="http://search.digikey.com">http://search.digikey.com</a>	LM7815ACT-ND		10	\$0.69	\$6.90
vtg regulator	LM78L05	<a href="http://search.digikey.com">http://search.digikey.com</a>	LM78L05ACZFS-ND		5	\$0.48	\$2.40
vtg regulator	LM1117	<a href="http://search.digikey.com">http://search.digikey.com</a>	LM1117T-3.3/NOPB-ND		5	\$1.49	\$7.45
PWM Controller	T1 UCC3895N	<a href="http://search.digikey.com">http://search.digikey.com</a>	296-11538-5-ND	IC phase shift PWM controller	4	\$10.50	\$42.00
Inductor	8108-RC	<a href="http://www.newark.com">http://www.newark.com</a>	63K4075	1 mH, 10A	1	\$6.07	\$6.07
Capacitor	EEUED2D330	<a href="http://www.newark.com">http://www.newark.com</a>	83K0577	33uF, 200V	2	\$0.62	\$1.24
Capacitor	EEUED2D101	<a href="http://www.newark.com">http://www.newark.com</a>	96K9451	100uF, 200V	2	\$1.31	\$2.62
							<b>\$1,916.20</b>