UNIVERSITY OF ILLINOIS

Solar Powered Converter Educational Display

Design Review

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Introduction

Title

Solar Powered Educational Display

The project is a portable educational display that demonstrates topics in power electronics and renewable energy. This display will convert solar energy into 120 V AC power, connected to an appropriate load. The display will target beginning engineers who will be able to view various measurements in real time, as well as switching between the loads, on a portable device via Bluetooth technology.

Objectives

The goals of the project include implementing a solar panel to power a battery which will in turn power various loads. A heat lamp with a dimmer will be the heat source for the solar panel acting as the sun, having the ability to be at full output or perform at a lower output. Furthermore, a user would be able to tell the difference between electrical and mechanical power as one could change the charger for the battery to a hand crank, comparing the difference between a solar panel and human power. A buck converter will be used in the intermediate step between the battery and load in order to accurately convert the power.

Another aspect to the project is that the user will be able to control the display wirelessly. By using a wireless product, a cell phone, tablet computer or laptop for example, the user will be able to turn on and off the display, switch between the loads, and read strategic values. These values would include the duty cycle from the buck converter, amount of voltage from the solar panel and hand converter, the efficiency of the solar panel and the percentage of charge on the battery. This wireless display would also include a description of the process for each section so that a freshman would be able to understand the progression

Benefits for the end customer include:

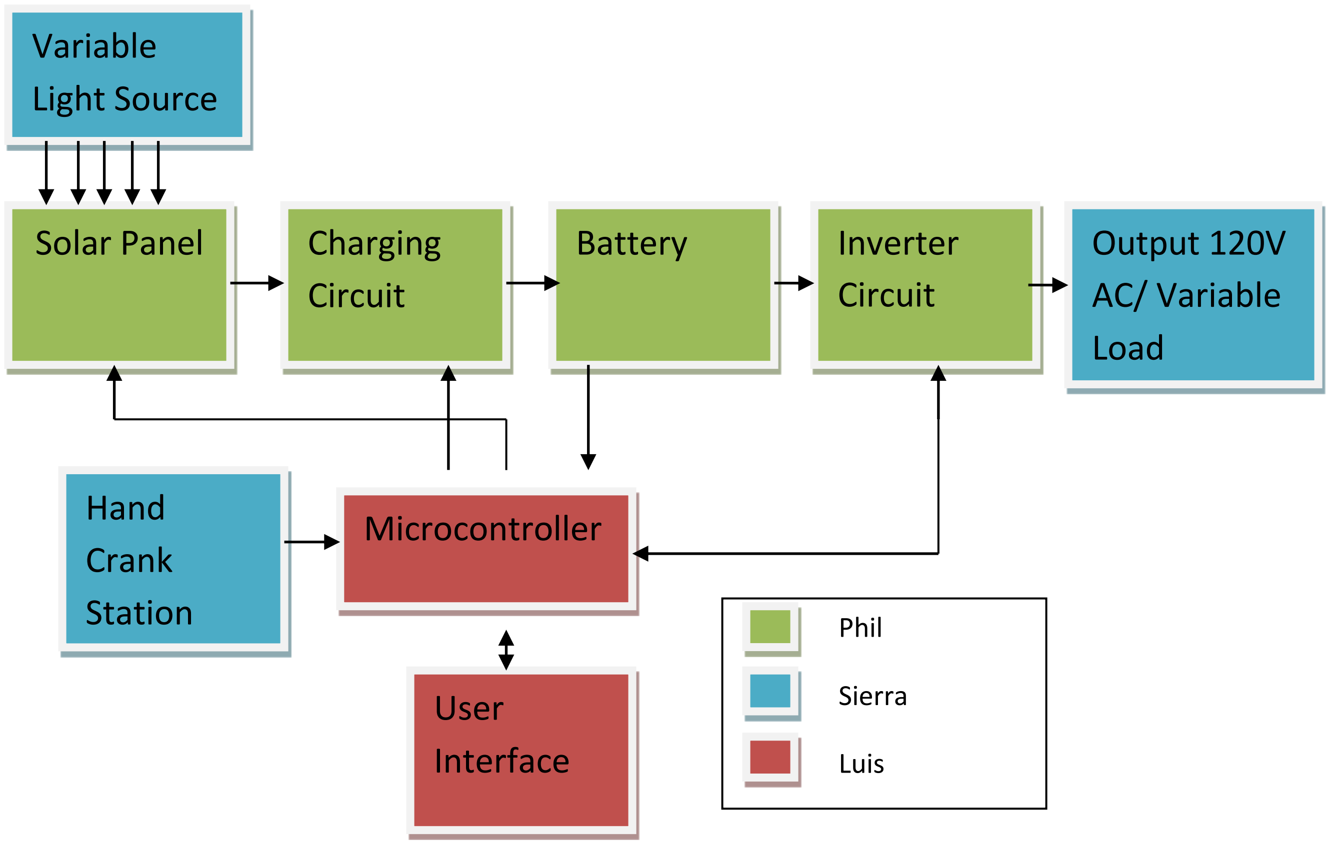
- Ability to examine the process of converting energy from a solar panel into usable power for a load
- Comprehensive description at each step of the process that provides students with a better understanding of power electronics
- Wireless control of the display at both the beginning, controlling whether or not the device is on as well as if it is using a traditional energy source or solar one, as well as controlling the load at the end
- Obtain real-time values of various power measurements
- A display that is easily portable and self-contained, easily constructed and destructed

Product features include:

- Hand crank station
- 120 V AC receptacle
- Variable load
- Bluetooth connectivity
- Android application providing a user interface

Design

Block Diagram



Descriptions

Variable light source: A variable light source will be used in order to provide adequate light for the solar panel. Since the solar panel will always be indoors, a light source other than the sun will be needed in order to charge the solar panel. The light source will vary in output to mimic the fact that the sun does not shine at a constant rate. A wall source of 120 V AC will be used to power the lamp and a dimmer will be used to control the output. The light source will consist of a standard desk lamp with a soft white 40 W incandescent bulb. Additionally, a sliding dimmer switch will be attached to this desk lamp that will control the light output manually. While the light source will not mimic a solar timeline, it will imitate varying values of sunlight.

Hand Crank Station: In order to compare mechanical power to solar power a hand crank and small 5 V motor will also be used to measure the difference in power between a person turning a motor and a solar panel. A small hand crank, which will be removable, will be attached to the shaft of the small 5 V motor. The hand crank will consist of a nob to grasp arm with and then once the user starts to rotate the nob circularly the motor will generate energy. The small motor will be attached to the microcontroller in order to allow the user to compare the difference between the amount of power produced by a human and the amount produced by the solar panel. Because the hand crank is attached to the microcontroller the comparison will be displayed on the mobile device along with other values.

Solar Panel: The solar resource is the main focus of the educational display and as such the solar panels are a critical part. The panel should be able to perform a 10% charge of the battery system within the time frame of a 50 min class period in order to demonstrate the generation and storage of solar energy. The panel will interface with the charging circuitry to efficiently charge the battery as well as with the microcontroller in order to display useful educational information such as voltage at the terminals. A six-cell solar array will be used with an open circuit voltage of approximately five volts and a short circuit current of five to six amps. With these measurements, a maximum power output of 30 Watts is expected.

Charging Circuit: The charging circuit is used to provide a constant float voltage to the Lead-Acid Battery. It will take the solar panels 4-6V as input and boost it to 13.7V +/- 0.1V in order to match the batteries charging requirements. The converter will be built with discrete parts and the schematic is given in Figure 1 below. A MTB30N06VL MOSFET will be used since its voltage and current ratings are well above the required values. To drive the MOSFET an IR2112 low-side gate driver will be used. The output capacitor and input inductor are sized in order to reduce the output ripple to the acceptable value. The circuit will utilize the microcontroller as a feedback loop to insure it meets the batteries charging specifications.

Battery: The battery should be able to handle a load up to 100W for at least a 50 minute class period. It will take a charge input from the charging circuit and output power to the inverter. It will also provide information to the microcontroller such as percent charge and voltage in order to be used by the charging circuit as well as be displayed for the user.

Inverter Circuit: The inverter is the final stage in the conversion process. It will take the output from the battery and convert it to 120VAC to drive the variable load station. It will be built discretely and the schematic is given in Figure 2 below. The MOSFETs used will be MTP52N06 which were selected because they had suitable voltage and current ratings. Two IR2112 Dual High/Low side gate drivers will be used to drive the FETs. The microcontroller will provide the PWM signal that is fed to the gate drivers. A transformer will be the final stage in the conversion and is used to boost the inverters output from the 10V to 170V peak value needed for $120V_{rms}$. The inverter should be able to handle 100W at the output. Finally, it will be monitored by the microcontroller to provide information on the power delivered to the load.

Output 120VAC/Variable Load: The output will be a standard 120VAC outlet as well as a variable load station. The load station should be variable from 0-100W in order to demonstrate the effects of increased load on converter efficiency. In order to simulate 0-100 W ten 1kΩ 20W resistors of the PF1260 series will be used. These specific resistors will be able to handle the amount of power and voltage outputted by the circuit. By using manual switches as well as placing these resistors in parallel, the power will be able to be controlled.

Microcontroller: The microcontroller, PIC 18LF2610, will control all the components in the project as it will determine power measurements of the power generation and charging process, the efficiency of the solar panel and hand crank power generation, and provide the user with descriptions on the whole process. It will also provide PWM signal for the inverter circuit and the duty cycle for the charging circuit. The PIC has 10 analog to digital I/O pins which will be used to control project components and to calculate performance data. It has an operating voltage range between 2.0V to 5.0V, so an LM7805 IC voltage regulator will be used to go from 12V at the battery to 5V on the PIC.

User Interface: The user interface for this project will be a Motorola droid phone for which an android app will be developed specifically to control all aspects of the project. They will have the ability to see a system map of all the components, and select the section they want to specifically monitor. As well as switch between active loads, monitor duty cycle, efficiency, voltage, percent charge, and review a brief description on each project component. The droid phone and the microcontroller will connect wirelessly through Bluetooth.

Schematics

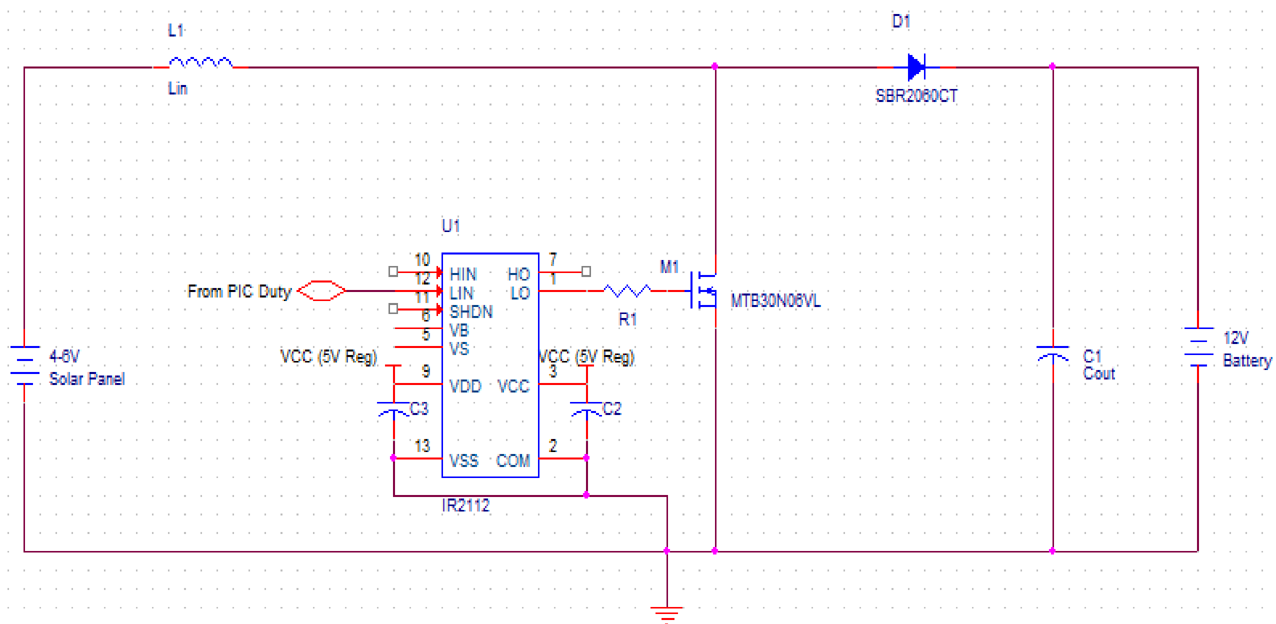


Figure 1:Boost Converter Schematic

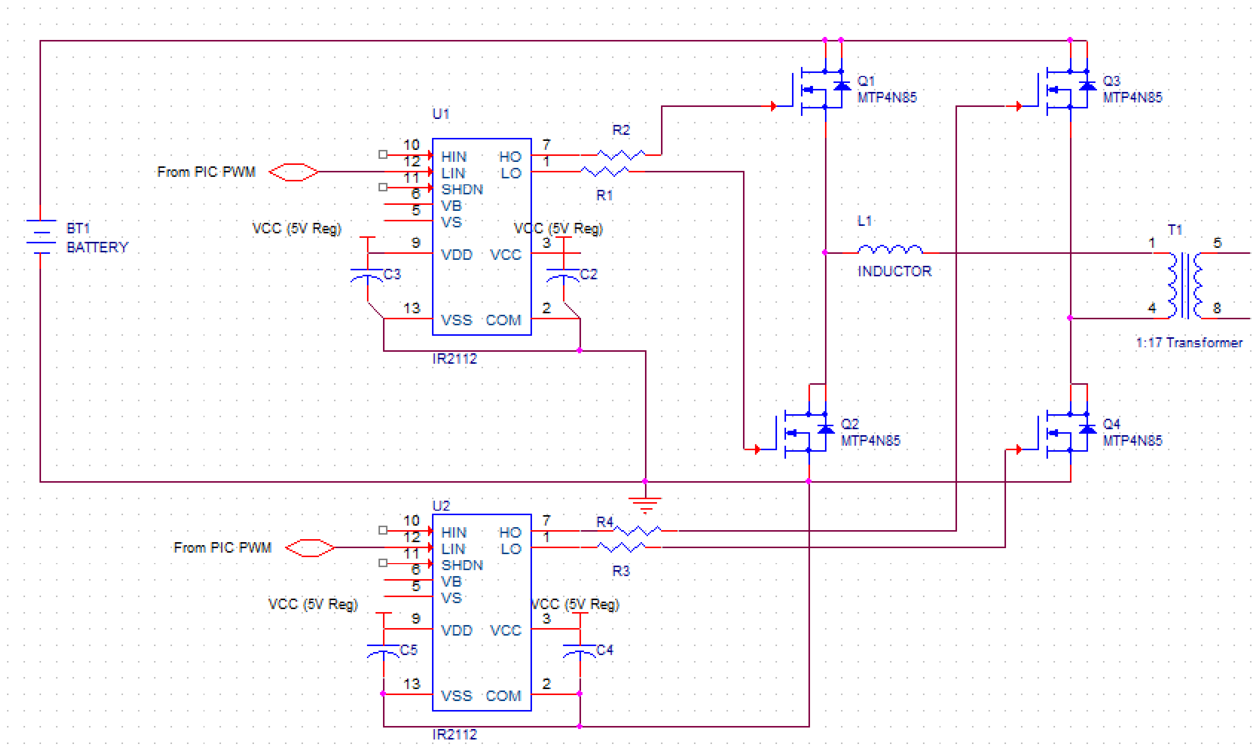


Figure 2: Inverter Circuit Design

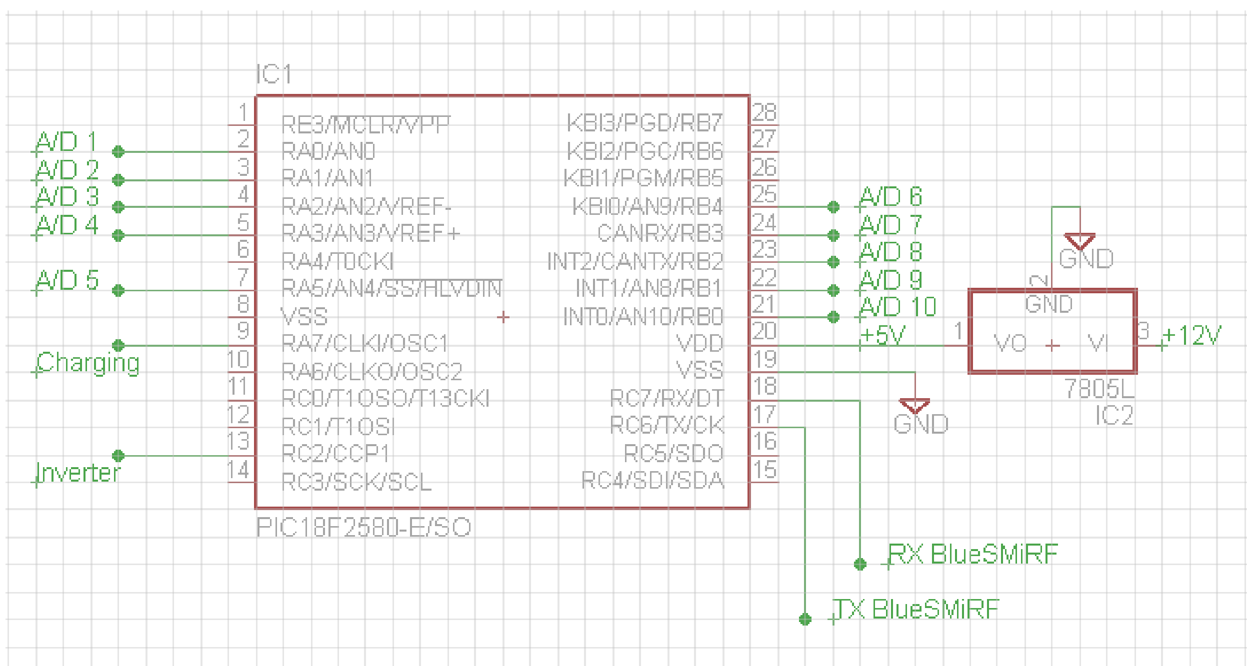


Figure 3: Microcontroller Circuit Design

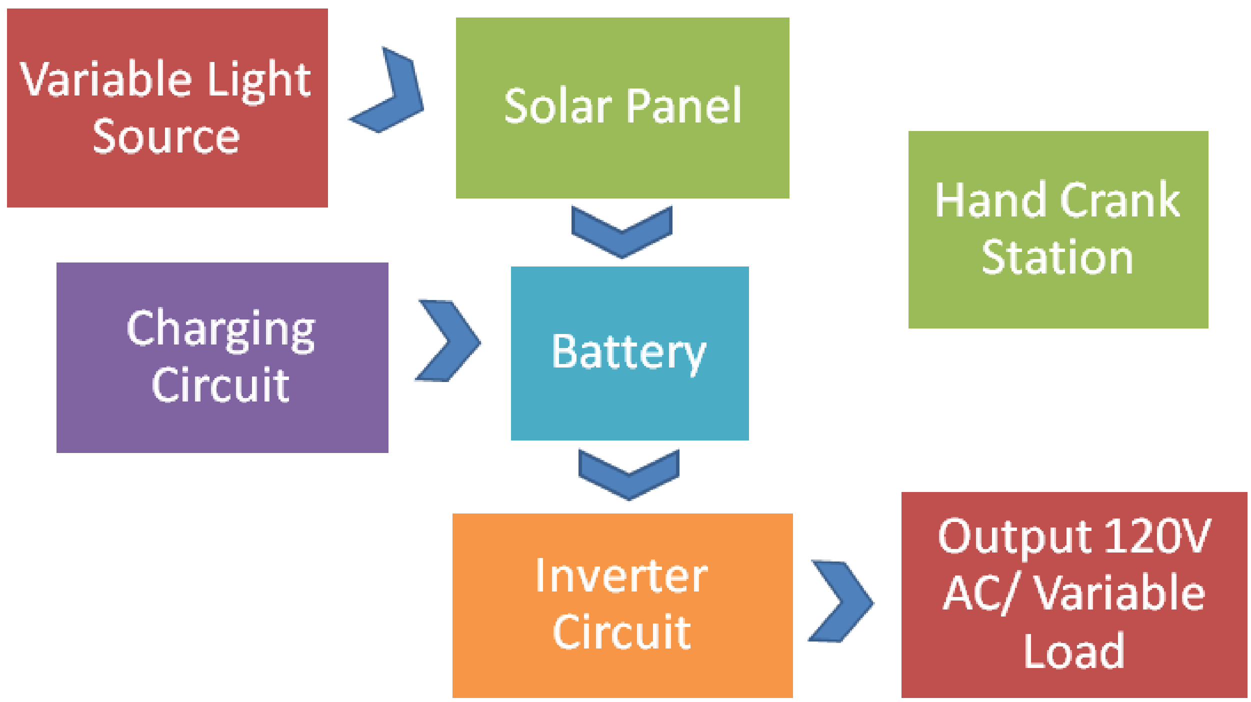


Figure 4: Android App Home Screen

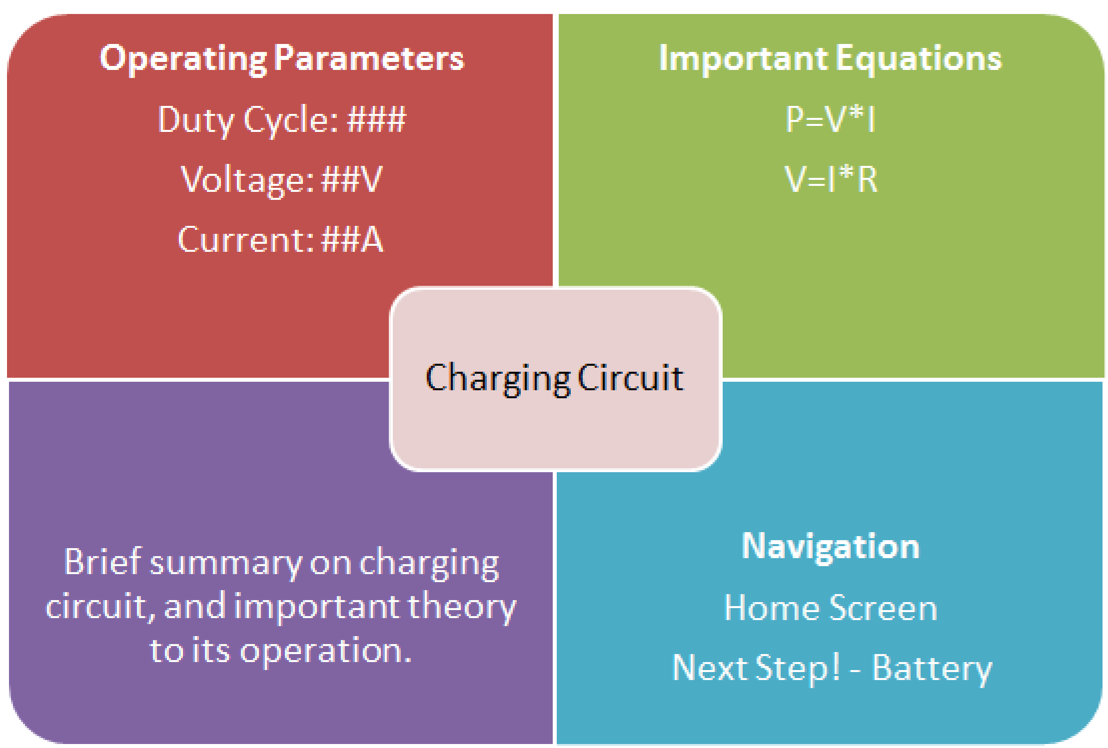


Figure 5: Charging Circuit Screen

<u>Design Calculations</u>

Battery Sizing:

Ideally the battery could power a 100W load for a 50 minute class period.

$$E_{batt} = 100 * \frac{50}{60} = 80 \text{ Wh}$$

This implies that the 12V, 7Ah (84Wh) battery just meets this requirement. This is ok since in reality the load will not be continuously connected and will be varied from 0-100W throughout the class period.

Solar Panel:

Ideally the Solar Panel will provide enough power to charge the battery 10% in the aforementioned 50 minute class period.

$$E_{solar} = \frac{84 * .1}{.8} = 10.5\text{W}$$

Our 30W panel should provide more than enough power to handle this functionality.

Charging Circuit:

Input: 4-6V_{dc} from Solar Panel
Output: 13.7V +/- 0.1V_{dc} to the Battery
MCU to deliver Switching Signal

The characteristic equation for a Boost topology converter is given in equation 1 below. This assumes ideal parts (i.e. no voltage drop across the diode) and was used when making the design calculation.

$$Vout = \frac{Vin}{1 - D}$$

As a quick check to see whether one or two boosts would be needed the Duty values were calculated in the extreme cases. These values should be between 20-80% and as can be seen below they came out within this range.

$$1 - D = \frac{Vin}{Vout}$$

$$D = 1 - \frac{Vin}{Vout}$$

$$D = 71\% \text{ or } 56\%$$

One issue is how close the duty cycle gets to 80% even when using a simplified model. This implies a need to check a more realistic model by including a voltage drop across the diode of 0.5V (the value for the SBR2060CT). The new equation for duty cycle is worked out below.

$$< V_L > = 0 = V_{in} + 0.5 * D + V_{out} * D - 0.5 - V_{out}$$

Solving for D yields:

$$D = \frac{Vin - Vout - 0.5}{Vout - 0.5}$$

D = 77%

This is close but still below the 80% mark so the design can be continued.

With the duty signal verified the parts now need to be selected. First is the capacitor sizing which determines the ripple on the output of the converter. This is done by using the characteristic equation for a capacitor given below.

$$i_c = C * \frac{\Delta V}{\Delta t}$$

$$C = i_c * \frac{\Delta t}{\Delta V}$$

For a Boost converter the current is simply the output current when the MOSFET is on. The current relationship is simply the inverse of the voltage relationship. Therefore, for our circuit, the output current will be either 1.45A or 2.2A in the worst case scenario when the solar panel is supplying its full 5A. Using the values above the Capacitance should be 66µF.

Now the diode and MOSFET must be sized for voltage and current ratings. Both the diode and MOSFET must be able to block:

$$Vout - Vin$$

Therefore, in worst case when the input is 4V they must be able to block 9.7V. The current they can carry must be I_{in} which in the worst case is 5A.

Finally, the inductor value must be large enough such that the converter remains in continuous mode. To find the inductor value the characteristic equation of an inductor was used.

$$V_L = L * \frac{\Delta i}{\Delta t}$$

$$L = V_L * \frac{\Delta t}{\Delta i}$$

Using this equation when the MOSFET is on yields an inductance value greater than 3µH.

Inverter:

Input: 11-13V_{dc} from the battery
Output: 120V_{ac}, 60Hz, sine wave to variable load
Take a PWM signal from the MCU

A Full-Bridge or H-Bridge inverter will be used in our design with PWM switching signal. In this set-up the MOSFETs must be able to block the peak voltage and carry the highest peak output current. For our design the current peak will be 8.33A and the peak voltage will be the 12V_{nom} from the battery. The output from the inverter will be sent to a step-up transformer. This transformer will have to take the 10V peak from the inverter and boost it up to 170V peak. This means a 1:17 winding will be used. The transformer should be able to handle 100W on either side which means 1.18A on the secondary (high-side) and 8.33A on the primary (low-side).

Performance Requirements

- At least a 25 foot range for the wireless Bluetooth technology
- 60% efficiency for the conversion process
- 0-100 W Variable load
- A battery that stays charged for a 50 minute class period

Verification

Performance Requirement	Testing and Verification Procedure
1) The solar panel will provide 8 Wh a) The open circuit voltage will be approximately 6 V outside on a day when the sun is unobstructed for at least 70% of the time b) The short circuit current of the solar panel will be 5-6 A outside on a day when the sun is unobstructed for at least 70% of the time c) Plot of the solar panel's I-V curve will be fitted to the curve of Figure 1 within 10%	1) Measure the output power when the lamp is on at full power and is shone directly onto the solar panel a) Obtain the open circuit voltage with the solar panel outside at noon on a day with >70% sun by measuring voltage with a known resistance b) Obtain short circuit current of the solar panel by dividing the obtained voltage by the known resistance c) Once the current and resistances are known, the results will be plotted on a graph and the output will be analyzed and included in documentation
2) The charging circuit will provide proper voltage level for charging of the battery over entire solar panel range. a) Can handle the 4-6V input variation with external Switching Signal. b) Able to accept switching signal from PIC c) Provide reverse current protection	2) Monitor the converter recording P_{in} ,P_{out}, V_{out}, V_{in} to see proper operation and record efficiency. a) Connect input to variable power supply and provide a duty signal from a function generator. Measure output voltage on oscilloscope to verify proper 13.7 +/- 0.1V output. Ensure duty cycle is within 10-90%. b) Check signal leaving PIC with oscilloscope. Check signal leaving gate driver using oscilloscope. c) Use a diode that can handle 5A to limit reverse current
3) The battery will charge >10% each hour and to a full 12 V	3) Connect the battery to a charging station for 1 hour and use a multimeter to measure the voltage then measure the voltage three more times to check the full 12 V
4) The inverter should convert the output from the battery into 120VAC to either of the loads a) Can handle $12V_{dc}$ to $120V_{ac}$ conversion over entire output range with external PWM signal. b) Can accept PWM signal from PIC	4) Test the converter over the entire load range. Record efficiency data as well as display output waveform on oscilloscope. a) Using external PWM from function generator view output waveform. Vary the load over entire range and check that ripple is ±10% and that none of the components burn b) Examine outputs from the oscilloscope to check that PIC is generating proper PWM signal and that gate-drivers are

	providing proper PWM.
5) The microcontroller will make accurate measurements of the inputs including the power measurements from the solar panel and hand crank, the charging of the batter, and the efficiency of the circuitry to within 5% of the actually value a) PWM signals to the inverter circuit b) Signals should be sent and received from the Bluetooth chip c) Duty cycle generated to the charging circuit d) 5 V voltage regulation at Vdd on the PIC	5) Because the output of the solar panel and the hand crank can be found from aforementioned processes, lab equipment will be used to test values from the microcontroller and a chart will be created to ensure functionality within 5% of the actual value. a) View oscilloscope to ensure the microcontroller is producing accurate values. b) The Bluetooth connectivity will be tested by using test text to check connectivity. c) An oscilloscope will be used to compare the actual duty cycle. d) Use a multimeter to ensure the LM7805 IC is regulating voltage properly from 12V.
6) Hand Crank Station should ouput 5V+/-1V a) The hand crank startup torque should be no greater than 6.87 Nm	6) Hook output to voltmeter and verify 5V +/-1V at the output under moderate human strain a) Measure torque by finding the product of the length of the arm, the magnitude of the force and the sine of the angle between the force vector and arm vector
7) The load station will not reach more than 21 degrees Celcius	7) Place a thermometer on the load station with all switches open for at least 5 minutes

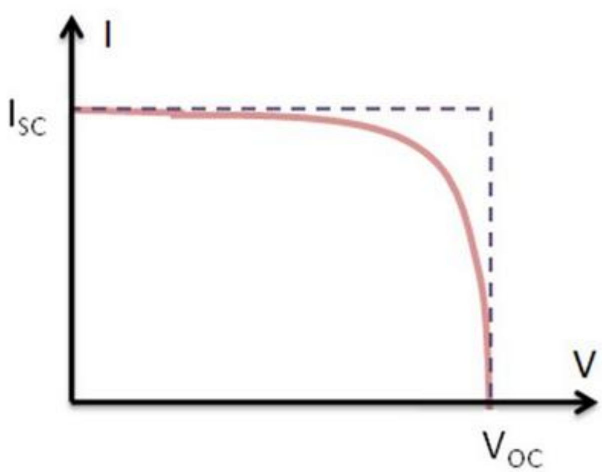


FIGURE 1: IDEAL SOLAR PANEL I-V CURVE

Tolerance Analysis

Batteries have tight voltage regulations when charging and as such the charging circuit must have a strictly regulated output. This means that the converter in the charging circuit will need to have a small voltage ripple in order to insure safe charging. This can be designed for through PSPICE in the early stages of the design and can be tested and verified using a bench power supply and oscilloscope once the circuit has been built.

Solar Panel Specifications

The projected output from the solar panel and the maximum power point is found by applying a known resistance in parallel with the panel and testing the voltage drop across the resistance. These two values will then be used to find current since

$$I = \frac{V}{R}$$

Once the current value is found, the output power is found by multiplying the known voltage and current since

$$P = IV$$

Cost and Schedule

Cost Estimate

Parts:

Part	Cost	Quantity	Total	Status
Motorola Droid phone	$125.00	1	$125.00	Obtained
Battery Model 718065F2 12V	$28.00	1	$28.00	Obtained
BlueSMiRF Gold Bluetooth Chip	$64.95	1	$64.95	Obtained
Universal Power Group Solar Panel	$40.00	1	$40.00	Obtained
PIC 18LF2610	$6.02	1	$6.02	Obtained
Electronic Components	$30.00	1	$30.00	To Order
Hand Crank	$25.00	1	$25.00	Obtained
Dimmer	$15.00	1	$15.00	To Order
Lamp	$23.00	1	$23.00	Obtained
PF1260 Resistor	$2.42	10	$24.20	To Order
AC Current sensor	$14.15	1	$14.15	To Order
DC Current Sensor	$20.38	2	$40.76	To Order
LM7805	$0.69	1	$0.69	To Order
DC Motor	$10.00	1	$10.00	Obtained
		Total	$446.08	

Labor:

Philip	$30/hour	2.5	13.5 weeks	12 hours/week	$12,150
Sierra	$30/hour	2.5	13.5 weeks	12 hours/week	$12,150
Luis	$30/hour	2.5	13.5 weeks	12 hours/week	$12,150
				Total	$36,450

Labor + Parts = $36,450 + $366.97 = $36,816.97

Schedule

			Philip	Sierra	Luis
Week 1	2/5/2012	2/11/2012	Block Diagram	Introduction/Description	Proposal Description
Week 2	2/12/2012	2/18/2012	PSPICE simulation for Buck and inverter	Order Parts, Sign up for Design Review	PIC circuit design / 5V Power Circuit
Week 3	2/19/2012	2/25/2012	Design Review, Build and test Buck converter	Design Review	Design Review
Week 4	2/26/2012	3/3/2012	Build and test inverter circuit	Test solar panel, PSPICE 5V circuit	Bluetooth Coding
Week 5	3/4/2012	3/10/2012	Compile solar power, battery, and inverter	Build hand crank	Develop Android App
Week 6	3/11/2012	3/17/2012	Individual Progress Report	Individual Progress Report	Individual Progress Report
Week 7	3/18/2012	3/24/2012	SPRING BREAK	SPRING BREAK	SPRING BREAK
Week 8	3/25/2012	3/31/2012	Mock Demo	Mock Presentation	Packaging design
Week 9	4/1/2012	4/7/2012	Interface with microcontroller	PCB fabrication design	Interface with microcontroller
Week 10	4/8/2012	4/14/2012	Testing power circuit	Revise PCB as necessary	Testing interface
Week 11	4/15/2012	4/21/2012	Final Presentation, Presentation sign-up	Final Presentation	Final Presentation, Demo sign-up
Week 12	4/22/2012	4/28/2012	Final Paper	Final Paper	Final Paper
Week 13	4/29/2012	5/5/2012	Editing final paper	Editing presentation	Editing final paper

Ethical Considerations

When designing a product, one must take certain precautions in order to ensure that the project meets ethical standards such as the IEEE Code of Ethics. For this specific project two major ethical considerations should be addressed. The first is that the end project must be safe since the end product is an educational display. In order to achieve this goal, the appropriate measures will be taken in limiting voltage, avoiding exposed circuitry and providing adequate information regarding the use of the product. The second ethical issue that this project encounters is providing accurate data. The user should not be misled regarding the efficiency of the solar panel or any other information that is given to the user. Other than these two subjects, the topics outlined in the IEEE Code of Ethics will be followed as well.

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