Solar powered battery charging system

B.E. Electronic Engineering

Final Year Project Report - Draft

Catherine Conaghan

Supervisor: Dr. Maeve Duffy
Abstract

In today's environmentally conscious climate there is more and more interest being taken in alternative forms of power supply. Currently there are plans underway for a new Engineering Building for the University, in which it is hoped that some of these alternative and more environmentally friendly technologies may be incorporated. The purpose of this project is to investigate the feasibility of implementing a mobile phone charging system, to be used by students, which is powered by energy generated from solar panels that may be integrated into the fabric of the building.

This project involves designing a small scale mobile phone charging system which is powered via a solar panel and that is capable of charging multiple mobile batteries simultaneously. The project also requires research into the different solar panels available for the small scale system being designed, as well as into larger solar panels that may be implemented into a building's design. Investigations will also have to be made into how the overall system would change if these larger solar panels were implemented. The small scale test system will also be able to display information visually to the user of the system regarding the system's overall capacity to charge at any given time and will also include power management functions.
Acknowledgements

I would like to begin by thanking my project supervisor Dr. Maeve Duffy, for her supervision and advice throughout this project. Without her help this project would not have been possible. I would also like to thank my co-supervisor Dr. Peter Corcoran for his advice throughout the year.

A special thanks must go to the Electronic Engineering department lab technicians, Myles Meehan and Martin Burke. There help over the last year, and the duration of the four years, has been invaluable and is very much appreciated. I also wish to extend my thanks to post-graduate student Sara Armstrong for providing the solar panel, as well as answering any of questions throughout the course of the project.

Finally, I would like to thank my friends and family for their support and patience throughout the year, especially to my parents Pat and Maria, who without their encouragement and financial support, the last four years would not have been possible.
Declaration of Originality

I declare that this thesis is my original work, except where stated.

Signature: _______________________

Date: ________________
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Chapter 1: Introduction

Solar power is a renewable source of energy, which has become increasingly popular in modern times. It has obvious advantages over non-renewable energy sources, such as coal, oil and nuclear energy. It is non-polluting, reliable and can produce energy anywhere that there is sun shining, so its resources are not going to run out anytime soon. It even has advantages over other renewable energy sources, including wind and water power. Solar power is generated using solar panels, which do not require any major mechanical parts, such as wind turbines. These mechanical parts can break down and cause maintenance issues and can also be quite noisy. Both of these issues are virtually non-existent with solar panels. Also, the solar cells, that connected together make up the solar panel, can last up to several decades without replacement.

However, there is a drawback to solar power – energy can only be produce when the sun is shining. To overcome this, usually solar panels are coupled with back up rechargeable batteries, which can store excess power generated during the day and use it to provide energy to systems when there is no sun shining. In this way solar power can be used to power houses and other large scale systems. In these systems DC-AC conversion is needed. This is because the solar panel produces an output that is DC (Direct Current) and the power supply in homes usually runs off AC (Alternating Current), so conversion is required. For this project, however, the load to be connected only requires DC input, so DC-AC conversion is not needed. Instead, DC-DC conversion would be used to provide the correct power to the system from the power generated by the solar panel. Using this information, a number of design solutions were determined and considered.
1.1 Design Solutions

In the early stages of the project various design solutions were employed. The initial design solution can be seen in Figure 1.1

![Design Solution with charging algorithm](image1)

**Figure 1.1 Design Solution with charging algorithm**

The solar panels voltage would be controlled a DC-DC converter, most likely a commercial one, and the main circuitry design would be in implementing the mobile phone charging algorithm to charge the mobile phones at the load. It was soon discovered that the charging algorithm for the mobile phones would not be needed as the phones charging algorithms are contained on the phones themselves. However, early research into solar panel powered systems highlighted the need to apply some form of power management to the panel to allow for optimum efficiency. It also became obvious that there would be a need for a storage device so that the solar panel could store energy when there is no load connected. The design was varied to suit these needs, as is shown in Figure 1.2

![Design solution including backup battery](image2)

**Figure 1.2 Design solution including backup battery**
A commercial charge controller IC was sourced that met with the specifications of the project. However, a number of problems were encountered with using the IC chip, which will be discussed in the final chapter, so a different, final, design approach was developed. It is seen in Figure 1.3

![Design solution for final system](image)

**Figure 1.3 Design solution for final system**

This is the design method that the final system is based on. It is comprised of a solar panel whose voltage is regulated by a DC-DC converter. The power management of the solar panel comes in the form of maximum power point tracking (MPPT), which will be discussed in greater detail further on. For this design it entails using an outside controller to control the duty cycle of the DC-DC converter. It was decided that the DC-DC converter would have to be built in the lab, as it was difficult to find a suitable commercial converter that could be controlled in this way. The output of the converter is then applied to the back-up battery and the load.
Chapter 2: Photovoltaic Array/Solar Panel Characteristics

2.1 Photovoltaic Array Background

A Photovoltaic (PV) array is the energy source used in this project. PV arrays essentially consist of a number of internal silicon based photovoltaic cells combined in series and in parallel, depending on the voltage or current requirements. These cells are used to convert solar energy into electricity. This occurs when the photovoltaic cells are exposed to solar energy causing the cells electrons to drift which, in turn, produces an electric current. This current varies with the size of individual cells and the light intensity.

2.1.1 PV Cell Chemistries

Photovoltaic cells, or solar cells as they are more commonly referred to, are available commercially in a number of different semiconductor materials. The most common materials are monocrystalline silicon, polycrystalline silicon, amorphous silicon and copper-indium selenide (CIS). These technologies consist of p-n junction diodes capable of generating electricity from light sources and usually have efficiencies of 6% - 20% in commercial use.

The most popular type of thin film photovoltaic technologies are CIS arrays and amorphous silicon arrays. These thin film panels consist of a layer of silicon sandwiched between a sheet of glass and a sheet of plastic. A laser scribe is then used to mark out individual cells. They have very good efficiency on sunny days, better than the crystalline silicon based cells mentioned below. However they do suffer from a considerable drop in efficiency under cloudy conditions.

Monocrystalline and polycrystalline silicon arrays are constructed in much the same way, however are made up of individual 0.5 V cells connected together to achieve the desired voltage. They weigh less than the amorphous and CIS arrays, and are about half
the size. Although they do attain as high efficiencies as the amorphous cells, they do perform better under cloudy conditions, making them very suitable for year round use.

2.1.2 Equivalent Circuit of a Photovoltaic Cell [2]
The equivalent circuit of a PV cell is demonstrated below in Figure 2.1.

![Figure 2.1 Equivalent circuit of a PV cell](image)

Derived from Kirchoff’s first law (also referred to as Kirchoff’s current law), the output current is given by

\[
I = I_{\text{ph}} - I_0 - I_p
\]

\[
I = I_{\text{ph}} - I_{\text{sat}} \left( \exp \left( \frac{q(V_o + I.R_s)}{n.K.T_{\text{cell}}.N_s} - 1 \right) - \frac{V_o + I.R_s}{R_p} \right)
\]

where

- \( I \) Output current
- \( I_{\text{ph}} \) Photo current
- \( I_{\text{sat}} \) Diode reverse saturation voltage
- \( V_o \) Output Voltage
- \( R_s \) Series resistance (Representing voltage loss on the way to external connectors)
- \( R_p \) Parallel resistance (Representing leakage currents)
- \( k \) Boltzmann’s constant
- \( q \) Charge on electron
- \( N_s \) Number of cells in series
- \( N \) Ideality factor
- \( T_{\text{cell}} \) Solar panel temperature
2.1.3 I-V Characteristic of the Photovoltaic Array [3]

From *Figure 2.1*, the current generated in the solar cell by the current source (Iph) is proportional to the amount of light falling on it. When there is no load connected to the output Vo almost all of the generated current flows through diode D. The resistors Rs and Rp represent small losses due to the connections and leakage respectively. There is very little change in Voc for most instances of load current. However, if a load is connected to the output then the load current draws current away from the diode D. As the load current increases more and more current is diverted away from the diode D. So, as the output load varies so too does the output current, while the output voltage Voc remains largely constant. That is until so much current is being drawn by the load that diode D becomes insufficiently biased and the voltage across it diminishes with increasing load. This results in an I-V characteristic as shown in *Figure 2.2*.

![I-V Characteristics of P* cell](image)

*Figure 2.2 I-V characteristic of a solar cell*

These characteristics of the solar cell can result in a loss of power when providing power to a load. This will be discussed in further detail in the next chapter.
2.2 10 Watt Solar Panel

2.2.1 10 Watt Solar Panel Characteristics\textsuperscript{[4]}
The PV panel used in this project is the Shell ST10 10 Watt solar module in Figure 2.3. It is composed of a monolithic structure of series connected Copper-Indium Selenide (CIS) based solar cells. It has the following electric characteristics at the standard test conditions (STC) of an irradiance level of 1000 W/m\textsuperscript{2} and cell temperature of 25°C

- Rated Power (Pr) = 10 Watts
- Peak Power (Pmpp) = 10 Watts
- Peak Power Voltage (Vmpp) = 15.6 Volts
- Peak Power Current (Impp) = 0.64 Amps
- Open Circuit Voltage (Voc) = 22.9 Volts
- Short Circuit Current (Isc) = 0.77 Amps
- Minimum Peak Power (Pmpp min) = 9 Watts

*Figure 2.3 Shell ST10*

2.2.2 Testing the Solar Panel
The solar panel was tested under a constant light source in the lab, using different resistances and was set-up as in Figure 2.4

*Figure 2.4 Testing solar panel circuit diagram*

Voltage V was measured across the solar panel terminals for varying resistances and current was calculated using ohms law: $I = \frac{V}{R}$
Voc = 11.4V

Table 2.1 Voltage and current readings for Shell ST10

<table>
<thead>
<tr>
<th>Resistance (kΩ)</th>
<th>Voltage (V)</th>
<th>Current (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.46</td>
<td>4.6</td>
</tr>
<tr>
<td>0.15</td>
<td>0.68</td>
<td>4.5</td>
</tr>
<tr>
<td>0.18</td>
<td>0.83</td>
<td>4.5</td>
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<tr>
<td>0.22</td>
<td>1.2</td>
<td>4.4</td>
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<td>0.68</td>
<td>2.8</td>
<td>4.1</td>
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<td>3.8</td>
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</tr>
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<td>10.8</td>
<td>0.6</td>
</tr>
<tr>
<td>27</td>
<td>11</td>
<td>0.4</td>
</tr>
</tbody>
</table>

The data was graphed in Figure 2.5:
Chapter 3: Maximum Power Point Tracking

As discussed in the previous chapter, from looking at the I-V characteristic of the photovoltaic cell (Figure 2.2), it can be seen when the array is operating at its short circuit current, the voltage across the output terminals will be zero. Since power is the product of current and voltage it is clear that the power is zero at this point. Furthermore, it can be seen that if there is no load applied to the output terminals of the array no current is being drawn and the array is operating at the so called open circuit voltage Voc. When the panel is operating at Voc the output power is also 0 Watts. So, the array will provide power when the voltage is between 0 Volts and Voc. For most system it is desired that that the array be operating at a point called the Maximum Power Point (MPP). This is the point where the product of voltage and current is at its maximum. The P-V characteristic of an ideal cell is shown below in Figure 3.1

![P-V & I-V Characteristic of a Solar Cell](image)

Figure 3.1 P-V characteristic of a Solar Cell [3]
3.1 Maximum Power Point of Shell ST10

Using the voltage and current data previously recorded in Table 2.1, power was calculated using the formula \( P = VI \)

<table>
<thead>
<tr>
<th>Resistance (kΩ)</th>
<th>Voltage (V)</th>
<th>Current (mA)</th>
<th>Power (mW)</th>
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<tbody>
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<td>0.6</td>
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</tr>
<tr>
<td>27</td>
<td>11</td>
<td>0.4</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Table 3.1 Power calculated for Shell ST10

The data was plotted and displayed below:

Figure 3.2 P-V characteristic for Shell ST10
The PV array is operating at peak power when $V = 6.7$. Using the graph in Figure 2.5 it can be seen that this voltage corresponds to a current of $3.04$ mA.

### 3.2 MPPT Algorithms

A MPPT tracking algorithm will be used to control the duty cycle of a DC-DC converter. In this way, the algorithm will force the solar panel to operate at, or very close to, its maximum power point. The algorithm will be implemented using the software program Labview.

There are a number of different MPPT algorithms have been developed over the years. The most dominant methods are the Perturb & Observe Algorithm and the Incremental Conductance Algorithm.

#### 3.2.1 The Perturb & Observe (P&O) Algorithm

The P&O is probably the most commonly used approach out of all the MPPT methods used today, as it is lacking in complexity and can be relatively easy to implement. It works by periodically incrementing or decrementing the voltage of the PV array. The change in power is then observed. If the perturbation has resulted in an increase in the output power then the algorithm continues to perturb in the same direction. If there is a decrease in power then the algorithm will perturb in the opposite direction. This is demonstrated in the flowchart in Figure 3.3. When the P&O algorithm has found the MPP it never actually settles on it, rather it oscillates around it.
Figure 3.3 P&O flowchart

'Set duty cycle' refers to duty cycle that will control the DC-Dc converter, which will in turn perturb the PV array voltage. 'Duty(+)' represents the duty cycle being perturbed in the same direction again and 'Duty(-)' means the duty cycle is perturbed in the opposite direction.
3.2.2 The Incremental Conductance (INC) Algorithm[6]

The INC algorithm uses the PV array's incremental conductance to determine the direction of perturbation. As can be seen in Figure 3.4, at the MPP \( \frac{dp}{dv} = 0 \). Also,

\[
\frac{dp}{dv} = \frac{d(iv)}{dv} = i + v\left(\frac{di}{dv}\right)
\]

Voltage and current are measured and if \( i + v\left(\frac{di}{dv}\right) = 0 \) then the PV array is operating at its maximum power point and no perturbation occurs. However, if it is not equal to zero a decision has to be made as to which direction the next perturbation will happen. From the graph below it can be seen that the direction of the next perturbation can be determined by detecting if \( \frac{dp}{dv} > 0 \) or \( \frac{dp}{dv} < 0 \).

![Incremental Conductance graph](image)

**Figure 3.4 Incremental Conductance graph**

The perturb and observe algorithm will be used in the project as the control method to manage the duty cycle of the DC-DC converter as it is the most reliable of the two methods.
Chapter 4: DC-DC Converters

A DC-DC converter is a circuit which takes in a DC voltage at the input and converts it to a different DC voltage level at the output. Linear DC-DC converters drop the input voltage to a lower output voltage only and can be useful in some applications as they are relatively low in complexity. However, they can prove inefficient as the dropped voltage is dissipated as heat. This also means that the regulator may require a heat sink, which can sometimes be impractical. Switch mode converters are more complex in their design as they use an inductor and a capacitor to store energy, as well as having a switch. This increase in complexity is offset by the fact that switch mode regulators are large more efficient than their linear counterparts. Also, as there is less energy being lost in the transfer, thermal management is not as important. Finally, because of the use of an inductor in the circuit, the energy stored in it can be used to output voltages that are greater than the input voltage. These basic components can be rearranged to form different converter, namely the buck converter, the boost converter and the buck-boost converter, which will be discussed in further detail.

4.1 Switch Mode Converters

4.1.1 Switch Mode Operation
They are called switch mode converters as they use power switching techniques to achieve the DC-DC conversion. The basics of the switch mode operation is explained in this simple chopper circuit in Figure 4.1

![Figure 4.1 DC-DC chopper circuit](image-url)
While the switch is closed, the voltage at the input $V_i$ is applied to the load. While the switch is open the voltage at the output $V_o$ is zero. It can be seen in Figure 4.2 that $V_o = <V_o>$.

![Chopper circuit output voltage waveform](image)

**Figure 4.2 Chopper circuit output voltage waveform**

The duty cycle, $D$, is the ratio of the on time of the switch (closed switch) to the total switching period, $T$. For example, if switching period is 10ms and the switch is on (closed) for 4ms, then the duty cycle would be 0.4.

From this it can clearly be seen that

$$<V_o> = DV_i$$

so,

$$V_o = DV_i$$

### 4.1.2 Pulse Width Modulation

The switch is usually controlled by using pulse width modulation (PWM). PWM is generated by comparing a triangular or a sawtooth waveform to a reference voltage, as can be seen in Figure 4.3.
As can be seen from above, whenever the amplitude of the reference voltage is greater than that of the sawtooth waveform the switch is turned on. Once the reference voltage amplitude is lower the waveform, the switch turns off. It is also clear from Figure 4.3 that varying the frequency of the sawtooth or triangular waveform will also vary the frequency of the pulse width modulated signal accordingly.

As it has already been mentioned, there are three main types of DC-DC regulators, the buck, the boost and buck-boost. The buck converter converts the voltage on the input to a lower voltage level on the output. The boost converter increases the input voltage to a higher voltage output. The buck-boost converter is a combination of the two and can operate in both modes.

4.1.3 The Buck Converter
The buck converter, also known as a step-down converter, produces a lower voltage on the output then received on the input. Its circuit consists of an inductor, a capacitor, a diode and a switch (usually a MOSFET) and can be seen in Figure 4.4
The buck circuit has two modes of operation:

**Mode 1:**

\[ Vo = V_i - V_L \]

**Figure 4.4 Buck Converter**

In the first mode the switch is on (closed). This causes all of the input voltage to be applied across the diode, D, causing it to be reverse biased. During the time the circuit is in this state, current builds up in the inductor increasing its stored energy. Hence, the output voltage is,

\[ V_o = V_i \cdot V_L \]

Manipulating this equation,

\[ \frac{V_i}{dt} = L_o \frac{di_L}{dt} + V_o = L_o \frac{\Delta I_L}{DT} + V_o \]
Mode 2:

![Diagram of Mode 2 buck converter](image)

*Figure 4.6 Mode 2 of buck converter* [8]

When the switch is off (opened) the current that was stored in the inductor now flows through the diode, making the diode forward biased. There is no voltage at $V_i$ so, for the output,

$$0 = V_o + L_o \frac{dI_L}{dt} = V_o - L_o \frac{\Delta I}{(1 - D)T}$$

The increase in current when the switch is turned on, must be equal to the decrease in current when the switch is turned off, as there cannot be a net change in flux in the inductor. Therefore,

$$\Delta I_+ = \Delta I_- = \Delta I$$

manipulating the equation in mode 1, we get

$$\Delta I_+ = \frac{V_i - V_o DT}{L_o}$$

manipulating the equation in mode 2, we get

$$\Delta I_- = \frac{V_o (1-D)T}{L_o}$$

it follows that,

$$\frac{V_i - V_o DT}{L_o} = \frac{V_o (1-D)T}{L_o}$$
\[ V_o = D V_i \]

assuming an ideal circuit,

\[ P_{in} = P_o \]

\[ V_i I_i = V_o I_o \]

\[ I_o = \frac{I_i}{D} \]

So the output voltage, \( V_o \), is determined by the duty cycle of the switch, \( S \). Since the duty cycle is a ratio and always between 0 and 1, it is clear that the voltage on the output will always be less than \( V_i \).

There are, however, some disadvantages of using a switch mode converter. They can be quite noisy and suffer current ripple and voltage ripple. In the buck converter these are calculated in the following way

**Current Ripple \( \Delta I \):**

\[
T = \frac{1}{f} = DT + (1 - D)T
\]

\[
T = \frac{\Delta I L_o}{V_i - V_o} + \frac{\Delta I L_o}{V_o}
\]

\[
\Delta I = \frac{V_i D (1 - D)}{f L_o}
\]

**Voltage Ripple \( \Delta V \):**

Since,

\[
\Delta V = \frac{\Delta S}{C} = \frac{\Delta I}{C} \cdot T = \frac{V_i D (1 - D)}{2.22 C \cdot 8 L_o C f^2}
\]

Then,

\[
\Delta V = \frac{V_i D (1 - D)}{8 L_o C f^2}
\]
4.1.3.1 Buck Converter Waveforms

**Figure 4.7** Buck converter duty cycle

**Figure 4.8** Buck converter output current

**Figure 4.9** Buck converter inductor current

**Figure 4.10** Buck converter diode current
4.2 DC-DC Converter Design

A buck converter was chosen as the dc-dc converter to be used in this project. It was chosen as the voltage, under most circumstances, would be greater than the voltage required at the load. The purpose of the converter is to drive the solar panel to operate at its maximum power point by controlling the duty cycle of the switch, and to bring the voltage to a low enough level to power the load. In designing the buck converter, the main components which had to be determined for the circuit are the inductor and the capacitor. A number of parameters have to be taken into consideration in choosing appropriate values for both circuit components. The input voltage was already specified from the output specifications of the 10 watt solar panel. The output range was chosen to be between 5 volts and 10 volts as this brought to a low enough voltage to be input into most 5 volt regulators to charge the mobile phone at the output.

**Voltage input range (Vi)**: 15.6V – 22.9V
**Voltage output range (Vo)**: 5V – 10V
**Switching frequency (fs)**: 20Khz
**Current Ripple (ΔI)**: 100mA
**Voltage Ripple (ΔV)**: 30mA

As already discussed, for the buck converter

\[ V_o = D V_i \]

Using this equation and the minimum and maximum voltage ranges we can deduce the ideal duty cycle range

\[ D_{min} = \frac{V_{o\ min}}{V_{i\ max}} \]

\[ D_{min} = \frac{5}{22.9} \]

\[ D_{min} = 0.32 \]

\[ D_{max} = \frac{V_{o\ max}}{V_{i\ min}} \]
\[ D_{\text{max}} = \frac{10}{15.6} \]
\[ D_{\text{max}} = 0.44 \]

Rounding these numbers, the ideal range for the duty cycle is between 0.3 and 0.5.

From the equation for current ripple described earlier we can determine the maximum and minimum values for the inductor

\[ \Delta I = \frac{V_i D (1 - D)}{f_s L_o} \]
\[ L_o = \frac{V_i D (1 - D)}{\Delta I f_s} \]

\[ L_{o \text{ max}} = \frac{(22.9) (0.5) (1 - 0.5)}{(0.1) (20000)} \]
\[ L_{o \text{ max}} = 2.8 \text{ mH} \]

\[ L_{o \text{ min}} = \frac{(15.6) (0.3) (1 - 0.3)}{(0.1) (20000)} \]
\[ L_{o \text{ min}} = 1.6 \text{ mH} \]

Two inductors with suitable values were found. A 2.2 mH inductor and a 3.3 mH inductor. From the equation discussed earlier, regarding the buck converter output current, is it known that the output current in a buck circuit will always be higher then input current,

\[ I_o = \frac{I_i}{D} \]

The 3.3 mH inductor could only hold very small currents, so 2.2 mH inductor proved the better option. The inductor chosen had a maximum rating of 900mA. Although the solar panel has a rated Isc of 770mA, the currents measured in testing conditions in the lab were far off this so it was decided that the 2.2 mH inductor would be suitable and is used in the final circuit.
To choose an appropriate capacitor for the circuit the equation for voltage ripple $\Delta V$ previously determined in the section 4.1.3 was used

\[
\Delta V = \frac{V_i D (1 - D)}{8 L_0 C f s^2}
\]

\[
C = \frac{V_i D (1 - D)}{8 L_0 \Delta V f s^2}
\]

\[
C = \frac{(22.9)(0.5)(1 - 0.5)}{(8)(2.8 \times 10^{-3})(20000^2)(30 \times 10^{-3})} = 21.3\mu F
\]

A 22$\mu$F was chosen for the converter circuit. For the switch a MOSFET was the chosen component as the gate of the MOSFET could be controlled by the duty cycle generated by the controller. The resistance of the load can be calculated by dividing the mobile phone voltage by the maximum current for a mobile phone. For a typical mobile phone battery, the voltage is 3.6V with a current of 700mA. The calculated resistance for this particular battery would be 5 ohms. The buck converter with these calculated components is shown below in Figure 4.8.

\[\text{Figure 4.11 Buck converter with selected components}\]
Chapter 5: Circuit Simulation

5.1 Pspice

Pspice (Simulation Program with Integrated Circuit Emphasis) is a simulation tool that models the behaviour of analog circuits. It is used to verify and predict circuit behaviour. Pspice is a very useful tool in the circuit design process as you can test and modify the circuit design before ever having to use any hardware. The circuit can be designed in two ways – by building the schematic of the circuit in Pspice, or by creating a netlist of the parameters of the circuit.

5.2 Testing the Buck Converter in Pspice

For the design of the buck converter the netlist was designed as below.

Buck converter netlist:

```
.PARAM INPUT=22.9 ;input voltage
.PARAM DUTY=.44  ;duty cycle
.PARAM RLOAD=5  ;resistance of load
.PARAM L=2.2mh  ;inductor
.PARAM C=22uF   ;capacitor
.PARAM FREQUENCY=20k  ;switching frequency

VS 1 0 DC {INPUT} ;dc voltage source between 0 & 1
SW 1 3 2 0 SMOD ;switch between 1, 3, 2 & 0
D1 0 3 DMOD ;diode between 0 & 3
L 3 4 {L} IC=0 ;inductor between 3 & 4
C 4 0 {C} IC=0 ;capacitor between 4 & 0
R 4 0 {RLOAD} ;resistance of load between 4 & 0

;generates pulse
VPULSE 2 0 PULSE {-1 1 0 1nS 1nS {DUTY/FREQUENCY} {1/FREQUENCY}}

;model
.MODEL SMOD VSWITCH (RON=0.001 VON=0.1 VOFF=-0.1 )
.MODEL DMOD D(N=0.001)
.OPTIONS NOPAGE ITL5=0
```
The netlist corresponds to the circuit schematic as displayed in *Figure 5.1*.

![Figure 5.1 Corresponding circuit for Pspice netlist](image)

The circuit was tested by entering a number of different voltage input values and changing the value of the duty cycle. To verify the correct operation of the circuit the maximum and minimum numbers that were used to calculate the inductor and the capacitor in *chapter 4* were used. Pspice assumes ideal conditions for each element of the circuit.

**Maximum values:**

```plaintext
.PARAM INPUT=22.9 ;input voltage
.PARAM DUTY=.44 ;duty cycle
.PARAM RLOAD=5 ;resistance of load
.PARAM L=2.2mh ;inductor
.PARAM C=22uF ;capacitor
.PARAM FREQUENCY=20k ;switching frequency
```
The resulting graph after running the simulation is shown in *Figure 5.2*

![Figure 5.2 Pspice simulation of maximum buck parameters](image)

The output voltage is simulated and is 10 V, thus corresponds to the earlier calculations in *chapter 4*.

The voltage ripple was also measured by placing a cursor at the highest amplitude of the voltage and a cursor at the lowest point and pspice calculated the difference as shown in *Figure 5.3*

![Figure 5.3 Voltage ripple measured](image)
The voltage ripple used in the calculations was 30 mV, and the measured voltage displayed here is 35.752 mV, which is very close.

Below are the figures and the graph simulated \textit{(Figure 5.4)} for the minimum values used

\begin{verbatim}
.PARAM INPUT=15.6 ;input voltage
.PARAM DUTY=.32 ;duty cycle
.PARAM RLOAD=5 ;resistance of load
.PARAM L=2.2mh ;inductor
.PARAM C=22uF ;capacitor
.PARAM FREQUENCY=20k ;switching frequency
\end{verbatim}

\textit{Figure 5.4 Pspice simulation of minimum buck parameters}

Under these conditions the output voltage is seen to 5v, which is in accordance with earlier calculations from \textit{chapter 4}.

Testing of the circuit parameters in pspice verified the circuit design.
Chapter 6: Backup Battery

In systems that utilize solar panels as the source of energy it is recommended to employ some sort of storage device. A storage device can prove very useful as it can store any unused energy generated by the solar panel throughout the day and, in turn, this stored energy can be used to power a system when no sunlight is available to the solar panel, thus making the system more practical. The most realistic choice for this storage device is a backup battery. There are many different backup batteries available on the market today, with various different battery chemistries. A number of battery chemistries that were researched for use in this project are discussed below, highlighting the advantages and disadvantages of each.

6.1 Battery Chemistries

6.1.1 Lead Acid Batteries
Lead acid batteries are the oldest rechargeable batteries in existence. They are inexpensive, reliable and widely used today. However, they are quite heavy and for a system like this storage may be a problem. Also charging times can be quite slow. Overall, lead acid batteries are more appropriate for larger power applications.

6.1.2 Nickel-Cadmium (Ni-Cad)
Nickel-Cadmium batteries have a long shelf life, they can be left to store energy for up to five years in some cases. They have other advantages as well, they prefer fast charging and work well under rigorous conditions, as well as having quite a high efficiency at 70% - 90%. However, they have a relatively low energy to weight ratio and can suffer from memory effect. Memory effect is a phenomenon observed in some rechargeable batteries, namely those with nickel-cadmium chemistries. It occurs when the rechargeable battery is repeatedly recharged without being fully discharged. This causes the battery to lose the capacity it originally had, and the performance of the battery is significantly lowered.
6.1.3 Nickel-Metal-Hydride (Ni-Mh)
Ni-Mh based battery cells have a larger capacity than the Ni-Cad batteries, so they are lighter, and are less prone to the memory effect described above. However, they can be more expensive and have a relatively short storage life with a high self discharge rate, making them less efficient.

6.1.4 Lithium-ion (Li-ion)
Li-ion preforms the most efficiently out of all the battery chemistries discussed, with efficiencies of up to 99.9%. It also has the best weight to ratio, weighing about half that of a Ni-Cad or Ni-Mh cell of the same capacity, making the batteries light and easy to store. The average voltage of a Li-ion cell (3.6v – 3.7v) means one cell would be required for use in charging most mobile phones, compared to 3 Ni-Cad or Ni-Mh batteries at 1.2v each. Li-ion cells also relatively good life cycle, as shown in Figure 6.1. Taking all of its advantages into account, it was decided that a Li-ion backup battery would be the most suitable for this system.

![Typical Li-ion Life Cycle Characteristics](image)

**Figure 6.1 Li-ion life cycle**

The typical charging profile for a Li-ion battery is shown in **Figure 6.2**
The battery charges under constant current, at almost 1C (capacitance), while the voltage rises. Once the voltage reaches the maximum of 4.2 volts, the charge enters the constant voltage portion of the charging. Under constant voltage charging the current begins to decrease, until the charge is terminated.

6.2 Determining the capacity of the battery

It is important that the backup battery has enough capacity to store the excess energy generated from the solar panel. To determine the capacity of the battery two things had to be taken into consideration – the maximum current output of the solar panel and the maximum number of hours of sunshine on a given day.

According to the datasheet obtained for the solar panel the peak power current for the solar panel while using MPPT is 0.64 Amps. This will be the average amount of current being supplied. The short circuit current is 0.77 Amps.
From information obtained on the Irish National Meteorological Service (Met Eireann) website, the highest monthly average of hours of sunshine is in May, with 5.08 hours.

Battery Capacity is the product of the current and number of hours:

\[
0.64A \times 5.08Hrs = 3.25AH \\
0.77A \times 5.08Hrs = 3.9AH
\]

So, if no load was connected over a period of time, for example at a weekend, a Li-ion battery with a capacity of 4AH would be more than sufficient to store all the excess energy generated in one day.

### 6.3 Li-ion Battery Pack

This Li-ion 18650 3.7V 4400 mAh rechargeable battery module in Figure 6.3 at a cost of $27.00 meets all of these requirements

*Figure 6.3 Li-ion battery pack*[^12]
6.4 Safety Concerns \cite{12} \cite{13}

Li-ion batteries are, however, not without their disadvantages. There are some safety issues to be taken into account when using them. A common protective circuit to help prevent damage to the battery is built into the battery pack in Figure 6.3. Overcharging is avoided as the circuit limits the charge voltage to 4.35V maximum. The circuitry also contains a thermal sensor which disconnects the charge if the battery reaches a temperature of over 90°C. There are preventative measures in the circuit to avoid over discharge by limiting the discharge voltage to between 2.7V and 3V. However, over discharging can still occur and if the voltage drops below 1.5V copper shunts may form inside the battery causing short circuits and the battery will become unstable and unsafe to use. Most commercial Li-ion battery packs have these circuits built in, but caution is still needed when using them.

6.5 Li-ion Battery Charger IC \cite{14}

Even with this protection circuit, it is still recommended to use a IC specifically designed for charging Li-ion batteries to ensure optimum safety precautions. There are a vast range of commercial charger ICs available for Li-ion batteries such as the ISL6291 Li-ion linear battery charger, as can be seen in Figure 6.4.

\textbf{Figure 6.4 ISL6291 Li-ion battery charger}

This charger would be ideal for this system, as it takes an 5V DC voltage at the input to charge the battery, as is shown in the following circuit diagram in Figure 6.5.
**Figure 6.5** ISL6291 Li-ion charger circuit diagram

It operates by charging at the various modes outlined in **Figure 6.2**.
Chapter 7: Implementing MPPT Algorithm

The perturb and observe algorithm discussed earlier was chosen as the method to control the duty cycle of the buck converter to force the solar panel to operate at its MPP. The flowchart for the P&O algorithm for this system is shown in Figure 7.1

![Flowchart](image)

Figure 7.1 P&O algorithm to be implemented [5]

The algorithm was implemented using a NI-USB 6009 which is controlled through a computer using the programming software LABVIEW.
7.1 NI-USB 6009 [15]

The NI-USB shown in Figure 7.2, is a module used for data acquisition which can be connected to PC via a USB. It has 8 analog inputs, two analog outputs and 12 digital I/O connections.

![NI-USB 6009](image)

*Figure 7.2 NI-USB 6009*

The module is compatible with programming software LABVIEW.

7.2 LabVIEW [16]

LABVIEW (Laboratory Virtual Instrumentation Engineering Workbench) is a development environment that utilizes a graphical programming language, called “G”, developed by National Instruments. It is mainly used for data acquisition, instrument control and industrial automation. The LABVIEW program contains tools for acquiring, analyzing, storing and displaying data. Programs created in LABVIEW are called virtual instruments (VIs). VIs are made up of block diagrams and front panels. Block diagrams are where the code is developed and contain all the sub VIs (or subroutines) within the program. The front panel acts like a user interface where the user can input and extract data from the VI.
7.2.1 Implementing P&O Algorithm in LabVIEW

Having never used LABVIEW before this project it was essential to get a good understanding of the software, especially that which would be relevant to implementing the algorithm. A tutorial provided with the LABVIEW software, named “LABVIEW - Getting Started” provided a good starting point. It demonstrated a simple program to read in voltage via a NI-USB 6009 and display the waveform on the front panel (user interface). From this basis the program was gradually built. The full LABVIEW block diagram is displayed in Figure 7.3
Figure 7.3 Labiew code – Block diagram
7.2.2 LabVIEW Block Diagram

The program runs inside a while loop, as can be seen in Figure 7.3. The first step of the P&O algorithm flowchart to be implemented is to set the initial duty cycle to 0.5. This is done by inputting 0.5 into the shift register from outside the loop, as can be seen in Figure 7.4. As it is placed outside the loop the shift register only holds this value for the first loop iteration. Every iteration thereafter the shift register only uses values obtained inside the while loop.

![Figure 7.4 Set initial duty cycle to 0.5](image1)

The next step is to read voltage and current. This is done using the data acquisition assistant (DAQ assistant) to communicate with the NI-USB 6009 which is connected to the output of the solar panel. This part of the code is represented in Figure 7.5

![Figure 7.5 Read in voltage and current](image2)
By double-clicking on the DAQ assistant, it opens up as window in which you can choose which analog inputs channels you wish to use, as highlighted Figure 7.6

![Figure 7.6 DAQ Assistant window](image)

The solar panel voltage is read from input channel ai0. The device itself cannot read current directly. To get an accurate reading for current a small resistor is placed on the output of the solar panel. The current is being read from physical channel ai1, so the connectors of this channel are placed in parallel with the resistor (as voltage is measured in parallel). The DAQ assistant then reads in the voltage across the resistor, and using ohm's law, \( I = \frac{V}{R} \), the current is calculation. To get a precise calculation the correct resistor value must be input into the DAQ assistant, highlighted in Figure 7.6 above. In this case the resistor is 3.3 ohms.
The voltage and current of the solar panel are measured continuously, at the rate of 1kHz, and the data is displayed in the form of a waveform, shown Figure 7.5, which is then displayed on the front panel.

Step 3 in the P&O flowchart involves calculating the power, which will become $P_{\text{new}}$. This task is represented with the code in Figure 7.7 below.

![Figure 7.7 Calculating power](image)

The voltage and current data read in from the DAQ assistant are converted into a numeric array every 2 seconds, as indicated by the time delay. They are then separated into two values and multiplied together to determine the power. The power value is then converted to an absolute value and is displayed on as a waveform on the front panel. The power value is also written to a specified file stored on the computer so previous power values can be read at anytime. The data is logged to the file in the following format:

---

```
LabVIEW Measurement
Writer_Version 0.92
Reader_Version 1
```
Finally, the power value calculated, \( P_{\text{new}} \), is put through a shift register, to become \( P_{\text{old}} \) on the next loop iteration, as well as being used to complete the next step in the algorithm.

The next step in the algorithm is to compare the new power value measured, \( P_{\text{new}} \), to the last power value measured, \( P_{\text{old}} \) and decide the next step based on the outcome.
P_old is taken from the shift register and compared to P_new. This is done using the G programming graphical equivalent of an ‘if statement’. If P_new is greater then P_old, then the statement is true and the duty cycle is incremented by 0.05. If the statement is false, as in Figure 7.9, the duty cycle is decremented by 0.05. The new duty cycle is then output to the display on the front panel and put in a shift register to be used as the old duty cycle for the next iteration. The initial duty cycle for the first iteration of the program is set to 0.5, as has been stated earlier.
The final part of the program was to convert this duty cycle in its numeric form into a digital pulse width modulation signal. This part of the program was based on a template to generate PWM obtained from the national instruments (NI) website. The code is shown in Figure 7.10

![Figure 7.10 Generating PWM signal](image)

The duty cycle, determined by the previous ‘if statement’, is decimal form between 0 and 1, e.g. 0.7. The duty cycle value is then multiplied by 100, this value will be referred to as N. So for 0.7 x 100, N is 70. The number 70 is then entered into a for loop and becomes the number of high values e.g. 70 x 1. A second loop takes in the value of low values, that is 100 – N, so for this case 100 – 70 = 30. The outputs of the two loops are combined in an array, so in this example the array would contain 70 high values, followed by 30 low values. This array is then the input to the for loop. In this for loop each value is put on the digital out line of the NI-USB 6009 via a second DAQ assistant sub VI. For the example of 0.7 as the duty cycle the output should look similar to that in Figure 7.11
This PWM signal then controls the gate of the MOSFET in buck converter circuit. However, the signal cannot be connected directly to the gate of the MOSFET as the signal is only a digital signal and has no current to drive the MOSFET. Therefore, the signal must first be connected to a MOSFET driver, which will then drive the MOSFET.

**Figure 7.11 Ideal generated PWM**

### 7.2.3 LabVIEW Front Panel

While the program is running, the block diagram can be viewed, but the user interface is typically the front panel. In this program the front panel contains one waveform displaying the voltage and current measured, and another waveform displaying power measured over time. It also displays the duty cycle at the output. The front panel is displayed in **Figure 7.12**
**Figure 7.12** Front Panel of LabVIEW VI
7.2.3.1 Displaying Backup Battery Voltage

The front panel of the VI could also be used to display other information visually to the user. A waveform of numeric indicator communicating the charge left on the back-up up battery could be easily implemented. The backup battery could be connected to a third physical channel on the NI-USB 6009 and the voltage and current read through the DAQ assistant as before., for the solar panel. The information could then displayed on the front panel in the following way.

Figure 7.13 Displaying voltage of battery
Chapter 8: Mobile Phone Charging

8.1 The Charging Algorithm

At the early stages of the project, it was thought that a mobile phone charging algorithm would have to be implemented. Early research indicated that mobile phone charging algorithm is employed on the phone itself and to charge a mobile phone it is just a matter of supplying the correct voltage to the charging input of the phone. It was decided that the best way to verify the operation of a mobile phone charger was to reverse engineer a commercial charger.

This was done with a Nokia phone car charger, shown below in Figure 8.1

![Figure 8.1 Nokia phone charger](image1)

![Figure 8.2 Mc34063a DC-DC converter](image2)

The charger is connected to the car cigarette lighter socket, which supplies a DC voltage of 12 V. After disassembling the charger a ‘mc34063a’ chip was found inside, as shown in Figure 8.2. From researching the chip in the internet it was found that the ‘mc34063a’ chip is a step-up, step-down DC-DC converter. The chip can be configured either way, but when configured as a step-down converter, which it would be in this case, it has an output voltage of 5 V.
This can also be seen in the charging of mobile phones from laptops. The phone is simply connected to the laptop via a USB (Universal Serial Bus). When devices are connected to the laptop the USB supplies 5 volts (DC) to the device. No other circuitry is required to charge the mobile phone.

These facts confirmed the findings during research that the charging algorithm for the mobile phone is located in the phone itself.

### 8.2 Charging a Mobile Phone from the Buck Converter Circuit

To charge a mobile phone from the DC-DC converter built, a regulator would need to be used to supply a constant voltage to the phone itself. From looking at the ‘Mc34063a’ DC-DC converter in Figure 8.2 above, it was decided that supplying 5V to the mobile phone would be sufficient. The output of the built buck converter should be between 5V and 10 V. These voltages would be low enough to be input to most 5V regulators. It was decided to use a simple 5V linear regulator to perform the task. The linear regulator selected was the ‘LM78M05C’ 3-terminal positive 5V voltage regulator, as shown in Figure 8.3 and Figure 8.4.

![Figure 8.3 LM78M05C regulator](image)

![Figure 8.4 LM78M05C pin-out](image)

The ‘LM78M05C’ regulator was ideal as it could handle currents in excess of 500mA, it output a regulated voltage of 5 volts and it can handle input voltages up to 35 volts, which is very high for a linear regulator. The regulator also contain internal short-circuit protection which limits the maximum output current, and safe-area protection.
for the pass transistor which reduces the short-circuit current as the voltage across the pass transistor is increased. The circuit was built as in **Figure 8.5**

![Linear regulator circuit](image)

**Figure 8.5** Linear regulator circuit [19]
Chapter 9: Building the Demonstration System

9.1 Demonstration System Design

The layout of the demonstration system is shown in Figure 9.1

![Diagram of the demonstration system]

**Figure 9.1 Final system design**

The output of the solar panel is connected to the DC-DC converter, as well as to the NI-USB 6009 where the measurements take place. A diode must be placed at the output of the solar panel to prevent voltage returning to panel when no power is being generated. The LABVIEW program takes in these measurements via the USB connection on the PC and changes the duty cycle accordingly. The duty cycle, as determined by the running program, is then output digitally via the NI-USB 6009 in the form of PWM. This PWM signal then drives the MOSFET of the DC-DC converter (via a MOSFET driver) which in turn controls the buck converter. All of these actions bring the voltage down to an
acceptable voltage level to connect to the load, as well as force the solar panel to operate at its MPP.

### 9.2 Buck Converter Components

When it came to building the buck converter circuit it was necessary to choose components that would be suitable for the circuit. The values of the different buck converter components were calculated previously, as discussed in chapter 4.

The inductor value calculated was to be between 1.6mH and 2.8mH. A 2.2mH inductor was selected, for reasons outlined in chapter 4. The ‘1422509C’ 2.2mH, high current (up to 0.9 Amps) inductor, as shown in Figure 9.2, was used in the circuit.

![Figure 9.2 Inductor used in demonstrator circuit](image)

The capacitor used was a 22µF capacitor, which corresponded with the 21.3 µF calculated for earlier. This capacitor is shown in Figure 9.3 and can handle a voltage up to 25V, which is suitable for this circuit.

![Figure 9.3 Capacitor used in demonstrator circuit](image)

The diode used in the built circuit is the 1N4001 diode. It was selected because of its high current capability (up to 1A), high voltage (up to 50V) and low forward voltage.
drop across the diode. It is important that the diode is placed correctly in the circuit, with the + and – in the correct order, as shown in Figure 9.4.

![Figure 9.4 Diode used in demonstrator circuit](image)

9.2.1 MOSFET
As previously mentioned, the switch in the buck converter would be a MOSFET (Metal Oxide Semiconductor Field Effect Transistor). MOSFETS are by far the most popular transistors used for switching in circuits today, along with BJTs (Bipolar Junction Transistors). The main difference between MOSFETs and BJTs is that the former are voltage controlled (little or no current is used), and the latter are current controlled (voltages are there to drive currents). Therefore, MOSFETs require less power to drive them, so they are the preferred choice.

MOSFETs are either N-channel, made mostly of N-type semiconductor material, or P-channel, where they are made mostly of P-type semiconductor material. They operate in two modes – enhancement mode and depletion mode. The circuit symbols for these are shown in Figure 9.5.
The MOSFET used in the circuit is the IRF740 \(^{23}\) N-channel power MOSFET, as shown in Figure 9.6 and Figure 9.7.

This particular MOSFET has a high current and voltage rating, 10A and 400V respectively. It was chosen because it has high switching speeds, high input impedance and is ideal for switching converters. The voltage in is applied at the source (3), the PWM signal is applied at the gate (1), and the voltage out is at the drain (2).

The PWM signal, which is generated in LabVIEW and output on the NI-6009 USB, is purely digital. A voltage is needed on the gate to drive the MOSFET, so a MOSFET driver device is needed.
9.2.2 MOSFET Driver

A MOSFET driver is used to provide enough voltage so to drive the gate of the MOSFET. The driver used to drive the IRF740 is the LM2722 [22] high speed synchronous MOSFET driver, whose pin-out is shown in Figure 9.8.

![Figure 9.8 Pin-out of LM2722 MOSFET driver](image)

The MOSFET and MOSFET driver were built as can be seen in the circuit schematic in Figure 9.9.

![Figure 9.9 Circuit schematic of MOSFET and MOSFET driver](image)
Chapter 10: Problems Encountered & Recommendations

In the initial stages of the project a lot of time was spent on different design for the system. One of the early system designs that was to be implemented is shown in Figure 10.1. The design incorporated a Single-Chip Li-Ion Linear Charger and System Power Path Management IC (the bq24071 chip). However, after further research, it was discovered that it was not possible to implement a MPPT algorithm using the IC chip. The chip worked by ensuring that enough power was being delivered to the load, and any excess power would charge a back-up battery using MOSFETs, but it did not actually employ maximum power point tracking. Also, dimensions of the chip were very small, as it is part of the bq-tiny range, and a suitable translator board could not be sourced early on. Because of these reasons, it was decided to change the system design. This ate into some of the time for the overall project.

Figure 10.1 bq24071

Another problem in designing the design system was driving the MOSFET using the NI-USB 6009. As was not initially realised, the NI-USB 6009 does not have a counter built in on the digital output, so the output is software timed rather the hardware timed. As it is software timed, each point on the PWM signal array can only be output at a minimum of 1ms. There is 100 points in each PWM signal, so the frequency at its highest will only reach 10 Hz. Downsizing each PWM signal to 10 points would increase the frequency to
100 Hz, but this means that the duty cycle could only be to only 1 decimal place, as the array can not output decimal points, e.g. if the duty cycle was 0.55, multiplying by 10 would give 5.5, which would be rounded to 5. A frequency of 100 Hz would still not be nearly high enough to drive the MOSFET, which was designed with a switching frequency of 20 kHz. Another problem is that since the output is software timed, a lot depends on the speed of the operating system. Depending on how much other code is being implemented, and if other programs are running, the PWM signal can be quite noisy. To overcome these problems an upgrade from the NI-USB 6009 would be needed. Any NI DAQ Acquisition M series include counters that can operate up to 10 MHz, making them ideal for generating PWM signals. Using a DAQ Acquisition M series USB would require little change to the software code which would have include a counter corresponding to the M series USB hardware counter on the ‘for loop’ which outputs the data.

As has been discussed previously, a back-up battery would be highly recommended for the system, and for any solar powered system no matter how big or small. Using a Li-ion battery as a back-up rechargeable battery has already been proposed. For system using larger amounts of solar power, the capacity of the back-up battery would be increased to ensure all available energy is being stored if not used. Even though most Li-ion battery packs come with protection circuits it is always recommended to use a suitable Li-ion charging IC to charge the battery, as this will ensure correct charging of the battery and prevent over-charging, under-charging and would terminate charging once completed, minimising safety concerns.

If building a larger solar power system, it should be noted that there are a wide range of commercial MPPT available. A commercial maximum power point tracker that could be used with the solar panel in this project is the Solar Boost SB2000 Charge Regulator with Digital Meter \(^{[25]}\). Using a commercial MPPT would that is suitable for your solar panel would be recommended for large scale systems, where cost is not an issue.
Conclusion

The overall aim of this project was to develop a small scale battery charging system, which include power management functions and a user interface. It required research into various solar cell technologies and the understanding of the various characteristics of photovoltaic panels to ensure an optimum solution for the project.

From the start, it was obvious that a DC-DC converter would be used as the source and the load are both DC. After it was found that a suitable DC-DC converter for the system could not be sourced it was decided to design and build a converter specifically for this project. This would also provide a greater understanding of the DC-DC conversion process and the theory behind choosing the components. A buck converter was designed, as the output voltage to the load would always be lower than the voltage output by the solar panel. The various component values were calculated using standard buck converter formulae and the simulated circuit worked as designed. Parts were sourced for the range of components and the circuit was built.

Power management functions came in the form of maximum power point tracking. Various algorithms were studied, which provided valuable insight into the design process for large scale solar systems. The algorithm chosen to be implemented was the perturb and observe algorithm. The algorithm would ensure maximum power point tracking by controlling the MOSFET of the buck converter by varying its duty cycle. To implement this algorithm it was realised that some form of microcontroller would need to be used. It was decided to use the NI-USB 6009 DAQ Acquisition device along with a computer based program developed in LabVIEW.

The NI-USB 6009 preformed a number of tasks and was used to communicate with the PC based Labview program. Using the analog inputs on the device voltage and current at the output of the solar panel were measured. Since current could not be measured directly, a small 3.3 ohm high power resistor was placed at the output of the solar panel, and the voltage across the resistor was measured. The Labview program itself calculated the current by using ohm’s law. A digital output on the NI-USB 6009 was used to output the PWM signal, which was determined from the algorithm running on
LabVIEW, which in turn controlled the duty cycle of the MOSFET of the buck converter. The PWM signal was input into the MOSFET driver.

The LabVIEW program had two uses. A program was developed to implement the P&O algorithm and it also provided a user interface. Having never used LabVIEW previously, initially implementing the algorithm was quite challenging, as LabVIEW programs are written using a graphical programming language ‘G’, which is quite different from text based code, such as C++ and Java. However, overtime LabVIEW became more and more intuitive and the algorithm was implemented successfully. The program determined the duty cycle based on the voltage and current readings of the solar and its calculated power. LabVIEW also provides a front panel window while the program is running in the background. This front panel can used to display waveforms and numbers of values that are being used at various stages of the program, so the front panel can be used as a user interface, as it displays all relevant information to the user. It also contains a ‘stop’ button, so the user can stop the program running at any time.

The charging algorithm for connecting a mobile phone at the load was researched and found that no algorithm was necessary on the external charger, as the algorithm takes place on the mobile phone itself. A 5V linear regulator was placed at the output of the buck converter to provide a constant voltage to a connected mobile phone.

Although a back-up battery was not used in the demonstration system, various battery cell chemistries were researched and recommendations made as to how to implement a back-up battery into the design.

There were a number of issues encountered in the design, which have been discussed and along with possible solutions to these, along with a number of recommendations for larger scale solar powered systems.
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