# MEMO

To: Dr. Thomas Acker

From: Ze Chen, Tyler Faulkner, Alexa Kearns, Yaqoub Molany, Thomas Penner

Date: 13 December 2013

Re: Project Proposal memo

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Dr. Acker,

We have chosen for our final design a grid tie connection with a pre-programmed display. Ideally we can charge a maximum of six laptops and six cell phones using only solar power at one time. As well, we will use 1000W inverters and 20 Amp charge controllers. There systems will be used with six solar panels with two in series and three rows in parallel. We hope that on average throughout the year each panel will produce 132W of energy per day.

To make the design we are going to apply for funding through the NAU Green Fund. If our project is selected it will cost around $946.30 to create, and because it is through the universities' facilities we will not be able to build the actual system ourselves. Instead, next semester we will test the solar panels to make sure they all work according to our assumptions.

Team 17

# ISES Solar Charging Station

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Team 17

# Project Proposal

Document

*Submitted towards partial fulfillment of the requirements for*
***Mechanical Engineering Design I – Fall 2013***

Department of Mechanical Engineering
Northern Arizona University
Flagstaff, AZ 86001

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## Nomenclature

### Symbols

ø – Latitude

S – Declination

ß – Slope

ɣ - Surface Azmuth Angle

w – hour angle

θ -Angle of Incidence

$\theta_Z$ - Zenith Angle

$\alpha_5$ - Solar Angle

### Definition

**Latitude** (ø) – The angular location north of south of the equator. North is positive $-90^\circ \leq \O \leq 90^\circ$.

**Declination** (S) – The angular position of the sun at solar noon (sin on local meridian) with respect to the plane of the equator, north positive; $-23.45^\circ \leq S \leq 23.45^\circ$.

**Slope** (ß) – The able between the plane of the surface on question and the horizontal; 0º ≤ ß ≤ 180º.

**Surface Azmuth Angle** (ɣ) – the deviation of the projection on a horizontal plane of the normal to the surface from the local meridian. 0 = due south, negative = east, positive = west, -180º ≤ ɣ ≤ 180º

**Hour angle** (w)– the angular displacement of the sun east or west of the local meridian due to Earth's rotation on its axis at 15º per hour, morning = negative, afternoon = positive.

**Angle of Incidence** (θ)– the angle between the beam of rotation on a surface and the normal to that surface.

**Zenith Angle** (θZ)– the angle between the vertical and the line to the sun.

**Solar Altitude Angle** ($\alpha_5$)– the angle between the horizontal and the line to the sun.

**Solar Constant** ($G_{sc}$)– Energy of the sun per unit time received on a unit area of surface

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## Abstract

The ISES Solar Charging Station for Northern Arizona University's mechanical engineering 2013—2014 senior design capstone has been working on creating a control system and display system for charging small electronics through solar power. For funding the team is applying to the NAU Green Fund, a fund that uses NAU student tuition to fund projects that will make the campus more environmentally friendly. Because the budget is dependent on the fund, the team must place their values as their own and follow within the funds constraints. Some of the consideration taken by the team include the display of the system, the aesthetics, the functionality, usability, and how the system educated the users.

The team designed the system around the goal of creating the product with those fixe criteria in mind. Because the Green Fund is the funder, everything must revolve around being as efficient as possible. The solar panels used are recycled from an old NAU project and each of the parts involved will be used to maximize the power output. The team will connect the system to the power grid but will hope that enough power will be outputted to that it is not strictly necessary. The system designed will have two solar panels in series with three rows in parallel for a total of six solar panels. From the panels, the power will go to a combiner box and then to an inverter where the power will be turned into usable energy. The whole system will cost around $946.65 and be able to output on average throughout the year 132W per day.

# Chapter 1. Introduction

## 1.1 Introduction

The Institute for Sustainable Energy Solutions (ISES) at NAU is a premier research division that works on renewable energy. ISES has in its possession multiple solar photovoltaic modules that can be designed to power small electronics such as cell phones and laptops. We will be looking into the control systems and display systems create a grid connected charging station

The client of this project is Dr. Tom Acker, Professor of Mechanical Engineering at Northern Arizona University. He is a reviewer of ASME Journal of Solar Energy and the director of ISES. His research field includes renewable energy systems, thermal-fluid systems analysis. [4]

## 1.2 Need and Goal

Northern Arizona University currently does not have a place that uses a sustainable, renewable energy source, that students and faculty could use in order to charge small electronic devices. The goal of the project is to design a solar charging station capable of providing enough power to charge small electronics.

## 1.2 Objectives

From our sponsor and the different constraints we have encountered, we have developed a set of objectives we would like to achieve (table 1). To begin, our goal is to charge small electronic, and thus that is one of our objective. The whole point of the project is to charge small electronics with solar power. Because we are working through the Green Fund and in turn, NAU, we need to keep the cost down. The funding comes from student tuition and we would like to use their money in the most efficient way possible. As well, one of the requirements from the Green Fund is to have the project be educational. We need to have an output display system that educates users on the amount of energy they are saving by using our product. Another objective is to have the power output maximized. We want this to be efficient and environmentally friendly. The best way to do that is to maximize the product we are providing. Finally, we want our design to withstand the environment. This will help with the longevity of the design as Flagstaff does have harsh weather conditions, especially in the winter.

*Table 1.1: Objectives*

| Objective | Measurement Basis | Units |
|---|---|---|

| | | |
|---|---|---|
| Charge Small Devices | Total power output | kW |
| Inexpensive | Cost of the system | $ |
| Educational | A digital readout to inform users of power output | kW |
| Maximize power output | Total power output | kW |
| Withstand Environment | Determine the total stress experienced by the system | kPa/psi |

## 1.3 Operating Environment

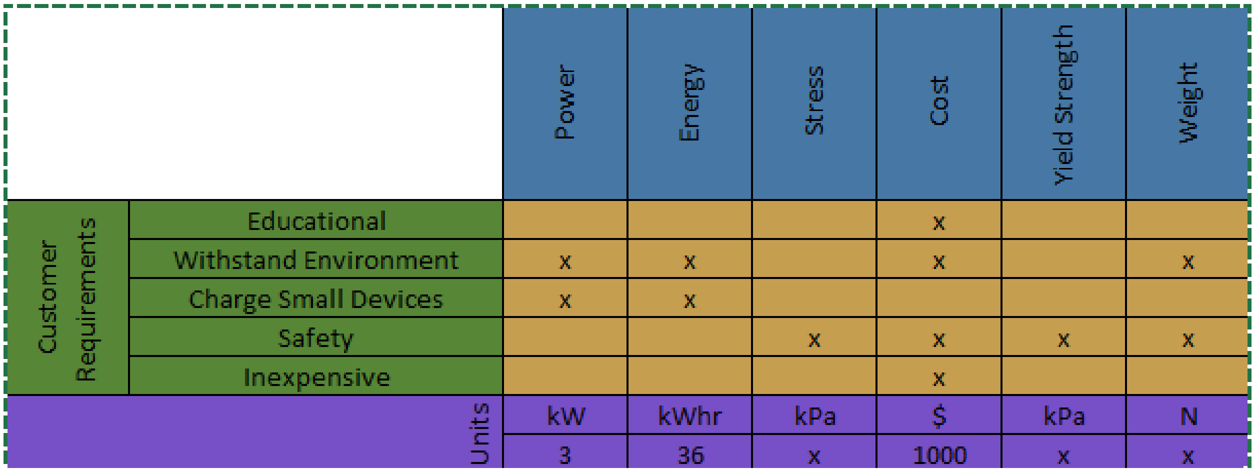
The target location for the project to be located would the patio outside of the W.A. Franke College of Business. Although it is sunny most of the year, we must be aware of the potential of rain, hail, snow, and high winds. All weather conditions of prevalent in Flagstaff during different times of the year. For example, the solar panels must be able to support the weight of snow during the winter, and the different components in the control system and display system must not freeze during the winter months.

## 1.4 Constraints

The different constraints associated with the project include those provided by building codes and electrical codes. We must follow all national, state, regional, and city wide ordinances and codes. In addition, we are restricted by the number of solar panels available and the weather conditions of flagstaff. The mountain weather can be temperamental, and we must be aware of that while testing and possible installing the solar panels.

## 1.5 Quality Function Development

The Quality Function Development (QFD) diagram is shown in Figure 1. This shows the customer requirements for the project. It also shows the engineering requirements. These are what the team believed to be the most important engineering measurement methods in order to satisfy the customer requirements. The units for each engineering requirement is shown below the corresponding measurement method. The diagram shows that safety is the most important of the customer requirements and cost is the most important engineering requirement.



| | | Power | Energy | Stress | Cost | Yield Strength | Weight |
|---|---|---|---|---|---|---|---|
| Customer Requirements | Educational | | | | x | | |
| | Withstand Environment | x | x | | x | | x |
| | Charge Small Devices | x | x | | | | |
| | Safety | | | x | x | x | x |
| | Inexpensive | | | | x | | |
| | Units | kW | kWhr | kPa | $ | kPa | N |
| | | 3 | 36 | x | 1000 | x | x |

*Figure 2.1: Quality Function Development*

## 1.6 House of Quality

Figure 2 shows the House of Quality diagram. This diagram shows the correlations that the engineering requirements from the QFD have with each other. A plus sign shows a direct correlation, while a minus sign shows an inverse correlation. From the diagram, power and energy have a direct correlation. As power goes up, so does energy. The same applies to the correlations for stress and yield strength and weight and stress. The diagram also shows that the cost and the energy have an inverse correlation. This means that as energy output increases, the cost of electricity will decrease.

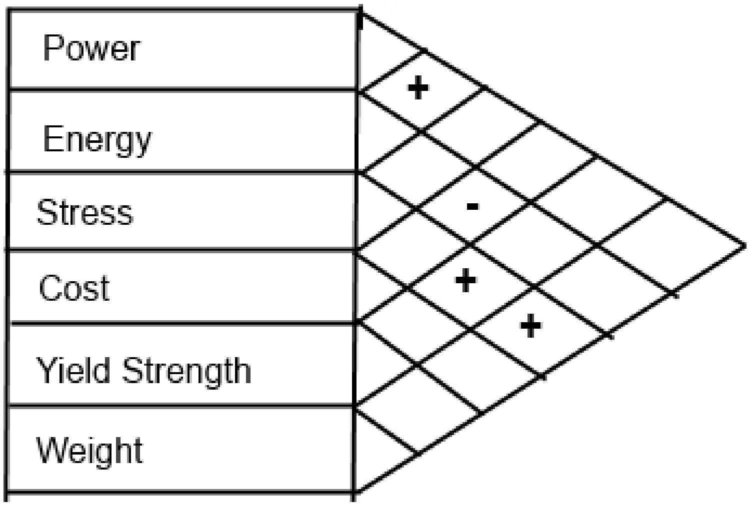


*Figure 1.2: House of Quality*

# Chapter 2. Concept Generation and Selection

## 2.1 Introduction

Our system was divided into two sub-systems: control system and display system. For each systems, we came up with three different concepts. Decision matrices will be made to compare and select one or two good concepts.

## 2.2 Control systems

There are three different types of control systems that are covered by solar energy. These are the off grid battery based control system, the grid tie only control system, and the grid tie with battery backup control system. Each of these systems have their own advantages and disadvantages. There are also various components that are incorporated with each system. The different components involved for each of the systems are defined in the subsequent sections.

### 2.1.1 Control System 1

This system has advantages and disadvantages that occur as a result of its components. The advantages don't have an equal amount to the disadvantages.

**Advantages**

- This system is inexpensive
- This system does not have as many components as the other two systems.

**Disadvantages**

- This system has energy losses from batteries that are not in operation
- This system requires battery replacement over time

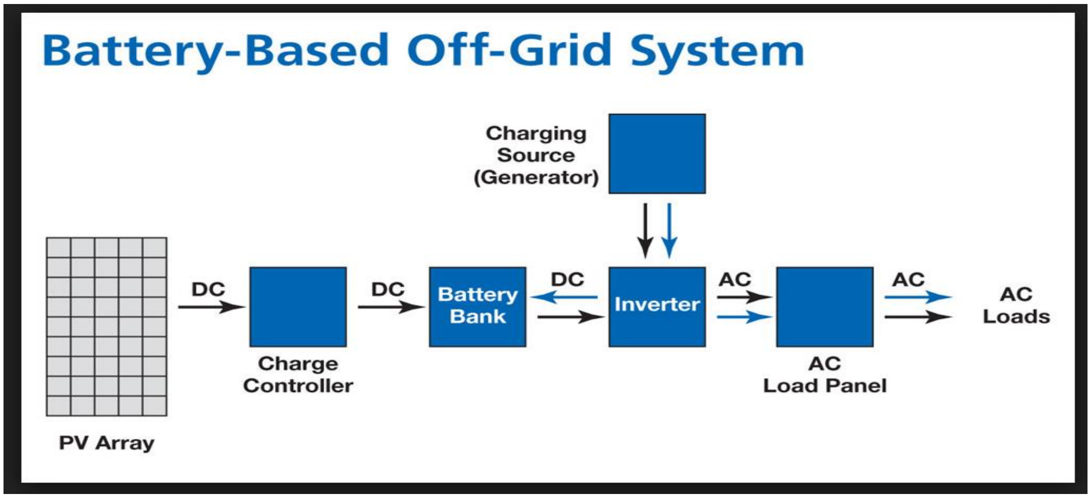


*Figure 2.1: Battery based off-grid system*

## 2.1.2 Control System 2

This system has mostly different components from the off grid battery based control system. This system connects only to the grid and allows for power to be pulled from the grid and also gives power while the solar panels are in operation.

**Advantages**

- This system can be used anytime during the day
- Extra energy goes into the grid to save money

**Disadvantages**

- This system does not work at night during power failure
- Money cannot be saved while the system is in use at night

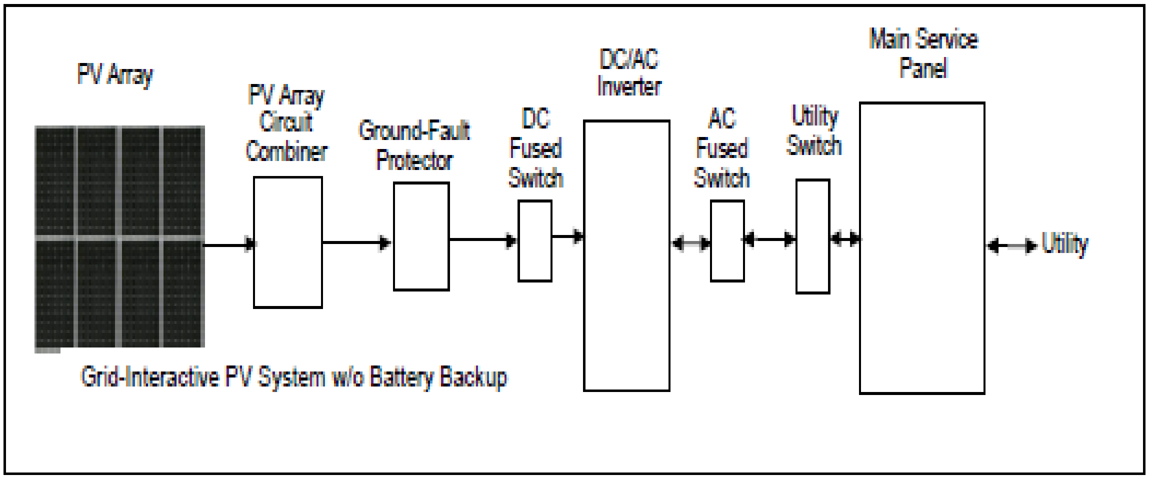


*Figure 2.2: Grid tie control system*

### 2.1.3 Control System 3

This system is a combination of the off grid battery based control system and the grid tie control system. This makes the amount of components that are required to operate the system to be higher than that of the other two systems. This increases the cost of the total system.

**Advantages**

- This system can still be used during a power outage.

**Disadvantages**

- This system becomes complicated when trying to get everything to work properly.
- Battery replacement must be considered with this system.
- The amount of components in this system increases the cost to higher than the other two systems.

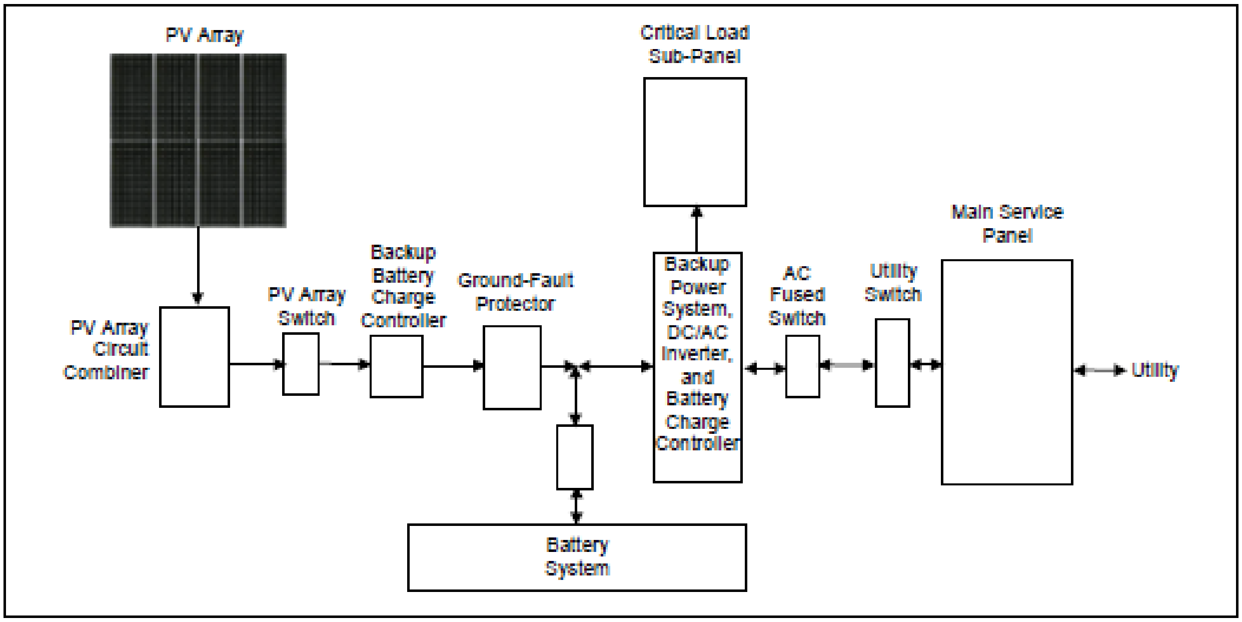


*Figure 2.3: Grid tie with battery backup control system*

## 2.1.4 Charge Controller

Since the brighter the sunlight, the more voltage the solar cells produce, the excessive voltage could damage the batteries. A charge controller is used to maintain the proper charging voltage on the batteries. As the input voltage from the solar array rises, the charge controller regulates the charge to the batteries preventing any over charging

## 2.1.5 Battery

They store the electrical power in the form of a chemical reaction. Without storage you would only have power when the sun is shining or the generator is running.

- RV or Marine type deep cycle batteries

Suitable for only very small systems, they can be used but do not really have the capacity for continuous service with many charge/discharge cycles for many years.

- Flooded

Lead acid batteries that have caps to add water. Many manufacturers make these types for Solar Energy use. They are reasonably priced and work well for many years. All flooded batteries release gas when charged and should not be used indoors.

- Sealed gel batteries

Will not release gas during the charging process like flooded batteries. This is a big advantage because it allows the batteries to maintain a more constant temperature and perform better.

- Absorbed Glass Mat batteries

Best available for Solar Power use. They are leak/spill proof, do not out gas when charging, and have superior performance. They have all the advantages of the sealed gel types and are higher quality, maintain voltage better, self-discharge slower, and last longer.

### 2.1.6 Inventers

The Power Inverters the heart of the system. It makes 220 volts AC from the 12 volts DC stored in the batteries. It can also charge the batteries if connected to a generator or the AC line. For 12v applications an inverter is not required. An inverter should only be required when it is necessary to convert the 12v input to power a 220v standard application [5].

### 2.1.7 Solar Array Combiner

The solar array combiner takes the wires from several solar panels and combines them into one main feed. Breakers and fuses, however, need to be purchased separately. There are two types of wiring combiners:

- Wires from panel junction blocks connected to terminal blocks.
- MC connecters which need an MC extender cable and cut in half to transition to array combiner junctions from panel wiring.

There are combiner boxes using MC connectors that plug in, but availability is scarce and very expensive. Nearly all combiners require fuses, not breakers to meet electrical and safety codes [6].

### 2.1.8 Ground Fault Protector

A ground fault is an undesirable condition of current flowing through the grounding conductor. This is caused by an unintentional electrical connection between current-carrying conductor in PV system and the equipment grounding conductor. The ground fault protection device is used to reduce the risk of fire hazard associated with ground fault [7].

### 2.1.9 DC/AC Disconnect Switch

The DC disconnect switch interrupts DC current between modules before reaching the inverter. Sizing is done by multiplying the number of PV modules that are connected in series with the open circuit voltage. The AC disconnect switch separates the inverter from the electrical grid. Sizing is done by multiplying the number of PV strings connected in parallel by the short circuit current [8].

## 2.2 Display Systems

There are three possible systems that could be used to display the power readings: Pre-programed, Team programed and Tablets. The advantages and disadvantages of each display is discussed in the following section.

### 2.2.1 Display system 1

A Pre-programmed display is an option designed especially for displaying information from the PV panels. Most of these display packages include everything that is required to display the information such as power monitors, transmitters, and the program to interpret the data.

**Advantages**

- Variety of interactive displays
- Most appealing display

**Disadvantages**

- Price

*Figure 2.4: Preprogrammed display-GEO Chorus PV*

### 2.2.2 Display system 2

A team programed display is a display where the team buys all the components separately, assembles them, and then programs the system. While this system is cheap to construct, it also requires programming knowledge. Each component must be compatible with one another for the system to work together.

**Advantages**

- Cheapest
- Less power consumption

**Disadvantages**

- Requires time to program
- Display is limited to simplistic designs

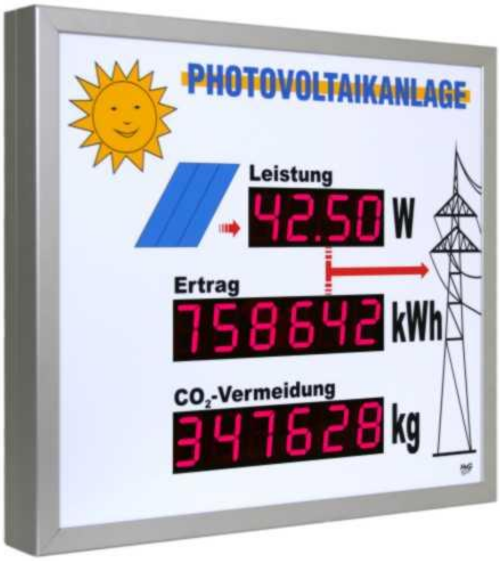


*Figure 2.5: Team programmed display*

### 2.2.3 Display system 3

For a tablet display, the team will purchase a tablet and design specified applications to display the power readings. This option is allows for a more interactive display but still requires programming knowledge. There is no assembly of the display components, making the design less complicated.

**Advantages**

- Appealing display

**Disadvantages**

- Specialized application programing
- Expensive

*Figure 2.6: Tablet display-Nexus 7*

## 2.3 Concept Selection

Below, Table 4.1and 4.2 describe how the team determined appropriate weights for each design criteria pertaining to the control system. An overview of what each criteria means is outlined below.

- Cost- How expensive the system is
- Efficiency- Power savings
- Simplicity- How easy the system is to build
- Reliability- Operates under various circumstances
- Environmentally friendly- How the design impacts the environment
- Customization- The various features of the display
- Man Hours- The amount of time required
- Adaptability- The compatibility of the system

*Table 2.1: Control system weighting (Scale: 1-POOR, 5-BEST)*

| **Criteria** | **Cost** | **Efficiency** | **Simplicity** | **Reliability** | **Environmentally friendly** | **Total** | **Weighted Value** |
|---|---|---|---|---|---|---|---|
| Cost | x | 0 | 1 | 0 | 0 | 1 | 0.10 |
| Efficiency | 1 | x | 1 | 0 | 1 | 3 | 0.30 |
| Simplicity | 0 | 0 | x | 0 | 1 | 1 | 0.10 |
| Reliability | 1 | 1 | 1 | x | 1 | 4 | 0.40 |
| Environmental friendly | 1 | 0 | 0 | 0 | x | 1 | 0.10 |

*Table 2.2: Display weighting (Scale: 1-POOR, 5-BEST)*

| **Criteria** | **Cost** | **Reliability** | **Customization** | **Man hours** | **Adaptability** | **Total** | **Weighted Value** |
|---|---|---|---|---|---|---|---|
| Cost | x | 0 | 0.5 | 0 | 0 | 0.5 | 0.05 |
| Reliability | 1 | X | 1 | 1 | 1 | 4.0 | 0.40 |
| Customization | 0.5 | 0 | x | 1 | 0 | 1.5 | 0.15 |
| Man hours | 1 | 0 | 0 | x | 0 | 1.0 | 0.10 |
| Adaptability | 1 | 0 | 1 | 1 | x | 3.0 | 0.30 |

Table 4.3 below describes the decision matrix for solar control systems and each criteria is graded from 1 to 5 where 5 is best and 1 is worst.

*Table 2.3: Decision matrix for solar control systems*

| **Decision Criteria** | **Decision Criteria Weights** | **Grid Only** | **Battery Only** | **Grid with Battery Backup** |
|---|---|---|---|---|
| Cost | 0.10 | 3 | 4 | 2 |
| Efficiency | 0.30 | 5 | 3 | 4 |
| Simplicity | 0.10 | 3 | 4 | 2 |
| Reliability | 0.40 | 5 | 3 | 4 |
| Environmentally Friendly | 0.10 | 4 | 2 | 2 |
| Total | | 4.5 | 3.1 | 3.4 |

From Table 4.3, we decided to choose the grid only option for our design. This is largely in part to the efficiency and reliability of the system compared to the other options. Since energy is lost in batteries, sending the electricity straight into the grid is more efficient. Also, if the system is connected to the grid, then the system will always be functional. The battery only system will still be considered in engineering analysis.

Table 4.4 below describes the decision matrix for the display options and each criteria is graded from 1 to 5 where 5 is best and 1 is worst.

*Table 2.4 Decision matrix for the display options*

| **Decision Criteria** | **Decision Criteria Weights** | **Pre-Programmed** | **Team Programmed** | **Tablet** |
|---|---|---|---|---|
| Cost | 0.05 | 3 | 4 | 3 |
| Reliability | 0.40 | 4 | 3 | 2 |

| | | | | |
|---|---|---|---|---|
| Customization | 0.15 | 4 | 5 | 2 |
| Man Hours | 0.10 | 5 | 2 | 2 |
| Adaptability | 0.30 | 4 | 4 | 1 |
| Total | | 4.05 | 3.55 | 1.75 |

Based on Table 4.4, we decided to choose the pre-programed display for our system. While a pre-programmed system can potentially be expensive, the benefits from this system outweigh the cost. Since this system is on the market, it has been through various tests ensuring product reliability. In addition, the man hours required to program the team programmed system and the tablet vastly outweighs that of the pre-programmed. This will allow for more time to be spent on other aspects of the project.

# Chapter 3. Engineering Analysis

## 3.1 Introduction

In this chapter, we figure out the orientation of our solar panel, solar analysis on PV panel and the size of battery analysis, inverter and charge controller.

## 3.2 Solar Panel

Figure 3.1 is the CAD drawing of our PV panel. The model is 7 ASE-300-DG/50. 300 represent the rated maximum power and 50 is the working voltage. The panel will be angled at 35° because of the latitude of flagstaff. The PV panel will also be facing due south. Combining the 35° and the direction the panel is facing will provide the maximum efficiency from the solar panel. All the solar analysis was based on how the PV panel is oriented.

*Figure 3.1: Solar panel angled at 35°*

### 3.3 Solar Analysis

All of the solar analysis are calculated by MATLAB. The solar constant (C) that makes it to the Earth is an average value over the course of the year. This is because the solar constant changes with time. This is because over time, the distance between the sun and the Earth varies. The coefficient for the time of the year that is taken into account by the equations:

$$B = \frac{2\pi}{365} \times \left( day\ of\ the\ year + \frac{hour\ of\ the\ day - 12}{24} \right)$$

E is the correction factor that is needed to find solar time based off of the standard time of the day. This is found in equation:

$$E = 229.2 \times (0.000075 + (0.001868 \cos B)) - (0.032077 \times \sin B)$$

The longitude of Flagstaff, Arizona is 111.6311°W. The latitude of Flagstaff, Arizona is 35°N

The representation of C throughout the year is modifying the solar constant before it reaches Earth's atmosphere by factors of B. This is shown in equation:

$$C = 1367 \times (1.000110 + (0.34221 \cos B)) + (0.001280 \sin B) + (0.000719 \cos 2B) + (0.00077 \sin 2B)$$

The solar constant is plotted over the course of one year as shown in Figure 3.2. This plot shows that the solar constant is actually lower in the summer months than it is in the winter months. The maximum solar constant value for the year is around 1850W/m$^2$. The minimum solar constant value for the year is around 900W/m$^2$. The average solar constant value over the course of the year, according to the plot is around 1367W/m$^2$.

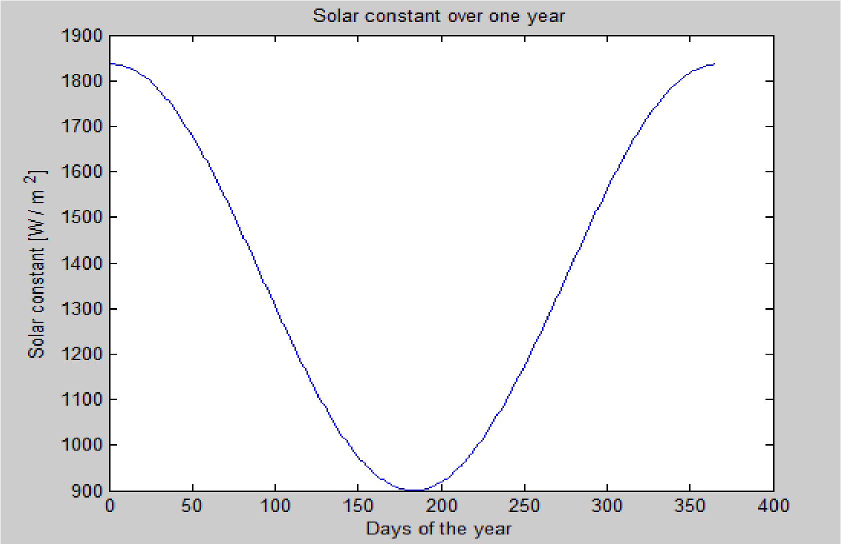


*Figure 3.2: Solar constant projected over the course of one year*

The declination angle is the angular position of the sun at solar noon (the sun is on the local meridian) with respect to the plane of the equator. For this angle, north of the equator is positive and south of the equator is negative. The declination angle is found by equation:

$$\delta = 0.006918 - (0.399912\cos B) + (0.070257\sin B) - (0.006758\cos 2B) + (0.000907\sin 2B) - (0.002679\cos 3B) + (0.00148\sin 3B)$$

In order to find the amount of daylight hours on any given day, there is a need to have a correction factor that takes into account the day of the year. This correction factor is found by equation:

$$D = \sin^{-1}\left(0.39795\cos\left(0.2163108 + 2\tan^{-1}\left(0.9671396\tan\left(0.0860 \times (day\ of\ the\ year - 1)\right)\right)\right)\right)$$

The amount of daylight hours during any given day are found by taking a fractional relationship between the latitude of the location and the factor P taken is sine and cosine forms as well as taking into account that there are 24 hours in one day. This is done through equation:

$$t = 24 - \left(\frac{24}{\pi}\right)\cos^{-1}\frac{\sin 0.8333 + \sin latitude \sin P}{\cos latitude \cos P}$$

The number of daylight hours can be seen in Figure 3.3. This is a projection of the number of daily average daylight values over the course of one year. The number of daylight hours that Flagstaff, Arizona experiences in the middle of winter is about 10.2 hours, while the number of daylight hours in summer reaches up to about 14.25 hours a day. [11]

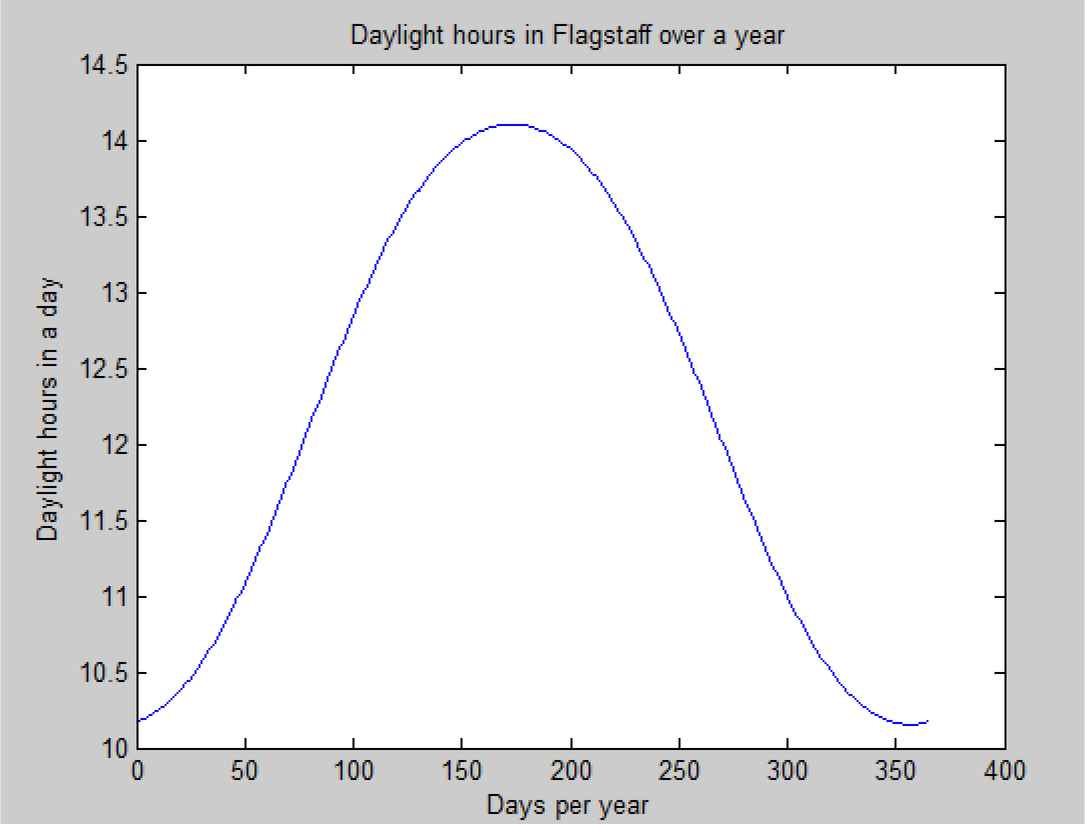


*Figure 3.3: Number of daylight hours each day over one year in Flagstaff, Arizona*

In order to calculate the irradiance that is actually affecting the solar panels, it is required to have a factor known as the zenith angle. The zenith angle is based upon the latitude of a location, the declination angle, and the hour angle. This can be found in equation:

$$\theta_z = \cos^{-1}(\sin latitude \sin\delta + \cos latitude \cos\delta \cos\omega)$$

The actual irradiance that affects the solar panels are calculated. This is done under the assumption that 1000W/m$^2$ of irradiance makes it to the solar panels. This is then multiplied by the cosine of the zenith angle, which allows for the calculation of the actual irradiance experienced by the solar panels. This is shown in equation:

$$I = 1000 \cos \theta_z$$

Figure 3.4 shows the yearly projection of irradiance in Flagstaff, Arizona. The irradiance is based on the ideal irradiance of 1000W/m² and the zenith angle. The zenith angle is the angle between the vertical and the line to the sun. Irradiance is lower in the winter than it is in the summer because of the number of daylight hours that are present throughout the year. The irradiance is based on the ideal irradiance of 1000W/m² and the zenith angle. [12]

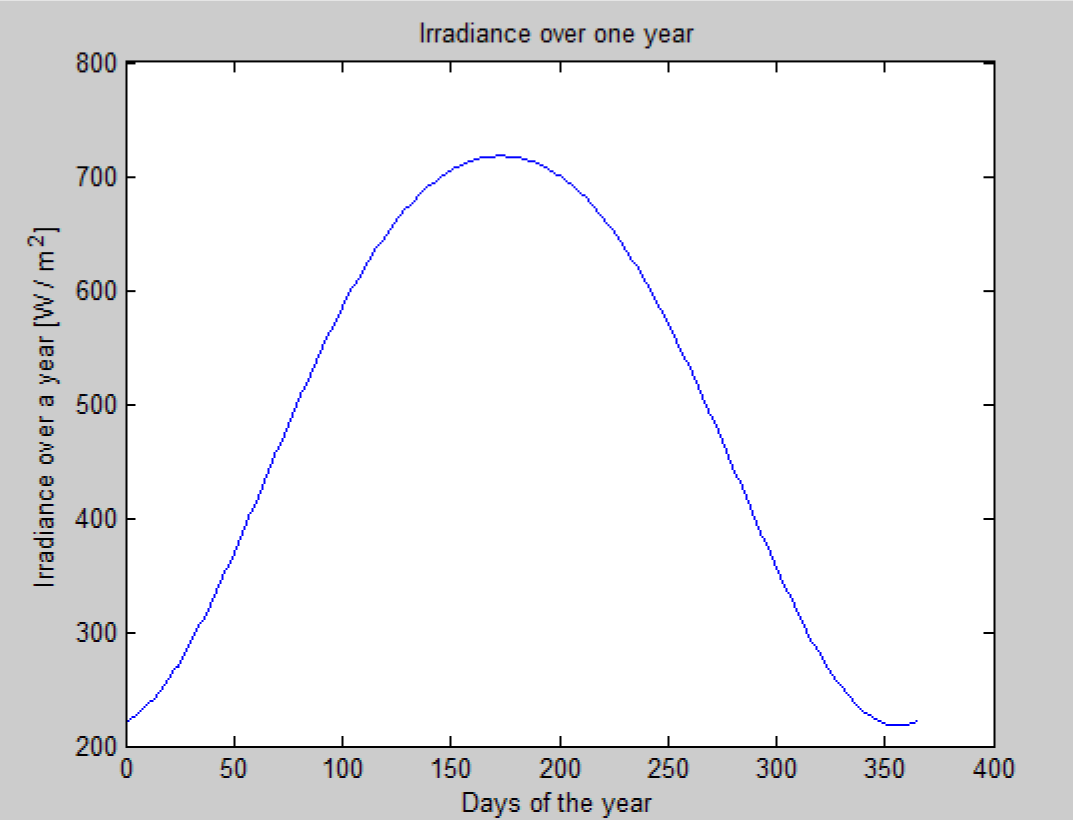


*Figure 3.4: The irradiance projected over one year in Flagstaff, Arizona*

## 3.4 Energy Loss

Solar panels will experience energy loss due to high temperature effect. The percentage loss can be estimated by two steps. The first step is to calculate the operating cell temperature.

$$\mathrm{T}_{cell} = T_{air} + \frac{NOCT - 25}{800} G$$

According to the specification of our solar panels, the nominal operating is 45 $^{o}$C and we estimate the air temperature to be 20 $^{o}$C. Thus, we have all information for the above equation.

The second step is to find the percentage loss:

$$\text{Percentage loss} = (\mathrm{T}_{cell} - 25)\ \text{x}\ \mathrm{T}_{\mathrm{cop}}$$

For our solar panel, $\mathrm{T}_{\mathrm{cop}}$ is 0.47% / $^{o}$C, which means the energy will decrease 0.47% per degree C when it is higher than 25 $^{o}$C. The result can be seen in Figure 3.5. It has about 6% energy loss in summer and the average energy loss is 3.4%.

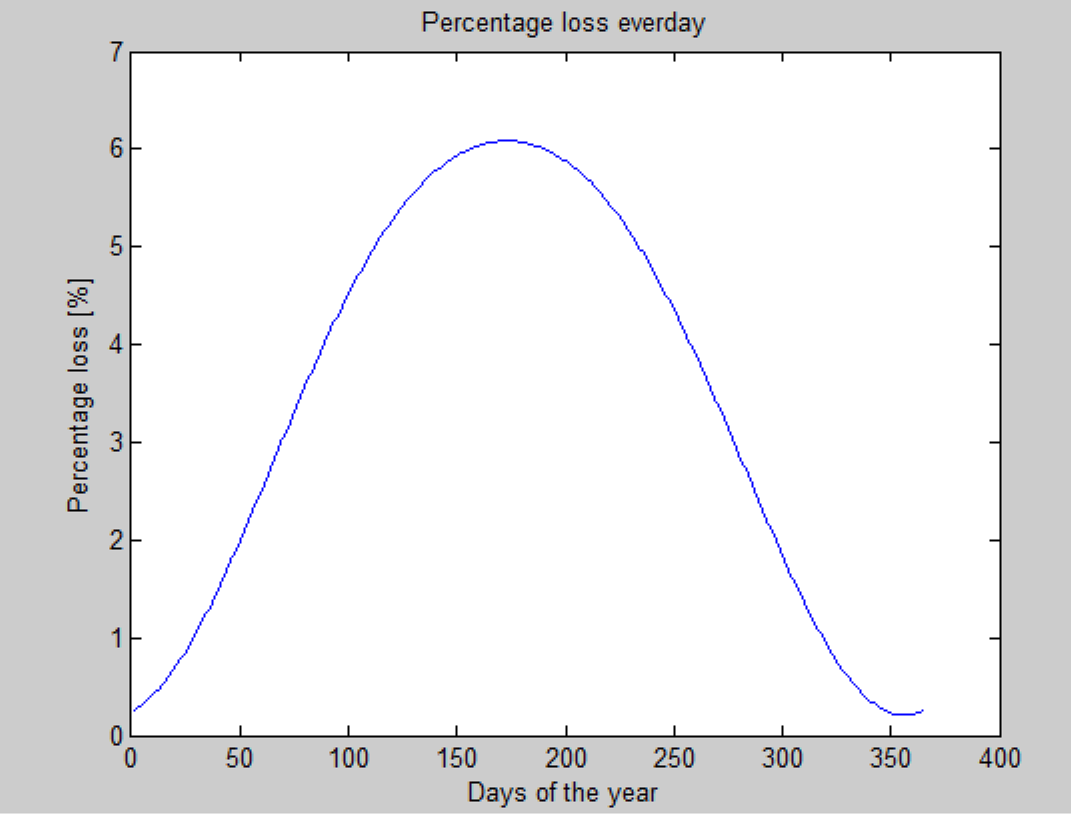


*Figure 3.5: Energy loss due to high temperature*

Power and yield:

The average power for each panel per day is calculate the by the equation:

$$P = G \cdot 0.19 \cdot (1 - T_{loss}) \cdot (1 - 0.05)$$

0.19 is the efficiency of our solar panel, the actual efficiency may be less than 0.19, and we just take 0.19 into our calculation. 0.05 is the estimation of loss due to dust and dirty build up occur once install [8].

The calculation was performed in MATLAB and the result is shown in Figure 3.6.

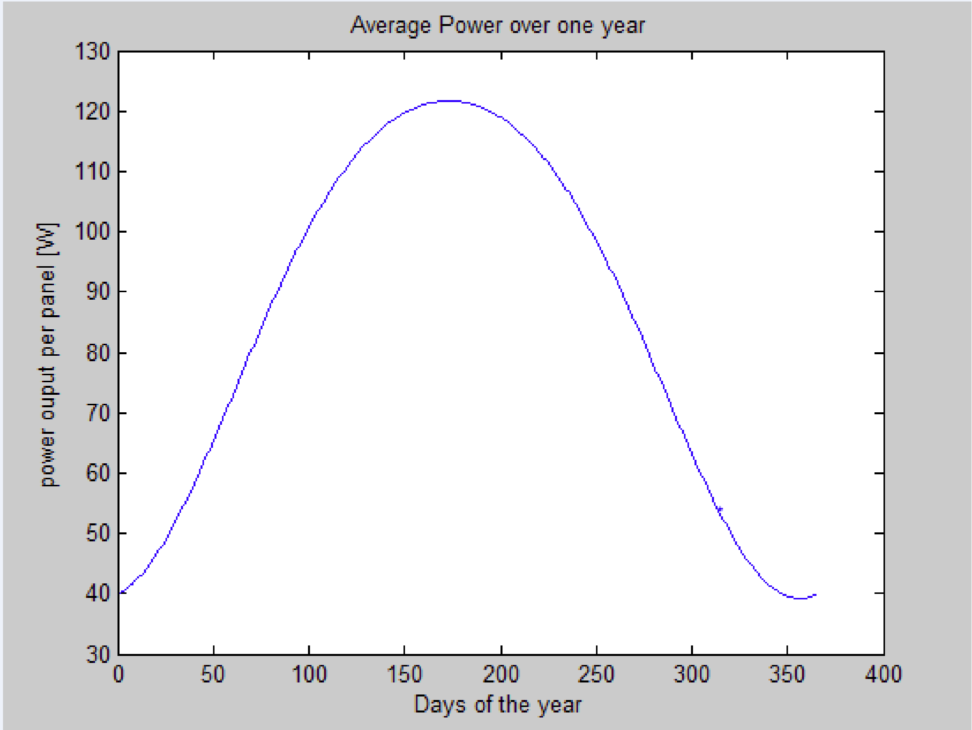


Figure 3.6: Average power per panel over a year

As we can see for each panel, it produces much more power around summer than winter. Based on the average values, each panel will be able to charge about four laptops in summer while it can only charge one in winter. The maximum average power is 125 W, which happens in summer.

The energy generated by each panel is calculated by the equation:

$$E = P \cdot t$$

The term t we used here represent the sunlight time every day. We did not use solar time here because our power is calculated based on the average irradiance during the daylight time. The result is shown in Figure 3.7.

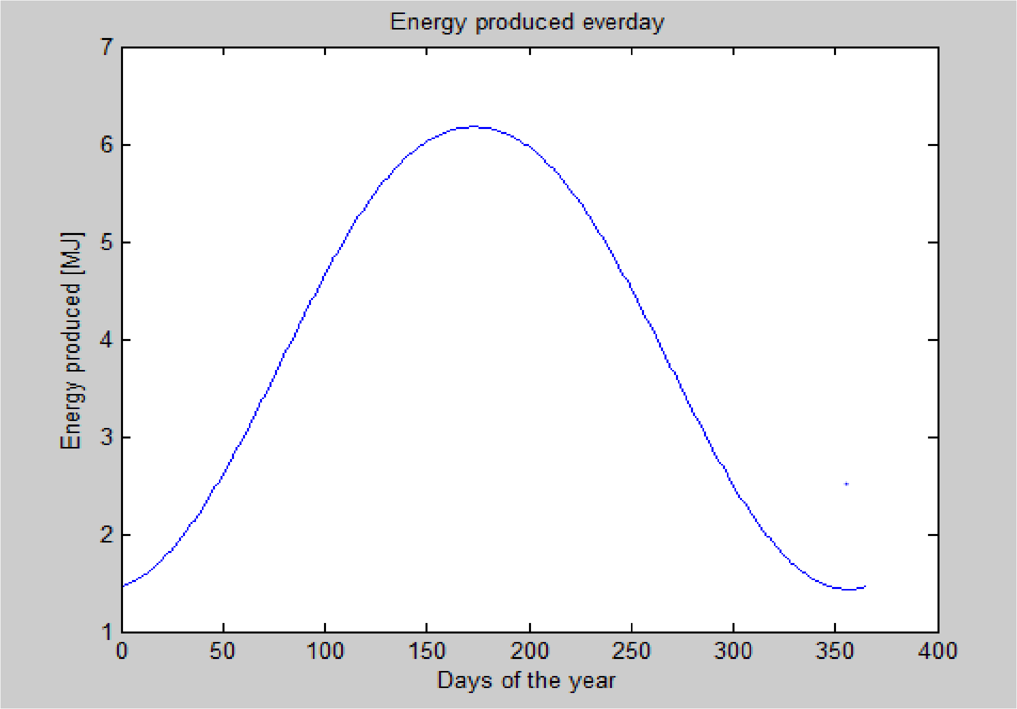


*Figure 3.7: Daily yield for each panel*

The plot shows a similar behavior like the power. The reason is in summer, the average power and daylight time are both larger when compared to winter. The maximum daily yield is 6.18 MJ, the minimum daily yield is 1.43 MJ and the average yield through the whole year is 3.86 MJ. The energy loss on inverter needs to be taken into account to get our actual energy output.

## 3.5 Battery Analysis

To determine how much battery back-up the system would require we had to decide on how many devices the system would charge. The team decided six cell phones and six laptops should supply enough charging capability to meet the demand. The typical cell phone draws four watts to charge and a laptop uses approximately 40 watts. To power all these devices simultaneously a total of 264W is required. The team assumed the devices should be capable of charging for eight hours without any recharge. A total of 2112W-h per day is required for the back-up battery system.

With 2112W-h required from the batteries, the battery bank capacity must be calculated. First, the watt-hours per day are multiplied by the amount of days the battery needs to hold the charge, which we chose to be two days. The batteries were assumed to have a 50% depth of discharge.

$$\frac{Watt - hours}{day} \text{ x } days\ of\ autonomy \text{ x } \frac{1}{depth\ of\ discharge}$$
$$= total\ amount\ of\ watt - hours$$

Allowing for a 1.15 factor of safety it was concluded the battery bank capacity required a total of 9715 watt hours and 203 amp hours. Four AGM 12V / 245Ah batteries were selected for use. These four batteries are wired in series to achieve a system voltage of 48V and 245Ah.

## 3.6 Inverter and Charge controller Analysis

The inverter size was determined based off the maximum amount of wattage the system could potentially use at one time [3]. Since the maximum was found to be 750W, an inverter of 1000W was selected for use. This inverter size will allow additional wattage for unforeseen power surges.

A charge controller is used to regulate the amount of power that is stored in the batteries. An overcharged battery causes potential danger to the system. The battery may simply die or transform into an explosive if the charge control is not sized properly. To size the controller, we first had to determine the power that the panels produce. Once we analyzed the power output, we had to determine the voltage at which the batteries would be connected, 48V. The following calculation illustrates how we found the proper charge controller size.

$$Amps_{req} = Power_{\ panels} / Voltage_{batteries}$$

The charge controller requires a minimum for 15.6 A, thus a controller of 20 amps will satisfy our specifications while allowing for minor error.

The circuit breaker size was based off of National Electrical Code (NEC). NEC specifies the max amperage in the system should be multiplied by 1.25 to find the circuit breaker size [11]. The max amperage was determined to be 16.5amps, thus the circuit breaker needs a minimum rating of 20.625A. A 30A circuit breaker was selected for use to allow for slight error in the calculations.

### 3.7 Final Design

The solar charging station is designed to a grid tie system. The system will use six PV panels. These will be wired in three parallel sets of two panels in series. How the panels are wired and a schematic of the final design is shown in figure 6.1 (see appendix A). The maximum voltage is going to be 100 volts. This then combined into a single feed combiner box as shown in Figure 6.2 (see appendix A). The DC disconnect is going to be incorporated in the MNPV6 combiner box. The HQRP inverter figure 6.3 (see appendix A) is going to be placed after the combiner box. The Murray 20-amp single pole AC disconnect switch is positioned after the inverter. This component is shown in figure 6.4 (see appendix A). From the AC disconnect switch, the system puts power into the grid and the charging station draws power from there.

## Chapter 4. Cost Analysis

### 4.1 Bill of Materials

The following table lists the products that need to be purchased in order to complete the final design.

*Table 4.1: Bill of Materials*

| Item | Cost ($) |
|---|---|
| Outlets | 19.49 |
| HQRP 1000W Inverter | 283.45 |
| Copper Wires (50ft) | 35.99 |
| AC Disconnect | 11.39 |
| MidNite MNPV6 Combiner | 97.00 |
| USB cables (phones) | Android: 29.95<br>Apple: (2x) 29.95<br>Windows: 3.95 |

| | |
|---|---|
| USB cables (laptops) | Apple: 38.95<br>HP/Dell: 9.22<br>Acer: 8.22<br>Sony: 28.95 |
| GEO PV Chorus Display | 320.19 |
| | Total: $946.65 |

## 4.2 Extra costs

The system can be assembled by the team so cost of man power is minimal. Northern Arizona University

Facilities takes responsibility for all structures built on campus, thus the building cost is not covered in our cost.

## 4.3 Payback Period

Because the whole project plus man power and the total cost of production will be under $2000, it is estimated that the product will pay for itself with in about two years. The energy to charge a laptop or cellphone is trivial in terms of the cost. It only cost about $5 a month to charge a laptop and with six laptops and cell phones it will be about $1000 of payback a year.

# Chapter 5. Conclusion

## 5.1 Progress

As a group we have progressed almost according to plan. (See the Gantt charts in appendix B) We have completed the initial analysis on the solar panels and explored other alternatives to our solution. All of our data to this point is theoretical and calculated using equations and tables. Next we will work on our application to the Green Fund and discus our budget with our sponsor. For the Green Fund we need to submit a cost analysis, maintenance plan, provide information on how the project will impact NAU and the environment, and finally display the project longevity. Initially we had anticipated building a structure for the solar panels, but after discussion with our sponsor we concluded to focus on the control systems aspect of the project. Because of this we have decided not to conduct a survey of the students, as there is no structure or aesthetic for them to contemplate. We will be submitting the application to the Green Fund in mid-January (see figure 7.3 in appendix B).

## 5.2 Conclusion

For optimal performance and energy usage, our group decided to provide power for a maximum of six laptops and six cell phones to charge simultaneously. This will allow for students, faculty, and staff to charge their devises in a timely manner, while still making sure the power usage is within the capability of the solar panels. As well, the PV panels will be angled at 35º to maximize on performance. Due to flagstaffs latitudinal coordinates, the sun's rays hit the panels at an angle that will optimize efficiency and produce the most power. The average output from the panels throughout the year creates about 132W per day. This power will be sufficient in creating enough power for all of the devices we would like to power. The charge controller selected will be one of 20 amps, and a 1000W inverter will be used to allow for unanticipated loads. Finally, for our back up system, if we choose to use the battery system we will use four 12V/245Amp-h batteries that will be wired in series to achieve a system voltage of 48W. Our ideal system will be grid tie, as per Dr. Acker's request, but of it no longer becomes feasible we are prepared to install a battery backed-up system. We have anticipated our budget to be around $1128.40 with a little room for product price fluctuation, unforeseen technical difficulties and product failures.

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## Appendix A
## Engineering Drawings

Because our project is a collection of parts, figure 6 is a schematic of how our parts will connect.

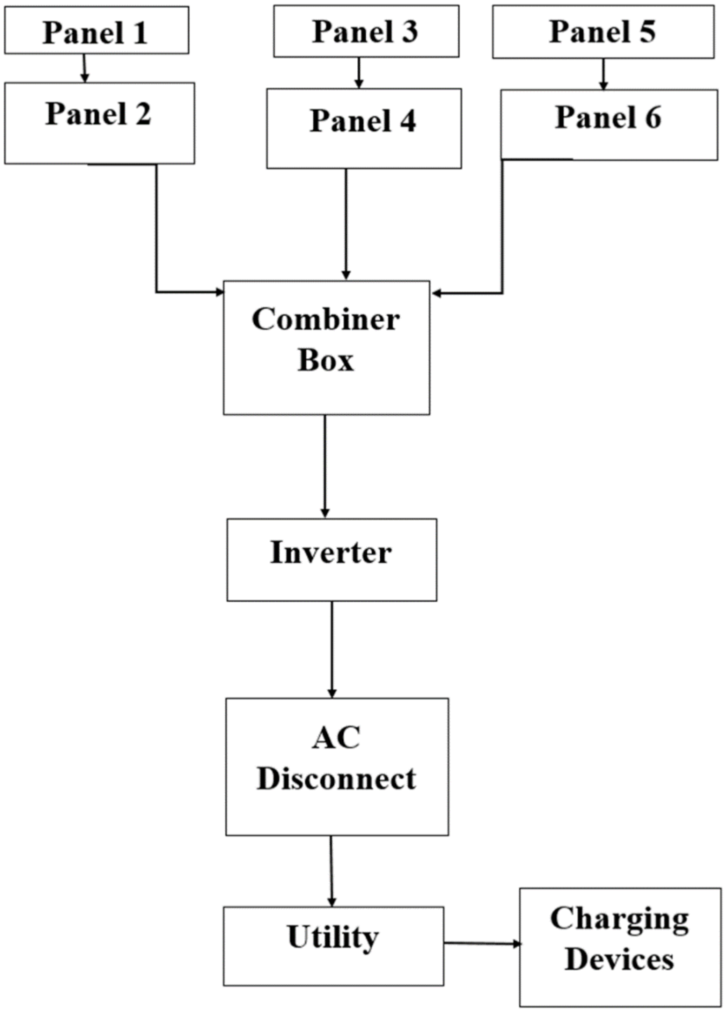


*Figure 6.1: Schematic of the System*

The following figures (figures 6.1-3) are of the different components features in figure 6.

*Figure 6.2: Combiner Box*

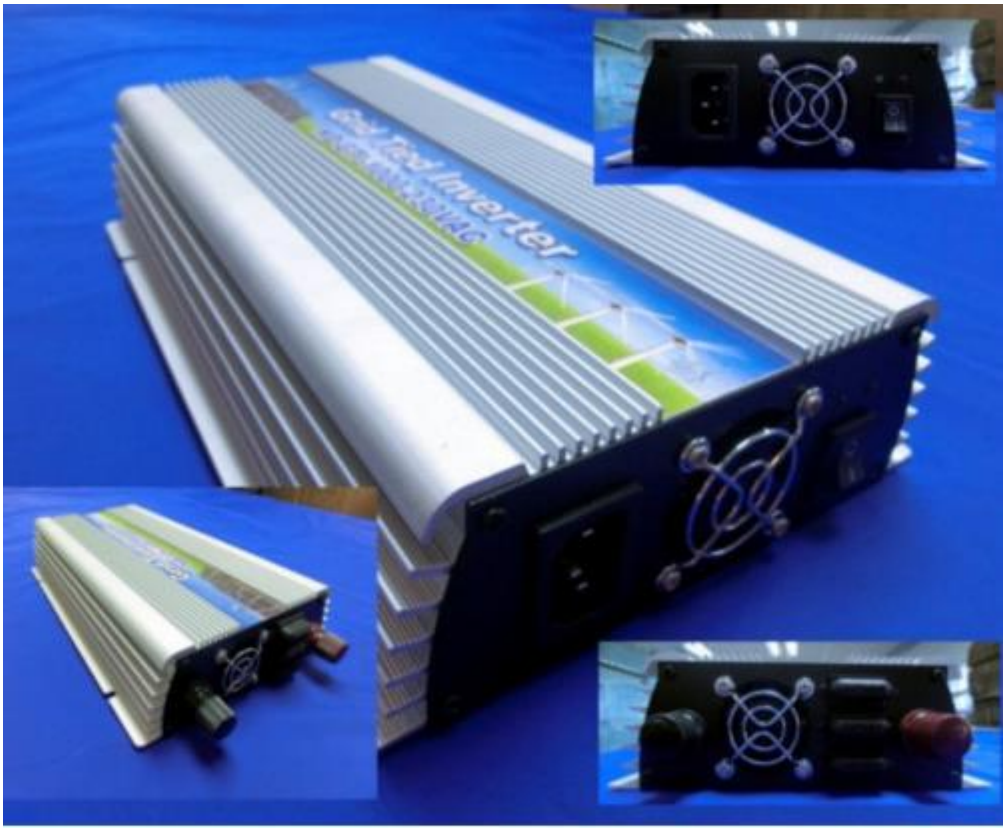
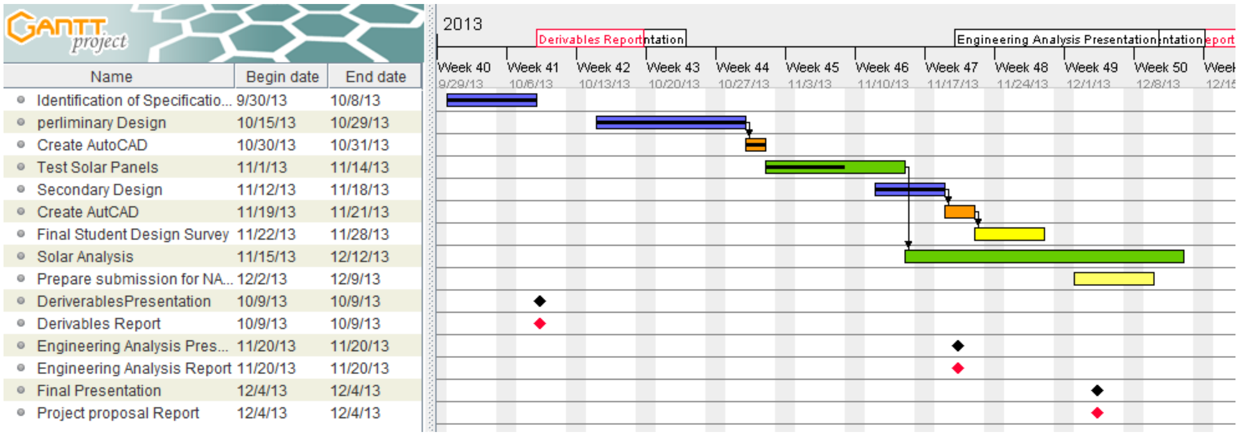


*Figure 6.3: HQRP inverter*

*Figure 6.4: Murray 20 Amp Single-Pole Circuit Breaker*

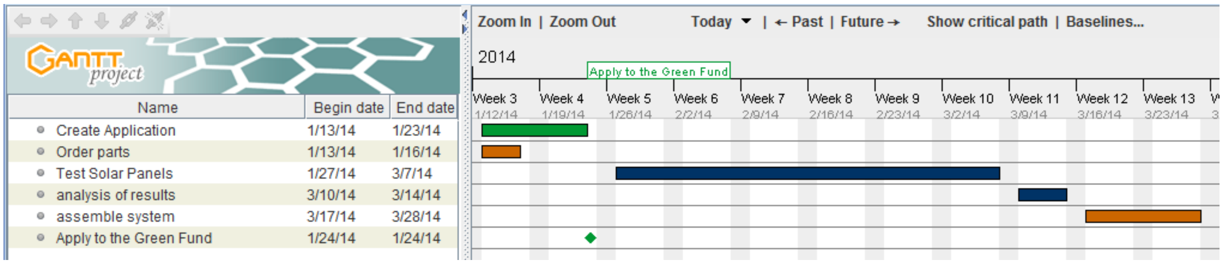
# Appendix B

The Following is in association with section 5.1: Progress.



| Name | Begin date | End date |
|---|---|---|
| Identification of Specificatio... | 9/30/13 | 10/8/13 |
| perliminary Design | 10/15/13 | 10/29/13 |
| Create AutoCAD | 10/30/13 | 10/31/13 |
| Test Solar Panels | 11/1/13 | 11/14/13 |
| Secondary Design | 11/12/13 | 11/18/13 |
| Create AutCAD | 11/19/13 | 11/21/13 |
| Final Student Design Survey | 11/22/13 | 11/28/13 |
| Solar Analysis | 11/15/13 | 12/12/13 |
| Prepare submission for NA... | 12/2/13 | 12/9/13 |
| DeriverablesPresentation | 10/9/13 | 10/9/13 |
| Derivables Report | 10/9/13 | 10/9/13 |
| Engineering Analysis Pres... | 11/20/13 | 11/20/13 |
| Engineering Analysis Report | 11/20/13 | 11/20/13 |
| Final Presentation | 12/4/13 | 12/4/13 |
| Project proposal Report | 12/4/13 | 12/4/13 |

*Figure 7.1: Fall Semester's Progress*



| Name | Begin date | End date |
|---|---|---|
| Create Application | 1/13/14 | 1/23/14 |
| Order parts | 1/13/14 | 1/16/14 |
| Test Solar Panels | 1/27/14 | 3/7/14 |
| analysis of results | 3/10/14 | 3/14/14 |
| assemble system | 3/17/14 | 3/28/14 |
| Apply to the Green Fund | 1/24/14 | 1/24/14 |

*Figure 7.2: Schedule for next semester*