Solar Charging Station

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Engineering Analysis

Document

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Table of Contents

1.0 Introduction

Our goal is to create a solar charging station that will be able to charge small electronics. This station will host seven solar panels from ISES, a control system, a display, and USB outputs to charge the devises. We have concluded that the best design encompasses a pre-programmed display and a grid tie connected control system. Along with the best option, we will be analyzing the second best idea, a battery system with a team-programmed display. We use a solar projection to estimate our projected power input for the system. We can use this data to then figure out the amount of power we will produce for the electronics, how much we need to allocate for the display, and if we will be able to add power to the grid.

2.0 Solar Panel

Figure 1- solar panel angled at 35°

The panel will be angled at 35° because 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 MATLAB code was based on how the PV panel is oriented.

3.0 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.

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

$$(2112\ W-h) * 2\ days * 2 = 8448\ W-h$$

$$(8448\ W-h) * 1.15 = 9715\ W-h$$

$$\frac{9715W-h}{48V} = 203\ A-h$$

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.

The inverter size was determined based off the maximum amount of wattage the system could potentially use at one time [5]. Since the maximum was found to be 792W, 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.

$$Amps_{req} = Power\ _{panels}/Voltage_{batteries}$$

$$Amps_{req} = \frac{792\text{W}}{48\text{V}} = 16.5\text{A}$$

The charge controller requires a minimum for 16.5A, 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 [6]. 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.

4.0 Solar Analysis

The solar constant (G) 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) is given by equation (1).

$$B = \frac{2\pi}{365} \times \left(day\ of\ the\ year + \frac{hour\ of\ the\ day - 12}{24}\right) \quad (1)$$

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 (2).

$$E = 229.2 \times \left(0.000075 + (0.001868 \cos B)\right) - (0.032077 \times \sin B) \quad (2)$$

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

ω is the hour angle, which can vary from -90° to 90°
$\omega = 15°$ per hour.
This value is negative for the morning hours and positive for the afternoon.

β is the slope of the PV panel
$\beta = 35°$
The representation of G throughout the year is modifying the solar constant before it reaches Earth's atmosphere by factors of B. This is shown in equation (3).

$$G = 1367 \times \left(1.000110 + (0.34221 \cos B)\right) + (0.001280 \sin B) + (0.000719 \cos 2B) + (0.00077 \sin 2B) \quad (3)$$

The solar constant is plotted over the course of one year as shown in Figure 1. 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.

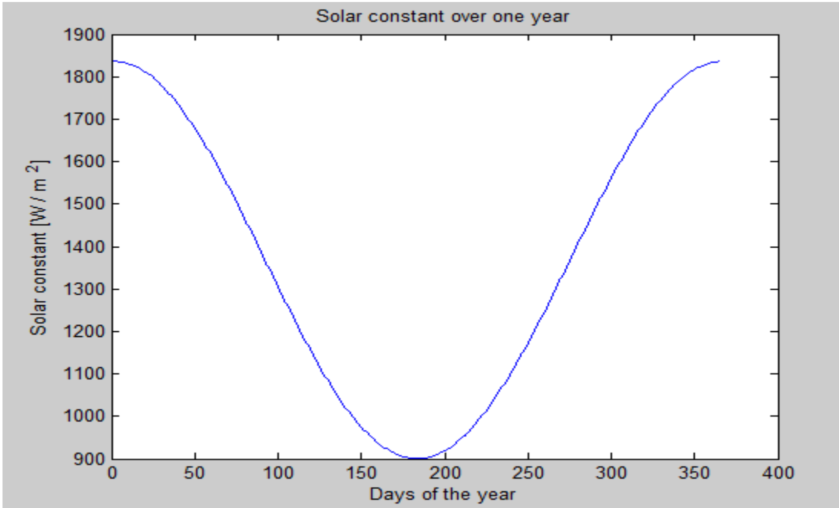

Figure 2: Solar constant projected over the course of one year

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 (4).

$$\delta = 0.006918 - (0.399912\cos B) + (0.070257\sin B) - (0.006758\cos 2B) + (0.000907\sin 2B) - (0.002679\cos 3B) + (0.00148\sin 3B) \quad (4)$$

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 (5).

$$P = \sin^{-1}\left(0.39795\cos\left(0.2163108 + 2\tan^{-1}\left(0.9671396\tan\left(0.0860 \times (day\ of\ the\ year - 1)\right)\right)\right)\right) \quad (5)$$

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 (6).

$$D = 24 - \left(\frac{24}{\pi}\right)\cos^{-1}\frac{\sin 0.8333 + \sin latitude \sin P}{\cos latitude \cos P} \quad (6)$$

The number of daylight hours can be seen in Figure 2. 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.[1]

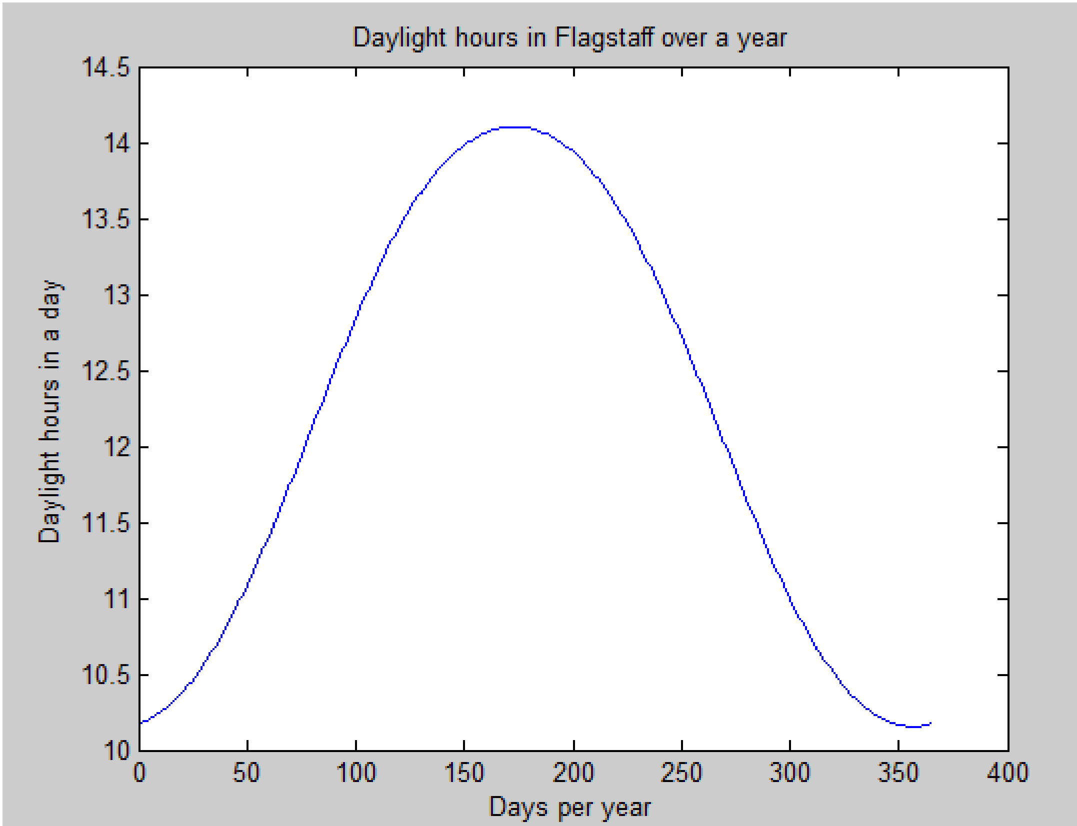

Figure 3 : Number of daylight hours each day over one year in Flagstaff, Arizona

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 (7).

$$\theta_z = \cos^{-1}(\sin latitude \sin\delta + \cos latitude \cos\delta \cos\omega) \quad (7)$$

The actual irradiance that affects the solar panels are shown by equation (8). 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 (8).

$$I = 1000\cos\theta_z \quad (8)$$

Figure 3 shows the yearly projection of irradiance in Flagstaff, Arizona. The irradiance is based on the ideal irradiance of 1000W/m^2 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/m^2 and the zenith angle. The zenith angle is the angle between the vertical and the line to the sun. [2]

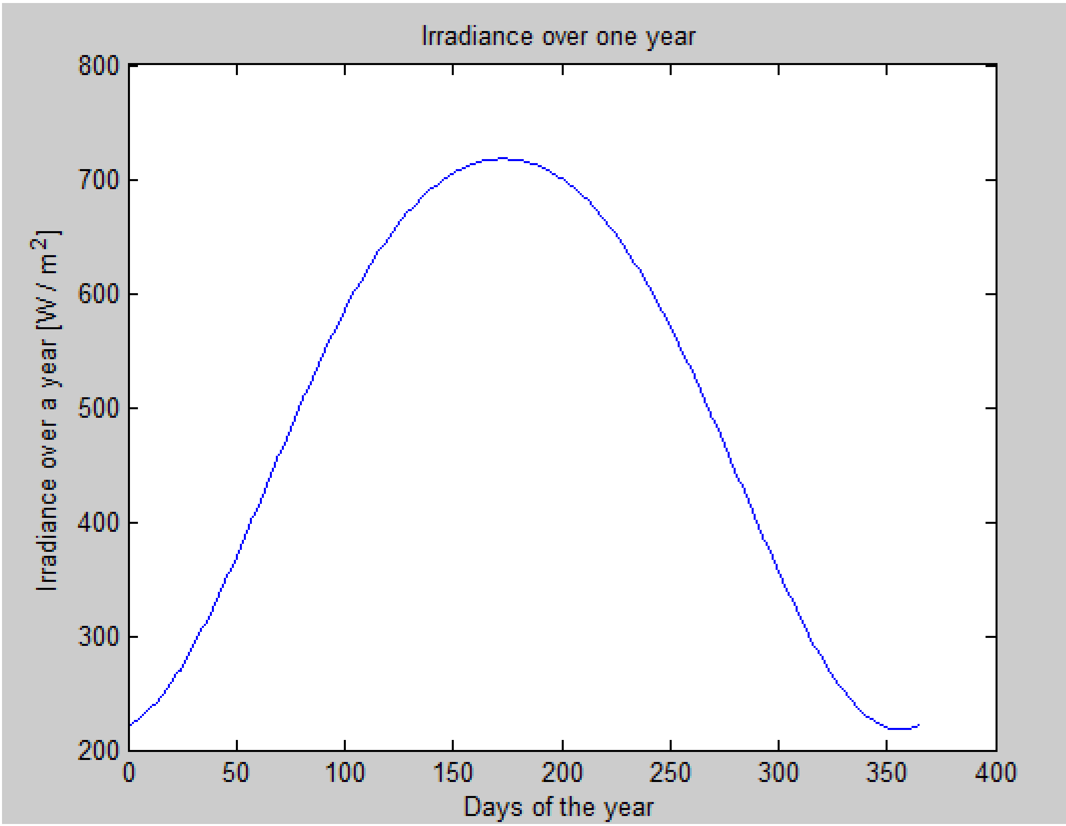

Figure 4: The irradiance projected over one year in Flagstaff, Arizona

Based upon the dimensions that were gathered from the solar panels, the surface area of one panel can be found by equation (9).

$$A = 1.3208m \times 1.8288m \tag{9}$$

Using the irradiance and the surface area, the ideal power for one solar panel can be found from equation (10).

$$P = A \times I \tag{10}$$

The ideal power for one panel over one year can be found in Figure 4. This plot shows that the maximum ideal power of one panel is around 1750W. The plot also shows that the minimum power for one panel is around 550W. The average power based off of the plot is around 1200W. This is the power going into the solar panels.

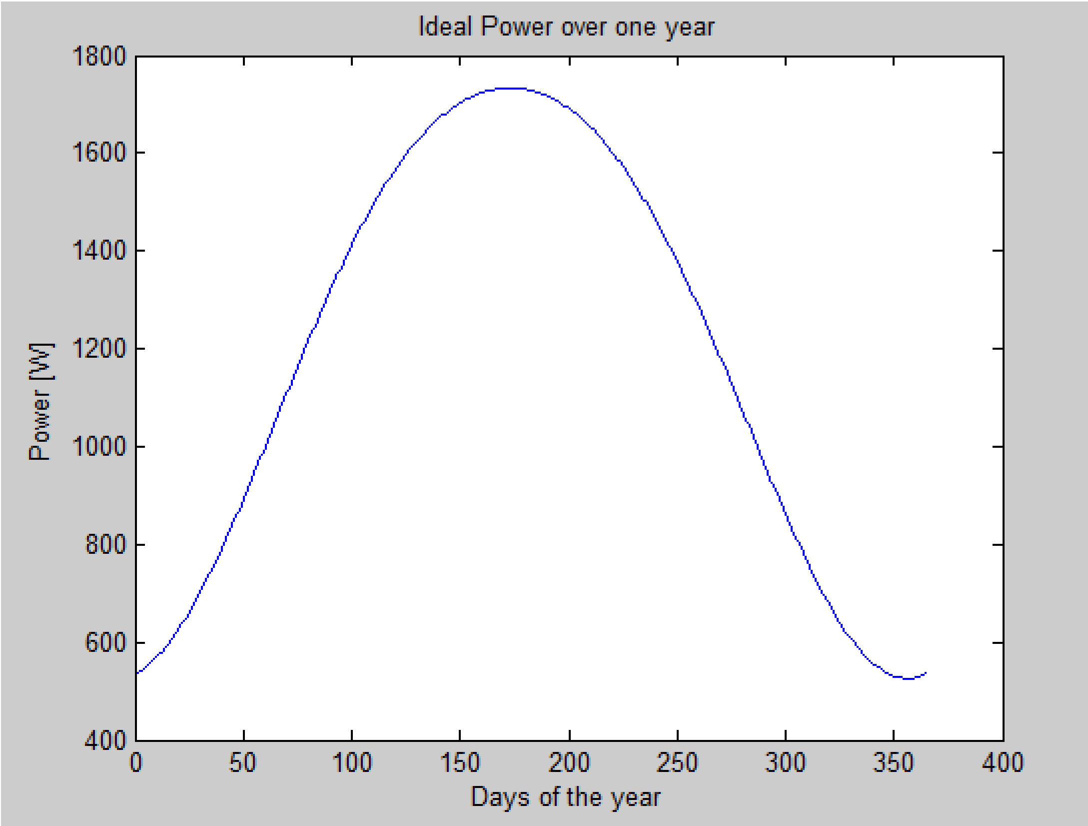

Figure 5: The ideal power of one solar panel over the course of one year in Flagstaff, Arizona

4.1 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.

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

Where,

T_{air} : is the expected air temperature

NOCT: is the nominal operating cell temperature

G: is the daily average solar irradiance hit on the solar panel surface

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:

$$\text{Percentage loss} = (T_{cell} - 25) \text{ x } T_{cop}$$

Where,

T_{cop} : is the temperature coefficient of power

For our solar panel, T_{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 6. It has about 6% energy loss in summer and the average energy loss is 3.4%.

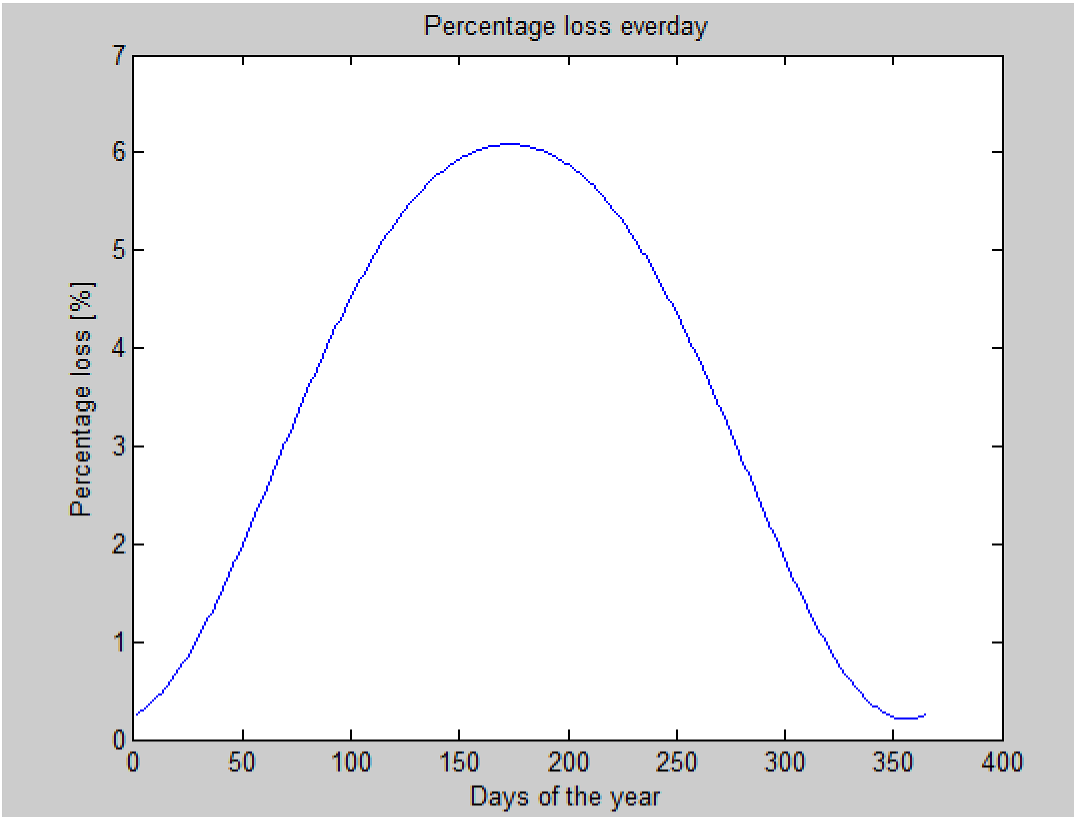

Figure 6: Energy loss due to high temperature

Power and yield

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

$$P = G \cdot 0.3 \cdot (1 - T_{loss}) \cdot (1 - 0.05)$$

0.3 is the coefficient to convert the average irradiance to power. From the model information of our solar panel, irradiance of 1000 W/m^2 can be converted into a rated max power of 300 W for each panel. According to this information, we estimated the coefficient to be $\frac{300\ \mathrm{W}}{1000\ \mathrm{W/m^2}} = 0.3\mathrm{m}^2/\mathrm{per\ \ panel}$. 0.05is 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 7.

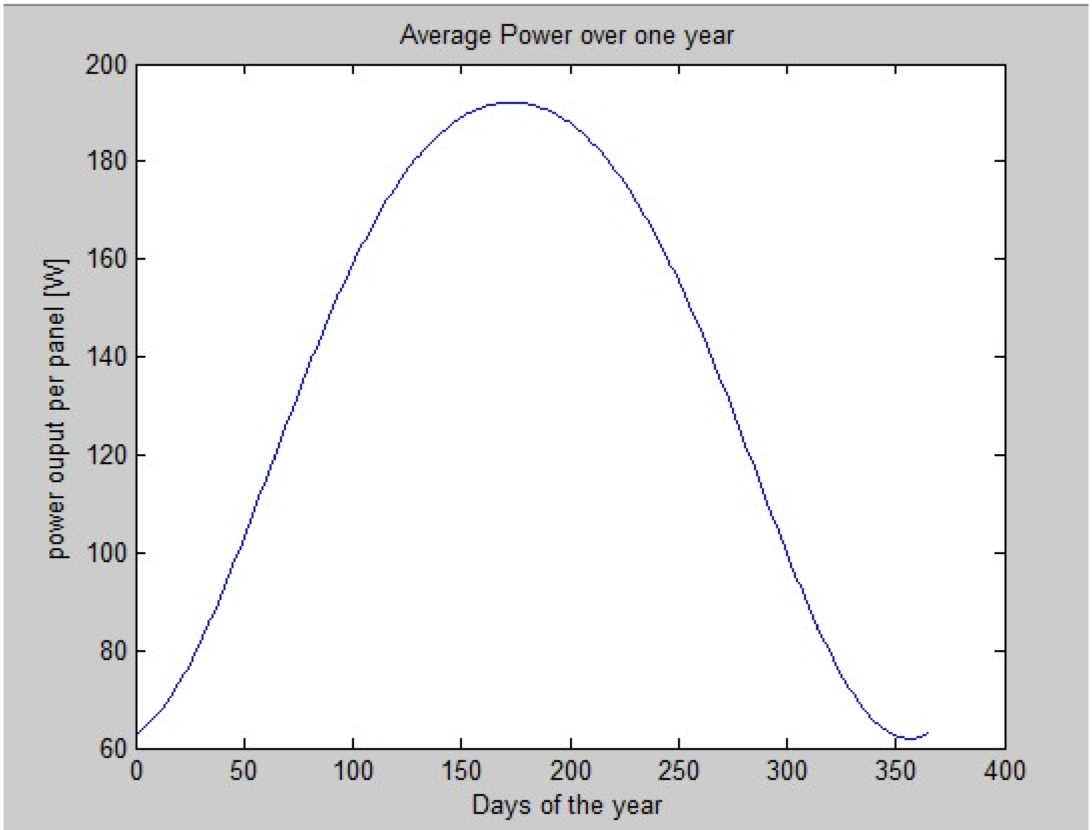

Figure 7: Average power per panel over a year

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 187.8 W and the overall average power is 131.6 W.

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

$$E = P \cdot t$$

Where,

P: is the average daily power

t: is the sunlight time

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 8.

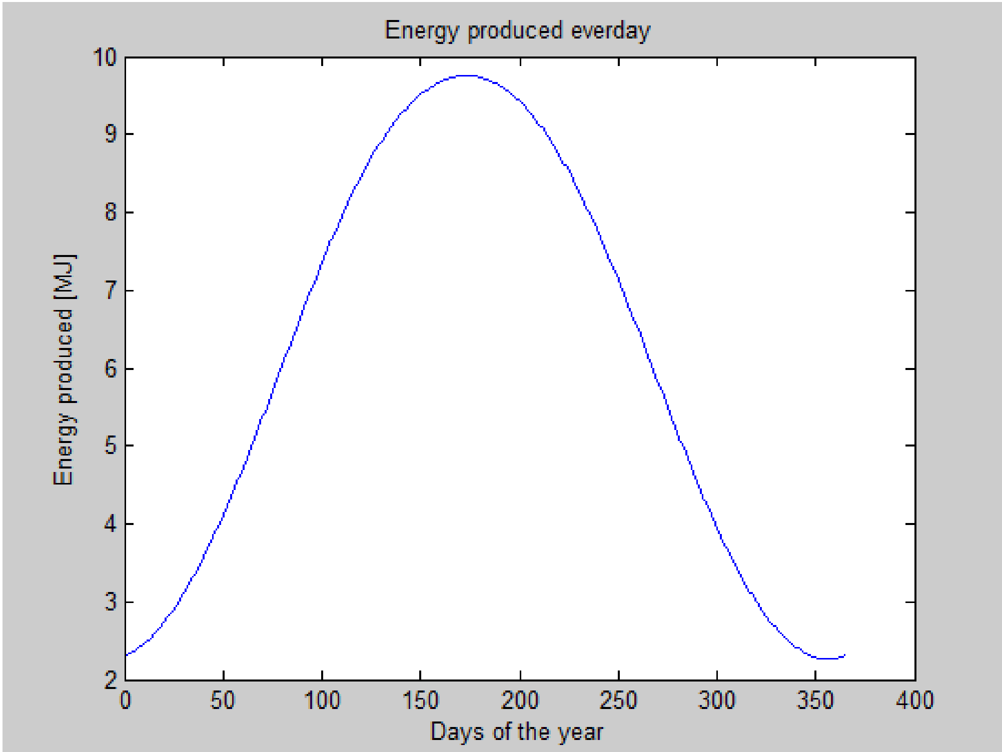

Figure 8: Daily yield for each panel

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 9.53 MJ, the minimum daily yield is 2.25 MJ and the average yield through the whole year is 6.00 MJ.

5.0 Gantt Chart

As a group we have progressed almost according to plan. (See the Gantt chart in appendix A) We have completed the initial analysis on the solar panels, but have not completed the actual testing. All of our data to this point is theoretical and calculated using equations and tables. Next we will continue with the solar analysis and continue using equations to figure out the information we need. 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. In the upcoming weeks we will also begin preparation on the submission to the green fund.

6.0 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. Ackers request, but of it no longer becomes feasible we are prepared to install a battery backed-up system.

References

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[2] M. Rahim, J. Yoshino and T. Yasuda, "Evaluation of solar radiation abundance and electricity production capacity for application and development of solar energy," *International Journal of Energy & Environment,* vol. 3, pp. 687-700, 09, 2012.

[3] "Choosing and Sizing Batteries, Charge Controllers and Inverters for Your Off-Grid Solar Energy System", Solar Town, http://www.solartown.com/learning/solar-panels/choosing-and-sizing-batteries-charge-controllers-and-inverters-for-your-off-grid-solar-energy-system/ , November 16, 2013

[4] "Circuit Breaker Sizing", Thomson Technology, http://www.nolensales.com/files/circuit_breaker_sizing.pdf, November 17, 2013

[5] A. Ahmad and R. Loganathan, "Real-Time Implementation of Solar Inverter with Novel MPPT Control Algorithm for Residential Applications," *Energy & Power Engineering*, vol. 5, pp. 427-435, 08, 2013.

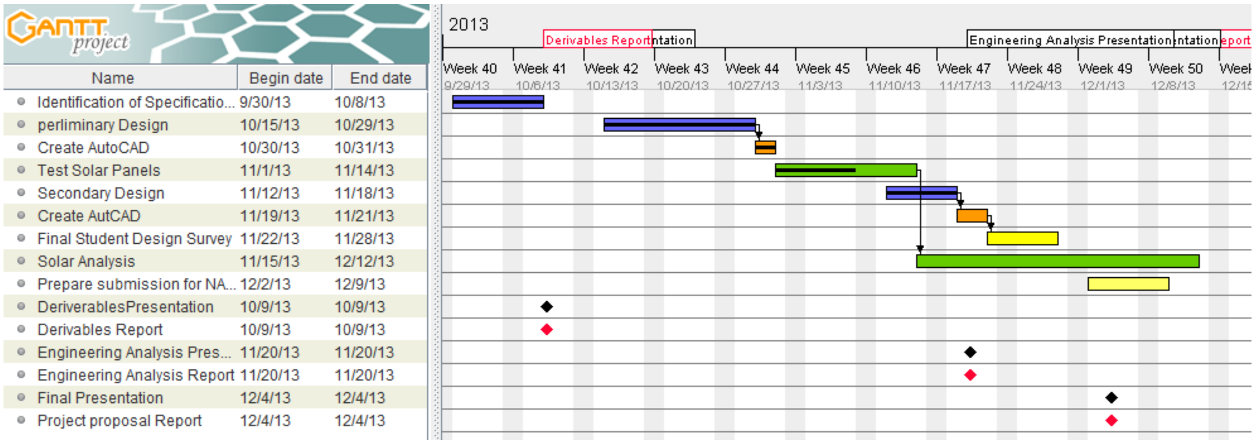
[6] "Circuit Breaker Sizing", Thomson Technology, http://www.nolensales.com/files/circuit_breaker_sizing.pdf, November 17, 2013.\

[7] "Standby Power Summary Table", Standby Power, http://standby.lbl.gov/summary-table.html , November 16, 2013

[8] "Estimating Solar System Yields," LETITGO, [Online]. Available: http://www.letitgo.com.au/solar-engineering/19--estimating-solar-system-yields.html. [Accessed 15 11 2013].

Appendix A

Gantt Chart



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 9: Project Progress

Appendix B

Symbols and definitions

Symbols

ø – Latitude
S – Declination
ß – Slope
ɣ - Surface Azmuth Angle
w – hour angle
θ -Angle of Incidence
θ_z - Zenith Angle
α_5 - Solar Angle

Definition

Latitude (ø) – The angular location north of south of the equator. North is positive -90° ≤ Ø ≤ 90º.
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; -23.45º ≤ S ≤ 23.45º.
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 (θ_z)– the angle between the vertical and the line to the sun.
Solar Altitude Angle (α_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