MEMO

TO: Dr. Thomas Acker

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

Date: 18 April 2014

Re: Final Report

Dr. Acker,

The final design for the ISES Solar Charging Station includes two parts, a structural design and a control system. The structural portion is intended to house components from the control system. The system will be placed on the patio outside the southern end of the W.A Franke College of Business on NAU's Flagstaff campus. The control system has eleven components including the Sunny-boy inverter and its conjoining display, the Sunny-Beam. With the provided six solar panels the system as a whole is able to charge small electronic devices such as cell phones and laptop computers.

Testing done on the solar panels demonstrated an average output of 6.87 kWh for six panels with the ability to reach 8.24 kWh. Assuming each laptop consumes 100 W-h and each cell phone consumes 10 W-h the system can power an average of 30-35 laptops and cellphones. The entire control system and labor costs creates a minimum estimated cost of about $10,000.

Solar Charging Station

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Team 17

Final Report

Document

Submitted towards partial fulfillment of the requirements for
Mechanical Engineering Design II – Spring 2014

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Nomenclature

Symbols

ω– Distributed Load

L – Length

E – Modules of Elasticity

I – Moment of Inertia

ø – Latitude

δ – Declination

n – Day Number

w – Hour Angle

θ_z – Zenith Angle

I – Solar Irradiance

A – Panel Area

η_{panel} – Efficiency of panel

t – Solar Hour

G – Solar Constant

Definition

Latitude (ø) – The angular location north of south of the equator. North is positive -90° ≤ Ø ≤ 90º.

Declination (δ) – 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.

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.

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

Solar Constant (G) – Radiation of the sun, 1367 w/m^2

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Abstract

Renewable energy has become increasingly important due to the dwindling sources of oil, coal, and natural gases. While only 16.7% of energy is being produced via renewable sources, this number continues to grow as recognition for a sustainable solution increases. For the NAU senior design capstone of spring 2014, our team is tasked with creating a location where students and faculty can charge small electronics with power generated by solar panels. Seven 300W solar panels are donated to the project by Institute for Sustainable Energy Systems (ISES) at NAU. The charging station will be located in a structure in the university campus. It can power up to six laptop devices simultaneously. An educational screen will be displayed at the station to inform patrons of the energy savings due to the panels. Another focus is designing the control system of the project. Through the advisement of professors and community members, the inverters, display system, transducers, and all other components were put together with intention of educating the general public on energy consumption.

The final design for the control system consisted of eleven parts that used the combination of grid and solar power to charge the devices. From the testing of the solar panels, it was found that on the average day 30-35 laptops and cellphones can be charge. These results coincided with the predicted power output from the solar panels' ratings. The calculated power output was 236 W with an efficiency of 9.45%. The summer energy produced was larger than that during the winter due to the irradiance and day light hours over the year. For the structure, it was determined that the roof would be angled at the optimal angle for Flagstaff, 35º. Constructed of ASTM A500 grade B rectangular steel tubing of size 10" x 5" x$\frac{3}{8}$", the structure will be located on the W.A. Franke College of Business south facing patio. The will provide the optimal amount of sunlight during the day throughout the year.

The cost of the control system came to about $2,500. With the addition of the labor, the minimum estimated cost was around $10,000. In this estimate the cost of the structural side was not included due to the fluctuation in construction materials and the uncertainty of the design. When presented to NAU's facilities the probability of adjustments to the current design are inevitable.

Chapter 1: Introduction

1.1 Problem description and Client

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 utilized to power small electronics such as cell phones and laptops. We will be looking into the control system and display system to 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.

1.2 State of the art research

The central component for the control system is the inverter. Inverters convert DC power into AC power, have an input voltage range, and often have a built-in DC disconnect. With home solar panels gaining popularity in the past two decades, the need for efficient, small, and reliable inverters has increased. It is being investigated as to whether or not a multi-level-H-bridge will increase the efficiency of the inverter. This design will "provide lower switching losses, simple switching techniques, modularity, and simpler charge-balancing approaches than conventional technology," [6]. Switching losses means that there will be less losses as the power is switched from DC to AC. This will create a more efficient inverter that will optimize the output of the power harvested from the sun. One of the top inverters currently on the market is manufactured by SMA (the Sunny-boy used in the system described below is from SMA). The current technological push is to have all the different interfaces of the system be able to communicate. For example, if a PV panel is not working, the inverter will be able to read the missing data and notify the user of the issue [16]. With the system management and monitoring technology, the user can immediate see how much power is being produced and if and where there is a problem occurring. These updates will make the system more efficient, easier to use and more accessible to the average adult. The only development that is still in the development stages is limiting the size and weight of the inverter. Technology is becoming more streamlined, and with that, in time the size will catch up. Before there is optimization, the components of an efficient system must be created.

Chapter 2. Problem formulation

2.1 Identification of need

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.

2.2 Project Goal

Design a solar charging station capable of providing enough power to charge small electronic devices. In addition, a structure to hold the solar panels and house the electrical components will be designed.

2.3 Objectives

From our sponsor and the different constraints we have encountered, we have developed a set of objectives we would like to achieve (Table 2.1). To begin, our goal is to charge small electronics, and thus that is one of our primary objectives. Because we are working through the Green Fund at NAU, we need to minimize the cost. 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 a monitoring 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 energy 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 2.1: 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

2.4 Operating environment

The system will be located outside the W.A. Franke College of Business, NAU, as shown in Figure 2.1. where it will be sunny throughout the day. The location is optimal for use of solar panel because there are not any trees or shades blocking the sun. The system should be able to withstand to withstand snow and high winds.

Figure 2.1: Business patio

2.5 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 possibly installing the solar panels.

2.6 Quality Function Development

Figure 2.2 shows a Quality Function Deployment (QFD) diagram. The left side of the diagram shows the customer requirements. These were determined by discussing the project with those whom came up with the project concept, along with the project sponsor. The upper portion of the diagram shows the engineering requirements. These are the requirements that seem to be the most important aspects of the project from an engineering aspect. They show what the main points of the project should be. The lower portion of the diagram shows the units of the engineering requirements. The units are what the engineering requirements will be measured and calculated in. The center area shows the relationship between the customer requirements and the engineering requirements. The diagram shows that there is a strong emphasis on cost because the station is to be designed to cost as small as possible.

		Engineering Requirements				
		Energy	Stress	Cost	Yield Strength	Weight
Customer Requirements	Educational			x		
	Withstand Environment	x		x		x
	Charge Small Devices	x				
	Safe		x	x	x	x
	Inexpensive			x		
	Units	kWhr	kPa	$	kPa	N

Figure 2.2: QFD

Chapter 3. Engineering Analysis

3.1 Solar Irradiance

The calculation of solar irradiance was done in MATLAB. In order to calculate the average irradiance that is 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 Flagstaff (35°), the declination angle, and the hour angle. The declination angle can be calculated by equation:

$$\delta = arcsin(sin(23.5)\, sin(\frac{360}{365}(n-81))$$

Cosine of zenith angle can be found in equation:

$$\cos\theta_z = \sin latitude \sin\delta + \cos latitude \cos\delta \cos\omega$$

Multiply it by the solar constant and the irradiance can be obtained by the following equation:

$$I = G\cos\theta_z$$

The result is shown in Figure 3.1.

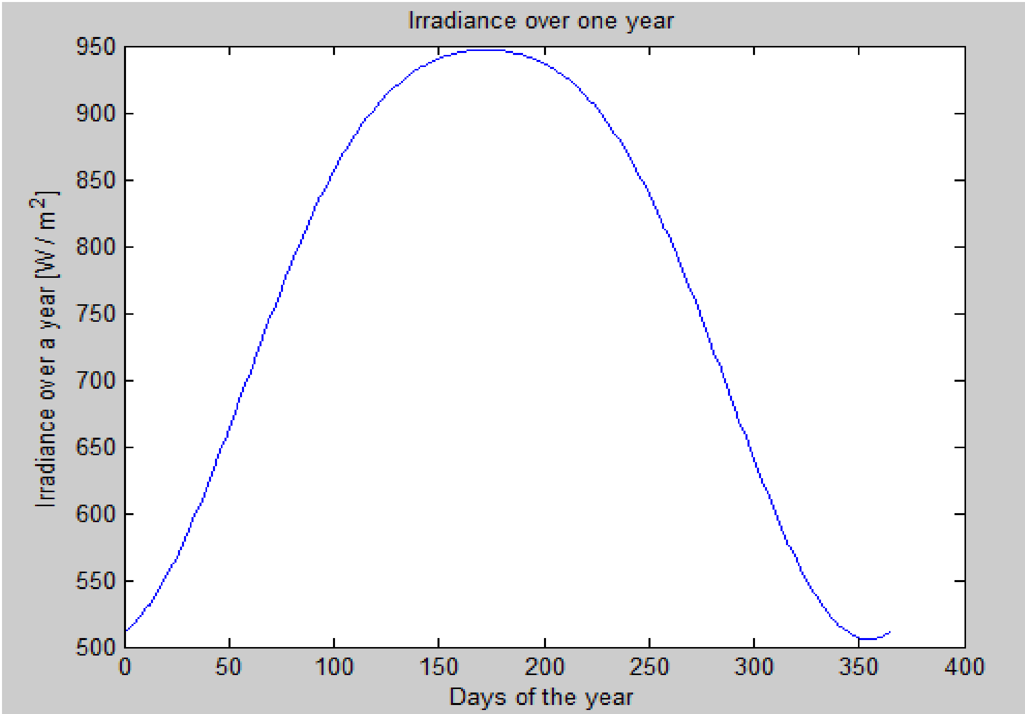

Figure 3.1: Solar irradiance in Flagstaff

From the result, the average irradiance around solar noon in summer is 950 W/m^2, while the irradiance in winter it is about 520 W/m^2, this will affect a lot in the energy produced by each panel between summer and winter.

3.2 Energy

The energy generated is related to irradiance, panel area, solar hours, the efficiency of panel and the efficiency of the inverter. The equation is shown below:

$$E = I \cdot A \cdot t \cdot \eta_{panel}$$

Since our irradiance is an 8 hours average around solar noon, the solar hours value will be 8 hours. The panel area is about 2.4 m^2, with the rated efficiency of 12.4%.

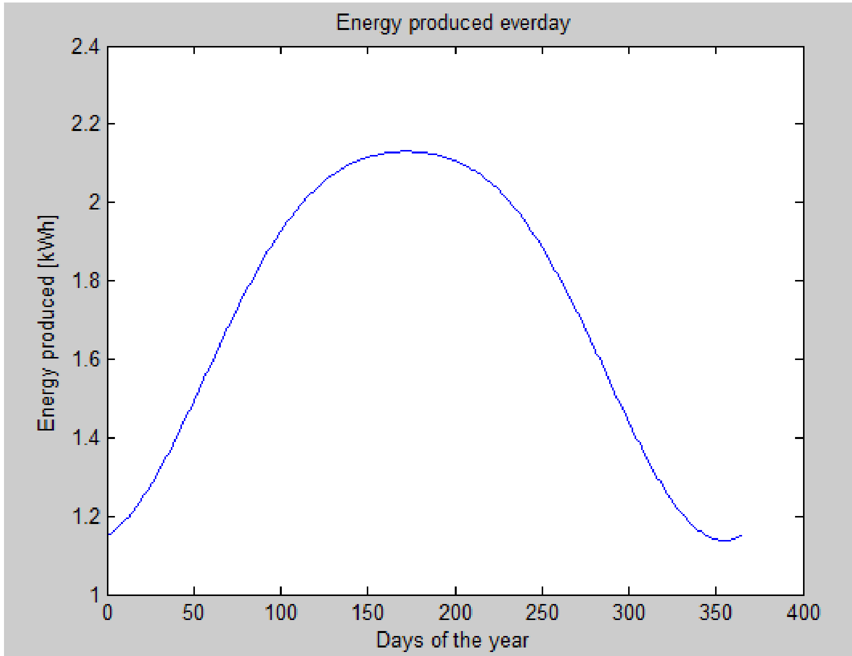

Figure 3.2: Daily yield for each panel

From Figure 3.2, there is a big difference in energy generation for each panel between summer and winter. The daily energy produced in summer could be up to 2.1 kWh, while in winter, it will be less than 1.2 kWh.

Monthly average is calculated to compare with the measured data from NASA Atmospheric Research Center to verify whether our estimation is valid.

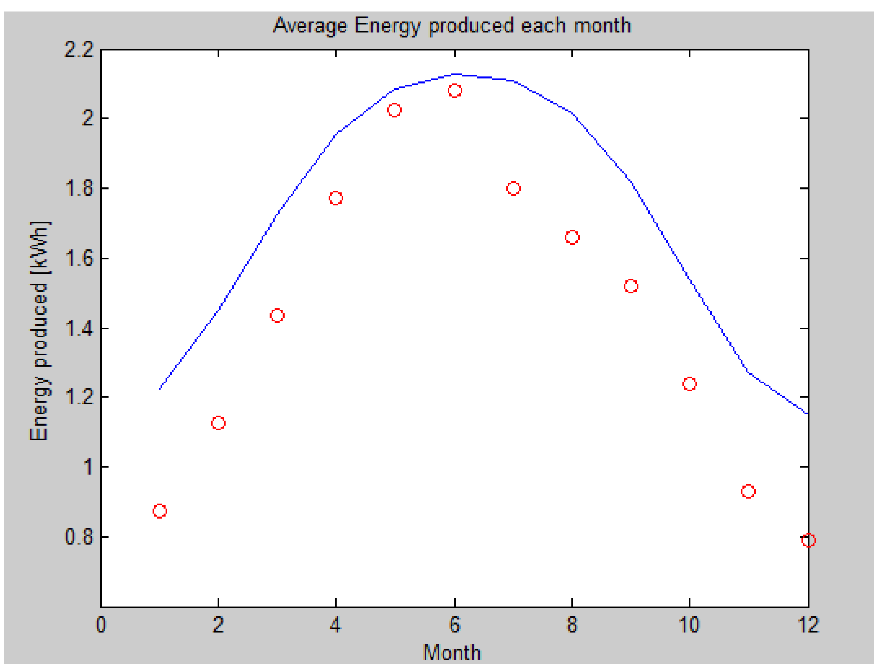

Figure 3.3: Monthly average energy produced

The blue line in Figure 3.3 is the estimated result, the red circle represents the measured data from NASA. As we can see, the estimated result is greater than the measured data. This is reasonable because we assume clear sky condition in our estimation, which is impossible in reality.

3.3 Solar Panel

Figure 3.4 is the CAD drawing of the PV panel. The model is ASE-300-DG/50. 300 represents the rated maximum power and 50 is the output voltage. The panel will be angled at 35°, which is same as the latitude of Flagstaff. Also, the PV panel will also be facing due south to maximize the irradiance going into the PV panel.

Figure 3.4: Solar panel angled at 35°

3.4 Structure

The team decided to go with a gable housing design. First, the team modeled the system using Solid Works as shown in Figure 3.5, 3.6 and 3.7. The dimensions are included for the critical sections. The roof is angled at 35° considering this angle is the optimum angle for solar panel use. The support beams are 12 feet long to keep the roof out of reach as shown in Figure 3.7. The width is 26 feet based on the solar panel sizes.

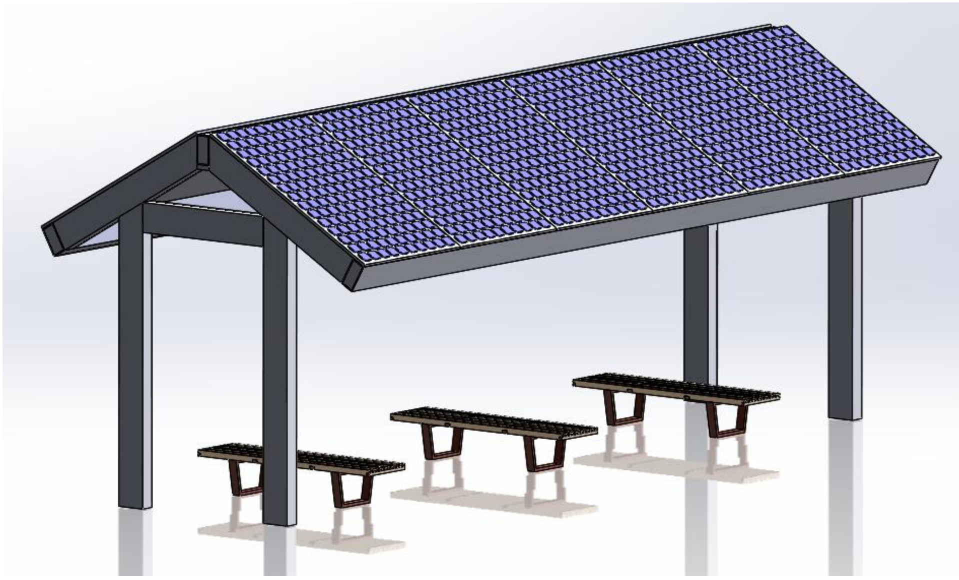

Figure 3.5: Structure for housing components

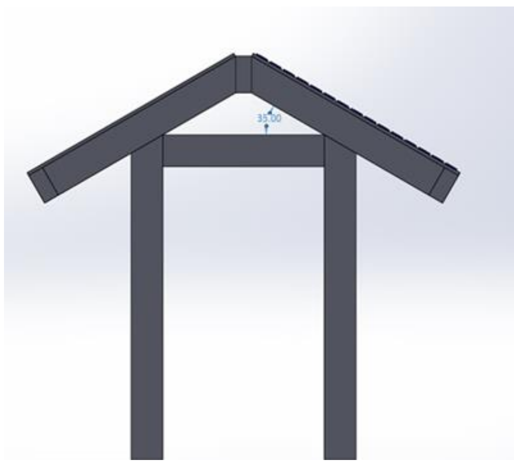

Figure 3.6: Structure for housing components side view

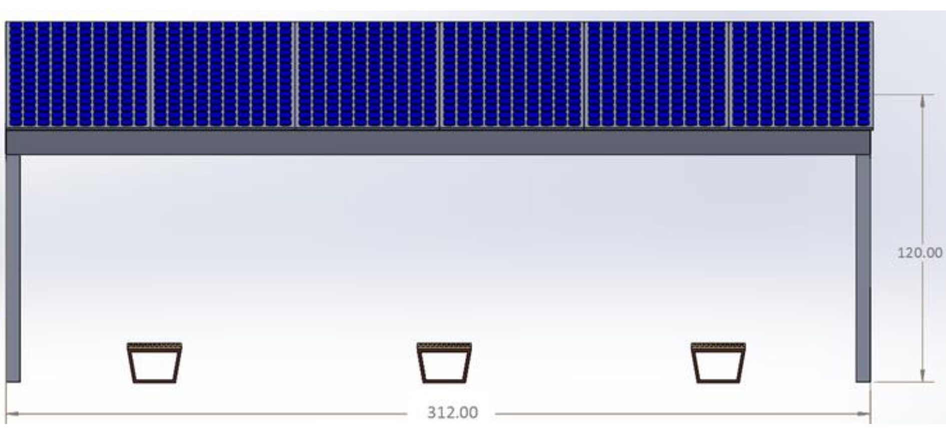

Figure 3.7: Structure for housing components front view

Once a design was selected, the team decided to choose a material for the structure to test whether the system can support the weight of the panel and to withstand snow and wind.

Calculations for choosing the material:

Assumptions:

Weight of beams = $30\frac{lb}{ft}$

Weight of snow = $40\ \frac{lb}{ft^2}$

Weight induced by wind = $25\frac{lb}{ft^2}$

With these numbers we were able to calculate the dead weight and the live weight.

Dead weight= weight of the structure + weight of the solar panels

Weight of the structure= $30\frac{lb}{ft}$, weight of the solar panels= $\frac{645}{26} = 24.81\frac{lb}{ft}$

$$\omega_{dead} = 30 + 24.81 = 54.81\frac{lb}{ft}$$

Live weight = (weight of snow x depth of panel) + (wind load x depth of panel)

$$\omega_{live} = 40 \times 6.21 + 24 \times 6.21 = 403.65\frac{lb}{ft}$$

So total weight

$$\omega_{total} = 403.65 + 54.81 = 458.46\frac{lb}{ft}$$

Once the total distributed load was calculated, the team started calculations on the highlighted beam in figure 3.8 shown below. As a general rule, the deflection of the highlighted beam should be limited to the length of the beam divided by 180.

Max Deflection $\delta \leq \frac{L}{180} \rightarrow \frac{312}{180} = 1.73\ in$

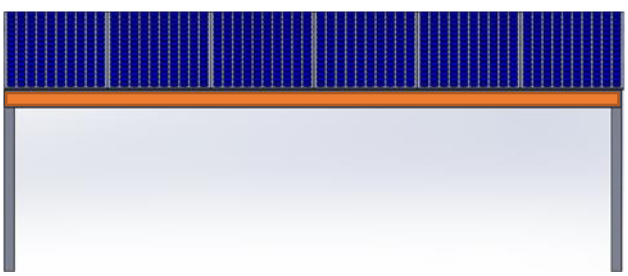

Figure 3.8: Highlighted beam

To find the maximum deflection we used the equation for a simply supported beam with an evenly distributed load.

Max Deflection $\delta = \frac{5\omega L^4}{384EI}$

Assuming the modulus of elasticity of 29.3 x 10^6 psi [18].

Solving for I,

$$I = \frac{5\omega L^4}{384\delta E} = 5 \times 38.21 \times \frac{312^4}{384 \times 1.73 \times 29.3 \times 10^6} = 93.008\ in^4$$

Based on moment of inertia that we calculated, we decided to choose a rectangular steel tube. In particular, ASTM A500 grade B steel with sizing of 10”x5”x3/8” was selected as shown in Table 3.9 below. This material possesses a moment of inertia of 120 in^4, thus will be strong enough for the system.

Table 3.1 Steel Tubing [17]

Nominal Size			Weight per Foot	Wall Thickness t	b/t	h/t	Cross Sectional Area	X-X Axis I_x	S_x	r_x	Z_x	Y-Y Axis I_y	S_y	r_y	Z_y	Torsional Stiffness Constant J	Torsional Shear Constant C	Surface Area Per Foot
in.	in.	in.	lb.	in.			in.^{2}	in.^{4}	in.^{3}	in.	in.^{3}	in.^{4}	in.^{3}	in.	in.^{3}	in.^{4}	in.^{3}	ft.^{2}
10	x 8	x 1/2	55.66	0.465	14.2	18.5	15.3	214	42.7	3.73	51.9	151	37.8	3.14	44.5	288	66.4	2.87
		3/8	42.79	0.349	19.9	25.7	11.8	169	33.9	3.79	40.5	120	30.0	3.19	34.8	224	51.4	2.90
		5/16	36.10	0.291	24.5	31.4	9.92	145	29.0	3.82	34.4	103	25.7	3.22	29.6	190	43.5	2.92
		1/4	29.23	0.233	31.3	39.9	8.03	119	23.8	3.85	28.1	84.7	21.2	3.25	24.2	155	35.3	2.93
		3/16	22.18	0.174	43.0	54.5	6.06	91.4	18.3	3.88	21.4	65.1	16.3	3.28	18.4	118	26.7	2.95
10	x 6	x 5/8	59.32	0.581	7.3	14.2	16.4	201	40.2	3.50	51.3	89.4	29.8	2.34	35.8	209	58.6	2.50
		1/2	48.85	0.465	9.9	18.5	13.5	171	34.3	3.57	43.0	76.8	25.6	2.39	30.1	176	48.7	2.53
		3/8	37.69	0.349	14.2	25.7	10.4	137	27.3	3.63	33.8	61.8	20.6	2.44	23.7	139	37.9	2.57
		5/16	31.84	0.291	17.6	31.4	8.76	118	23.5	3.66	28.8	53.3	17.8	2.47	20.2	118	32.2	2.58
		1/4	25.82	0.233	22.8	39.9	7.10	96.9	19.4	3.69	23.6	44.1	14.7	2.49	16.6	96.7	26.2	2.60
		3/16	19.63	0.174	31.5	54.5	5.37	74.6	14.9	3.73	18.0	34.1	11.4	2.52	12.7	73.8	19.9	2.62
10	x 5	x 3/8	35.13	0.349	11.3	25.7	9.67	120	24.1	3.53	30.4	40.6	16.2	2.05	18.7	100	31.2	2.40

After selecting the material and the size we calculated the deflection to make sure that it does not exceed the general rule of $\frac{L}{180}$. In our case, the maximum deflection should not exceed 1.73 inches.

$$\delta = \frac{5 \times 43 \times 312^4}{384 \times 29000 \times 10^3 \times 120} = 1.52\ in \leq 1.73in$$

The material deflection is less than 1.73in, which means that the size and material we selected fulfills our requirement. Next, we constructed a bending-moment diagram to calculate the reaction forces at the supporting legs as shown in Figure 3.9 below.

Bending-moment diagram:

Calculations:

$$\sum M_A = -4840 \times (156) + F_B(312) = 0$$

$$F_B = 2420\ lb\ , \qquad F_A = 2420\ lb$$

For the moment diagram:

$$M = area\ of\ triangle = 0.5 \times b \times h = 0.5 \times 2420\ \times 156\ = 188760\ lb.in$$

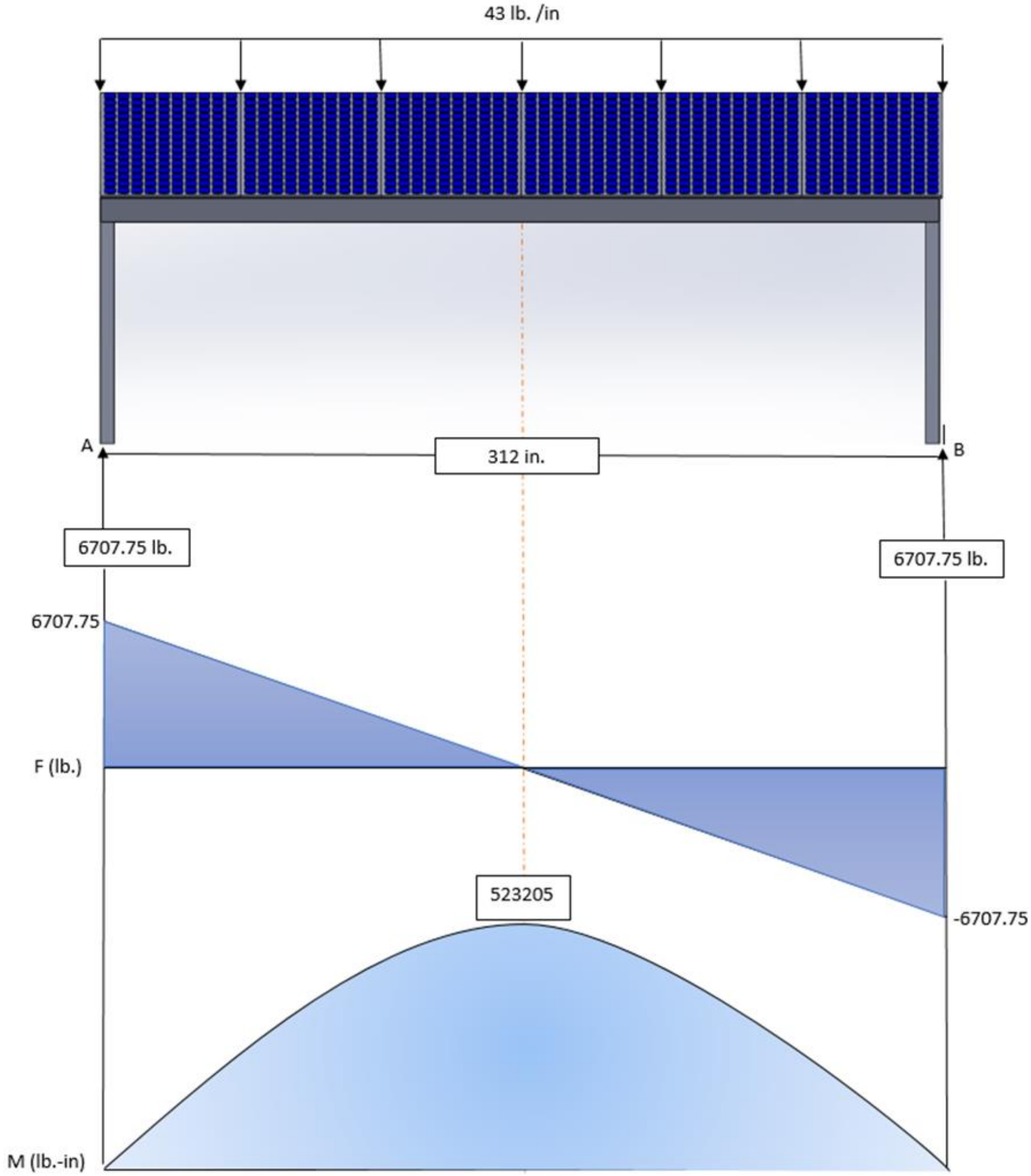

Figure 3.9: Bending- moment diagram

Buckling load calculations:

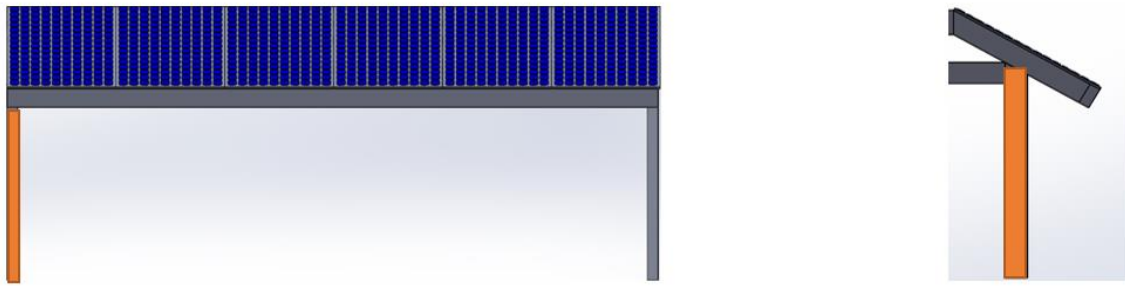

Figure 3.10: Buckling beam

Assuming the highlighted beam in Figure 3.10 is between two fixed points:

Effective length = $0.5\ L$

The equation the critical buckling load is computed by [19]:

Critical Buckling load = $\frac{4\pi^2 EI}{L^2} = \frac{[4\pi \times (29000 \times 10^3) \times (40.6\ )]}{(0.5 \times 60)^2} = 1.27208 \times 10^7 lb$

Since the force on each beam is 6707.75 lb and the buckling load is $1.27\text{x}10^7$ lb, the beams can support the weight of the structure without buckling.

Chapter 4. Proposed Design

The proposed design consists of a solar system that will be connected directly to the grid. This connection will allow for the continuous charging of devices regardless of weather conditions, time of day, and the instantaneous power being produced by the panels. The panels will be angled at 35° facing due south for optimal sun exposure throughout the day and year. Below is a simple schematic of the proposed design.

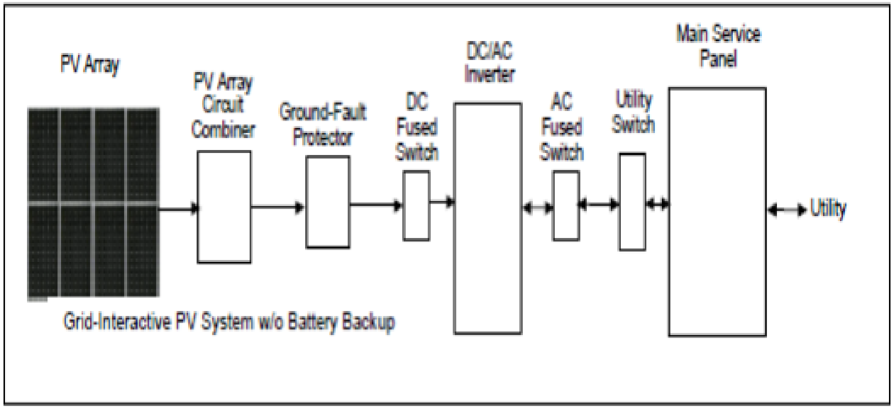

Figure 4.1: Schematic of Grid-Tied Solar System

4.1 Component Selection

The solar panels were provided by Northern Arizona University and the remaining system was designed to work in junction with these panels. Six ASE-300-DGF/50 panels will produce the power for the system and will be wired in series. Each panel produces a maximum of 300 watts and 50 volts with an efficiency of 12.4%. With all six panels wired in series, an array voltage of 300 volts is achieved.

The first feature after the solar panels is a solar combiner box. A Midnite Solar MNPV3-Circuit Combiner was selected for use. A fuse holder is mounted inside the combiner box and a 600V DC fuse will be placed inside. This fuse preserves the remaining components by providing overcurrent protection in case of a short in the system. This box also provides the system with a method of grounding the PV array. Our system will be setup as a negatively grounded PV array, which effects how the remaining components are wired.

Figure 4.2: Combiner Box

After the combiner box, the wires connect to a DC disconnect box. Our system uses a Square D, DC disconnect rated at 600V and 30 amps. This component provides a safety feature for the system by allowing the power to be disconnected via a switch. This feature is useful when there is a need for immediate shutoff of the system before the inverter is reached. The disconnect box is housed in the structure that supports the panels.

Figure 4.3: DC Disconnect

The inverter comes directly after the combiner box and converts the DC power produced by the solar panels into AC power. A SMA Sunny Boy 2000W high frequency grid-tied inverter was selected for our system. This inverter requires an input voltage range of 175V to 600V, so the 300V panel array proves compatible. Additionally, the six panels will produce a maximum of 1800W, thus a 2000W inverter is sufficient. The AC signal produced matches the frequency of the grid at 60Hz at an efficiency of 97%. The Sunny Boy comes standard with a built-in DC disconnect switch that provides an extra safety feature. The inverter is located inside at the main circuit board connection.

Figure 4.4: SMA Sunny Boy Inverter

A monitoring system will be used to record key data from the solar array. The Sunny Beam monitoring system was selected because of the compatibility with the inverter. Via Bluetooth, the inverter sends data to the compact display that can be altered to the desired settings. These settings include what information is displayed, recorded, and how the display is powered. Options for what information is displayed includes the daily profile, current output, total energy yield for the day or year, and CO_2 emissions savings. The display can be powered via three methods. First, the display has a built in solar panel that can be used to power the monitor during daylight hours. The monitor includes rechargeable batteries that can power the display during dark hours and a power cord can be directly inserted into the display for all other charging needs. The monitoring system will be located at the solar panel structure so patrons can be informed of the savings.

Figure 4.5: Sunny Beam Display

Once the power is converted into AC form, another disconnect switch is needed. A Square D, AC Disconnect switch rated at 600V and 30 amp was selected for use. This component provides an additional safety switch that will be located at the main circuit board connection.

A system that produces or draws power from the grid is required to be metered via a standardized utility meter to comply with the National Electric Code. A Bidirectional Focus Digital Utility Meter S1 rated for 240V was selected for our system. The bidirectional feature provides a method to measure the energy input to the grid by the solar panels and then measures how much energy is drawn from the grid to change the devices. All of the readings are done in kWh. A Square D, Meter Socket Ring Type rated at 600VAC and 125 amp will be used to house the utility meter. These components will be located at the main circuit board along with the inverter and AC disconnect box.

Figure 4.6: AC Disconnect

The entire system will be wired using a dual conducting 600V direct burial wire. It will be sized to #12 AWG copper wire. This wiring size is large enough to handle the voltage and amperage requirements of the system and minimize power loss throughout the wire.

4.2 Design Schematic

A schematic was produced to illustrate how the entire system is wired. First, the six solar panels are wired in series and one output is sent into the combiner box to ensure overcurrent protection. Next, the wires leads to the DC disconnect box and then to the inverter. From the inverter, messages containing energy production data are sent to the wireless display system, where the information will be visible to the public. The output wire from the inverter runs into the AC disconnect box and then to the digital utility meter. From the meter, the systems energy is input into the grid and the instantaneous power required by the charging devices is then drawn back through the meter and to the charging sockets.

Figure 4.7: Design Schematic including selected components

Chapter 5. Testing and Results

5.1 Panel Testing

In order to properly test the solar panels, an experimental procedure and setup were needed. Figure 5.1 shows the diagram of the experimental setup.

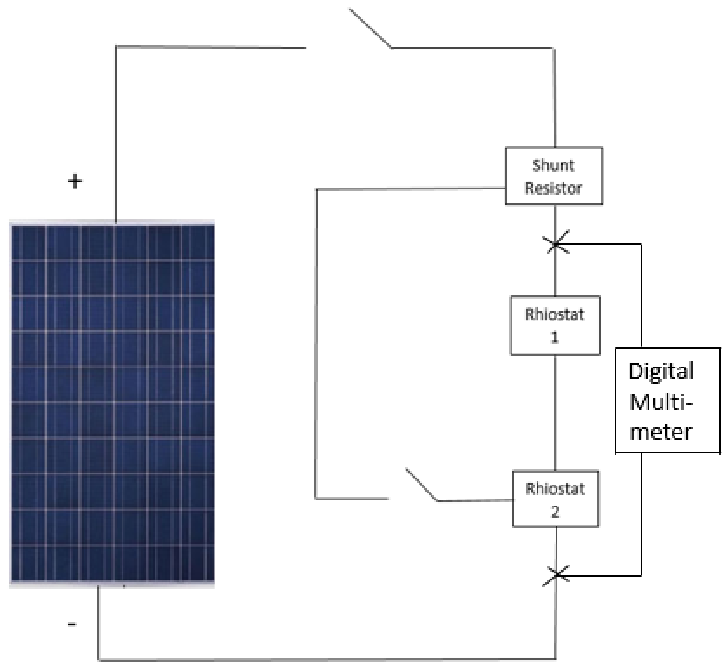

Figure 5.9: Schematic of the panel testing setup

This setup was used to test only one solar panel at a time. This was done in order to obtain data on all of the individual solar panels that were tested. As shown in Figure 5.1, the setup has a switch wired to the positive end of the solar panel that is being tested at the time. This allows for the circuit to be turned on or off as needed. This is a safety feature used to interchange components as needed. Immediately wired to that switch is a 0.05 Ω shunt resistor. This allows for the measurement of current in the system. From the shunt resistor, two rheostats are wired in series. This allows for the overall load from the solar panels to be split between the two rheostats and allows for a wider range of resistances that measurements can be taken from. The rheostats range from 0 to 10 Ω each, but neither one is set below 2 Ω as a safety precaution in order to prevent overheating and melting. The shunt resistor also has a switch wired from it to the end of the circuit. This allows for the simulation of a short circuit, which allows for the measurement of the maximum current that the panels produce. The measurements of the current and voltage were taken with the use of a digital multi-meter. This allows for the analysis of the data that the panels were outputting. In order to obtain the panel efficiency, a pyronometer was used to measure the irradiance that the sun was giving off. This is done by measuring the current across the pyronometer and using calibration numbers to find the irradiance. This method led to an irradiance of about 1000 W/m^2. Figures 5.2 shows the positive end connection of the solar panel to the test setup.

Figure 5.10: Solar panel positive end connection

Figure 5.3 shows the negative end connection of the solar panels to the test setup. Both of the connections were done using connectors that allow for the testing of the solar panels.

Figure 5.11: Solar panel negative end connection

Figure 5.4 shows the physical test setup. The two gray components are two rheostats that are used to test the solar panels. The object with three wires attached to it is the shunt resistor. Attached to the shunt resistor are the switches that are used in the system. The wires used in the test system were #12AWG single conducting copper wire.

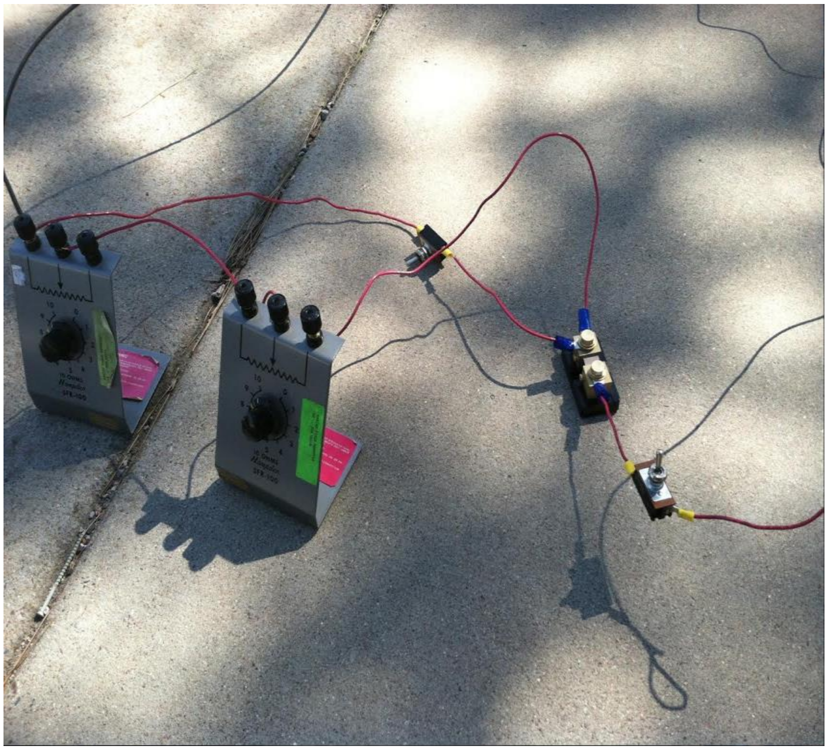

Figure 5.12: Panel testing setup

5.2 Panel Testing Results

From the measured voltage and current values that were obtained, the results were calculated and plotted. The average values of the experimental data over the six solar panels that were tested are shown in Table 5.1. This gives the voltage and the current as it was measured on the digital multi-meter. The power that is shown in Table 5.1 was calculated by using the measured voltage and current values averaged out over the six panels by using the following equation.

$$P = V \times I$$

Where P = Power

V = Voltage

I = Current

This calculation is performed over the entire data range, from the open circuit voltage (where there is no current value) to the short circuit current (where there is no voltage value).

Table 5.3:Voltage, current, and power average over six panels

Voltage(V)	Current(A)	Power(W)
61.64	0	0
57.18	2.86	163.48
56.53	3.14	177.54
55.64	3.48	193.49
54.58	3.9	212.79
52.65	4.39	231.08
50.98	4.63	236.34
48.59	4.86	236.24
44.61	4.96	221.62
39.14	4.89	192.37
33	4.71	156.29
27.23	4.54	124.14
17.71	4.43	78.69
0	6.3	0

Plots were made to show the I-V curves and the power curves that represent the data from the six panels. These plots include all of the individual panel results as well as the average over the six panels. Figure 5.5 shows the I-V curve that was obtained from the testing of the solar panels.

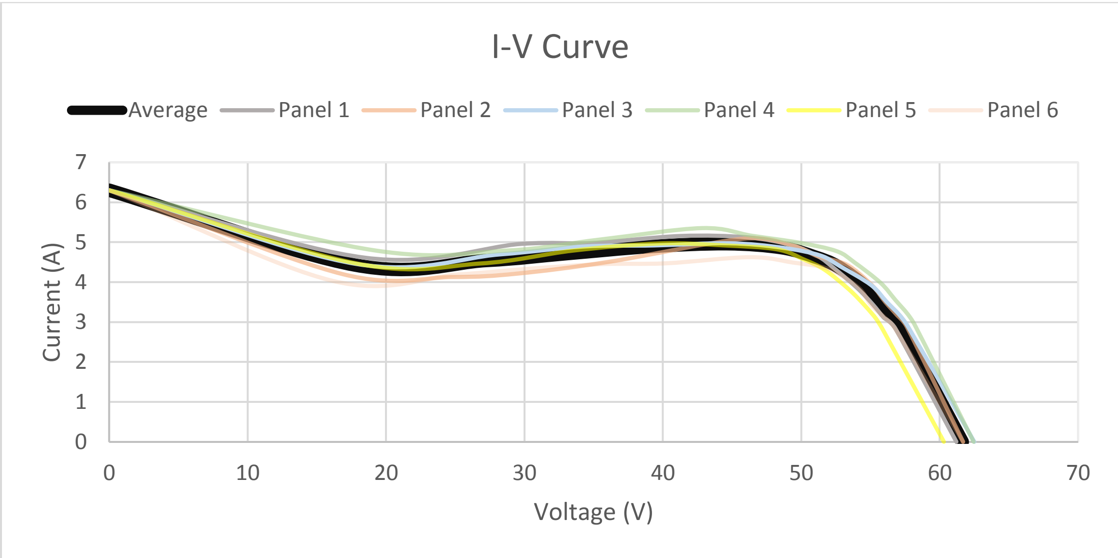

Figure 5.13: I-V Curve for all individual panels and the average values over them.

This chart shows that the short circuit current for all of the panels, and the average over the panels are all around 6.3A. It also shows that the open circuit voltage for all of the panels and the average over the panels are all around 63V. On the chart, there is a knee that occurs towards the open circuit voltage. This knee indicates the area that the optimum power output can be expected to occur in. From the chart, it is expected that the optimum power output will occur around 50V. Figure 5.6 shows the power curve that represents all of the individual power curves and the average power curve over the six panels.

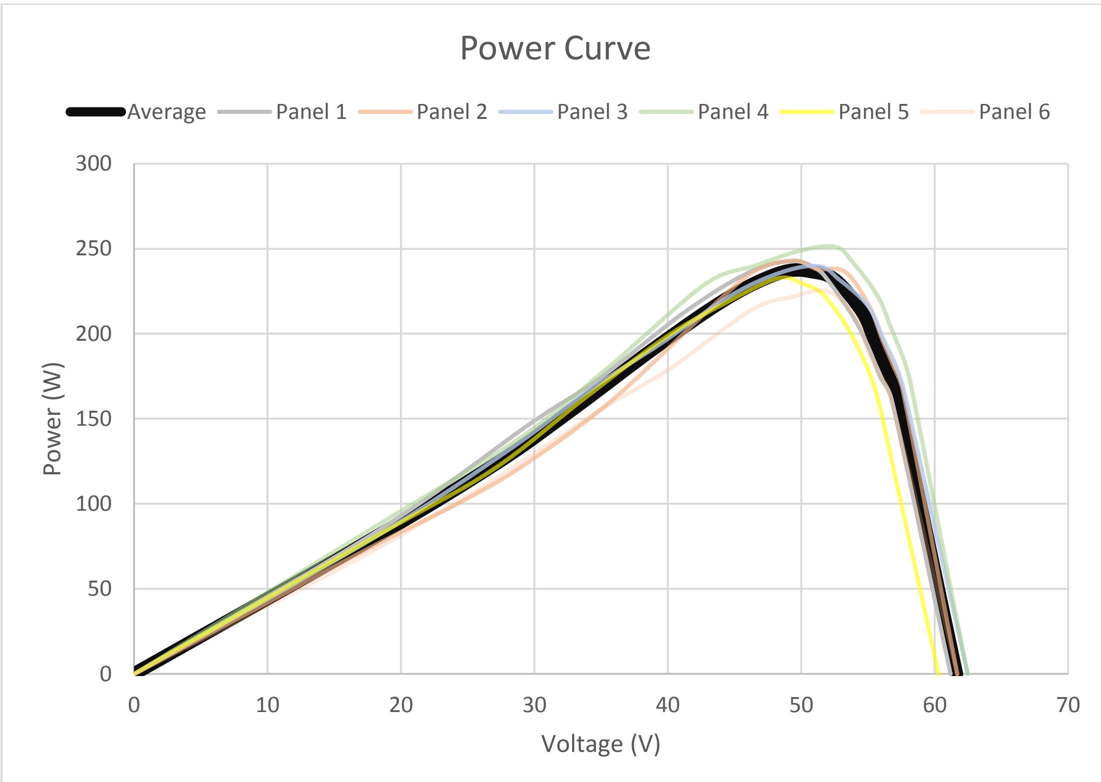

Figure 5.14: Power curve of all individual panels and the average over the six panels

This chart shows the power distribution over the measured range of voltages. This shows that the power is zero when the voltage is equal to zero and when the data is at the open circuit voltage. The chart also shows that the optimum power output is around 50V for each panel as well as the average power output over all six panels. This coincides with the prediction that was obtained from the I-V curve in Figure 5.5. From the power curve, during the useful daylight hours, it is expected that an average of about 230-240W will occur for the power output. The panel efficiency, based upon this data is calculated by the following equation.

$$Efficiency = \frac{P_{optimum}}{1000 \times 2.417} \times 100$$

$P_{optimum}$ is the optimum power from the power curve, 236W. This is then divided by the measured irradiance from the testing and the area of a solar panel. This efficiency is equal to 9.45%.

5.3 Amount of Charging Devices

The amount of devices that are able to be charged efficiently during one day by the charging station are calculated based upon the averaged optimum power output over the six panels that are being used. This value is about 236W, and includes the panel efficiency of 9.45%. This is used for the energy output that the panels produce. This output also takes into account the inverter efficiency of 97%, the number of useful daylight hours, and the number of panels used. The following equation illustrates the way that this procedure was performed.

$$E = 236 \times 0.97 \times useful\ daylight\ hours \times number\ of\ panels$$

Table 5.2 shows the energy output for different panel configurations, all wired in series.

Table 5.4: Energy output of different number of panels

	Energy Output		
Number of Panels	Summer	Winter	Average
1 Panel	1.37 kWh	0.92 kWh	1.15 kWh
4 Panels	5.49 kWh	3.66 kWh	4.58 kWh
5 Panels	6.87 kWh	4.58 kWh	5.73 kWh
6 Panels	8.24 kWh	5.49 kWh	6.87 kWh

The table shows the energy outputs for different panel numbers in the summer, winter, and an average over the year. This data is used to obtain the expected number of laptops and cellphones that the charging station will be able to charge in a year based on the average energy output of the year. The calculation for the number of laptops and cellphones that can be charged in a day on average is based upon the average energy output, the combined total of energy the devices take, and the assumption that each device will have an equal number charged. Assuming that laptops take 100W-h and cellphones take 10 W-h on average, the following calculation was performed.

$$Number\ of\ devices = \frac{E}{110}$$

Figure 5.7 shows the number of laptops and cellphones that can be charged in a day on average. This is given in a range of devices, and only shows the number for four, five, and six panels. This is because of the minimum voltage required by the inverter.

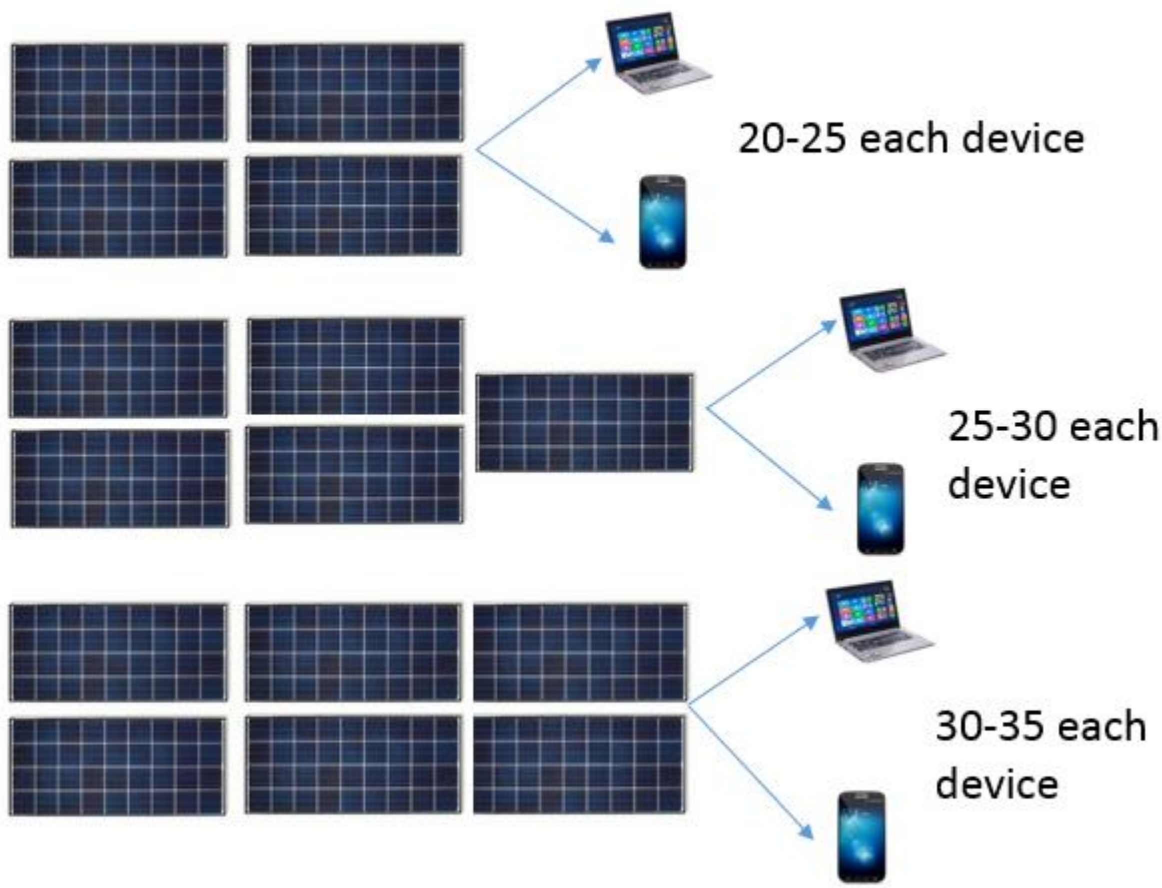

Figure 5.15: Number of devices charged for three different numbers of solar panels

Figure 5.7 shows that if four solar panels are used, 20-25 laptops and cellphones can be expected to be charged on average in a day. If five solar panels are used, 25-30 laptops and cellphones can be expected to be charged on average in a day. With six solar panels being used, the expected range of laptops and cellphones that can be charged in a day is 30-35 of each device.

Chapter 6. Cost Analysis

6.1 Bill of Materials

The Table 6.1 below shows the components purchased for the control system. There are eleven different components that rage in price from the 12 AWG double conducting wire at $0.90 to the Sunny-Boy inverter at $1597.00. The final cost from these products in $2512.60.

Table 6.1: Bill of Materials

Item	Unit Price	Quantity	Total Cost	Application
Sunny-Boy inverter	1597	1	1597	High frequency inverter, 240 VAC, 2000 Watts, 10 year warranty
Sunny-Beam Display	236.9	1	236.9	Wireless System monitor with Bluetooth. Will display consumption information for educational purposes.
DC Disconnect	170	1	170	This pulls the solar panels off line in case of emergency
Digital utility meter	156	1	156	Bidirectional meter for utility reasons
Square D meter socket	121	1	121	The main plug for the system, box for meter
Combiner box	73.75	1	73.75	MidNite solar PV combiner box, protects the system from overcurrent
AC disconnect	58.67	1	58.67	Square D disconnect switch. 240v ac, NEMA 3R, 2pole, 30 amp
Fuse holder	4.65	1	4.65	Required by Arizona code, protects the system from having a power surge
Charging sockets	3.25	6	19.5	Where students can charge their electronic devices.
Fuse (600V DC)	3.05	1	3.05	Required by Arizona code, protects the system from having a power surge
12AWG double conducting wire	0.9	80	72	Connecting electrical components of the system
Total			2513	

The Sonny-Boy inverter was the most expensive purchase because the team wanted a top quality inverter that will withstand the weather extremes experienced in Flagstaff along with the daily wear of students, faculty, and staff. As previously stated, the inverter is an integral part of the system that converts DC power into usable AC power. Without this component functioning, there would be no power provided to the sockets and the electronic devices would not be charged. Additionally, one component on the list not previously mentioned are the charging sockets. These sockets are where the electronic devices will be plugged in and charged. The team decided that no more than six sockets were needed. This conclusion was based on the energy output of the solar panels at one time and the predicted number of patrons using the charging station at any given moment. All other components are detailed in Chapter 4: Proposed Design.

6.2 Extra costs

The cost for the system is dependent on many factors outside of the different components and materials purchased. The locations, distributer, and fluctuating costs alter the projected amount significantly, thus the team only included prices of the components that have already been purchased or that do not have fluctuating economies. In particular, the construction costs for the structural system were excluded from the final total make the amount below the minimum estimated total.

6.3 Analysis

An important component to cost includes the labor needed to set up a functioning system. To calculate this cost there was an assumed $15.00 per hour wage for each worker. As well, it was predicted that ten workers would be needed and the project would take about 50 hours per worker to complete. At these rates it would cost $7,500 in labor to complete the project. Added to the cost of products outlined in Table 6.1, the minimum estimated cost is roughly $10,000.

Chapter 7. Conclusion

7.1 Conclusion

With the task of creating a solar charging station, the team created a system with 11 main components. Throughout the day the system can produce up to 8.24 kWh of energy with 6 panels. The average energy produced per day for the entire year is 6.87 kWh. This power can fully charge up to 30-35 laptops and cellphones. The cost of labor for the structure along with the control system the minimum total cost estimate for the project comes to around $10,000. This number does not include the cost of materials for the structure.

7.2 Project future

The next steps in the solar charging station begin with approvals for building by NAU's facilities. With the approvals, purchasing of all other materials and construction may begin. Further analysis in the structural component will need to occur as well as a review of location. Ideally, the NAU Green Fund will be involved in the process by helping with cost and advocating for the completion of the project.

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