# Senior Project

# Off Grid Solar Array

**Courtney Elliott**

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**Introduction:**

Figure 1 below shows the percentages of renewable and non-renewable energies, renewable making up thirteen percent. Increasing this number will help save the Earth's natural resources and is part of moving into the future. This project will consist of designing, installing, and wiring an off grid solar system which will use the sun's energy instead of the Earth's resources. Renewable energy will not only save the environment but will also save the owner's money.

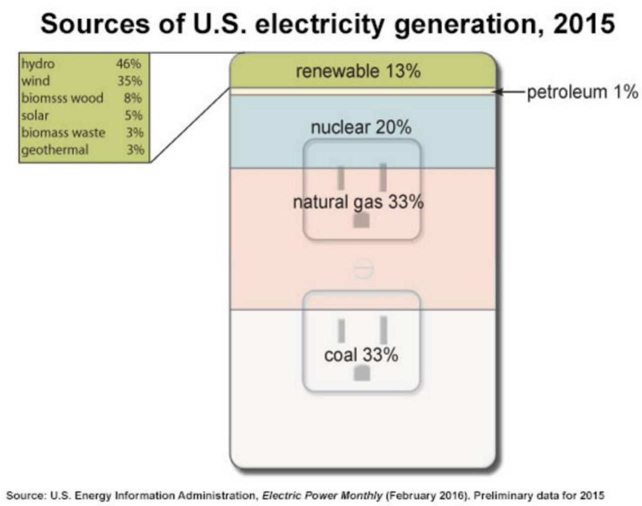


Figure 1: U.S. Electricity Generation in 2015 [3]

Most of today's power comes from resources like coal, natural gases, and nuclear fission. However, renewable energy sources are growing more and more every year. Solar panels work through their solar cells which convert the sunlight into electricity. When the sunlight shines on solar panels (which contain many solar cells) the photons that the sun emits collide with the atoms in the solar cells causing them to move around. Silicon is most commonly used for solar cells because it can generate a path for the atoms to move once they have the energy from the sun's photons. Silicon does this by having two regions; one with extra electrons (n-type) and one with missing electrons (p-type). The electrons from the n-type move to fill the p-type creating an electric current. When solar panels are placed together in series, they have a larger voltage across them and a lower current. Placing them in parallel increases the current but keeps the voltage lower. The connection depends on whether the system has current or voltage limits.

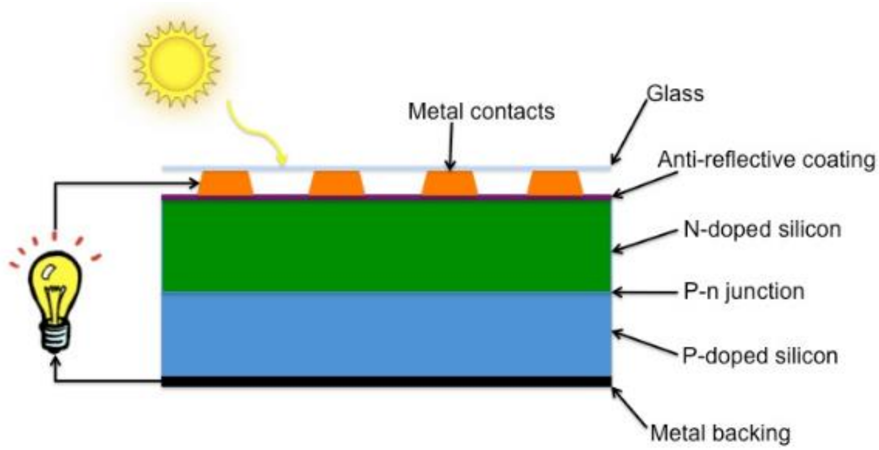


Figure 2: Solar Cell Structure [1]

According to the U.S. Energy Information Administration, the amount of solar energy produced tripled from 2013 to 2015 and is only growing [6]. Every residential and commercial installation helps save Earth's resources, even if each system produces on a smaller scale compared to other forms. The more renewable sources used decreases the consumption of natural resources which will ultimately decrease the carbon footprint. The United States Census Bureau predicts the U.S. population to grow by fifty million in about twenty years [7]. This increase will only cause a larger consumption of energy but if more people start to use solar, this growth will not cause the amount of natural resources used to grow with it.

Solar systems can be tied to the grid or can stand on their own. When the system is off grid, once the energy produced from the panels is out there is no other source that can be utilized whereas a grid-tie system can use an electric company as back up when the energy produced runs out. Grid-tie systems are most commonly used residentially and commercially because most households need energy throughout the day and do not want to worry about not being able to run their microwave, hairdryer, or turn lights on. Off-grid systems are used when there is no electric company around and in this case, if the house is mobile.

**Project Goals:**

This project is an off-grid solar array on a tiny house, a 160 square foot house on a trailer. It will include doing an analysis of power needed to keep this tiny house up and running with the current appliances. The house is mobile and therefore the peak hours will also be evaluated for different places in the United States. By the end of this project, the system will be installed and ready to use.

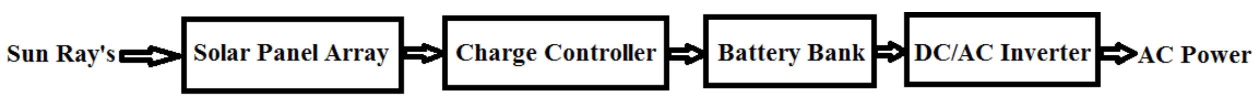


Figure 3: Black Box Diagram

**Design:**

Comparing bids, common household utility usages, and equipment gave the basis of what to order and how big to make the system. Meeting the needs of the homeowners by powering their off grid house so they can rely solely on solar energy is the main goal. In this specific customer's case, they wish to install a reasonably sized system based on the expected usage and sell the tiny house where the buyer can add on if they need more power. Based on the homeowner's needs they will need to be able to power a refrigerator, microwave, lights, and more. The estimated size is around 520W based off of appliances power consumption.

| Appliances | Power Use [W] | Hours/Day | Watt Hour |
|---|---|---|---|
| Lights | 50 | 8 | 400 |
| Microwave | 500 | 0.5 | 250 |
| Refrigerator | 50 | 24 | 1200 |
| TV | 30 | 5 | 150 |
| Chargers | 70 | 3 | 210 |
| | | Total Wh | 2210 |
| | | After 30% loss from system | 2873 |
| | | kWh/mo | 86190 |

Table 1: Estimated Power Consumption

Using the total estimated electricity usage in a month and the system size calculator from Wholesale Solar, the following system sizes were presented. Since the tiny house can move, different zones needed to be considered since they can have a different number of peak sun hours per day [4].

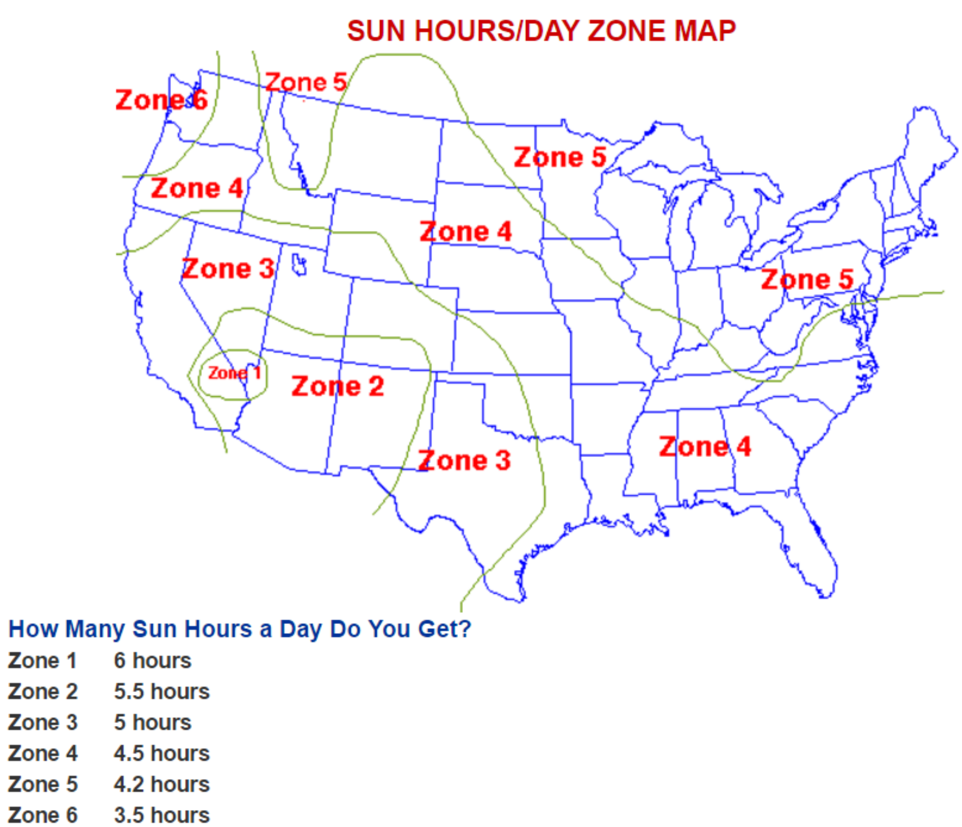


Figure 4: Peak Sun Hours Based on Location [4]

| Zone | Peak Sun [Hours] | Minimum System Size [W] | Solar Panels Needed |
|---|---|---|---|
| 1 | 6 | 478 | 2 |
| 2 | 5.5 | 522 | 3 |
| 3 | 5 | 574 | 3 |
| 4 | 4.5 | 638 | 3 |
| 5 | 4.2 | 684 | 3 |
| 6 | 3.5 | 820 | 4 |

Table 2: System Size Based on Peak Sun Hours [4]

Since the homeowners want to build a system that can be expanded on if needed, they chose to install 2 panels at a rating of 260W each in series to raise the voltage to 520W and keep the current low around 9A. The homeowners plan on selling the tiny house with the capabilities of adding more panels if more energy is needed by the buyers.

The tilt and placement of the panels was another concern. The roof has a pitch of 8 degrees with a peak in the middle, making the panels face opposite directions when placed one on each side of the peak. The optimum tilt for California is around 15 degrees facing south. Placing the panels with a 15 degree tilt, one on each side, will allow one panel to get maximum power but the other to get less. We decided on making the panels flat with the roof so both panels could be hit by the sun when one panel faces south. This also reduces the cost of racking, which is minimal but when considering the loss of power on the north facing panel by adding an extra tilt did not seem as reasonable as minimizing cost and getting more power from the north facing panel.

When choosing the charge controller, inverter, and batteries they must have the same rating and acceptable current ratings. The rating in this system is 12V. Since the current rated from the panels is close to 9A, the rating must be greater. Anticipating that the buyer of this tiny house may want a larger system they will need to add more panels which means raising the current to 18A if you have two extra panels in series with each other but in parallel with the previously installed panels. The battery bank can also be expanded upon, 2 batteries are being used for this project. The only factor for choosing batteries is making sure the voltage is what the inverter and charge controller are rated at. In this project, there are 2 batteries rated at 12V each placed in parallel to maintain the 12V rating but increase the bank to store more power. The inverter and charge controller chosen for this project are larger than the system required but means there will be more room to expand upon later. The inverter has a 2500W rating which is much greater than the system size but can handle much more if needed. The charge controller can be rated at 12, 24, or 48V which fits this system and can have up to 96A when using 12V. The highest current the system could possibly have is around 20A and that is with adding 2 panels in parallel with the 2 installed currently.

The next step is to pick the correct wire size. Depending on the current flowing from the panels will determine the size. We used 6 gauge wire which was also much larger than needed for this system size. The wire size from the batteries to the inverter needs to be larger than the wire size from the panels. 1 gauge wire was used from the batteries to the inverter because the current to the inverter pulled from the batteries is much greater than that coming from the panels. Another safety concern is adding breakers in on both sides of the charge controller. This prevents excess current from flowing into the charge controller and shorting it. 100A circuit breakers were used in this system to ensure a safe system and charge controller.

The diagram on wiring the system together is shown below in Figure 5 and the market specifications are shown in Table 3. When wiring, be sure to connect the negative terminals before the positive to avoid injury and use one hand as often as you can when dealing with live wires.

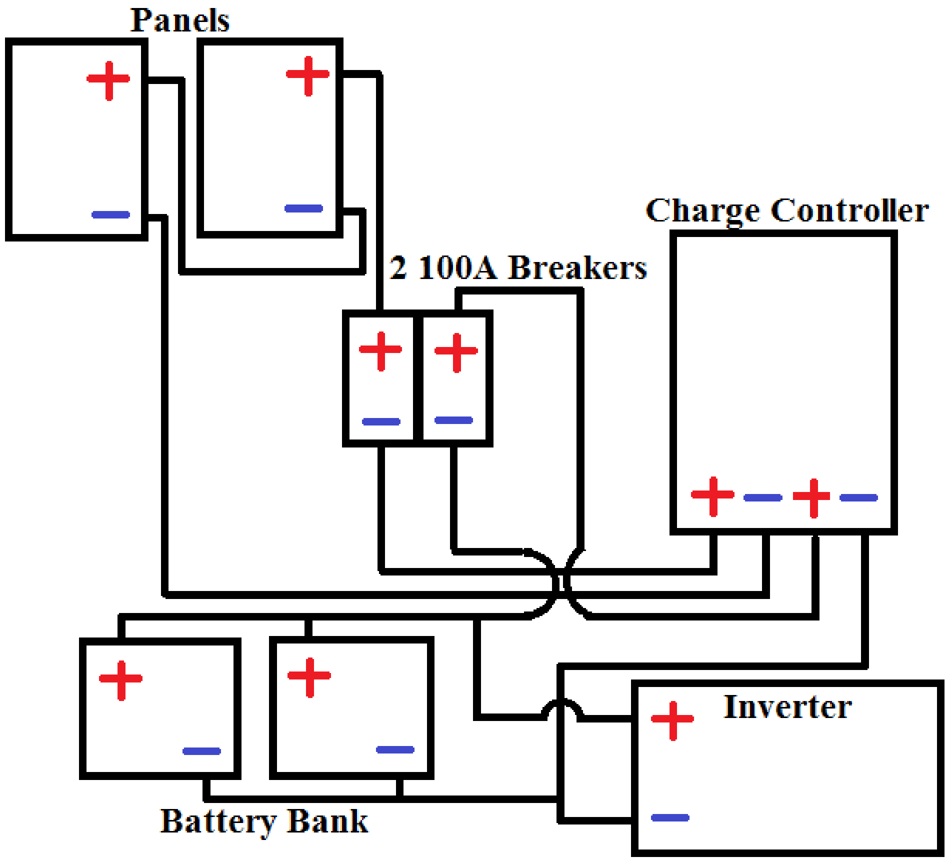


Figure 5: Schematic of System

| Marketing Requirements | Engineering Specifications | Justification |
|---|---|---|
| Compact Size of System | 2 panels, each 65.12 x 38.94 in | Number of panels that roof or ground can fit, two more panels could be added for additional energy and savings. |
| | Panels will have a rating of 260 W | Based off of the size of the system and the power needed, the rating can be determined to achieve the desired output for the given space and usage. |
| Power Produced To Cover Bill | System will produce 62.5kWh monthly output | Amount of power that can be generated by panels based off of the size of the system. This may come from the customer's previous billing history or from an estimation of appliance consumption (Table 1). |
| | System will have a pure sine-wave inverter with an input voltage of 12VDC and output voltage of 120 VAC | One inverter will be used to convert DC into AC. It is rated at 2500W which is much larger than the system size required here but allows the system to be expanded upon if desired. |
| Durability | System will use racks per 65" x 39" Module | This will depend on the type of roof, size of the system, types of panels used, and tilt the roof has (if there is any) and will serve to hold the system steadily to the roof or ground. The racking here gives the panels an 8 degree tilt but an optimum tilt would be around 15 degrees if all panels were facing south[5]. |

Table 3: Marketing Requirements and Engineering Specifications

**Bill of Materials:**

| Company | Model | Quantity | Price Per Unit |
|---|---|---|---|
| Astronergy | 260 Watt Module Silver MC4 CHSM610P-260 40mm Frame | 2 | $225.00 |
| MidNite | MNPV-3, 3 Position Combiner Box | 1 | $72.00 |
| MidNite | Breaker DC DIN 15 amp 150VDC DIN, 13mm | 1 | $12.50 |
| MidNite | Solar Classic MPPT Charge Controller 150V | 1 | $607.00 |
| 4 Star Solar | 10 AWG-PV Wire – 30' cable extension | 1 | $31.00 |
| Cotek | SD series 2500 12V Pure Sine-wave Inverter SD2500 | 1 | $769.00 |
| MidNite | Breaker DC Panel Mount MNEDC-100 amp 150VDC ¾" | 2 | $25.00 |
| MidNite | Breaker Box MNEDC Quad for panel mount DC breakers | 1 | $50.00 |
| Universal | RV Mount-Z Flush Mount Feet (4pc) – SLB-0102 | 4 | $14.29 |
| | | Total Parts Cost $2098.66 | |

Table 4: Bill of Materials

**Testing and Verification:**

The input voltage, power, and energy from the panels and battery voltage and current were recorded for an entire day from sun up to sun down. The plots below display the data according to the time it was produced.

| Time | Voltage In From Panels [V] | Power From Panels [W] | Energy Produced by Panels [kWh] | Battery Voltage [V] | Battery Current [A] | Charge Controller State |
|---|---|---|---|---|---|---|
| 7:00 AM | 65.1 | 0 | 0 | 11.6 | 0 | Resting |
| 8:00 AM | 59.5 | 50 | 0 | 11.6 | 4.3 | Bulk MPPT |
| 9:00 AM | 59.8 | 168 | 0.1 | 12.4 | 13.5 | Bulk MPPT |
| 10:00 AM | 55.2 | 252 | 0.2 | 12.6 | 19.9 | Bulk MPPT |
| 11:00 AM | 55.5 | 236 | 0.5 | 12.8 | 18.3 | Bulk MPPT |
| 12:00 PM | 53.7 | 377 | 0.8 | 13.3 | 28.2 | Bulk MPPT |
| 1:00 PM | 54.3 | 360 | 1.1 | 13.6 | 26.5 | Bulk MPPT |
| 2:00 PM | 55.3 | 360 | 1.5 | 14.1 | 25.6 | Bulk MPPT |
| 3:00 PM | 59.4 | 193 | 1.7 | 14 | 13.8 | Bulk MPPT |
| 4:00 PM | 63.3 | 169 | 1.9 | 14.5 | 11.7 | Absorb |
| 5:00 PM | 62.1 | 126 | 2.1 | 14.5 | 8 | Absorb |
| 6:00 PM | 59.1 | 19 | 2.1 | 12.9 | 1.5 | Float MPPT |
| 7:00 PM | 52.3 | 0 | 2.1 | 12.9 | 0 | Resting |

Table 5: Verification Data

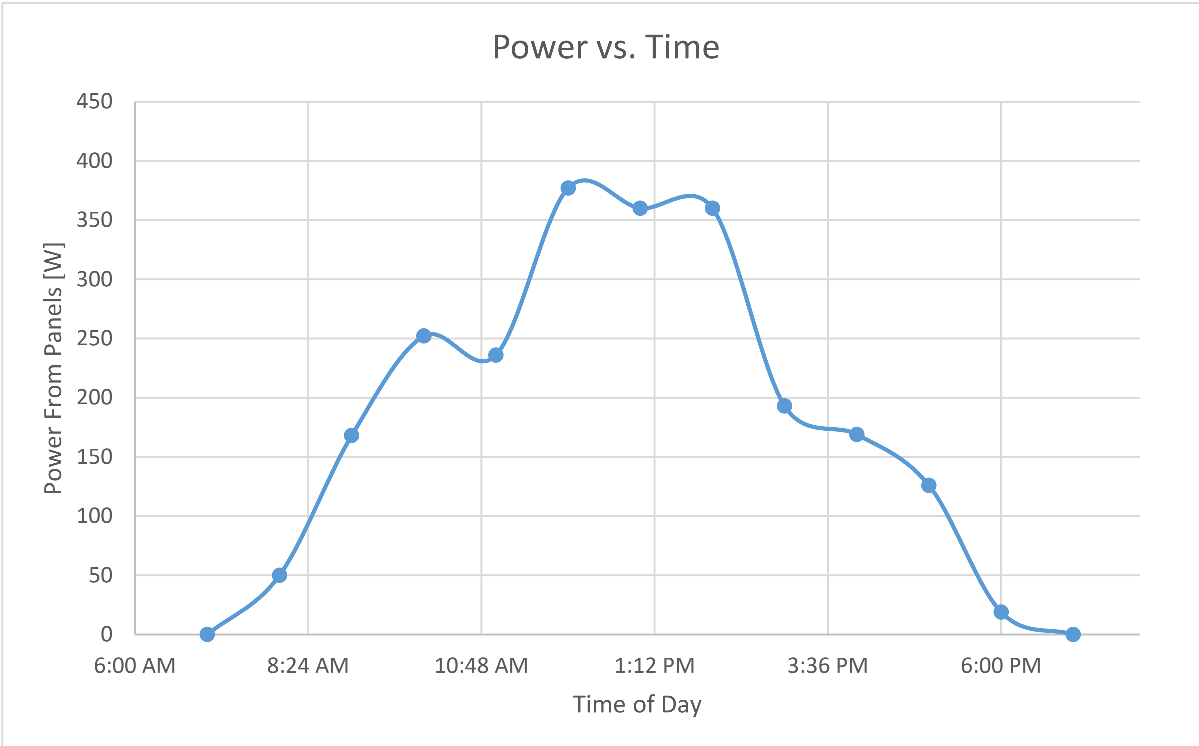


Figure 6: Power vs. Time

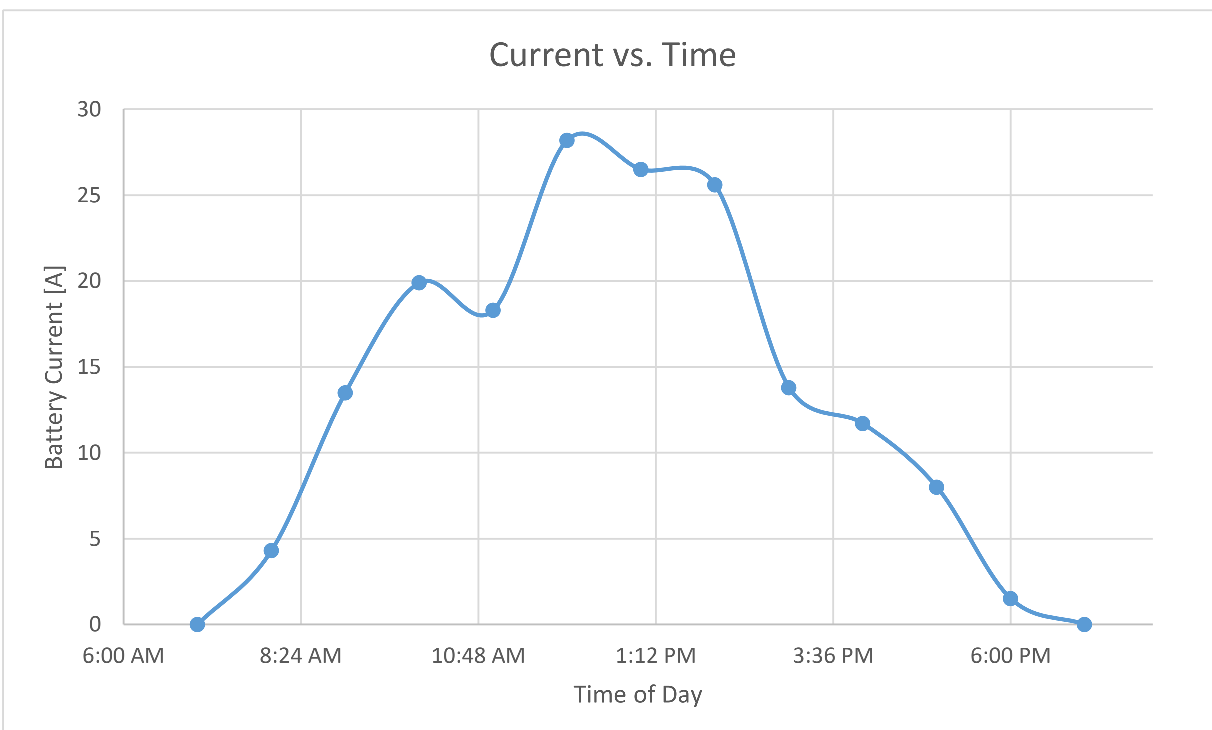


Figure 7: Energy vs. Time

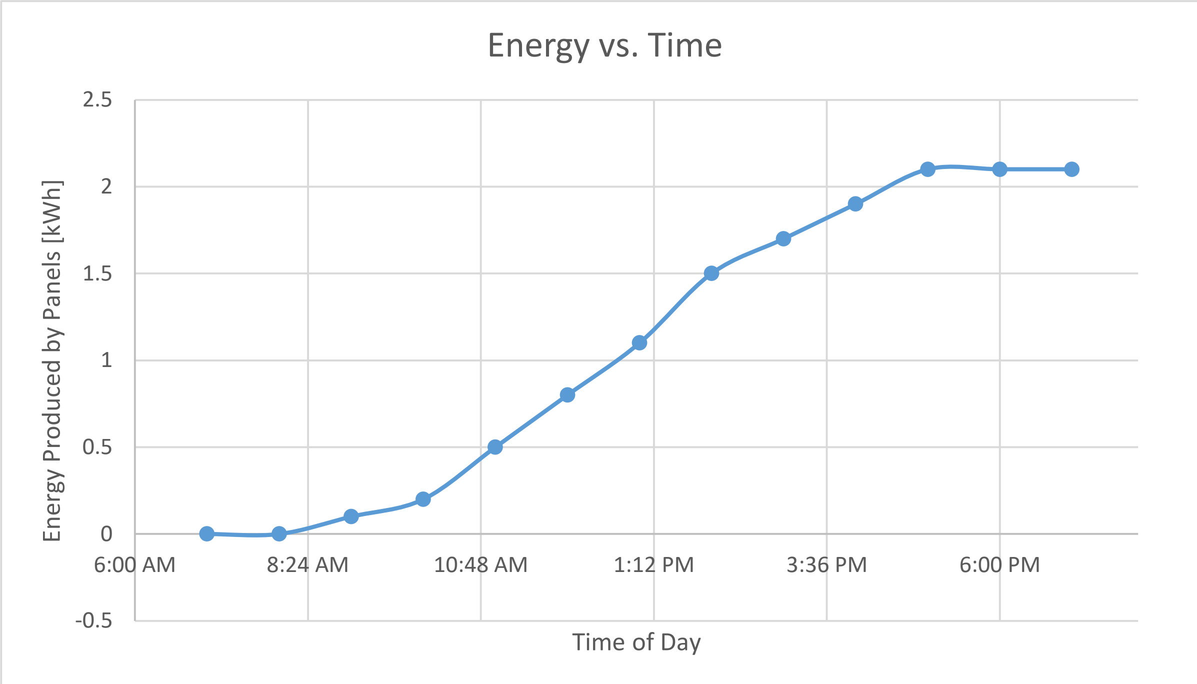


Figure 8: Current vs. Time

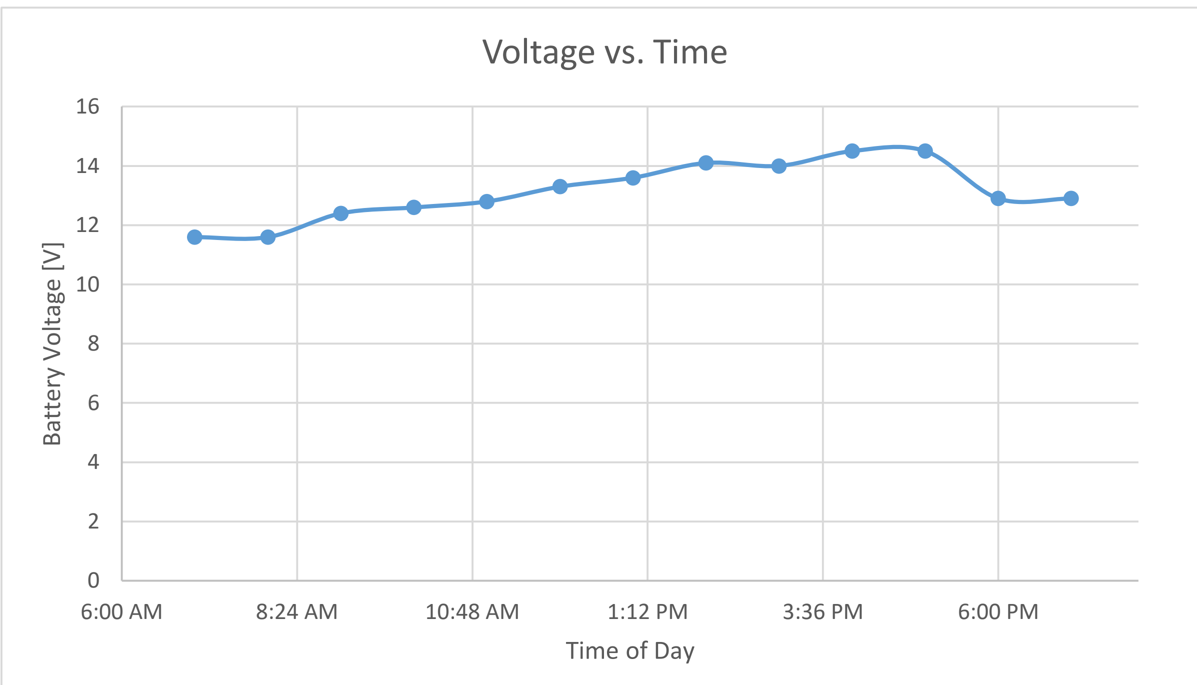


Figure 9: Voltage vs. Time

After observing the system for an entire day, the data shows the peak time and power, 12:00 PM and 377W, that can be achieved with this system in Palmdale, Ca. The max power will vary from place to place as the tiny house gets moved but this gives a general idea of what to expect as an output from the system. To test the system, there was no load and the batteries were observed being charged by the panels. Viewing Figures 6 and 7, the power drawn from the panels and the current taken from the batteries have the same shape. This satisfies that power equals voltage times current. The voltage of the batteries averaged at 13.14V over the entire day and the voltage from the panels averaged at 58.05V. Given the ratings from the panels, 30.9VDC, the max should be 61.8V. Some is lost from the tilt and positioning of the panels but is still achieving a high voltage.

At 6:00PM, a refrigerator was hooked up to the inverter and was powered. Once the load was added, there is a drop in the battery voltage down to 12.9V, shown in Figure 9, whereas the rest of the day it had a steady increase. Figure 8 shows that the energy provided by the system increased over time as expected since the system had been generating for longer periods of time throughout the day. The data is clear with what was expected and the system is working to power household appliances as intended.

**Conclusion:**

This project taught me more than I expected it would. Deciding what parts to buy and how to wire the system took the longest time. Choosing the parts depended mainly on price, time, and convenience. Getting multiple bids on systems of this size proved this was the cheapest when buying the entire system together. However after more research and experience, there are ways to get the price down even further when buying parts separately. Some things to improve in this system have to do with the cost and size of the parts purchased. The wire size used did not need to be that thick and caused more difficulty when cutting and stripping, instead 8 or 10 gauge wire from the panels to the charge controller would have been suitable to handle the current even if adding more panels. The gauge from the batteries to the inverter are sized correctly due to the higher current that runs from the batteries. Another improvement would be the inverter size and charge controller size. The inverter could have been a 1500W inverter rather than the 2500W that was installed. As for the charge controller, this could handle a current of 96A which the current will never reach close to the level with the available system space on the roof. Changing these things would have saved money and would have made installing the system easier and faster. Overall this is a stable system but could easily be improved and on future projects the specifications of the system will be utilized better while choosing parts.

Figure 10 below shows the breakers, charge controller, and inverter. Figures 11 and 12 show the batteries that are hooked up outside and the panels that are placed on the roof of the tiny house.


Figure 10: Physical Wiring of System

Figure 11: Panels

Figure 12: Battery Bank

**References:**


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