

**Off Grid Solar System for Profitable Energy
Source in Missouri**

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In Partial Fulfillment of the Requirements for the
Degree Master of Science

by

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The undersigned, appointed by the Dean of the Graduate School, have examined the Thesis entitled

**SOLAR ENERGY FOR PROFITABLE
ENERGY SOURCE IN MISSOURI**

Presented by Nahom Ghirmatzion

A candidate for the degree of Master of Science

And hereby certify that in their opinion it is worthy of acceptance.

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GLOSSARY OF UNITS AND NAMES

Units	Names
AH	Ampere Hour
h	Hour
Kwh	Kilowatt hour
PV	Photo Voltaic
V	Volts
W	Watt

SOLAR SYSTEM FOR PROFITABLE ENERGY SOURCE IN MISSOURI

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ABSTRACT

The main purpose of this project is to prove how much a solar system as source of energy could save us a huge amount of money and how it can completely replace the electric utility system in Missouri. Over 80% of today's energy source is from non-renewable energy sources such as coal, diesel, and natural gas. One of the main choice to reduce the consumptions of these non-renewable sources and to provide a cheaper and healthier energy usage to the public is using a solar energy system. As the technology is growing faster, the number of solar panel industries is growing, and this brings a decline in the price of the panels to give a better opportunity for the public to use a solar energy system for their home. There are two main choices of solar installation, on-grid and off-grid system of solar panel installation. At this time the state of Missouri has a strict rule about solar installation that all solar panel installations must be tightly connected to the public utility. And because of these reasons, this research will be a proposal for the state to consider an off grid system of solar installation as a possible choice for home owners, because it has a greater benefit on saving money comparing to the electric utility and the on grid system of solar installation. Both on grid and off grid systems have their own advantages and disadvantages, and even though the research will cover some information on how the on-grid system of solar installation could save you some amount of money over the course twenty five years, the main research is directed at off-grid systems that could save a huge amount of money by being almost free from any non-renewable energy sources. A small amount of non-renewable energy such as natural gas for the generator can be used for this system at the time where there is no sun shine.

So, this research will start with some choices on the on-grid system, and it will later discuss in detail on how the design and cost of the off grid system could provide an efficient and affordable renewable energy source in Missouri

CHAPTER 1 INTRODUCTION

The first thing that we have to calculate is how much power we are looking for our solar panel. This means how big is the house, how much energy does the family consume every day or every week. In order to calculate the Kwh, we need to know the capacity of the battery in Amp hours, and its voltage. For example if the capacity of the battery is 20AH and its voltage is 12V, the battery could supply 240W. Another thing on this calculation is the actual gain and loss of energy that we could get from the solar panel in order to compare the efficiency with respect to the cost. On this research, we will also compare the options between on grid and off-grid method of designing the solar energy system as the solar energy by itself cannot be the only source because of the possible climate change from one season to another. Most of the topics that will be discussed will be on the off grid method, I choice a generator as my main option for the back-up energy.

On this research understanding the size of the PV is important. Different size of PV modules will produce different amount of power. To find out the size of PV module, the total peak watt produced needs. The peak power (Wp) produced depends on the size of the PV module and climate of site location. I will also need inverter in this research since most of our home's power appliance needs AC power output. The input rating of the inverter should never be lower than the total watt of appliances. The inverter must have the same nominal voltage as my battery. Solar charge controller sizing is also important part of my research. The solar charge controller is typically rated against Amperage and Voltage capacities. I will select the solar charge controller to match the voltage of PV array and batteries and then identify which type of solar charge controller is right for my application.

The block diagram below is the diagram for the beginning of my research, and how the supportive equipment's of the solar energy are connected.

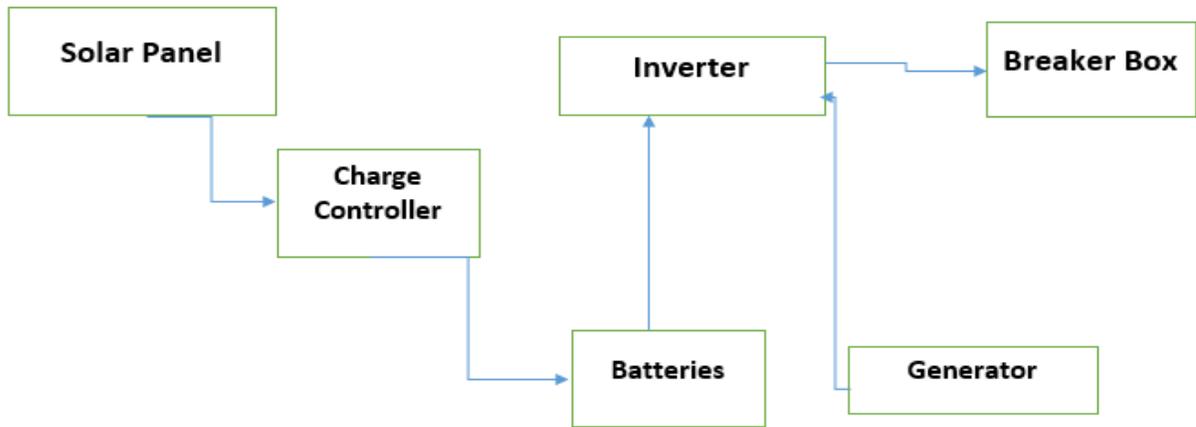


Figure 1.1 Solar system Design Block Diagram

1.1 Solar panel

According to the definition of, Martin DeBono, Photovoltaic (PV) solar panels are made up of many solar cells that are made of silicon, like semiconductors. They are constructed with a positive layer and a negative layer, which together create an electric field, just like in a battery. At this time there are two main types of solar panels, Monocrystalline and Polycrystalline. Solar cells made of monocrystalline silicon (mono-Si), also called single-crystalline silicon (single-crystal-Si), and The first solar panels based on polycrystalline silicon, which also is known as polysilicon (p-Si) and multi-crystalline silicon (mc-Si) (Mathias Aarre Maehlum). The Monocrystalline solar cells are more efficient, but more expensive. This could be helpful in saving a lot of space, and it gives the house hold to install more solar panels on the roof of the house.

1.2 Photo Voltaic Supportive Equipment's

1.2.1 Inverter

Inverter is a device that is used to convert from Direct Current (DC) to an Alternative Current (AC). Most of the efficiency of the inverters that are used in the solar installation has an efficiency of 90%. A lot of solar inverters uses a proprietary Maximum Power Point Tracking

(MPPT) technology to harvest the maximum amount of energy from the solar array. MPPT learns your array's specific characteristics, maximizing its output at all times (sunpower.com).

1.2.2 Battery

We use batteries to store our solar energy and transfer it to the inverter. There are many kinds of batteries that can be used for this function. Lead acid is one the most used batteries in the case of solar installation, and most solar companies use these kind of batteries on their solar kit. Lead acid batteries have an average efficiency of 50%, but it is durable and very cost effective. The battery represents more than mere storage capacity. It can serve as a power conditioner by being part of the circuit 60 Basic Photovoltaic Principles and Methods into which electricity from the PV supply flows, the battery keeps the electrical load more nearly constant, and the PV array can be designed to operate more nearly at its optimum power output (www.nrel.gov).

1.2.3 Charge Controller

Charge controller is used to control the power going to the inverter from the battery. It ensures that the deep cycle batteries are not overcharged during the day, and that the power doesn't run backwards to the solar panels overnight and drain the batteries (www.altestore.com).

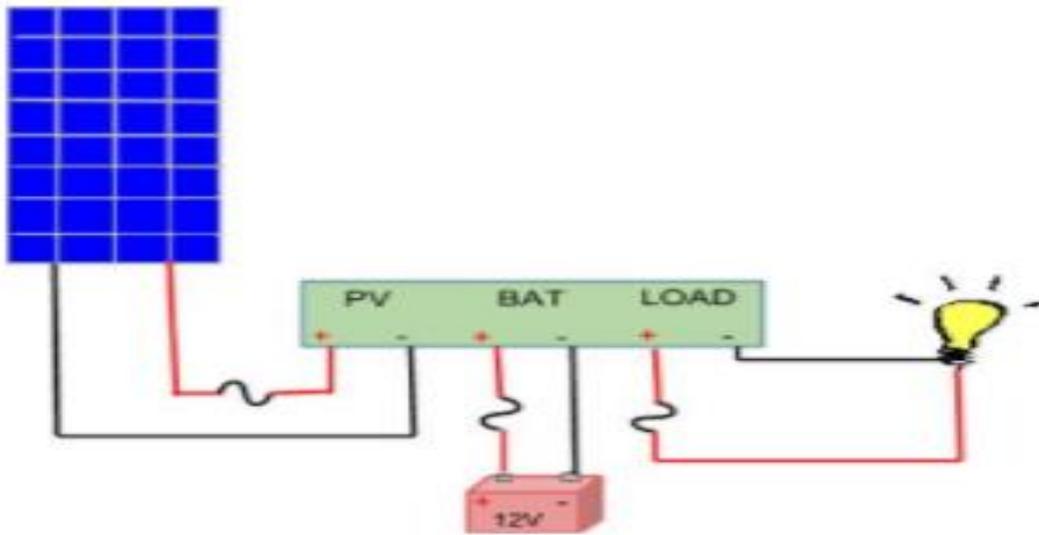


Figure 1.2 Charge Controller 1

1.3 Solar Installation Policies in Missouri

Regarding the benefits of installing solar panel in Missouri, the state of Missouri has enacted a mandate that requires 15% of the state's power come from renewable energy by 2021. (<https://solarpowerrocks.com/missouri/>). This is very encouraging for the solar companies to increase their market in Missouri, and many other United States Countries who are also mandating similar rules. At the present majority of the renewable energy source come from either hydropower, wind or solar energy. Even though the state of Missouri enacted that law, it is lacking state wide solar rebates and state tax credits. This state tax credits is significant rebate programs and special policies that can help the residents of the state to save thousands on the cost of installing a solar energy system on their roofs (www.energysage.com). So since there is no a state sale tax credit, the installer has to pay sales tax on your solar power installation purchase. But, the most promising thing is that the installer has a 30% federal tax credit based on the entire cost, and get this amount at the beginning. Most of the payment or the loans are for 15 years, so to start with 30% returned tax could greatly encourage the homeowner to for solar system installation.

CHAPTER 2 GRID SYSTEM

2.1 On Grid System

Even though my main research is based on how off-grid solar energy installation in Missouri could save you a lot of money in thirty to forty years, by comparing to the electric bills, it is also important to understand what other choices might have such as on-Grid system of solar panel installation, where the system is tightly connected to the public utility. On Grid system solar installation is the most known type of installation in United States. And this choosing an on-Grid systems in Missouri can be divided in to three options: Solar Power purchase Agreement, Solar Loans, and buying solar. These options helps the individual to check with their budget and choice the right option that fits with their income. There is a detail research done by a group of researchers, www.solarpowerrock.com, on these different options of on-grid solar installation in different states including Missouri. Their research on the on-grid system is based on the average energy consumption, 5KWh.

2.1.1 Solar Power-Purchase Agreement

Solar Power-Purchase Agreement method is the most popular method. A PPA just means your solar company owns the panels on your roof, and you pay for the electricity they produce (Zientara). In this case you don't pay any down payments, simply you pay monthly bill for both the electric bills and solar loads. At the beginning of the year, you only save \$94 dollar, and you save around \$3,140 in twenty years. Even though this saving is not very great, it is good for people who don't want to pay cash at the beginning. The graph below shows, how the PPA save you over three thousand dollars in 20 years (Zientara).

Solar Power-Purchase Agreements in Missouri

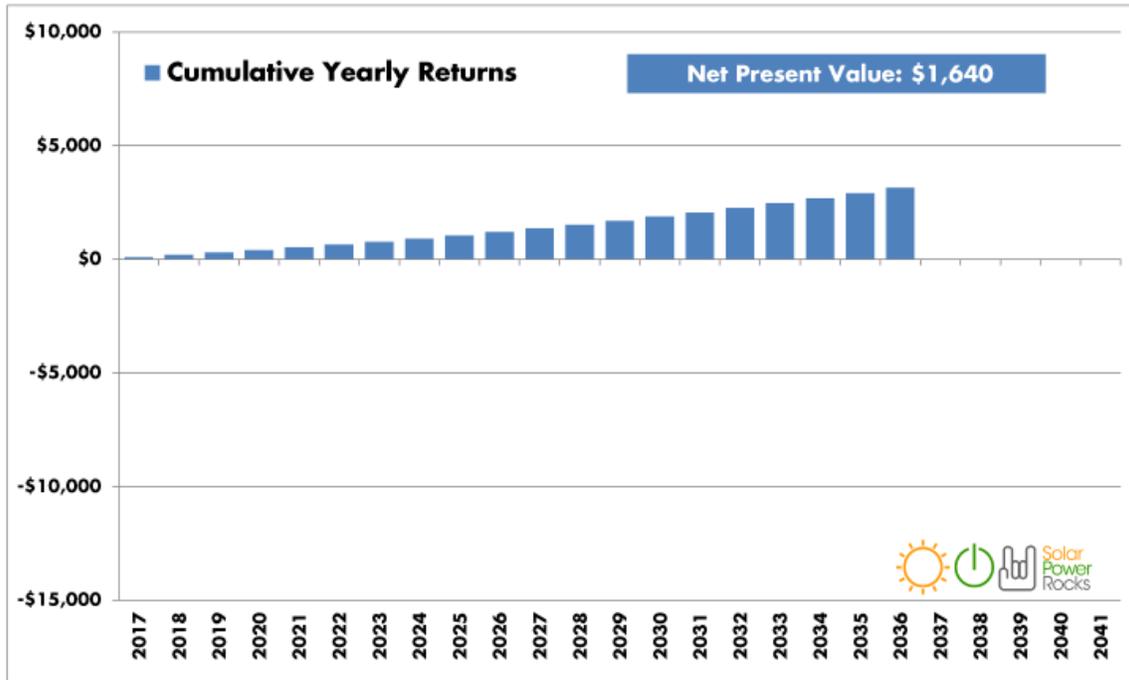


Figure 2.1 Solar Power Purchase Saving 1

2.1.2 Solar Loans in Missouri

Solar Loans is one of the three main options, where you buy the solar, and pay it in twenty years. The solarpowerrock.com website researchers also did a great research on how this method of installing solar panels could work and help the solar owners to save some amount of money in twenty five years. It is similar to Solar Power-Purchase Agreement that you will have a monthly bills, but the difference is you own the solar panels. And similar to Solar Power-Purchase Agreement, you pay around \$1775 every month, \$624 is for the bill, and \$1,151 is for the solar loan (Zientara). And the federal tax credit that is 30% will also apply at the beginning of the year, and this reduce the total amount from \$20,000 to \$14,000 and makes the solar owner to start with positive \$6000. Five years after you pay your loans, you will save around \$1000, and in 25 years you save around \$1,463. The good part about this option is when you own the panels after 15 years, you will own the solar panels and the benefit will keep increasing. Even though the

efficiency of the solar panels may decrease after 25 years, they could still last for longer years. The graph below shows, how the solar loans in Missouri could save you around \$1, 463 in 25 years (Zientara).

Solar Loans in Missouri

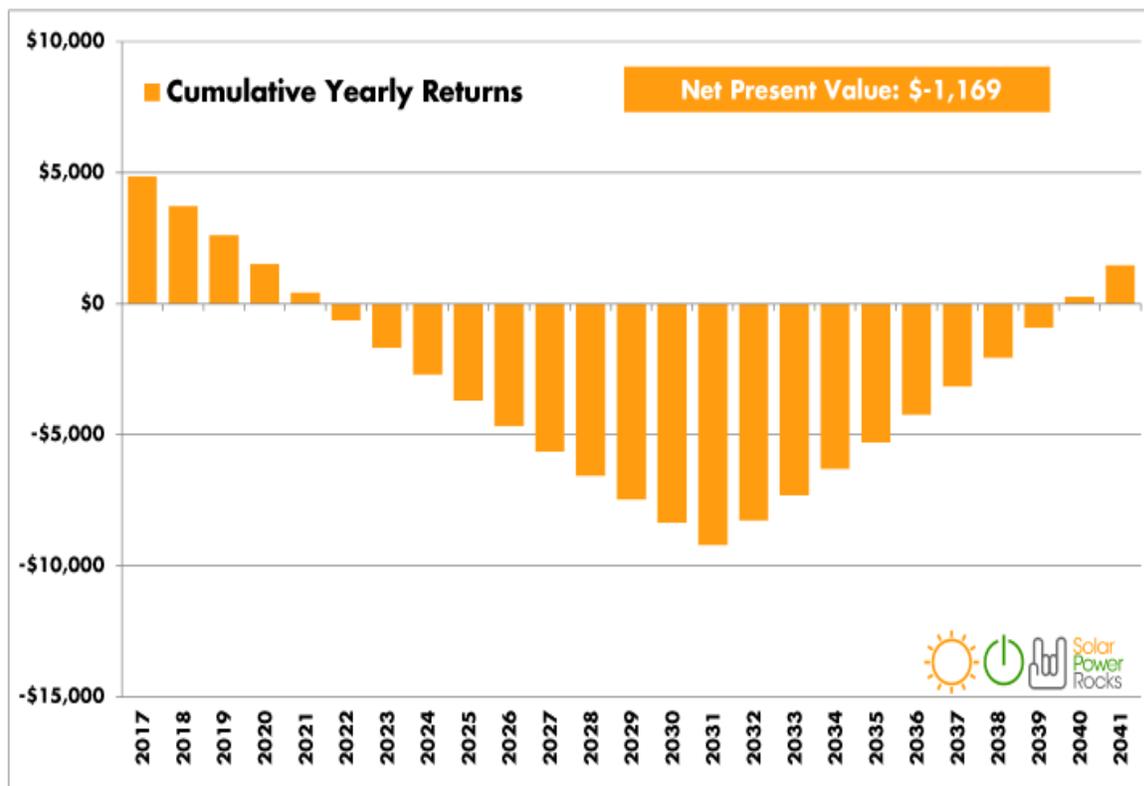


Figure 2.2 Solar Loans in Missouri Saving

2.1.3 Buying a Solar in Missouri

The third option of installing a solar panel is buying the solar panels and installing them on your own expense. This plan is the most beneficial and you save a lot of money in the twenty five years of the system. Most people in United States have a culture of buying items in credit system, so this plan may not suit with many people, and because of this few people are expected to install solar panels on their own expense. In this \$20,000 investment plan, you start will spend \$14,000 at the beginning of the year, since you will have a 30% tax break. After the tax the first

year you save around \$624, and that reduces your cost after the first year to only \$13,376 (Zientara). By saving that amount of money for eighteen years, you will save around \$8,092 in twenty five years. And one of the best advantages of this plan is your home’s value will be increased by more than \$18,000 because of your expected electricity saving over twenty five years(Zientara). Investing \$14, 000 amount of money may seem a very big investment, however, it is just saving \$583 per month for two years. If you have a dream of saving this amount, you can be wise in saving that money by working some over times or adding part time for two years, and enjoy the big electric bill saving for twenty five years. The graph below shows, how buying solar in Missouri could save you around one \$8,092 in 25 years (Zientara).

Buying Solar in Missouri

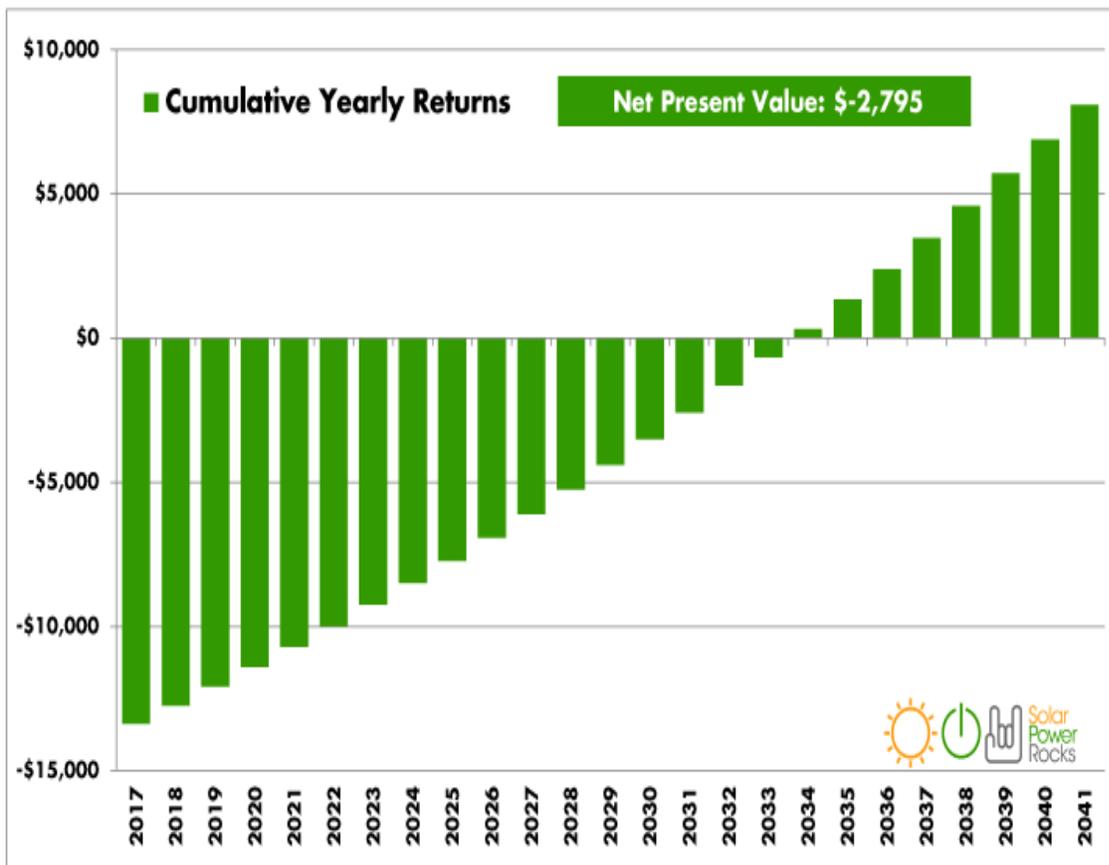


Figure 2.3 Buying a Solar in Missouri Saving

2.2 Off-Grid System

2.2.1 Assumption

Before we did the actual research on the use of solar energy in Missouri, I did an ideal calculation on how much the solar energy would save money if the sunrise and sun hours per day is twenty four hour, which is there is always sun light and all of its rays are on the peak angle that they call it sun hours. Recent studies had showed that the average bill of electricity in Missouri is \$107.8, this means the average consumption of electricity is 35.3KWH per day or 1060KWH per month or 12720KWH per year. This are a good start in gathering the information's to find the size of our solar panel. One of the most important thing that we need understand is unlike the electricity the solar panels can only store energy for one or three days if there is any unused energy left. So we have to be careful in using the energy. If we left our devices turned on for long hours without using it we could consume all of our energies that are supposed to be for the whole day. Whenever we want to find the size of our solar panel one of the first thing that will be asked is how many hours per day do we consume energy. Different people may have different input on this, but for now I will take an average, which is eight hours. From this I can find how much energy do I consume each day. To find the total energy per day, we can derive a formula from the general formula of calculating average energy usage (Energy we need, 2):

Average Daily Energy Usage in Missouri= *Daily Energy Consumption* × *Average Hour* (2-1)

$$\text{Average Daily Energy Usage in Missouri} = \frac{35.5\text{Kwh}}{24\text{h}} \times 8 \text{ hours}$$

$$=11.83\text{KWH}$$

As I stated earlier since in our assumption our sun hour is twenty four, in order to find the size of the solar panel, I need to divide the total energy per day by 24 hours, and in this case I get 493 W, and this tell me I have to look for a solar panel that could generate about 493W per day.

After we decided the size of my solar panel, I have to find the size of my batteries, solar charge controller, and inverter, as it shows in the block diagram. To find the size my battery, I use the following formulas (The Do It Yourself World).

$$\begin{aligned}
 \text{Size of the Battery} &= \frac{\text{Average Daily Energy Usage in Missouri}}{\text{Voltage of the System}} && (2-2) \\
 &= \frac{11.83\text{Kwh}}{12\text{V}} \\
 &= 980\text{AH}
 \end{aligned}$$

To find the size of my charge controller, use the following formulas (The Do It Yourself World)

$$\begin{aligned}
 \text{Size of the Controller} &= \frac{\text{Average Daily Power Usage in Missouri}}{\text{Voltage of the System}} && (2-3) \\
 &= \frac{35.5\text{Kwh}}{24\text{H}} \times \frac{1}{12\text{V}} \\
 &= 123\text{Amps}
 \end{aligned}$$

And to find the size of the inverter, I just need to find the power load, 35.25KWH divided by 24 hours, which is 1.48KW. In this case, I will not need any backup generator for I assumed I have 24 peak hours of the sun. In this assumption, I did a rough calculation on collecting the price of the solar panel, installation cost, and repairing cost in twenty years. This calculation gave me an estimation cost of \$7500 in 30 years. When I compare this with the amount of money we spent using the electricity in 30 years, which is \$38,808, we can see a big difference in 30 years. However, since the peak sun light is mostly between 3 to 6 hours, so there will be a big difference in the overall installation cost.

2.2.2 Solar Energy in Missouri

Missouri is a state in the Midwestern United States. It generally has a humid continental climate with cold snowy winters and hot, humid, and wet summers. In the southern part of the state, particularly in the Bootheel, the climate becomes humid subtropical. Located in the interior United States, Missouri often experiences extreme temperatures.

Temperature	Date	Maximum	Average	Minimum	Total Sun light Hours	Sun Hours
January	01/01-01/15	41	32	22	9.62	3.64
	01/16-01/31	39	31	22	10	
February	02/01-02/15	41	33	24	10.5	4.2
	02/16-02/29	57	46	34	11	
March	03/01-03/15	63	53	42	11.67	4.95
	03/16-03/31	61	50	39	12.25	
April	04/01-04/15	64	52	39	13	5.43
	04/16-04/30	74	65	55	13.5	
May	05/01-05/15	72	62	51	14.1	5.56
	05/16-05/31	76	66	56	14.5	
June	06/01-06/15	87	76	65	14.83	5.76
	06/16-06/30	91	81	69	14.8	
July	07/01-07/15	85	77	68	14.75	5.88
	07/16-07/31	90	81	71	14.4	
August	08/01-08/15	85	78	70	13.85	5.89
	08/16-08/31	85	76	67	13.4	
September	09/01-09/15	83	73	63	12.75	5.68
	09/16-09/31	82	71	60	12	
October	10/01-10/15	73	63	52	11.5	4.8
	10/16-10/31	74	64	53	11.5	
November	11/01-11/15	67	56	45	10.75	4
	11/16-11/31	55	46	37	10.45	
December	12/01-12/15	55	46	37	9.8	3.5
	12/16-12/31	44	34	24	9.4	

Table 2.1 Total Sun Hours and Average Sun Hours in Each Month in Missouri

In 2016 there is a history of weather which shows the highest peak sun hours is 5.89, the lowest is 3.50 and the average is 4.94. I also have a table that shows the number of peak sun hours in each month (Please see the table below).

Month	Peak Sun Hours
January	3.64
February	4.2
March	4.95
April	5.43
May	5.56
June	5.76
July	5.88
August	5.89
September	5.68
October	4.8
November	4
December	3.5

Table 2.2 Peak Sun Hours in Each Month in Missouri

These hours help us to find the average peak sun hours in Missouri in each season. As we can see August has the highest peak sun hours, and December the lowest. In order to find the size of our solar panel we need to look on these table, and find the average peak sun hours in each season. It would be great if we can design our system of the solar panel installation based on the summer peak sun hours, but since the solar system energy is based on daily source we get from the sun, we will definitely have a shortage of energy during the winter season. So, we will consider the size of our solar panel based on the winter peak sun hours. In order to find the winter we add the peak sun hours from December to February and divide that by 3, and when I did that I got 3.78 hours. As it is found earlier the average energy consumption of energy per day in Missouri is 11.83Kwh, we divide that by the summer peak sun hour, 3.78 hours, and we get 3129.6W. A solar panel with this amount power would be good enough in generating the amount of energy we need every day. However, there are several things that we have to consider about the efficiency of our battery and the inverter. I am using lead acid battery and the average efficiency of this battery is 50%, and most inverters have an efficiency of 90%. In order to consider these limitation on finding

the right solar panel for our solar system, first we will divide the 3129.6W by the battery efficiency, 0.50, and we get 6259.2W, and then we divide that result again by the efficiency of the inverter, 0.9, and we get 6885.12W. Now we can look on the prices of our solar panel, and the installation cost to pass to the next comparison. As the price of the solar panel is decreasing every year, and as the number of installers is also increasing, the overall price of the solar system installation is decreasing. Instead of buying the parts separately, it is much better and cost effective to buy them as a kit. So, I found one with a price of \$7,712 dollars, and the installation cost is approximately \$10,000 for this big system. Since our main goal is to show using a solar panel could save you a large amount of money in years, we will account the repair and replacement cost that could happen in 30 years. When we say that cost includes our main thing is replacing the battery, since lead acid battery has 5 to 7 years of lifespan. There is also replacement cost of the inverter, repairing cost of the panels if they broke up or got any other problems. I did a rough calculation on this and, we expect to spend about \$8000 in the 30 years. Even though this research is a proposal for the Missouri state to allow an Off-Grid system of solar installation, 30% tax credit at the first year is included in this research as part of the proposal. So, when I included that I arrived in the price \$17,290 for 30 years. And if we compared this with the average electric bills in Missouri, \$38,808, there is a difference of \$21,518. Please see the figure for a better information.

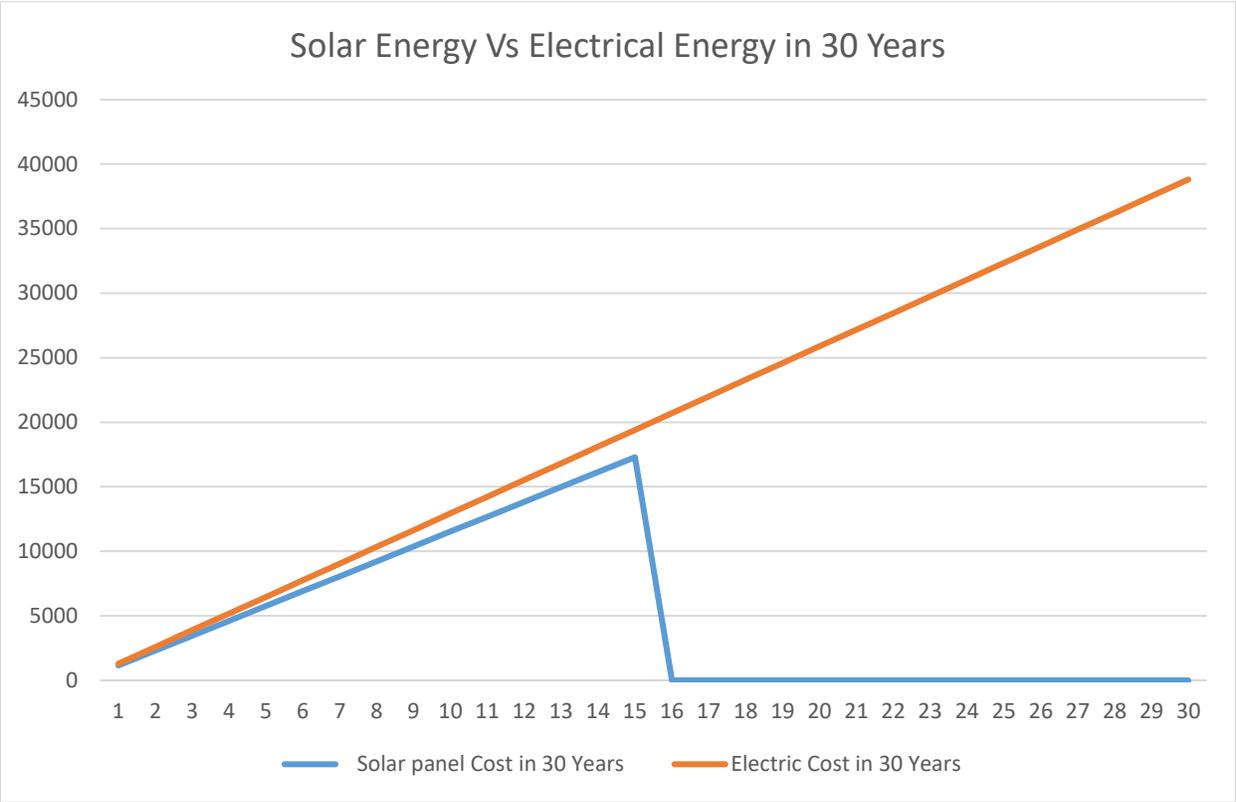


Figure 2.4 Solar Energy Cost Vs Electric Bill in Missouri in 30 years

CHAPTER 3 GENERATOR FOR BACKUP SYSTEM

Considering a generator is one of the best choices in providing a backup for the solar panels. There are different kinds of generators in the market, so there are a lot of choices in which type of generator you want to buy. When thinking about buying the generator, you have to consider, the price, the durability, and what type of gas does it use to generate electricity. Especially the type of gas is the most important thing, because when we are talking about saving, the different prices of gases make a great difference in forty-five years. There are two experiments in using the generator as a backup source. First, to buy a solar panel kit according to the price of the average sun hours, and to use a generator during the winter time for a few hours. And the second is to buy a solar kit according to the price of the winter sun hours, and to use a generator just for a backup source in order to be safe 24 hours a day having some kind of energy source. When we choose the size of our generator, we have to make sure we are choosing a generator that will generate the amount of energy we use per day. In this case, in order to be safe 24 hours a day, and in whole year, we need to choose a generator for the winter season. As we stated earlier for the winter season, the inverter needs around 3130W per day to generate an electricity for eight hours, average electricity usage per day. So, in today's market the average price of a generator that can generate that amount of energy in eight hours is \$400. These kinds of generators take a gasoline that we use for our cars. The average price of the gasoline, in the last two years in Missouri, is around \$2.25/gallon. At the present since the American government is drilling its fossil fuels, and reducing the oil market with different countries in the world, the price of the gasoline is expected to stay in its low price for years.

3.1 Buying Solar Panels based on Average Sun Hours

To start with the first experiment, using a solar panel kits that could generate energy, 5000W for the day during the three seasons except the winter season give us a price of \$6,520 without including the maintenance, and the installation cost. Even though most the calculations that we see today is based on thirty year of time, it is good to include fifteen more years in order to go more in detail the benefit of using a solar panel. This means most of the cost of using the solar system after the thirty years is the maintenance cost. If anyone has a house, we expect to live in the house from thirty to forty years, and if the person wants to sell the house before that, he has to think about the people who are buying his house. If he has to explain them about the benefit of using a solar panel, such as how much money they should expect to spend in the next fifteen or twenty years. In this case, we will use forty five years of time in comparing the prices of using solar system with generator and the electricity.

The average life span of the generator that we need is 20,000 hours. With a full tank, the generator can run for twelve hours. As we stated earlier this first experiment is based on the solar system installation for the seasons with an average sun hour such as fall and spring. The average energy needs using a solar energy in these seasons is 2395W per day, and for winter seasons we will need 3130W. This number is just the output since the generator directly connect to the inverter. To calculate the amount energy we need from the generator, subtract the energy needs of the average, 2395W, from the energy needs during the winter season, 3130W, and this give us 735W. So, in the whole year the amount of energy we use from the generator is 735W. In order to convert this amount into number of hours, we can derive a formula below from equation 2-1:

$$\text{Winter Generator Hours} = \frac{(\text{Daily Electricity hours} \times \text{Generator Energy})}{\text{Average Energy}} \quad (2-4)$$

$$= \frac{8 \text{ hours} \times 735 \text{ W}}{2395 \text{ W}}$$

16

$$=2.5 \text{ Hours}$$

As we stated earlier the maintenance cost is one of the major part that could make a great difference in comparing the solar system to electricity. In the case of using generator the price of the gas and the life span of the generator are the main things that we have to consider when applying it to our solar system as a backup source. To calculate the life span of the generator that we need for this system, the number of hours that we use per day is the most important factor, and from that if we want to find how many hours we use in 45 years, we can extend the equation 2-4 by multiplying the number of days and years and get:

$$\text{Generator Hours in 45 years} = \text{Winter Generator Hours} \times \text{Winter Days} \times 45 \quad (2-5)$$

$$=2.5 \frac{\text{Hours}}{\text{day}} \times 90 \text{days} \times 45$$

$$=10,125 \text{ Hours}$$

The life span of the Generator is 20,000 hours, and from the result above we can see that we consume this amount of energy per year we could use it for over eighty years. And to calculate the cost of using unlead gas with current average price, \$2.25/gallon, for forty five years, first calculate the amount of gallons we use during the winter per day. As we stated earlier a full tank of the generator is 4.2 Gallons and it can run for 12 hours. During winter time we only run this generator for 2.5 hours, if we use a direct proportional method, the amount of gas the generator consume during in one day is 0.875gal. If we change this amount to the price, we again use a direct proportional method with \$2.25/gallon, and we get that the price for that day will be \$1.97. To understand how much money we would spend in 45 years, we will use the formula below.

$$\text{Cost of Using Generator in 45 years} = \text{Daily Generator price} \times \text{Winter Days} \times 45$$

$$= \frac{\$1.97}{\text{day}} \times 90 \text{ days} \times 45 = \$8000$$

From the result above we can see that the approximate cost of using the generator for forty five years is \$8400 when we add the price of the generator. Now if we calculate the total cost of using a solar panel using a generator as a backup source by adding the costs of solar panel kit (\$6,520), Installation cost (\$9000), repairing cost (\$12,000), and the calculated cost of using generator for forty five years (\$8400) will be averaged to \$35,900. As we stated earlier the federal government help you to cut 30% of the solar system installation cost. However using a generator obviously is not included in this case. Now since this tax credit only works on solar system, subtract the cost of using generator, \$8,400, from the total cost, \$35,900, and we get \$27,000. If we cut 30% from this amount we get \$19,250, and when we add this amount to the cost of using a backup generator, we get \$27,650. When we compare this amount with an average bill of electricity in forty five years, \$58, 212, we can see a difference of \$30,562. For more detail see the graph below.

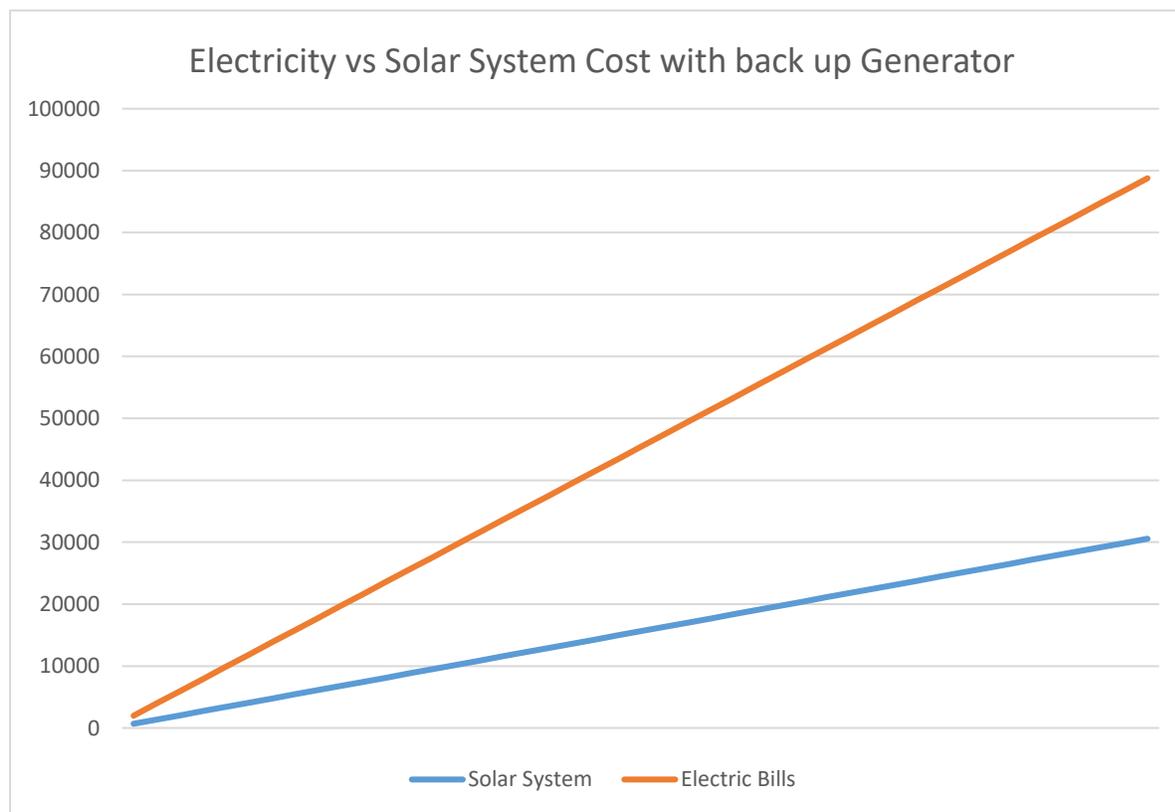


Figure 3.1 Solar Energy with a backup Generator Cost Saving Based on Average Sun Hours

3.2 Buying Solar Panels based on Winter Sun Hours

To go back to our second experiment, we use a generator only as a backup source and install a solar system according to the energy needs during the winter time. In this case since it is off-grid system and batteries discharge is calculated according to one day, there could be a time where there is power, because of a strange consecutive cloudy days during the winter time. There are 90 days in winter, and out of these days there are always days where there is no-sunlight to power the solar panels. The weather forecast shows that the average cloudy days, and foggy days in Kansas City and St. Luis is 48, and 39 days consecutively. Even though the average weather history of Missouri is not stable like many other Cities and States in United States, we will take that to approximate the possible consecutive cloudy days where alternative source is needed. Now we approximate 8 days out of those 90 days of winter as a cloudy and foggy where there is no sunlight to power up the solar panels, the generator will be used as a backup source for the system in those days. We will do the same calculation as the first experiment, and use the same generator to power up the system. First we start by calculating the number generator hours in 45 years using equation 2-5

$$\begin{aligned} \text{Generator Hours in 45 years} &= \text{Winter Generator Hours} \times \text{Winter Days} \times 45 \\ &= 8 \frac{\text{Hours}}{\text{day}} \times 10 \text{days} \times 45 \\ &= 3,600 \text{ Hours} \end{aligned}$$

To calculate the amount of gallons that the generator consume in 45 years, and then the price, we again use the same method, and the calculation will give us 1.31gal per day during the possible cloudy and foggy days, and \$2.95 in money wise. From this we can calculate the total cost of using a generator in 45 years using the simple formula below

$$\text{Cost of Using Generator in 45 years} = \text{Daily Generator price} \times \text{Winter Days} \times 45..(2-6)$$

$$= \frac{\$2.95}{\text{day}} \times 10 \text{ days} \times 45$$

$$=\$1,329$$

From this result we can see that the approximate cost of using a generator for forty five years is \$1729 when we add the price of the generator, \$400 to it. In this experiment since we are using a solar system based on the sun hours of the winter season, we need to add additional solar panels, and batteries to our system, and hence the cost of the solar system will increase significantly. In winter season the amount of solar energy we need to power up the system is about 6885W, and when we add the additional panels to the system the cost of the solar kit will be around \$7,710. And since we are also adding panels, the repairing cost will also increase in small number, around \$500, and make the repairing cost to around \$12500. Also the installation cost will increase since the installers charge you with respect to the solar energy needs, and that cost jumps up to around \$10000. Now we add all the solar system costs, without including the generator costs, just like we did in the first experiment the total cost will be approximated to \$30210. Again if we add that 30% tax credit to that cost drops to \$21147, and since the tax credit is only for the solar system, we add the cost of using generator, \$1729, to this amount, and get \$22,876. This method looks more beneficial than what we already saw in the first experiment, and is another promising method to save a huge amount of money when comparing it with an average bill of electricity in forty five years, \$58, 212. For more detail see the graph below.

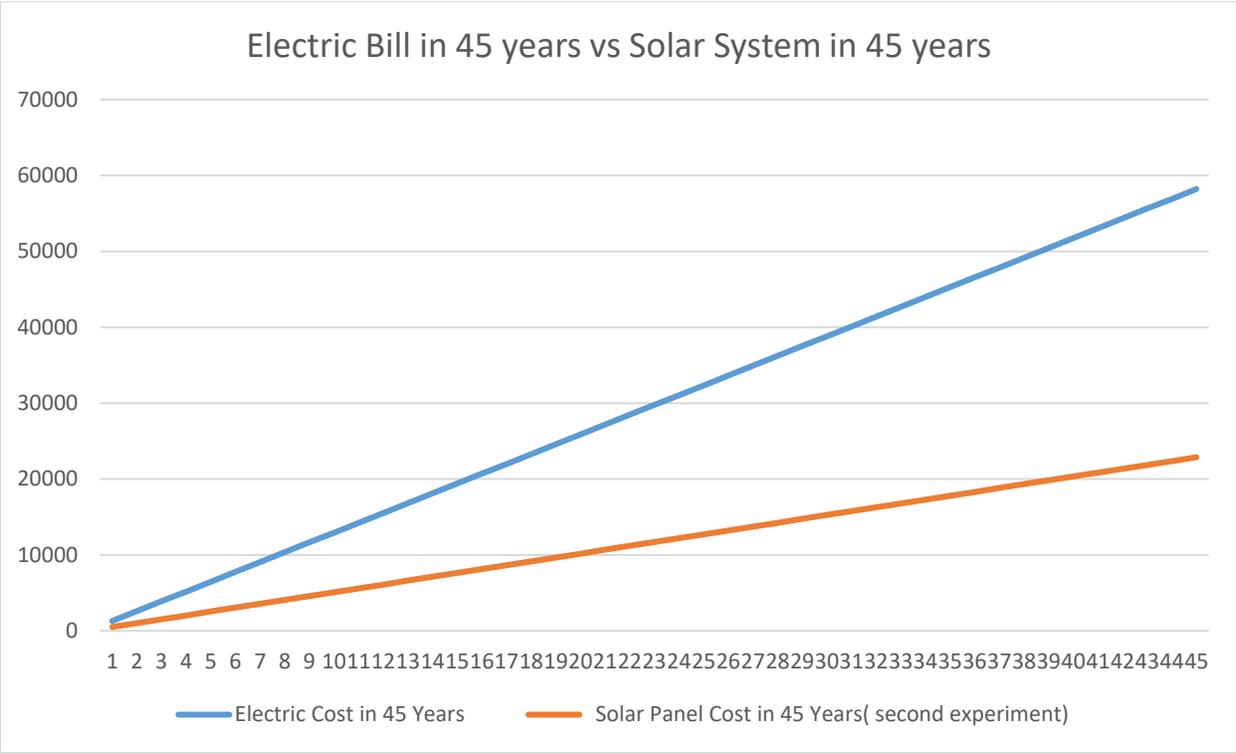


Figure 3.1 Solar Energy with a backup Generator Cost Saving Based on Winter Sun Hours

As we can see in the graph, the cost solar system is a linear function just like the electric bill cost. We put all the cost of the solar system together even though we may spend more in some range and less in others. When we subtract the peak cost in the graph it give us 35,336. So, using a generator as a backup source is both beneficial in terms of money and safety. As we already stated earlier the weather forecast of Missouri, during winter season, changes every year, so the need of the generator may change from one season to the other evenly, but it may not affect that number greatly, as the winter season constitute one fourth of the whole season.

CHAPTER 4 FUTURE COSTS AND PROSPECTIVE TECHNOLOGY

4.1 Powerwall

Almost thirty percent of the cost of using solar system in forty five years is the repairing and maintenance cost, and the battery replacement covers most of this cost. As we stated in the previous discussion about the life span of the batteries and their efficiency, our cost effective batteries such as lithium batteries have short life span and are less efficient. There are other batteries that are more efficient and have better efficiency, but their cost is much higher which doesn't help the solar installers to save money through time. However, a recent technology is opening another better opportunity of battery system, Powerwall, that is very efficient and have a long life span, and is cost effective.

According to the definition Ashley Watters, The Tesla Powerwall is a battery pack designed for your home. This lithium-ion battery can also be used as an alternative for powering up your home. Depending on your needs and goals, you can utilize the Tesla Powerwall to power your home at night with built-up solar energy, use as a backup, or even develop a system to go off-grid.

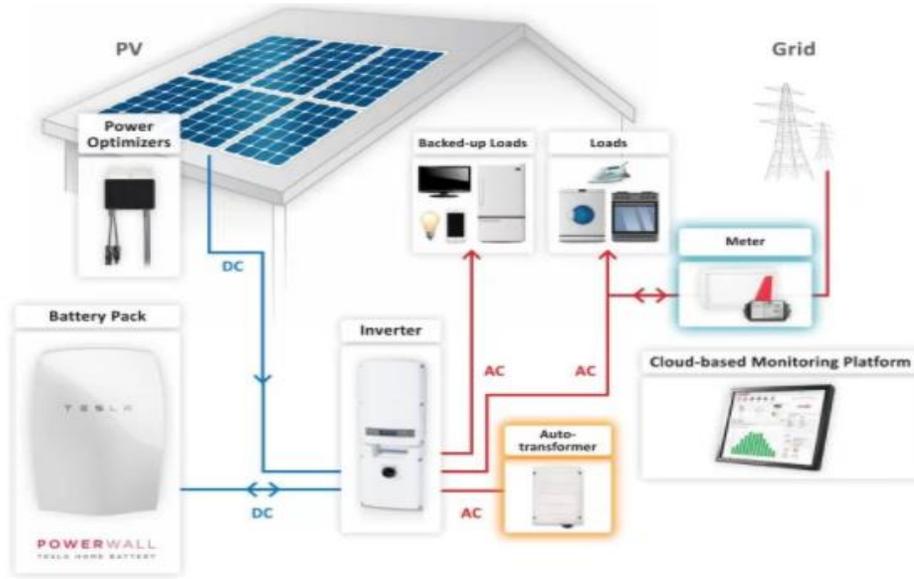


Figure 4.1 Schematics of Power Balls 1

At this time there are two models of a Power wall batteries. Model 1 has a capacity to store up to 6.4KWh, and Model 2 has a capacity to store up to 13.5KWh. Both have more than enough amount to store energy for the average daily electrical consumption in Missouri. As it is already discussed the solar panels size depends on the sun hours of the area and the efficiency of the batteries and the inverters. This tesla Powerwall has an efficiency of 90% for ten years, and their efficiency will drop to about 80% after that. With less efficiency, the battery could be replaced in every 15 years. The price of one Powerwall battery, model 1, with its tools is about 3,700. In forty five years by changing the batteries three times, we could spent \$11, 100. And since the efficiency of this battery is 90% to 80%, the size of the solar system will be much smaller. If we consider an efficiency of 85% for the battery in fifteen years, and the efficiency of the inverter 90%, the size of the solar energy could be determined by dividing the actual need by the efficiency of the battery and the inverter:

$$\begin{aligned}
 \text{Size of Solar Energy} &= \frac{\text{Solar Energy needed on Winter}}{\text{Efficiency of Battery}} \times \frac{1}{\text{Efficiency of Inverter}} \quad (3-1) \\
 &= \frac{3129.6W}{0.85} \times \frac{1}{0.90} \\
 &23
 \end{aligned}$$

$$=4090.1W$$

This amount of energy is much smaller comparing to the 6885.12W energy requirement with the lead acid batteries. Then the smaller the solar size is the less amount of money we spend on both the buying the solar panels and installing them. Again the possible amount of money that could be spent with the Powerwall battery and the previous lead acid batteries in forty five years is similar, \$11,100 and \$10,200 respectively. However the model 1 Powerwall has a great advantage over the Lithium batteries that we have used in our calculations, in the case of storage, because it has a lot of extra space to store energy during the windy or foggy days.

4.2 Cost of solar Cells over time

When talking about any comparison with respect to time, there is always a change in cost and quality of the required tools. As the technology is growing fast, the importance of using the solar systems is already known that is beneficial, it is inevitable that the number of companies who would involve in this technology will increase. According to the NREL research report in 1977, the solar cost was \$77/watt, but in 2017 the cost is \$0.64/watt. If the difference is change to a percent it is 99.2% change in forty years. This is showing us a lot of companies are in a big competition, and this is giving the public a big opportunity to choice the cheapest one possible. Even in the last eight years, there was a breakthrough in the cutting price of the solar cells. In 2009, the cost of installing solar panels was \$7.06/watt, and in 2016 the cost dropped to \$2.93/watt. This is also showing us that, even the sharp decrease in the cost is happening in the last decades. At this time there are a lot of big and small residential solar installers such as, INTEGRATESUN, BRILLIANT HOMES, FREEMAN SOLAR, SOLAR WATT SOLUTIONS and soon. Since the number of solar companies is keep increasing, the GTM research on the solar cost is expecting to see 27 percent drop in average global project prices by 2022, and 4.4 percent each year.

One of the most important thing that the public has to understand is that the Solar system is a renewable source of energy, and there is no doubt that there will be no more sun light unlike the fluctuating cost of fossil fuels that depends on the market of the world. Once you understand the sun hour of your location with respect to the four seasons, the only worry is the possible slight change in the climate change of the area, and since there is a backup generator, it cannot give a huge difference in the expected cost.

CHAPTER 5 CONCLUSION

Solar energy for public energy system is promising method of saving money from a monthly electric utility bills. Today most of the states are required by law that certain amount of their energy source should be from the renewable energy, and since the presence of the sun is unquestionable, the number of solar companies is keep increasing. As the number of the solar companies increase, the price for the solar panels is also dropping with a great percent, and this is giving the public a great chance and is advising to use this opportunity into their advantage. At this time Missouri is holding the rule that all the solar installations to be tightly connected to the public utilities, which is called On-grid system. The way someone choices how to install solar panels is mostly based on his financial status. The more a person can pay the down payment, the more he will save money.

Even though the state of Missouri is not allowing the person to be independent of the public utilities, this research is aiming to show that the an Off-grid system of solar installation is the best way for the public to save a huge amount of money in forty five years. On this research all of the calculations that is done is based on the user to completely pay for the system from his own at the beginning. And as shown in the calculated results, choosing an Off-grid for your energy system save you a lot of money. Using a generator as a back system is the primary choice for this system design, and it shows that the average the amount of money you would spend in forty five years is \$22,876, and comparing this amount to the amount of money you would spend using the electric bill in forty years, \$58,021, brings a big saving, \$35,145. And one of the promising thing about choosing solar system is that the continuously dropping in the price of the panels. Even though the state of Missouri is not allowing the Off-grid system, a person can individually buy the panels, and choice the installers, and since numbers of installers is increasing the people is getting more opportunities in getting the cheaper ones, from different angles. So, using this detailed

calculated result, based on the present cost of the solar installation needs, I would like remind the state of Missouri to allow an Off-grid solar energy system for a better saving.

REFERENCE

- [1] Electricity Local, *Residential Electricity Rates & Consumption in Missouri*. [Online] Available <https://www.electricitylocal.com/states/missouri/>
- [2] Justine Sanchez (December 2013), *PV Array Sizing for kWh*. [Online] Available <https://www.homepower.com/articles/solar-electricity/design-installation/pv-array-sizing-kwh>
- [3] Mathias Aarre Maehlum (August 5, 2017), *Which Solar Panel Type is Best? Mono- vs. Polycrystalline vs. Thin Film*. Available [Online] Available <http://energyinformative.org/best-solar-panel-monocrystalline-polycrystalline-thin-film/>
- [4] Solar Power Rocks, *Your guide to going solar in Missouri*. [Online] Available <https://solarpowerrocks.com/missouri/>
- [5] Energy Usage, *How to Calculate Solar Panel Payback Period (ROI)*, [Online] Available <https://news.energysage.com/understanding-your-solar-panel-payback-period/>
- [6] SunCal, [Online] Available <http://suncalc.net/#/37.9643,-91.8318,6/2016.01.02/22:33>
- [7] Civic Solar, *How Does Heat Affect Solar Panel Efficiencies?* [Online] Available <https://www.civicsolar.com/support/installer/articles/how-does-heat-affect-solar-panel-efficiencies>
- [8] U.S. Climate Data, *Temperature - Precipitation - Sunshine – Snowfall*. [Online] Available <https://www.usclimatedata.com/climate/columbia/missouri/united-states/usmo0193>
- [9] Astronomical Applications Dept., *Columbia, MISSOURI Central Standard Time*, [Online] Available http://aa.usno.navy.mil/cgi-bin/aa_durtablew.pl?form=1&year=2016&task=-1&state=MO&place=Columbia
- [10] Solar Direct, *Solar Electric System Sizing Step 4 - Determine the Sun Hours Available per Day*, [Online] Available <http://www.solardirect.com/pv/systems/gts/gts-sizing-sun-hours.html>

- [11] Worst Case Peak Sun Hours by Month, *Month: Peak Sun Hours*, [Online] Available http://tyconsystems.com/html/nrel_lookup.htm
- [12] New 5KW Solar Power Generator System for 110v/220v Home Use Shipped by Sea, [Online] Available https://www.ebay.com/itm/New-5KW-Solar-Power-Generator-System-for-110v-220v-Home-Use-Shipped-By-Sea-/372122405005?_trksid=p2385738.m2548.14275
- [13] NPP 12V 100Ah Sealed Deep Cycle AGM Battery Solar, RV, Off Grid, [Online] Available <https://www.ebay.com/i/253099672347?chn=ps&dispctrl=1>
- [14] The Inverter Store, [Online] Available <https://www.ebay.com/i/253099672347?chn=ps&dispctrl=1>
- [15] Blue Pacific Solar, *Solar Edge 5.4 kW HD-Wave Pre-Engineered Solar Kit*, [Online] Available <https://www.bluepacificsolar.com/solaredge/solaredge-hd-5.4-kw-kit-qcells-300w.html>
- [16] Grape Solar Panel, [Online] Available https://jet.com/product/detail/4d06c04a581846c78e6718245fd92cda?jcmp=pla:ggl:nj_du_r_gen_electronics_a1:electronics_adaptors_cables_power_cables_a1:na:PLA_785706707
- [17] Energy Sage, *What are the top solar panel companies & manufacturers in 2018?* [Online] Available <https://news.energysage.com/best-solar-panel-manufacturers-usa/>
- [18] Sportsman 2200 Watt Digital Inverter Gasoline Generator with Parallel Capability - CARB Approved, [Online] Available <https://www.samsclub.com/sams/2000w-generator-sine-wave->
- [19] Energy Sage, *Solar panel incentives, rebates & tax breaks*. [Online] Available <https://www.energysage.com/solar/cost-benefit/solar-incentives-and-rebates/>
- [20] Energy Sage, *Tesla Powerwall: the complete review*, [Online] Available <https://www.energysage.com/solar/solar-energy-storage/tesla-powerwall-home-battery/>
- [21] Zachary Shahan (May 9, 2015), Clean Technica, *Tesla Powerwall & Powerpacks Per-kWh Lifetime Prices vs Aquion Energy, Eos Energy, & Imergy*. [Online] Available

<https://cleantechnica.com/2015/05/09/tesla-powerwall-powerblocks-per-kwh-lifetime-prices-vs-aquion-energy-eos-energy-imergy/>

- [22] Marc Saltman (May 13, 2017) USA TODAY, *Solar power is getting cheaper; here are some smart options for your* [Online] Available home, <https://www.usatoday.com/story/tech/columnist/saltzman/2017/05/13/solar-power-for-the-home-we-there-yet-yes/101561294/>
- [23] Ashley Watters, What is the Tesla Powerwall? [Online] Available www.dummies.com/home-garden/green-living/tip-uber-driver/
- [24] Current Result, Total Cloudy and Foggy Days at US Cities in January. [Online] Available <https://www.currentresults.com/Weather/US/cloud-fog-city-january.php>
- [25] Eric Wesoff (June 27, 2017), gtm, *Solar Costs Are Hitting Jaw-Dropping Lows in Every Region of the World*. [Online] Available <https://www.greentechmedia.com/articles/read/solar-costs-are-hitting-jaw-dropping-lows-in-every-region-of-the-world#gs.i8F6l=0>
- [26] The Guardian (January 26, 2016), *Solar panel costs predicted to fall 10% a year*. [Online] Available <https://www.theguardian.com/environment/2016/jan/26/solar-panel-costs-predicted-to-fall-10-a-year>
- [27] AltEstore, *What is a Solar Charge Controller*. [Online] Available <https://www.altestore.com/store/info/solar-charge-controller/>
- [28] Dasolarenergy, *FREE SOLAR EVALUATION*, [Online] Available <https://www.dasolar.com/energytaxcredit-rebates-grants/missouri>
- [29] The Do it Yourself World, *The Solar Panel Requirements Calculator*, [Online] Available <http://www.thedoityourselfworld.com/articles/article.php?id=11503>
- [30] ENERGY WE NEED, *Formulas and User Guide*, [Online] Available <http://energyweneed.com/files/models/Energy%20We%20Need%20%20Formulas%20%20User%20Guide.pdf>