RESEARCH ARTICLE OPEN ACCESS

The Economic Feasibility of a Solar PV Array with Battery Storage for a Residence in Dayton, OH.

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I. Introduction

Dayton is one of the largest cities in Ohio, with the population exceeding 140,000 people. It is a part of a large metropolitan area with over 1 million residents. The latitude of Dayton, OH, USA is 39.758949, and the longitude is -84.191605. Dayton, OH, USA elevation is 226 meters height, that is equal to 741 feet.

Weare trying to determine the economic feasibility of a solar PV array with battery storage for a residence in Dayton, OH. The system is to be designed for the lowest simple payback period, but it must meet a minimum of 50% of the annual load.

The following research includes the methodology and approach of the design and the input data. The input data will include site data, PV module data, Battery System data and economic data. At the end of the paper, it will talk about result and conclusions.

II. Description and Approach

The methodology of this research is to Construct a computer model of a solar PV array with battery in Excel and simulate its performance on an average daily basis per month. In most jurisdictions, 'net metering' is allowed, but for this research, we will assume that the utility will not accept energy produced by residential customers.Although this is currently not true in the Dayton area, it may be some day in the future, and is certainly true in other locations in the US and throughout the world. Thus, this research will give you experience in modeling electrical energy storage in batteries.

Construct a computer model of a solar PV array with battery in Excel and simulate its performance on an average daily basis per month. What does this mean? Here, we will use the concept of the 'average day' per month and track hourly solar radiation, hourly electric loads, and hourly battery performance over the course of the day using assumed/approximated hourly profiles based on monthly data input. Calculate the simple payback period in a manner. Take advantage of the U.S. Federal Tax Credit, which is equivalent to a 30% rebate on the installation cost. We do some research on battery costs. An approach to completing the research is as follows:

- An Excel template file is designed for this research.
- There are VBA functions created for this research that facilitate solar angle and radiation data processing.
- Retrieve the monthly weather data from the usual NASA website.
- The monthly electric loads (in kWh) are as follows in order from January to December: 533, 501, 512, 379, 363, 658, 843, 1496, 1566, 786, 364, 439
- Determine the hourly solar radiation for the average day of the month.
- Designed ourPV array. Choose a PV manufacturer and input the appropriate module specifications into the PV worksheet. Decide on an appropriate tilt angle and orientation(s) of the modules. The available roof area on the home is 500 ft2, and this roof area is sloped 27° and faces south.
- Designed our battery bank.
- Conducted our economic analysis. We used the PV cost resources found on web resources

to estimate the installation cost of our array and battery bank. Determined the lowest simple payback period of the system that meets at least 50% of the annual load, assuming that the homeowner pays $0.125/kWh for electricity.

III. Input Data

Energy delivered by the solar photovoltaic system construct a computer model of a solar PV array with battery in Excel and simulate its performance on an average daily basis per month. The input data that we need at this research divided into four categories: Site Data, PV module Data, Battery System data and economic data.

3.1 Site Data

The project is in Dayton, OH with latitude 39.759° N and Longitude 84.19° W. The PV system will be installed on the residence's roof. The available roof area on the home is 500 ft2, and this roof area is sloped 27° and faces south. Table (1) will show the detailed monthly electric loads (in kWh)

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Load (KWh)	533	501	512	379	363	658	843	1496	1566	786	364	439
Total (KWh)	8440											

Table 1: detailed monthly electric loads (in kWh).

3.2 PV Module Data

There are several types of the solar modules that can be used to convert the sun lights to electricity with different efficiency and rated power. In this research, We select SunPower X-Series (X22-360-COM). SunPower has long held a leadership position when it comes to high quality, high efficiency PV modules, and the X-22 is its top of the line. SunPower estimates that 99% of its PV modules will still deliver 70% of rated power after 40 years. The input data that we need from the solar module is rated power (W), the area of the module 1.678 (m^2), and module rated efficiency 22.2(%). Also, we need the Nominal Operating Cell Temperature (NOCT) (C), and the Temperature Coefficient (C^{-1}). The photo below (figure1) shows the characteristics and the dimensions of the solar module.

Electrical Data	
	SPR-X22-360-COM
Nominal Power (Pnom)[12]	360 W
Power Tolerance	+5/ 3%
Avg. Panel Efficiency[13]	22.2%
Rated Voltage (Vmpp)	59.1 V
Rated Current (Impp)	6.09 A
Open-Circuit Voltage (Voc)	69.5 V
Short-Circuit Current (Isc)	6.48 A
Max. System Voltage	1000 V UL & 1000 V IEC
Maximum Series Fuse	15 A
Power Temp Coef.	−0.29% / °C
Voltage Temp Coef.	-167.4 mV / °C
Current Temp Coef.	2.9 mA / °C

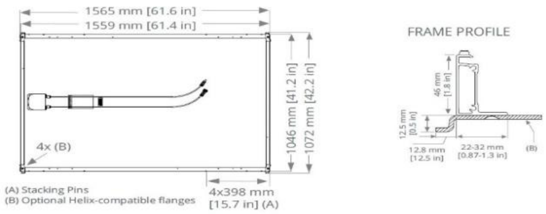

Figure 1: the characteristics and the dimensions of the solar module.

3.3 Battery System Data

In this system design, electricity generated by the PV system charge the batteries which provide the electrical energy to the house and store the remaining energy to use it when the PV system cannot cover the load. We chose Crown 12CRV8D, 240Ah 12V Battery for our system. It is suitable for marine, RV, backup power and off-grid PV systems, Crown's 12CRV8D battery offers exceptional quality and performance at a competitive price. 12CRV8D batteries are standard 8D size and use AGM (absorbed glass-mat) technology to control and contain electrolytes. The number of batteries that we need to my system is **four**. The online cost of the battery is**530$**. The specification of the battery is showed in the following Table 2.

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BCI Group Size	Model Reference	Electrical Capacity		RC Minutes	Terminal Type	Inches				Millimeters				Weight	
		20 Hr Rate	5 Hr Rate			Length	Width	Container Height	Terminal Height	Length	Width	Container Height	Terminal Height	Lbs	Kgs
8D	12CRV8D	240	206	500 / 75A	Standard	20.52	10.59	7.99	9.02	521	269	203	229	162	73.5

Table 2: Crown's 12CRV8D battery specification of the battery

3.4 Economic Data

To calculate the simple payback of the system we can use equation (1)

$$Simplepayback = \frac{InitialCost}{CashFlow} \qquad (1)$$

Therefore, we need the total cost of the system (Initial Cost $) and the annual savings of the system (Cash Flow $/year). To estimate the system cost, we used the median install price for small nonresidential building for 2012, 2013, 2104 and 2015

(figure 2) average declinedabout 0.5($/W). We predict the installation cost for 2017 will be about 2.5 ($/W).

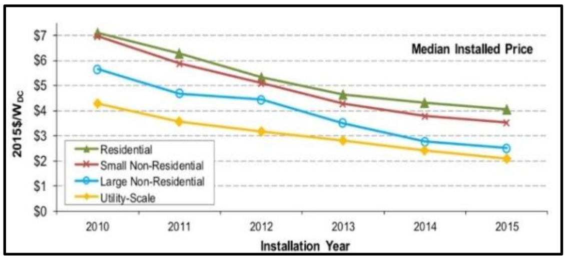


Figure 2: Median Installed Price

The initial system cost could be fined by equation (2)

Initial Cost = [P_{module} X N_{module} X Installation cost per watt (2.8$/W)] +$N_{Battery}$X Battery Cost(2)

Where P_{module} is the rated power of the module (360W), and N_{module} is the number of modules installed in the system (8 modules). To calculate the annual energy savings from the system (Cash Flow) I used equation (3)

$$CashFlow = [P_{system}\left(\frac{KWh}{Year}\right) - P_{Excess}\left(\frac{KWh}{Year}\right)] \text{ X } Cost\left(\frac{\$}{KWh}\right) \qquad (3)$$

where P_{system} is the energy generated from the system and P_{Excess} is the excess energy. The energy cost will be$0.125/kWh because the homeowner pays that amount for electricity. At the end of the economic data, we need to find the Net Present Value (NPV) of the project which it could be calculated by equation (4). We assumed the discount rate 5% because one of our alternative investments is a 5% per year bank account. Since it is a not a capital project (n)should probably be about 20 years.

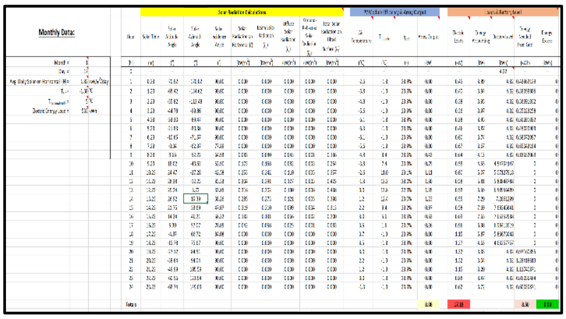
$$NetPresentValue = -IntialCost + CashFlowx\left[\frac{1-(1+i)^{-n}}{i}\right] \qquad (4)$$

PV Array Data:			
η_{ref} =	0.222	(-)	panel efficiency at the reference temperature
NOCT =	47.5	(°C)	Normal Operating Cell Temperature
T_{coeff} =	0.0029	(1/°C)	temperature coefficient
Area =	1.67768	(m^2)	module area
Modules =	8		number of modules
T_{ref} =	25	(°C)	reference temperature for efficiency calculation
$\eta_{inverter}$ =	0.97	(-)	inverter efficiency
Tilt =	27	deg.	tilt angle of array from horizontal
Surface Azimuth =	0	deg.	facing direction of array

4. Result and Conclusions

4.1 Output Data

From the Excel template file, we can see the electric loads, annual energy generated by the system, energy taken from the grid, and excess energy produced. In addition, the annual fraction of loads met by your solar PV system shows in the excel template file. Also, it shows the total cost of the system, the annual cost savings, the simple payback of the system and the net present value for the project. The input and output data of the system could be illustrating at the tables3, 4,5, and 6below respectively.



Month	Load	Solar Energy Produced	Energy Taken From Grid	Excess Energy Produced
	(kWh)	(kWh)	(kWh)	(kWh)
1	533	250.52	266.49	0.00
2	501	283.25	202.72	0.00
3	512	374.92	141.37	19.65
4	379	419.26	39.74	91.36
5	363	443.68	12.67	104.24
6	658	470.27	203.42	35.43
7	843	487.29	330.42	0.00
8	1496	463.19	1036.30	0.00
9	1566	439.67	1079.35	0.00
10	786	372.68	389.74	0.00
11	364	260.74	92.34	0.00
12	439	222.28	203.55	0.00
Total	**8440**	**4487.74**	**3998.11**	**250.68**
Fraction Met	**53.17%**			

Table 3: Hourly Energy Calculations

PV Array Data:			
η_{ref} =	0.222	(-)	panel efficiency at the reference temperature
NOCT =	47.5	(°C)	Normal Operating Cell Temperature
T_{coeff} =	0.0029	(1/°C)	temperature coefficient
Area =	1.67768	(m^2)	module area
Modules =	8		number of modules
T_{ref} =	25	(°C)	reference temperature for efficiency calculation
$\eta_{inverter}$ =	0.97	(-)	inverter efficiency
Tilt =	27	deg.	tilt angle of array from horizontal
Surface Azimuth =	0	deg.	facing direction of array

Battery Data:			
Charge Capacity =	240	A-h	the charge capacity of the battery in amp-hours
Voltage =	12	V	the battery voltage
Min. Charge Fraction =	0.5	--	the minimum allwable battery charge as a fraction of 1
Number of Batteries =	4	--	number of batteries in the battery bank
Maximum Battery Bank Level =	11.52	kWh	
Minimum Battery Bank Level =	5.76	kWh	

Intial cost ($)	$9,320
Intial cost after Govement reward ($)	$6,524
Cash Back ($/Year)	530
Simple Pay Back (Year)	12.32
Net Present Value (NPV) ($)	$76

Table 4: Monthly Result Summary
Table 5: PV Module Data
Table 6:Battery Data
Table 7: Economic Data Calculations

From the tables4,5,6,7 and 8 we can see the total system cost is **6,524$** after the 30% government rebate. Federal, state, and local governments offer solar energy tax credits and rebates to encourage homeowners to switch to renewable solar energy and lower their energy usage. The average amount of the solar rebate covers up to 30% of your solar power system cost ("Solar Energy Tax Credit & Rebates for Solar Panels"). The annual system savings is**530 ($/year)** and the simple payback of the system is**12.32 (Year)**.

4.2 Energy Reduction
The annual fraction of the energy met by the system is around **53.17%** of the residence load. This percentage calculated by divided the annual energy to the load over the annual electric load. The array rating for the system is **2.88 KW**.

4.3 Output Plots
The graphsbelow x-y plots (figure 3, 4, 5, 6 and 7) are showing hourly data for March, June, September, and December (i.e., Solar Radiation, PV array Output and Loads, Battery Level and Excess energy produced)

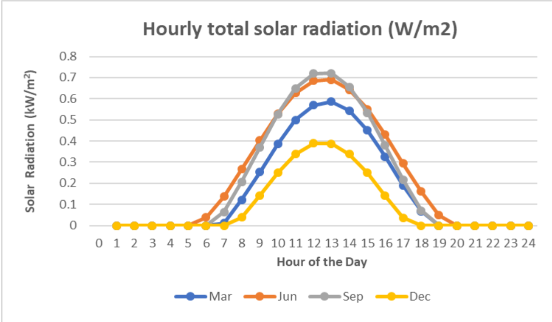


Figure 3: Hourly total solar radiation (W/m2)

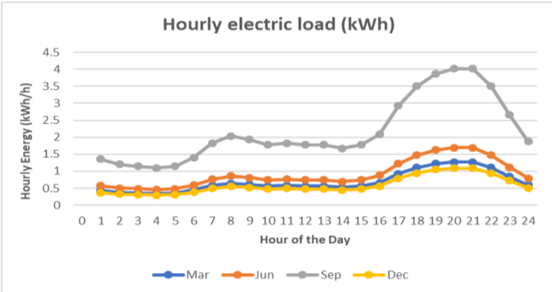


Figure 4: Hourly electric load (kWh): the average hourly load per day

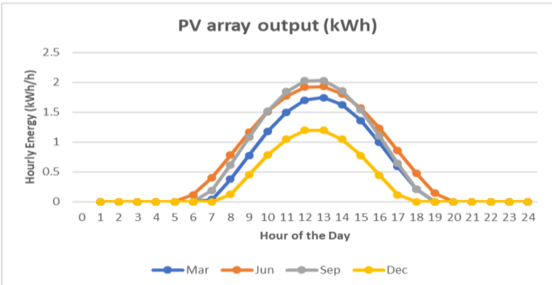


Figure 5: PV array output (kWh): the hourly energy produced by the PV system

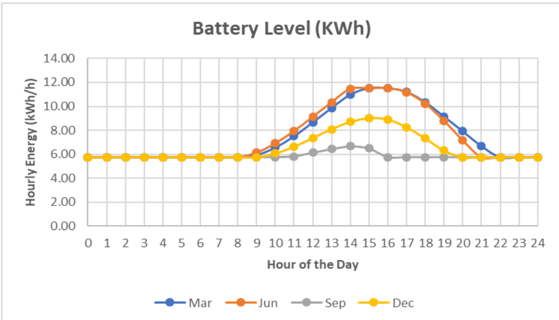


Figure 6: Battery Level (KWh)

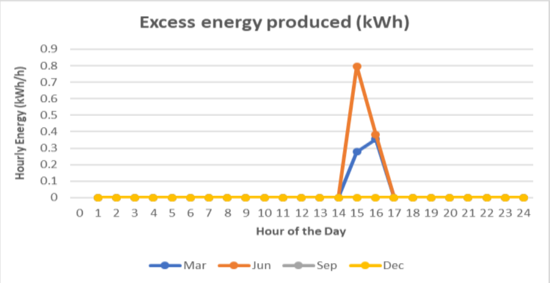


Figure 7: Excess energy produced (KWh)

4.4 Monthly Data

The graph below (Figure 8) compares between the monthly of the electric load of the house, the energy generated by the PV array, the excess energy, the energy from the system to the load and the energy needed from the grid to cover the electric load of the house. Also, table 4 show the annual electrical load required, produced by the system, excess energy, from the grid and the annual load from the battery to the house.

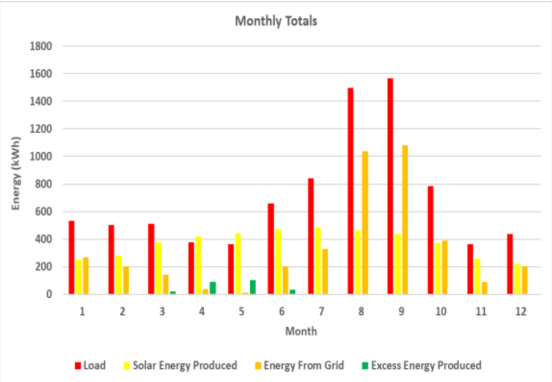


Figure 8: Monthly totals

4.5 Solar Module

As discussed before the available roof area on the home is 500 ft^2 about 46.5 m^2, and this roof area is sloped 27° and faces south. The total number of the solar modules will be 8 modules because we do not want to increase the excess energy produced which will be wasted not selling that excess energy to the grid system. There's no other feasible use for it and I cannot increase number of batteries more than 4 batteries to store the excess energy due to economic consideration.

4.6 Lowest Simple Pay Back

The payback period is the length of time required to recover the cost of an investment. We tried to use a different module characteristic to reduce the simple payback and increasethe annual fraction of the energy met by the system. SunPower X-Series (X22-360-COM)module wasused in the system design and the simple pay back of the new module reduced to **12.3**and we got positive NPV in this module, which was **$76**. Moreover, the annual fraction of the energy met by the system is**53.17%**. That would be a big achievement in the annual fraction of the energy met by the system because we were considering about the two factors during choosing our solar module and batteries. The two factors were the lowest simple payback and the lowest value of excess energy produced. Because this excess energy must be subtracted from what the system produces of the energy in our economic analysis. The lowest excess energy we got using SunPower X-Series (X22-360-COM) module was about **250**KWh. The simple payback that we picked depends on the lowest energy excessed and the highest energy produced by the system to meet the load.

Thus, changing number of the buttery will not change the annual energy reduction but will reduce the annual excess energy which is waste energy. Also, increasing the number of PV module will increase the annual energy reduction but increases the simple payback period and increase the excess energy produced.

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