Journal of Engineering Science and Military Technologies
Volume (1) - Issue (2) - 2017

ISSN: 2357- 0954
DOI: 10.21608/ejmtc.2017.743.1034

Sizing of a Photovoltaic System for a House in Qassim, Saudi Arabia

Original Article

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Key words:

PV, modeling, economy, electrical efficiency

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Abstract

Consumption of electricity in the Middle East is quite high due to the cooling needs in each home. However, Saudi Arabia has high solar energy resources that could be used to meet all home energy needs. In this project, a solar energy system is designed using BEopt and Homer softwares. BEopt was used to build a thermal model for an actual house in Qassim, Saudi Arabia, to stimulate the hourly kilowatt electricity consumption. Mathematical equations have been used to calculate the necessary photovoltaic and battery size. The collected data and BEopt results are used by Homer software to design various options for a photovoltaic system (PV). Results indicate that a 18.85 kW PV system, 52 batteries 200 Ahr (Ah) each and a 10kW inverter can meet all house energy needs.

I. INTRODUCTION

In the past twenty years, the demand on residential cooling has increased air conditioners. PV modules' efficiency depend on three parameters: location and sunlight availability; installation design, and orientation with altitude; and materials used. However, even if all these parameters have been achieved, there are other depending factors, such as dust, that will affect its efficiency. This paper focuses on evaluating the PV system performance for a chosen house in Qassim. Additionally, it will indicate multiple options for electricity production for residential applications. This research is to identify which methodology is valuable to convert solar energy into air cooling for residential application. Air conditioning is an application of energy use, as it is estimated that 45% of house energy consumption is used for cooling. Furthermore, 10-20% of all electricity produced is consumed for refrigeration and air conditioning[3]. Solar energy is a major target for any energy source, as peak radiation levels typically occur when peak refrigeration and air conditioning is needed[4].

II. INSTALLATION OF PV SYSTEM IN A HOUSE

The primary issue to consider while designing a successful PV system, is ensuring the panels are tilted in such a manner to obtain maximum sunlight exposure. In the next page, a photo of a house is shown for which such system is designed. In spite of the fact that the PV panels are installed and fixed and without a tracking system, these panels were tilted to the exact location altitude which is 26 towards south. This system is yet nonetheless adequate to meet the energy demand for this house.

Noticeably from 40 GW to 120 GW in Saudi Arabia[1], making a significant demand (putting a significant load) on the electrical grid consumption during the summer months[2]. Solar energy could be expanded to meet demand increases. Solar energy could be used for the generation of the required electricity to meet air conditioning demand.

Fig. 1: A north view of the selected house, with the sun direction to the East.

Typical houses in Saudi Arabia are similar to the house shown in Figure 1. The roof is flat, and could be used for PV system installation. Batteries and inverters could also be stored on the roof in a purpose-built small shed. The roof is accessible from inside the home, and a person could go up and dust the PV installation when necessary.

A. Thermal modeling for the house using BEopt

(A) thermal modeling of the house is needed to determine house hourly load data. (A) free BEopt software is used for the thermal modeling of the house[8]. The actual measurements of the house are used in the BEopt design to start calculating the energy consumption. Figure 2 shows the house's actual area to design the model based on it.

Fig. 2: The house's actual measurements.

Using BEopt a model is designed with all the actual measurements and characteristics of the house. Moreover, the data include house measurements, walls material, windows, roof, doors, appliances, ventilation, and air conditioners typical of people living in the a home, as shown in figure 3.

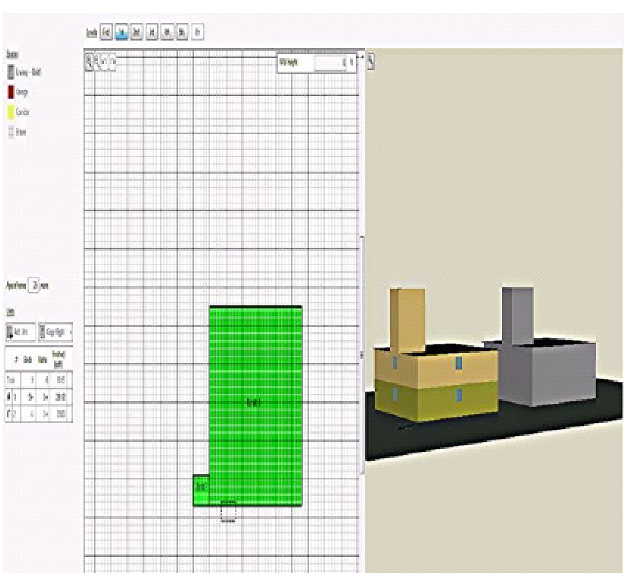

Fig. 3: The floors area units and house characteristic.

Using supplied input data and house design, BEopt calculates energy consumption in the house for each hour in a year. It uses the National Renewable Energy Laboratory (NREL) ('s) EnergyPlus engine for calculations and site data, as well as solar resources from the NASA website. The house orientation is also an input to the software.

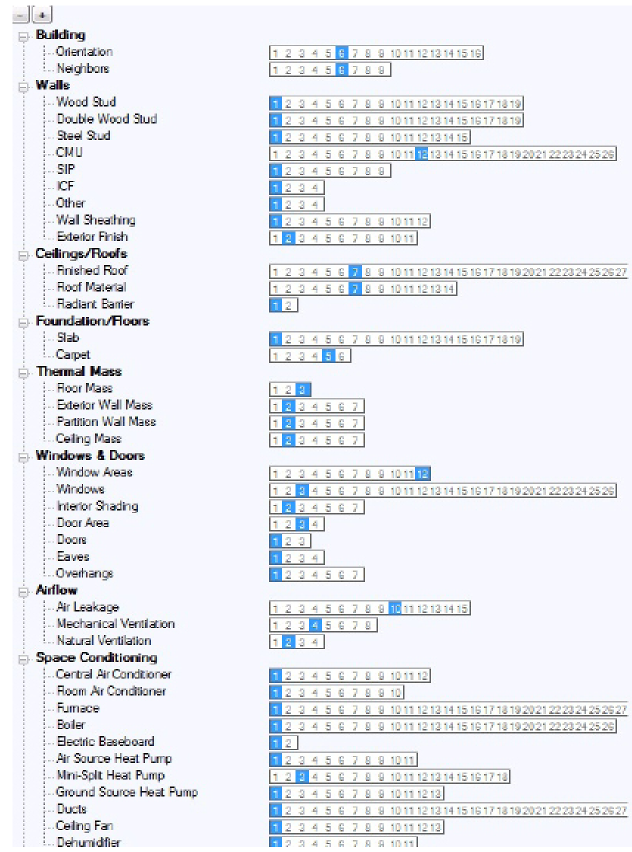

Fig. 4: Screenshot of the site design in BEopt.

The home's actual electricity monthly bills are shown below in table 1, which shows that the total annual consumption used was 23114 kWh.

Table.1: The collected Electricity bill(s) of 12 months.

Reading Date	Days in Billing Period	Read/Estimated	Total kWhs Used	Average kWhs Used Per Day	Total kWhs Billed	Actual Charge	HST	Residential Energy Rebate	Total Charge
9/14/2015	21	Estimated	29	52	1096	125.34	16.29	0	141.63
8/24/2015	32	Estimated	740	23	740	92.53	12.03	0	104.56
7/23/2015	28	Estimated	652	23	652	84.06	10.93	0	94.99
6/25/2015	31	Read	1113	36	1113	137.99	17.94	11.04	144.89
5/25/2015	32	Read	1774	55	1774	210.77	27.4	16.86	221.31
4/23/2015	31	Read	2901	94	2901	334.85	43.53	26.79	351.59
3/23/2015	28	Estimated	2737	98	2737	316.8	41.18	25.34	332.64
2/23/2015	32	Read	3111	97	3111	357.98	46.54	28.64	375.88
1/22/2015	31	Estimated	3032	98	3032	349.28	45.41	27.94	366.75
12/22/2014	27	Read	1960	73	1960	231.25	30.06	18.5	242.81
11/25/2014	32	Read	1894	59	1894	223.98	29.12	17.92	235.18
10/24/2014	31	Read	1413	46	1413	171.03	22.23	13.68	179.58
9/23/2014	32	Estimated	691	22	691	91.53	11.9	7.32	96.11
		total	23114					total	2887.92

III- SIMULATIONS AND RESULTS

BEopt gives a yearly kW energy estimate for the 365 days needed, for the design with or without a PV solution. It can be obtained as shown below.

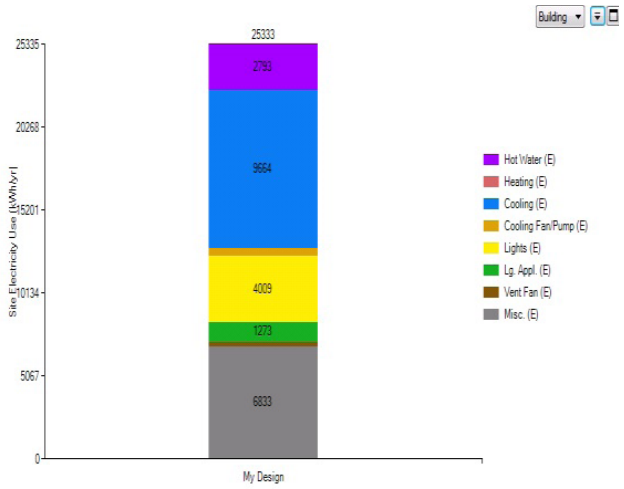

Fig. 5: Yearly energy consumption for the site without PV.

It is clear that the most of the consumption goes to cooling as shown in figure 5 which is estimated around 9700 kWh/year, due to daily needs. Table 2, shows the quantity and power rating of the air conditioning units and their specifications. This proved the literature about the huge consumption of the electricity due to air conditioning[8].

The second largest consumption share was from miscellaneous load; electrical devices, kitchen electronics and plug-in devices. It is estimated around 6833 kWh/year. The reason why heating shows almost zero-consumption is that most residents of Saudi Arabia prefer wood or propane over power resources.Reasons that made the hot water consumption around 2793 kWh/year are the use of hot tube and washing machines. The ventilation section had a minor consumption share of around 500 kWh/year due to the availability of natural ventilation.

Table 2: Air conditioning parameters used in the house[10]

Amount	Type	Power rating ((kWh))	Cooling capacity (BTU/h)
5	Split Unit	5.27	18,000
3	Split unit	8.00	24,000

B. PV system sizing by Homer

Upon entering all the above data into the Homer software[6], the program will provide an optimal electrical solution. Note, the changing load indicated is a result of using heaters and air conditioners in the house[4]. Site solar energy resource is shown in Figure 7. The load data provided by BEopt are used in Homer. The single line diagram of the system which contains load, converter, PV and batteries is shown in figure.

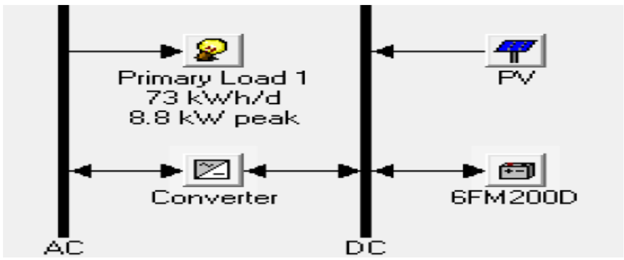

Fig. 6: System single line diagram.

Below is the sun's radiant curve for the selected location. The solar data were used to calculate the electricity production for the house.

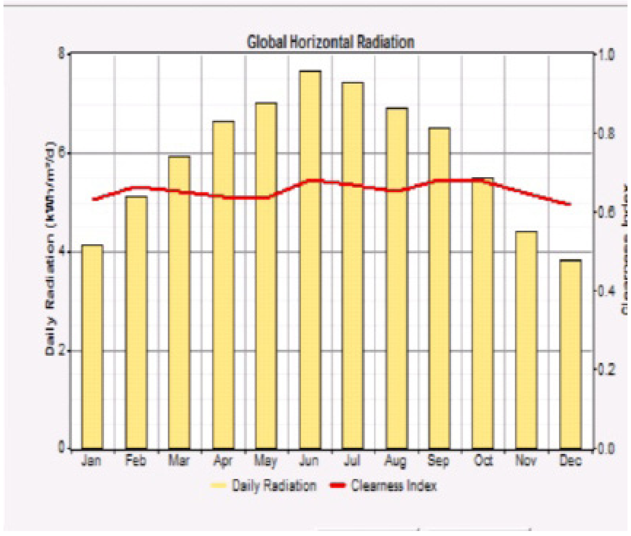

Fig. 7: Solar resource data using the correct site coordinates.

The actual load profile was included in the design, due to meet the demand requirements by the PV system. Figure 8 shows the load profile in Homer.

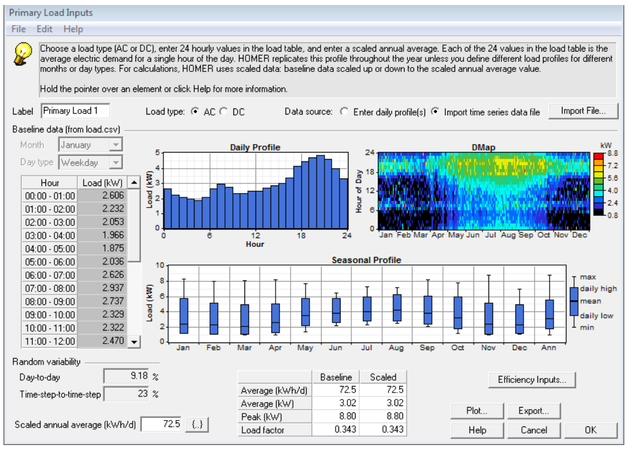

Fig. 8: Monthly average energy consumption for the site.

The cost curve of the converter is shown in figure 9, which include (includes) the capital, replacement, operation and maintenance costs.

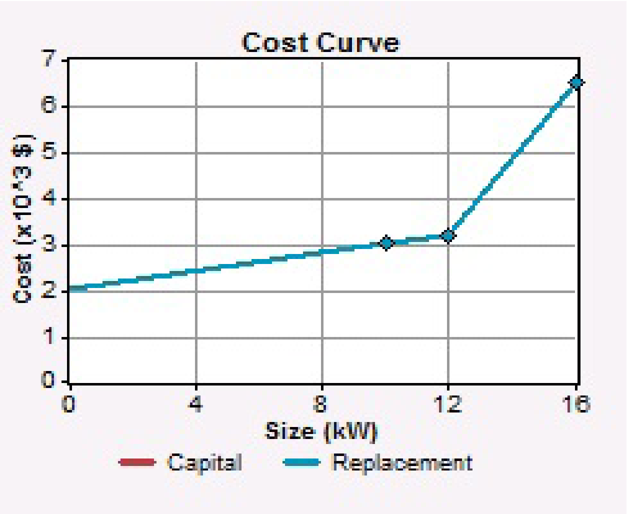

Fig. 9: Cost curve of the converter.

The selected life time for the batteries was 4 years. Homer software can estimate the cost curve of the batteries as shown in figure 10.

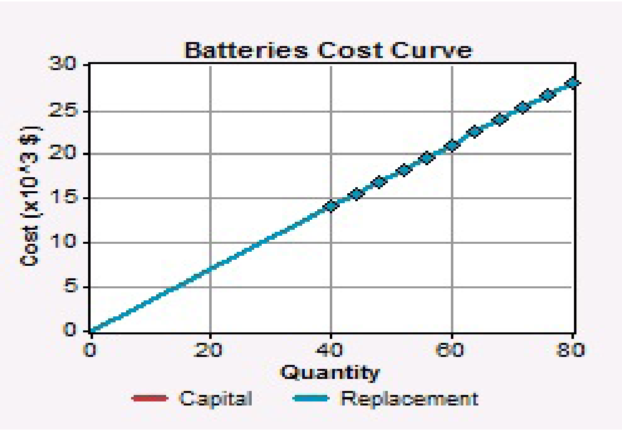

Fig. 10: Cost curve of the batteries.

The possible scenarios and feasible systems for this model are shown in figure 11.

	PV (kW)	6FM200D	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
	18.85	52	10	CC	$ 39,760	8,901	$ 194,747	0.441	1.00	0.05
	18.85	52	10	LF	$ 39,760	8,901	$ 194,747	0.441	1.00	0.05
	18.85	52	12	CC	$ 39,960	8,908	$ 195,078	0.442	1.00	0.05
	18.85	52	12	LF	$ 39,960	8,908	$ 195,078	0.442	1.00	0.05
	20.15	48	10	CC	$ 39,640	8,932	$ 195,173	0.440	1.00	0.05
	20.15	48	10	LF	$ 39,640	8,932	$ 195,173	0.440	1.00	0.05
	20.15	48	12	CC	$ 39,840	8,939	$ 195,504	0.441	1.00	0.05
	20.15	48	12	LF	$ 39,840	8,939	$ 195,504	0.441	1.00	0.05
	22.75	44	10	CC	$ 40,800	8,961	$ 196,837	0.443	1.00	0.05
	22.75	44	10	LF	$ 40,800	8,961	$ 196,837	0.443	1.00	0.05

Fig. 11: The system simulation and optimization results in Homer.

The sensitivity variables for the system, show the optimal combination to be as follows: 18.85 kW PV, 52 battery unit and 10 kW converter as shown in Figure 12. The evelized cost of electricity (LCOE) of PV energy by Homer was 44 US cents/kWh, compared to the real (LCOE) of electricity generation from the grid system between 1.3 – 6.93 US cents/kWh[11]. However, the long financial matters (aspects) of renewables in Saudi Arabia stay positive, given that the sun- powered PV system is almost free of charge for the next (10-15) years, unlike the grid cost which is more prone to increase in the nearest future[11].

Sensitivity Results | Optimization Results

Double click on a system below for simulation results.

	PV (kW)	6FM200D	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
	18.85	52	10	CC	$ 39,760	8,901	$ 194,747	0.441	1.00	0.05

Fig. 12: The system simulation and optimization results.

By examining the cash flow results, we see that homeowners can expect a huge monthly bill reduction by 100%, as shown in Figure 12. Note, the renewable fraction is one, indicating that the size of the monthly energy bill reduction equals 100%. Many homeowners are considering the value of installing a PV system, and the return of investment (ROI) should be in the green range. By evaluating Homer results and making a few simple calculations, the ROI estimated was between 15 to 18 years.

Homeowners are sensitive to the upfront investment costs of installing a PV system. These results should be an encouragement for those considering such an investment. It is important to consider that one of the primary determinants of the energy production output is ensuring an optimal design of an installation for maximum solar irradiance. Otherwise, the benefits may be undermined[4]. Electricity power costs in Saudi Arabia have been settled in fixed terms. The power tariff for a house started at (1.33 US cents) per kWh for the initial 2 megawatt hour (Mwh) a month and logically expanded to 6.93 US cents per kWh for each unit that utilized more than 10 MWh a month[12].

C. System sizing by BEopt Software with PV

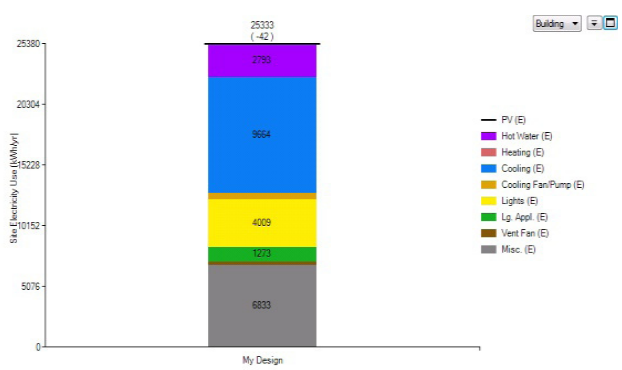

Fig. 13: The system energy consumption and PV production.

A PV system size determined by Homer is also used in BEopt. The simulation results of BEopt show that the PV system of 19 kW can supply the entire load. The reason is because most of the demand is cooling which is required in the summer season, when the sunlight or solar energy are conveniently in abundance. Although the PV panels are fixed and tilted to the same altitude angle which is 26 south, the system is still sufficient and meets the demand as shown in figure 13.

IV- ACKNOWLEDGMENT

We might want to earnestly thank the Saudi Arabia government for their financing support, without which, we would not have accomplished this research.

V- CONCLUSION AND DISCUSSION

PV systems are widely recognized and used throughout the world, but unfortunately, Saudi Arabia has not yet effectively embraced the use of such systems. As we know the energy consumption for each home is high, thus there is substantial benefit that could be realized[13]. Given the typical design and construction of Saudi homes, and with the aid of Homer and BEopt softwares, we can conclude that installing a 19 kW PV system would be a beneficial as an alternative electricity source by reducing the grid consumption every month to zero. The PV system was sized by Homer and BEopt, and the ROI results indicated about (12-15) years for cost recuperation, which is fairly good, relative to a life expectancy of 25 years. The effectiveness and efficiency of a PV system can be enhanced by reducing wiring system losses and using a micro inverter, improving reliability for homeowners[13].

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