© Universiti Tun Hussein Onn Malaysia Publisher's Office

JQSR

http://publisher.uthm.edu.my/ojs/index.php/jqsr
e-ISSN : 2773-5532

Journal of Quranic Sciences and Research

Computational Method for Sizing and Cost Analysis of Grid-Connected Photovoltaic System

Nurul Izzati Ahmad[1], Ahmad Fateh Mohamad Nor[1*]

[1]Green and Sustainable Energy Focus Group, Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/jqsr.2022.03.01.001
Received 29 September 2021; Accepted 8 December 2021; Available online 30 June 2022

Abstract: This study is focuses on the computational method used for a sizing and cost analysis of grid-connected photovoltaic system. These calculations include total load consumption, photovoltaic sizing, total energy production, tariff calculation, costing and return on investment. This calculation is important to ensure that the equipment used does not produce excessive energy which is related to cost and Return on Investment (ROI). This study will cover the computational method in house at Taman Impian, Parit Raja, Batu Pahat, Johor.

Keyword: Photovoltaic system, grid-connected, ROI

1. Introduction

In Surah Fussilat, 41:37, it is stated the sun was made by Allah S.W.T. so that people can know and see His power. The sun or know as solar energy made by Allah S.W.T. is energy that does not produce pollution and is known to be inexhaustible compared to other energy sources. The solar energy emitted on the earth's surface every minute already exceeds the energy needed on earth in a year. Therefore, the solar energy provided must be utilized as much as possible as an energy source to ensure the development of the country in the future is not affected by the problem of population growth and continuous development because the dependence on fossil energy resources today actually exposes the country's development to great risks such as greenhouse gas emissions.

Renewable energy is the way to generate energy from unlimited natural sources such as air, wind and water. These resources are available without a short time and time to renew the energy. Based on the above surah, clearly explains that solar energy is given to be utilized as best as possible as an energy source that will not cause pollution such as greenhouse gas emissions (Jasmi and Samseh, 2013). But, until now, power is generated by a traditional process that uses fossil fuels and heat, which can pollute the atmosphere by emitting carbon dioxide (CO2) (Samsudin, Rahman, and Wahid, 2016). As fossil fuels are burnt, carbon dioxide and other greenhouse gases are emitted, trapping heat in the atmosphere and rendering fossil fuels the main cause of global warming and climate change (Abdallah and El-Shennawy, 2013; *Sagar et al.*, 2019). Non-renewable energy would be depleted sooner or later (Azman *et al.*, 2011). There are many solutions to overcome this problem. One of them is by using a Photovoltaic system (PV).

Photovoltaic (PV) is the most important source of clean, renewable energy, with the biggest potential for solving the world's energy problems (Kumar, 2020). PV generates electricity from sunlight and converts it to electrical energy due to its low cost and high efficiency. In addition, the weather in Malaysia is suitable for the use of PV system because there is more sunlight than rain. There are two options for photovoltaic system which is by using stand-alone PV system or combination of PV system with the grid known as grid-connected PV system (NEM, 2021).

**Corresponding author: afateh@uthm.edu.my*

Malaysian government has been always supporting the installation of grid-connected PV system by introducing the Net Energy Metering (NEM) back in 1st January 2019 (NEM, 2021). Starting 2021, the NEM has been improved from the existing net billing to true net energy metering (Solar System Malaysia, 2021). This is to help for the return of investment of solar PV under NEM. PV panels, batteries, inverters, and load are all things to consider when sizing. By sizing the design of the PV system, it may help to set up configuration easily. To prevent misuse, it must be measured in great detail.

2. Methodology

This section will explain each step that will be used to calculate the load consumption until Return on Investment (ROI) for the overall PV system. All the information related to the sizing of a grid connected PV system really needs to be understood to ensure there is no mistake during the installation of PV system.

2.1. Load Consumption Calculation

The first step to do is calculate the total load consumption for a single-storey terrace house in Taman Impian, Parit Raja, Batu Pahat, Johor. This step is important to know how much energy is used in a month and how many monthly electricity bills have to be paid to Tenaga Nasional Berhad (TNB). Then, these prices will be compared before and after the installation of a grid-connected PV system. The electrical load is different for each house depend to the consumer's load. The more electrical load used in the house, the higher total energy consumption. Equation 1 can be used to calculate the total energy consumption. Next, the monthly energy consumption can be calculated using Equation 2 (Dunlop, 2021).

$$\sum \text{EAC} = \sum E(Q \times PR \times t) \tag{1}$$

where,

E = Total Energy Consumption (Wh/day)

Q = Quantity of the Electrical Load

PR = Power Rating of the Electrical Load (Watt)

t = Operating Time of Electrical Load (hour/day)

$$\text{Mec} = \sum \text{EAC} \times 30 \text{ days} \tag{2}$$

where,

Mec = Monthly Energy Consumption (kWh)

∑EAC = Total Energy Consumption (Wh/day)

2.2. Photovoltaic Sizing

Before proceeding to use Grid-Connected PV, the important thing that should be considered is size of the house and the rooftop area to determine how many panels can be installed on the rooftop area. In this study, the load consumption that has been calculated is below 1kWh. to use 1kWp of the PV. The space required for every 1kWp is 6.0m2 The PV panel used in this project is 300-watt poly-crystalline solar module and it is approximate to 2m2. So, only 4 solar panel will be used for 1kWp of PV which is 4 x 2 meter is equal to 8m^2. Space is one of the factors that can affect the costing of the grid-connected PV system installation. The less rooftop space for solar panel can limit the size of the rooftop solar array and the smaller array will less the cost of installation. There are 4 steps to calculate the average daily energy production. The equation can be referred in Equation 3 to Equation 9 (Dunlop, 2021).

Step 1

$$P_{arr-g} = P_{mp} \times P_g \times nm \tag{3}$$

where,

P_{arr-g} = Minimum Guaranteed Power Output of the Array

P_{mp} = Maximum DC Power Rating

P_g = Manufacturer Power Guaranteed

nm = Number of Module in Array

Step 2

$$PV_{con} = P_{arr-g} \times \left[(\text{Avetemp} - STC) \times C_{temp}\right] \tag{4}$$

$$P_{arr-T} = P_{arr-g} - PV_{con} \tag{5}$$

where,

PV_{con} = PV Consideration

P_{arr-T} = Temperature-Corrected Array Power Output

Avetemp = Array Average Operating Temperature

STC = Standard Test Conditions
C_{temp} = Temperature Coefficient for Power

Step 3

$$P_{arr-net} = P_{arr-t} - [P_{arr-t}] \times \text{wiring losses} \tag{6}$$

where,
$P_{arr-net}$ = Net Array Power Output
P_{arr-t} = Temperature-Corrected Array Power Output
wiring losses = 3% or 0.03

Step 4

$$\text{Inv. PoutAC} = P_{arr-t} \times \text{Inveff} \times \text{InvMPPT} \tag{7}$$

where,
Inv. PoutAC = Inverter Maximum AC Power Output
Inveff = Inverter Power Conversion Efficiency
InvMPPT = Inverter MPPT Efficiency

Average Daily Energy Production

$$\text{Poutave} = \text{Inv. PoutAC} \times \text{Aveinsolation} \tag{8}$$

where,
Poutave = Average Daily Energy Production
Inv. PoutAC = Inverter Maximum AC Power Output
Aveinsolation = Average Daily Insolation (PSH)

Monthly Energy Production

$$MEP = \text{Poutave} \times 30 \text{ days} \tag{9}$$

where,
MEP = Monthly Energy Production
Poutave = Average Daily Energy Production

2.3. Selective PV Panel Data

The PV panel selected in this project is a 300 W poly-crystalline solar module. The power tolerance to +3% to ensure the high reliability of power output. The electrical characteristic of the 300 W - 320 W Poly-crystalline Solar Module is shown in Figure 1.

Electrical Characteristics

SOLAR CELLS	POLY-CRYSTALLINE 156 × 156 MM 72 PCS. (6×12) – 4 BUS BARS				
Maximum Power (Pmax)	300 Wp	305 Wp	310 Wp	315 Wp	320 Wp
Voltage at Pmax (Vmp)	37.23 V	37.24 V	37.32 V	37.46 V	37.62 V
Current at Pmax (Imp)	8.06 A	8.19 A	8.31 A	8.41 A	8.51 A
Open-Circuit Voltage (Voc)	44.71 V	44.72 V	44.76 V	44.82 V	44.84 V
Short-Circuit Current (Isc)	8.947 A	9.094 A	9.234 A	9.371 A	9.515 A
Maximum System Voltage (V DC)	1000 V (Iec), 600 V (UL)				
Cell Efficiency	17.46 %	17.75 %	18.05 %	18.34 %	18.63 %
Module Efficiency	15.46 %	15.72 %	15.98 %	16.23 %	16.49 %
Number of By-pass Diodes	6				
Maximum Series Fuse	15 A				
Temperature Coefficient of Pmax	-0.45 % / °C				
Temperature Coefficient of Voc	-0.34 % / °C				
Temperature Coefficient of Isc	-0.05 % / °C				
Nominal Operating Cell Temperature	47 ± 2 °C				

Fig. 1 - Specification of 300 Watt PV panel

2.4. Tarif Calculation

To calculate the monthly energy production, the value of average daily energy production will multiple by 30 days. Once kWh is produced, the next step is to multiply with the rates given by Tenaga Nasional Berhad. To ensure that the calculation is accurate, the calculation will be compared with NEM calculator provided by SEDA (NEM, 2021).

2.5. Costing

The next calculation is about the costing of the overall system including PV panel price, inverter, installation and maintenance price. As a user, cost is an important part because the requirements of the PV system are dependent on the user's budget. The calculation can be obtained by using Equation 10 to Equation 15 (Dunlop, 2021).

PV Panel Price

$$\text{Total PV Panel Price} = \text{Cost Per Panel} \times \text{Total Needed Panel} \tag{10}$$

Inverter Price

$$\text{Total Inverter Price} = \text{Inv. PoutDC} \tag{11}$$

where,
Inv. PoutDC = Inverter Maximum DC Power

Installation Price

$$\text{Total Labor Price} = \text{Labor Rate} \tag{12}$$

$$\text{Total Wiring Price} = \frac{\%}{100} \times (\text{PV Panel} + \text{Inverter} + \text{Labor})\ \text{Price} \tag{13}$$

*Note that the percentage is set by 30% from the total price of panel, inverter and labor in this project.

Maintenance Price

$$\text{Total Maintenance Price} = \text{Annual Cleaning} + \text{Annual Inspection} \tag{14}$$

Total Costing Price

$$\text{Total} = \sum (\text{PV Panel} + \text{Inverter} + \text{Labor} + \text{Installation} + \text{Maintenance})\ \text{Price} \tag{15}$$

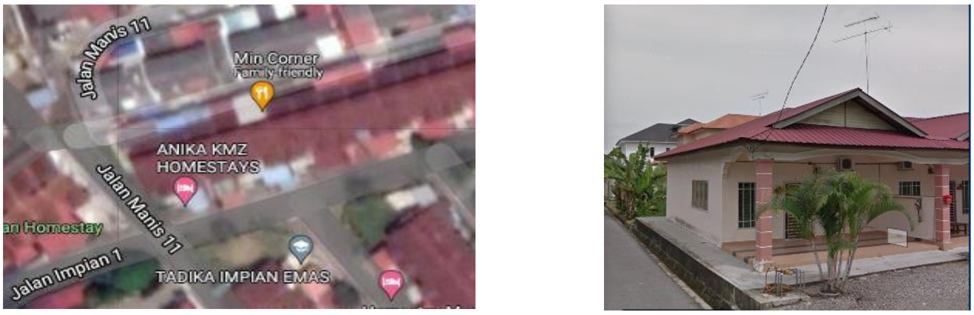
2.6. Return on Investment (ROI)

The Return on Investment (ROI) refers to the effective returns generated by investment during the life of the solar system (Itsmy, 2021). The greater the monthly savings on electricity costs from solar, the faster original investment will be returned and the higher ROI. Usually, the residential consumer should expect the payback in 5 to 7 years. Solar panel cost is one of the factors that need to be considered in return on investment of solar panels. Solar system consists of a PV panel, inverter and other equipment. The lower the cost of the solar system, the shorter the payback period. Equation 16 shows the formula that can be used to calculate total payback period (Dunlop, 2021). Peak-Sun Hours are also an important factor in determining return of investment. ROI will be shorter when the sun hour is better. This is because the production of solar energy is higher (Alhaddad and Alsaad, 2016).

$$\text{Total Payback Period (Year)} = \frac{\text{Total Costing Price (RM)}}{\text{Total Monthly Saving (RM)/ 12 months}} \tag{16}$$

2.7. Location of Observation

This project is focusing on the single-storey terrace house at Taman Impian, Parit Raja, Batu Pahat, Johor. After making a few observations, this house is suitable because it has a strong roof without leaks or damage and has a spacious roof or ground yard to accommodate all the solar equipment. Figure 2 shows the location of the house.



(a) (b)

Fig. 2 - Location of the single-storey house

3. Results and Discussion

3.1. Load Analysis

This section shows the computational method for the total energy consumption at a single-storey terrace house in Taman Impian, Parit Raja, Batu Pahat, Johor. The electrical load used in this house is shows in Table 1. The total energy consumption in day and month can be calculated by using Equation 1 and Equation 2 (Dunlop, 2021). This calculation will be used to calculate the monthly electricity bill. Based on calculations for load consumption, the total energy consumption for a month is 885.42 kWh. This amount of energy is dependent on the amount of load present in the consumer's house. In addition, the factor that affects the amount of power used is operating time. The more operating time, the more total energy consumption. Table 1 shows the total energy consumption in day and month after the load consumption has been calculated.

Table 1 - The estimated load consumption

No.	Electrical Load	Quantity (Q)	Power Rating (Watt)	Total Connected Load (Watt)	Operating Time (Hour/Day)	Energy Consumption (E, Watthour/ Day)
1	Ceiling Fan	3	75	225	11	2475
2	Compact Fluorescent Light	13	18	234	8	1872
3	Air-Conditioner (1 Hp)	2	746	1492	5	7460
4	Television (32 Inch)	1	60	60	4	240
5	Printer	1	30	30	0.5	15
6	Water Heater	1	3600	3600	0.5	1800
7	Electric Kettle	1	1800	1800	0.3	540
8	Refrigerator	1	200	200	24	4800
9	Rice Cooker	1	400	400	0.5	200
10	Washing Machine	1	500	500	1	500
11	Mobile Charger	4	7	28	1	28
12	Laptop Charge	4	73	292	2	584

3.2. Photovoltaic Sizing

On this study, the PV Panel Rated DC Power Output used is 300 Watt. This calculation can be calculated after the PV panel selection is done. The calculation for this section can be referenced on Equation 3 until Equation 9 (Dunlop, 2021). The average energy production is from the PV system at single-storey terrace house which is 3,318.80 Wh/days. Then, after the calculation has been done, the monthly energy production will be export to the grid and the amount of bill supposed to be deducted by the TNB.

The formula for monthly energy produce (MEP) is average daily production multiply by 30 days. Therefore, the current monthly bill will be reduced. The result of data of the calculation for sizing a grid-connected PV system shows in Table 2.

Table 2 - Grid-Connected PV (GCP)

Description	Step	Consumption
PV Panel Rated DC Power Output	1	300W
Manufacturer Power Guarantee		0.90
Number of Panel in Array		4
Array Guarantee Power Output		**1080 Watt**
Array Avg. Operating Temperature	2	55°
Temperature Coefficient for Power		0.0040
Standard Test Condition Temperature		25°
Temperature-Corrected Array Power Output		**950.40 Watt**
Array Wiring and Mismatch Losses	3	0.03
Net Array Power Output		**921.89 Watt**

Table 2 - Grid-Connected PV (GCP) (con't)

Inverter Maximum Dc Power Rating	4	1200 Watt
Inverter Power Conversion Efficiency		0.90
Inverter MPPT Efficiency		1.00
Inverter Maximum AC Power Output		**829.70 Watt**
Average Daily Insolation (PSH)		**4**
Average Daily Energy Production		**3318.80 Wh/days**

3.3. Tarif Calculation

3.3.1 Total Import Charge

After the calculation for the total energy production, the tariff calculation can be calculated by using tariff rate from TNB. Tariff calculation is used to total the monthly electricity bill. Total import charge means the amount of energy produced by TNB and used by consumers in each residence for a month. So, this monthly electricity bill has to be paid to Tenaga Nasional Berhad (TNB). Table 3 shows the calculation for the tariff in Ringgit Malaysia (RM).

Table 3 - Total import charge

Block kWh	Usage kWh	Rate (RM/kWh)	Amount (RM)
1 - 200	200	0.218	43.60
201 - 300	100	0.334	33.40
301 - 600	300	0.516	154.80
601 - 900	15	0.546	8.19
901 onwards	0	0.571	0.00
Total (import)	**615.42**		**239.99**

3.3.2 Total Export Charge

The total export charge is the amount of bill that is supposed to be deducted by the TNB when installing the PV system. The selection of the photovoltaic sizing will affect the amount of energy exported to the grid. The amount of energy exported will result in a reduction in the cost of the consumer's monthly bill. The computational method can be calculated by multiplying the total export charge with the rate 0.546. The Table 4 shows the total export charges.

Table 4 - Total export charge

Block kWh	Usage kWh	Rate (RM/kWh)	Amount (RM)
1 - 200	0	0.218	0.00
201 - 300	0	0.334	0.00
301 - 600	0	0.516	0.00
601 - 900	99.56	0.546	54.36
901 onwards	0	0.571	0.00
Total (import)	**99.56**		**54.36**

3.3.3 Amount of Bill

Table 5 shows the total amount of bill which is before and after installation of the PV. The actual bill is RM239.99 and the exported to the grid supposed to be deducted is RM54.36. Then, the monthly bill after the installation of 1kWp PV to the house is RM185.63.

Table 5 - Amount of bill

Actual Bill (RM)	239.99
Total Bill After Install PV (RM)	185.63
Total Monthly Saving (RM)	54.36

3.4. Costing

There are 4 types of costing that need to be considered when installing the PV which is PV panel, inverter, installation and maintenance. The equation that can be used to calculate the costing is Equation 10 until 15 (Dunlop, 2021). This calculation is needed to calculate the return on investment for the Grid-Connected PV system. Table 6 shows the result of costing.

Table 6 - Results of costing

No.	Types of cost	Costing Results (RM)
1	PV Panel Price	2,200.00
2	Inverter Price	500.00
3	Installation Price	3410.00
4	Maintenance Price	350.00
5	Total Overall Costing	6,460.00

3.5. Return on Investment

The last part for the computational sizing method for this project is to calculate the return on investment. Return on investment is the amount of time it will take to earn back the money that has been spent on a photovoltaic system. The calculation on this part can be calculated by using the data from the previous part in table 6 which is costing. Table 7 is the result for the computational method. It is important to do the correct sizing because the total payback period depends on total monthly saving and total cost of the PV installation.

Table 7 - Results of Return on Investment (ROI)

No.	Types of cost	Costing Results (RM)
1	Actual Monthly Bill	387.41
2	Total Bill After Install PV	333.05
3	Total Monthly Saving	54.36
4	Cost Estimation of PV System	6,460.00
5	Total Payback Period	9.9 years

4. Conclusion

Based on the Surah Fussilat, 41:37 that has been stated, it can be concluded that the sun was created to provide benefits to humans such as generating electricity. The collection of data for the whole project and sizing a grid-connected PV has been presented in this report shows that the electricity is generated from sunlight through a certain process in order to provide cost savings to users.. This project includes load analysis, PV sizing, tariff bill, costing for installing grid connected PV system and return of investment (ROI) for single-storey terrace house in Taman Impian, Parit Raja, Batu Pahat, Johor. The overall computational method shows that sizing a grid connected photovoltaic system is important because it is related to the cost and return of investment. This sizing method will help the consumer to get a lower price with the better system at the house.

Acknowledgement

The authors take this opportunity to express their thanks to the Green and Sustainable Energy (GSEnergy) Focus Group, Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia (UTHM) for providing a suitable research field.

References

Abdallah. L., El-Shennawy, T. (2013). Reducing Carbon Dioxide Emissions from Electricity Sector Using Smart Electric Grid Applications. Journal of Engineering, Vol. 2013, doi: 10.1155/2013/845051.

Alhaddad, Y., Alsaad, A. (2016). Grid-Connected Photovoltaic Power Systems: Domestic Simulation and Design in Kuwait (Case study ofThe Public Authority Applied for Education and Training), International Journal of Engineering and Science, vol. 5, no. 2319–1805, pp. 38–55, 2016.

Azman, A. Y., Rahman, A. A., Bakar, N. A., Hanaffi, F., Khamis, A. (2011). Study of renewable energy potential in Malaysia. In Proceedings of the 2011 IEEE 1st Conference on Clean Energy and Technology, CET 2011, 2011, pp. 170–176, doi: 10.1109/CET.2011.6041458.

Dunlop, J. P. (2011). Photovoltaic Systems: In partnership with NJATC: 9780826913081: Amazon.com: Books.

Itsmy. (2021). What is the return on investment (ROI) and payback period of solar PV?" https://www.itsmysun.com/faqs/what-is-the-return-on-investment-roi-and-payback-period-of-solar-pv/ (accessed Jun. 08, 2021).

Jasmi, K. A., Samseh, S. H. (2013). Al-Quran dan Tenaga Suria. Bootani, Zoologi dan Tenaga dari Perspektif al-Quran, pp. 33–47.

Kumar, M. (2020). Social, Economic, and Environmental Impacts of Renewable Energy Resources. In: Wind Solar Hybrid Renewable Energy System, IntechOpen, 2020.

NEM. (2021) Sustainable Energy Authority Malaysia, "NEM 3.0 – Renewable Energy Malaysia." http://www.seda.gov.my/reportal/nem/ (accessed Jun. 13, 2021).

Sagar, N., Tiwari, A., Kumar, S., Kumar, L., Belwal, M., Kumar, S. (2019). Identifying and using Viable Alternative Energy Resources (WIND Energy). In Proceedings of the 2019 Women Institute of Technology Conference on Electrical and Computer Engineering, WITCON ECE 2019, Nov. 2019, pp. 40–44, doi: 10.1109/WITCONECE48374.2019.9092940.

Samsudin, M. S. N., Rahman, M. M., Wahid, M. A. (2016). Akademia Baru Power Generation Sources in Malaysia: Status and Prospects for Sustainable Development.

Solar System Malaysia. (2021). Understanding Your Net Energy Metering Bill | Solar System Malaysia. https://www.solarsystemmalaysia.com/nem/understanding-your-net-energy-metering-bill/ (accessed Jun. 10, 2021).