7International Journal of Engineering & Technology, 7 (4.22) (2018) 67-71

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Techno-economic Analysis on Grid-Connected Photovoltaic System (GCPV) in Mersing, Johor, Malaysia using Homer Simulation

Mohd Sufian bin Ramli[1,*], Siti Sufiah bte Abd Wahid[1], Noor Amalina binti Zakaria[2], Nur Najihah binti Abu Bakar[3], Khairul Kamarudin bin Hasan[1], Shakira Azeehan binti Azli[1]

[1] Universiti Teknologi MARA UiTM Cawangan Johor Kampus Pasir Gudang, 81750 Pasir Gudang, Malaysıa
[2] Universiti Teknologi Malaysia UTM, 81310 Skudai, Malaysıa
[3] Universiti Malaysia PerlisUNIMAP , Kampus Puah Putra, 02600 Arau, Malaysia
*** *Correspondence: sufian6037@johor.uitm.edu.my*

Abstract

Power generation relies heavily on fossil fuels such as coal, crude oil and natural gas to produce electricity. Fossil fuels are non-renewable which will eventually dwindle becoming too expensive. Therefore world nowadays are going towards sustainable renewable energy that are constantly replenished and will never run out. Malaysia also has introduced Feed-In Tariff (FiT) in order to promote and encourage consumer to shift towards renewable energy. Among all renewable energies available in Malaysia, solar photovoltaic (PV) is seen to be the most promising renewable energy in Malaysia. This paper presents the techno-economic analysis of a grid-connected photovoltaic (GCPV) system installation for a house in Mersing, Johor, Malaysia. Techno-economic feasibility study is done using HOMER software. Design specifications of PV panels and inverters which include the size, type, cost and rating are selected based on the load profile and solar radiation data at Mersing. The result from GCPV system designed is the electricity export and import data obtained which then be analyzed to examine the feasibility of the system installed. FiT rates have been taken into account in the analysis. At the end of this paper, suitability of utilizing GCPV system in a house at Mersing, Johor, Malaysia has been discussed whereby the configuration with PV rating of 5kW and 5kW converter gives the optimum result with total NPC and COE of $2587 and $0.030/kWh respectively. In terms of economic analysis, with simulated payback period of 14 years, the total revenue of the optimum configuration exceeds initial capital cost with an amount of $1083 per year. Technically, 56% of electricity is generated from the PV array which equals to 6595kWh/yr. At FiT rate of RM0.7775/kWh, 33% of electricity production is sold to the grid with a total payment of RM238.24⁄month.

Keywords: *solar; GCPV; FiT; renewable energy*

1. Introduction

Fossil fuels are non-renewable where the resources will eventually exhaust. Since most of traditional electricity generation relies on fossil fuels as source of energy, continuous increase in global fossil fuels price has drawn serious attention to reduce the dependence on fossil fuels source towards renewable energy to generate electricity. Besides, global warming due to excessive greenhouse gas (GHG) emission that is contributed by traditional electricity generation using fossil fuels has also been a concerning issue. In contrast, renewable energy resources are constantly replenished and clean. Malaysian government is committed in reducing greenhouse gas (GHG) emission by 40% in 2030 compared to 2005 level [1]. Therefore, the government has launched various programs to promote renewable energies.

There are several renewable energies sources available in Malaysia such as biomass, biogas, mini-hydro and solar. Among other renewable energies available, solar photovoltaic (PV) are the most assuring renewable energy source in Malaysia due to abundant of solar radiation in Malaysia [2]. The outlook is expected to exceed all other renewable energies in Malaysia by 2050. A PV system can be stand-alone, hybrid with another system or connected to the grid. In this paper, PV system is connected to the grid due to availability of grid connection in Mersing, Johor, Malaysia. A grid connected system comprises of PV modules and inverter . Inverter functions to convert direct current (DC) electricity generated by PV array into alternating current (AC) electricity that is synchronized with utility electricity so that excess electricity generated can be exported into the grid. With agreement, the owner of GCPV system could import and export electricity from utility which means utility backs up the PV system like batteries do in stand-alone system. Therefore the cost of the system is reduced by eliminating the need of a battery bank.

In Malaysia, the first installations of GCPV systems were in 1998 when three systems with total capacity of 16.86 kWp were installed [1]. One of the GCPV system was installed in August 1998 on the rooftop of College of Engineering, Universiti Tenaga Nasional (UNITEN), Kajang, Selangor, Malaysia. The 3.15 kWp of GCPV installation was initiated by TNB Research Sdn. Bhd. (TNBR) as part of a pilot for "Demo Renewable Energy". The research was supported by Malaysia Electricity Supply Industry Trust Account (MESITA) and Tenaga Nasional Berhad (TNB). Under MESITA and TNB as co-funding, six other pilots GCPV systems were installed in between 1998 and 2001. Another two GCPV systems were installed by BP Malaysia and Universiti Kebangsaan Malaysia (UKM). A 7.95 kWp GCPV system has been installed at BP petrol station along KESAS highway and a 5.76 kWp PV at Solar Energy Research Group in UKM. In October 1999, a bungalow used as a PV research centre was built with 3.60 kWp of GCPV system in TNB research Centre, Kajang, Selangor. Other than that, a family of a TNB's senior officer became the first Malaysian family to experience BIPV system at their house in Port Dickson, Negeri Sembilan.

Previously, PV installation increase drastically in year 2001 when a one-off 361.9 kWp of total capacity has been installed by Technology Park Malaysia (TPM) at Enterprise Four Technology Park Malaysia, Bukit Jalil as shown in Figure 2 [2]. This installation demonstrated Malaysian capability to handle and manage large PV installations which is the biggest PV installation in South-East Asia Pacific region at that time. Figure 1 shows the installed capacity of commissioned solar installation (in MW) in Malaysia [3]. About 374.97 MW of installed PV capacity were installed from 2012 until 2018.

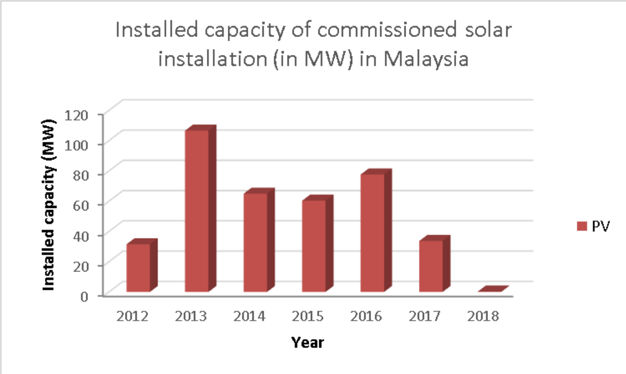


Fig. 1: Installed capacity of commissioned solar installation (in MW) in Malaysia

Fig 2: The largest of GCPV System with 361.9 kWp at Enterprise Four Building, Technology Park Malaysia (TPM), Malaysia (Source: TPM)

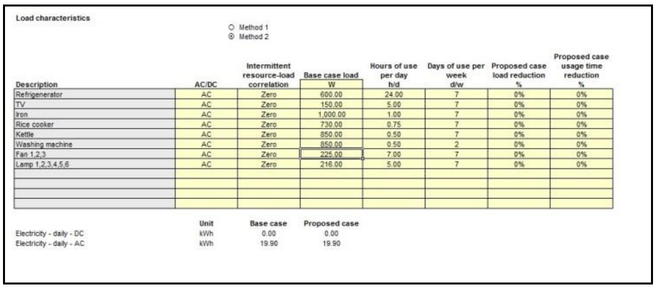
To encourage continuous growth, Malaysian government has introduced various solar energy programmes such as Suria 1000, Malaysia Building Integrated Photovoltaic (MBIPV) and Feed-In Tariff (FiT) mechanism [3]. In this paper, FiT was used in the system cost and return analysis. FiT is a policy mechanism designed to accelerate investment in renewable energies technologies [3]. By guaranteeing access to the grid and setting a favourable price per unit for renewable energy generated, FiT mechanism would ensure that renewable energy becomes inviting long term investment for companies and individuals. FiT rate differs for different renewable resources and installed capacity. Technology such as wind power is awarded a lower per-kWh price compared to technology such as solar PV is offered a higher price, reflecting cost that is higher at the moment.
In this paper, based on the load demand and the solar radiation in Mersing, Johor, the optimum configuration of GCPV in terms of size and cost is obtained from the Homer simulation. Consequently, the economic, technical followed by the FiT analysis is performed on the system.

2. Methodology

This section contains the details of the estimated load profile for the system as well as the solar radiation data at the selected site location.

2.1. Load Profile

In this project, the load consists of a typical medium house in an urban area. Electricity consumption per household is influenced by several factors such as living habits, family size as well as quantity and operating hours of electrical appliances [4]. By referring to the typical wattage and electrical equipments usage per house reported by TNB, an estimation of load profile for the load is done. Figure 3 summarizes the estimated quantity and operating hours of the selected electrical equipments which includes a refrigerator, TV, iron, rice cooker, kettle, washing machine, 3 fans and 6 lamps.



Load characteristics

○ Method 1
⊙ Method 2

Description	AC/DC	Intermittent resource-load correlation	Base case load W	Hours of use per day h/d	Days of use per week d/w	Proposed case load reduction %	Proposed case usage time reduction %
Refrigenerator	AC	Zero	600.00	24.00	7	0%	0%
TV	AC	Zero	150.00	5.00	7	0%	0%
Iron	AC	Zero	1,000.00	1.00	7	0%	0%
Rice cooker	AC	Zero	730.00	0.75	7	0%	0%
Kettle	AC	Zero	850.00	0.50	7	0%	0%
Washing machine	AC	Zero	850.00	0.50	2	0%	0%
Fan 1,2,3	AC	Zero	225.00	7.00	7	0%	0%
Lamp 1,2,3,4,5,6	AC	Zero	216.00	5.00	7	0%	0%

	Unit	Base case	Proposed case
Electricity - daily - DC	kWh	0.00	0.00
Electricity - daily - AC	kWh	19.90	19.90

Fig. 3: Estimated quantity and operating hours of the selected electrical equipments in RETScreen

In Figure 3, RETScreen software is used to calculate the daily electricity usage per house and the final load demand is calculated to be 20kWh/day. Following this step, the daily load profile is built by estimating the hourly electricity usage per day and consequently inserted in the primary load input in HOMER software. As the result, a daily load profile with load demand of 20.4kWh/day and peak load of 2.51kW is produced as presented in Figure 4.

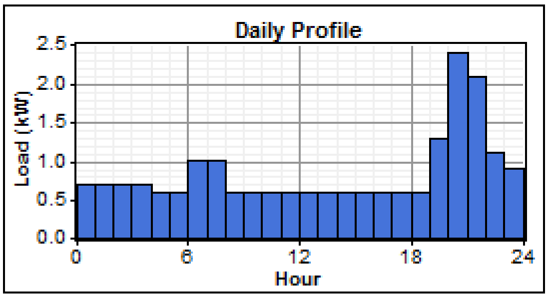


Fig. 4: Daily load profile for GCPV system

The load profile displays higher load demand from 7pm to 11pm whereby the people living in the house has come back from work and school and start to do the chores, cooking as well as watch the television. The lamps are also turned on during the night. Besides, it is observed that the demand is also high from 6am to 8am due to the preparation made before the school and work time starts.

2.2. Solar Radiation

Since the a GCPV system depends largely on the solar energy resource, the site for the system is chosen to be located at Mersing, Johor whereby the daily solar radiation is relatively high with an annual average value of 5.08 kWh/m^2/day [5].

Mersing is situated at coastal area at the south part of Malaysia with coordinates of 2º 26' N 103º 49' E [6]. By simply inserting the coordinates value in the solar resource window of HOMER, the monthly solar radiation of Mersing is imported from the NASA Surface Meteorology and Solar Energy website. By using this data, HOMER estimates the clearness index and the hourly solar radiation throughout the year as shown in Figure 5 that is later used to calculate the solar power output for a PV system [7].

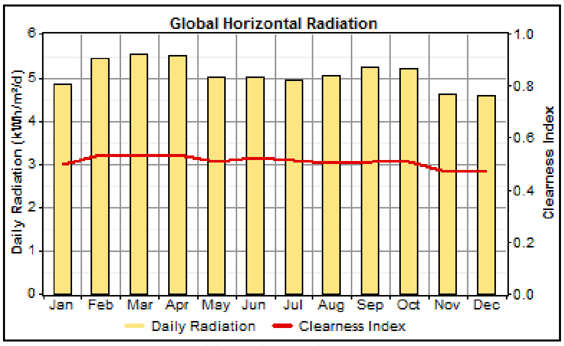


Fig. 5: Monthly Solar Radiation in Mersing

3. Sizing of Components and Cost Calculation

All paragraphs must be justified alignment. With justified alignment, both sides of the paragraph are straight.

3.1. Sizing of PV Array dan PV Module

First step to be taken is selecting the PV panels that must to meet the energy requirements and other constraints such as space area. In this project, mono crystalline type of modules is used because its offer higher efficiency thus it will reduce a number of modules used. Mitsubishi Electric Photovoltaic Modules was chosen in this project and its specifications as well as parameters' values used are listed in Table 1. Next step is to determine the PV modules size corresponding to the energy requirements. In this design, it was assumed that, the PV system will fulfil 100 percent of energy demand. The PV array power as well as number of modules can be calculated by using equation 1 and 2 respectively.

$$PV\ Array = \frac{E_L}{PSH_{period} x f_{temp-avg} x f_{dirt} x f_{mm} x \eta_{inv}} \quad (1)$$

$$N\ modules = \frac{PV\ array}{Max\ PV\ power\ rating} \quad (2)$$

Where,
PV Array = peak rating of the PV array (kWp)
E_L = load demand (kWh/annum)
PSH_{period} = Peak Solar Hour (kW/m^2/day)
$f_{temp-avg}$ = de-rating factor due to average daily maximum ambient temperature
f_{dirt} = derating factor for dirt
f_{mm} = derating factor for manufacturer's tolerance and mismatch
η_{inv} = efficiency of inverter

Table 1: Electrical specifications of Mitsubishi Electric Photovoltaic Modules and parameters' values used

Parameters	Value
Type of cell	Monocrystalline silicon
Maximum power rating	260 Watt
Maximum power voltage	31.4 V
Maximum power current	8.29 A
Module efficiency	15.7%
NOCT	45.7℃
PSH_{period}	5.08 x 365 = 1854.2 kW/m^2/annum
$f_{temp-avg}$	0.8784 (typical value for Malaysia)
f_{dirt}	0.97
f_{mm}	0.95
η_{inv}	0.96

3.2. Sizing of Inverter

After PV array power and number of PV modules are known which is 5.1kWp and 20 modules (after round up)respectively, next is to determine size of inverter that match the estimated number of PV modules. Besides that, it also to ensure the inverter will operate in safety condition. To matching the inverter size and PV modules it's involved a few steps shown as follow and the calculated values are summarized in Table 2. The typical de-rating factor for mono-crystalline PV ranges from 0.77 to 0.82.

Step 1: Estimate the range of inverter nominal power.

$$(P_{array}\ x\ k) \leq P_{nominal\_inv} \leq (P_{array}\ x\ k) \quad (3)$$

Where,
P_{array} = peak rating of the PV array (Wp)
k = de-rating factor

Step 2: Determine the minimum and maximum number of PV module per string at maximum and minimum temperature respectively.

$$V_{min\_mp} = V_{mp\_stc} x \left[1 + \frac{\gamma_{vmp}}{100} x (T_{cell} - T_{stc})\right] \quad (4)$$

V_{min_mp} = minimum MPP voltage at maximum effective cell temperature (V)
V_{mp_stc} = MPP voltage at stc (V)
γ_{vmp} = Temperature coefficient for MPP voltage (% per ℃)
T_{cell} = cell effective temperature (℃)

Step 3: Determine maximum number of parallel string

$$Np_{max\_string} = \frac{I_{max\_dc\_inverter}}{f_{safety} x I_{sc\_stc}}$$

Where,
$I_{max\_dc\_inverter}$ = maximum possible dc input current into inverter (A)
Np_{max_string} = maximum number of parallel sting at stc
$I_{sc\ stc}$ = short circuit current of string at stc

Thus, the inverter size is selected to be slightly higher than the range of the optimum values calculated earlier and Apollo G-4500 Leonics 5kW AC output types of inverter is selected. The specifications for this inverter is met the design requirement as shown in Table 3.

Table 2: Calculated parameters value of inverter

Parameters	Value
Range of inverter nominal power	3941W $\leq P_{nominal\_inv} \leq$ 4197W
Min PV module per string	9.5≈ 10 modules
Max PV module per string	15 modules
Max number of parallel string	1.7≈ 2strings

Table 3: Inverter specifications

Parameters	Value
PV input power (kWp)	5.5 kWp
Ac output	5 kW

Max PV voltage	550V
Current limiting	110%
Power Factor	0.98
Efficiency	95.4%

3.3. Cost Estimation of Components

The total cost of capital and replacement for Mitsubishi Electric photovoltaic PV panel is $ 2290 per kW [8] and cost of capital and replacement for Apollo G-4500 Leonics inverter is $ 711 per kW[8]. While cost for operation and maintenance (O&M) is $10 per kW per year for both components [9]. Miscellaneous cost (installation, design, electrical components and labour cost) for this PV system is $1155.84 per kW [16]. All the cost with respective components will be inserted into HOMER for analyzing purposes.

4. Result and Discussion

Figure 6 shows the schematic diagram of the GCPV system simulated in HOMER which comprises of load 1, PV module and converter that are connected to the grid.

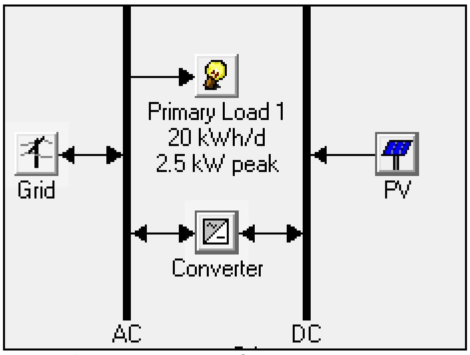


Fig. 6: Schematic Diagram of GCPV system in HOMER.

4.1. Economical Analysis

The main output of the HOMER software is the overall optimization result of the system which is presented in Figure 7. HOMER arranges the final optimization result in increasing value of total net present cost, NPC. The total NPC of a system is given by the present value of capital, replacement, O&M and fuel costs minus the present value of revenue or salvage value that is earned over its lifetime [10]. From Figure 7, it is observed that the configuration with PV rating of 5kW and 5kW converter gives the most optimum result in terms of total NPC and COE with values of $2587 and $0.030/kWh respectively. Meanwhile, the configuration with 1kW PV module gives the highest total NPC of $12254 and COE of $0.140/kWh.

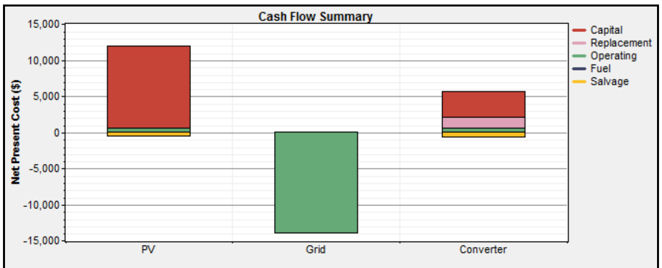
Sensitivity Results | Optimization Results

Double click on a system below for simulation results.

PV (kW)	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
5	5	1000	$ 15,005	-1,056	$ 2,587	0.030	0.56
4	5	1000	$ 12,715	-593	$ 5,736	0.065	0.50
3	5	1000	$ 10,425	-147	$ 8,696	0.099	0.42
2	5	1000	$ 8,135	261	$ 11,205	0.128	0.32
1	5	1000	$ 5,845	545	$ 12,254	0.140	0.17

Fig. 7: Overall optimization result in HOMER

Figure 8 presents the cash flow summary for the optimal system configuration. PV module is dominated by the extremely high capital cost of $11450 due to the large number of PV modules required which is 20 units. However, a PV system is fuel cost-free and once installed, is very cheap to maintain and operate with an O&M cost of $588. With 25 years of lifetime duration which is longer than the project's lifetime of 21 years, there is no replacement required for the PV module. At the end of project lifetime at the 21th year, PV module has a salvage value of $539, resulting in PV total NPC of $11499. On the other hand, the system gains a large amount of revenue from the electricity sold to the grid which is indicated by the operating cost in the cash flow with final total NPC of -$13912. Finally, converter has the least impact on the system's total NPC with an initial capital of $3555, O&M cost of $588 and one time replacement cost of $1483. With a salvage value of $627, the final total NPC for inverter equals $4999.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	11,450	0	588	0	-539	11,499
Grid	0	0	-13,912	0	0	-13,912
Converter	3,555	1,483	588	0	-627	4,999
System	15,005	1,483	-12,735	0	-1,166	2,587

Fig. 8: Cash flow summary by components in HOMER

A clearer view of the system's cash flow throughout the project' lifetime of 21 years is displayed in Figure 9.

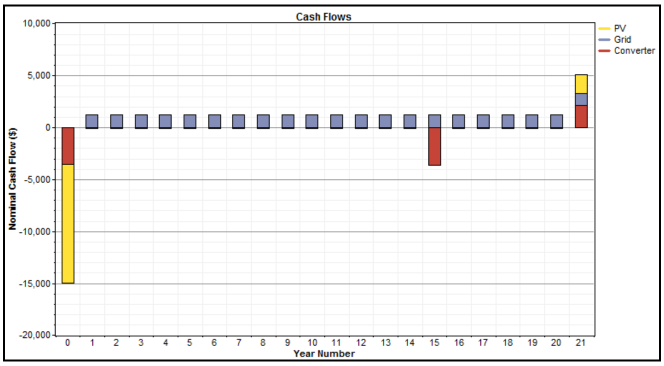


Fig. 9: Cash flow throughout the 21 years of project's lifetime in HOMER

At the beginning of the year, the project requires high initial capital of $15005 which is contributed mostly by the PV modules. In the following years until the end of project's lifetime, the system gains revenue of $1083 per year. The estimated payback period is 14 years whereby the total revenue has reached $15162, more than the initial capital cost. As stated in [11], the energy payback estimates for rooftop PV systems equals 3 to 4 years. At 15^{th} year the overall system revenue is reduced to -$2427 due to the replacement of the converter that costs a total of $3555 after the 15 years lifetime of converter ends. At the end of life time of the project, the salvage value of the system is totaled up to be $3965 which comprises of $1832 from PV modules and $2133 from inverter.

4.2. Technical Analysis

The technical potential of the GCPV system can be analyzed based on the electricity production as displayed in Figure 10. It can be observed that the electricity produced by the PV system from February to April and from September to October is high compared to other months due to the higher solar radiation during the duration. The PV output power produced is directly proportional to the daily solar radiation received. With a total of 6595kWh/yr, HOMER optimized 56% of electrical production comes from PV array while the remaining 44% is purchased from the grid which equals 5188kWh/yr. This results in a total renewable fraction of 0.56 for the system. Besides, from Figure 10 it is noticed that electricity purchased from the grid is equal throughout the year due to the fact that the load is assumed constant. Meanwhile, about 67% of electricity is consumed by the AC primary load while another 33% is sold to the grid with an amount of 7446kWh/yr and 3677kWh/yr respectively. Since the electricity consumption is less than the production, HOMER calculated the excess electricity to be very small, 0.0000388 kWh/yr. In fact, despite having the PV array operating at a capacity factor as low as 15.1% with PV penetration of 88.6%, the system produced zero unmet load throughout the 21 years of the project's lifetime. Thus, it is proven that the load demand has successfully been fulfilled.

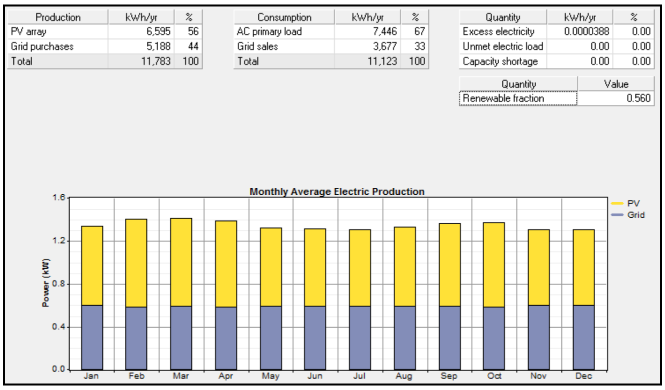


Fig. 10: Monthly average electricity production by HOMER

Figure 11 illustrates the electricity purchases and sales between PV system and grid within 24 hours. Starting from midnight, electricity demand (red colour) is met by purchasing from the grid (green colour) due to zero electricity generation by PV system. PV system (yellow colour) starts to generate electricity approximately at 7.00 in the morning. During this hour, only small amount of electricity is generated by the system thus the system still requires electricity to be imported from the grid. As time passes, the production of electricity from PV gradually increases and reaches its maximum point at 12 noon. During the duration whereby the PV output power is high, the load is fully supplied by the PV power and the excessive electricity is sold to the grid (blue colour). As the load starts to increase significantly after 7pm, more power is purchased from the grid as PV output power reduces at night. In overall, the load of the GCPV system is fulfilled first by the PV array. Whenever the PV output is less than the load, the system will purchase electricity from the grid. On the other hand, during PV peak power production at noon, the excessive electricity is sold to the grid.

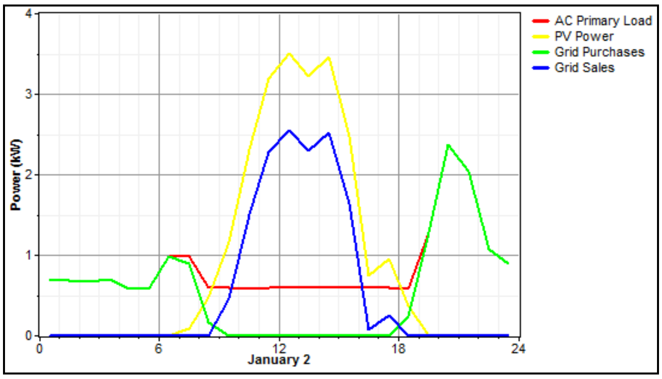


Fig. 11: Electricity purchases and sales between PV system and grid within 24 hours in HOMER

4.2.3. FiT Analysis

The GCPV system in this project is categorized under the capacity of above 4kW and up to and including 24kW which has a FiT rate of RM0.6519/kWh [12]. Apart from that, the system also eligible to obtain a bonus FiT rate of RM0.1256/kWh because it is installed as the building structure. In total, the FiT rate for the system equals RM0.7775/kWh. Based on the result obtained from HOMER, the total grid sales of the system is equal to 3677kWh/yr or 306.42kWh/month. The system's revenue per month gained from the FiT scheme can be calculated as follows.

Payment received from utility

=Grid sales x FiT rates

=306.42 kWh/month x RM0.7775/kWh
=RM238.24/month

5. Conclusion

In conclusion, from HOMER software simulation, it has been demonstrated that Malaysia has sufficient solar energy potential to provide electricity supply. Along with the beneficial Feed in Tariff scheme offered by the government, it has been found that the grid-connected PV system is profitable to the consumers despite its high initial capital investment. Besides, GCPV system is capable in assisting Malaysia towards developing green renewable energy sources which eventually leads to pollution reduction and a cleaner environment.

References

[1] Jianhui Wong, Yun Seng Lim, Jun Huat Tang, Ezra Morries, (2013), "Grid-Connected Photovoltaic System in Malaysia: A Review on Voltage Issues".
[2] M. Z. Hussin, N. Hasliza, A. Yaacob, Z. M. Zain, A. M. Omar, S. Shaari, (2012), "A Development and Challenges of Grid-Connected Photovoltaic System in Malaysia".
[3] Sustainable Energy Development Authority of Malaysia (SEDA Malaysia) official website. http://seda.gov.my/.
[4] Tenaga Nasional Berhad Malaysia official website. http://www.tnb.com.my/
[5] Surface meteorology and solar energy. http://eosweb.larc.nasa.gov/sse/
[6] Helders, Stefan. "Malaysia: largest cities and towns and statistics of their population". World Gazetteer.
[7] John Furtado, (2012), "Analysis of a biomass-based hybrid energy system for rural electrification - A case study in Uganda." Industrial Ecologyroyal Institute of Technology.
[8] Module prices in retail price environment. [Online]. Available: www.solarbuzz.com.
[9] Ngan, M. S. and C. W. Tan (2012). "Assessment of economic viability for PV/wind/diesel hybrid energy system in southern Peninsular Malaysia." Renewable and Sustainable Energy Reviews 16(1): 634-647.
[10] Lambert T, Gilman PG, Lilienthal P. Micropower system modeling with HOMER, integration of alternative source of energy 2006. Citing internal sources. Available at: http://www.pspb.org/e21/media/HOMERModelingInformation.pdf
[11] (2004), "PV Energy Payback." U.S. Department of Energy Energy Efficiency and Renewable Energy