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Design of 4.0 kWp Solar PV System for Residential House under Net Energy Metering Scheme

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ABSTRACT

Renewable Energy Act (RE Act) has been gazetted by Malaysian Government in 2011 to catalyse energy generation from renewable resources. The Feed-in Tariff (FiT) scheme was introduced to promote energy generation from solar PV, biomass, biogas and small hydroelectric up to 30 MW. Solar PV is the most popular resource due to its high FiT rates. However, the FiT scheme for PV expired in 2016 and has been replaced by the Net Energy Metering (NEM) scheme. The objective of this project is to design a 4.0 kWp solar PV system for a residential house under NEM scheme. The methodology involves analysing meteorological data, configuring daily load demand, PV array and grid-connected inverter sizing and lastly simulation of the system by using PVsyst. Based on the results obtained, the amount of energy generated is 5704.4 kWh per year where 9.7% of it has been utilized by the residential load while the other 90.3% has been exported to the grid. The average daily energy production is 3.91 kWh/kWp with 79.6% of annual performance ratio. This NEM design set-up is expected to gain profit of RM 1187 per annum to the residential consumers and avoiding almost 4.0 tons of CO_2 emission to the environment.

Keywords: Net Energy Metering, PVsyst, Renewable Energy, Residential Load, Solar PV).

INTRODUCTION

The Government of Malaysia has gazetted Renewable Energy Act (RE Act) in 2011 together with the Sustainable Energy Development Authority Act (SEDA Act) to catalyse energy generation from renewable resources in Malaysia. This is in line with government's inspiration to reduce dependency on fossil fuel based energy resources such as natural gas, petrol and coal. In addition, the use of renewable energy will reduced greenhouse gas emissions to the environment that cause global warming consistent with Malaysia's commitment to the World during the 15th Conference of the Parties (COP15) under the United Nations Framework Convention on Climate Change (UNFCCC) at Copenhagen in 2009.

Through RE Act 2011, the Feed-in Tariff (FiT) scheme was introduced to promote energy generation from renewable energy resources up to 30 MW. Four potential resources covered under FiT scheme are solar PV, biomass, biogas and small hydroelectric. Through FiT scheme, each kWh of energy generated from these renewable resources will be sold to the grid at a fixed rate for contractual period of 21 years [1]. Among these four, solar PV is the most popular and has the highest demand due to its high FiT rates compared to others. However, the FiT scheme for solar PV has expired in 2016, and been replaced by the Net Energy Metering (NEM) scheme. This NEM scheme is different from the former scheme in which the energy produced from the solar PV system will be consumed first by the loads, and any excess energy is exported and sold to the grid at a predetermined rate which is RM 0.31 per kWh for residential customers (low voltage connection point) and RM 0.23 per kWh for commercial and industrial customers (medium voltage connection point). By generating their own clean energy, consumers will contribute to the reduction of CO_2 emission, hence reducing the carbon foot print and mitigating climate change. According to SEDA portal, the baseline CO_2 for electricity generation for Peninsular of Malaysia is 0.694 tCO_2/MWh in 2014 [2]. Figure 1 shows basic block diagram comparing between FiT and NEM connection to grid through low voltage connection point.

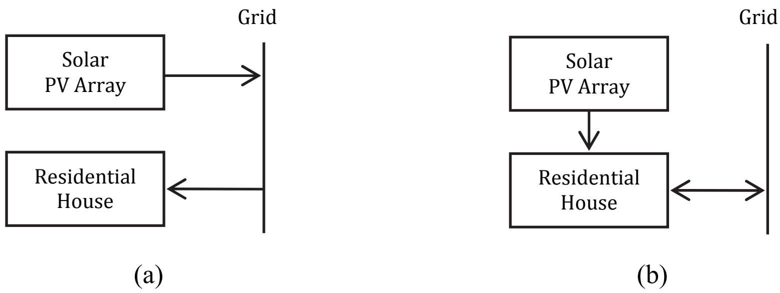

Figure 1: Basic block diagram for (a) solar PV FiT connection to grid and (b) solar PV NEM connection to grid

This paper proposed on implementation of 4.0 kWp of solar PV system under NEM scheme for a residential house at Changlun, Malaysia. The study has been carried out to determine the impact of solar PV generation to the residential load demand, economic and also environmental aspect of its implementation.

Up to date, various studies have been conducted to evaluate the performance of solar PV system for both FiT and NEM schemes. For example, a comparative study on FiT and NEM implementation at university building was performed by Tan (2016). Tan concluded that the FiT scheme have shorter return of investment years while NEM scheme will reduced maximum demand and overall load consumption of the campus [3]. A study by Sahanaa Sree (2014) on three residential categories which are low, medium and high energy demand has concluded that NEM implementation is favourable and economically viable for high energy consumers [4]. Another study done by Dellosa (2015) on the impact NEM implementation on daily load profile and its economic aspect has shown that the grid's load demand were significantly reduced during daytime. Although the computed payback period was considered long, it was worthwhile considering the long operating life of the PV systems [5].

METHODOLOGY

This project aim to design a 4.0 kWp solar PV system for a residential house under NEM scheme. The methodology involves analysing meteorological data (solar irradiation and ambient temperature), configuring daily load demand, PV array and grid-connected inverter sizing and simulation of the system by using PVsyst.

Solar Energy Resource

Changlun (6.44°N, 100.43°E) which is located at the northern of Peninsular Malaysia has been chosen as the project site. Information on solar energy has been preloaded in PVsyst software which is obtained from Meteonorm 7.1 that provides monthly meteorological data. The PV array plane is set at tilt angle of 15° facing South. The annual global solar irradiation is 1,798 kWh/m^2 and the average ambient temperature is 27.4°C. Figure 2 shows the monthly global solar irradiation and average ambient temperature for Changlun.

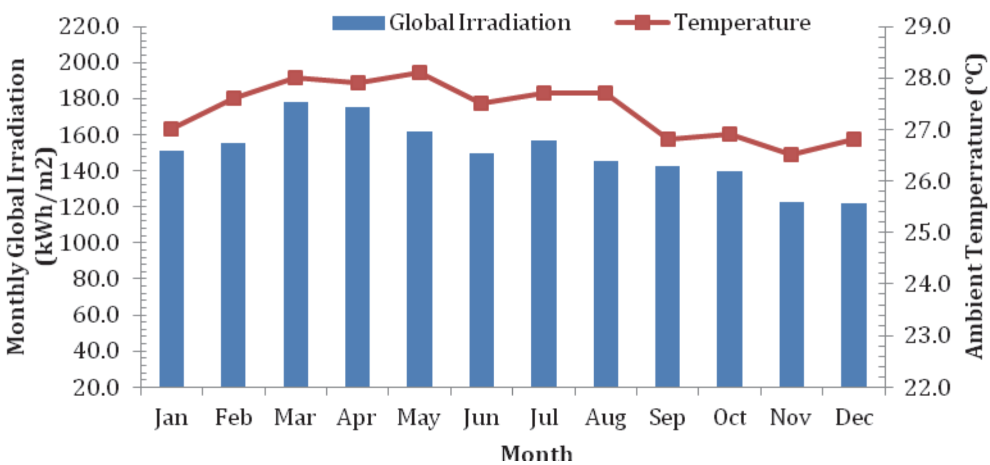

Figure 2: Monthly global solar irradiation and average ambient temperature for Changlun, Malaysia

Residential Load Profiling

The implementation of NEM for residential house requires information regarding the use of electricity by the occupants so that the energy generated from PV array can be fully utilized for optimum energy saving. At present, the electricity consumed is totally from the grid. However, with the implementation of NEM, some portion of the energy used will be supplied by the solar PV system. Typically, household appliances consist of lightings, fans, television, washing machine, refrigerator and phone chargers. The pattern of daily usage is according to the routine of the residents.

To study the daily energy profile, a power monitoring device has been installed to monitor power consumption for a week at several houses in Changlun that used in average of 200 kWh per month. The electricity tariff rate for those who used electricity in this range is RM 0.218 per kWh. The average daily load profile is shown in Figure 3 where the average daily consumption in 6.67 kWh with 0.86 kW of peak power demands. The hourly trend shows that the high demand occurs twice a day between 6.00 am to 9.00 am in the morning and between 7.00 pm until 11.00 pm in the evening. Assuming this daily load is constant throughout a year, the total energy demand is 2,434 kWh per year.

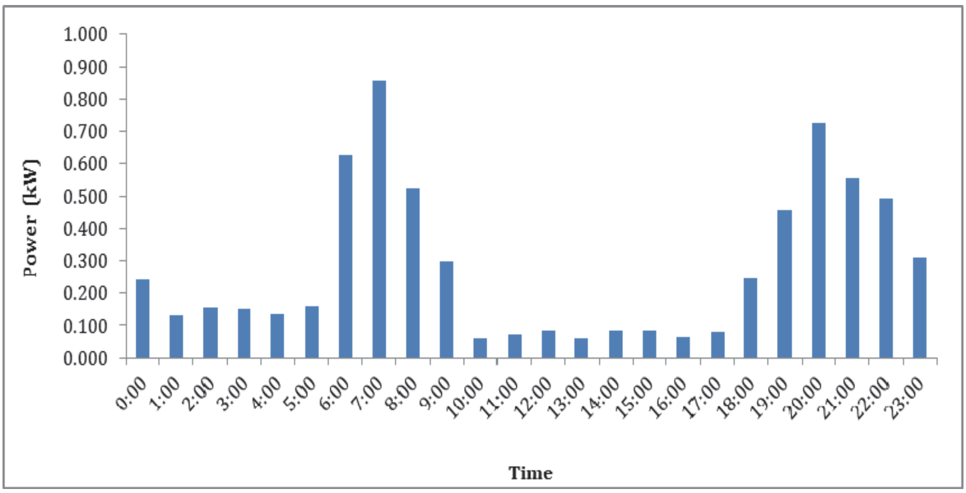

Figure 3: Average hourly load demand for a residential house using 200 kWh per month

PV Module

The Yingli Solar YL250P-29b, a 250Wp PV module is used in this project. Selected module specification which has been preloaded in the PVsyst database is shown in Table 1.

Table 1: PV module specification

Parameter	Value at Standard Test Condition
Power output, P_{max}	250.0 Wp
Voltage at Pmax, V_{mpp}	30.23 V
Current at Pmax, I_{mpp}	8.27 A
Open-circuit voltage, V_{oc}	37.73 V
Short-circuit current, I_{sc}	8.83 A
Module efficiency	15.40 %
Temperature coefficient at Pmax, γ_{mpp}	-0.42 % / ^{o}C

Grid Connected Inverter

A grid connected inverter model Conext RL 4000E by Schneider Electric with rated output power of 4.0 kW is selected for this project. The selected specification for the inverter that is preloaded in the PVsyst database is shown in Table 2.

Table 2: Inverter specification

Parameter	Value
Input (DC)	
MPPT voltage range , full power	180 – 540 V
Starting voltage	100 V
Maximum input voltage, open circuit	550 V
Number of MPPT	2
Maximum input current per MPPT	12 A
Output (AC)	
Nominal output power	4.0 kW
Nominal output voltage	230 V, single phase
Maximum efficiency	97.5 %

System Performance

The output energy of solar PV array is a function of peak sunshine hours and temperature. The estimation of energy generation from solar PV array is calculated based on Equation (1) [6];

$$E_{array} = P_{array\_stc} \times PSH_{period} \times f_{temp} \quad (1)$$

where E_{array} is PV array yield in kWh, P_{array_stc} is power of the PV array at STC in kWp, PSH_{period} is Peak Sun Hour over certain period of time and f_{temp} is temperature de-rating factor. The temperature de-rating factor, f_{temp} is given by the Equation (2);

$$f_{temp} = 1 + \left[\left(\frac{\gamma_{pmp}}{100} \right) \times \left(T_{cell\_ave} \times T_{stc} \right) \right] \tag{2}$$

where γ_{pmp} is temperature coefficient for P_{mp} in % per °C, T_{cell_ave} is average daily maximum cell temperature and T_{stc} is cell temperature at standard test condition which is 25°C . The average cell temperature, T_{cell_ave} is given by Equation (3);

$$T_{cell\_ave} = T_{amb\_ave\_\max} + \left[\left(\frac{NOCT - 20}{800} \right) \times G_{amb\_ave\_\max} \right] \tag{3}$$

where $T_{amb\_ave\_max}$ is average daily maximum ambient temperature in °C, NOCT is nominal operation cell temperature in °C, $G_{amb\_ave\_max}$ is average daily maximum solar irradiance in Wm^{-2}. Specific yield is the amount of energy generated by the solar PV system per unit of installed capacity. It is calculated by using Equation (4);

$$SY = \frac{E_{array}}{P_{array\_stc}} \tag{4}$$

where E_{array} is the energy generated from solar PV system in kWh while P_{array_stc} is power of the PV array at STC in kWp. Performance ratio is a dimensionless quantity that gives the overall quality of the system. It is calculated by using Equation (5);

$$PR = \frac{E_{array}}{E_{ideal}} \tag{5}$$

where E_{array} is the energy generated from solar PV system in kWh while E_{ideal} is energy which would be produced at STC with the same irradiation.

PVsyst Simulation

PVSyst professional software package has been developed at the University of Geneva for study, simulation, and design of PV systems [7]. PVSYST is mostly used for studying, sizing and performance analysis of photovoltaic stand alone, grid connected and water pumping systems [8]. It has a large database of meteorological data sources that available all over the world [9]. Figure 4 shows the PVsyst schematic diagram for NEM configuration.

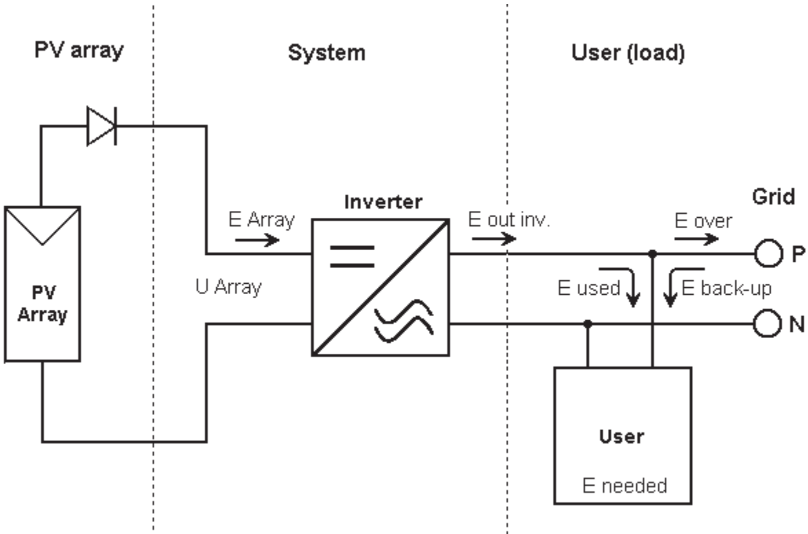

Figure 4: PVsyst schematic diagram for NEM configuration

Many researchers used PVsyst to design and simulate the performance of their PV systems either grid-connected or standalone systems. For example, Soualmia (2016) has modelled and evaluated the energy performance of 15MW grid connected PV system by using PVsyst software [10]. Moreover, Tallab (2015) studied the feasibility of 1.0 MW PV power plant under two configurations which is fixed tilt plane and seasonal tilt plane to get the most efficient and maximum energy production [11]. In addition, study has been carried out on 100 kWp grid connected PV system using PVsyst simulation tool in order to get the amount of energy injected into the grid annually and its performance ratio [12]. For this project, all necessary information has been set according to the design requirement before the simulation is performed.

RESULTS AND DISCUSSION

Results are obtained from the simulation of the solar PV system by using PVsyst as summarized in Table 3. The amount of energy available from the system at the inverter output is 5704.4 kWh per year where 550.65 kWh (9.7%) has been utilized by the load while 5153.7 kWh (90.3%) has been exported to the grid. Looking from the demand side, the amount of energy required annually by the load is 2434.2 kWh. Most of it was met by the grid supply which is 1883.55 kWh (77.4%) while only 550.65 kWh (22.6%) is supplied by the solar PV system.

Table 3: Balance and main result

	GlobHor kWh/m²	GlobEff kWh/m²	T Amb °C	E Avail kWh	E Load kWh	E User kWh	E_Grid kWh	SolFrac
January	151.0	160.9	26.96	529.2	206.7	47.52	481.7	0.230
February	155.0	159.9	27.59	518.7	186.7	43.32	475.4	0.232
March	178.0	174.4	28.00	564.5	206.7	49.18	515.3	0.238
April	174.9	162.6	27.90	530.3	200.1	48.26	482.0	0.241
May	161.8	144.2	28.09	475.0	206.7	48.58	426.4	0.235
June	149.5	130.6	27.51	435.6	200.1	47.15	388.4	0.236
July	156.6	137.3	27.72	456.3	206.7	47.82	408.5	0.231
August	145.3	132.9	27.71	440.9	206.7	46.89	394.0	0.227
September	142.3	136.0	26.80	449.2	200.1	45.01	404.2	0.225
October	139.5	139.8	26.85	460.2	206.7	45.18	415.0	0.219
November	122.8	127.1	26.51	419.8	200.1	40.13	379.7	0.201
December	121.6	129.5	26.79	424.7	206.7	41.60	383.1	0.201
Year	1798.4	1735.2	27.37	5704.4	2434.2	550.65	5153.7	0.226

From the result obtained, most of the energy generated by the solar PV system is exported to the grid whereas only small portion of it is utilized by the load. In fact, most of the load's energy is supplied by the grid. This is due to the load profile that contradicts with the solar energy profile as shown in Figure 5 where the load peak demand occurs twice a day between 6.00 am to 9.00 am in the morning and between 7.00 pm until 11.00 pm in the evening. In contrast, solar energy is only available during day time and reaches its peak in the afternoon. This condition has caused almost all the energy generated from the solar PV system will be exported to the grid especially during noon as shown in Figure 6.

From the aspect of system performance, Figure 7 shows the normalized production per installed kWp. The daily energy from the inverter output is 3.91 kWh/kWp. The PV array loses is 0.86 kWh/kWp per day while the system losses is 0.14 kWh/kWp per day. The overall performance ratio is shown in Figure 8 which is 79.6%. Figure 9 summarized the system's energy loss throughout the year. The nominal PV array energy at STC is 6942 kWh but only 5704 kWh is available as output from the inverter. The losses are due to the PV array (14.8%) and inverter efficiency (3.6%). From the inverter output, 551 kWh has been utilized by the users while 5154 kWh is exported to the grid.

From the economic aspect, the 4.0 kWp solar PV system has exported 5153.7 kWh of solar energy to the grid. At NEM rate of RM 0.31 for every kWh exported, the residential house will earn RM 1598 per annum as income. However the residential house still needs to import 1883.55 kWh of energy from the grid for its consumption. At rate of RM 0.218 per kWh, it will cost RM 411 per year. In total, this NEM system has gained a profit of RM 1187 per annum.

From the environmental aspect, a 4.0 kWp solar PV system has generated 5704.4 kWh of useful energy annually where 9.7% of it has been utilized by the residential house and the other 90.3% has been exported to the grid. This amount of energy is equivalent to almost 4.0 tons of CO_2 emission to the environment annually that could be avoided from fossil fuel based energy generation

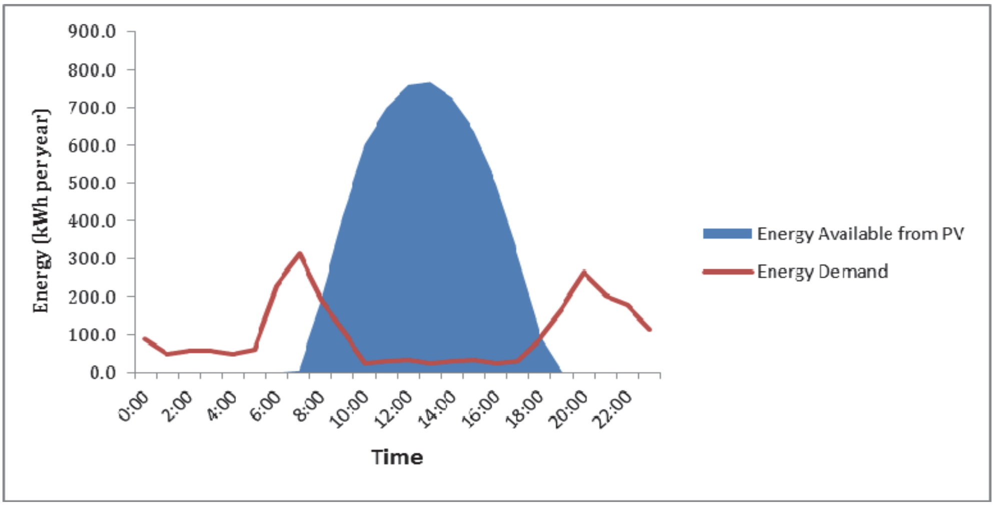

Figure 5: Average hourly energy from solar PV and energy demand

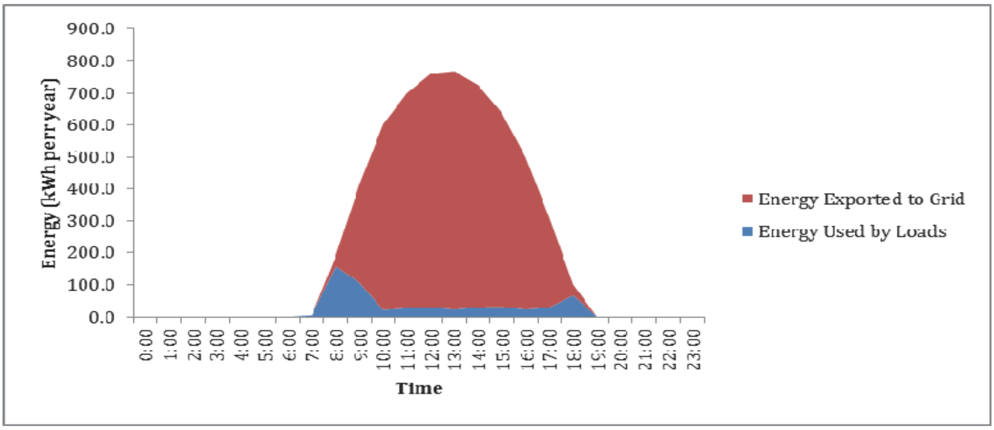

Figure 6: Average hourly energy utilized by loads and exported to grid

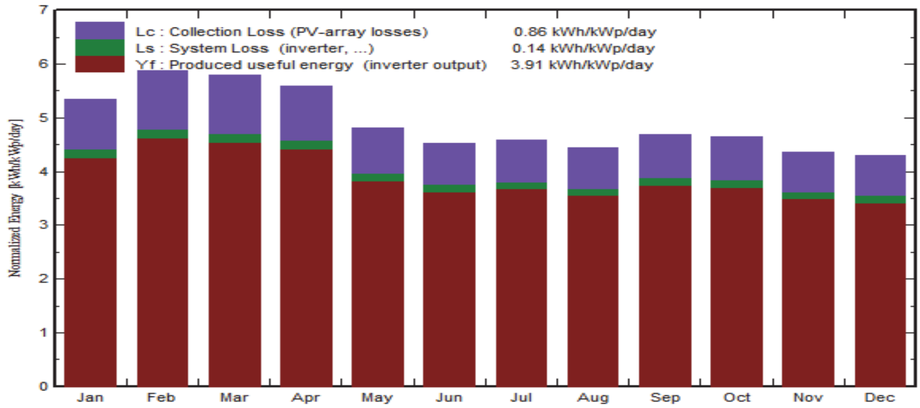

Figure 7: Normalized production per installed kWp

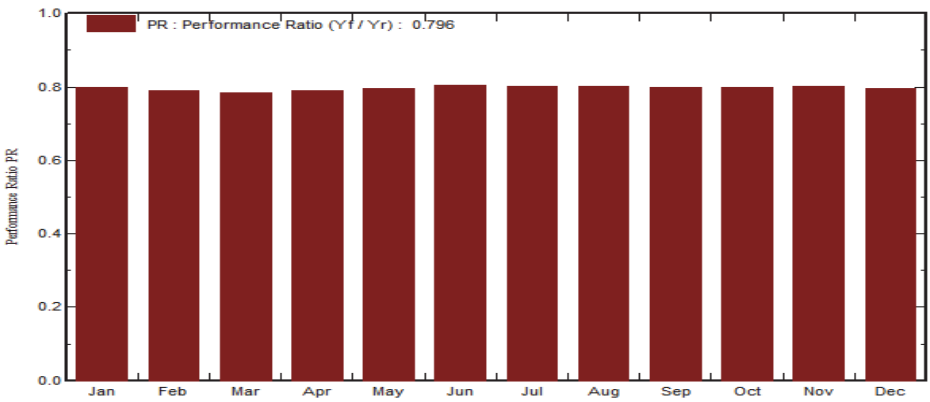

Figure 8: Performance ratio

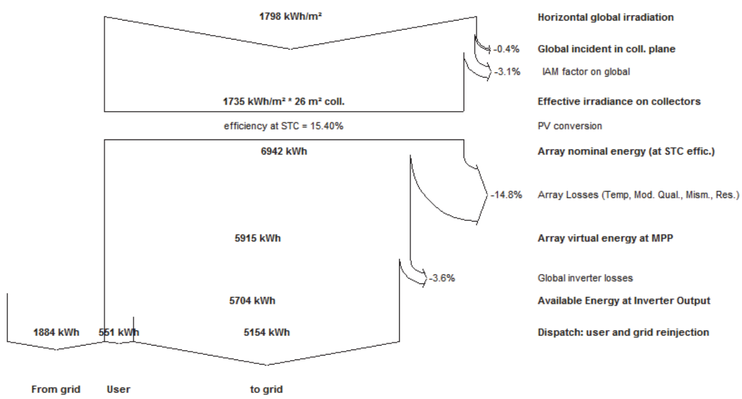

Figure 9: Loss diagram

CONCLUSION

The design and performance analysis of a 4.0 kWp solar PV system for a residential house under NEM scheme in Changlun, Malaysia has been presented in this paper. The analysis has been carried out by using PVsyst software simulation. Based on the results obtained, the conclusions were:

The amount of energy available from the system at the inverter output is 5704.4 kWh per year where 550.65 kWh (9.7%) has been utilized by the load while 5153.7 kWh (90.3%) has been exported to the grid. From the demand side, the amount of energy required annually by the load is 2434.2 kWh where 1883.55 kWh (77.4%) is supplied by the grid and the other 550.65 kWh (22.6%) is from the solar PV system. Besides that, from the aspect of system performance, the average daily energy from the inverter output is 3.91 kWh/kWp with 79.6% of overall performance ratio. The losses are contributed by the PV array (14.8%) and inverter efficiency (3.6%). From the economic aspect, this NEM system has gained profit of RM 1187 per annum where RM 1598 is income from energy exported to the grid. However the residential house still needs pay RM 411 per year for its utility bill. From the environmental aspect, a 4.0 kWp solar PV system has generated 5704.4 kWh of useful energy which is equivalent to almost 4.0 tons of CO_2 emission to the environment that could be avoided from fossil fuel based energy generation.

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