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Preliminary Investigation into the use of Solar PV Systems for Residential Application in Bandar Sri Iskandar, Malaysia

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Abstract: Photovoltaic technology is widely used around the worlds in locations with scarce power generation options. It is used for various applications and Building Integrated Photovoltaic system is one of them. However, photovoltaic are still expensive compared to conventional methods of generating electricity. So, a careful design of the system is required to ensure economic viability. This study describes a preliminary investigation of a Solar PV System for residential applications in Bandar Sri Iskandar. Sizing procedures based on the peak sun hour concept is described for a Malaysian typical terraced house. Current and voltage measurements of the solar panel were carried out to predict the output under actual conditions at site.

Key words: Solar energy, photovoltaic, peak sun hour, I-V measurement

INTRODUCTION

In the near future, Malaysia is expected to be a net importer of oil, and the nation will have to live up to issues related to the security of supply and their economic consequences. It is also anticipated that the energy demand for the country would increase with the increase in population and GDP. Based on the current economic growth rates, Pusat Tenaga Malaysia have projected that Malaysia would become a net importer of energy between 2010 and 2015 (Aun, 2004).

Realizing the situation, it is important that further emphasis is given into the diversification of energy resources. One method is the exploitation of renewable energy to minimize the effects of global warming. Although technology and design play an important role, individual energy consumption patterns have a great impact on reducing the national energy demand. Therefore energy saving initiatives need to be practiced within the society at large.

The Malaysian governments have carried out programs to promote energy efficiency and renewable energy (Taha, 2003). One of them is to introduce subsidies for on-grid solar PV system installations. As shown in Fig. 1, the peak electricity load occurs during the daytime (office hours) which means that the electricity energy demand comes from industries and office buildings. An on-grid renewable energy system would be applicable for industries and offices at this time. As opposed to the high day-time energy consumption, the peak demand for residential users occurs towards the end of the day.

On-grid PV systems are considered as distributed power generation and do not require energy storage. They will supply excess energy to the grid and reduce dependency on centralized power generation during the day. At night, customers that use on-grid PV systems will use electricity from the grid whereas off-grid system users will use energy from energy storage. This means on-grid system users will still need to pay for their electricity consumption.

The other factors which hinder the usage of PV systems, include high initials cost and the lack of support from the Malaysian government. The only form of available support from the government is the on-grid PV installation and even so, has not been able to provide significant reduction in capital cost.

Solar PV systems are commercially available for residential power supply. Such systems are attached to houses or buildings and commonly known as Building Integrated Photovoltaic systems (BIPV) (Ruther *et al*., 2008; Bloem, 2008; Bakos *et al*., 2003). It is expected that the BIPV system will be able to play an important role in the reduction and subsequent replacement of fossil fuels to provide electricity (Bakos *et al*., 2003).

Sizing is an essential part of solar PV system design to ensure reliability of the system. Sizing considers reliability of energy supply by ensuring the number of

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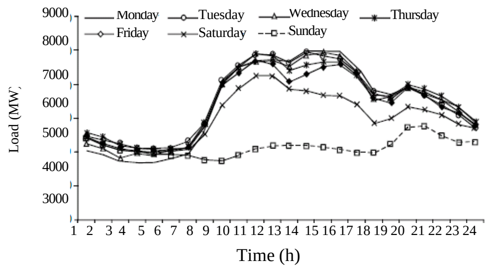

Fig. 1: Malaysia typical weekly load pattern (Ismail *et al*., 2008)

Fig. 2: Global solar energy map (South East Asia)

solar panels used to capture solar energy and the capacity of the batteries for energy storage is sufficient (Pascual, 2007). Some researchers developed a sizing method based on the direct use of solar radiation data near the installation site. The results were presented in the form of a sizing curve. The approach claimed to have several advantages compared to the traditional Loss of Load Probability (LLP)-based method (Markvart *et al*., 2006; Fragaki and Markvart, 2008).

MATERIALS AND METHODS

Deterministic method of solar panel and battery sizing: A simple deterministic method using the Peak Sun Hour (PSH) concept can be used to obtain a quick sizing estimate of the PV system (Markvart and Castener, 2003). Other researcher used sunshine hour and sunshine duration to develop simple deterministic method (Yilmaz *et al*., 2009). A deterministic method refers to the assumption that the load profiles and energy resources are constant, neglecting the statistical phenomenon of each component of the system. Although this method will be less accurate than the statistical approach, it can be used to provide quick estimate of the annual energy consumption and sizes of the panel and storage systems. This method is suitable for sites where daily solar radiation data is not available.

PSH is defined as the length of an equivalent day in STC, solar irradiance = 1000 W m^{-2}, cell temperature = 25°C, in such a way that the radiation (time integral of the irradiance over the day) is the same as one sun-equivalent day (Markvart and Castener, 2003).

To calculate the size of the PV panel needed by using the simple deterministic method, first, the electricity demand per day and solar energy availability for the sites with respect to PSH have to be determined. The following equation is then used to size the PV array.

$$W_{peak} = \frac{P_{load}}{PSH} \qquad (1)$$

After W_{peak} is determined, the battery sizes can be calculated using the following equations:

$$C(Ah) = \frac{P_{load} \times N}{DoD \times V_{rated}} \qquad (2)$$

where, C is the battery capacity in Ah and N is number of autonomy days (day without minimum solar irradiation) required consecutively. DoD is the depth of discharge and V_{rated} is voltage of the system in Volts.

Solar radiation data: It can be seen in Fig. 2 that Malaysia has a PSH value of about 4-5 h. PSH is particularly useful for first order sizing of flat plate arrays, which operate under global radiation. Estimating energy that is collected by the PV panels is not a task due to the stochastic nature of solar irradiation, ambient and surface temperature. NOTC (Nominal Operating Cell Temperature) method will give a better estimation of the PV panel output if temperature data is available (Markvart and Castener, 2003).

The PSH presented above in the global solar power maps represent the worst case seasonal PSH (kWh m^{-2} day) values used for calculating year-round applications. Malaysia receives between 4.21 to 5.56 kWh m^{-2} solar energy radiations on average (Azhari *et al*., 2008). The example of solar radiation data for Bandar Sri Iskandar is shown in Fig. 3. The data was taken on the 14th of February 2010 on a sunny day from morning to afternoon and cloudy sky in the afternoon. The total radiation during the day can be converted to PSH as shown in the Fig. 3. Figure 4 shows radiation profile during 5 days in April 2010.

The total radiation is an integral of solar flux radiation G (t) dt described as follow:

$$G_{total} = \int G(t)dt \qquad (3)$$

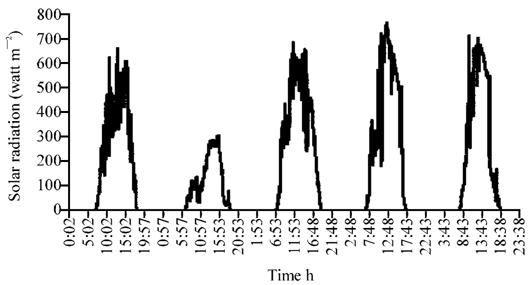

Fig. 3: Measured solar radiation in sunny day

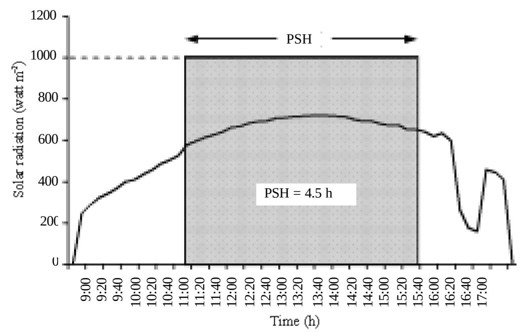

Fig. 4: Measured solar radiation 25-30 April 2010

Table 1: Residential house energy consumption

Item	P (Watt)	Qty	Op. Hrs	Wh day^{-1}	%
Lamp 1	18	3	12	648	23
Lamp 2	18	3	6	324	
Lamp 3	18	2	2	72	
Lamp 4	40	2	4	320	
Ceiling Fan	80	2	6	960	16
Refrigerator	85	1	24	2040	34
Television	100	1	6	600	10
Misc.	-	-	-	1000	17
TOTAL				5964	

Adapted from Tang (2005) and Shen (2009)

The total radiation for the day is 4521.8 Wh m^{-2}. It is equal a PSH value of about 4.5 noted that this PSH value has taken from measurement in sunny day. To plot a sizing curve based on time series solar radiation data, a good availability of solar radiation data is required at least from the nearest weather station to the site.

Load profile for Malaysian typical house: If the PV Systems are used to supply residential electricity, it is more efficient to use DC lamps for lighting since DC lamps do not need inverters. However, it is an option for occupants to use DC or AC lamps. The operation hours of household appliances vary due to the occupant behavior. Refrigerator consumes the highest energy compared to other electrical appliances. The average energy consumption of a domestic refrigerator for households in Malaysia is about 2.03 kWh day^{-1} (Saidur *et al.*, 2008).

Based on the available data, the average household electricity consumption was computed to be approximately 2200 kWh/year per household in Malaysia. Table 1 shows an example of a residential house energy consumption where the electricity devices may vary, but their average total value, as reported from previous studies is about 6 kWh day^{-1}.

It is shown in Table 1 that the electrical energy demand for house lighting is 23% of the total house energy consumption. The configuration of the electrical energy load for lighting can vary according to the behavior of the occupants and electrical appliances used. Other examples for load profile for lighting energy demand can be made, for example if there are 8 DC lamps 18 Watt each that operate for the whole night (12 h), the total energy consumption is 1728 Wh day^{-1}. Or if there are 5 AC lamps 40 Watt which operate for the whole night, the total energy consumption would be 2400 Wh day^{-1}.

RESULTS AND DISCUSSION

Equation 1 is used to calculate Solar Panel Size needed for the 3 load examples above. For the calculation, a PSH value of 4.5 h was used for the site. So the minimum number of solar panel required for this purpose is shown in Table 2.

For the load energy demand option number 2, the solar panel size required is about 400Wp, as indicated in Table 2.

The next step is to calculate the battery sizes using Eq. 2. The reliability of batteries depends on the DoD design. If the DoD design is small, the battery life cycle will be longer and if the DoD design is larger the battery life time will become shorter. Battery life cycle decreases as DoD increases, as shown in Fig. 5.

A DoD greater than 80% should be avoided due to the limited capability of lead acid battery which is mostly cannot be discharged below 80%. The "sweet spot" (optimum DoD for the greatest amount of power produced over the service life) is generally somewhere between 20% and 60% on the average. A DoD of 50% is used for the calculation in the present study, with a battery bank voltage of 12V. Table 3 shows the battery size calculation results.

Where, N is the number of autonomy days. For critical systems such as telecommunication equipment, a reasonable number of N is 5 and for low cost client equipment, it can be reduced to a N of 3. House lighting is considered to be a low cost client, so N value of 3 can be used. For a 1728 Wh day^{-1} constant load, the size of the battery required is about 864 Ah for 12 V systems.

Table 2: Solar panel calculation

Load (Wh day^{-1})	%	Solar panel size (Wp)
1364	23	303.1
1728	30	384
2400	40	533.3

Table 3: Battery size calculation

	Battery capacity (Ah)				
Load (Wh day^{-1})	N = 1	N = 2	N = 3	N = 4	N = 5
1364	227	454	682	909	1136
1728	288	576	864	1152	1440
2400	400	800	1200	1600	2000

From the calculation above, for a typical house in Malaysia which has a constant load of about 1728 Wh day^{-1}, the solar panel required for the system is 400 Wp with battery storage of about 864 Ah for a 12 V system. This result need to be plotted and tested in a sizing curve to find out whether the system is reliable or not. Since the solar radiation data for the site is not available, therefore the sizing curve can't be plotted. However, the data from the nearest weather station can be used for this purpose. For the site at Bandar Sri Iskandar, the Ipoh Weather Station data will be used.

Figure 6 shows the scheme of an off-grid solar PV system, that is consist of 4 solar panels, combiner box for panel connection, battery charge controller, deep cycle battery as energy storage and the DC load for this case is lamps. If the user wants to use an AC load, an inverter need to be added into the system.

Experimental measurements of Solar Panel I-V: This experiment intends to measure actual output of the solar panel during an on-site generation at UTP weather station area. To fulfill this purpose, an actual I-V curve of the panel need to be plotted (Hussein *et al*., 2004). Figure 7 shows the testing configuration. A configuration of several power resistors with different value were used to plot the I-V curve. The power resistor values need to be calculated first using the I-V curve on the solar panel data sheet. This is carried out to estimate the value in the I-V curve and determine the resistor power rating required.

Table 4 presents the specification of the tested solar panel.

The resistance value required can be determined from the I-V curve shown in Fig. 8. The values of voltage and current from the solar panel I-V curve at STC are then used to determine the resistance value through the following equation:

$$R = \frac{V}{I} \tag{4}$$

Total power rating of the resistor configuration need to be observed, it should not be less than the power of

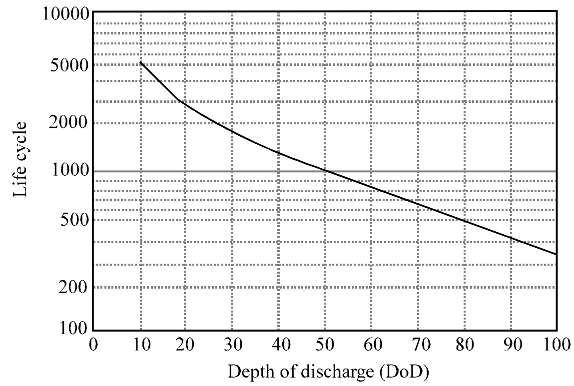

Fig. 5: Life cycle vs DoD of deep cycle battery (http://www.powerstridebattery.com/sidebar/deep-cycle-batteries.html)

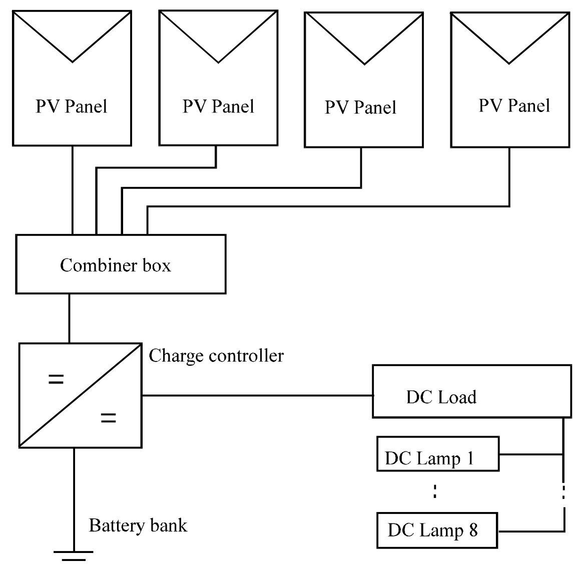

Fig. 6: Off-grid solar power system for lighting scheme

the peak point in the I-V curve. If the power rating of the resistors is lower than the power obtained from I-V curve the resistor will burn out. To calculate the minimum required power rating, the following equation is used:

$$P = I^2 R \tag{5}$$

Monitoring and measurements were carried out on 14th February 2010, at the UTP weather station area. The value of I and V of the solar panel was monitored and recorded as well as solar radiation. To plot the I-V curve, several power resistors with different values and power ratings were used. Two standard multi-meters were used to measures I and V of solar panel during an on-site generation. Kipp and Zonen pyranometer (SP-LITE series)

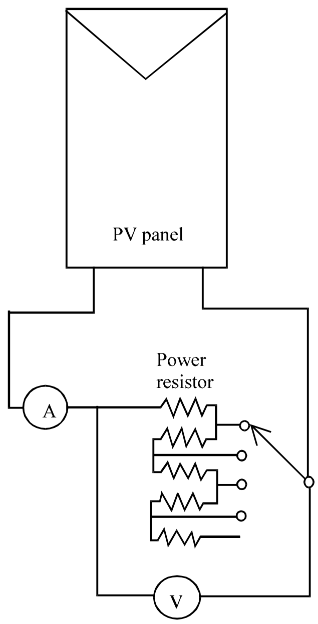

Fig. 7: Solar panel testing configuration

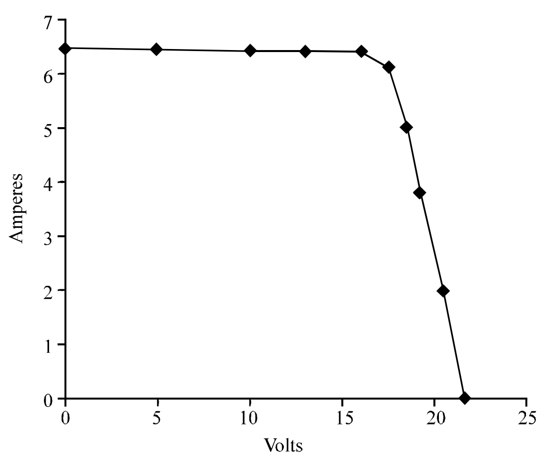

Fig. 8: Solar Panel I-V curve datasheet, adapted from (Solar Panel Data Sheet, Photon Solar India)

Table 4: PV panel specification (solar panel data sheet, photon solar india)

Description	Characteristic value
PV Module	
Type	Multi-Crystalline Silicon
Nominal Peak Power (Pp)	100 Watt
Rated Voltage (Vr)	17.2 Volt
Rated current (Ir)	5.81 Ampere
Open Circuit Voltage (Voc)	21.6 Volt
Short Circuit Current (Isc)	6.46 Ampere
Temperature Coefficient	-0.074 V/°C; +2.80 mA/°C
Company/Country of origin	Photon Solar - India

was used to measure solar irradiation. The pyranometer and several J-type thermocouples connected with the FLUKE Hydra logger 2620A was used to measure air

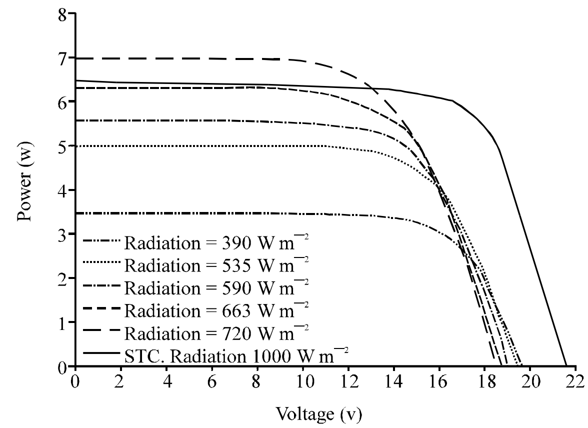

Fig. 9: I-V curve characteristics of solar panel from experimental data

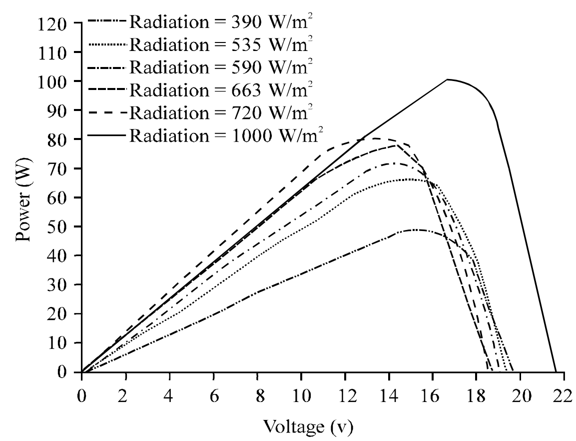

Fig. 10: Power curve characteristics of solar panel from experimental data

temperature and Solar Panel surface temperature. The variable resistor value was changed several times in different irradiance to get paired I-V value and plotted I-V curve at the desired irradiance on-site.

The I-V and power curves were plotted from experimental data are presented in Fig. 9 and 10. I-V curve from solar Panel datasheet (at STC) can be compared with experimental results. The measurements show that actual output of the solar panel is lower than the output at STC. As shown in Fig. 8, the short circuit current of the PV panel increased with irradiance. It increased from 3.4 Amperes at 390 W m^{-2} to 6.9 Amperes at 720 W m^{-2}. The open circuit voltage decreased with the increase of the irradiance.

The maximum power output at 720 Watt m^{-2} irradiance is about 80 Watt. It occurred at a 14 Volt operation voltage. For a charging voltage at about 15-16 Volts lower power due to the shifting of maximum power point was observed. For 390 Watt m^{-2} irradiance, maximum power occurred at 15.4 Volt. For 663 Watt m^{-2} irradiance, maximum power occurred at 14.1 Volts.

The maximum power of the solar panel is shifted to a lower voltage as irradiance increases and this can be seen in Fig. 10. In a small system, the charge controller usually doesn't support maximum power point tracking. This result in power lost due to the shifting of the maximum power point. Charge controller operation voltage is recommended to be set at about 15 Volt considering the shifting in maximum power point and to make sure that the operation voltage is always above the battery voltage. Maximum battery voltage when it is 100% charged is about 13.8 Volt, so the controller operation voltage should be above this number.

CONCLUSION

A simple deterministic method was used to estimate the sizing of a solar panel and battery system. For a Malaysian typical terrace house, the average value of electrical energy demand is about 6000 Wh day^{-1} and about 23% of the daily load is used for lighting. The PSH value for Malaysia is 4-5 h and the measured data in the month of February, indicates a PSH value of 4.5 h. According to the calculations, the solar panel size required to provide energy for residential lighting is about 400 Wp. The battery capacity required for the above panel size was found to be 864 Ah. The short circuit current value of the panel increased from 3.4 Amperes at 390 W m^{-2} to 6.9 Amperes at 720 W m^{-2}. The open circuit voltage values of the solar panel reduced from 19.5 Volts at 390 W m^{-2} to 18.5 Volts at 720 W m^{-2}. The maximum power point was found to be dependent on the irradiance. The I-V measurements during actual conditions show that the solar panel output is dependent on irradiance. This output is also found to be lower than the output at STC.

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