Design and Analysis of Photovoltaic (PV) Power Plant at Different Locations in Malaysia

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Abstract. Power generation from sun oriented vitality through a photovoltaic (PV) system is ended up prevalent over the world due to clean innovation. Geographical location of Malaysia is very favorable for PV power generation system. The Malaysian government has also taken different steps to increase the use of solar energy especially by emphasizing on building integrated PV (BIPV) system. Comparative study on the feasibility of BIPV installation at the different location of Malaysia is rarely found. On the other hand, solar cell temperature has a negative impact on the electricity generation. So in this study cost effectiveness and initial investment cost of building integrated grid connected solar PV power plant in different regions of Malaysia have been carried. The effect of PV solar cell temperature on the payback period (PBP) is also investigated. Highest PBP is 12.38 years at Selangor and lowest PBP is 9.70 years at Sabah (Kota Kinabalu). Solar cell temperature significantly increases the PBP of PV plant and highest 14.64\% and lowest 13.20\% raise of PBP are encountered at Penang and Sarawak respectively.

1. Introduction

Energy is the basic needs of various types of industrial facilities development, economic growth, automotive and modernization in the social development around the world. So the development of a country directly depends on its capacity of energy harvesting. Currently, most extensively used power generation system is based on fossil fuel burning, which produces a huge amount of carbon dioxide emission. Moreover, the nonrenewable energy sources are limited and the amount of stock is declining day by day. So for sustainable energy harvesting, people’s propensity is going to the renewable sources of lowest environmental pollution. Among the renewable sources of energy, solar energy is one of most abundant and largest carbon-free energy source and hourly near about 6.3×10\textsuperscript{20}J energy strikes the Earth as sunlight. Electricity generation from the sunlight by utilizing photovoltaic (PV) system is becoming an encouraging over the world due to clean technology. Likewise, other developed country, the Malaysian government has also started a Feed in tariff (FIT) program since 2004. Geographical location of Malaysia is very favorable for PV power generation system. That’s why different international companies are invested to build up both solar cell and module manufacturing industries in Malaysia. The authority of the Malaysian government name as Sustainable Energy Development Authority (SEDA) has also taken on many strategies to increase the use of solar energy and they have a target solar will be the main source energy supply by 2050 as shown in Figure 1. However, it has been reported that the total PV electricity production as a % of total electricity consumption was 0.04 % in a year of 2013. Table 1 shows a scenario of PV installation with a year of 2014. So the growth rate of the PV power plant either in small scale kW range (roof top building integrated) or in a large scale MW range is not sufficient in respect of Malaysia due to lack of proper designing and economic analysis. Several reports have been found in literature, such as Sopian et
al. [1] have investigated only the performance of 5.76 kWp grid-connected PV at UKM, Bangi, Malaysia. Kassim et al. [2] have reported performance and economic effects of 5 MWp solar PV plant installed at Perlis, Malaysia. However, authors do not include the effect of temperature in the analysis. Therefore, a detailed investigation on the feasibility, cost effectiveness and initial investment cost of solar PV power plant at different sectors of Malaysia is necessary. So the objectives of this study are (i) to compare the performance and cost effectiveness of the PV plant located in different places in Malaysia (ii) to investigate the effect of temperature on the PV plant payback period.

Table 1. PV power installed during calendar year 2014 [3].

| Type of Connection | Category     | MWdc installed in 2014 |
|--------------------|--------------|------------------------|
| Grid-connected     | Individuals  | 13.46                  |
|                    | Non-individuals | 73.27                 |
| Off-grid           | Residential  | 0.15                   |
|                    | Hybrid system | 1.587                  |
| Total              |              | 88.467                 |

Figure 1. National renewable energy Goals of the Sustainable Energy Development Authority (SEDA) [4].

2. Research methodology

2.1 PV plant design and output estimation

The study has been carried out for the grid connected PV systems having rooftop building integrated (12kW range). Daily average global solar radiation and ambient temperature data has been taken from the Malaysian Meteorological Department and NASA Surface meteorology and Solar Energy [5]. Table 2 shows average global solar radiation and ambient temperature of different zones of Malaysia. Electricity generation has been calculated according to average global solar radiation and average ambient temperature. 3% losses due to partial shading or dust are encountered in the analysis. PV module cell temperature is calculated by using nominal operating cell temperature (NOCT), solar irradiation and ambient temperature according to the following equation.

\[ T_c = T_{amb} + (NOCT - 20) \times \frac{E}{800} \]

Where \( T_c \) is cell temperature, \( T_{amb} \) is ambient temperature, \( E \) is the solar radiation. The above expression is widely used to estimate in a for open rack systems. The roof integrated modules operate at temperatures higher than those in open rack, having NOCT values from 10 to 20 °C above depending on the convective cooling [6]. The power loss due to increase of cell temperature has been calculated based on a polycrystalline type PV module, locally manufactured, brand name of “LB250QM-60”. The detail module specification is shown in the Table 3. The NOCT has taken 10°C.
higher than that of the nominal value due to considering a roof top installation. The number of the required PV module is calculated as:

$$\text{No. of module required} = \frac{\text{Total watt peak rating}}{\text{PV module peak rated output}}$$

The inverter is necessary for the grid connected PV power system. Normally the inverter size should be 25-30% higher than that of the watt required [7].

### Table 2. Average meteorological data of different area of Malaysia [8].

| Area                        | kWh/kWp/Year | Average daily ambient temperature (°C) |
|-----------------------------|--------------|---------------------------------------|
| Johor                       | 1171         | 27                                    |
| Kelantan (Kota Baharu)      | 1229         | 27.3                                  |
| Kuala Lumpur                | 1132         | 27.7                                  |
| Melaka                      | 1215         | 27.5                                  |
| Pahang (Kuantan)            | 1154         | 26.9                                  |
| Penang                      | 1286         | 27.8                                  |
| Perak (Ipoh)                | 1253         | 27.7                                  |
| Sabah (Kota Kinabalu)       | 1369         | 27.4                                  |
| Sarawak (Kuching)           | 1157         | 26.4                                  |
| Selangor                    | 1072         | 27.7                                  |
| Terengganu                  | 1235         | 26.8                                  |

### Table 3. Specifications of LB250QM-60 polycrystalline module.

| Place of origin | Malaysia |
|-----------------|----------|
| Brand name      | EPV      |
| Materials       | Polycrystalline silicon |
| Number of solar cells | $6 \times 10 = 60$ |
| Maximum power   | 250W     |
| Open circuit voltage ($V_{oc}$) | 37.8V |
| Short circuit current ($I_{sc}$) | 8.73A |
| Voltage at Pmax. ($V_{mppt}$) | 30.6V |
| Current at Pmax. ($I_{mppt}$)  | 8.17A |
| Maximum system voltage | 1000V |
| Maximum reverse current | 15A |
| NOCT            | 46°C     |
| Temperature coefficient Pmax | $-0.39%/°C$ |

#### 2.2 Installation cost and revenue estimation

Sustainable Energy Development Authority (SEDA), Malaysia has reported the PV module and system prices in at different years. The average module and system prices in Malaysia have decreased per year from 2005 to 2015 as shown in the figure 2. At 2005 the module price was 21.39 MR per watt and at 2015 the price reduced to 3.07 MR per watt. The grid connected PV plant system cost includes different sorts such as PV module cost, inverter cost, wiring and racking cost and installation labor cost, etc. An average system cost for a PV plant having capacity up to 12kW have been reported by SEDA as 31.41 and 7.79 MR/W for 2005 and 2015 respectively. The Feed in Tariff (Fit)) rate for solar PV system is shown in table 4 which is effective from 1st January 2016. Activation year of this Fit rate is 21 years from the commencement date. SEDA also has installation capacity boundary limitation as: for individual the installation capacity of solar PV system must be up to and including 12kW and for non-individual the installation capacity is up to and including 30MW [9].
Table 4. Fit rate of PV power system provided by Sustainable Energy Development Authority (SEDA) effective from 1st January 2016 [10].

| Installed capacity                                      | Fit rates (RM per kWh) |
|---------------------------------------------------------|------------------------|
| Up to and including 4kW                                 | 0.8249                 |
| Above 4kW and up to and including 24kW                  | 0.8048                 |
| Above 24kW and up to and including 72kW                 | 0.6139                 |
| Above 72kW and up to and including 1MW                  | 0.5930                 |
| Above 1MW and up to and including 10MW                  | 0.4651                 |
| Above 10MW and up to and including 30MW                 | 0.4162                 |

**Bonus Fit rates having following criteria**

| Use as installation in building and building structures  | +0.1550                |
| Use as building materials                               | +0.1325                |
| Use of locally manufactured or assembled solar PV module | +0.0500                |
| Use of locally manufactured or assembled solar inverters | +0.0500                |

3. Result and discussion

The installation cost of different size PV plants is shown in Figure 3. The total cost for 12 kW BIPV grid connected PV plant installation is near about RM 93480. Electricity production has been varied according to the solar radiation at different places in Malaysia as shown in Figure 4. The ambient temperature reduces the PV module performances and consequently electricity production is hampered. The highest electricity production has been found near about 10960 kWh per year at Sabah and followed by Penang where the value is 10282 kWh/year. The lowest value of electricity production has been observed at Selangor 8587 kWh/year. Payback periods (PBP) of the PV power plant at different locations have shown in Figure 5. The temperature has a significant effect on the PBP. The power generation is decreased due to an increase of PV cell temperature as a consequence the PBP is also increased. The highest amount of effect is found at Penang with a figure of 14.64% addition of PBP and the lowest effect is observed at Sarawak with a figure of 13.20% raise of PBP.
Figure 3. Total installation cost of a grid connected BIPV system up to 12kW in Malaysia

Figure 4. Electricity generation per year from 12 kW PV system at different places in Malaysia

Figure 5. Payback periods of 12kW BIPV system at different places in Malaysia
4. Conclusion
Total installation cost for 12 kWp building integrated grid connected PV system is near about RM 93,480. The highest and lowest amounts of electricity generated per year are in the location of Sabah (Kota Kinabalu) and Selangor with the values of 10,961 kWh and 8587 kWh respectively. Payback periods at Sabah and Selangor are 9.70 and 12.38 years respectively.

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