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Performance evaluation of two PV technologies (c-Si and CIS) for building integrated photovoltaic based on tropical climate condition: A case study in Malaysia

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ABSTRACT

This paper presents two grid-connected photovoltaic (PV) systems (monocrystalline silicon, c-Si; copper–indium–diselenide; CIS) situated on the rooftop of the solar lab building in the National University of Malaysia, southwestern Malaysia. Various parameters were used to analyze the system performance; including array yield, final yield, capacity factor, and performance ratio. The recordings were noted down under the actual climatic conditions for an entire year. The variables of energy cost and payback period were also considered to calculate the economic feasibility of the system. Variations in the final yield of CIS were as low as 2.98 h/day in July to the highest value of 4.31 h/day in March. The final yield for c-Si power plant ranged from 2.92 h/day in July to 4.14 h/day in March. The calculated capacity factors for CIS and c-Si power plants were 15.6% and 14.4%, respectively, in July as the worst value, and 21.12% and 20.2%, respectively, in March as the best value. In the case of CIS power plant, the performance ratio ranges from 63.8 in July to 84.12 in March, and for c-Si power plant, it ranges from 59.92 in July to 79.14 in March. The energy cost and the payback period of the suggested system were evaluated as 0.045 USD/kWh and 28.44 years, respectively. Finally, this study provides valuable information for those who are interested in PV system installation in the tropical zones.

1. Introduction

Solar energy has become immensely popular as an alternative energy source due to the fact that solar energy is clean, environmentally friendly and secure power source. This makes it a valuable energy source. The amount of energy absorbed by the earth from the sun is hundred times more than the actual global energy demand [1].

However, the uncertainty in solar radiation, such as shadow conditions and other negative phenomena (e.g., the rapid change in the irradiance and temperature), makes the supply of energy by the photovoltaic (PV) systems unstable [2–4]. Due to these imposed realities, it becomes very important to investigate the performance of the PV systems. In addition to this, the continually growing demand of PV cells requires prediction and performance analysis of the PV systems with various PV technologies in actual climatic conditions [5]. These evaluations become more necessary when the PV systems integrate with the electrical power systems (grid-connected system). The performance of the PV systems is dependent on the variety of locations, which implies that the system performance is either negatively or positively affected by the geographical locations [6]. To determine the best candidate behavior of these systems, the performance of the systems must be analyzed and compared with different PV technologies. Therefore, it is important to consider PV system's performance under highly uncertain weather conditions such as the tropical climate [7,8]. Recently, many researchers conducted researches on PV system performance assessment under tropical climate conditions for better understanding of the impact of climate nature on the system's performance.

Research work on PV system performance in different tropical countries such as Indonesia, Singapore, Thailand and Malaysia

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can be found in the literature [9–16]. In Indonesia, some studies were done to investigate the performance of PV systems. In Ref. [9], a hybrid PV system that consists of micro PV-hydro system was evaluated. The micro PV plant comprised of mono-crystalline and poly-crystalline silicon PV modules. The results showed that the performance ratio of this system was in the range of (70.2–79) %. However, these studies are conducted to investigate the system performance based on the aging factor (to test the system performance after long lifetime) of PV modules. In Singapore, Ref. [11] studied the performance of PV system from different PV technologies (silicon wafer and thin film) and under different illumination levels. The study highlighted that, thin film technology exhibits inconsiderable performance comparing with silicon wafer which registered considerable PV performance in the range of (73–82%), but for thin film in range of (63–71%). Nevertheless, in this system each plant was configured in different ways of connections. A comparison of the performance of different three PV plants, from different technologies, amorphous silicon (a-Si), poly-crystalline silicon (p-Si) and hybrid solar cell (HIT) PV under wet climate conditions (Tropical) in Thailand accomplished in Ref. [12]. This study had been analyzed to show the effect of irradiance and temperature on the performance of these three PV technologies based on the climate of each season. The results showed that change of irradiance and temperature affect more on the p-Si plant than on the HIT and a-Si PV plants. Meanwhile, another study was conducted in the equatorial savannah region of Thailand by Kamkird et al. [13], involving performance assessment of a-Si, p-Si, and HiT PV modules. This region has a winter dry climate [14]. Lower impacts were observed of module temperature on PV performance in the presence of a-Si PV than p-Si and HiT PV modules. Also same impacts on other factors recorded, like current, voltage, power outputs, and lowest negative coefficients for a long-term performance.

Recently, some studies have been performed in Malaysia to analyze the performance criteria of PV systems under tropical climate [15]. In this purpose, a comparative study of three different PV module technologies was conducted for the grid-connected system under climatic conditions of Malaysia [16]. The performance ratio was calculated as follows: 78.2% for polycrystalline, 94.6% for a-Si thin film, and 81% for monocrystalline PV modules. High performance was obtained using the Si-thin film PV modules in terms of the final yield, performance ratio, and array/system efficiency of the grid-connected system over the entire duration of the experiment. However, PV modules with different technologies were installed in different tilt angles and therefore it might decrease the value of performance comparison. Furthermore, comparison and assessment on performance of a-Si TEPV and c-Si PV technology showed that a-Si TFPV modules achieved a better performance than the c-Si PV modules and also was less dependent on the operating array temperatures [17]. Nevertheless, the study considered only a variety of temperature levels for the tests on the PV system performance.

On the other hand, the studies on the feasibility of PV grid-connected systems must be conducted [5,15,18–20]. Therefore, the feasibility of PV grid connected system should be examined in terms of system performance, productivity and its economic influence. In Ref. [19], a PV system installed in Malaysia was evaluated using the yield factor within a specific climate and was found the yield factor as 2.6 ± 0.15 kWh/kWp. Moreover, the authors in Ref. [15] used the payback period and in Ref. [18] used the impact of the cost of the generated energy to investigate the system feasibility. Nonetheless, in this study, both of the energy cost and the payback period are considered in the assessment of the economic feasibility of the proposed PV system.

This article includes the outdoor performance results and system economic feasibility of two different PV module technologies such as mono-crystalline silicon (c-Si) and copper–indium–diselenide (CIS) PV modules implemented over

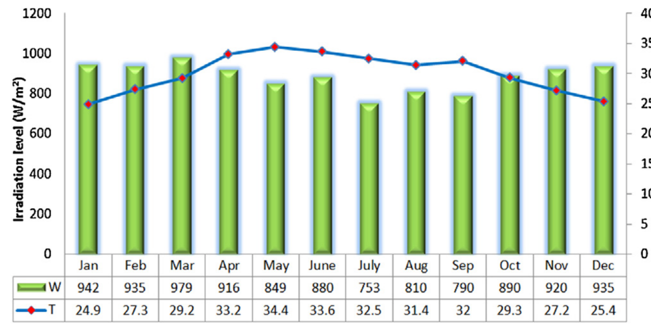

Fig. 1. The mean monthly solar radiation and temperature for Bangi.

12 months (January to December 2014) under Malaysian climate on the roof of energy' lab building (The National University of Malaysia) in Bangi. Bangi is a city that mostly has a weather condition with a completely clear sky in the noon time (usually from 11.00am to 3.00pm), which is the duration of the high solar radiation. This study also considered the aging factor in the performance evaluation. This scheme was launched on February 11, 2004 as a roof-top project of solar power electrical energy in Malaysia.

The main objective of the current study is to analyze and compare the performance of two main types (technologies) of PV modules, c-Si and CIS. The first type (c-Si PV modules) is listed as the most famous and used type over the world [21], with a stable and expectable performance over the time period. The second one (SIC PV modules) is capable to achieve a very high energy conversion efficiency for civil uses which is actually available on the market [22]. This study performed to elucidate detailed information of PV performance for the future installations of PV systems in the region. No such study has been carried out on the aspects of performance analysis and economic feasibility of such PV technologies with a grid-connected system in such geographic location. In the current study, the authors demonstrated that the CIS PV plant is more productive in such weather conditions. Therefore, the outcomes of this study could be considered as a benchmark for PV performance in the places with a similar weather conditions. Finally to make a comparison of PV performance on PV modules came from other different technologies.

2. Potential of solar energy in Malaysia

Malaysia's location on the equatorial zone is favorable for the expansion of the solar energy. Malaysia was found among the top 5 countries in PV energy production with energy generation up to 1600 kWh/KWp.Year using rooftop integrated photovoltaic systems [23]. The annual average daily solar irradiations for Malaysia ranged 4.21–5.56 kWh/m^2. Solar energy could be harnessed to generate electricity during 12 h of daylight. Energy production of about 900–1600 kWh/kWp per year was estimated from the solar power installations in Malaysia[24]. About 1000–1500 kWh/kWp per year of power was obtained from a plant in Kuala Lumpur [25]. The solar radiation values in Bangi, Malaysia are presented in Fig. 1.

Hourly, direct and diffuse, solar radiation (the irradiance incident on the plane-of the array (POA) and ambient temperature measured, from January to December 2014. The source of the data is Sunny Boy data logger from SMA brand, manufactured in Germany. Configuration of the system constructed in seven strings where each string from six PV modules (series-parallel configuration), and this for each PV plant. The PV modules are installed at a fixed tilt angle of 17° (optimum tilt angle for Malaysia) toward the true south in order to maximize the average generated power [26]. In the current study, the Perez model [27] has been used for the transposition

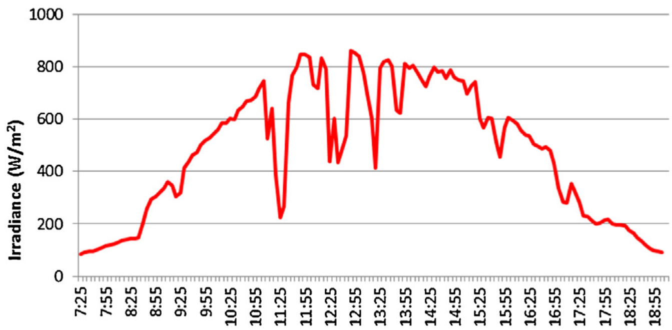

Fig. 2. Sample daily irradiance level for Bangi area.

determine the plane-of-array insolation, because of it is confirmed an extreme accuracy level [28].

The global and diffuse solar radiation was measured from January to December 2014. During the middle of the day (12–2PM), the solar radiation values were recorded as a high irradiation value. In the early (7AM–9AM) and late (5–7PM) daytime, the minimum solar radiation value was recorded, as shown in Fig. 2. In this tropical region, Bangi has almost a clear sky for most days (at noon time). Furthermore, direct radiation is obtained most of the time. The average solar radiation obtained in Bangi is 4.885 kWh/m^2/day. The ambient temperature profile for Bangi is shown in Fig. 1. It was recorded along the period with an average value of 30 °C, while the temperatures fluctuated from 24 °C to 35 °C [24,29].

3. Evaluation criteria of the PV system performance

Technical and economic criteria for comparing and evaluating the productivity of two different PV technologies (c-Si and CIS) in Bangi city, Malaysia is used in this study and presented in Fig. 3a. Also, Fig. 3b, employed to show a precise photos on the PV plants. These two PV plants were combined in parallel to produce a single point of interconnection with the grid. The feasibility of the proposed PV system also investigated in the same manner. At the first, general comparison between the two PV plants is presented in Table 1 to show the specification of each PV technology. Various between the two PV module type's technical factors were applied in this study, such as the array yield *YA*, final yield *YF*, reference yield *YR*, Performance Ratio *PR*, and Capacity Factor *CF*.

The Eqs. (1) and (2) show the daily $E(d)$ and monthly $E(m)$ generated energy by the PV power system.

$$E(d) = \sum_{h=1}^{h=24} E(h) \quad (1)$$

$$E(m) = \sum_{d=1}^{d=n} E(d) \quad (2)$$

where n represents the day numbers in the month.The energy generated by the solar PV power plant was measured after the DC/AC conversion to obtain the instantaneous energy output. The energy output from a PV over a defined period divided by its rated power is termed as the array yield (*YA*). Eq. (3) states this condition:

$$\mathrm{Y_A} = \frac{\mathrm{E_{DC}}}{\mathrm{P_{PV}}} \quad (3)$$

Eqs. (4) and (5) state the daily array yield (*YA (d)*) and monthly array yield (*YA(m)*):

$$\mathrm{Y_A(d)} = \frac{\mathrm{E_{DC}}(d)}{\mathrm{P_{PV}}} \quad (4)$$

$$\mathrm{Y_A}(m) = \frac{1}{n}\sum_{d=1}^{d=n} \mathrm{Y_A}(d) \quad (5)$$

The yearly, monthly, or even daily output AC energy of the system divided by the rated power of the connected PV system at standard test conditions (1 kW/m^2 and 25 °C cell temperature) is termed as the final yield. The intention of comparison of similar solar PV power plant in a specific geographic region led to the formulation of this representative. The type of mounting, vertical, or inclined to a roof or its location has no effect on this figure. The Eq. (6) state the annual final yield (*YA(y)*) is as follows [30].

$$\mathrm{Y_A(y)} = \frac{\mathrm{E_{AC}}(y)}{\mathrm{P_{PV}}} \quad (6)$$

where E_{AC} *(y)* is the yearly total *AC* energy output.

However, Eqs. (7) and (8) give the daily final yield (*YF(d)*) and the monthly average daily final yield (*YF(m)*).

$$\mathrm{Y_A(d)} = \frac{\mathrm{E_{AC}}(d)}{\mathrm{P_{PV}}} \quad (7)$$

$$\mathrm{Y_F}(m) = \frac{1}{n}\sum_{d=1}^{d=n} \mathrm{Y_F}(d) \quad (8)$$

The total in-plane solar insolation (G) divided by the array reference irradiance (irradiance at standard test conditions) (1000 W/m^2), is the reference yield *YR*.

Eq. (9) represents this quantity, which is given by the number of peak sun-hours [30].

$$\mathrm{Y_R} = \frac{G}{G_R} \quad (9)$$

The total weight of losses on a PV module's usual power output is denoted by the *PR*, which is determined by the array temperature and incomplete usage of incident solar radiation with the system component inefficiencies or failures. The proximity of the performance of the solar plant to the ideal performance during real operations is given by the *PR*. This can be used to compare the solar power plant independent of its location, tilt angle, orientation, and their normal rated capacity. A comparison between the solar PV power plant efficiency and the nominal efficiency of the PV generator under standard test conditions is performed. Eq. (10) gives the performance ratio [31], or also can be expressed on it as the percent of the net ratio of the actual to the theoretical energy outputs of the PV array, as stated in (12) [32,33] which was used in this study. Thus it is denote the final yield divided to the reference yield; which represents the total losses in the system through converting from DC rating to AC output, which is as follows:

$$\mathrm{PR} = \frac{E_{AC}}{G\eta_{\mathrm{STC}}} \quad (10)$$

here

$$\eta_{\mathrm{STC}} = \frac{\mathrm{P_{AC(STC)}}}{G_{STC} \times A} \quad (11)$$

where A is the array area. *PR* is also expressed by Eq. (12).

$$PR = \frac{E_{real}}{E_{ideal}} = \frac{Y_F}{Y_R} \quad (12)$$

The energy delivered by an electric-power-generating system is determined by the capacity factor (*CF*). The *CF* of a system is unity if the system offers continuous full power. The ratio of the actual annual energy output to the amount of energy the solar PV power plant would generate is termed as the *CF*. Its value is calculated to

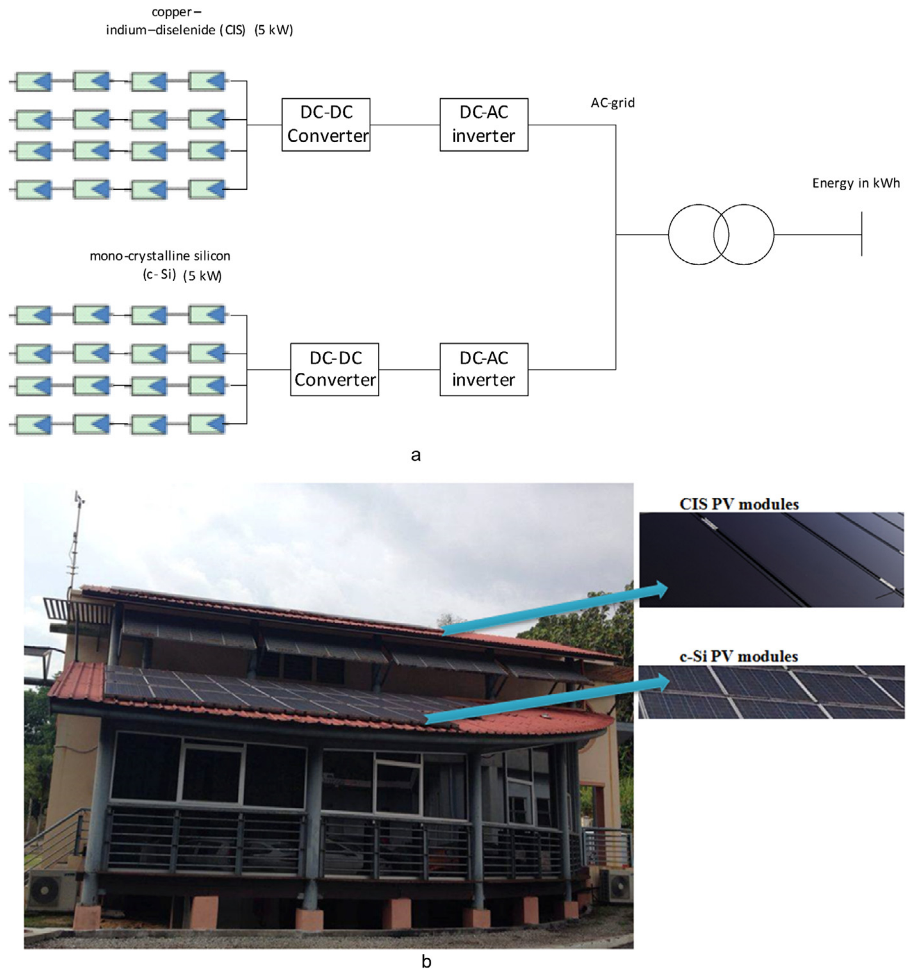

Fig. 3. (a) Schematic of the two 5 kW solar PV plants installed in Bangi, Malaysia. (b) Two PV plants (c-Si) and (CIS) installed in Bangi, Malaysia.

Table 1
General comparison between the mono-crystalline silicon (c-Si) and copper–indium–diselenide (CIS) PV modules.

PV Technology Type	mono-crystalline silicon (c-Si)	Copper–indium–diselenide (CIS)
Frame type	Aluminium	Thin layer of glass
Vmp/Voc (out of 100%) at STC	80–84%	82–86%
Affected by temperature	High	Low
Area	Standard	Up to 40% more compared to (c-Si)
Efficiency at STC	The general solar cells efficienciy around 20%, at STC conditions	The general solar cells efficienciy around 17.5%, at STC conditions
Cost per watt	≤1.5 USD	≤0.7 USD
Number of Module in System	Low	High

verify that the operation is performed under full rated power (PPV, rated) for 24 h/d for a year. Eq. (13) states this value [33].

$$CF = \frac{Y_F}{8760} \tag{13}$$

The *CF* for a grid-connected solar PV power plant is also given by Eq. (14) [34].

$$CF = \frac{\text{h per day of"e; peak sun"e;}}{\text{24h per day}} \tag{14}$$

4. Performance evaluation of two 5 kW pv plants

The weather station at Universiti Kebangsaan, Malaysia was used to extract the monthly average in-plane solar radiation of the PV system from January to December 2014. This is shown in Fig. 1. Variation in the monthly average solar radiation was recorded from 753 W/m^2 in July to 979 W/m^2 in March. The temperature varied from 24.9 °C in January and 34.4 °C in May.

Based on the above mentioned evaluation criteria for the PV system performance, Figs. 4 and 5 show the recorded monthly energy generation and efficiency trends for the c-Si and CIS power plant.

The solar irradiation and ambient temperatures determine the energy generation. A positive increase in the output current and generated power from the solar PV modules was seen with increasing radiation intensity, as shown in Fig. 6. The increase in the number of photons striking the solar PV module results in the positive increase in the current, which in turn leads to electron-hole pair generation and then to the higher photocurrent. The performance of the solar PV module is negatively affected by the module temperature. A minor increase in the short circuit current was noticed with increasing device temperature; however, the open-circuit voltage reduces speedily owing to the exponential dependence of the reverse saturation current on the temperature. The effect of the

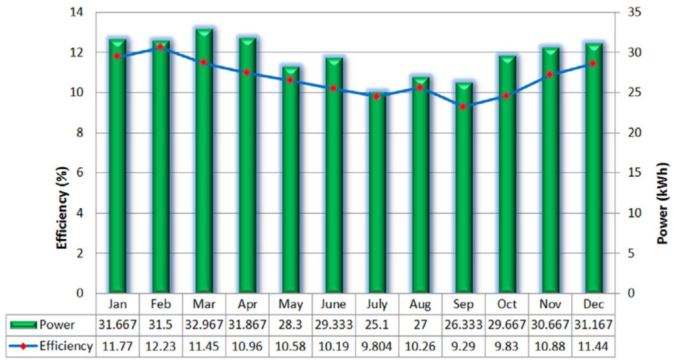

Fig. 4. Average monthly generated energy (in kWh) with PV modules efficiency of c-Si power-system.

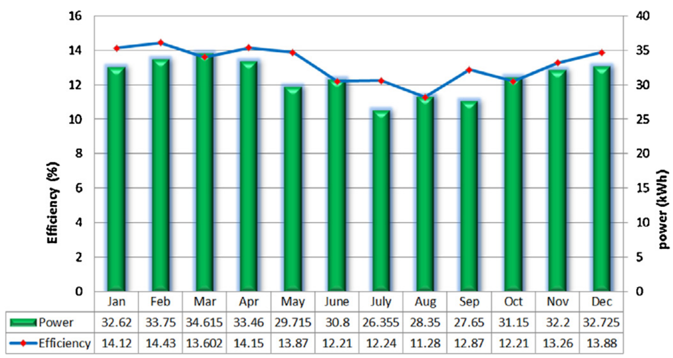

Fig. 5. Average monthly generated energy (in kWh) with PV modules efficiency of CIS.

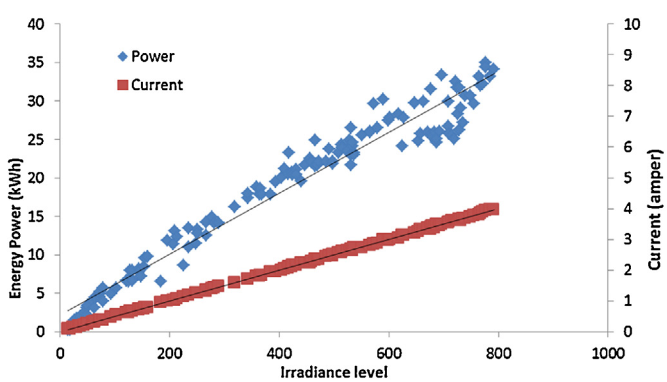

Fig. 6. Energy generated and current values as a function of the irradiance values.

module temperature is evident in the theoretical evaluation, which results in the reduction of the open circuit voltage with the increase in TC. This is because the rise in temperature leads to the reduction in the band gap of the intrinsic semiconductor. The photocurrent will increase with the increase in the temperature for a given irradiance. The high injection of electrons from the valence band to the conduction band of a semiconductor material was the main reason behind this phenomenon [35].

Eqs. (1) and (2) were used to evaluate the average monthly energy generated by the PV plant. Figs. 4 and 5 show the monthly average generated and the efficiency of PV modules for the c-Si and CIS power plants. Variations in the energy generation were observed in the recordings from July to March from 25.1 kWh to a maximum value of 32.96 kWh for c-Si PV modules. This was in the presence of the monthly average of 29.63 kWh with a yearly gross power generation of 355.5667 kWh. The energy generation variation for CIS PV plant was recorded from 26.36 kWh in July to a maximum value of 34.62 kWh in March. The monthly average was calculated as 31.12 kWh with yearly gross generated electricity per year as 373.39 kWh. The energy generated is low in July, as shown in Figs. 4 and 5. This is because of the low radiance level with high temperatures and cloudy days during this month, as shown in Fig. 1. In other words, the PV efficiency for both the technologies in these months is low due to low irradiation and higher module temperature. The efficiency of CIS technology is almost higher than the c-Si technology by 23% throughout the year, as indicated by the comparison between Figs. 4 and 5. In terms of energy generation in the remaining months of the year, both the technologies of equal capacity would be operating in high generation level due to the high irradiation level. The final yield, reference yield, performance ratio, and capacity factor are the performance indicators, which may be applied to define the overall PV system performance in terms of energy production, solar resources, and overall effect of the system losses. The energy produced is equalized by the final yield in terms of system size. The comparison of the performance of PV systems with variations in sizes is rather easy which is expressed in terms of the number of peak sun-hours per day (h/d). The number of peak sun-hours per day (h/d) is a term refers to the average daily solar radiation that indicates the solar insolation in a specific location that would receive it if the sun were shine at its maximum value for a certain number of hours. For example, to have a location with 8 kWh/m^2 per day while the peak of solar radiation for the standard condition is 1 kW/m^2, 8 h/d is needed. In this study, it was denoted by the reference yield, which is the function of location, orientation, and inclination of solar PV array. Eqs. (3)–(13) are used to evaluate the final yield, reference yield, array yield, performance ratio, and

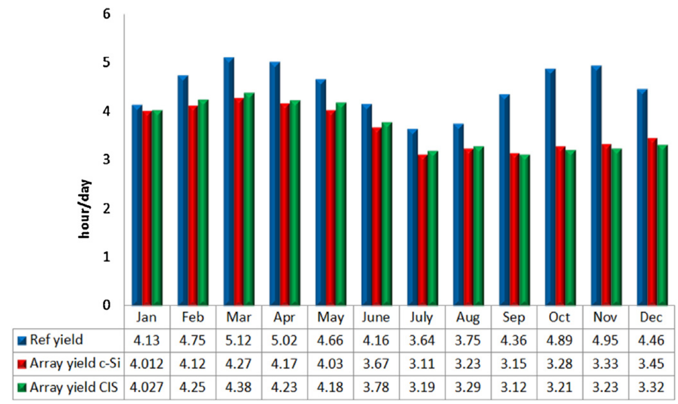

Fig. 7. The array yield of c-Si and CIS PV technologies compared with the reference yield.

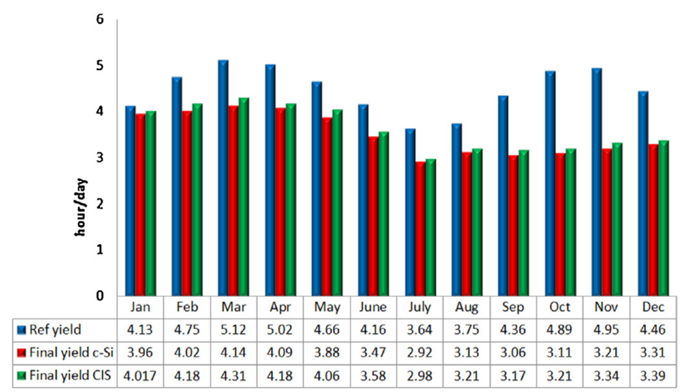

Fig. 8. The array final yield of c-Si and CIS PV technologies compared with the reference yield.

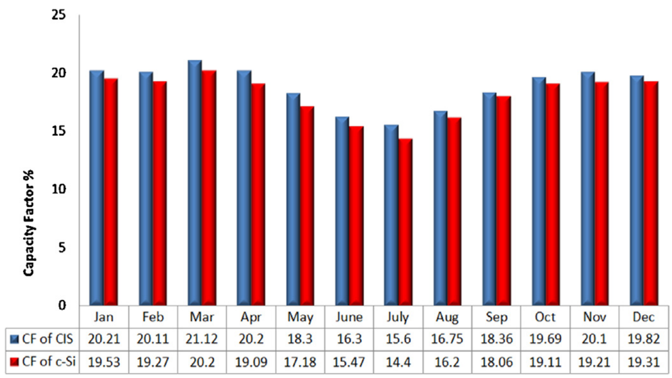

Fig. 9. Average CF of CIS and c-Si technologies over 12 months in 2014.

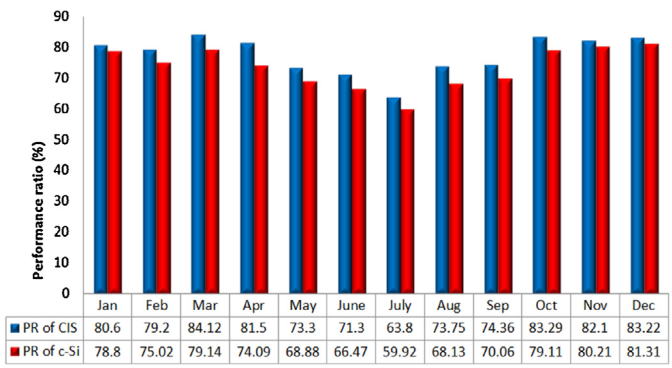

Fig. 10. Average *PR* of CIS and c-Si technologies over 12 months in 2014.

the capacity factor. Figs. 7 and 8 present the brief of the normalized performance parameters.

The variation in the array yield of CIS power plant was observed from 3.19 h/d in July to 4.38 h/d in March. However, the array yield variation in the c-Si power plant was observed from 3.11 h/d in July to 4.27 h/d in March. In comparison with the c-Si technology under humid climatic conditions, the CIS technology performed better, as evident from Fig. 7. The c-Si technology will begin to operate better in comparison with the CIS technology during the rainy season (September–December), where a diffuse light component is higher in the solar radiation and the temperatures are relatively lower. The results are owing to the better efficiency under diffused radiations.

The final yield will indicate the AC energy fed into the grid. Fig. 8 shows the comparison between the reference yield and the monthly variations in the c-Si and CIS technologies. Variation in the final yield of CIS power plant was observed from 2.98 h/d in July to 4.31 h/d in March. Variations in c-Si power plant were observed from 2.92 h/d in July to 4.14 h/d in March.

The capacity factor will indicate the ratio of real annual energy output divided by the amount of energy that the PV system can generate at full rated power. Fig. 9 shows the monthly capacity factor for the c-Si and CIS technologies. The calculated capacity factors for CIS and c-Si power plants were 15.6% and 14.4%, respectively, in July as the worst value, and 21.12% and 20.2%, respectively, in March as the best value. Performance ratio is a dimensionless quantity that denotes the overall effect of losses on the rated output. The ratio of AC energy delivered to the load to the energy production of an ideal lossless solar PV power plant with 25 °C temperature at 1000 W/m^2 is termed as the *PR*. The occurrence of a problem in a system can only be identified because of the *PR*, but it cannot identify the real cause. The monthly average *PR* for c-Si and CIS power plants is presented in Fig. 10.

The range of the *PR* for a CIS plant varied from 63.8 to 84.12; for the c-Si power plant, *PR* ranges from 59.92 to 79.14. The monthly radiation trends and negative trend of temperature in comparison with Fig. 1 was followed in Fig. 10. Table 2 shows the comparison of different existing solar PV power plants from various locations.

Therefore, the above-mentioned outcomes are still reflected and assigned to the type, connections, site (location), and applications of a PV system. A brief result is summarized in Table 2.

On the other hand, a concise result presented in Table 2 for the system performance studied for systems implemented in tropical countries as found in literature, in addition to the current research analysis. Table 2 is focusing on four parameters which are considered to be the most effective performance parameters, such as PV efficiency, PV performance, capacity factor, and finally the yield factor. According to Table 5, the average value of the module efficiency is 10.92% and average performance is 74%. While the average value of the capacity factor is 15.6% in terms of system productivity, whereas the yield factor is found to be 3.8% with an average inverter efficiency of 94.2%. All these results are found to be quite comparable with the ones found in literatures as the validation of the approach used in this study.

In terms of performance comparison between these two PV technologies, a brief result is abridged in Tables 3 and 4. Results indicate the effect of different factors on the two PV technologies and its performances. Based on the results of presented in these tables, the CIS PV modules were operated in better performance than the c-Si PV modules, also its performance was less affected by the aging factor, increasing temperature level, and decreasing the irradiance level, while the c-Si plant was more affected in all of these factors. Table 3 used to present the results of the energy generated and its efficiency, along the lifetime of these PV plants and to show which PV plant affected more by the aging factor.

Bangi PV plants were installed in 2004 for the first time. Based on the data recorded at that time of installation, the yearly data recorded till 2014 as shown in Table 3. The results of the energy generated and energy efficiency in the first time of installation and after ten years show the CIS PV plant which was produced 459.943 kWh with efficiency of 13.6867% in 2004, in 2014 it produced 434.512 kWh with efficiency of 13.1767%. However, the c-Si PV plant in the first investment produced 405.754 kWh with efficiency of 11.9373% and in 2014 it produced 353.568 kWh with efficiency of 10.7236%. This indicates that the c-Si PV plant was more affected by the aging and this is because of the effect of the temperature as indicated in Table 1. In addition, at the first time of investigation the PV system was operate also in lower efficiency, and this is because of the effect of the temperature level on the c-Si which is lower compared to the CIS.

5. Evaluation of the economic PV system feasibility

The energy costs and the payback period are considered in the assessment of the economic feasibility of the proposed PV system. The costs of the site preparation, system design, installation labor, permits, and operations are included in the life cycle cost of a PV system [40]. The following equation is used to calculate the PV life cycle costs (*PVLCC*).

$$PV_{LCC} = C_{\text{mainly}} + \sum_{1}^{n} C_{maintenance} \times R_{CW} + \sum_{1}^{n} C_{replacement} \times R_{CW} - C_{recover} \times R_{CW} \quad (15)$$

The mainly capital cost C_{mainly}, replacement cost $C_{replacement}$, maintenance cost $C_{maintenance}$, and recovers value $C_{recover}$ are considered in the calculation of PV life cycle cost (*PVLCC*). The current worth of each factor is represented by the *RCW*. When the future

Table 2
Different PV systems performances installed under different tropical climates.

Author	PV Technology	System Capacity	Locatiom	PV eff.	PV Perf.	Cap. Factor	Yield Factor kWh/kWp/d
Chimtavee and Ketjoy [36]	multi-crystalline	11 kWp	Thailand	10.41%	73.45%	14%	3.84
Sharma et al. [37]	monocrystalline silicon	10 kWp	India	12.29%	64%	21.3%	2.97
Ge et al. [38]	polycrystalline silicon	142.5 kWp	Singapore	11.2%	81%	15.7%	3.12
Tarigan and Purba [39]	multi-crystalline silicon	5.4 kWp	Indonesia	8%	75.4%	12%	5.15
Masoud et al. [18]	mono-crystalline silicon	3 kWp	Malaysia	10.11%	77.28%	15.7%	3.8
This study	copper–indium–diselenid	5 kWp	Malaysia	13.2%	77.5%	18.9%	3.63
This study	mono-crystalline silicon	5 kWp	Malaysia	10.7%	73.5%	18%	3.52

Table 3
Effect of different factors on performance of the PV plants and its results.

PV Technology Type	mono-crystalline silicon (c-Si)		copper–indium–diselenide (CIS)	
Year of collecting data	Energy Generated Energy	Efficiency (kWh) (%)	Energy Generated Energy	Efficiency (kWh) (%)
2004	405.754	11.93735	459.943	13.68667
2006	399.881	11.82954	455.583	13.59628
2008	390.749	11.61467	449.463	13.46788
2010	379.465	11.33647	445.367	13.37635
2012	366.647	11.08887	438.466	13.28735
2014	353.568	10.72367	434.512	13.17667

Table 4
Effect of lifetime on energy generated and its efficiency for the PV plants.

PV Technology Type	mono-crystalline silicon (c-Si)	copper–indium–diselenide (CIS)
Area needed per kWp for module	7 m^2	10.5 m^2
Annual energy generated per m^2	107 kWh/m^2	132 kWm^2
Annual energy generated	353.568 kWh	434.512 kWh
Actual performance	Performance best at standard test condition	Performance best at higher temperature
Performance and temperature effect	Performance degrade in high temperatre	Performance not affected much in higher temperature
Performance and irradiance effect	Performance highly affected by decreasing irradiance level	Performance affected but not much by decreasing irradiance level
Performance affected by aging factor	High	Medium

Table 5
Proposed system unit cost.

ITEM	UNIT PRICE	PRICE (USD)
PV modules 84 × 120Wp	0.96 USD/Wp	9676.00
PV module accessories (Supporters, wires, breakers, ..etc.)	–	9000.00
Inverters and Converters (2 × 2 × 5.8 kW)	2600 USD	10,400.00
Cost of installation	–	9000.00
	The sum	38,076.00

sum of money (*FSM*) in an assumed year (*N*) through an assumed rate (*I*) is used to calculate *RCW*.

$$R_{CW} = \frac{FSM}{(1+I)^N} \quad (16)$$

Subsequently, the energy cost (*CE*) is calculated using Eq. (17) based on *PVLCC*.

$$CE = \frac{PV_{LCC}}{\sum_{1}^{n} E_{annaual}} \quad (17)$$

The annual production of the PV system is represented by E_{annual}, while *n* is the system lifetime in years.

Finally, Eq. (18) is used to calculate the payback period (*PayBP*), which is the second most important factor for evaluating the economic feasibility of the proposed PV system.

$$Pay_{BP} = \frac{C_{mainly}(\mathrm{USD})}{[\ E_{annual}(kWh/year) \times CEM(USD/kWh) \times R_{CW}]} \quad (18)$$

The system lifecycle time was assumed as 30 years. [15] The energy cost in Malaysia (CEM) is 0.109 USD/kWh. The assumed unit cost for the system is shown in Table 5, which is used to calculate PV_{LCC}, *CE*, and *PayBP*.

In summary, the system's economical evaluation criterion was evaluated using *CE* and *PayBP*. Therefore, based on the above information, the system cost is 38,076 USD, and *CE* has been calculated as 0.045 USD/kWh. In comparison with the conventional power systems, the *CE* of the PV systems in Bangi was much better. Since, the *CE* of the conventional system was calculated in the literature and found to be in a value of 0.109 USD/kWh [15]. Investment in such a system shows promising prospects considering the 28.44 years *PayBP* period, which means it is close to the assumed lifestyle time.

6. Summary

In this study, the evaluation of the actual performances of PV system is conducted by calculating the overall system performance indices, including the module conversion efficiency, array yield, final yield, capacity factor, and performance ratio over the reference period of one year, starting from January 2014 to December 2014 based on the IEC Standard 61724. It was found that efficiency of CIS technology was higher than the c-Si technology by 23% over the whole period. In addition to this, CIS demonstrated its performance with better results in all the other evaluation parameters, as shown in Figs. 7–10. Therefore, the summarized results show that the CIS PV module which is slanted at an optimum tilt angle for Malaysia has a better performance than the a-Si PV module fixed with the same tilt angle, configuration and operating conditions. This is because of the fact that CIS is capable to attain a supreme energy conversion efficiency compared to other available PV products in the civil uses [22]. Based on these outcomes, it can be pointed out that the CIS is better suit of PV modules for installation purpose in such area with such weather conditions compared to the most used PV modules (a-Si) over the world [21]. Moreover, in general, by reviewing different types of system performances from different PV technologies, an average performance has been estimated. It was found to be in the range of 74% in Malaysia and nearby countries.

On the other hand, in order to investigate the economic feasibility of the proposed PV system, the energy cost and the payback period were considered in this research. Based on the results, the system cost is found to be equal to 36,792 USD, and the *CE* as 0.045 USD/kWh. Finally, it can be concluded that the *CE* of the PV system in Bangi is reduced to approximately 41% compared with the conventional system with the *CE* equal to 0.109 USD/kWh [15].

7. Conclusions

In this study, two 5 kWp grid-connected PV systems (c-Si and CIS) in the same area were used to determine the solar PV energy generation. Similar fluctuations in temperature and radiation were observed in both the power plants. The array yield of the CIS and c-Si power plants varied between 3.19 and 3.11 h/d in July to 4.38 h/d and 4.27 h/d in March, respectively. Variations in the final yield of the CIS and c-Si power plants were between 2.98 and 2.92 h/d in July to 4.31 h/d and 4.14 h/d in March, respectively. Furthermore, the capacity factor for CIS and c-Si power plant was also calculated, and found as 15.6% and 14.4% in July as a worst value, and 21.12% and 20.2% in March as a best value, respectively. In addition, variations in the *PR* of the CIS power plant were observed from 63.8 in July to 84.12 in March and for c-Si power plant, the *PR* ranges from 59.92 in July to 79.14 in March. The *CE* of the system was 0.045 USD/kWh. This led to the payback period of 28.44 years. In comparison with the subsidized price of energy generated through fossil fuels, the study showed that the price of the energy generated by the PV systems in Malaysia was much lower.

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