Energy Conversion and Management 78 (2014) 8–13

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

A comparative study of three types of grid connected photovoltaic systems based on actual performance

M. Effendy Ya'acob [a], Hashim Hizam [a,b], Tamer Khatib [c,*], M. Amran M. Radzi [a,b]

[a] Department of Electrical & Electronics Engineering, Faculty of Engineering, Universiti Putra Malaysia, Serdang 43400, Selangor, Malaysia
[b] Centre of Advanced Power and Energy Research (CAPER), Universiti Putra Malaysia, Serdang 43400, Selangor, Malaysia
[c] Institute of Networked & Embedded Systems/Lakeside Labs, Alpen-Adria-Universität Klagenfurt, 9020 Klagenfurt, Austria

ARTICLE INFO

Article history:
Received 27 August 2013
Accepted 22 October 2013
Available online 16 November 2013

Keywords:
PV system
Concentrating PV system
Sun tracking PV system
Linear regression

ABSTRACT

In this study, three photovoltaic (PV) systems are evaluated based on actual performance. The energy generation of three types of PV systems namely concentrating PV system (6 units × 1 kWp), PV system with sun tracking flat (2 units × 1 kWp) and fixed flat PV system (2 units × 1 kWp) is analyzed in this research. Data analysis for ten consecutive months consisting of 12,190 samples of 15 min interval is done. The performance evaluation is done using energy yield, yield factor, capacity factor, power efficiency and PV array efficiency. Based on the experiment data, it is concluded that tracking flat PV system is the most suitable system for Malaysia in normal operation mode with average daily generation of 4.7 kW h (141 kW h as a monthly average), system efficiency of 11%, power efficiency of 85%, average daily yield factor of 2.3 kW h/kWp and capacity factor of 32%. This study also highlights the PV energy (E_{PV}) models for each PV generators with respect to the environmental factors. The advantage of employing a tracking flat system as compared to the fixed flat system is considered based on the effectiveness of the dual-axis tracking mechanism tracking the sun for maximum power output.

1. Introduction

The Government of Malaysia has approved and officially started the Fit-In-Tariff (FiT) enactment of the renewable energy law by third quarter of 2011. Solar PV received the highest FiT rate as compared to the other renewable energy resources with the rates of 0.4–0.57 USD per kW h for the duration of 21 years with 8% degradation [1]. According to this, the ministry of science, technology and innovations (MOSTI) has played an important role in funding 51 PV projects worth more than 13,000,000 USD. This policy highlights the importance of analyzing the performance of different types of PV systems in order to find out the most suitable system for Malaysia where highlights are also given to ability to mitigate CO_2 reduction [2,3].

Most research studies in the field of solar photovoltaic technology and application applies a single or multiple PV modules configured in stacks for the testing and verification. Research outcomes reflect parameters such as power, energy, system's yield factor (YF), capacity factor (CF), system efficiency, and overall performance. Fuentes et al. in [4] studied PV systems performance under natural sunlight and highlighted two issues namely data uncertainty and site-specifications when analyzing a PV system in order choose suitable PV system in the Mediterranean zone. Almonacid et al. in [5] highlighted the importance of predicting the characteristics of a PV module using artificial neural network (ANN). In [6,7], the authors provided an optimization of PV/Diesel systems and highlighted that the PV system technology is of the most suitable renewable energy technologies for Malaysia. Meanwhile, Mekhilef et al. in [8] reviewed the PV technology adaptation in Malaysia based on chronological flow and highlighted some corporate involvement such as BP Malaysia for the 8 kWp PV project in KESAS Highway and Fraunhofer ISE Germany for the prototype of solar house application in urban areas.

However, the PV manufacturing sector as well as researchers normally estimate the total energy generated from a collection of PV modules considering data incorporated with pertinent percentage energy conversion capability. It is shown that the module efficiency estimated by this method does not reflect the collective efficiency of a PV system made up of a set of single modules stacked in bundles of either parallel or series configuration. Due to factors such as cost, equipment, space and bulkiness of the system, the PV system cannot be tested in laboratories based on standard requirements at sites with different climate characteristics.

In this study, a practical approach is proposed to define PV systems potential using energy generation amount for each PV system in order to evaluate the productivity of different types of PV systems in Malaysia and nearby tropical regions. To do so, a 10 kWp PV pilot plant has been installed, monitored and tested

* Corresponding author.
E-mail address: tamer_khat@hotmail.com (T. Khatib).

0196-8904/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enconman.2013.10.064

at Universiti Putra Malaysia, Serdang, Malaysia. This plant is consisted of a 2 kWp Fixed Flat PV system (FF), 2 kWp tracking flat PV system (TF) and 6 kWp PV system with concentrating mirrors and tracking mechanism (CPV) (see Figs. 1a–1c) with details specifications in Table 1. The fixed flat generator in Fig. 1a is slanted at 15° facing south based on the recommendation reported by [9]. In this research, performance data is analyzed for a period of ten consecutive months (September 2011 to June 2012) for the named PV systems with the aim to define energy potential from each system [10].

The study duration on PV performance is considered sufficient based on the fact that weather condition for Malaysia fluctuates all year round as described earlier and supported by some PV field studies by [11–15].

2. Field condition at the testing site

Malaysia experiences tropical weather condition almost all year round. Amin et al. [16] have conducted field test for various types of photovoltaic modules and concluded that weather condition in Malaysia is sufficient for PV application due to the availability and predictability of sunlight with the possibility of having 6 h of direct irradiation of 800 W/m^2 to 1000 W/m^2. This statement is supported by "report compared assessment of selected environmental indicators" of PV electricity in selected OECD cities where Malaysia was found among the top 5 countries in PV system production with energy generation up to 1600 kW h/KWp. Year for a rooftop integrated photovoltaic systems [17]. The solar farm approach is basically a large scale project for which to implement the proposed PV generator configuration. The system efficiency is more likely produce a much realistic figure because of the huge area usage and the exposure of the stochastic tropical environment. Specifically for this pilot project, we intend to highlight some fieldwork findings as supportive reference towards adapting tracking flat PV generators in solar-farm scale maybe in the near future. Typical example of large scale solar PV implementation and technology application in the tropics is described in [8,18,19].

In this research, it is concluded based on the data recorded at the selected site that the average daily radiation level is in the range of (253–512) W/m^2 with highest daily radiation recorded in the range of (556–1094) W/m^2. In the meanwhile, it is found that the daily maximum ambient temperature is in the range of (30.2–36.6) °C with average monthly value of 29.6 °C (see Fig. 2).

The sun hours throughout the monitoring period is calculated at 3047.5 h with 11.34 h/day of solar radiation received. The peak solar radiation level recorded is 1438 W/m^2 in 15th May 2012. Meanwhile, the minimum recorded solar radiation is found 3 W/m^2 for most of the days as early as 4.08 AM. The average solar radiation recorded for 15 min interval during generation days is 339.7 W/m^2. On the other hand, the recorded ambient temperature ranges from 22.2 °C up to 38.4 °C with an average value of 29.41 °C.

Fig. 1a. Installed fixed flat PV system.

Fig. 1b. Installed tracking flat PV system with 2-axis movement.

Fig. 1c. Installed CPV system with mirror concentrating elements.

3. Experiment description and setup

The installed PV pilot plant which covers approximately 450 squared meter of area with total generating capacity of 10 kWp. These PV systems consists of 2 × 1 kWp units of fixed flat (FF) PV system, 2 × 1 kWp units of tracking flat PV system (TF) generator and 6 × 1 kWp units of CPV System. All of the three types of the PV systems are made up of CEEG 95W Mono crystalline PV Module as described in Table 2.

The system is directly connected to UPM electrical distribution line via Feeder Pillar (FP) as shown in Fig. 3 which links to the Main Switch Board (MSB). Grid connected system ensures full capacity generation with assumption of highest generator efficiency during the operation period compared to a standalone system which has some limitations. The ten units of PV generator are connected to three units of Aurora Inverter system with the capacity of 2 × 3.6 kW and 6.0 kW for the purpose of grid-tied operation.

The difference between the systems lies in the quantity of PV modules, dual-axis tracking mechanism and mirror with twice concentration. The uniqueness of CPV generator implies the concept of V-through configuration by installing mirror reflector with certain degree of concentration to enhance the solar radiation received at the PV module surface to increase photonic effect inside the crystalline semiconductor. Recent studies done by [20–24] imply the optical efficiency of V-through technology in solar PV application which creates alternative means of reducing the overall

Table 1
Technical specifications for multiple PV generator configurations.

Fixed flat PV (FF)	Tracking flat PV (TF)	Concentrating PV (CPV)
– Flat PV array with slanting angle	– Dual axis sun tracking	– Dual-axis sun tracking with 12 units of 2× mirror concentrator
– Configuration: 12 modules in series	– Configuration: 12 modules in series	– Configuration: 12 modules in series
– Built up area: 8.64 m	– Built up area: 8.64	– Built up area: 8.64 (including mirror)
– Power (at STC): 1 kW	– Power at STC: 1 kW	– Power at: 1 kW
– V_{oc}: 270 V_{dc}	– V_{oc}: 270 V_{dc}	– V_{oc}: 135 V_{dc}
– I_{sc}: 5.56 A_{dc}	– I_{sc}: 5.56 A_{dc}	– I_{sc}: 5.56 A_{dc}

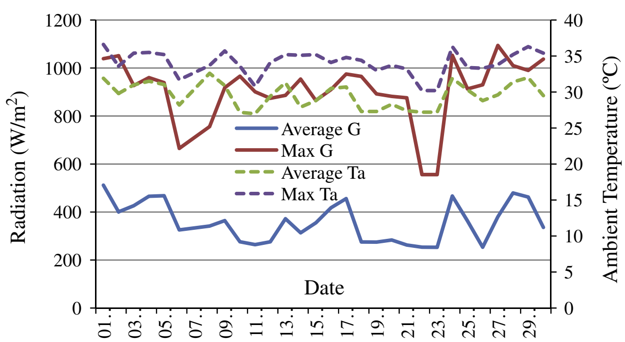


Fig. 2. Daily maximum solar radiation and ambient temperature at the selected site.

Table 2
Electrical characteristic of 95 W CEEG monocrystalline PV module.

Electrical characteristic	CEEG CSUN 95W-36M
P_{mpp} (W)	95
V_{oc} (V)	22.5
I_{sc} (A)	5.56
V_{mpp} (V)	18.3
I_{mpp} (A)	5.21
Practical module efficiency	17.05%
Voltage temperature coefficients	−0.307%/K
Current temperature coefficients	+0.039%/K
Power temperature coefficients	−0.423%/K

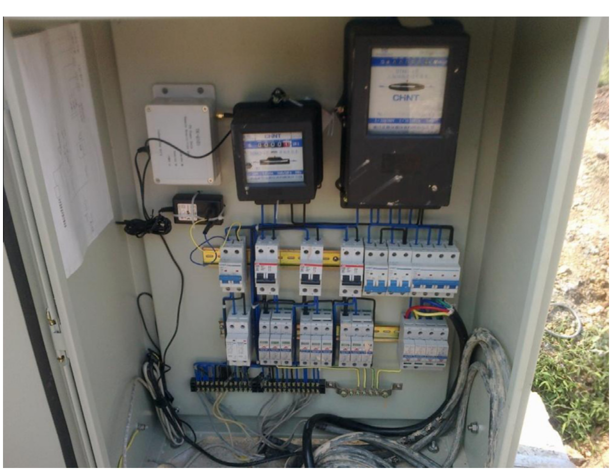


Fig. 3. Arrangement of distribution box for DC and AC breakers connecting to the GPRS data logger and UPM electricity grid (Feeder Pillar).

built-up area, quantity of module, heat dissipation, and consequently, lower installation cost.

The PV generator which uses tracking mechanism (TF and CPV) consumes a nominal power of 50 W_{max}/day for its controller and timely sequence motorized tracker with the power supply taken directly from the grid (separate kW h meters). The PLC controller box and technical specification are shown in Fig. 4. Based on the power generation capability of each generator reaching 1000 W at STC, the internal power consumption for tracking mechanism is assumed to be negligible.

On the other hand, an automatic weather station data monitoring system has been set up at site comprising wind speed sensor, ambient temperature sensor and solar radiation sensor. All of these devices and PV generator outputs are link directly via Wireless Network Sensor (WNS) configurations where data from the site is transferred to cloud database through General Packet Radio Service (GPRS) on 3G cellular communication. The site uses online monitoring system which can be accessed through www.smartpv.net website. These measurements were taken every 15 min in order to consider the uncertainty nature of the recorded data.

In this study, the standard parameters of PV performance are calculated referring to MS-IEC standards [25] and recent study in [26]. The maximum power, P_{dc} is recorded for each system by searching for the power value which occurs at 1000 W/m^2 in the recorded data with tolerance equals to 5%.

Due to the difference in generator quantity, per unit PV generator calculations are done based on the following conversion process:

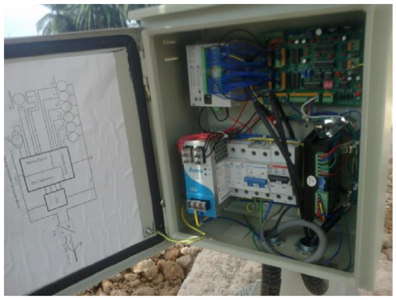
$$\textit{Array Power}\ (\text{p.u.}) = \textit{Output Power}\ (P)/\textit{Array quantity}\ (n) \qquad (1)$$

where P is the actual DC power generated from each PV generator system and n is the number of the 1 kWp units in the system. The DC power is calculated by multiplying DC Current (I_{DC}) with DC Voltage (V_{DC}) from PV module output. On the other hand, the standard definition of PV array efficiency is used which is the ratio of the output PV array power to input solar power expressed in percentage [26].

In addition to that, Hajjah et al. [26] defines yield factor (YF) as the annual, monthly, or daily net AC energy output of the system divided by the peak power of the installed PV array at standard test conditions by the units of kW h/kWp. In [25], the yield value is define as the duration that a PV device would need to operate at its rated power in order to generate the same amount of energy that it actually did generate and usually calculated over a day. Meanwhile, the capacity factor (CF) is defined as the ratio of the actual annual energy output to the amount of energy that the PV array would generate if it is operated at full rated power (Pr) for 24 h per day for a year [26].

4. Results and discussion

The nominal power generation for each PV system (1 kWp) is estimated to be 1 kW based on module performance under standard testing condition (STC). Fig. 5 shows the maximum power generated by each system unit for a period of time. From the figure, it shown that, the maximum recorded power value comes from TF generator with 1268 W followed by FF generator with 1115.5 W and the least from CPV generator achieving only 819 W. Moreover, it is found that all of the generated power data have been recorded at 32.5–34.5 °C ambient temperature.



Electrical Specification (DVP-28SV)

- Power supply: 24 Vdc (with counter –connection protection on the DC input polarity)
- Inrush current: 2.2 A max
- Power consumption: 6W
- Insulation resistance: > 5MΩ
- Operation: 0^0C – 55 ^{0}C (temp), 50 – 90 % (RH humidity)
- Storage: -40^0C – 70 ^{0}C (temp), 5 – 95 % (RH humidity)
- Weight: 260 g
- International Standards: IEC1131-2, IEC 68-2-6, IEC 68-2-27

Fig. 4. PLC controller box for 2-axis tracking mechanism with DC and AC supply.

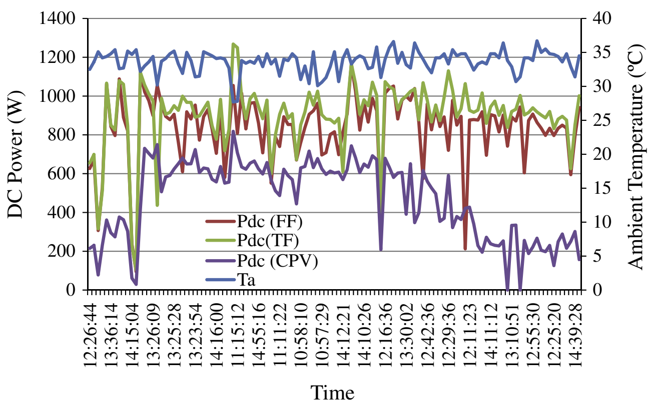


Fig. 5. Maximum DC power per unit of 1 kWp for the three proposed systems.

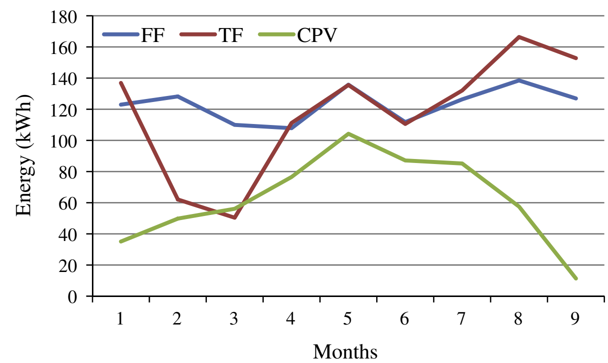


Fig. 7. Energy generation per 1 kWp unit for the three proposed systems.

In addition to that, Fig. 6 shows overall energy generation from 3 types of PV systems. From the figure, the total generation based on operational days for all PV systems is 7708.59 kW h with the energy generation of 2216.31 kW h (28.75%) from fixed flat, 2115.62 kW h (27.45%) from tracking flat and 3376.66 kW h (43.8%) from CPV generator. The maximum monthly generation recorded was on April 2012 with total value of 954.58 kW h comprises of 276.94 kW h from FF system, 332.72 kW h from TF system and 344.92 kW h from CPV system.

However, to give more clear comparison, Fig. 7 shows energy generation per unit system (1 kWp) for the three types of PV systems. The total energy generation is 2728.74 kW h with 1108.16 kW h (40.6%) from fixed flat, 1057.81 kW h (38.8%) from tracking flat and 562.78 kW h (20.6%) from CPV. The TF generator experiences some technical faulty and has to be restarted few times which affected the daily operation where it only operates for 226 days compared to FF generator for 268 days and CPV for 263 days. If the TF generator operates in a normal mode condition, the expected energy generation can reach up to 2400 kW h. This is to say that based on field measurement, the daily generation of the TF generator still projects the highest energy value of 4.68 kW h/day followed by FF generator with 4.13 kW h/day and CPV with 2.14 kW h/day.

Fig. 8 shows the power efficiency value for each unit system. The power efficiency value is defined as the DC power value at the terminal of the PV array to the AC power value at the load bus bar. This value shows the impact of the wire and inverter losses in the proposed systems. It is found that the power efficiency for CPV is the lowest with 72.4% followed by FF Generator with 80.14% and the highest from TF generator with 83.15%.

On the other hand, systems' array efficiency values are shown in Fig. 9. The average efficiency values for the fixed flat system unit, the tracking system unit and the concentrated PV system

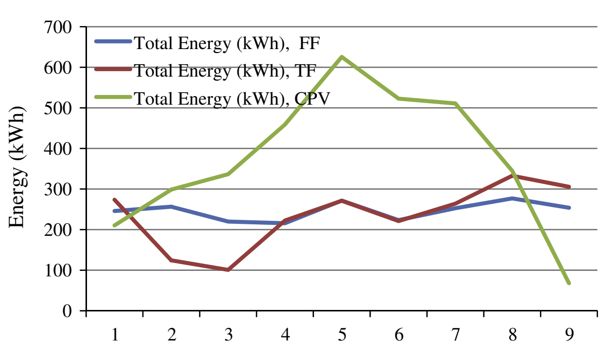


Fig. 6. Average monthly generation for the three proposed systems.

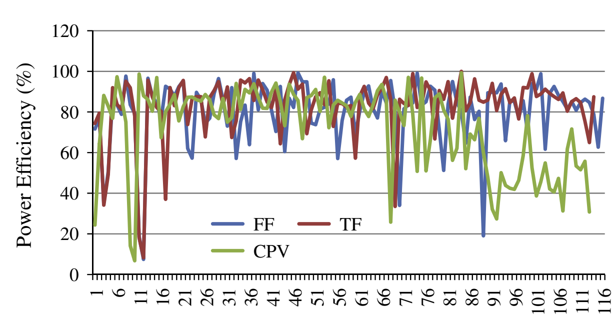


Fig. 8. Power efficiency for the three proposed systems.

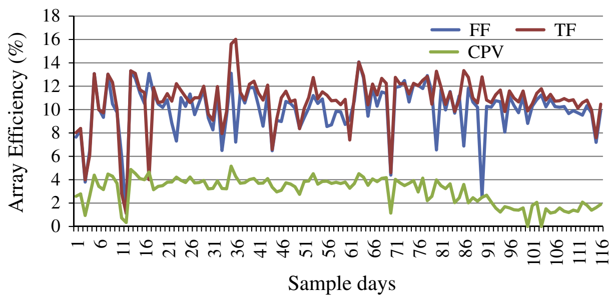


Fig. 9. PV array efficiency for the three proposed systems.

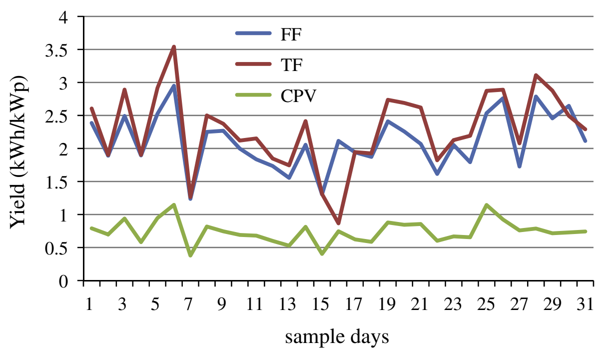


Fig. 10. Yield factor of the three proposed systems.

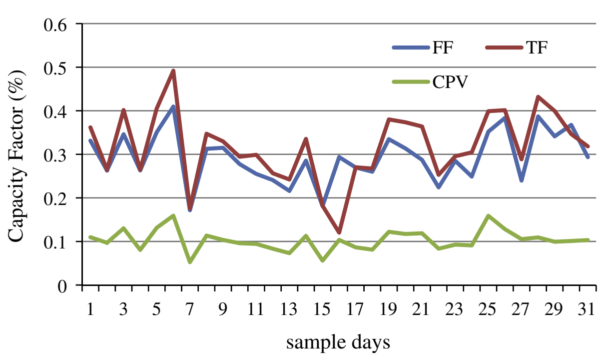


Fig. 11. Capacity factor of the three proposed systems.

unit are 10.04%, 10.78%, 3.04% respectively. These values are much lower than the claimed efficiency of 17% of the 95 W PV module. This is obviously and realistically true because of the stochastic condition at site and the series configuration of an array.

As for the yield factor values, the average daily values are 2.1 kW h/kWp for FF generator, 2.3 kW h/kWp for TF generator and 0.7 kW h/kWp for CPV generator as illustrated in Fig. 10.

Meanwhile, the Capacity Factor (CF) values are shown in Fig. 11. The capacity factor for the TF system is 32% which is the highest followed by the FF system (29%) while, the lowest value is recorded for the CPV system (10%).

The CPV generator seems to be the weakest generator based on the field output. The maximum power output for six PV modules connecting in series can reach 570 W but referring to the standard test condition (STC) and the location of testing, the manufacturer claims that this system can project twice the energy of a standard PV array where this assumption contradicts the tropical field result. The peak generation recorded for CPV clocks at 819 W at 12.00 noon which is approximately 40% increment but still not reaching 1000 W. This finding shows that the 2× concentration mirror has quite a significant effect in PV energy conversion but the most important factor is still the quantity of the PV modules applied.

Table 3 shows a summary of the performance of the three systems investigated in this research. Based on the field data of the average monthly energy generated from each PV generators, some linear correlation models can be proposed with respect to the three environmental factors, i.e. radiation (in W/m^2), ambient temperature (in °C) and wind speed (in m/s). Multiple linear regressions (MLR) with the Analysis of Variance (ANOVA) test are applied to project the correlation models as shown in

$$E_{\mathrm{FF}} = -8.52 + 1.75e^{-3} * G + 0.97 * T_a + 1.08 * v, \quad R^2 = 0.49 \tag{2}$$

$$E_{\mathrm{TF}} = -36.15 + 1.29e^{-3} * G + 1.28 * T_a + 1.27 * v, \quad R^2 = 0.63 \tag{3}$$

$$E_{\mathrm{CPV}} = 177.2 + 3.92e^{-2} * G - 6.79 * T_a + 14.53 * v, \quad R^2 = 0.65 \tag{4}$$

The summarized results in Table 3 show that the fixed flat PV system which is slanted at an optimum tilt angle for Malaysia has a performance that close to the active tracking PV system. This is because of the energy consumed by the tracking system as well as the latitude of the location (Malaysia where the selected location is 3.2°) is merely the same angle. This is to say that the sun is almost perpendicular on the horizontal surface but still, a system with an active tracking system is expected to gain more energy as compared to the fixed flat. Obviously, when it is capable to track the sun at perpendicular angle during sunrise (East) and sunset (West) the photonic effect for energy conversion will be much higher. Another important issue relates the CPV system where the performance of the system was below the expected performance. It is clear that the installed concentrating mirrors not only increases the sun radiation but also projecting heat energy especially on the top surface of the CPV generator which eventually affected the conversion efficiency of the array strongly [27–30] and consequently the generated energy by the system. The authors of this research recommend an investigation for the CPV system in terms of the PV modules quality as well as the installed mirrors situation. This future investigation wills height the problem of the CPV system whether it is technical or fundamental problem.

Table 3
Summary of the field performance for 3 PV generators based on per unit generator calculation.

System	E_{total} p.u. (kW h)	η_{Gen} (%)	η_{Power} (%)	YF (kW h/kWp)	CF (%)
Fixed Flat (FF)	1108.155	10.035	80.14	2.114	29.36
Tracking Flat (TF)	1057.810	10.784	83.15	2.291	31.82
CPV	562.777	3.044	74.4	0.742	10.31

5. Conclusions

A 10 kWp PV plant was designed and installed at a specific site in Malaysia in order to determine the most suitable system in the tropical weather condition. This PV plant is consisted of three different types of photovoltaic systems. Detailed performance evaluation of PV systems working under tropical conditions is presented. As a result, the tracking flat (TF) system is found suitable and assumed to be the trend for future grid-connected PV generators in tropical climate area. This is supported by linearly correlated energy correlation (E_{TF}) with strong correlation factor. However, technical investigation is suggested for the CPV system whereas the performance of the system was found much below the expected plus some in-depth study on the performance and techno-economical benefits for PV generators in solar farm scale.

Acknowledgements

The author thanks Mdm Jiang Shuhung from Sichuan Zhonghan Solar Power Co. Ltd. for the generous support throughout this project period. Furthermore, we delegate our thanks to the Research Management Centre (RMC), Universiti Putra Malaysia for the approval of research funding under the Project Matching Grant (Vote No: 9300400) and Ministry of Higher Education, Malaysia for the approval of Exploratory Research Grant Scheme (ERGS Vote No: 5527132).

References

[1] Haidar A, John P, Shawal M. Optimal configuration assessment of renewable energy in Malaysia. Renew Energy 2011;36:881–8.
[2] Masjuki HH, Mahlia TMI, Choudhury IA, Saidur R. Potential CO_2 reduction by fuel substitution to generate electricity in Malaysia. Energy Convers Manage 2002;43(6):763–70.
[3] Gan PY, Komiyama R, Li Z. A low carbon society outlook for Malaysia to 2035. Renew Sustain Energy Rev 2013;21:432–43.
[4] Fuentes M, Nofuentes G, Aguilera J, Talavera DL, Castro M. Application and validation of algebraic methods to predict the behaviour of crystalline silicon PV modules in Mediterranean climates. Sol Energy 2007;81:1396–408.
[5] Almonacid F, Rus C, Pérez PJ, Hontoria L. Generation of ambient temperature hourly time series for some Spanish locations by artificial neural networks. Renew Energy 2013;51:285–91.
[6] Khatib T, Mohamed A, Sopian K, Mahmoud M. Optimal sizing of the energy sources in hybrid PV/diesel systems: a case study for Malaysia. J Green Energy 2013;10(1):41–52.
[7] Kabalci E. Design and analysis of a hybrid renewable energy plant with solar and wind power. Energy Convers Manage 2013;72:51–9.
[8] Mekhilef S, Safari A, Mustaffa WES, Saidur R, Omar R, Younis MAA. Solar energy in Malaysia: current state and prospects. Renew Sustain Energy Rev 2012;16(1):386–96.
[9] Khatib T, Mohamed A, Sopian K, Mahmoud M. Optimization of tilt angle for solar panel for Malaysia. J Energy Sources A 2011, http://dx.doi.org/10.1080/15567036.2011.588680 [in publish].
[10] Ya'acob ME, Hizam H, Htay MT, Radzi MAM, Khatib T, Adam MB. Calculating electrical and thermal characteristics of multiple PV array configurations installed in the tropics. Energy Convers Manage 2013;75:418–24.
[11] Trinuruk P, Sorapipatana C, Chenvidhya D. Estimating operating cell temperature of BIPV modules in Thailand. Renew Energy 2009;34:2515–23.
[12] Daut I, Zainuddin F, Irwan YM, Razliana ARN. Analysis of solar irradiance and solar energy in Perlis, Northern of Peninsular Malaysia. Energy Proc 2012;18:1421–7.
[13] Khatib T, Mohamed A, Mahmoud M, Sopian K. Modeling of daily solar energy on a horizontal surface for five main sites in Malaysia. Int J Green Energy 2011;8:795–819.
[14] Sasitharanuwat A, Rakwichian W, Ketjoy N, Yammen S. Performance evaluation of a 10 kW_p PV power system prototype for isolated building in Thailand. Renew Energy 2007;32(8):1288–300.
[15] Ye Z, Nobre A, Reindl T, Luther J, Reise C. On PV module temperatures in tropical regions. Sol Energy 2013;88:80–7.
[16] Amin N, Lung CW, Sopian K. A practical field study of various solar cells on their performance in Malaysia. Renew Energy 2009;34(8):1939–46.
[17] Compared Assessment of Selected Environmental Indicators of PV. Electricity in selected OECD cities and Malaysian cities, PTM/MBIPV/C3, 14th August, 2006.
[18] Ekechukwu OV, Norton B. Experimental studies of integral-type natural-circulation solar-energy tropical crop dryers. Energy Convers Manage 1997;38(14):1483–500.
[19] Khatib T, Mohamed A, Sopian K. Optimization of a PV/wind micro-grid for rural housing electrification using a hybrid iterative/genetic algorithm: case study of Kuala Terengganu, Malaysia. Energy Build 2012;47:321–31.
[20] Solanki CS, Sangani CS, Gunashekar D, Antony G. Enhanced heat dissipation of V-trough PV modules for better performance. Sol Energy Mater Sol Cells 2008;92(12):1634–8.
[21] Tang R, Liu X. Optical performance and design optimization of V-trough concentrators for photovoltaic applications. Sol Energy 2011;85(9):2154–66.
[22] Sangani CS, Solanki CS. Experimental evaluation of V-through (2 suns) PV concentrator system using commercial PV modules. Sol Energy Mater Sol Cells 2007;91(6):453–9.
[23] Li M, Li GL, Ji X, Yin F, Xu L. The performance analysis of the trough concentrating solar photovoltaic/thermal system. Energy Convers Manage 2011;52(6):2378–83.
[24] Thomas A. Solar steam generating systems using parabolic trough concentrators. Energy Convers Manage 1996;37(2):215–45.
[25] M.S IEC 61836:2010 solar photovoltaic energy systems – terms, definitions and symbols.
[26] Hajjah A, Khatib T, Sopian K, Sebzali M. Performance of grid-connected photovoltaic system in two sites in Kuwait. Int J Photoenergy 2012: 178175.
[27] Skoplaki E, Palyvos JA. On the temperature dependence of photovoltaic module electrical performance: a review of efficiency/power correlations. Sol Energy 2009;83(5):614–24.
[28] Minemoto T, Takahashi H, Nakada Y, Takakura H. Outdoor performance evaluation of photovoltaic modules using contour plots. Curr Appl Phys 2010;10(2):S257–60.
[29] Nagae S, Toda M, Minemoto T, Takakura H, Hamakawa Y. Evaluation of the impact of solar spectrum and temperature variations on output power of silicon-based photovoltaic modules. Sol Energy Mater Sol Cells 2006;90(20):3568–75.
[30] Park KE, Kang GH, Kim HI, Yu GJ, Kim JT. Analysis of thermal and electrical performance of semi-transparent photovoltaic (PV) module. Energy 2010;35(6):2681–7.