International Journal of Power Electronics and Drive Systems (IJPEDS)
Vol. 14, No. 1, March 2023, pp. 506~515
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v14.i1.pp506-515

Simulation and prediction of residential grid-connected photovoltaic system performance

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Article Info

Article history:

Received Aug 26, 2022
Revised Nov 9, 2022
Accepted Nov 25, 2022

Keywords:

Equatorial region
GCPV
Mathematical model
PVsyst
Technical performance

ABSTRACT

This paper presents the analysis of the actual, predicted, and simulated technical performance of a residential 2.835 kW_p retrofitted grid-connected photovoltaic (GCPV) system under the feed-in-tariff (FiT) scheme in Klang, Malaysia located in the equatorial region. The technical performance indices of the GCPV system were assessed based on the three-year energy production in 2018, 2019 and 2020. The actual and predicted technical performance were calculated using SEDA mathematical model, which the solar irradiation data was acquired from PVsyst software. Meanwhile, the simulated technical performance was obtained using PVsyst software. The results showed that the prediction using mathematical model has higher percentage difference within the range of 12.54%-13.29%, compared to PVsyst simulation that was within 7.93%-11.93%. This study has highlighted the factors that contributed to the technical performance underprediction of both mathematical model and PVsyst simulation, which are the estimation of losses and annual irradiation data accuracy. Lastly, the annual FiT gross income calculated for the three consecutive years were within the range of 3310.80 MYR and 3357.30 MYR. This FiT gross income result conveys an example of Malaysian case study, to enlighten the public, on the economic aspect of installing GCPV system under FiT scheme.

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1. INTRODUCTION

Electricity demand in the residential building industry expanding fast due to revenue growth, rise in population, and escalating request for electronics products and personal items [1]. Asia experienced the fastest rise in household power consumption between 2012 and 2017, with an average annual increase of 3.7% [2]. It is estimated that the amount of power consumed by residential buildings will double over the course of 32 years, rising from 22 quadrillion BTU in 2018 to 50 quadrillion BTU in 2050 [3]. The depletion of coal and fossil fuels resources is another major factor contributing to the surge in utilization of renewable energy particularly solar energy through solar photovoltaic (PV) technology. This is also supported by the declining and promising trend of PV modules cost over the conventional energy cost. Therefore, the demand of solar energy sources have increase and it is predicted that it will cover 50% of the total world electricity generation in 2050 [3], [4].

Southeast Asia's electricity consumption increase, approximated at 6% per year, has become one of the highest globally [5]. Malaysia has lately made way among Southeast Asian countries in expanding installed solar PV capacity. Solar irradiation (H) map for Malaysia that was developed using 40 sites meteorological stations data spanning from 2 to 65 years reported daily solar irradiation ranging from 3.83 kWh/m^2 to 5.39 kWh/m^2 [6]. A study in Monash University, Bandar Sunway, Selangor on the performance of grid-connected photovoltaic (GCPV) system reported daily solar H ranging from 4.21 kWh/m^2 to 5.56 kWh/m^2 [7]. Leading up ahead other renewable energy sources, solar PV is one of Malaysia's fastest-growing sectors [8]. Due to its proximity to the equator, Malaysia enjoys abundant solar energy resources all year round [9]. According to international renewable energy agency (IRENA) statistics 2021 [10], Malaysia's amount of solar PV production increased rapidly which recorded 420 GWh, 440 GWh and 490 GWh for year 2018, 2019 and 2020 respectively.

The government of Malaysia (GoM) plays it roles in promoting the widely usage of PV systems. One of the initiatives is by providing incentives and enabling policies. Under national renewable energy policy and action plan (2010), the GoM has launched the feed-in tariff (FiT) program. Malaysia's FiT mechanism is currently implemented by Ministry of Energy, Green Technology and Water (KeTTHA) via the SEDA Malaysia [11]. FiT generally refers to the tariff of electricity in kilowatt-hours (kWh) for renewable energy. FiT is believed to bring attention about the relevance and necessity of renewable resource, on that account FiT promotes exportation of electricity as a form of investment towards users [12]. Based on the experience of other nations and international energy policy specialists, most studies concluded that FiTs are the most effective renewable energy policy system for encouraging and maintaining renewable energy growth [13].

There are a few parameters used to analyze the performance of GCPV system which include energy production, daily yield, annual yield, seasonal yield, reference yield, final yield, array yield, performance ratio, capacity factor, system efficiencies, and system losses [1]. Several sizing models are accessible globally, including mathematics, simulation, and artificial intelligence. SEDA's GCPV system design model is reported to be the recommended mathematical-based design approach for scenarios in Malaysia tropical climate [14]. Numerous software are available to simulate and analyze the performance of GCPV systems such as PVsyst, HOMER, PVSOL, PVGIS, solar GIS, and SISISFO [1]. The simulated performance of a GCPV system comprises the design, technical, economical, and environmental performances.

A study on a 1 kW$_p$ GCPV system which is located at Swamibag, Bangladesh was designed, and the performance was predicted using PVsyst software [15]. In the north equatorial, a 1 MW$_p$ GCPV system performance analysis was conducted, located at the Benina International Airport (BIA), Benghazi, Libya using PVsyst 6.8 [16]. Another study conducted at Marine and Fisheries Polytechnic of Kupang, which is under equatorial climate region also analyzed the predicted performance of PV system at a potential spot for solar energy using PVsyst 7.1 software [4]. Moreover, another similar study under the same climate region, which site was in Sungai Petani, Kedah, Malaysia presented design and simulation on technical performance of a 45 MW$_p$ fixed-tilt ground-mounted GCPV system using PVsyst 7.2 software [17]. Due to the limited case studies on the technical performance of the GCPV system in the equatorial region, this study aims to present the analysis of the actual, predicted and simulated technical performance of a GCPV system in Klang, Malaysia. However, in this study, the technical performance indices are limited to energy yield (Y), specific yield (SY), performance ratio (PR) and capacity factor (CF).

2. METHOD

The four parameters of technical performance indices of the GCPV system analyzed in this study were Y, SY, PR, and CF. All these technical performance indices were compared annually for actual, predicted, and simulated values. Lastly, the annual gross income generation from the exported energy was calculated based on the FiT approval by SEDA Malaysia. Figure 1 shows the framework of this study.

2.1. GCPV system and site descriptions

The chosen case study was a retrofitted residential GCPV system located in Klang, Malaysia with a capacity of 2.835 kW$_p$. The system was set up at the rooftop of the residential with a 30° tilt angle as shown in Figure 2. There were three years set of data, from 2018 to 2020 that was analyzed in this study. Table 1 describes the general information of the GCPV system while Table 2 provides the PV module and inverter descriptions and specifications.

2.2. Technical performance

2.2.1. Actual

The actual annual energy yield for this GCPV system was obtained from data logger system of Solar-log website [18] for the three years data which were 2018, 2019 and 2020. The website is a SEDA certified PV service provider which is accessible by the owner of the PV system. This website offers a range of services as an aid to the PV system customers so that they can manage energy costs through a strategic energy management system.

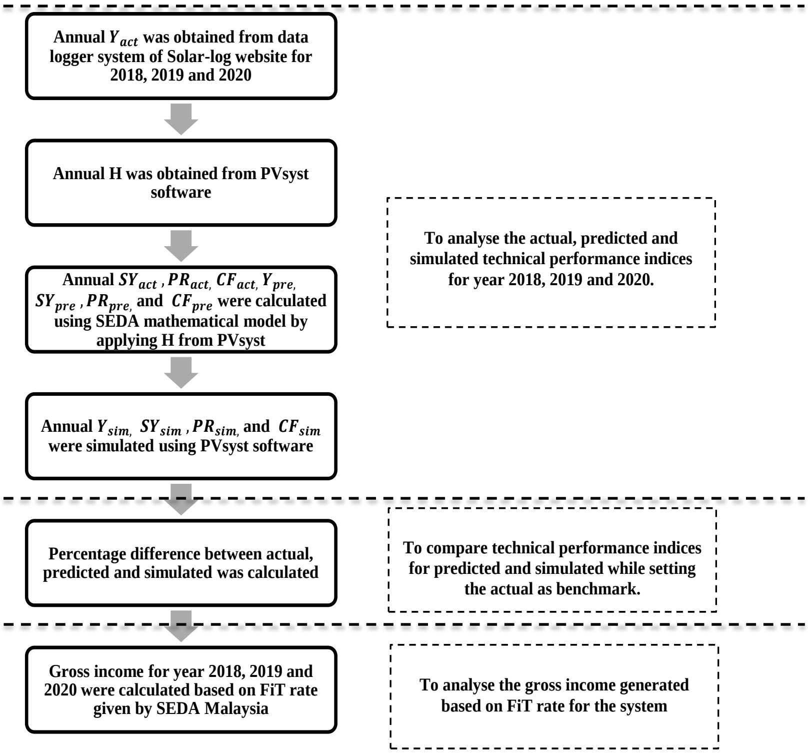

Figure 1. Framework of the study

Figure 2. 2.835 kW_p retrofitted GCPV system in Klang, Selangor

Table 1. General information of selected GCPV system

Subjects	Descriptions
Location	Klang, Malaysia
Latitude and Longitude	3.00° N and 101.50° E
Altitude	7 m
Time zone	UTC +8
System type	Grid-connected system
Mounting type	Retrofitted (RF)

Table 2. PV module and inverter descriptions/specifications

Subjects	Descriptions
PV module model	JKM 315PP-72-V
Unit nominal power	315 W_p
Nb. of modules	9 units (1 string x 9 in series)
Nominal power (STC)	2835 W_p
P_{mpp}	315 W_p
V_{mpp}	37.2 V
I_{mpp}	8.48 A
Inverter model	Steca grid 3010
Nb. of units	1 unit
Nominal power	3000 W
Operating voltage	125-500 V

2.2.2. Predicted

The predicted technical performance was analyzed using mathematical model [19]. The predicted annual H was obtained from PVsyst software. The value of H obtained from PVsyst for 30° tilt angle is 1472.6 $kWhm^{-2}$ [20]. This value was kept as constant for predicted and simulated technical performance to ensure significant comparison analysis.

Next, the calculation using mathematical model was conducted. Y_{pre} was calculated as expressed by [19]:

$$Y_{pre}(kWh) = P_{pmp_{array_{stc}}}(kW) \times PSH(h) \times LF_{env} \times LF_{tec} \quad (1)$$

$$PSH\ (h) = \frac{H\ (\mathrm{kWh/m^2})}{G_o\ (\mathrm{kW/m^2})} \quad (2)$$

$$L_{env} = k_{dirt} \times k_{shade} \quad (3)$$

$$L_{tec} = k_{mm} \times k_{age} \times k_{tem} \times \eta_{cable} \times \eta_{inv} \quad (4)$$

$$k_{tem} = 1 + [\left(\frac{\alpha_{power}\left(\frac{\%}{°C}\right)}{100\%}\right) \times (T_{cell\_ave\_max}(°C) - T_{stc}(°C)) \quad (5)$$

$$T_{cell\_ave\_max}\ (°C) = T_{amb\_ave\_max}\ (°C) + T_{elevated}(°C) \quad (6)$$

where Y_{pre} is predicted energy yield, $P_{pmp\_array\_stc}$ is the power of photovoltaic array at standard test condition (STC), PSH is the peak sun hour per annum, G_o is the solar irradiance at STC which is 1000 ($\mathrm{kW/m^2}$), LF_{env} is the environmental loss factor, LF_{tec} is the technical loss factor, k_{dirt} is dirt de-rating factor, k_{shade} is shade de-rating factor, k_{mm} is module mismatch de-rating factor, k_{age} is aging de-rating factor, η_{cable} is DC cable efficiency from PV to inverter while η_{inv} is inverter efficiency. All mentioned loss factor parameters were set the same values as PVsyst, as tabulated in Table 3 except for temperature de-rating factor, k_{tem} as the value was calculated using mathematical model. α_{power} is the temperature coefficient of maximum power which was obtained from manufacturer datasheet whereby $T_{cell\_ave\_max}$ is average maximum cell temperature was calculated using (6). Average maximum ambient temperature, $T_{amb\_ave\_max}$ was obtained from timeanddate.com website which the data is based on the weather station in Sultan Abdul Aziz Shah Airport in Subang, Malaysia. T_{stc} is the cell temperature at STC whereby $T_{elevated}$ is elevated temperature [21].

Table 3. Environmental and technical losses for mathematical model and PVsyst

No	Mathematical Model		PVsyst		References		
	Parameters	Values (%)	Parameters	Values	Manufacturer Datasheet	PVsyst Default	Other
1	k_{mm}	2.0%	Module mismatch losses: power loss at MPP	2.0%	M, P		
2	k_{tem}	14.0%	Temperature losses	9.9%		P	M, [19]
3	k_{dirt}	3.0 %	Soiling	3.0%		P	M,
4	k_{age}	0.63%/year	Aging average degradation factor	0.63%/year	M, P		
5	k_{shade}	-	Shading	-	-	-	-
6	η_{cable}	3.0%	η_{cable}	3.0%		P	M, [23]
7	η_{inv}	2.0%	η_{inv}	2.0%	M, P		
8			Module quality	-0.8%		P	
9			Light induced degradation	2.5%	P		
10			Strings voltage mismatch	0.1%		P	
11			Incidence angle modifier losses	3.46%		P	

'M' for mathematical model and 'P' for PVsyst

Next, the predicted specific yield, SY_{pre} which is the amount of energy generated by the system per unit capacity [19]. The value was calculated by using (7). The (8) shows the expression of predicted performance ratio, PR_{pre} while (9) is the ideal yield, Y_{ideal}.

$$SY_{pre}\left(\frac{\mathrm{kWh}}{\mathrm{kW}_p}\right) = \frac{Y_{pre}}{\mathrm{P}_{pmp\_array\_stc}} \quad (7)$$

$$PR_{pre} = \frac{\mathrm{Ypre}}{Y_{ideal}} \quad (8)$$

$$Y_{ideal}\ (kWh) = \frac{\mathrm{Ppmp\_array\_stc}}{PSH} \quad (9)$$

The last parameter calculated was the predicted capacity factor, CF_{pre} of the system. The parameter can be expressed by (10). All the technical performance parameters were compared between actual and predicted, and actual and simulated by calculating their percentage differences. The percentage difference can be expressed by (11) for predicted indices, and (12) for simulated indices [22].

$$CF_{pre}(\%) = \frac{Y_{pre}}{P_{pmp\_array\_stc} \text{x } 365 \text{ x } 24} \times 100\% \tag{10}$$

$$Percentage\ difference_{pre}\ (\%) = 2 \times \left|\frac{(Y_{act}-Y_{pre})}{(Y_{act}+Y_{pre})}\right| \times 100\% \tag{11}$$

$$Percentage\ difference_{sim}\ \ (\%) = 2 \times \left|\frac{(Y_{act}-Y_{sim})}{(Y_{act}+Y_{sim})}\right| \times 100\% \tag{12}$$

2.2.3. Simulated

The annual energy yield was simulated by using PVsyst software [20]. There are two important sections comprise relevant parameters must be defined to carry out the design simulation. First section is to state the chosen geographical location for the GCPV system installed. PVsyst database provides the meteorological file based on the user input on latitude, longitude and altitude which must be associated with data source that is provided by the software. In this case, Meteonorm 8.0 is the database used for meteorological file.

The second section is to state out the technical parameters which undertake the orientation, system definition and losses. PVsyst defines azimuth angle in northern hemisphere as the angle between south and collector plane. This angle is taken as negative toward east. The orientation is appertaining to the azimuth and tilt angle of the system which are 180° and 30° respectively. Other than that, the system definition sets out the PV module and inverter description as shown in Table 2.

Next, the detailed losses must be estimated based on the system to obtain accurate simulation result. Table 3 shows the environmental and technical losses input for both PVsyst software and the mathematical model. All the parameters were set as the same values for both methods except for k_{tem} calculation in the mathematical model, by referring to (5). However, in this study, there are some additional losses in PVsyst compared to the mathematical model. The additional losses which are module quality, strings voltage mismatch, and incidence angle modifier were set using PVsyst default values except for light induced degradation that was set using value from manufacturer's data sheet as shown in Table 3.

2.3. Gross income generation from feed-in tariff scheme

FiT was enacted by Ministry of Energy, Green Technology and Water by virtue of the SEDA Malaysia. FiT was brought under the 10th Malaysian Plan with a few aims. One of the aims is to enhance awareness on the role and importance of renewable energy. Besides that, it is an incentive to increase renewable energy utilization [24]. Furthermore, the FiT was also created to encourage the sale of electricity to National Grid. Nevertheless, the information on the profit from the FiT scheme in Malaysia is still limited. Therefore, this study has conducted calculation on the gross income generation of the GCPV system. The annual gross income generation can be determined based on the annual energy generation multiplied by the FiT rate. The FiT rate was obtained from the Feed-in Approval given by SEDA Malaysia on the 21$^{st\ of}$ December 2016. The (13) shows the expression of the gross income generation in MYR.

$$\text{Gross income generation (MYR)} = \text{Energy Yield} \times 0.93 \text{ MYR} \tag{13}$$

3. RESULTS AND DISCUSSION

In this section, the actual, predicted, and simulated technical performance for year 2018, 2019 and 2020 were analysed. The data was presented in bar charts. The actual results were set as benchmark to compare with both predicted and simulated technical performance indices comprises of Y, SY, PR and CF. In addition, this section also includes the comparison of actual, predicted, and simulated annual gross income obtained by the owner of the GCPV system based on the approved FiT rate by SEDA Malaysia for three consecutive years. The results were presented in a line graph.

3.1. Energy yield

Figure 3 shows that the three years, which Y_{act} for year 2018 was 3.61 MWh. Interestingly for both years of 2019 and 2020, the Y_{act} were the same which was 3.56 MWh. Typically, the value of Y_{act} will be decreasing as the year increases because of the aging factor. This aging factor is related to the power output degradation rate of the PV module. In this case, the average power degradation rate for the PV module is 0.63%/year. However, Y_{act} is also greatly dependable to the H obtained throughout the entire year [11] and this might be one of the factors that causes Y_{act} for both years to be the same.

The Y_{pre} was calculated using the mathematical model as mentioned in (1). $P_{pmp\_array\_stc}$ was a constant value of 2.835 kW_p, which was presented in the mathematical model of (1). The values present in LF_{env} formulas were the same for the three years analysis except for LF_{tec}, which consist of the k_{age} of the system. As the system get older, the cumulative k_{age} will increase with the rate as claimed by the manufacturer.

Y_{sim} was obtained by using PVsyst 7.2 software for three consecutive years. The PVsyst simulated design of the GCPV system indicated that the rated inverter power installed was slightly oversized, which is 3 kW. Furthermore, there are four additional losses in PVsyst software as stated in Table 3 and were set as default values according to [23].

Figure 3 shows the Y_{act}, Y_{pre} and Y_{sim} comparison for year 2018, 2019 and 2020 of the GCPV system in Klang. Y_{act} has the highest value for all three years, 3610 kWh, 3560 kWh and 3560 kWh, respectively. Meanwhile, Y_{pre} shows the lowest value of 3160.2 kWh, 3139.8 kWh and 3119.4 kWh for the respective years. The Y_{pre} values are underpredicted by 13.29%, 12.54% and 13.19% when compared to Y_{act}. Furthermore, Y_{sim} values are also underpredicted by 8.69%, 7.93% and 8.57% when compared to Y_{act}. The percentage differences of Y_{sim} are slightly lower than Y_{pre}, which implies that PVsyst is more accurate as compared to SEDA mathematical model. The possible reason contributed to the significant underprediction of the mathematical model results was due to higher temperature losses calculated (k_{tem}) compared to PVsyst.

3.2. Specific yield

The SY of the systems for both actual and predicted were calculated by using (7) whereby the SY_{sim} values were obtained directly from PVsyst report. Figure 4 shows the actual, predicted and simulated specific yield for 2018, 2019 and 2020. Referring to the energy yield results for 2018, the SY_{act} showed the maximum value of 1294.53 kWh/kW_p concurrently the minimum value was 1100.32 kWh/kW_p which was SY_{pre}. The SY_{sim} was ranging from 1116.00 kWh/kW_p to 1130.00 kWh/kW_p. The specific yield results obtained for the actual, predicted and simulated showed similar pattern to energy yield results because they are corresponded and inter-related.

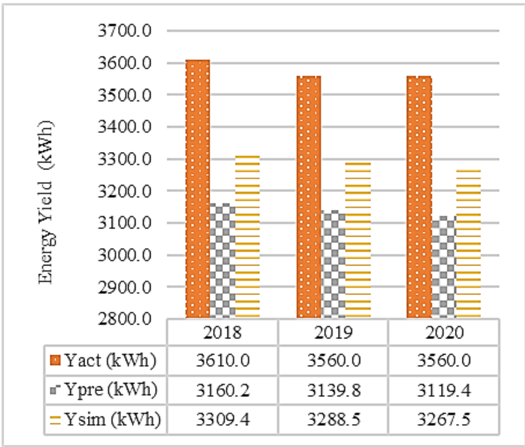

Figure 3. Comparison of Y_{act}, Y_{pre} and Y_{sim} for year 2018, 2019 and 2020

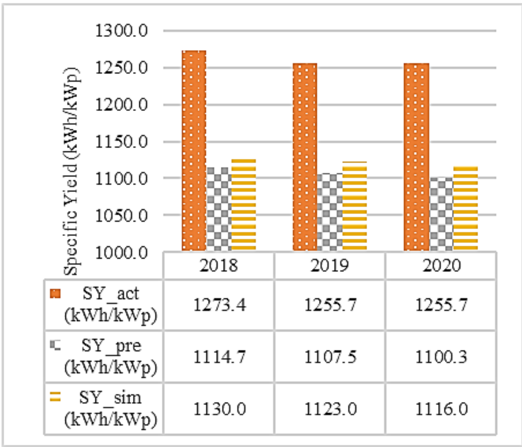

Figure 4. Comparison of SY_{act}, SY_{pre}, and SY_{sim} for year 2018, 2019 and 2020

3.3. Performance ratio

Figure 5 presents the actual, predicted, and simulated PR for 2018, 2019 and 2020. The PR of the system for both actual and predicted were calculated using (8) and the simulated was obtained from the PVsyst report. The PR_{sim} for year 2018, 2019 and 2020 were ranging from 0.76 to 0.77. The maximum PR was PR_{act} for year 2018, which is 0.86. The percentage difference between PR_{sim} and PR_{act} is ranging between 11.15% to 11.89%. The lowest PR was PR_{pre} for year 2019 and 2020, which was 0.75. The percentage difference between PR_{pre} and PR_{act} is ranging between 12.54% to 13.29%. Based on the values of PR calculated in this study, it is evidently shown that the range obtained for the prediction and simulation system in Klang for three consecutive years is acceptable but quite alarming since the minimum PR values required by Malaysia's procedure for the testing and commissioning of GCPV systems is 0.75 [25].

3.4. Capacity factor

Figure 6 presents the actual, predicted, and simulated CF for 2018, 2019 and 2020. The CF of the systems for both actual and predicted were calculated using (10) and the simulated was obtained from the PVsyst report. The CF_{act} were in the range of 14.33% -14.54%, which for both years of 2019 and 2020, possessed the same value. This was due to the similar value of Y for the respective years. CF_{pre} were in the range of 12.56% to 12.72%. Next, CF_{sim} were found within the values of 13.16% to 13.33%. The CF results obtained for the actual, predicted and simulated showed similar pattern to energy yield results because they are corresponded and inter-related.

Table 4 presents the results of the technical performance indices along with the percentage difference of predicted values and simulated values when comparing with actual values. From the overall point of view, PVsyst simulation has a lower percentage difference compared to prediction using SEDA mathematical model. The range of predicted percentage difference was between 12.54% to 13.29% while the range of simulated percentage difference was between 7.93% to 11.93%. The reason is due to k_{tem} declared in mathematical model was higher than PVsyst. The value also surpassed the four additional losses declared in PVsyst simulation.

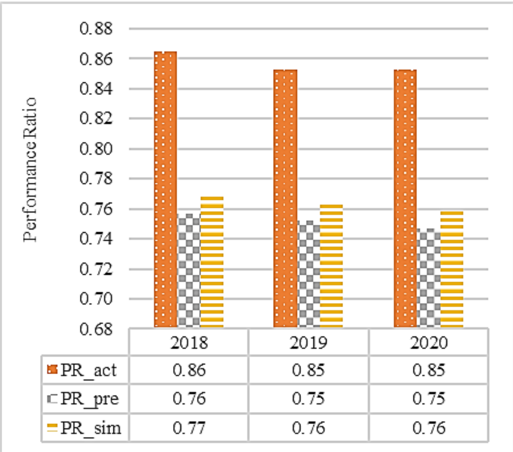

Figure 5. Comparison of PR_{act}, PR_{pre}, and PR_{sim} for year 2018, 2019 and 2020

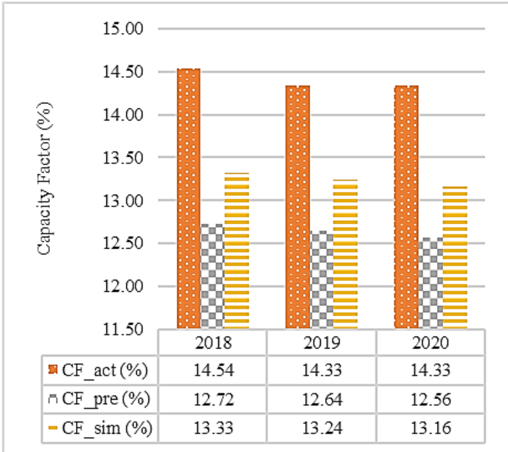

Figure 6. Comparison of CF_{act}, CF_{pre}, and CF_{sim} for year 2018, 2019 and 2020

Table 4. Summary of technical performance indices results with respective percentage difference.

Year	Performance Indices	Actual (A)	Predicted (P)	Simulated (S)	Percentage difference pre (%)=$2\times\left\|\frac{(A-P)}{(A+P)}\right\|$ x 100%	Percentage difference sim (%)=$2\times\left\|\frac{(A-S)}{(A+S)}\right\|$ x 100%
2018	Y (MWh)	3.61	3.67	3.41	13.29	8.69
	SY (kWh/kWp)	1273.37	1294.53	1179.00	13.29	11.93
	PR (%)	75.98	77.24	78.07	13.29	11.89
	CF (%)	14.54	14.78	13.73	13.29	8.69
2019	Y (MWh)	3.56	3.65	3.32	12.54	7.93
	SY (kWh/kWp)	1255.73	1287.48	1171.00	12.54	11.16
	PR (%)	74.92	76.82	77.55	12.54	11.15
	CF (%)	14.33	14.70	13.37	12.54	7.93
2020	Y (MWh)	3.56	3.62	3.30	13.19	8.57
	SY (kWh/kWp)	1255.73	1276.90	1162.00	13.19	11.78
	PR (%)	74.92	76.19	77.01	13.19	11.79
	CF (%)	14.33	14.58	13.29	13.19	8.57

In summary, for the technical performance indices, mathematical model and PVsyst was observed tend to underpredict but SEDA mathematical model was perceived to be more inaccurate. It is noteworthy to emphasize that one of the implications due to underprediction of GCPV technical performance, is the inaccuracy of estimating the payback period of the initial investment especially when applying financial loans.

3.5. Feed-in tariff

The FiT_{act}, FiT_{pre} and FiT_{sim} represent the annual gross income generated based on the FiT rate for actual, predicted and simulated respectively. Figure 7 shows the actual, predicted and simulated gross income generation from the exported energy to utility based on FiT rate of 0.93 MYR/kWh or 0.22 USD/kWh for year 2018, 2019 and 2020. The FiT_{act} acts as the benchmark to be compared with the predicted and simulated value. The range for FiT_{act} is between 3310.80 MYR and 3357.30 MYR or equivalent to 743.67 USD and 754.11 USD for three consecutive years. The percentage differences between FiT_{act} and FiT_{pre} were in the range of 12.54% to 13.29%. Meanwhile the percentage differences between FiT_{act} and FiT_{sim} were ranging between 7.93% to 8.69%.

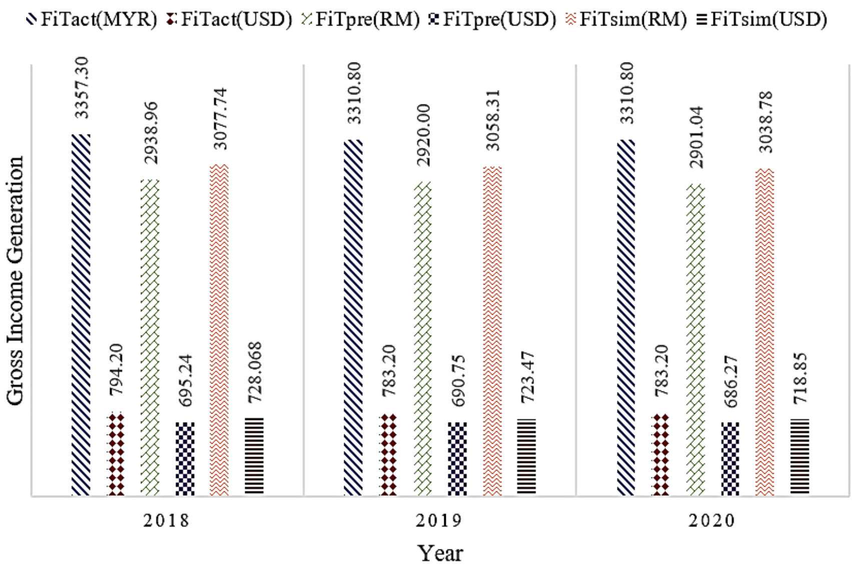

Figure 7. Annual gross income generation from the exported energy

4. CONCLUSION

This study has presented the analysis on the technical performance indices of a GCPV system under the equatorial climate region, consisting of Y, SY, PR and CF. This study has succeeded to compare the indices between actual, predicted using mathematical model and simulated using PVsyst software. The prediction using mathematical model has a percentage difference within the range of 12.54% to 13.29% compared with actual results. On the other hand, the simulation using PVsyst has the percentage difference within the range of 7.93% to 11.93%. Based on the comparative study among the annual actual, predicted, and simulated results of the technical performance, it can be concluded that the analysis using PVsyst software is more accurate than SEDA mathematical model in analyzing the technical performances for residential GCPV system in Malaysia. The comparison between both methods were made by setting all controllable parameters as close as possible to reduce uncertainty on the comparison analysis. The comparison analysis concluded that the two main factors that contributed to the percentage difference were the accuracy of the irradiation data and estimation of the supplementary losses in PVsyst software including module quality, light induced degradation, strings voltage mismatch and incidence angle modifier. In addition, the gross income analysis based on the FiT rate has been presented for actual, predicted, and simulated case study for GCPV system under FiT incentive in Malaysia. This analysis has delivered an example of a case study to inform the public on the economic point of view of installing GCPV.

ACKNOWLEDGEMENTS

The authors express gratitude to the owner of the GCPV system and Solar Photovoltaic Energy Conversion Technology and Research Application (SPECTRA) group for the valuable inputs, and Geran Insentif Penyeliaan (GIP) research grant 600-RMC/GIP 5/3 (090/2021) for funding this research.

REFERENCES

[1] N. Anang, S. N. A. Syd Nur Azman, W. M. W. Muda, A. N. Dagang, and M. Z. Daud, "Performance analysis of a grid-connected rooftop solar PV system in Kuala Terengganu, Malaysia," *Energy and Build.*, vol. 248, p. 111182, 2021, doi: 10.1016/j.enbuild.2021.111182.

[2] S. Kusch-brandt, "Urban renewable energy on the Upswing: REN21's renewables 2019 global status report," *Resources*, vol. 8, no. 3, pp. 1–5, 2019, doi: 10.3390/resources8030139.

[3] U.S. EIA, "International energy outlook 2019 (IEO2019) reference case," U.S. Energy Inf. Adm., vol. 2019, 2019. [Online]. Available: https://www.eia.gov/outlooks/ieo/pdf/ieo2019.pdf

[4] I. M. A. Nugraha, and I. G. M. N. Desnanjaya, "Technical, economic, and social impact of photovoltaic at dormitory building," vol. 13, no. 3, pp. 1666–1674, 2022, doi: 10.11591/ijpeds.v13.i3.pp1666-1674.

[5] IEA, "Southeast asia energy outlook 2019," Paris, 2019. [Online]. Available: https://www.iea.org/reports/southeast-asia-energy-outlook-2019

[6] SEDA Malaysia, 2016, "Solar Irradiance Data For Malaysia," Putrajaya, Malysia: Sustainable Energy Development Authority Malaysia, 2016.

[7] M. Z. Saleheen, A. A. Salema, S. M. Mominul Islam, C. R. Sarimuthu, and M. Z. Hasan, "A target-oriented performance assessment and model development of a grid-connected solar PV (GCPV) system for a commercial building in Malaysia," *Renew. Energy*, vol. 171, pp. 371–382, 2021, doi: 10.1016/j.renene.2021.02.108.

[8] S. C. Chua, and T. H. Oh, "Solar energy outlook in Malaysia," *Renew. Sustain. Energy Rev.*, vol. 16, no. 1, pp. 564–574, 2012, doi: 10.1016/j.rser.2011.08.022.

[9] F. Muhammad-Sukki, R. Ramirez-Iniguez, S. H. Abu-Bakar, S. G. McMeekin, and B. G. Stewart, "An evaluation of the installation of solar photovoltaic in residential houses in Malaysia: Past, present, and future," *Energy Policy*, vol. 39, no. 12, pp. 7975–7987, 2011, doi: 10.1016/j.enpol.2011.09.052.

[10] Renewable Energy Statistics 2021, vol. 56, no. January 2019. 2021.

[11] S. L. Wong, N. Ngadi, T. A. T. Abdullah, and I. M. Inuwa, "Recent advances of feed-in tariff in Malaysia," *Renew. Sustain. Energy Rev.*, vol. 41, pp. 42–52, 2015, doi: 10.1016/j.rser.2014.08.006.

[12] S. C. Chua, T. H. Oh, and W. W. Goh, "Feed-in tariff outlook in Malaysia," *Renew. Sustain. Energy Rev.*, vol. 15, no. 1, pp. 705–712, 2011, doi: 10.1016/j.rser.2010.09.009.

[13] S. A. Koerner, W. S. Siew, A. A. Salema, P. Balan, S. Mekhilef, and N. Thavamoney, "Energy policies shaping the solar photovoltaics business models in Malaysia with some insights on Covid-19 pandemic effect," *Energy Policy*, vol. 164, 2022, doi: 10.1016/j.enpol.2022.112918.

[14] F. A. M. Shukor, H. Zainuddin, A. Manja, and F. L. M. Khir, "Sizing verification of a 4kWp retrofitted grid-connected photovoltaic system: A case study in Shah Alam, Malaysia," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 17, no. 2, pp. 654–661, 2019, doi: 10.11591/ijeecs.v17.i2.pp654-661.

[15] S. Das, D. Chowdhury, and M. A. Razzak, "System efficiency prediction of a 1kw capacity grid-tied photovoltaic inverter," *Int. J. Power Electron. Drive Syst.*, vol. 12, no. 2, pp. 1177–1186, 2021, doi: 10.11591/ijpeds. v12.i2. pp1177-1186.

[16] M. Almaktar, A. M. Albreki, F. A. Mohamed, K. Yahya, and T. Hussein, "Performance evaluation of different solar photovoltaic technologies in Libya," *11th Int. Renew. Energy Congr. IREC 2020*, no. Irec, pp. 11–15, 2020, doi: 10.1109/IREC48820.2020.9310421.

[17] N. S. S. Mohamed, S. I. Sulaiman, and S. R. A. Rahim, "Design of ground-mounted grid-connected photovoltaic system with bifacial modules using PVsyst software," in *Journal of Physics: Conference Series*, 2022, vol. 2312, no. 1, doi: 10.1088/1742-6596/2312/1/012058.

[18] Pekat Solar-log, Pekat Solar-log Retrieved, 2020, [Online] Available: https://pekat.solarlog-web.com.my/PO.html

[19] SEDA Malaysia Grid-connected Design Course. Putrajaya, Malysia: Sustainable Energy Development Authority Malaysia, 2016.

[20] PVsyst 7.2. (2022). [Online]. Available: https://www.pvsyst.com/help/

[21] timeanddate. (1995 - 2022). [Online]. Available: https://www.timeanddate.com/

[22] N. Z. Zakaria, H. Zainuddin, S. Shaari, A. M. Omar, and S. I. Sulaiman, "Grid- connected photovoltaic system performance prediction using long-term weather data," *Scientific Research Journal*, vol. 17, no. 1, 2020, doi: 10.24191/srj.v17i1.6321.

[23] B. Marion *et al.*, "Performance parameters for grid-connected PV systems," *Conference Record of the IEEE Photovoltaic Specialists Conference*, 2005, pp. 1601–1606, doi: 10.1109/PVSC.2005.1488451

[24] H. Zainuddin, H. R. Salikin, S. Shaari, M. Z. Hussin, and A. Manja, "Revisiting solar photovoltaic roadmap of tropical malaysia: Past, present and future," *Pertanika J. Sci. Technol.*, vol. 29, no. 3, pp. 1567–1578, 2021, doi: 10.47836/pjst.29.3.25.

[25] *MS 2692:2020 Testing and commissioning of grid-connected photovoltaic system (GCPV)*, Department of Standards Malaysia, pp. 1-61, 2020.

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