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PERFORMANCE OF 4KW$_p$ GRID-CONNECTED PHOTOVOLTAIC (GCPV) SYSTEM USING MICRO-INVERTER TECHNOLOGY FOR RESIDENTIAL APPLICATION

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Abstract

Even though the cost of a grid-connected photovoltaic (GCPV) system has decreased significantly as a result of widespread commercial acceptance, current technologies are continually improved to reduce cost and increase efficiency. By contrast, relatively recent technologies such as maximizers and micro-inverters seek to encourage new techniques of solar energy production at a reasonable cost. While micro-inverters are gaining popularity in the solar industry, industry claims of improved system performance remain unproven. Third-party validation is critical for assessing the efficiency of micro-inverter technology. The objective of this research is to analyze the service provider's reported yearly availability performance for a 4kWp residential grid-connected photovoltaic (GCPV) system with micro-inverter technology located in Shah Alam, Malaysia, as well as gauging the owner's satisfaction with the system. The actual data for the years 2017, 2019, and 2020 were analyzed to determine the annual specific yield (SY_{mea}) and performance ratio (PR_{mea}). The results show that the actual annual SY_{mea} varies between 1,144 kWh kWp-1 and 1,196 kWh kWp-1, while the PR_{mea} for the system ranges from 0.729 to 0.762. This research presents actual data to support the conclusion that the system is underperforming, resulting in a dissatisfied system owner since the PR_{mea} for 2019 and 2020 falls short of the GCPV PR requirement as announced by Sustainable Energy Development Authority (SEDA) Malaysia.

Keywords: Micro-inverter, specific yield (SY), performance ratio (PR), photovoltaic systems, Grid-Connected

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Introduction

As reported in IRENA's Renewable Energy map in 2019, over the next decade, solar PV will accelerate overall renewables growth across many regions due to ample resource availability, significant demand potential, and low cost (IRENA, 2019). In the forthcoming decade, worldwide solar PV implementation could practically double from 2,840 GW (2030) to 8,519 GW (2050). This means that the total installed capacity will be almost eighteen times greater in 2050 than today. By 2050, approximately 60% of all solar PV installations will be utility-scale, while the 40% residual will be apportioned.

To acquire solar energy, the PV inverter must convert the acquired PV energy and transport them to the utility grid or load (Kouro et al., 2015). As cited by Hedge (2014), there are researcher suggested that along with improvements in the PV business, the inverter provides the consumer a major advantage that was not feasible many years ago. There are three types of inverters generally used in GCPV systems: central inverters, string inverters, and AC module inverters or also widely known as micro-inverters. Micro-inverter is a single-phase inverter with PV module integration which creates a unique Maximum Power Point Tracker (MPPT) for each PV module, reducing mismatch losses and increasing the system's maximum power output by 20% (Alonso-García et al., 2006). Additionally, micro-inverter technology is convenient as it simplifies mass production, which might result in cheaper system costs. The most critical characteristic of it is Plug-N-Play (PNP) also improve scalability, where the consumer can theoretically purchase their PV module and connect it into their system like any other device (Rezaei, 2015); under current standards and laws, it is illegal for unskilled individuals to purchase and install a PV system without a permit. Many efforts have recently been made in topological developments that can be used to improve the execution of micro-inverters.

The altering efficiency of power reduction is fairly poor (9-17%), notably during low radiation occurrences (Faranda & Leva, 2009). In essence, as stated by National Renewable Energy Laboratory (NREL), solar PV energy generation is inefficient even today when it weights up to conventional energy sources, as PV modules have a theoretical efficiency limit. Commercial PV modules currently have a conversion efficiency of roughly 20% to 25% in the field (Ranganatha, 2015). From such low efficiency, it's indeed critical that the entire amount of energy produced by the PV module is harvested. Additionally, the point on a power (I-V) curve with the greatest product of its associated voltage and current, or the point with the greatest output power, is referred to as Maximum Power Point (PMPP). As depicted in Figure 1, the darkened region indicates the greatest power available. This point constantly shifts in response to changes in insolation and physical conditions. To maximize energy yield, it is vital to continuously monitor the PV module's PMPP and operate it at this value. Although the position of PMPP is unknown, it can be determined using computation models or algorithms. Some of the simplest yet most successful algorithms often employed are the hill-climbing approach, commonly known as the perturb and observe (P&O), and the incremental method of conductance (Ranganatha, 2015).

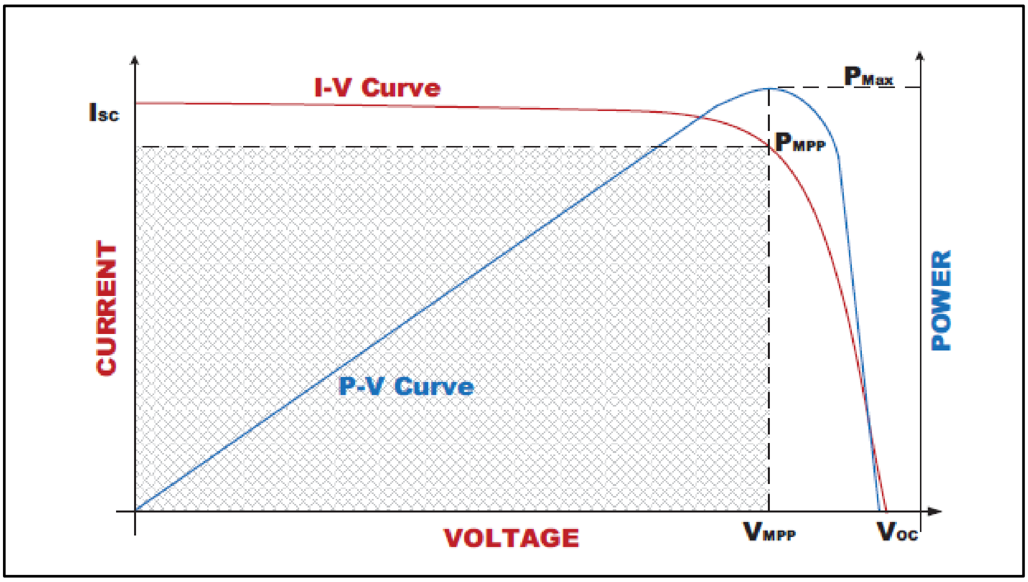

Figure 1. Characteristics of PV module (Ranganatha, 2015)

Despite extensive study in academics and industry related to micro-inverter GCPV system topology to maximize the system performance, the expected and actual availability performance evaluation for micro-inverter GCPV systems in Malaysia is still lacking. Numerous studies have proven that installed solar systems underperform significantly (Usman et al., 2020). Despite its lack of attention, this has been one of the most significant barriers to PV system adoption. Because installed solar systems are inefficient, they are unable to deliver the projected returns. The conclusions of this study will have ramifications for future solar growth in Malaysia incorporating micro-inverter technology since they analyze the PV system's actual and expected annual availability performance in 2017, 2019, 2020 using actual data and a core mathematical technique. Due to a lack of data integrity, the study excludes data from 2018. The absence of data integrity is due to multiple modules being serviced, which resulted in data being unavailable for the first half of 2018. Increased demand for photovoltaic systems will invariably increase the demand for an in-depth study comparing the technical performance of a simulated model to actual measured output. Additionally, owner satisfaction with their system is critical in this study because it will serve as a good guide for educating potential consumers about the risks associated with photovoltaic system investment, as it is critical for consumers to understand whether investing in a GCPV system is profitable. As a result, this research will have a significant impact on the growth of PV systems in Malaysia.

Methodology

This study was conducted on an existing installation. The location chosen was Shah Alam, Selangor (3°N, 101.5°E), which has a tropical rainforest environment and is quite humid as classified by Köppen-Geiger (Kottek et al., 2006). Malaysia is showered with an abundance of solar irradiance, thus resulting in 1.643 kWh/m^2 of solar irradiance annually (Hussin et al., 2013). As illustrated in Figures 2, 3, and 4, this system consists of 13 multi-crystalline silicone (PV1 until PV13 in Figure 3) and is a 4kWp GCPV system that makes use of micro-inverter technology. The system under consideration features collector planes that are 25° tilted and 0° azimuth facing South. This system is for a residential application that is not shaded and has a PV area of 26.0m^2, as illustrated below.

Figure 2. 4kWp GCPV system in Shah Alam, Selangor

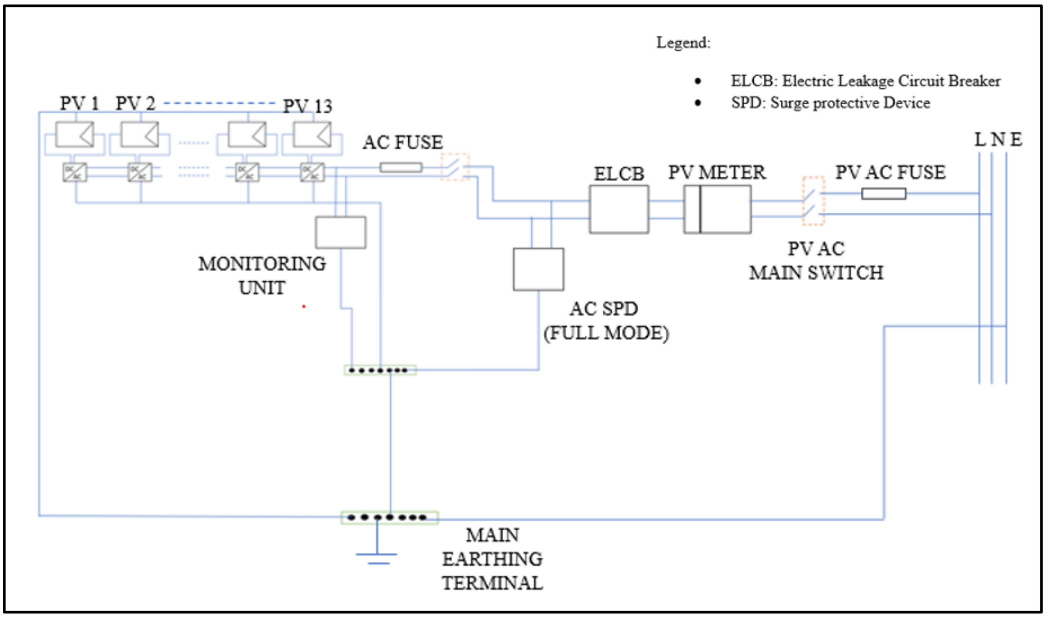

Figure 3. Schematic Diagram of 4kWp GCPV system in Shah Alam, Selangor. Legend- L N E, is the Tenaga Nasional Berhad grid and AC, the Alternating Current

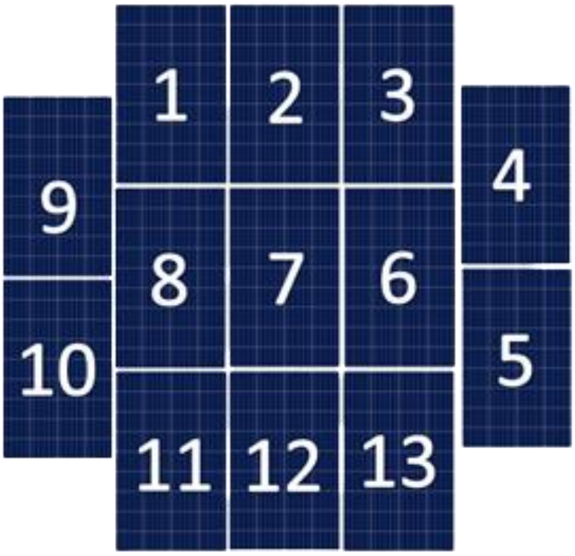

Figure 4. Arrangement of PV modules

This GCPV has a built-in data logger, which recorded the data by one-minute intervals for optimal monitoring of data quality. The actual data of this system are obtained daily and compiled monthly and annually to assess their SY and PR. After done analyzing the data, it was then compared to the predicted values declared by the service provider in order to determine the actual performance of the GCPV system. In GCPV system designing, there are four main steps which are dimensioning of PV array, sizing of PV array to the inverter, sizing of BOS component, and key performance indices. The assessment in this study is performed at the last stage of system designing, which is key performance indices. Here the SY and PR are determined to assess the performance of the system. In order to calculate the actual SY and PR, a straightforward mathematical approach was used to determine the values using Equation (1) and Equation (2), respectively.

$$SY = \frac{Yield}{P_{array_{STC}}} \tag{1}$$

$$PR = \frac{Yield}{Yield_{ideal}} \tag{2}$$

Where Yield is the output yielded and $\text{Yield}_{\text{Ideal}}$ is the ideal yield from the GCPV system (kWh), $\text{P}_{\text{array}_{\text{STC}}}$ is the yield of the system at STC, SY is the specific yield (kWh kWp^{-1}), and PR is the performance ratio of the system, which is dimensionless. Due to the interest in tracking the performance of a 4kWp GCPV system with microinverter technology for a residential application in Shah Alam, this study took a quantitative approach. As this study is concerned with assessing the actual performance along with the owner's level of satisfaction with their GCPV system, virtual interaction (interview, discussion, and questionnaire) is utilized to elicit and understand the system better. The virtual interaction used in this study has the potential to provide insight into the true nature of the challenges and a detailed description of the GCPV system. By applying this method, the owner's level of satisfaction with their GCPV system can be determined.

Results and discussions

The service provider has predicted yearly yield values of 6,280 kWh, 6,230 kWh, and 6,210 kWh for 2017, 2019, and 2020, respectively. The actual monthly yield for the 4kWp GCPV system using micro-inverter technology in 2017, 2019, and 2020 is shown below.

Table 1. Yield of 2017, 2019, and 2020

Month	Monthly Yield 2017 (kWh)	Monthly Yield 2019 (kWh)	Monthly Yield 2020 (kWh)	Average monthly Yield (kWh)
JAN	334.3	345.5	327.6	335.8
FEB	372.7	345.0	386.8	368.2
MAR	439.6	442.5	452.4	444.8
APR	451.0	409.1	476.7	445.6
MAY	447.2	477.4	456.0	460.2
JUN	482.0	422.3	422.3	442.2
JUL	485.7	448.2	435.0	456.3
AUG	434.7	422.4	477.7	444.9
SEP	395.7	388.8	390.1	391.5
OCT	403.9	371.2	384.2	386.4
NOV	313.1	310.5	310.2	311.3
DEC	338.3	299.8	311.0	316.4
Annual Yield (kWh)	4,898	4,683	4,830	4,804

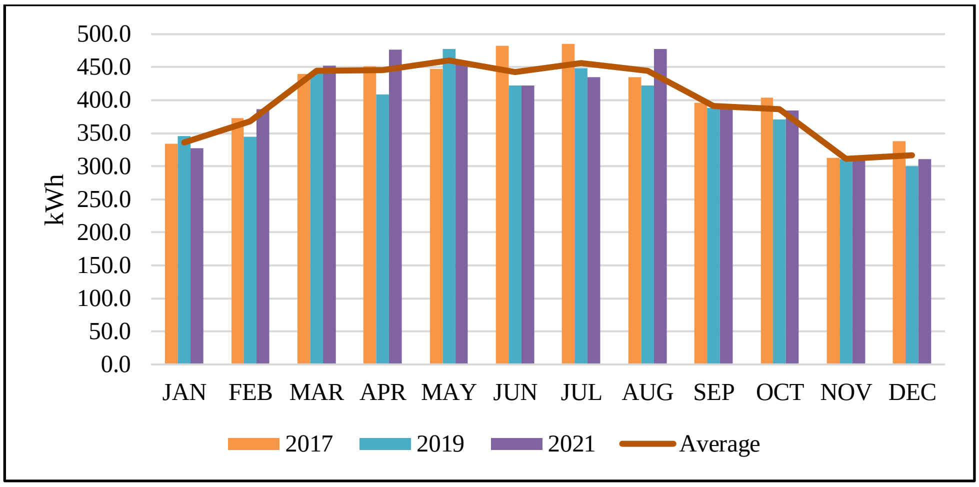

Figure 5. Monthly yield for the whole system in 2017, 2019, and 2020

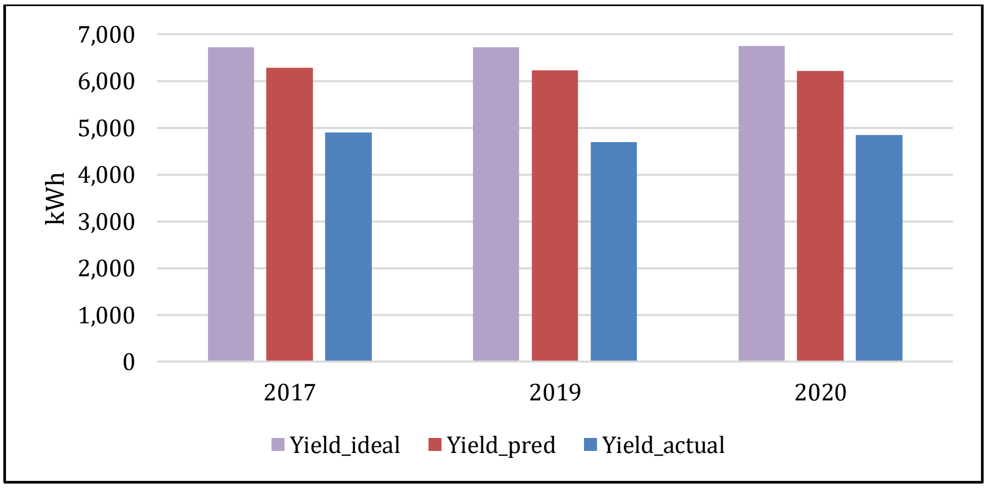

Figure 6. Annual ideal, predicted, and actual yield

Table 1 and Figure 5 illustrate the actual monthly yield of the GCPV 4kWp micro-inverter system in 2017, 2019, and 2020, respectively, while Figure 6 shows the annual predicted and actual clustered column for yield in kWh. The system's average monthly yield is between 311.3 kWh and 460.2 kWh. For 2017, 2019, and 2020, the highest yields were 485.7 kWh for July, 477.4 kWh for May, and 477.7 kWh for August. The lowest yield for 2017, 2019, and 2020 was 313.1 kWh for November, 299.8 kWh for December, and 310.2 kWh for November.

As mentioned above, despite numerous months in each year yielding below the minimum average yield, only 2019's annual yield is below the average annual yield. To aid in visualizing system performance and gauging the owner's satisfaction with their GCPV system, the monthly yield of each micro-inverter (MI) is determined, as shown in Table 2, Table 3, Table 4. Micro-inverter No. 10 (MI No 10) was assessed as underperforming as it delivered the least annual production in two of three years. Meanwhile, micro-inverter No. 6 was determined to be the most performed as it delivered the highest annual yield in two out of a few years.

Analysis of specific yield (SY) and performance ratio (PR)

Annualized figures for the specific yield (SY) and performance ratio (PR) are shown in Table 5, Figures 7, and Figure 8. SY_{pred} and PR_{pred} are derived using the service provider's declared values, whereas measured values correspond to the actual performance parameters. The PSH used in this study to calculate PR is 4.3 and is used in this system simulation by the service provider. The SY_{pred} is predicted to be between 1,516 and 1,534 kWh kWp^{-1}, with the maximum value in 2017 and the lowest value in 2020. Meanwhile, the SY_{mea} varies between 1,144 kW kWh kWp^{-1} and 1,196 kWh kWp^{-1}, with a peak in 2017 and a trough in 2019. PR_{pred} values range between 0.964 and 0.977, with the highest values in 2017 and the lowest values in 2020. Finally, the PR_{mea} varies between 0.729 and 0.762, with the highest value recorded in 2017 and the lowest value recorded in 2019.

SY and PR values for each micro-inverter are calculated to determine the system's performance. By determining the SY, we can define the system's overall performance in terms of energy generation, whereas by determining the PR, we can identify component failures by calculating PR at shorter time intervals (monthly). As a result, annualized data for each micro-inverters SY_{mea} and PR_{mea} is provided in Table 6 for the years 2017, 2019, and 2020.

Annual SY_{mea} for 13 micro-inverters ranged from 89 kWh kW_p^{-1} to 103 kWh kW_p^{-1} in 2017, while the annual PR_{mea} ranges between 0.679 to 0.785, with both micro-inverter No. 6 having the highest values and No. 10 having the lowest. In 2019, the annual SY_{mea} ranged between 85 kWh kW_p^{-1} to 101 kWh kW_p^{-1}, while the annual PR_{mea} ranges between 0.469 to 0.773, with micro-inverter No. 6 having the highest values for SY and PR followed by No. 1, No. 10 having the lowest SY and No. 5 having the lowest PR. Data integrity for 2019 lacks, as data from January until April for micro-inverter No. 5 are missing, thus resulting in lower SY. After analysis, it has been determined that micro-inverter No. 10 is the second least performing after No. 5. Therefore, micro-inverter No. 10 with good data integrity is assessed to be the least performing micro-inverter in 2019 despite having higher PR compared to micro-inverter No. 5, followed by No. 5 being the second least performing micro-inverter in the system. Lastly, in 2020, the annual SY_{mea} for each micro-inverter ranges between 87 kWh kW_p^{-1} to 102 kWh kW_p^{-1}, while the annual PR_{mea} ranges between 0.661 to 0.775, with both micro-inverter No. 1 having the highest values and No. 10 having the lowest.

Table 2. Monthly yield (kWh) for each micro-inverter in 2017

MI No.	1	2	3	4	5	6	7	8	9	10	11	12	13	Monthly Yield 2017 (kWh)
JAN	26.2	26.0	26.2	25.8	26.1	26.8	25.4	26.2	26.2	21.7	25.4	25.9	26.4	334.3
FEB	29.0	28.9	29.2	28.9	29.0	29.7	29.7	29.1	29.1	23.9	28.4	28.8	29.3	372.7
MAR	34.1	33.9	34.2	34.0	34.2	34.8	34.1	34.3	34.2	29.5	33.7	34.0	34.5	439.6
APR	34.9	34.7	35.0	34.8	35.1	35.7	35.0	35.1	35.0	30.8	34.7	34.9	35.2	451.0
MAY	34.7	34.5	34.6	34.3	34.5	35.3	34.7	34.7	34.8	31.6	34.6	34.5	34.6	447.2
JUN	37.3	37.1	37.1	37.0	37.2	37.9	37.4	37.3	37.5	34.8	37.3	37.0	37.1	482.0
JUL	37.7	37.5	37.5	37.3	37.5	38.3	37.7	37.6	37.9	34.4	37.5	37.3	37.4	485.7
AUG	33.8	33.6	33.6	33.4	33.6	34.3	33.8	33.6	33.9	31.0	33.4	33.3	33.5	434.7
SEP	30.7	30.6	30.7	30.5	30.8	31.2	30.7	30.6	30.8	28.1	30.1	30.2	30.6	395.7
OCT	31.5	31.5	31.8	31.5	31.7	32.2	31.4	31.4	31.7	27.0	30.5	30.7	31.2	403.9
NOV	24.6	24.5	24.7	24.4	24.5	25.0	24.4	24.4	24.7	20.8	23.4	23.6	24.0	313.1
DEC	26.6	26.6	26.8	26.4	26.5	27.0	26.4	26.5	26.7	22.1	25.2	25.5	26.1	338.3

Table 3. Monthly yield (kWh) for each micro-inverter in 2019

MI No.	1	2	3	4	5	6	7	8	9	10	11	12	13	Monthly Yield 2019 (kWh)
JAN	29.9	29.5	28.9	29.6	0.0	30.0	29.3	29.7	29.7	22.9	27.9	28.6	29.5	345.5
FEB	29.7	28.6	29.9	29.6	0.0	29.8	29.1	29.4	29.6	23.4	28.2	28.6	29.3	345.0
MAR	37.7	37.2	37.8	37.7	0.0	38.0	37.3	37.5	37.8	32.0	36.5	36.8	36.3	442.5
APR	34.6	34.1	34.3	34.6	0.0	35.0	34.4	34.6	34.8	30.4	33.8	34.1	34.5	409.1
MAY	37.7	37.0	37.4	37.4	34.0	37.7	37.2	37.5	37.8	33.5	36.7	36.7	36.9	477.4
JUN	33.1	32.5	32.8	32.9	31.0	33.2	32.8	33.0	33.3	30.4	32.4	32.3	32.5	422.3
JUL	35.2	34.6	34.9	34.9	33.0	35.2	34.9	34.9	35.4	32.0	34.4	34.3	34.5	448.2
AUG	33.2	32.6	32.8	32.8	31.1	33.2	32.9	32.9	33.3	30.5	32.2	32.3	32.6	422.4
SEP	30.6	30.0	30.4	30.4	28.8	30.7	30.3	30.3	30.7	27.1	29.6	29.8	30.2	388.8
OCT	29.4	28.8	29.5	29.3	27.7	29.5	28.9	29.1	29.3	24.1	28.1	28.4	29.1	371.2
NOV	25.4	24.9	25.5	25.2	23.6	25.4	24.8	25.0	21.6	18.2	23.4	23.5	24.0	310.5
DEC	24.36	23.88	24.42	24.01	22.59	24.40	23.85	24.00	22.40	18.00	21.90	23.00	23.00	299.8

Table 4. Monthly yield (kWh) for each micro-inverter in 2020

MI No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Monthly Yield 2020 (kWh)**
JAN	28.3	27.9	28.3	27.9	26.0	28.3	27.6	27.7	27.8	21.2	26.0	26.8	3.8	327.6
FEB	30.9	30.5	30.9	30.7	28.4	30.8	30.2	30.2	30.7	24.6	29.1	29.6	30.2	386.8
MAR	35.8	35.4	35.8	35.8	33.4	35.9	35.2	35.2	35.7	29.7	34.3	34.8	35.3	452.4
APR	37.6	36.2	37.7	37.9	33.4	38.0	37.4	37.4	37.6	32.1	36.6	37.3	37.5	476.7
MAY	36.1	35.6	35.8	35.8	33.3	35.9	35.6	35.6	36.1	32.3	34.9	33.9	35.1	456.0
JUN	33.3	32.8	33.0	33.0	30.7	33.2	32.8	32.7	33.3	29.6	32.2	33.4	32.3	422.3
JUL	34.3	33.8	34.2	34.2	31.7	34.1	33.8	33.8	34.3	30.7	33.2	33.3	33.4	435.0
AUG	37.4	37.0	37.3	37.5	34.9	37.6	37.2	37.2	37.6	33.8	36.5	36.8	36.9	477.7
SEP	30.7	30.3	30.8	30.7	28.7	30.7	30.4	30.3	30.7	26.8	29.6	30.0	30.3	390.1
OCT	30.1	29.7	30.8	30.0	28.1	30.0	29.7	29.7	30.2	26.5	28.8	29.0	31.6	384.2
NOV	25.0	24.6	24.3	24.8	23.1	24.8	24.5	24.4	24.9	20.3	23.5	23.8	22.4	310.2
DEC	24.8	24.3	24.8	24.6	23.0	24.7	24.4	24.4	24.6	20.2	23.2	23.8	24.3	311.0

Table 5. Annual specific yield (SY) and performance ratio (PR)

YEAR	**2017**	**2019**	**2020**
Yield$_{ideal}$ (kWh)	6,427	6,427	6,445
Yield$_{pred}$ (kWh)	6,280	6,230	6,210
Yield$_{actual}$ (kWh)	4,898	4,683	4,830
SY$_{pred}$ (kWh kW$_p^{-1}$)	1,534	1,521	1,516
SY$_{actual}$ (kWh kW$_p^{-1}$)	1,190	1,144	1,179
PR$_{pred}$	0.977	0.969	0.964
PR$_{actual}$	0.762	0.729	0.749

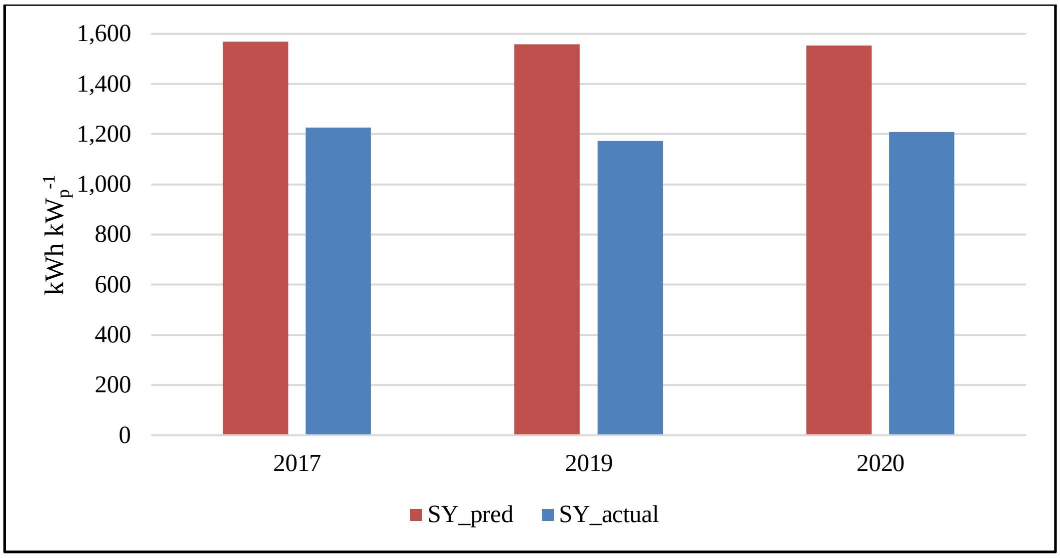

Figure 7. Annual predicted and actual specific yield (SY)

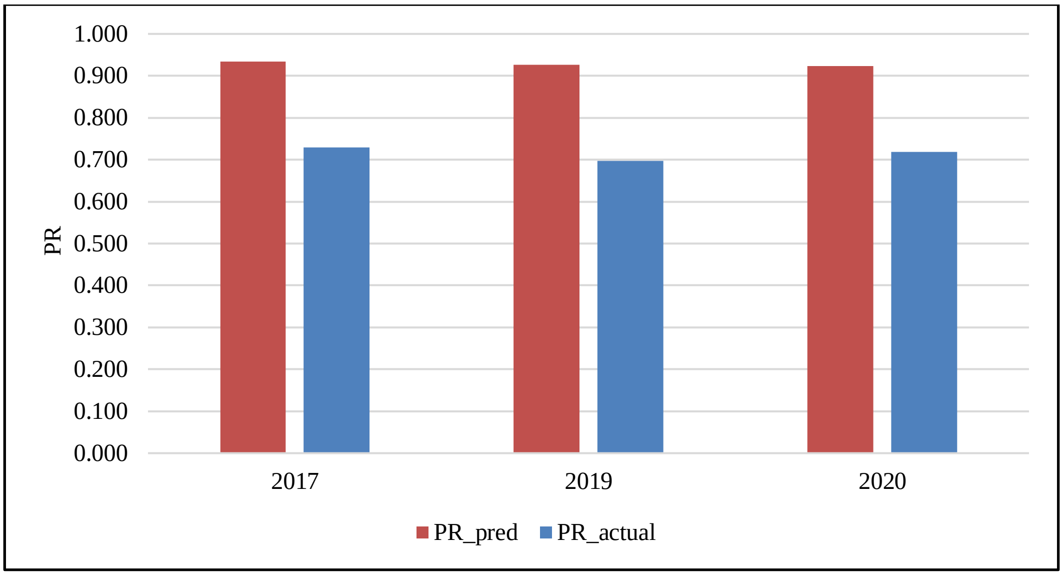

Figure 8. Annual predicted and actual performance ratio (PR)

Table 6. Annual measured specific yield (SY) and performance ratio (PR) for each micro-inverter

MI No.	**SYannual_2017 (kWh kWp-1)**	**Prannual_2017**	**Syannual_2019 (kWh kWp-1)**	**Prannual_2019**	**Syannual_2020 (kWh kWp-1)**	**Prannual_2020**
1	100	0.771	101	0.770	101	0.775
2	100	0.767	99	0/756	99	0.763
3	101	0.772	100	0.766	100	0.774
4	100	0.765	100	0.765	100	0.773
5	101	0.770	92	0.469	92	0.716
6	103	0.785	101	0.773	101	0.775
7	101	0.770	99	0.760	99	0.764
8	101	0.770	100	0.765	100	0.764
9	101	0.774	99	0.760	99	0.774
10	89	0.679	85	0.653	85	0.661
11	99	0.757	97	0.738	91	0.742
12	99	0.760	97	0.745	97	0.751
13	100	0.768	99	0.753	99	0.712

Yields and performance ratios are used to establish quantitative estimates of the expected energy production of PV systems. The yield parameters normalize performance against system size; as a result, it's indeed useful for comparing systems of varying sizes to evaluate the benefits of design, components, or locations. Yield characteristics are temperature dependent and do not account for solar radiation variability, making them less helpful in identifying operational problems. Meanwhile, PR is a performance metric for PV systems that are calculated based on environmental factors such as solar irradiation, power dissipation, shade, and ambient temperature, as well as any other climatic parameters affecting the output of a PV system.

PR is not always proportional to the amount of energy produced. A low-PR system in a region with abundant solar resources can produce more energy than a high-PR system in a region with limited solar resources. However, if a modification in component or design raises the PR performance ratio for a given system, location, and period, the final yield increases accordingly. PR values can be used to determine if the system operates as planned. A significant drop in PR shows events that have a negative impact on performance, such as underperforming inverters, which have been assessed to be micro-inverter No 10 for this system. If PR drop is mild or tiny, it implies a less dangerous condition. PR performance ratio may suggest a problem, but not its source. To discover the source of the on-site study is required. In Malaysia, the PR values for the three module technologies were revealed to be different: polycrystalline at 0.782, monocrystalline at 0.810, and Si thin film at 0.946 (Hussin et al., 2013), where all three exceeds the acceptable Performance Ratio (PR) required by Malaysia's Procedure for the T&C of GCPV Systems which is a minimum of 0.75 (SEDA, 2014). From this study, the PR_{mea} ranges from 0.729 to 0.762, which PR_{mea} in 2019 and 2020 are below the defined minimum PR for GCPV by SEDA.

There are many reasons for the difference in the actual and predicted performance of the PV system. There are a variety of factors that influence the performance of installed PV systems, such as geographical location, solar irradiation, dust, and shading (Usman et al., 2020). It is difficult to get a solid judgment regarding the system's performance because this study's primary objective is to compare the actual and expected annual availability performance of a $4kW_p$ GCPV system equipped with micro-inverter technology as reported by the service provider. Thus, the various circumstances affecting the performance of photovoltaic systems will not be discussed.

Consumer satisfaction is contingent upon the system's comprehension and expectations. Consumers who are adequately informed on the capabilities and limitations of a PV system will know what to expect and will be able to make an "informed decision" about whether or not to invest in a PV system, as well as pique their interest. These individuals frequently express greater satisfaction with their current system than those promised ' heavens on earth.' PR is a widely accepted indicator for measuring a GCPV system's performance (Rahman et al., 2010). As previously stated, the measured PR for the GCPV system used in this work is less than the SEDA-defined minimum PR for GCPV, and the system is equipped with two underperforming micro-inverters. The owner's degree of satisfaction is measured via a virtual interview and questionnaire. The owner was asked to respond to a series of questions regarding their degree of satisfaction with the installation quality, the system's performance, the system's maintenance and reporting services, and the system's overall level of satisfaction.

The owner is pleased with the majority of the installation as being deduced in the questionnaire. The service provider was extremely efficient during the installation process and always ensured the owner's convenience. The owner, on the other side, is disappointed with their handover approach, which includes system explanations and technical documentation. As the absence of an appropriate handover mechanism and explanations will limit the owner's ability to analyze any potential problem even if the source cannot be determined. With a proper technical handover and explanations of the system, an owner who is sufficiently informed about the capabilities and limitations of a PV system will know what to expect and will be able to assess and report any emergent problems to the service provider for further inspection.

Following that, the owner was asked to evaluate their service provider's performance. It has been determined that the owner is satisfied with the service provider's installation of the GCPV system. However, the owner is quite disappointed with the information they provide on system maintenance and assistance. Inadequate explanation and exposure from the service provider will have a significant impact on the system's functioning since the owner will be unable to maintain the system properly. Along with the lack of explanation and assistance provided by the service provider, aftercare services are also not provided, resulting in an increase in the possibility of affecting the system's performance, such as dust accumulation. The residential sector should clean their photovoltaic system monthly, while the industrial sector should clean every two months in order to maximize their financial returns (Mat, 2014), thus proving the importance of the aftercare GCPV system.

Apart from the lack of aftercare, the owner is disappointed with the reporting capabilities of their system. The owner does not receive a report summarising the system's performance. The absence of a standardized method for reporting and interpreting operational problems has a detrimental effect on the owner's level of satisfaction. The necessity of accurate reporting defining system performance cannot be overstated, as it will result in insufficient monitoring, which has been identified as one of the primary causes of premature PV system failures in Malaysia (Han et al., 2018). Due to the lack of a comprehensive report detailing the system's performance, the owner is uninformed of two underperforming micro-inverters in their system (No. 5 and 10), as well as PR values lower than the SEDA-mandated PR value for a GCPV system. As a result of this research, the owner is now aware of the real system configuration, which consists of two underperforming micro-inverters. The owner may then file a complaint with the service provider for additional investigation, as a low PR may indicate a problem but not its source. As a result, a systematic approach to reporting and feedback is critical for fully exploiting the system's capabilities.

In general, the owner is unsatisfied with their system since its PR in 2019 and 2020 is less than the minimal criterion of 0.75 specified by SEDA. Additionally, the owner is unsatisfied with the financial performance of their system. As this study discovered a difference between actual and predicted yields, it is noteworthy because it necessitates a recalculation of the payback period and returns on investment (ROI). As a result, it has been concluded that the owner is unlikely to recommend friends and family to install an FCPV system using micro-inverter technology because it costs twice as much as a string inverter (Hegde, 2014), notwithstanding the system's poor performance.

Conclusion

Despite growing interest in implementing photovoltaic systems, many existing systems perform poorly. This research details the actual performance of a $4kW_p$ GCPV system integrated with micro-inverter technology installed in a residential application in Shah Alam. The study's major objective is to determine the real functioning of the GCPV system and to assess the owner's degree of satisfaction with it. Additionally, a range of elements such as geographic location, sun irradiation, dust, and shadow all have an influence on the performance of installed photovoltaic systems. It is difficult to make definitive statements about the system's performance since this study compares the actual and anticipated yearly availability performance of a 4kWp grid-connected photovoltaic (GCPV) system equipped with micro-inverter technology as claimed by the service provider. Thus, the several factors impacting PV system performance have been discussed theoretically in the discussion section. This research discovered that the GCPV system is underperforming, with yearly PR_{mea} values ranges from 0.729 to 0.762, which fall below SEDA's specified minimum PR for GCPV of 0.75 for 2019 and 2020. Additionally, this system has a subpar micro-inverter, resulting in reduced power production. In essence, it may be concluded that the owner is extremely unsatisfied with the system and is looking for ways to optimize its performance. Thus, more long-term data should be analyzed and results reviewed in order to offer a more realistic assessment of PV performance. Additionally, future assessments should add environmental variables that were only discussed conceptually in this study.

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