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# Actual performance evaluation of a 4.5 kWp residential on-grid PV system in Surabaya, Indonesia

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**Abstract.** This study evaluates the actual performance of a 4.5 kWp on-grid photovoltaic (PV) system installed on a residential building in Surabaya, Indonesia. The research aims to assess the system's energy output under real operating conditions, providing valuable insights for residential PV deployment. Data was collected through an online monitoring system, recording daily energy production ranging from 8.0 kWh to 24.0 kWh. The total annual energy generation was approximately 6,122 kWh, resulting in an average specific energy yield of 1,360 kWh/kWp. The findings indicate that residential rooftop PV installations in Indonesia can contribute significantly to household energy needs and carbon reduction efforts. This study highlights the practical implications for homeowners, policymakers, and researchers, offering empirical data to support policy development and investment decisions in solar energy.

## 1. Introduction

The transition toward sustainable energy solutions is essential in addressing global environmental challenges, with photovoltaic (PV) systems playing a crucial role in reducing reliance on fossil fuels [1]. These systems convert solar radiation into clean electricity, significantly lowering greenhouse gas emissions and contributing to energy security. The increasing adoption of residential on-grid PV systems reflects their potential to support sustainable urban development and align with global renewable energy targets. However, evaluating their actual performance across different climatic conditions remains vital for optimizing system design and policymaking.

Several studies have assessed PV system performance under various real-world conditions. Bhavani et al. [2] examined the impact of weather variability on PV efficiency, highlighting the influence of temperature, irradiance, and shading. Allenspach et al. [3] compared field measurements with simulation models, revealing discrepancies due to system configuration, component degradation, and site-specific factors. Long-term monitoring studies [4]–[6] tracked energy production trends and efficiency losses, emphasizing the importance of ongoing performance evaluation.

Dust and soiling effects have also been investigated [7]–[10], demonstrating their impact on energy generation and the necessity of effective cleaning strategies. Additionally, the performance of bifacial PV modules has been studied [11]–[13], showing potential gains from capturing light on both sides of the panel. The impact of partial shading on PV efficiency has been explored [14]–

[16], emphasizing the role of module arrangement and bypass diodes in mitigating energy losses. Furthermore, research on amorphous silicon PV panels [17]–[19] has provided insights into their long-term viability and degradation patterns.

Surabaya, Indonesia, represents a critical case study for evaluating residential PV systems due to its rapid urbanization and growing energy demands. The city faces significant environmental challenges, including rising carbon emissions and air pollution, necessitating sustainable energy solutions. Residential PV installations offer a viable alternative to conventional electricity sources, reducing the strain on the grid while contributing to energy independence and local economic development. The adoption of solar power in Surabaya aligns with broader sustainability goals, fostering energy resilience and job creation in the renewable energy sector.

This study aims to provide an empirical performance evaluation of a 4.5 kWp residential on-grid PV system in Surabaya, assessing its actual energy output under real operating conditions. By analyzing energy production data and system efficiency, this research offers valuable insights for optimizing PV deployment in urban Indonesia. The findings contribute to the growing body of knowledge on PV system performance, supporting policymakers, researchers, and homeowners in making informed decisions regarding solar energy adoption.

## 2. Methods

A 4.5 kWp grid connected PV system was installed on the roof of a residential building at the end of 2021 located in Wiguna residence in Surabaya, Indonesia. The system consists of 10 solar modules with a capacity of 450 Wp for each module. The specification of a single module is presented in Table 1.

**Table 1.** Specification of PV module

| Module Parameters | Stated Value |
|---|---|
| Peak power | 450 W |
| Maximum current [Ipm] | 10.85 A |
| Maximum voltage [Vpm] | 41.50 V |
| Short circuit current [Isc] | 11.6 A |
| Open circuit voltage [Voc] | 49.53 V |
| Efficiency | 20.7 % |

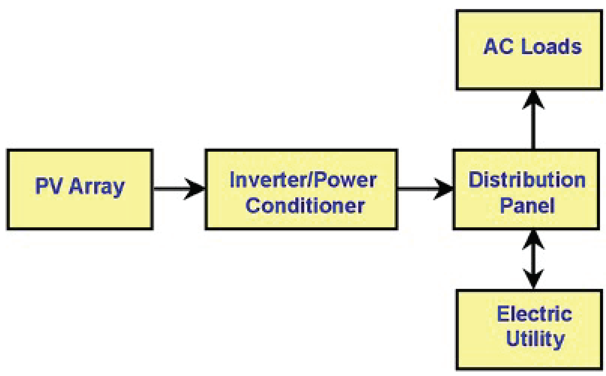


**Figure 1.** Grid-Connected PV system diagram

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**Figure 2.** Solar modules, inverter, and export-import kWh meter

The PV modules produced DC electricity when they are exposed to the solar radiation. After converting the power into AC, it is then delivered to the utility grid of a building through an export-import kWh meter. The system was converted using a DC-AC 4000 Watt on-grid Inverter. Figure 1 shows the schematic diagram for an on-grid solar system. The array of modules is mounted on the roof of the residential buildinga. Figure 2 shows a photograph of the entire PV system, including PV modules, inverter, and export-import kWh meter.

EyeM4 device Wi-Fi was used to establish a wireless connection (Figure3) for monitoring. This device was an addition to the inverter. Wireless communication module was connected to inverter via standard RS485 interface. This allows for the collection of inverter operating data. Running data was sent to the remote server via Wi-Fi wireless communications.


**Figure 3.** EyeM4 Wi-Fi device

iSolarCloud mobile Apps allow us to monitor the performance of your PV system online. The iSolarCloud app provides mobile operation, operational analysis, and maintenance services for plants. The services provided are mainly WLAN configuration, remote parameters configuration, plant connections, device monitoring and fault management, alarm reports push, knowledge repository etc[20]. In this paper, we will only discuss a few of the many features that are available in the iSolarclod app. These features are mostly related to PV system monitoring and energy yield. The PV system performances were analyzed in terms of energy yield daily, monthly and total.

## 3. Results and Discussions

Results of monitoring PV system performance can be obtained instantly. The data can also be recorded and presented on a monthly, daily or annual basis. As previously mentioned, the results are monitored by using the smartphone iSolarcloud Apps (Android). The Apps have three main features: Overview, Device, and Fault. The main feature/menu to monitor the performance of the

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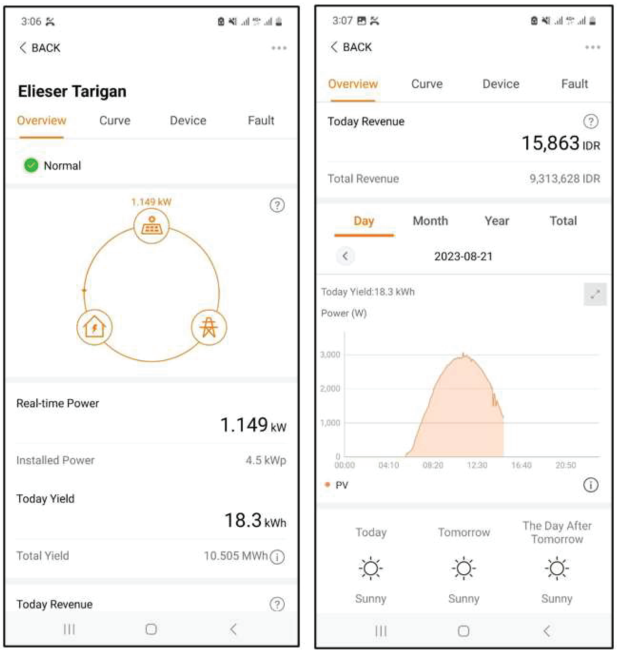


**Figure 4**. Overview feature of iSolarcloud

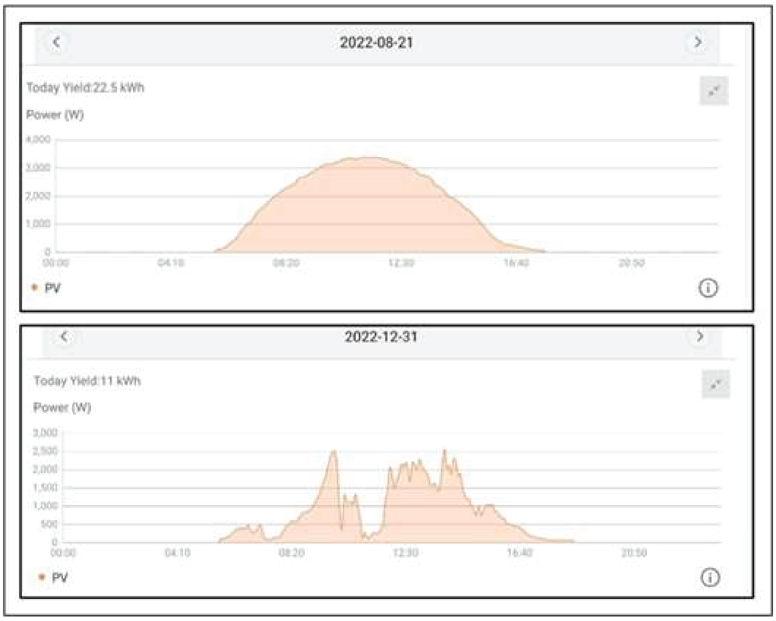


**Figure 5.** Diurnal power output and the total energy yield for two different weather conditions: clear day (upper), and cloudy day (lower)

PV System is the Overview. This feature displays Real-time Power, Installed Power, Today Yield and Total Yield. Today Revenue and Total Revenue can also be displayed. Figure 4 shows a screenshot of a typical real-time appearance of the Overview, taken on August 21, 2023, at 3.07 PM. The graph shows that the power output fluctuates with time and corresponds to the solar radiation received by the panel system.

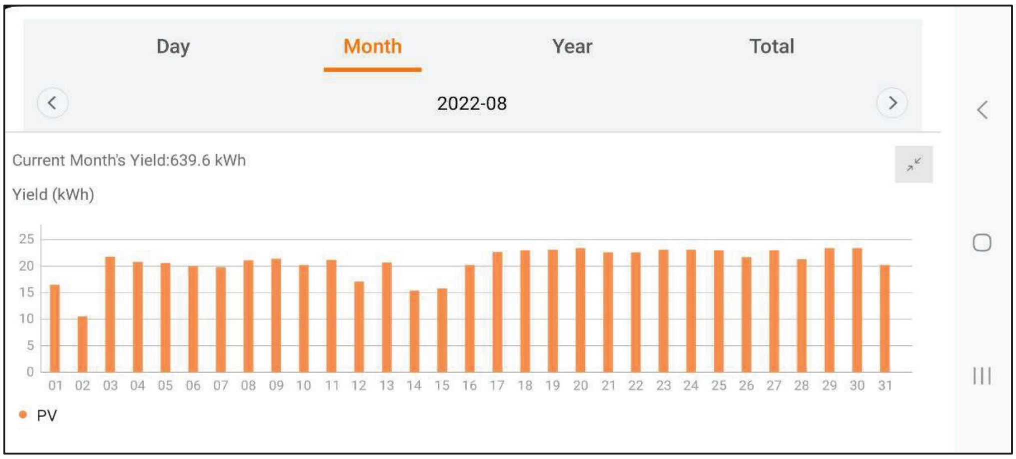


**Figure 6.** Daily performance of PV system during August 2022


**Figure 7**. Monthly energy output of PV system for 2022

The daily performance of the PV system in terms of power output can be monitored by selecting a particular day from the overview menu. Figure 5 (upper) shows the average daily power output as well as the total energy yield for August 21 2022. The total energy yield was 22.5 kWh. The day was significantly clear day. While, Figure 5 (lower) shows a typical power output for rainy or cloudy weather (December 21, 2022) with total energy output was 11.kWh. Figure 6 displays the performance of the PV system monitored for August 2022. The monthly performance is shown in terms of daily energy yield and the total energy output for the month. Selecting the graph bar in Figure 6 will show the energy yield of a specific day. The performance of the PV system monitored during August 2022 shows a fluctuating daily energy yield, from 10.4 to 23.3 kWh. This totals 639.6 kWh for the month. It is again that it correlates with the weather which impacts solar irradiation.

The iSolarclod app has many features, but the most common way to measure the performance of a PV system is the energy yield. This paper explains how this is done. Online monitoring of PV system performance can be useful to know the energy yield and identify if there are any problems or errors in the system that would affect energy yield. The data for this study is the entire year of monitored data, which covers the period from January – December 2022.

Figure 7 shows the monthly energy output in kWh. The lowest monthly energy output is approximately 236.2 kWh in January, and the highest, about 639 kWh, is produced in August. The daily energy yield ranged from 8.0 kWh to 24 kWh with a value average of 19.5 kWh. The annual energy yield is about 6,122 kWh. With this information, it was found that the annual specific energy output for the system is 1360 kWh/kWp.

The period of low energy yield was in January. This was the rainy season. It is expected that the low energy yield is due to the periods of the clouds covering solar panels. On the other hand, It is recommended that further studies be conducted on the effect of dust on energy production by the PV system during the dry seasons. The peak rainy season in Surabaya is between January and February. It is possible that this could be the cause of low energy production in January.

## 4. Conclusions

This study evaluated the actual performance of a 4.5 kWp residential on-grid PV system in Surabaya, Indonesia. The system's daily energy yield ranged from 8.0 kWh to 24.0 kWh, with an average of 19.5 kWh, and an annual energy generation of approximately 6,122 kWh. The calculated annual specific energy output was 1,360 kWh/kWp. Online monitoring proved essential for tracking energy production and detecting potential issues affecting system efficiency.

While the findings provide valuable insights into PV system performance in an urban Indonesian setting, certain constraints, such as variations in solar irradiance, module degradation, and environmental factors like shading and soiling, may impact energy output. Future research should explore long-term performance trends, degradation analysis, and the integration of energy storage systems to enhance grid reliability. Additionally, comparative studies on different PV technologies and optimization strategies for urban installations could further improve system efficiency and adoption rates. These directions will contribute to the continued advancement of rooftop PV applications, supporting Indonesia's renewable energy transition and climate resilience efforts.

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