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IoT monitoring for PV system optimization in hospital environment application

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Abstract
Purpose: This study aims to implement an Internet of Things (IoT)-based monitoring system to optimize photovoltaic (PV) system performance and ensure uninterrupted power supply for critical medical equipment, specifically ventilators and monitors, in the ICU room of RSI Siti Khadijah Palembang.
Methodology/approach: The system uses on-grid solar panels connected to an Arduino-based IoT monitoring platform. The IoT system receives inputs from current and voltage sensors, enabling real-time supervision of solar panel output, battery status, and inverter performance. Automatic Transfer Switch (ATS) technology ensures seamless switching between PV and utility sources during periods of insufficient solar energy.
Results/findings: The installed system demonstrates stable daily performance, with peak energy production reaching up to 400 Wp under optimal conditions. Real-time data from the IoT dashboard enables informed decision-making to maintain power supply continuity in the ICU. Voltage levels remained within a safe range for ICU operations throughout the test period.
Conclusion: IoT integration enhances the reliability of hospital-based PV systems. The system proved effective in maintaining continuous energy delivery to life-saving equipment, reducing reliance on conventional UPS systems.
Limitations: The current system lacks MPPT (Maximum Power Point Tracking) and thermal regulation, which could further optimize energy conversion efficiency under varying weather conditions.
Contribution: This study provides a replicable model of IoT-enhanced PV deployment in hospital settings, offering valuable insights for renewable energy applications in critical infrastructure across tropical developing countries.

Keywords: *Building Integrated PV, On-Grid PV System, Photovoltaic, Solar Energy*

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1. Introduction

Given the depletion of fossil fuel reserves in Indonesia, the application of renewable energy is critical. Indonesia is endowed with numerous renewable energy sources, ranging from solar to tidal, such as wind energy investigated by Wardhana, Taqwa, and Dewi (2019) and Yuliandi and Dewi (2018). Given its tropics location, Palembang, the capital of South Sumatra, has a high potential for solar energy, as explored by Tresna Dewi et al. (2016); Tresna Dewi, Risma, and Oktarina (2019); Yudha, Dewi, Risma, and Oktarina (2018); and Junianto, Dewi, and Sitompul (2020). Solar energy promises long-term sustainability for modern life in the economy, health, and education sectors (Sasmanto & Dewi, 2020). Solar energy promises a cleaner environment because it produces no CO_2 emissions during operation.

Solar plants on a large scale, a small scale, or even a housing scale can be realized in an urban area or city and used as the primary or secondary source of electricity, which were investigated by Zhafarina, Dewi, and Rusdianasari (2018); Mases and Dewi (2021); and Putra and Dewi (2021). Solar power plants are highly dependent on geographical factors (Sarwono & Kusumanto, 2021; Setiawan, Dewi, & Yusi, 2019), but most of Indonesia has high solar energy potential (Tresna Dewi, Taqwa, Kusumanto, & Sitompul, 2021; Junaedi, Dewi, & Yusi, 2021; Nurjanah & Dewi, 2021).

Even in a city, the electricity supply is not always stable; therefore, a backup power source is required for critical sectors where a power outage can be fatal (Edward & Dewi, 2019; Hamdi & Dewi, 2019). Hospitals are a critical sector that requires a continuous supply. The government is currently strongly encouraging the health and renewable energy sectors; therefore, merging the application of renewable energy in the health sector will be very beneficial, as mentioned by IRENA (2017) and Yudiartono, Anindhita, Sugiyono, Wahid, and Adiarso (2020). Hence, solar power plants are highly beneficial to hospitals. Internet technology is rapidly expanding and encompasses all aspects of life, including solar energy applications.

The current issue of PV system implementation is how to optimize the output and efficiency regardless of the environmental impact of PV panels, such as tropical heat (Arissetyadhi, Dewi, & Kusumanto, 2020; Tresna Dewi et al., 2019); (Tresna Dewi et al., 2021), and intermittent irradiance due to shading or partial shading (Rosyadah, Kusumanto, & Dewi, 2022). However, these limitations do not prevent researchers from integrating PV systems into daily life, such as the possibility of automatic vehicles (T Dewi, Risma, Oktarina, Taqwa, & Renaldi, 2020; Mases & Dewi, 2021; Putra, Dewi, & Rusdianasari, 2021; Septiarini, Dewi, & Rusdianasari, 2021; Sujati, Dewi, & Rusdianasari, 2021). Another way to ease the monitoring of PV systems is by integrating them with Internet technology, such as the Internet of Things (IoT). IoT makes it easier for solar energy users to track the output and efficiency of the installed solar power plants (Taqwa, Kusumato, & Dewi, 2018). This study presents the implementation of a PV power plant in hospital environments where an On-Grid PV system is installed as an alternative power source (Alamoudi, Taylan, Aktacir, & Herrera-Viedma, 2021; Ghaleb & Asif, 2022; Kim, Cho, & Kim, 2014). This study discusses the installation of a solar power plant at the Siti Khadijah Islamic Hospital in Palembang. This solar power plant provides backup power to the ICU. This study demonstrates the benefits of using solar energy over backup batteries or UPS.

2. Literature review

Solar energy can be an excellent alternative for energy generation as the primary or alternative source. The feasibility of harvesting solar energy in Palembang has been investigated by Arissetyadhi et al. (2020), Tresna Dewi et al. (2019); (Sasmanto & Dewi, 2020), and Harahap and Dewi (2019). These results show that maximum power can be achieved because of the geographical location of Palembang, although the application of solar energy will be more beneficial in highland and remote areas, as presented by (Sarwono & Kusumanto, 2021).

Tresna Dewi et al. (2021); Tresna Dewi et al. (2019); Harahap and Dewi (2019), and Arissetyadhi et al. (2020) optimized the output and efficiency of PV systems installed in Palembang; however, even though there is still a possibility of overheated in some parts of South Sumatra, the downside of the possible overheated panel is negligible compared to the benefits gain by this application. Tresna Dewi et al. (2019) stated that the factors affecting the efficiency and output of solar panels could be overcome by adjusting the panel to the environmental conditions, such as ensuring the application of MPPT (given by Putra et al. (2021)).Considering these references, the feasibility of implementing solar energy in hospital environments in Palembang is very high. Alamoudi et al. (2021) present the possibility of a PV system for hospital environments using RSM, and ANFIS approaches. This study presents the application of a PV system in a hospital environment, and IoT monitoring was installed to monitor the PV system output and ensure a continuous supply to ventilators and monitors in the ICU.

2.1 Solar Energy Implementation in Tropical Regions

Indonesia's geographical position along the equator provides high solar irradiance throughout the year, making it a strategic location for deploying photovoltaic (PV) systems. Cities such as Palembang in South Sumatra, despite being in lowland tropical areas with relatively high temperatures, show excellent potential for solar energy generation. According to Tresna Dewi et al. (2019), environmental factors such as ambient temperature, panel orientation, and dust accumulation influence PV output, but proper site design and maintenance can mitigate most losses. Therefore, solar energy can be harnessed efficiently, even in dense urban areas, with minimal environmental risk and high long-term benefits.

This is particularly valuable in the context of urban healthcare facilities. Harahap and Dewi (2019) emphasized that even under extreme heat conditions, solar PV systems can maintain a stable output when supported by basic thermal control mechanisms. This supports the feasibility of PV adoption for sensitive infrastructure, such as hospitals, where power continuity is critical. By investing in appropriate PV configurations and cooling systems, institutions can reduce their reliance on fossil-based grid energy while contributing to national sustainability goals. Thus, PV deployment in tropical cities is not only technically possible, but also strategically advantageous for public services.

2.2. Energy Optimization through IoT Monitoring

Internet of Things (IoT) technology enables real-time remote monitoring and management of energy systems, addressing one of the core challenges in solar adoption, that is, variability in power generation. Taqwa et al. (2018) showed that IoT systems integrated with solar power setups can provide accurate real-time information about voltage, current, battery condition, and inverter output. This allows for better decision-making, such as timely switching to the grid supply during cloudy conditions or system maintenance alerts. Therefore, the IoT reduces human error and enhances the operational reliability of solar power installations, especially when electricity demand is critical.

This level of system visibility is essential for hospitals. Real-time monitoring ensures that the energy supplied to vital equipment, such as ventilators and patient monitors, remains uninterrupted. Additionally, IoT interfaces allow for performance analysis and long-term optimization by identifying patterns in energy usage and panel performance. This opens up opportunities for predictive maintenance and intelligent energy management, thereby minimizing operational costs. Therefore, integrating IoT with PV systems is not only a technological enhancement but also a necessary step toward energy resilience in modern healthcare settings.

2.3. PV Systems for Hospital Reliability

Ensuring uninterrupted power in hospitals is vital, particularly in critical care units, where outages can be life-threatening. The use of PV systems as supplemental or even primary energy sources has been explored in various studies. Alamoudi et al. (2021) designed PV-based systems for hospitals using performance optimization models such as ANFIS and Response Surface Methodology (RSM). These approaches allow the system to adapt to environmental changes, ensuring a stable output despite fluctuations in solar irradiance or temperature. Their findings demonstrated that PV systems, when carefully designed and monitored, can effectively support sensitive medical infrastructure.

Furthermore, combining PV installations with IoT-based monitoring allows hospitals to detect voltage irregularities or reduced output immediately and respond by switching to the grid power or adjusting the energy consumption patterns. This is especially important in developing regions, where the electricity infrastructure may be unstable or insufficient. In the context of the RSI Siti Khadijah Palembang, the integration of an on-grid PV system with IoT monitoring provides a robust solution for the ICU's energy needs. With further enhancements, such as MPPT implementation and active cooling, this model can serve as a replicable standard for energy-smart hospital design in Indonesia.

3. Research methodology

This study presents the implementation of on-grid solar panels in a hospital environment. Figure 1 shows the block diagram of this implementation, where the on-grid solar panel is connected to the solar charge controller to ensure the safety of battery charging; hence, overcharging or undercharging does not occur, and battery life is preserved. The inverter converts the DC output from the PV panels to power a Ventilator in the ICU room of RSI Siti Khadijah. IoT Monitoring receives inputs from current and voltage sensors; therefore, the user can monitor the production of PV panels installed on the rooftop of RSI Siti Khadijah. Exercise

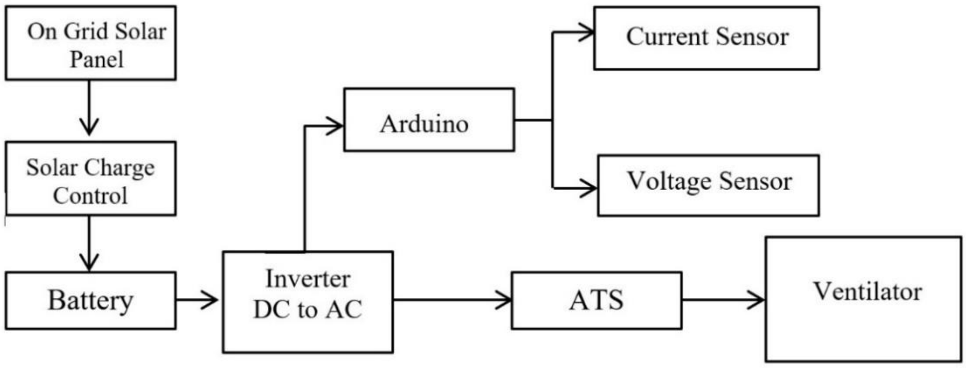


Figure 1. Blockchain distributed ledger technology.

3.1. Output and Efficiency Solar Cell

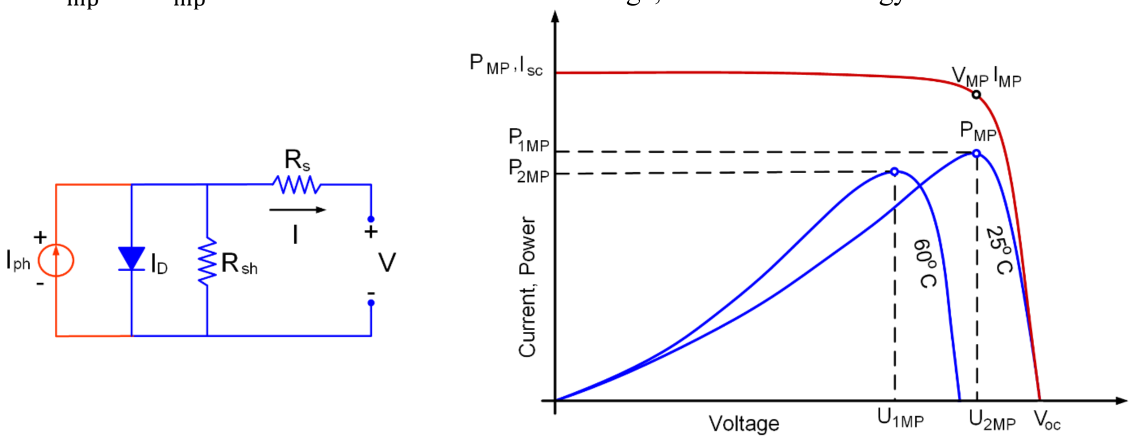
Figure 2a shows a PV panel modelled as an ideal diode. This model is obtained when a PN-junction semiconductor is wired and electricity is applied. Electrons flow to the positive side, and holes flow to the opposite side. During this motion, the number of electrons and holes in the middle of the junction is the same, forming a neutral barrier (Jäger, Isabella, Smets, van Swaaij, & Zeman, 2014). The generated current (I) is given by

$$I = I_{ph} - I_0\left(e^{q\left(\frac{V+IR_s}{AkT}\right)} - 1\right) - \frac{V + IR_s}{R_{sh}} \quad (1)$$

where I_{ph} is the photocurrent, R_s is series resistance, R_{sh} is shunt resistance, $I_D$is voltage-dependent current due to recombination, and V is voltage. The IV curve gives the maximum power produced by a solar cell (P_{MP}) in Figure 2b, which is the function of short-circuit current (I_{sc}) and open-circuit voltage (V_{oc}). The efficiency of a solar panel is

$$\eta = \frac{\rho_{out}}{\rho_{in}} x100\%, = \frac{I_{mp} \cdot V_{mp}}{P_{in}} x\ 100\%, = \frac{I_{sc}V_{oc}FF}{P_{in}}\ x\ 100\%, \quad (2)$$

where I_{mp} and V_{mp} are the maximum current and voltage, E is the solar energy and is the fill factor.



(a) *Ideal Diode* (b) *IV curve*

Figure 2. Solar cell modeling as an ideal diode

3.2. IoT Monitoring

The IoT Monitoring installed in this study gets input from voltage sensor ZMPT101B, voltage divider to supply sensor which consists of Resistors R1=150 K Ohm, R2=5,7K Ohm, wifi sensor NODEMCU

8266, microcontroller Arduino Nano and shield, and https://io.adafruit.com/as IoT interface as illustrated in Figure 3.

Figure 3. IoT monitoring of PV system installed in RSI Siti Khadijah Palembang

4. Result and discussion

This study presents the On-Grid PV System installed on the rooftop of a hospital building in Palembang, Indonesia, as shown in Figure 4. The PV system consists of 15 120 Wp panels, charge controllers for four batteries, ATS for switching to on-grid utilities, and an inverter connected to ventilators and monitors in the ICU Room of RSI Siti Khadijah Palembang; and Figure 5 shows the combiner box of the PV system.


Figure 4. IoT Monitoring Result

Figure 5. Combiner Box

The PV system can produce a maximum power of 1800 Wp as a result of 15 installed panels with 120 Wp each; however, due to the efficiency limitation of silicon-based solar panels, the highest power produced is 300-400 Wp per day. Figure 6 shows the IoT monitoring interface consisting of battery capacity (AKI), inverter input, and the power produced by the solar panels. The objective of IoT monitoring is to ease the task of PV system operators in monitoring the conditions of PV panel output and determining whether they should switch to the utility grid during cloudy/rainy days or continue using the battery charged by the PV system.

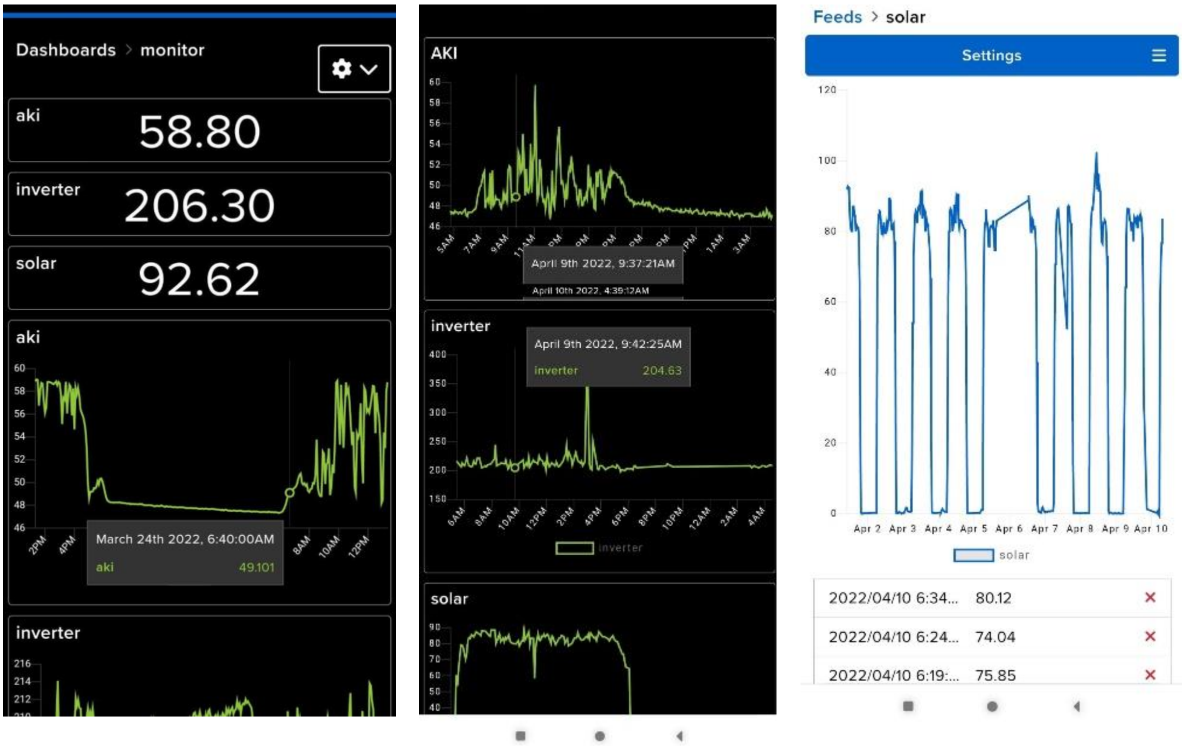


Figure 6. IoT Monitoring Interface

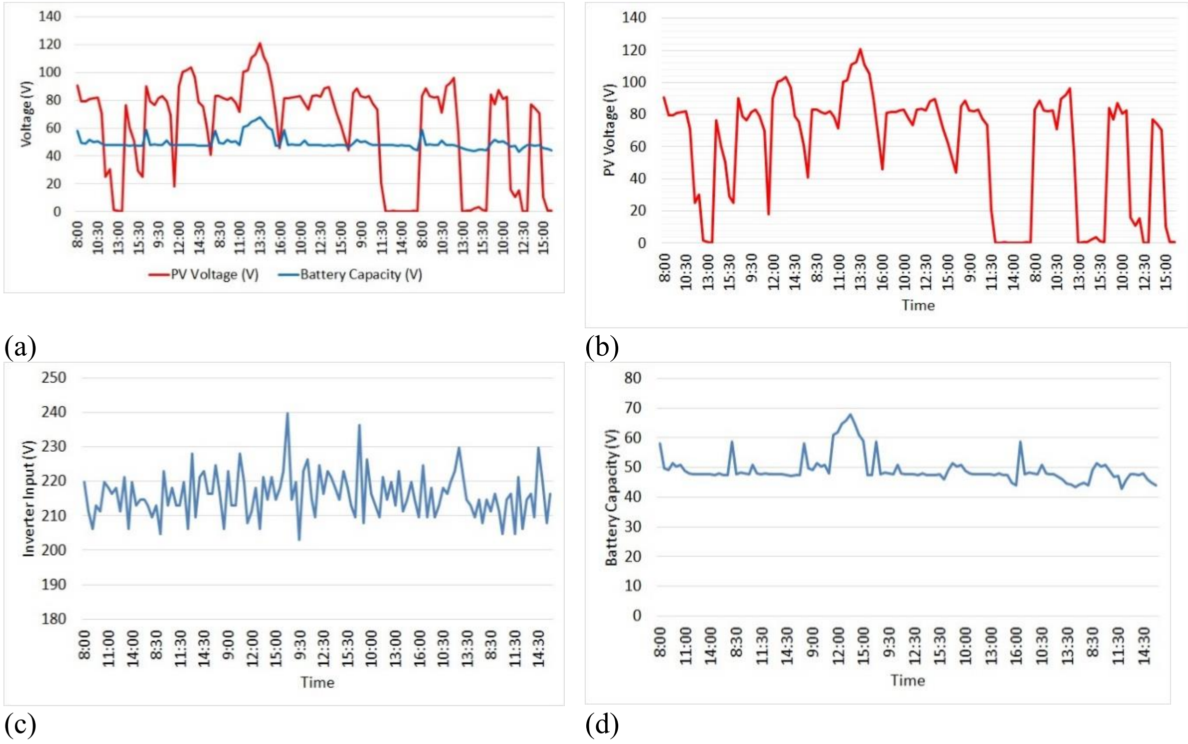


Figure 7. PV systems output for 7 days

Figure 7 shows the PV system output for a week, where the data were taken from 08.00 AM to 04.00 PM. Figure 7a shows the PV panel voltage output compared to the battery capacity, and Figure 7c shows the inverter output to power the ventilators and monitors. Figure 7c illustrates how the voltage is always in the safe range to power the equipment in the ICU rooms. The IoT monitoring results show that the proposed method effectively monitors the continuity of the supply for the load in a hospital environment. Future research should focus on implementing MPPT algorithms and active cooling devices to improve the output and efficiency of PV systems.

The IoT-based monitoring system is essential not only for tracking the real-time performance of PV panels but also for identifying potential faults or drops in efficiency. For instance, voltage inconsistencies or sudden decreases in inverter input may indicate issues with panel cleanliness, shadowing, or wiring faults, allowing the operator to act promptly before any failure occurs. This proactive maintenance capability enhances the reliability of the power supply to critical equipment, such as ventilators. Furthermore, IoT monitoring promotes data-driven decision-making. By collecting daily voltage, current, and battery capacity logs over time, hospital engineers can evaluate the patterns of solar energy availability and system performance. This information can be used to plan future energy scaling, adjust load balancing, and propose system upgrades, such as MPPT controllers or thermal management systems. Therefore, the combination of PV and IoT not only secures the energy supply but also empowers hospitals with long-term energy resilience strategies.

5. Conclusion

This paper presents the implementation of IoT monitoring on an On-Grid PV system installed on the rooftop of a hospital. The PV system is used to power the ventilator and monitors in ICU rooms, which are crucial to a patient's life, as any electricity outage can be fatal. The experimental results show that the PV system output is stable for charging batteries and ensures that the inverter output voltage is always within the safe range to provide continuous power to the load. Applying a PV system is much more beneficial than using a pricey and short-lifetime UPS battery. Future research should focus on implementing MPPT algorithms and active cooling devices to improve the output and efficiency of PV systems.

In addition to improving technical performance, the implementation of IoT-based PV systems in hospitals contributes to the sustainability of the energy infrastructure in the healthcare sector. With further research and scale-up, this model has the potential to be replicated in other medical facilities in Indonesia. Not only does it reduce operational dependency on fossil-fuelled electricity, but it also enhances energy resilience and supports the government's renewable energy goals, particularly in critical service environments, such as intensive care units.

5.1. Limitation/s and study forward

This study implemented IoT monitoring to ensure that the PV system was functioning well, providing a continuous supply to ventilators and monitors in ICU rooms. However, the system can be further optimized by implementing MPPT algorithms and active cooling devices to improve the output and efficiency of the On-Grid PV systems installed on the rooftop of RSI Siti Khadijah. In addition, the current monitoring platform focuses primarily on voltage, current, and inverter performance; expanding the system to include predictive maintenance analytics, environmental sensors for irradiance and temperature, and automated fault detection could further enhance reliability. The scope of this study was limited to a single hospital site, which may restrict the generalizability of the results. Future studies should involve multiple healthcare facilities with varying environmental conditions to validate performance consistency and explore scalability. Furthermore, the economic feasibility analysis, long-term degradation patterns of the PV modules, and the impact of seasonal weather variations were not examined in depth and should be addressed in subsequent research to strengthen the practical application of the proposed model.

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