

Performance Analysis of a Portable Solar Panel Charging System for Urban Parks

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ABSTRACT

The increasing use of portable electronic devices in urban parks has created a growing demand for independent and environmentally friendly charging facilities. This study aims to analyze the performance of a portable solar panel charging system under variations in solar irradiance, panel capacity, and panel configuration. Three irradiance levels (2.5, 4.5, and 5.5 kWh/m²/day), three panel capacities (100 Wp, 150 Wp, and 200 Wp), and three configurations (single panel, parallel, and series) were evaluated. Engineering-based energy calculations were validated using MATLAB/Simulink through the PV Array Model to analyze the current–voltage (I–V) and power–voltage (P–V) characteristics of the photovoltaic system. The results show that solar irradiance is the dominant factor affecting daily energy production. Under medium irradiance conditions (4.5 kWh/m²/day), the estimated daily energy outputs of the 100 Wp, 150 Wp, and 200 Wp panels were approximately 315 Wh/day, 472.5 Wh/day, and 630 Wh/day, respectively, while the highest energy output of 770 Wh/day was achieved by the 200 Wp panel under high irradiance conditions (5.5 kWh/m²/day). Among the evaluated configurations, the parallel arrangement provided the most suitable performance for portable charging applications because it delivered higher output current and improved battery charging capability. Based on the obtained results, a portable solar panel system with a capacity of 150–200 Wp in a parallel configuration is recommended for charging electronic devices in urban parks. These findings demonstrate that combining appropriate panel capacity, solar irradiance conditions, and system configuration can significantly improve the performance and practicality of portable photovoltaic charging systems for public outdoor facilities.

Keywords: Portable solar panel system, photovoltaic, solar irradiance, MATLAB/Simulink, PV Array Model, urban parks.

ABSTRAK

Meningkatnya penggunaan perangkat elektronik portabel di taman kota telah mendorong kebutuhan akan fasilitas pengisian daya yang mandiri dan ramah lingkungan. Penelitian ini bertujuan untuk menganalisis kinerja sistem pengisian daya panel surya portabel berdasarkan variasi intensitas radiasi matahari, kapasitas panel, dan konfigurasi panel. Penelitian ini mengevaluasi tiga tingkat intensitas radiasi matahari (2,5; 4,5; dan 5,5 kWh/m²/hari), tiga kapasitas panel (100 Wp, 150 Wp, dan 200 Wp), serta tiga konfigurasi panel, yaitu panel tunggal, paralel, dan seri. Perhitungan energi berbasis rekayasa divalidasi menggunakan **MATLAB/Simulink** melalui **PV Array Model** untuk menganalisis karakteristik arus–tegangan (I–V) dan daya–tegangan (P–V) sistem fotovoltaik. Hasil penelitian menunjukkan bahwa intensitas radiasi matahari merupakan faktor yang paling dominan dalam memengaruhi produksi energi harian. Pada kondisi radiasi sedang (4,5 kWh/m²/hari), estimasi energi harian yang dihasilkan panel berkapasitas 100 Wp, 150 Wp, dan 200 Wp berturut-turut mencapai sekitar **315 Wh/hari, 472,5**



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Wh/hari, dan 630 Wh/hari, sedangkan keluaran energi tertinggi sebesar **770 Wh/hari** diperoleh pada panel 200 Wp dengan intensitas radiasi tinggi (5,5 kWh/m²/hari). Di antara konfigurasi yang dievaluasi, konfigurasi paralel memberikan kinerja paling optimal untuk aplikasi pengisian daya portabel karena menghasilkan arus keluaran yang lebih tinggi serta meningkatkan kemampuan pengisian baterai. Berdasarkan hasil penelitian, sistem panel surya portabel berkapasitas **150–200 Wp** dengan konfigurasi paralel direkomendasikan untuk pengisian daya perangkat elektronik di taman kota. Temuan ini menunjukkan bahwa kombinasi kapasitas panel, kondisi intensitas radiasi matahari, dan konfigurasi sistem yang tepat mampu meningkatkan kinerja serta kepraktisan sistem pengisian daya fotovoltaik portabel pada fasilitas ruang terbuka publik.

Kata Kunci: sistem panel surya portabel, fotovoltaik, intensitas radiasi matahari, MATLAB/Simulink, PV Array Model, taman kota.

1. Introduction

Electrical energy has become an essential requirement in modern life, including for activities carried out in public spaces such as urban parks. The increasing use of portable electronic devices, including smartphones, cameras, and laptops, has led to a growing demand for charging facilities in outdoor environments. However, the installation of permanent electrical infrastructure in public areas is often constrained by high installation costs, aesthetic considerations, and safety concerns. Therefore, an alternative energy solution that is independent, portable, and environmentally friendly is required to support public activities in open spaces.

Indonesia has significant solar energy potential, with an average daily solar radiation intensity ranging from 4 to 5 kWh/m²/day. Variations in solar irradiance, commonly expressed as peak sun hours (PSH), have been shown to exhibit a strong correlation with the energy productivity of photovoltaic (PV) systems. Megantoro et al. [1] (2022) reported that an increase in PSH directly enhances the daily energy output that can be harvested by portable solar panels. In addition to solar irradiance, module temperature also has a significant influence on the current–voltage characteristics and power output of PV panels, as demonstrated by Al-Ghezi [3] (2022), who found that an increase in operating temperature leads to a reduction in operating voltage and overall solar cell efficiency.

The configuration of photovoltaic panel arrays, including series and parallel arrangements, also affects overall system performance, particularly under non-uniform irradiance conditions. Patel and Agarwal [7] (2008) demonstrated that partial shading in series-connected arrays has a significant impact on output voltage, whereas parallel-connected configurations primarily lead to a reduction in system current. Furthermore, a study by Gonzales [4] (2022) emphasized that panel configuration and lighting conditions play a crucial role in determining the effectiveness of solar PV–based charging systems in outdoor environments.

As an additional reference from a local institution, a study conducted by Brahmana and Panjaitan [6] (2023) and published by Universitas Sumatera Utara (USU) compared the energy efficiency of sun-tracking solar panels with that of static 40 Wp panels. The results indicated that variations in panel orientation and solar irradiance have a direct impact on the amount of energy that can be harvested by PV modules. These findings further highlight the importance of conducting comprehensive performance analyses of photovoltaic systems under different irradiance conditions and panel configurations. Although these studies have significantly contributed to the understanding of photovoltaic system performance, they primarily investigate individual factors affecting PV systems. Consequently, a comprehensive evaluation that integrates solar irradiance, panel capacity, and panel configuration, supported by engineering calculations and MATLAB/Simulink validation for portable charging applications in urban parks, remains limited.

Despite the considerable number of studies on photovoltaic system performance, most previous research has focused on a single technical aspect, such as the influence of solar irradiance, panel capacity, or array configuration, without comprehensively evaluating their combined effects on portable photovoltaic systems intended for public outdoor applications. Furthermore, many studies primarily emphasize electrical performance under laboratory or fixed operating conditions, providing limited practical guidance for designing portable charging systems that operate under varying environmental conditions encountered in urban parks. Consequently, there remains a need for a more comprehensive performance evaluation that integrates these key parameters within a single analytical framework.

This study addresses this gap by simultaneously investigating the effects of solar irradiance (2.5, 4.5, and 5.5 kWh/m²/day), panel capacity (100 Wp, 150 Wp, and 200 Wp), and panel configuration (single, parallel, and series) on the performance of a portable solar panel charging system. Engineering-based energy calculations are validated using MATLAB/Simulink through the PV Array Model to evaluate energy output, current–voltage (I–V) characteristics, and power–voltage (P–V) characteristics under different operating conditions. Therefore, the objective of this study is to determine the most suitable panel capacity and configuration for portable charging applications in urban parks while providing a comprehensive technical reference for the design of sustainable photovoltaic charging systems in public spaces.

2. Method

In this study, the performance analysis of the portable solar panel system is conducted based on the technical specifications of photovoltaic components and the solar radiation conditions in Indonesia. The research process begins with the collection of data on solar irradiance, solar panel characteristics, batteries, and other supporting components. Subsequently, system variations are defined, including variations in solar irradiance levels, panel capacity, and panel array configuration. All collected data are then processed using analytical calculations and simulation methods to estimate the daily energy output generated by each system variation.

In general, the research stages consist of a literature review, data collection, determination of variation parameters, solar panel energy calculation and simulation, result analysis, and conclusion drawing. The overall research flow is illustrated in the following figure:

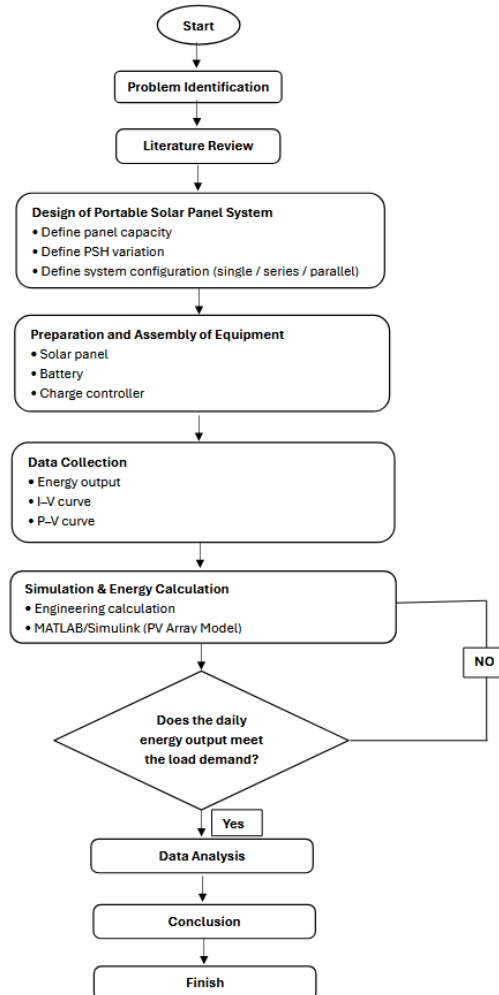


Figure 1. Research Flow Diagram

2.1. Literature Review

Figure 1 presents the overall research workflow adopted in this study. The research began with a literature review to identify the key factors influencing photovoltaic system performance, followed by the collection of secondary data from photovoltaic module datasheets, battery specifications, meteorological databases, and relevant scientific publications. Engineering-based energy calculations were then performed under various operating conditions and validated using MATLAB/Simulink through the PV Array Model. Finally, the analytical and simulation results were evaluated to determine the most suitable portable solar panel configuration for charging electronic devices in urban parks.

This stage aims to examine the fundamental theories related to solar radiation, solar panel characteristics, series-parallel configurations, battery systems, and overall photovoltaic (PV) system efficiency. In addition, a review of relevant studies is conducted, including the work of Megantoro (2022) on the effect of peak sun hours on energy output [1], the study by Al-Ghezi (2022) on PV characteristics under varying irradiance conditions [3], and the research by Gonzales (2022) related to portable solar-powered charging systems [4]. These studies serve as the basis for selecting the system variations and the parameters used in the MATLAB simulation.

2.2. Data Collection

The data collection stage is conducted to obtain all technical parameters required for the MATLAB simulation process and the performance analysis of the portable solar panel system. The data used in this study are secondary data obtained from the following sources:

- solar panel manufacturer datasheets,
- battery and electronic component datasheets,
- previous research articles,
- technical reports (PV performance tests),
- solar radiation data from official databases (Meteorological, Climatological, and Geophysical Agency (BMKG), PVGIS, and NREL), and
- commonly accepted efficiency values from the photovoltaic system literature.

The collected data are described in detail along with their acquisition and validation methods to ensure that the simulation process can be accurately reproduced.

Solar Irradiance Data (Peak Sun Hours – PSH)

Data Sources:

The average daily solar radiation data for Indonesia were obtained from the following sources:

- PVGIS and SolarGIS databases for tropical regions,
- Indonesian solar energy research journals, and
- the Meteorological, Climatological, and Geophysical Agency (BMKG), where available.

Data Acquisition Procedure:

- Peak sun hours (PSH) are calculated based on the daily global solar radiation values (kWh/m²/day).
- The data are categorized into three representative conditions: low irradiance (2.5 h/day PSH), medium irradiance (4.5 h/day PSH), high irradiance (5.5 h/day PSH), to reflect variations in real field conditions.

Data Validation:

- The PSH values are compared with the findings reported by Megantoro [1] (2022) and Al-Ghezi [3] (2022).
- A maximum tolerance deviation of $\pm 5\%$ from the literature values is applied.

The validated PSH values were used as input parameters for the engineering calculations and MATLAB/Simulink PV Array Model. The selected irradiance levels (2.5, 4.5, and 5.5 kWh/m²/day) represent low, medium, and high solar radiation conditions in tropical regions.

Solar Panel Specification Data

Data Sources:

The data are obtained from manufacturer datasheets of 100 Wp, 150 Wp, and 200 Wp solar panels that are commonly available on the Indonesian market.

Collected Parameters:

- Panel rated power: 100 Wp, 150 Wp, and 200 Wp
- Maximum power voltage (V_{mp})
- Maximum power current (I_{mp})
- Open-circuit voltage (V_{oc})
- Short-circuit current (I_{sc})
- Panel efficiency
- Panel dimensions

Data Acquisition Method:

- Datasheets were obtained directly from solar panel manufacturers (such as Luxen, SolarWorld, and other commercially available polycrystalline and monocrystalline photovoltaic modules).
- The collected data are cross-checked with reference studies reported by Handoko, Megantoro, and Gonzales to ensure consistency.

Validation and Calibration:

- The V_{oc} and I_{sc} values are compared with the IEC 61215 standard.
- A maximum mismatch tolerance of $\leq 3\%$ is applied.

Relation to Simulation:

The collected photovoltaic module parameters were implemented in the MATLAB/Simulink PV Array Model for engineering-based energy calculations.

Solar Panel System Configuration Data

Three system configurations are evaluated through simulation:

- 1) Single 12 V Panel
 - Constant voltage output
 - Suitable for low-power applications such as USB charging and park lighting
- 2) Two Panels Connected in Parallel
 - Higher output current
 - Constant operating voltage
 - Suitable for high-power and fast-charging applications
- 3) Two Panels Connected in Series
 - Higher output voltage
 - Constant current
 - Suitable for applications requiring higher operating voltage

Configuration Data Acquisition Method:

The photovoltaic configurations were defined based on the theoretical principles of series and parallel PV connections and verified using relevant literature, including the study *Effect of Series and Parallel Shading on PV System Performance*. These configurations were evaluated to determine the most suitable arrangement for achieving the targeted daily energy output.

Battery and Energy Storage System Data

Data Source:

The data are obtained from datasheets of lithium and AGM batteries designed for portable energy systems.

Parameter:

- Battery capacity: 10 Ah – 30 Ah (12 V)
- Battery type: Lithium or AGM deep-cycle
- Nominal voltage: 12 V
- Depth of discharge (DoD): 70–80%

Validation:

The battery specifications were validated using the design considerations reported by Gonzales [4] (2022) to ensure compatibility with the estimated daily photovoltaic energy output and portable electronic device charging requirements.

Battery capacities of 10 Ah, 20 Ah, and 30 Ah were selected to evaluate compatibility between the estimated daily energy production and storage requirements. Although battery charging was not modeled separately in MATLAB/Simulink, these capacities served as design references for assessing system feasibility under different operating conditions.

Electronic Load Demand Data

Data Source:

The load demand data are obtained from device datasheets and power consumption studies.

Collected data:

- Smartphone chargers: 5–20 W
- Laptop devices: 30–45 W
- LED lighting systems: 10–15 W
- Device usage duration: 1–2 hours per day

These representative power ratings were selected based on commonly available portable electronic devices and were used to establish the daily energy demand considered in this study.

Data Acquisition Method:

- Average power consumption values are determined based on the specifications of commonly used commercial devices.
- The values are verified through direct measurements using:
 - Power Meter (AC/DC Watt Meter)
 - Measurement accuracy of $\pm 1\%$, and
 - Factory calibration, as indicated by the calibration certificate attached to the instrument datasheet.

The selected electronic loads represent the most common portable devices used in urban parks, including smartphones, laptops, and LED lighting systems. These load profiles were used to evaluate whether the estimated photovoltaic energy output was sufficient to satisfy daily charging requirements for each system configuration.

System Efficiency and Loss Data

Data Source:

The efficiency and loss data were obtained from photovoltaic system literature and MPPT technical documentation.

Parameters:

- Panel efficiency: 15–20%
- MPPT efficiency: 90–98%
- Cable losses: 2–6%
- Total system losses: 10–15%

These parameter ranges were selected based on commonly reported values in photovoltaic system literature and international technical standards to represent realistic operating conditions.

Data Acquisition Method:

The efficiency and loss values are adopted based on the findings reported by Al-Ghezi [3] (2022) and IEEE photovoltaic technical standards.

Relation to Simulation:

The efficiency and loss parameters were incorporated into both the engineering-based calculations and the MATLAB/Simulink model to represent practical operating conditions. Considering panel efficiency, MPPT efficiency, cable losses, and overall system losses enabled a more realistic estimation of photovoltaic system performance under outdoor operating conditions.

2.3. System Variation Design

This study evaluates three groups of system variations based on the studies by Megantoro (2022) and Al-Ghezi (2022) [1], [3].

1. Solar Irradiance Variation (PSH): low, medium, and high PSH levels
2. Panel Capacity Variation: 100 Wp, 150 Wp, and 200 Wp
3. System Configuration Variation: single panel, two panels connected in parallel, and two panels connected in series

Each combination of these variations is tested to examine its influence on the daily energy output of the system. The selected parameter variations represent practical operating conditions commonly encountered in portable photovoltaic charging systems. They were chosen to evaluate the effects of solar irradiance, panel capacity, and electrical configuration on the daily energy output under different operating conditions.

2.4. Simulation and Energy Calculation

The photovoltaic system was analyzed using the MATLAB/Simulink environment with the PV Array block available in Simscape Electrical (formerly SimPowerSystems). The simulation model was configured using the photovoltaic module parameters collected during the data collection stage, including panel capacity, electrical characteristics, solar irradiance (Peak Sun Hours), and system efficiency. The primary objective of the simulation was to estimate the daily energy output and evaluate the electrical performance of different photovoltaic system configurations under representative operating conditions.

Energy Calculation Formula

The engineering-based energy calculation was performed to estimate the daily electrical energy produced by the photovoltaic system under different operating conditions. The calculation considers the nominal panel capacity, the available Peak Sun Hours (PSH), and the overall system efficiency. The calculated results serve as a reference for comparison with the MATLAB/Simulink simulation outputs to evaluate the consistency and feasibility of the proposed photovoltaic charging system.

The daily energy output of the solar panel system is calculated using the following equation:

$$E = P_{panel} \times PSH \times \eta_{system}$$

Where:

E = estimated daily energy output of the photovoltaic system (Wh/day)

P_{panel} = nominal photovoltaic panel capacity (Wp)

PSH = Peak Sun Hours, representing the equivalent daily solar irradiance (hours/day)

η_{system} = overall photovoltaic system efficiency, including panel, MPPT, cable, and system losses (decimal)

Evaluation Target (Decision Point):

The feasibility of each photovoltaic system configuration was evaluated by comparing the estimated daily energy output with the daily energy demand of the connected electrical loads. A configuration was considered feasible when the generated energy was equal to or greater than the required load demand, as expressed by the following criterion:

$$E_{panel} \geq E_{load}$$

- If $E_{panel} \geq E_{load}$, the photovoltaic system configuration is considered capable of meeting the daily energy demand and is classified as feasible.
- If $E_{panel} < E_{load}$, the selected panel capacity and/or system configuration must be adjusted, and the evaluation process is repeated until the required energy demand is achieved.

The engineering-based calculations were validated using the MATLAB/Simulink PV Array Model by comparing the estimated daily energy output, I–V characteristics, and P–V characteristics under identical operating conditions. The comparison employed identical panel capacities (100, 150, and 200 Wp), PSH values (2.5, 4.5, and 5.5 h/day), and system efficiency assumptions to evaluate the consistency between analytical calculations and simulation results.

3. Result and Discussion

This section presents and discusses the performance evaluation of the proposed portable solar panel charging system under various operating conditions. The analysis combines engineering calculations and MATLAB/Simulink simulations to evaluate the effects of solar irradiance, panel capacity, and system configuration on daily energy output. The simulation results are further analyzed using current–voltage (I–V) and power–voltage (P–V) characteristics to identify the most suitable photovoltaic configuration for portable charging applications in urban parks.

3.1. Daily Energy Calculation Results of the Solar Panel System

The estimated daily electrical energy output of the solar panel system is calculated using the fundamental photovoltaic system equation as follows:

$$E = P_{panel} \times PSH \times \eta_{system}$$

The system efficiency is assumed to be 70%, which accounts for losses in the solar panel, solar charge controller, cabling, and energy storage system. This value falls within the typical efficiency range commonly adopted in simulation-based studies of portable solar panel systems.

Engineering Calculation Example

For a solar panel with a rated capacity of 150 Wp operating under a PSH condition of 4.5 hours, the estimated daily energy output is calculated as:

$$E = 150 \times 4,5 \times 0,70 = 472.5 \text{ Wh/day}$$

Meanwhile, for a 200 Wp solar panel operating at a PSH level of 5.5 hours, the estimated daily energy output is:

$$E = 200 \times 5,5 \times 0,70 = 770 \text{ Wh/day}$$

The analytical calculations provide the initial reference for validating the MATLAB/Simulink simulation results presented in the following sections.

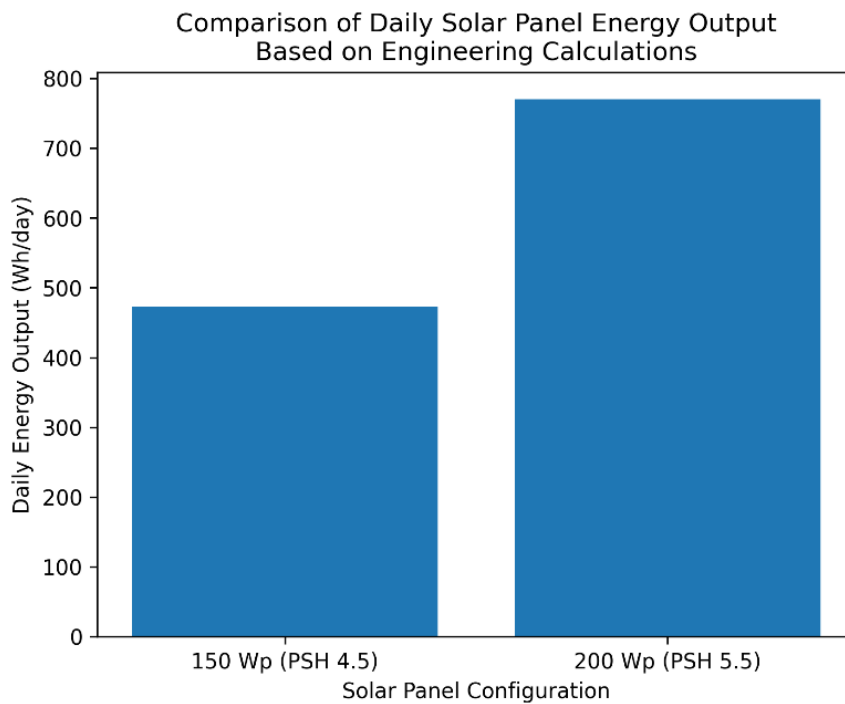


Figure 2. Comparison of Daily Solar Panel Energy Output Based on Engineering Calculations

The analytical results indicate that increasing panel capacity from 150 Wp to 200 Wp under higher irradiance conditions increases the estimated daily energy output from 472.5 Wh/day to 770 Wh/day, representing an improvement of approximately 63%. This trend is consistent with photovoltaic theory, where higher solar irradiance and larger panel capacity increase the amount of electrical energy generated. Similar findings have been reported in previous studies, confirming that irradiance and panel capacity are the dominant factors affecting photovoltaic energy production.

3.2. Effect of Solar Irradiance Variation (PSH)

This analysis evaluates the influence of Peak Sun Hours (PSH) on the daily energy output of the proposed portable photovoltaic charging system. Since solar irradiance determines the amount of solar energy received by the photovoltaic modules, variations in PSH directly affect the electrical energy that can be generated. To isolate the effect of solar irradiance, the photovoltaic panel capacity was maintained constant while only the PSH values were varied.

As an example, for a 150 Wp solar panel, the following results are obtained:

- PSH of 2.5 hours produces 262.5 Wh/day of energy,
- PSH of 4.5 hours produces 472.5 Wh/day of energy,
- PSH of 5.5 hours produces 577.5 Wh/day of energy.

The calculated energy outputs demonstrate a clear positive relationship between solar irradiance and photovoltaic energy production, as illustrated in Figure 3.

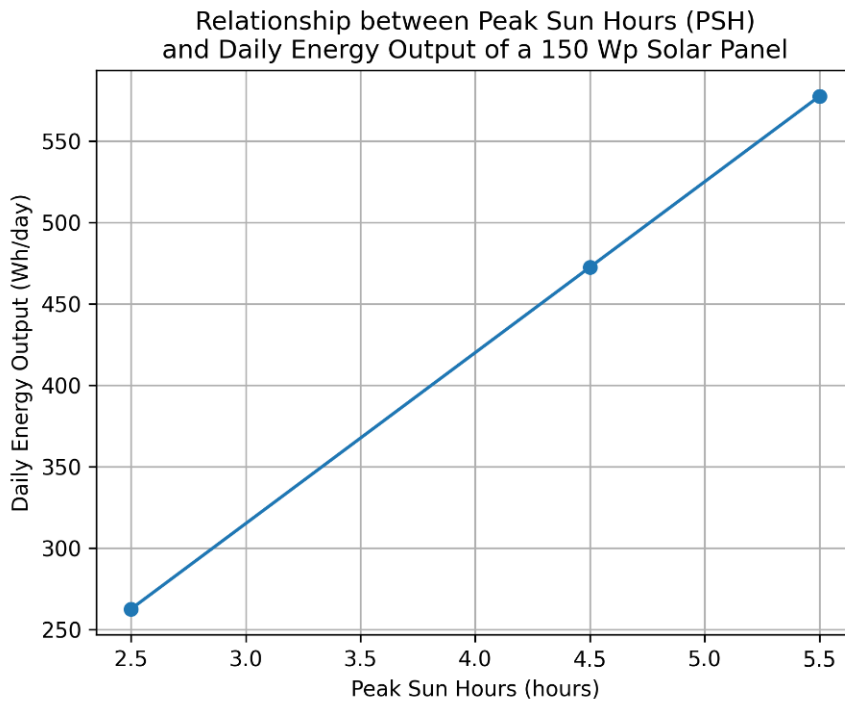


Figure 3. Daily Energy Output of Solar Panels Based on Engineering Calculations

Figure 3 shows a linear relationship between Peak Sun Hours (PSH) and daily energy output. Increasing PSH from 2.5 to 5.5 hours increases the estimated energy production from 262.5 Wh/day to 577.5 Wh/day, confirming that solar irradiance is the dominant factor affecting photovoltaic energy generation. These findings are consistent with photovoltaic theory and the study by Megantoro et al. [1], which reported that higher solar irradiance directly increases photovoltaic energy production. Therefore, portable photovoltaic charging systems installed in urban parks are expected to perform more effectively under higher solar radiation conditions.

3.3. Effect of Solar Panel Capacity Variation

This analysis evaluates the effect of photovoltaic panel capacity on the daily energy output of the proposed portable photovoltaic charging system. To isolate the effect of panel capacity, the Peak Sun Hours (PSH) value was maintained at 4.5 hours/day while the nominal panel capacities were varied between 100 Wp, 150 Wp, and 200 Wp. This approach allows the contribution of panel capacity to the system's energy generation capability to be evaluated independently.

- 100 Wp solar panel generates approximately 315 Wh/day,
- 150 Wp solar panel generates approximately 472.5 Wh/day,
- 200 Wp solar panel generates approximately 630 Wh/day.

The calculated results indicate a progressive increase in daily energy production as the photovoltaic panel capacity increases.

These results demonstrate a linear relationship between panel capacity and the generated energy output. The 100 Wp panel is considered sufficient for light-load applications, while the 200 Wp panel provides a larger and more stable energy margin. These findings are consistent with the study conducted by Al-Ghezi et al. [3], which reported that increasing the installed photovoltaic capacity significantly improves the electrical power output and energy production of photovoltaic systems. The agreement between the present study and previous research further supports the reliability of the proposed analytical and simulation approaches.

The observed increase in daily energy output is expected because the generated electrical energy is directly proportional to the rated capacity of the photovoltaic module, as described in Equation (1). With identical solar irradiance conditions, larger photovoltaic modules are capable of converting a greater amount of solar energy into electrical energy, thereby increasing the available energy for charging portable electronic devices. This finding confirms that increasing panel capacity is an effective approach for improving the reliability and operational capability of portable photovoltaic charging systems.

Based on the simulation results, from a practical perspective, the simulation results suggest that different panel capacities are suitable for different application scenarios, as summarized below:

- 100 Wp panel is suitable for light loads such as smartphone charging and power banks,
- 150 Wp panel is capable of supplying combined medium-load applications,
- 200 Wp panel delivers the highest and most stable energy output.

3.4. Effect of Solar Panel System Configuration

This analysis evaluates the influence of photovoltaic panel electrical configurations on the performance of the proposed portable photovoltaic charging system. Three commonly used configurations—single panel, series connection, and parallel connection—were analyzed to determine their effects on voltage, current, and the resulting daily energy output. The objective was to identify the most suitable configuration for portable charging applications in urban parks while maintaining reliable electrical performance under varying operating conditions.

Table 1. Comparison of Electrical Characteristics of Photovoltaic Panel Configurations for Portable Charging Applications

Configuration	Voltage	Current	Advantages	Recommended Application
Single Panel	Constant	Standard	Simple installation	Small portable loads
Series	Higher	Constant	Higher operating voltage	Long cable distance
Parallel	Constant	Higher	Higher output current	Portable photovoltaic charging systems

Table 1 summarizes the electrical characteristics and recommended applications of the evaluated photovoltaic panel configurations.

(1) Parallel Configuration

In the parallel configuration, the operating voltage remains relatively constant while the output current increases with the number of connected photovoltaic modules. Consequently, this configuration delivers higher power output and is well suited for portable charging applications.

- Maintains stable operating voltage
- Provides higher output current
- Suitable for high-power portable charging applications
- Supports faster battery charging

(2) Series Configuration

In the series configuration, the output voltage increases while the current remains approximately constant. This arrangement is advantageous for applications requiring higher operating voltages or longer cable distances, although it is less suitable for high-current portable charging applications.

- Increased system voltage
- Constant current level
- Suitable for applications with long cable distances
- Improves power transfer efficiency

(3) Single Panel Configuration

The single-panel configuration is the simplest arrangement with minimal installation complexity. However, its electrical power is limited by the capacity of a single photovoltaic module, resulting in the lowest daily energy output among the evaluated configurations.

- Stable output characteristics
- Lowest energy output
- Suitable for small-scale systems

The analysis of solar panel array configurations reveals significant differences in electrical characteristics among single, series, and parallel configurations. The parallel configuration demonstrated the best overall performance because it provides higher output current while maintaining a stable operating voltage. This characteristic makes it well suited for portable charging systems that require reliable power delivery for multiple low-voltage electronic devices.

These findings are consistent with previous photovoltaic studies, which reported that parallel-connected modules are more suitable for low-voltage, high-current applications due to their ability to increase current while maintaining stable operating voltage. Overall, the parallel configuration demonstrated the most balanced electrical performance and is therefore recommended for portable photovoltaic charging systems installed in urban parks and other public open spaces.

3.5. Validation of the MATLAB/Simulink Simulation Model

The validity of the proposed MATLAB/Simulink photovoltaic model was evaluated by analyzing the current–voltage (I–V) and power–voltage (P–V) characteristics generated by the PV Array Model under different Peak Sun Hours (PSH) conditions. The simulated electrical characteristics were compared with the theoretical of photovoltaic modules reported in previous studies to determine whether the developed simulation model accurately represents the electrical performance of practical photovoltaic systems.

Figure 4 illustrates the simulated I–V characteristics of the photovoltaic module under three representative solar irradiance conditions corresponding to PSH values of 2.5, 4.5, and 5.5 hours/day.

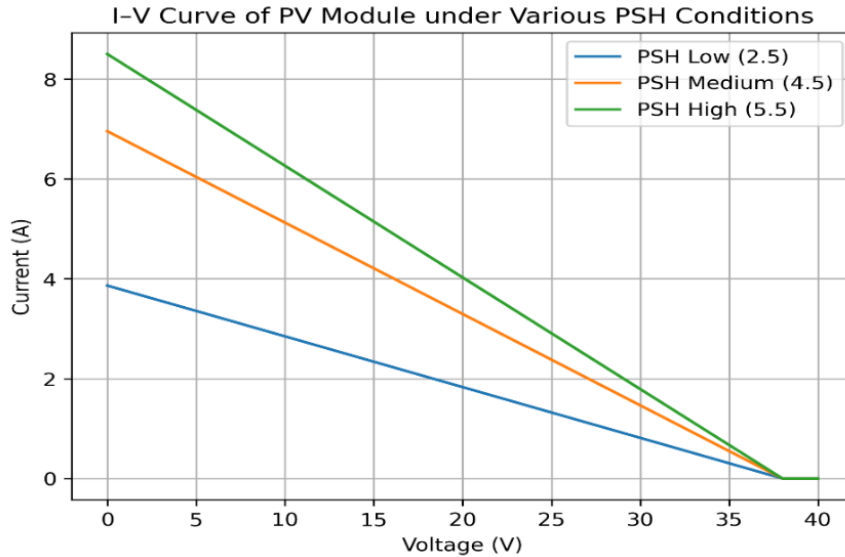


Figure 4. I–V Curves of the Solar Panel Module under PSH Variations

The simulated I–V characteristics confirm the expected behavior of photovoltaic modules, where increasing solar irradiance primarily increases the output current while having only a minor effect on the open-circuit voltage. These results indicate that the developed PV Array Model successfully reproduces the electrical characteristics of photovoltaic modules under different irradiance conditions. Based on the I–V curves, it can be observed that an increase in PSH leads to a higher short-circuit current (I_{sc}), while the open-circuit voltage (V_{oc}) remains relatively stable. This behavior is consistent with the findings of Al-Ghezi et al. [3], confirming that solar irradiance primarily affects the output current of photovoltaic modules.

In addition to the I–V characteristics, the corresponding P–V curves were analyzed to evaluate the influence of solar irradiance on the maximum power output of the photovoltaic module.

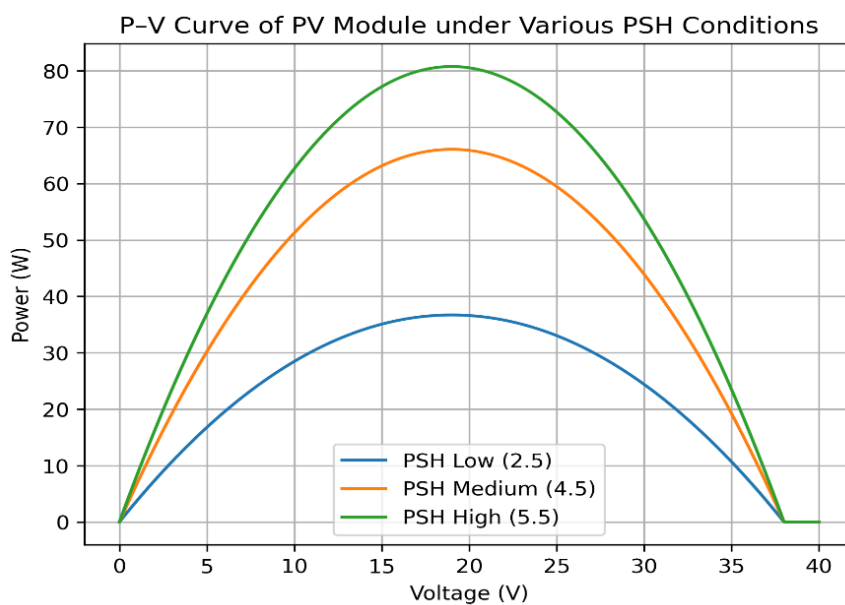


Figure 5. P–V Curves of the Solar Panel Module under PSH Variations

The simulated P–V curves show that increasing PSH shifts the maximum power point (MPP) toward higher power values, consistent with the findings of Megantoro et al. [1]. The close agreement between the simulated P–V characteristics and previous studies demonstrates that the developed MATLAB/Simulink model provides reliable predictions of photovoltaic system performance under different operating conditions.

Overall, the agreement between the engineering calculations, MATLAB/Simulink simulations, and previous studies confirms the validity of the proposed PV Array Model for evaluating portable photovoltaic charging systems under various operating conditions.

3.6. Comparison between Energy Output and Load Demand

This section compares the estimated daily energy output of the proposed photovoltaic system with the typical energy requirements of portable electronic devices commonly used in urban parks. The objective is to evaluate whether the generated energy is sufficient to satisfy practical charging demands under different photovoltaic capacities and solar irradiance conditions.

Representative electrical loads considered in this study are summarized below:

- Smartphone: 5–20 W
- Power bank: 10–18 W
- Laptop: 30–45 W

Table 2. Comparison of Daily Energy Output and Load Fulfillment Capability of the Proposed Portable Photovoltaic System

Panel Capacity & PSH	Daily Energy Output (Wh/day)	Load Fulfillment Capability
100 W _p – PSH 4.5	315	Charging 8–12 smartphone units
150 W _p – PSH 4.5	472.5	Charging one laptop and several smartphones
200 W _p – PSH 5.5	770	Charging one laptop and 3–4 smartphones

Table 2 summarizes the relationship between the estimated daily photovoltaic energy output and the charging capability of representative portable electronic devices. Table 2 indicates that increasing photovoltaic panel capacity and solar irradiance significantly improves the charging capability of the proposed system. While the 100 W_p module is suitable for smartphone charging, the 150 W_p configuration can simultaneously support one laptop and several smartphones. Under high irradiance conditions (5.5 PSH), the 200 W_p configuration provides the highest energy availability and the greatest operational margin for multiple portable devices. These findings are consistent with the study by Gonzales et al. [4], confirming that appropriate photovoltaic capacity selection is essential for maintaining reliable charging performance under varying operating conditions.

3.7. General Discussion

Overall, the results demonstrate that solar irradiance, photovoltaic panel capacity, and electrical configuration are the three principal factors governing the performance of portable photovoltaic charging systems. Both the engineering calculations and MATLAB/Simulink simulations consistently show that increasing solar irradiance and panel capacity enhances daily energy output, while appropriate electrical configuration improves energy delivery performance.

Unlike previous studies that generally focused on a single design parameter, this research simultaneously evaluates the combined effects of solar irradiance, panel capacity, and electrical configuration within a single analytical framework. This integrated evaluation provides a more comprehensive understanding of the operational performance of portable photovoltaic charging systems intended for urban park applications.

From a practical perspective, the obtained results provide useful design recommendations for the development of independent charging facilities in public open spaces. The findings suggest that photovoltaic systems employing 150–200 W_p panels connected in parallel under medium to high solar irradiance conditions are capable of satisfying typical charging demands while maintaining reliable electrical performance.

The agreement between engineering calculations, MATLAB/Simulink simulations, and the theoretical behavior reported in previous studies confirms that the proposed analytical approach provides a reliable basis for the preliminary design and performance evaluation of portable photovoltaic charging systems for public-space applications.

4. Conclusion

Based on the results of the engineering calculations and MATLAB/Simulink simulation analyses, it can be concluded that solar irradiance intensity (Peak Sun Hours/PSH), solar panel capacity, and photovoltaic array configuration are the primary factors influencing the performance of a portable solar-powered charging system for

electronic devices in urban parks. Higher PSH significantly increases daily energy production, while larger solar panel capacities provide greater electrical energy to accommodate increasing charging demands. Among the evaluated configurations, the parallel photovoltaic arrangement demonstrates the most favorable performance by delivering higher output current, improving daily energy generation, and enabling faster battery charging compared with single-panel and series configurations. Furthermore, the MATLAB/Simulink PV Array Model shows good agreement with the engineering calculations, indicating that the simulation accurately represents the electrical behavior of the photovoltaic system under the investigated operating conditions. Based on the comparison between daily energy production and load demand, a parallel configuration using 150–200 Wp solar panels under medium to high PSH conditions is identified as the most suitable design for portable charging applications in urban parks, as it provides sufficient energy and reliable performance for charging multiple electronic devices. Overall, the integration of engineering calculations and MATLAB/Simulink simulations offers a dependable framework for the design and evaluation of portable photovoltaic charging systems and can support the development of sustainable solar-powered charging facilities in urban parks and other public open spaces. However, this study is limited to simulation-based analysis, and future work should include experimental validation using a physical prototype, along with investigations of battery management strategies and long-term system performance under varying environmental conditions.

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