Design and Performance Analysis of a Portable Solar Panel for Smartphone Charging

[1]Tri Joko, [2]Erlina, [3]Doni Pratama
[1,2,3] Institute Technology of PLN, Jl. Lingkar Luar Barat Duri Kosambi, Cengkareng Jakarta Barat, 11750
[1]tri.joko@itpln.ac.id, [2]erlina@itpln.ac.id, [3]doni.pratama@itpln.ac.id

Abstract - This study aims to design, construct, and evaluate the performance and efficiency of a portable solar panel system for smartphone battery charging as an environmentally friendly alternative energy solution. With the increasing reliance on portable electronic devices and the growing demand for off-grid energy sources, a highly mobile and efficient charging system is required for outdoor applications. The novelty of this research lies in the integration of a 20 Watt-Peak (WP) monocrystalline solar panel, a Solar Charge Controller (SCC), a 12 V 7 Ah storage battery, and a buck converter into a compact suitcase-based portable system specifically designed for smartphone charging under real operating conditions. A quantitative experimental approach was employed, and system performance was evaluated over seven consecutive days from 08:00 to 16:00 by measuring voltage, current, output power, charging duration, and overall system efficiency. The results indicate that the output power strongly depends on solar irradiance, reaching a maximum value of 15.40 W at midday while maintaining a relatively stable output voltage. The proposed system successfully charged smartphone batteries safely and gradually up to 80% capacity. The highest charging efficiency achieved during the testing period was 55.5%. These findings demonstrate that the developed portable solar panel system provides stable performance and satisfactory efficiency, making it a practical, reliable, and sustainable off-grid power source for charging portable electronic devices in outdoor environments.

Keywords — Portable Solar Panel, Smartphone Charging, System Efficiency, Performance Analysis, Solar Charge Controller.

I. Introduction

The rapid development of technology in the digital era has changed various aspects of human life. One of the greatest innovations felt by almost all circles is the presence of smartphones, which have now become multifunctional devices that are very important in everyday life. Smartphones are used not only for communication, but also for work, study, shopping, entertainment, and even as productivity tools. With the increasing number of applications and features offered by smartphones, the energy or power consumption of the battery is also getting higher. This results in users increasingly facing the problem of running out of battery power, especially when they do not have direct access to a power source to charge[1].

However, the main problem often faced by users is the battery running out quickly, which sometimes cannot be overcome with conventional power sources, especially when outdoors, traveling, or in areas not covered by the electricity grid. As a result, efficient and easily accessible charging solutions are needed, especially in emergencies or when users are in hard-to-reach places [2]. Furthermore, there is an urgent need worldwide to reduce dependence on fossil energy, which is a resource that is harmful to the environment. An environmentally friendly solution comes from the use of renewable energy, especially solar energy.

Limited access to electrical infrastructure in remote areas, disaster-prone regions, and outdoor environments can hinder the continuous operation of smartphone devices. Considering that smartphones play an essential role in communication and information access, the availability of portable and renewable energy sources has become increasingly important to ensure uninterrupted device operation [17], [22]. Therefore, a solution to overcome this power shortage problem is urgently needed, especially for those who frequently do outdoor activities or even for those who live in areas that have not been reached by electricity. One reliable solution is the use of a portable solar panel. A solar panel is a device capable of converting solar energy into electrical energy through the photovoltaic process[3]. Portable solar panels, in particular, are devices that can be carried anywhere, allowing users to utilize solar energy as an alternative power source to charge electronic devices, such as smartphones [4]. This portable solar panel offers great advantages, especially for those who need independent charging, without depending on the electricity grid.

However, due to the fluctuating intensity of sunlight and the dependence on limited solar panel capacity, the efficiency of charging with portable solar panels is still a problem [5], [6]. Therefore, a solution that can increase the efficiency of using portable solar panels is very important to meet the need for sustainable and efficient energy for portable devices. Combining a Solar Charge Controller management into a portable solar panel system is a solution to this problem. Solar Charge Controller management uses control technology that allows monitoring and regulation of energy flow according to the intensity of sunlight and the charging status of the device's battery [7]. By using this system, charging can be done more efficiently even in shaded sunlight conditions.

Although solar panel technology has been widely developed, several challenges remain in the implementation of portable solar panel systems. Previous studies have reported that the performance of portable solar panels is strongly influenced by factors such as panel orientation, tilt angle, solar irradiance, and environmental conditions, resulting in inconsistent power output and suboptimal charging performance [18], [20].

Furthermore, research by Kunatsa et al. [11] highlighted that efficient charging management and energy optimization remain critical issues in solar PV-powered portable electronic devices, particularly in achieving faster charging while maintaining high energy efficiency. These limitations indicate that further improvements are still required to enhance both the energy conversion efficiency and charging performance of portable solar panel systems.
Moreover, Alimul and Huda [9] highlighted that improving the efficiency of solar panels remains a major challenge in maximizing their utilization as an alternative energy source. In addition, the relatively long charging time remains a significant challenge in portable solar charging systems. Previous studies have shown that the charging process of solar-powered portable devices is often slower than conventional grid-based chargers because the output power depends on solar irradiance and environmental conditions [11], [16]. This limitation reduces the practicality of portable solar chargers for smartphone users, who generally expect a fast and convenient charging process [10], [20]. This efficiency problem is generally caused by several factors, such as the quality of the solar panels used, the size of the panel, and the technology applied in the conversion system. In addition, many portable solar panel products available have not been optimized for the specific needs of smartphone charging, so often smartphone charging takes longer compared to charging using conventional power sources. Users need a solution that can charge smartphones quickly and efficiently, especially when outdoors with no electricity supply or in emergency conditions.
The increasing use of portable electronic devices, particularly smartphones, has led to a growing demand for reliable and sustainable electrical energy sources. Almost all human activities, ranging from household activities to industry, rely heavily on the availability of electrical energy. Along with the increase in population, the need for electrical energy is also growing. The sun is one of the largest energy sources in the universe that has many benefits for life on earth [8]. Rapid technological advancements have significantly increased the development and utilization of portable electronic devices in various aspects of daily life. Solar Energy can also be utilized as a backup energy source to meet the need for electrical energy, and can be applied in Indonesia because Indonesia is a tropical country that receives very good sunlight every year. In addition, natural conditions in Indonesia are very difficult to reach and in the form of an archipelago, making the application of Solar energy highly appropriate for reaching underdeveloped, remote, and outermost areas [9].
The use of solar panels with a power of 20Wp to charge a portable battery is an effective solution to reduce dependence on electrical energy from PLN. By using a Buck Converter, this system is capable of converting solar energy into electricity efficiently, resulting in stable and reliable battery charging [10]. By using a priority system based on device usage patterns and operational needs, this research provides a solution to maximize the operational time of essential devices such as GPS and radio, which are very important in emergencies or when energy is limited [11]. This research succeeded in designing a miniature portable Solar Power Plant (PLTS) that has small dimensions and is easy to carry, which can be used to charge mobile phones [12]. This renewable energy-based charging system suggests the use of solar panels to reduce dependence on fossil energy [13]. The resulting portable Solar Power Plant (PLTS) is not only used as a learning tool, but can also be utilized for lighting and charging electronic devices such as smartphones [14].
A Solar Power Plant (PLTS) basically works by utilizing solar radiation energy captured by photovoltaic panels to be converted directly into electrical energy. Solar panels do not require rotating parts or fuel like conventional power plants, so their operation is simpler and environmentally friendly. The amount of electrical energy generated depends heavily on the intensity of sunlight received by the panel surface [15].

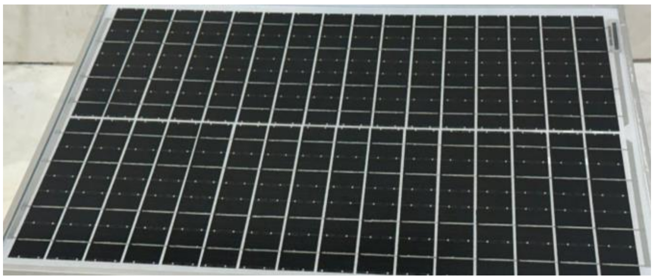

Figure 1. PV Module

An important component in PLTS is the solar charge controller. This tool functions to regulate current and voltage from the panel before being distributed to the battery or load [16]. Solar panels are a technology that converts solar light energy into electrical energy through a photovoltaic process, using semiconductor cells such as silicon [17]. The basic principle of the p-n diode in semiconductor materials is the basis of this process, which allows the transformation of light energy into electrical energy [18].

Figure 2. Solar Charge Controller

Monocrystalline Solar Panel is one type of solar cell made of silicon with a single crystal structure [19]. This uniform crystal structure allows the process of converting solar energy into electrical energy to take place more efficiently compared to other types of solar cells [20]. A monocrystalline solar panel was selected in this study due to its higher energy conversion efficiency compared with polycrystalline and thin-film solar panels. Monocrystalline panels generally exhibit efficiencies ranging from 15% to 22%, making them more suitable for portable applications where installation area is limited. In contrast, polycrystalline panels typically have lower efficiencies and require larger surface areas to produce the same power output, while thin-film panels offer greater flexibility but generally exhibit lower efficiency and reduced durability. Therefore, monocrystalline technology was considered the most appropriate choice for developing an efficient and compact portable solar charging system [21]. A buck converter is a DC–DC converter that functions to reduce the voltage generated by an energy source, such as a solar panel, to a lower level according to system requirements [22]. Although previous studies have demonstrated the application of buck converters in solar energy systems, most of these studies focused mainly on converter design and output characteristics under specific operating conditions [22]. Furthermore, the performance of buck converters in portable solar charging systems under fluctuating solar irradiance conditions has not been extensively investigated. Therefore, further research is required to evaluate and optimize the implementation of buck converters in portable solar charger applications.

Previous studies have investigated portable solar charging systems; however, most of them focused primarily on the design and implementation aspects without comprehensively evaluating charging effectiveness and efficiency under varying operating conditions [10], [20]. In addition, limited studies have integrated buck converter technology to optimize the charging performance of portable solar panels for smartphones. Therefore, this research aims to design and develop a portable solar panel integrated with a buck converter that can provide sufficient electrical energy for smartphone charging effectively and efficiently. This research will include the design of a solar panel system that considers various factors, such as the selection of appropriate components, panel design, as well as the technology used to maximize the conversion of solar energy into electricity that can be used for charging.

This research uses a Solar Charge Controller that has not been widely applied thoroughly in portable solar panels, so that it can optimize the management of energy flow in real-time for smartphone charging efficiency. The portable solar panel designed prioritizes the portability aspect with a small and light size, but is still able to produce sufficient electrical energy for smartphone charging effectively and efficiently. This portable solar panel provides an environmentally friendly charging solution by utilizing solar energy and is designed so that production and usage costs remain economical.

II. Research Method

A. Research Design

This research aims to design and build a portable solar panel to increase the efficiency of smartphone battery charging. In the digital era, which is increasingly dependent on electronic devices, the need for environmentally friendly alternative energy sources is essential. Portable solar panels are expected to be a solution for energy needs outdoors, especially during activities in places difficult to reach by conventional power sources.

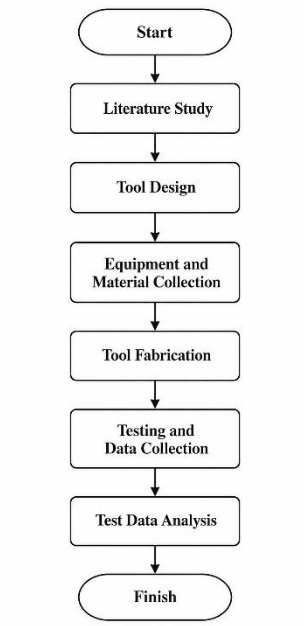

Figure 3. Research Design Flowchart

The flowchart shows the steps taken to test the performance and efficiency of portable solar panels using a Solar Charge Controller. The process begins with an initial step marking the beginning of all research stages. This is followed by a literature study to search for relevant information and references. Next is the design of the tool to be built, followed by the procurement of necessary tools and materials. After the tool is manufactured, data is collected by measuring solar panel performance under various conditions, such as sunlight and temperature. The data obtained is then analyzed to evaluate system efficiency. If the results are not satisfactory, the tool is improved. The research is considered complete once the results are evaluated.

B. Block Diagram and System Scheme

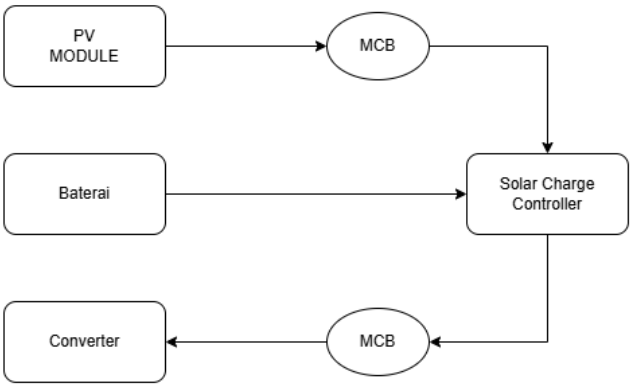

Figure 4. System Block Diagram

The block diagram shows the workflow of a portable solar power system from the energy source to the load. The process starts with the PV Module (solar panel), which converts sunlight into direct current (DC) electricity. The generated electricity passes through an MCB, which acts as a safety device to prevent component damage from overcurrent or short circuits. After the MCB, the current enters the Solar Charge Controller (SCC), which regulates the battery charging process and protects the battery from overcharge and overdischarge conditions. The SCC is essential because the output voltage generated by the solar panel fluctuates depending on solar irradiance and environmental conditions, potentially damaging the battery if not properly regulated. The energy is then stored in a battery, which serves as an energy buffer to ensure a continuous power supply when solar irradiance is insufficient or unavailable, thereby enhancing the reliability of the system. When required, energy from the battery is supplied to a buck converter, which was selected due to its high efficiency in stepping down DC voltage while maintaining stable output with minimal power losses. The buck converter adjusts the voltage according to the smartphone charging requirements. Finally, the regulated electrical energy is delivered to the smartphone as the end load.

C. Data Collection Method

In this research, data analysis was performed to assess the influence of various factors on the Solar Power Plant (PLTS) system performance. This research uses quantitative data collection methods with experimental and measurement approaches to obtain accurate data.

1. Measurement of Time and Battery Charging Characteristics: This is conducted to evaluate the system's performance in charging smartphone batteries. The testing aims to determine the duration required to charge from a specific initial percentage to a set level. Characteristics like voltage stability and current are also analyzed.
2. Measurement of Output Power from Battery to Smartphone: Conducted to determine the electrical power used by the smartphone during charging. Parameters observed include voltage and current flowing from the battery through the SCC or Power Meter to the smartphone.
3. Measurement of Ambient Temperature Over Time: Conducted using the integrated sensor on the SCC and Power Meter to observe the influence of temperature changes on the performance and efficiency of the portable solar panel.
4. Portable Solar Panel Efficiency Data Collection: Conducted by recording electrical energy on both input and output sides. Input data is obtained from the solar panel output to the battery, while output data is power distributed from the battery to the smartphone.

D. Data Analysis Method

The data analysis method is performed to process and interpret measurement results to assess performance and efficiency.

Measurement of Solar Panel Input Power

Power generated by the solar panel is calculated using Ohm's Law:

$$P = V \times I \quad (1)$$

Efficiency Calculation

System efficiency is determined by comparing the electrical energy used by the smartphone (output) with the energy produced by the solar panel (input). Mathematically, it is expressed as:

$$\eta = \frac{P_{out}}{P_{in}} \times 100 \quad (2)$$

where η is the system efficiency (%), P_out is the output power delivered to the load (W), and P_in is the input power supplied by the solar panel (W).

III. Results and Discussion

A. Project Description Results

In this research, the portable solar panel is designed with the aim of increasing the efficiency of smartphone charging using solar energy. The design of this portable solar panel system is to create a device capable of generating electrical power from solar energy and converting it into power that can be used to charge smartphones efficiently. The system is designed to be easy to carry and use. In this design, a 20 Watt Peak solar panel is used, which is connected to a 12V 7Ah battery to store the generated energy. This battery is sufficient to charge a smartphone several times, depending on the capacity of the smartphone battery itself. Battery charging is carried out with the help of a solar charge controller that functions to regulate the flow of energy from the solar panel to the battery efficiently, prevent overcharge, and extend battery life.

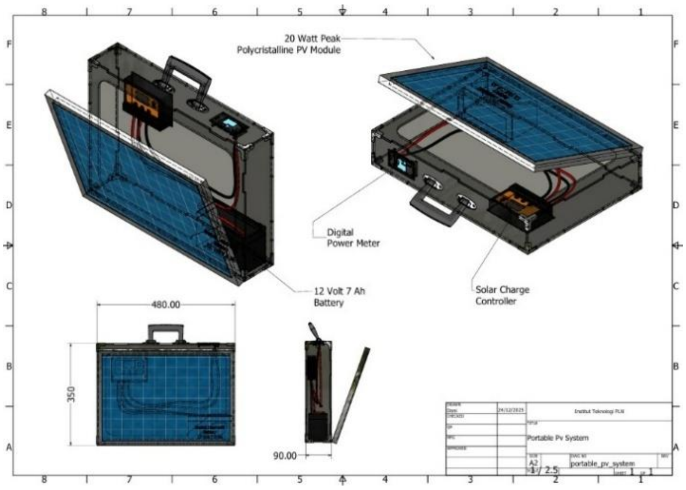

Figure 5. Portable Solar Panel Design

In addition, this system is equipped with a digital power meter to monitor energy flow, providing information about the charging status as well as the amount of power generated and used. With this feature, users can easily monitor the remaining power capacity and ensure the charging process is running well. For smartphone charging, this system is equipped with a Type-C converter to connect to the smartphone, ensuring charging with the appropriate power output. For optimal charging, the solar panel must be positioned so that it is exposed to direct sunlight and not blocked by any objects that could reduce efficiency.

System testing was conducted by charging several smartphone models under various sunlight conditions to evaluate the charging efficiency of the portable solar panel system. During the experiments, several environmental and operational parameters were monitored, including ambient temperature, which ranged from 28°C to 34°C, the solar panel tilt angle, which was fixed at 30° relative to the horizontal plane, and the panel orientation, which was directed toward the sun to maximize solar irradiance. In addition, weather conditions, such as clear and partly cloudy conditions, were considered to evaluate their influence on the system performance.

The device developed is a suitcase-shaped portable solar panel specifically designed for smartphone charging using solar energy. With a practical shape that is easy to carry everywhere, this tool provides an efficient solution for users who need charging outdoors or while traveling. The suitcase design chosen for this tool not only provides high portability but also extra protection for internal components. With dimensions of 480 mm x 350 mm x 90 mm, high ease of use, and flexibility, this portable solar panel device becomes an environmentally friendly solution that reduces dependence on conventional electrical resources, providing sustainable benefits for its users.

Figure 6. External View of the Device

B. Tool Wiring

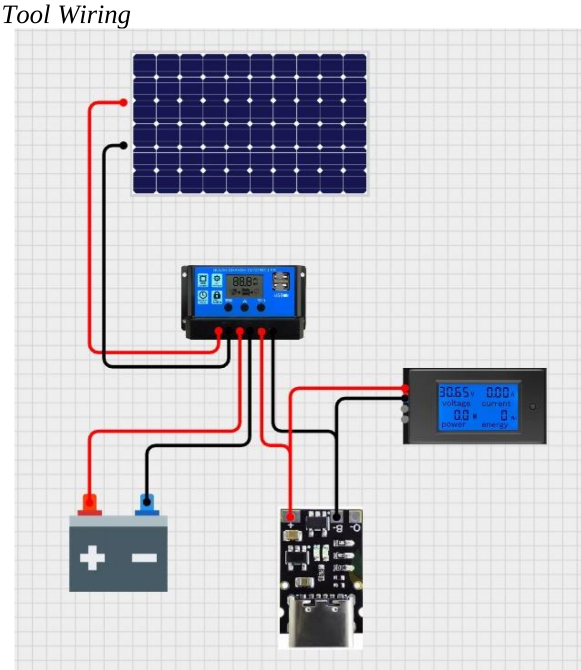

Figure 7. Tool Wiring Diagram

In the shown wiring scheme of the solar power plant system, there are several interconnected components with the aim of converting solar energy into electrical energy that can be used for smartphone charging. The main components in this system include the 20W Monocrystalline Solar Panel, Solar Charge Controller (SCC), 12V 7Ah Battery, Type C Converter, and Digital Power Meter. The 20W Monocrystalline Solar Panel is the primary source of electrical energy in this system. This panel functions to capture sunlight and convert it into electrical energy through the photovoltaic effect. This solar panel is directly connected to the Solar Charge Controller (SCC). In this case, the solar panel has two cables, namely the red cable for the positive terminal and the black cable for the negative terminal. The positive cable from the solar panel is connected to the positive terminal on the SCC, while the negative cable is connected to the negative terminal on the SCC. With this configuration, the SCC receives electrical energy from the solar panel and regulates it before it flows to the battery.

The Solar Charge Controller (SCC) is a very important component in this system because it functions to regulate the current and voltage entering the 12V 7Ah Battery. The SCC ensures that the battery is not overcharged or underpowered, which could damage the battery. The SCC flows energy adjusted to the battery's needs, ensuring that the incoming current and voltage do not exceed safe limits. In the SCC, there are two main terminals connecting this system to the 12V 7Ah Battery: the positive terminal (red) and the negative terminal (black). The 12V 7Ah battery functions to store electrical energy generated by the solar panel for use when needed. The energy entering from the SCC is stored in this battery.

After being stored in the battery, the electrical energy is delivered to the smartphone through a USB Type-C converter that provides the required output voltage. A Digital Power Meter is installed in the circuit to monitor system performance by measuring voltage, current, power, and charging duration in real time. Overall, the system converts solar energy into electrical energy, regulates it through the SCC, stores it in the battery, and supplies it to the smartphone while continuously monitoring the charging process.

C. Testing

Solar Panel Performance Testing Results

Portable solar panel performance testing was conducted to determine the solar panel's ability to generate electrical energy used as a source for smartphone charging. The solar panel used in this research has a nominal capacity of 20 WP and was tested in real environmental conditions without the help of conventional electrical power sources. The test was carried out for seven consecutive days with the aim of obtaining a more representative picture of the solar panel's performance against variations in weather conditions and sunlight intensity.

Data collection was carried out in the time range of 08:00 to 16:00 WIB with measurement intervals every 30 minutes. The measured parameters included the solar panel output voltage and solar panel output current while the solar panel output power was calculated based on the product of the measured voltage and current. All measurements were performed directly using measuring instruments connected to the portable PLTS system.

Based on the test results, it is known that the performance of the portable solar panel shows a consistent pattern of change throughout the day. In the morning, the solar panel output power is relatively low because the intensity of sunlight received by the panel is not yet optimal. As the sun's position increases, the panel output power increases and reaches its maximum value during the midday period. After passing that time, the panel output power decreases again until the afternoon due to reduced sunlight intensity.

The seven-day test results also show that although the solar panel output power value fluctuates, the system is still able to generate enough electrical energy to support smartphone charging. The solar panel voltage tends to be in a relatively stable range, while power changes are more influenced by variations in current that follow changes in sunlight intensity. This indicates that the portable solar panel used in this research has fairly good performance and can function optimally in adequate lighting conditions.

The measurement of time and battery charging process characteristics was conducted as part of the evaluation of the portable PLTS system's output power in supporting smartphone charging. The testing was conducted under different sunlight intensity conditions, namely morning, noon, and afternoon, to see the effect of PLTS output power variations on the speed and stability of the smartphone battery charging process.

Solar Panel Performance Testing

After testing the performance of the portable solar panel system in general, the next stage is the presentation of the measurement data for the solar panel output power. This measurement aims to obtain a quantitative picture of the amount of electrical power generated by the solar panel at various testing times. The measurement data was taken periodically from morning to afternoon to represent the variations in data obtained in one daily cycle.

The following shows the results of the testing to obtain the output power from the solar panel on Day 1.

Table 1. Testing Data for Day 1

Time	Vpv (V)	Ipv (A)
08:00	13.75	0.70
08:30	15.88	0.65
09:00	16.52	0.66
09:30	16.28	0.79
10:00	16.42	0.71
10:30	16.12	0.73
11:00	15.76	0.76
11:30	16.21	0.85
12:00	16.36	0.87
12:30	16.47	0.88
13:00	16.84	0.83
13:30	14.30	0.91
14:00	14.74	0.80
14:30	14.11	0.80
15:00	15.26	0.68
15:30	16.10	0.60
16:00	13.13	0.61

To see the consistency of the portable solar panel's performance in generating output power, the next test was conducted on Day 2 with the same procedure and time intervals. This test aims to compare the solar panel output power patterns under different

environmental conditions, and to ensure the stability of the system's performance over several testing days.
The following shows the results of the testing to obtain the output power from the solar panel on Day 2.

Table 2. Testing Data for Day 2

Time	Vpv (V)	Ipv (A)
08:00	13.80	0.74
08:30	14.74	0.83
09:00	16.26	0.75
09:30	16.54	0.72
10:00	16.42	0.77
10:30	16.57	0.71
11:00	15.65	0.79
11:30	16.23	0.84
12:00	16.82	0.96
12:30	16.76	0.68
13:00	15.86	0.75
13:30	15.20	0.89
14:00	14.75	0.90
14:30	14.43	0.78
15:00	14.39	0.67
15:30	14.30	0.57
16:00	12.67	0.46

As a continuation of the previous testing, data collection for solar panel output power was again carried out on Day 3 with the same procedure and measurement time intervals. This test was conducted to strengthen the previous test results and see the consistency of the generated solar panel output power patterns. The following shows the results of the testing to obtain the output power from the solar panel on Day 3.

Table 3. Testing Data for Day 3

Time	Vpv (V)	Ipv (A)
08:00	13.76	0.72
08:30	13.90	0.53
09:00	15.55	0.65
09:30	15.43	0.76
10:00	16.54	0.84
10:30	16.32	0.77
11:00	16.78	0.61
11:30	16.27	0.78
12:00	16.39	0.94
12:30	16.43	0.90
13:00	16.86	0.81
13:30	15.32	0.74
14:00	15.67	0.79
14:30	14.43	0.66
15:00	14.82	0.54
15:30	13.49	0.72
16:00	13.20	0.59

Testing on Day 4 was conducted to obtain additional data regarding the portable solar panel performance under different environmental conditions, while still using the same method, location, and measurement time intervals. This data is used to strengthen the analysis of overall solar panel performance.
The following shows the results of the testing to obtain the output power from the solar panel on Day 4.

Table 4. Testing Data for Day 4

Time	Vpv (V)	Ipv (A)
08:00	13.68	0.66
08:30	15.47	0.65
09:00	16.08	0.69
09:30	16.33	0.76
10:00	16.38	0.71
10:30	16.21	0.74
11:00	15.98	0.78
11:30	16.17	0.82
12:00	16.27	0.84
12:30	16.34	0.85
13:00	16.52	0.83
13:30	14.42	0.86
14:00	14.58	0.79
14:30	14.19	0.77
15:00	15.03	0.69
15:30	15.68	0.61
16:00	13.12	0.59

To complete the series of tests and obtain a better understanding of how the solar panel performs, testing was again conducted on Day 5 with the same procedure. This test aims to observe the stability of the solar panel output power over several consecutive testing days.
The following shows the results of the testing to obtain the output power from the solar panel on Day 5.

Table 5. Testing Data for Day 5

Time	Vpv (V)	Ipv (A)
08:00	13.53	0.63
08:30	15.18	0.62
09:00	15.79	0.66
09:30	16.02	0.72
10:00	16.09	0.68
10:30	15.91	0.70
11:00	15.73	0.74
11:30	15.87	0.78
12:00	16.02	0.80
12:30	16.12	0.82
13:00	16.18	0.81
13:30	14.23	0.83
14:00	14.38	0.77
14:30	14.04	0.75
15:00	14.82	0.67
15:30	15.47	0.60
16:00	12.88	0.57

The next test was conducted on Day 6 to strengthen the results of previous measurements and ensure that the generated solar panel output power pattern is consistent under different environmental conditions.
The following shows the results of the testing to obtain the output power from the solar panel on Day 6.

Table 6. Testing Data for Day 6

Time	Vpv (V)	Ipv (A)
08:00	13.82	0.69
08:30	15.73	0.68
09:00	16.28	0.72
09:30	16.53	0.78
10:00	16.58	0.74
10:30	16.39	0.77
11:00	16.19	0.81
11:30	16.34	0.85
12:00	16.48	0.87
12:30	16.61	0.88
13:00	16.74	0.86
13:30	14.72	0.84
14:00	14.91	0.80
14:30	14.43	0.78
15:00	15.23	0.70
15:30	15.91	0.62
16:00	13.19	0.60

As the final stage of the solar panel output power testing series, data collection was again carried out on Day 7 with the same method and measurement time range. This test aims to complete the testing results data and provide a comprehensive picture of solar panel performance.
The following shows the results of the testing to obtain the output power from the solar panel on Day 7.

Table 7. Testing Data for Day 7

Time	Vpv (V)	Ipv (A)
08:00	13.41	0.62
08:30	15.06	0.61
09:00	15.62	0.65
09:30	15.91	0.70
10:00	16.02	0.66
10:30	15.83	0.68
11:00	15.65	0.72
11:30	15.78	0.75
12:00	15.92	0.77
12:30	16.01	0.78
13:00	16.08	0.76
13:30	14.12	0.78
14:00	14.28	0.74
14:30	13.97	0.72
15:00	14.61	0.65
15:30	15.19	0.58
16:00	12.74	0.55

Smartphone Battery Charging Process Testing Results
Smartphone battery charging process testing was conducted to determine the capability of the portable solar panel system in providing electrical energy directly for device charging. Data collection was carried out gradually every 10-minute interval, with observed parameters including charging voltage, charging current, charging power, and changes in smartphone battery capacity percentage. This test was conducted when the mobile phone battery was at 10% or at minute 0.

First Testing Results

Table 8. First Mobile Phone Battery Charging Test Results

Time	V	A	W	Battery (%)
10 Menit	12.1	0.81	9.86	26
20 Menit	12.1	0.65	7.95	37
30 Menit	12.1	0.61	7.49	46
40 Menit	12.1	0.58	7.01	55
50 Menit	12.1	0.52	6.29	63
60 Menit	12.1	0.38	4.68	73
70 Menit	12.1	0.28	3.38	78
80 Menit	12.2	0.25	3.15	83
Avg	12.1	0.51	6.22	

Based on the results of the first mobile phone battery charging test, it shows that the charging process takes place quite quickly in the initial phase and then slows down as time increases. The charging voltage is in a stable condition in the range of 12.1–12.2 V, while the charging current decreases from 0.81 A at the 10th minute to 0.25 A at the 80th minute, which impacts the decrease in power from 9.86 W to 3.15 W. The first mobile phone test has the highest initial power of 9.86 W. This indicates that the first mobile phone has a better charging response, especially in the initial stage of charging, with a process that remains stable until the end of the test.

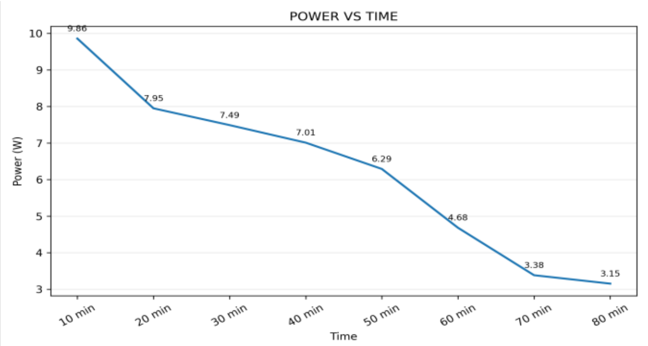

Figure 8. Power vs. Time Curve for First Smartphone Charging
Figure 8 shows that the output power of the portable solar panel decreased gradually as the charging time increased. The highest power output was recorded at 10 minutes, reaching 9.86 W, and continuously declined to 3.15 W at 80 minutes. This trend indicates that the charging performance of the portable solar panel diminishes over time, which may be attributed to variations in solar irradiance and the decreasing charging

current as the smartphone battery approaches full capacity. Nevertheless, the system was able to provide sufficient power throughout the charging process, demonstrating its feasibility for smartphone charging applications.

Second Testing Results

Table 9. Second Mobile Phone Battery Charging Test Results

Time	V	A	W	Battery (%)
10 Menit	12.0	0.73	8.81	29
20 Menit	12.0	0.67	8.04	38
30 Menit	12.0	0.60	7.24	45
40 Menit	12.1	0.59	7.13	53
50 Menit	12.1	0.46	5.92	62
60 Menit	12.1	0.38	4.59	69
70 Menit	12.1	0.29	3.60	75
80 Menit	12.1	0.26	3.14	80
Avg	12.0	0.49	6.05	

Based on the table above, it can be seen that during the mobile phone battery charging test process, the charging voltage tends to be stable in the range of 12.0–12.1 V. As charging time increases, the generated current and power decrease, with the current dropping from 0.73 A at the 10th minute to 0.26 A at the 80th minute, while the power decreases from 8.81 W to 3.14 W. This decrease coincides with the increase in battery percentage from 29% to 80%, suggesting that the charging demand diminishes as the battery state of charge increases. Such behavior follows the conventional CC–CV charging mechanism of lithium-ion batteries, in which the battery is initially charged at a relatively constant current and subsequently transitions to a constant-voltage stage, causing the charging current and power to gradually decrease as the battery nears full charge. Therefore, the observed charging profile indicates that the proposed portable solar charging system operates in accordance with standard smartphone battery charging characteristics.

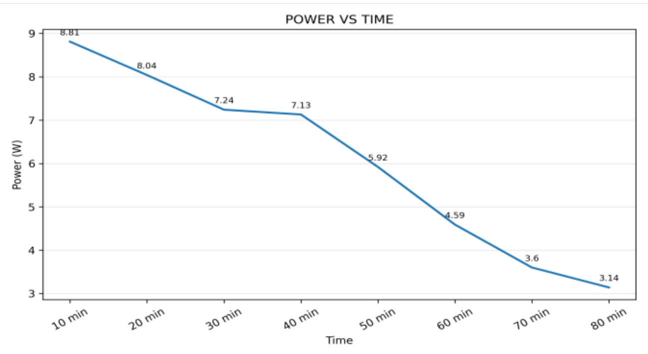

Figure 9. Power vs. Time Curve for Second Smartphone Charging

Figure 9 illustrates the relationship between output power and charging time during the second smartphone charging test. Similar to the first test, the output power decreased progressively as the charging time increased, starting from 8.81 W at 10 minutes and declining to 3.14 W at 80 minutes. The reduction in power output indicates that the charging performance of the portable solar panel diminishes over time, which may be influenced by fluctuations in solar irradiance and the reduction in charging current as the smartphone battery approaches full charge. Despite this decline, the portable solar panel was still able to provide sufficient power throughout the charging process, demonstrating its capability to support smartphone charging applications.

Third Testing Results

Table 10. Third Mobile Phone Battery Charging Test Results

Time	V	A	W	Battery (%)
10 Menit	12.0	0.78	9.36	28
20 Menit	12.0	0.69	8.28	37
30 Menit	12.1	0.63	7.62	45
40 Menit	12.1	0.57	6.90	54
50 Menit	12.1	0.50	6.05	61
60 Menit	12.1	0.40	4.84	70
70 Menit	12.1	0.30	3.63	76
80 Menit	12.2	0.26	3.17	81
Avg	12.0	0.51	6.23	

Based on the results, the third mobile phone battery charging test shows a similar but slightly more optimal charging pattern compared to the test results in the previous table. The charging voltage remains in a stable condition in the range of 12.0–12.2 V, while current and power decrease as charging time increases. Compared to the second charging, the initial current and initial power in this test tend to be larger, reaching 0.78 A and 9.36 W, indicating the initial charging process proceeds faster. In addition, the increase in battery percentage also shows slightly better results, where at the 80th minute the battery reaches 81%, higher than the previous test. Overall, this indicates that although the charging characteristics are similar, the third mobile phone has a more effective charging response in the initial phase, with an average power of 6.23 W, while still working stably and safely during the charging process.

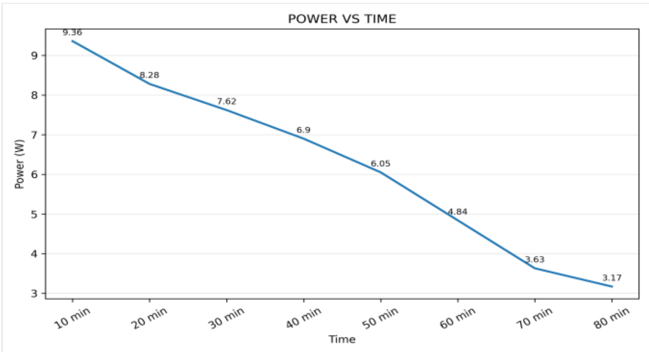

Figure 10. Power vs. Time Curve for Third Smartphone Charging

Figure 10 presents the relationship between output power and charging time during the third smartphone charging test. The graph shows a gradual decrease in output power as the charging time increased, with the highest power output of 9.36 W recorded at 10 minutes and the lowest power output of 3.17 W at 80 minutes. This declining trend indicates that the charging performance of the portable solar panel decreases over time, which can be attributed to fluctuations in solar irradiance and the reduction in charging current as the smartphone battery nears full capacity. Nevertheless, the system consistently supplied sufficient power throughout the charging process, demonstrating the reliability of the portable solar panel for smartphone charging applications.

Fourth Testing Results

Table 11. Fourth Mobile Phone Battery Charging Test Results

Time	V	A	W	Battery (%)
10 Menit	12.0	0.76	9.12	27
20 Menit	12.0	0.68	8.16	36
30 Menit	12.1	0.62	7.50	44
40 Menit	12.1	0.56	6.78	52
50 Menit	12.1	0.48	5.81	60
60 Menit	12.1	0.39	4.72	68
70 Menit	12.1	0.31	3.75	74
80 Menit	12.2	0.27	3.29	81
Avg	12.0	0.50	6.14	

Based on the results of the fourth mobile phone battery charging test, it shows relatively consistent charging characteristics with the two previous tests. The voltage during the charging process is in a stable condition in the range of 12.0–12.2 V, signifying the voltage supply does not experience significant disruption. The charging current and power decrease gradually as time increases, from 0.76 A and 9.12 W at the 10th minute to 0.27 A and 3.29 W at the 80th minute, which shows the charging mechanism works according to the battery condition. When compared to the second and third tests, the average power of the fourth test of 6.14 W is between the two, with the same final battery percentage achievement, which is 81%. This indicates that the charging performance of the fourth mobile phone is classified as stable and balanced, not too aggressive at the beginning like the third test, but still effective in increasing the battery capacity until it is nearly full.

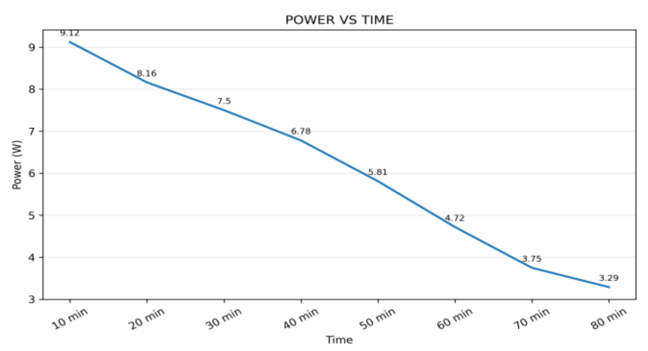

Figure 11. Power vs. Time Curve for Fourth Smartphone Charging

Figure 11 illustrates the relationship between output power and charging time during the fourth smartphone charging test. The graph shows that the output power decreased steadily as the charging time increased, starting from 9.12 W at 10 minutes and reaching 3.29 W at 80 minutes. This trend indicates a reduction in the charging performance of the portable solar panel over time, which may be caused by fluctuations in solar irradiance and the decreasing charging current as the smartphone battery approaches full charge. Despite the gradual decline in power output, the system was able to continuously supply sufficient power throughout the charging process, demonstrating the effectiveness of the portable solar panel for smartphone charging applications.

Fifth Testing Results

Table 12. Fifth Mobile Phone Battery Charging Test Results

Time	V	A	W	Battery (%)
10 Menit	12.0	0.75	9.00	30
20 Menit	12.0	0.66	7.92	38
30 Menit	12.1	0.61	7.38	46
40 Menit	12.1	0.55	6.66	53
50 Menit	12.1	0.47	5.69	61
60 Menit	12.1	0.37	4.48	69
70 Menit	12.1	0.29	3.51	75
80 Menit	12.2	0.25	3.05	80
Avg	12.0	0.49	5.96	

The results of the fifth mobile phone battery charging test show a consistent charging pattern with previous tests, but with a relatively lower power level. The charging voltage is in a stable condition in the range of 12.0–12.2 V, while current and power decrease as time increases, from 0.75 A and 9.00 W at the 10th minute to 0.25 A and 3.05 W at the 80th minute. When compared to the third and fourth tests, the average power of the fifth test is the smallest, although the increase in battery percentage still proceeds effectively up to 80%. This condition indicates that the charging process proceeds in a controlled and stable manner, with the charging current and power gradually decreasing as the battery state of charge increases.

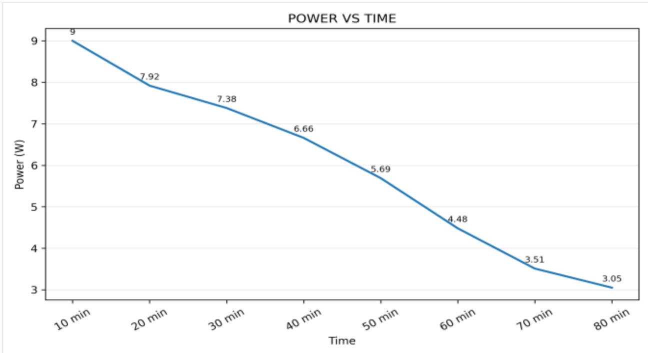

Figure 12. Power vs. Time Curve for Fifth Smartphone Charging

Figure 12 presents the relationship between output power and charging time during the fifth smartphone charging test. The graph indicates that the output power gradually decreased as the charging time increased, with the highest power output of 9.00 W recorded at 10 minutes and the lowest power output of 3.05 W at 80 minutes. This decreasing trend suggests that the charging performance of the portable solar panel declined over time, which may be attributed to fluctuations in solar irradiance and the reduction in charging current as the smartphone battery approached full capacity. Nevertheless, the portable solar panel consistently delivered sufficient power throughout the charging process, demonstrating its potential as a reliable alternative power source for smartphone charging applications.

Sixth Testing Results

Table 13. Sixth Mobile Phone Battery Charging Test Results

Time	V	A	W	Battery (%)
10 Menit	12.0	0.74	8.88	29
20 Menit	12.0	0.65	7.80	37
30 Menit	12.1	0.60	7.26	45
40 Menit	12.1	0.54	6.53	52
50 Menit	12.1	0.46	5.57	60
60 Menit	12.1	0.36	4.36	67
70 Menit	12.1	0.28	3.39	73
80 Menit	12.2	0.24	2.93	80
Avg	12.0	0.48	5.84	

The results of the sixth mobile phone battery charging test show a charging pattern that is still in line with previous tests, with the characteristics of decreasing current and power as charging time increases. The charging voltage is in a relatively stable condition in the range of 12.0–12.2 V, while the charging current decreases from 0.74 A at the 10th minute to 0.24 A at the 80th minute, which impacts the decrease in power from 8.88 W to 2.93 W. When compared to the fifth test, the average power of the sixth test is slightly lower, which is 5.84 W, but the increase in battery percentage still proceeds gradually up to 80%. This indicates that the charging process on the sixth mobile phone runs stably and controlled, despite relatively small power requirements at the end of the test.

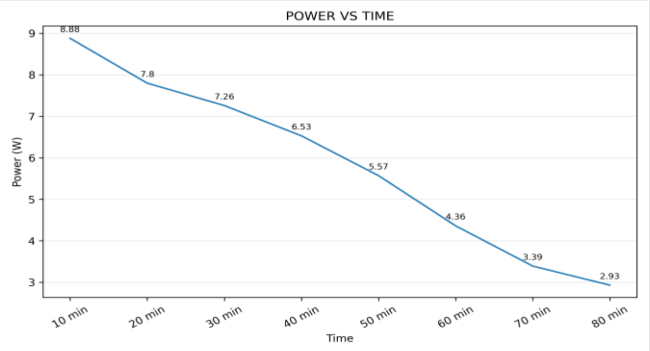

Figure 13. Power vs. Time Curve for Sixth Smartphone Charging

Figure 13 shows the relationship between output power and charging time during the sixth smartphone charging test. The graph demonstrates that the output power gradually decreased as the charging time increased, beginning at 8.88 W at 10 minutes and declining to 2.93 W at 80 minutes. This downward trend indicates that the charging performance of the portable solar panel diminished over time, likely due to variations in solar irradiance and the reduction in charging current as the smartphone battery approached full capacity. Despite the decrease in power output, the system continuously supplied sufficient power throughout the charging process, indicating that the portable solar panel can effectively support smartphone charging applications.

Seventh Testing Results

Table 14. Seventh Mobile Phone Battery Charging Test Results

Time	V	A	W	Battery (%)
10 Menit	12.0	0.72	8.64	31
20 Menit	12.0	0.64	7.68	39
30 Menit	12.1	0.59	7.14	47
40 Menit	12.1	0.53	6.41	54
50 Menit	12.1	0.45	5.45	62
60 Menit	12.1	0.35	4.24	69
70 Menit	12.1	0.27	3.27	74
80 Menit	12.2	0.23	2.81	80
Avg	12.0	0.47	5.70	

The results of the seventh mobile phone battery charging test show a consistent and stable charging pattern during the test time. The charging voltage remained relatively constant within the range of 12.0–12.2 V, whereas the charging current gradually decreased from 0.72 A at the 10th minute to 0.23 A at the 80th minute, causing the power output to decline from 8.64 W to 2.81 W. The stable voltage and decreasing current indicate that the charging process followed the constant current–constant voltage (CC–CV) profile commonly employed in lithium-ion battery charging, where the current is reduced as the battery approaches full capacity. When compared to the sixth test, the average power of the seventh test is slightly lower, which is 5.70 W, but the increase in battery percentage still proceeds effectively up to 80%. This indicates that the charging process on the seventh mobile phone proceeds more efficiently at the end of charging, with power that is increasingly small but still capable of gradually and safely increasing battery capacity.

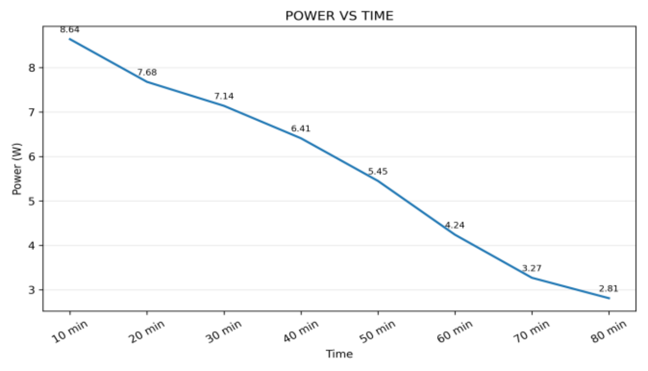

Figure 14. Power vs. Time Curve for Seventh Smartphone Charging

Figure 14 illustrates the relationship between output power and charging time during the seventh smartphone charging test. The graph shows that the output power gradually decreased as the charging time increased, with the highest power output of 8.64 W recorded at 10 minutes and the lowest power output of 2.81 W at 80 minutes. This declining trend indicates that the charging performance of the portable solar panel decreased over time, which may be attributed to fluctuations in solar irradiance and the reduction in charging current as the smartphone battery approached full charge. Nevertheless, the portable solar panel was able to continuously supply sufficient power throughout the charging process, demonstrating its capability and reliability for smartphone charging applications.

D. Discussion

Design Implementation of Portable Solar Panel

In this system, the implementation of the portable solar panel design starts from the main source of energy coming from a 20 Watt monocrystalline solar panel installed on the top of the suitcase. This solar panel can be opened and closed with a hinge mechanism, making it easier for users to direct it towards optimal sunlight when in use and fold it back when not operating. This design considers the balance between maximum energy needs and system portability. The solar panel generates energy through integrated cables neatly arranged inside the suitcase. This cable connects the panel to the solar charge controller, which regulates the energy flow from the panel to the storage media and protects the system from overcharging. In addition, voltage and current control remain safe. The presence of this component allows for more stable control of power changes caused by sunlight. To store energy, this system uses a 12 Volt battery with a capacity of 7 Ah placed inside the suitcase. This battery stores energy from the solar panel, allowing the system to continue functioning even if sunlight is not maximal or non-existent. To monitor system performance directly, a digital power meter is installed on the front of the suitcase. This tool measures electrical parameters such as voltage, current, power, temperature, and time, providing information and facilitating the evaluation of solar panel performance and energy management.

Based on measurement data for voltage, current, and output power of the 20 WP solar panel from 08:00 to 16:00, it can be seen that the performance of the portable PLTS device is highly influenced by sunlight intensity. In the morning, the generated power is still relatively low, namely 9.62 W at 08:00, because sunlight has not hit the panel optimally As time increased, the output power gradually increased and reached a maximum value of 14.81 W at 13:00, corresponding to the period of highest solar irradiance. The panel voltage remained relatively stable within the range of 14–16 V, whereas the current fluctuated according to changes in solar radiation conditions. Entering the afternoon, the output power decreases again until reaching the lowest value of 8.01 W at 16:00 due to reduced light intensity. Overall, the test results demonstrate that the 20 WP solar panel was capable of maintaining a relatively stable output voltage while delivering sufficient power to support smartphone battery charging, particularly during periods of high solar irradiance.

Based on power measurement results, the best time for charging is at 13:00, because at that time the highest power was recorded, which is 14.81 W. For more efficient charging, the highest power was obtained at that time.

From the seven tests conducted, the test on Day Six appears to be the most optimal because it produces an average power of 12.00 W, which is the highest value compared to other days. This makes Day Six the test with the best performance. On Day Six, an average voltage of 15.65 V and a current of 0.76 A were recorded, indicating fairly good stability throughout the day. This voltage and current stabilization contributes to higher power production. Smaller power fluctuations on that day show that the solar panel can maintain its performance well despite changes in sunlight intensity over time.

Compared to other days, especially Day Five which only produced an average power of 10.88 W, and Day Seven with an average power of 10.42 W, the Day Six test shows higher power stability. On Days Five and Seven, although there were power spikes at certain times, the variation was quite large, indicating instability in the solar panel performance during those hours. For example, on Day Five, the power generated at 08:00 was only 8.52 W, while at 12:00 power reached 12.82 W, showing quite significant fluctuations that could affect energy usage efficiency. Conversely, the Day Six test showed better stability, with the power generated not experiencing a drastic drop at certain hours. For example, in the morning, the power generated was 9.53 W, and continued to increase until reaching its peak at 14.62 W at 12:30. This signifies that the solar panel on Day Six can absorb and convert solar energy more effectively, especially when solar intensity reaches its peak at midday. Furthermore, the recorded power fluctuations on Day Six were relatively smaller compared to other days, indicating that the solar panel system is more efficient in maintaining the stability of the generated power. In comparison, on Day Three, although the average power generated was 11.23 W, larger fluctuations indicated instability in the system's performance, which could impact long-term energy usage efficiency. On Day Six, fluctuations in environmental conditions did not result in a significant reduction in power output, indicating that the proposed system was capable of maintaining stable performance under varying operating conditions. Overall, the Day Six test provided more stable and optimal results in terms of power generation compared to other test days. With the highest average power and minimal fluctuations, this test can be considered the best among the seven tests, showing that the solar panel works very well in stable conditions and is capable of achieving maximum performance at midday.

Battery Output to Smartphone Testing Analysis

The results of testing that measures the performance of the battery used to charge smartphones for seven consecutive days. This test aims to observe how the battery performs in supplying power to the smartphone by looking at changes in voltage, current, power, and the remaining battery capacity over time. Testing was conducted with varying charging times from 10 minutes to 80 minutes, and the collected data shows a fairly consistent downward trend in power.

Overall, from Day One to Day Seven, testing shows a consistent decrease in power every day. Although there are small fluctuations in the power value, the average power generated during testing decreases over time, indicating a decrease in battery charging efficiency. The average power on Day One of 6.22 W is slightly higher than the average power on Day Seven of 5.70 W. Based on the test results conducted for seven days, Day Three is the most optimal day in terms of battery charging efficiency. The power generated at the first minute was 9.36 W, with a power decrease that was still relatively controlled until the 80th minute, where power was recorded at 3.17 W and the remaining battery was 81%. The average power generated on Day Three was 6.23 W, which was the highest among other days.

Overall, the efficiency of this portable solar panel shows varying fluctuations every day. The highest efficiency was recorded on Day Three with 55.5%, while the lowest was recorded on Day Six with 48.7%. From the overall test results conducted over seven days, Day Three shows the highest efficiency compared to other days. At Day Three, the efficiency reached 55.5%, which is the highest figure among all testing days. This indicates that on the third day, the solar panel was able to convert more solar energy into electrical energy distributed to the battery compared to other days. Although there are fluctuations in efficiency from day to day, with a lower efficiency value on Day Six of 48.7%, efficiency on the seventh day also increased slightly again to 54.7%, but still did not exceed the efficiency on the third day. Overall, it can be concluded that Day Three is the most efficient day in converting energy from the solar panel into electrical energy stored in the battery.

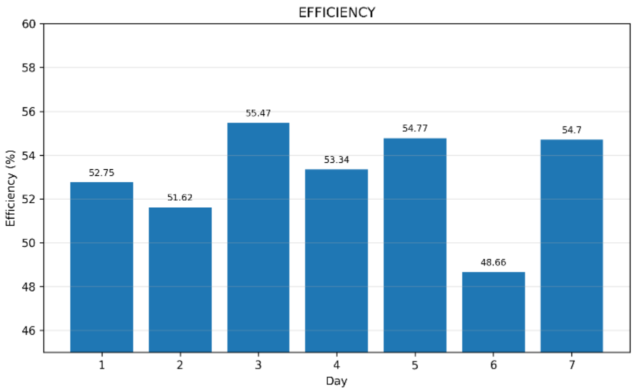

Figure 15. Efficiency Comparison Curve

Figure 15 presents the efficiency comparison of the portable solar panel system over seven testing days. The results show that the system efficiency varied from day to day, ranging from 48.66% to 55.47%. The highest efficiency was achieved on the third day, reaching 55.47%, while the lowest efficiency was recorded on the sixth day at 48.66%. Overall, the efficiency values remained relatively stable, with most measurements exceeding 50%, indicating that the portable solar panel system was able to convert solar energy into electrical energy effectively. The observed variations in efficiency are likely influenced by changes in solar irradiance, environmental conditions, and operational factors during the testing period.

IV. Conclusion

Based on the design, testing, and data analysis of the portable solar panel system for smartphone battery charging, the following conclusions can be drawn:

1. The portable solar panel system is capable of generating sufficient electrical energy to charge a smartphone battery effectively. The combination of a 20 W solar panel, a 12 V 7 Ah battery, and a Solar Charge Controller enables safe energy management and stable charging performance.
2. The charging performance and efficiency of the system are strongly influenced by solar irradiation intensity. The highest charging performance was achieved during midday when solar radiation reached its maximum level, while lower performance was observed during the morning and afternoon due to reduced sunlight intensity.
3. Variations in voltage, current, and output power are significantly affected by environmental conditions. The output voltage remains relatively stable, whereas the current is more sensitive to changes in solar irradiation, making current fluctuations the primary factor affecting output power.
4. A decrease in output power may occur even when current increases, mainly due to voltage reduction caused by factors such as panel temperature rise and temporary shading. This indicates that maintaining

voltage and current stability is essential for achieving optimal system performance.

5. The maximum output power was recorded at 12:00, with an average power output of approximately 11.79 W. Therefore, proper panel placement with direct exposure to sunlight is necessary to maximize energy generation and charging efficiency.
6. Future studies should investigate the performance of the portable solar panel system under different weather conditions and seasonal variations.
7. Additional research may focus on improving charging efficiency through the implementation of maximum power point tracking (MPPT) technology and advanced energy management systems.
8. The integration of real-time monitoring and Internet of Things (IoT)-based systems can be explored to enhance performance evaluation and user convenience.

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