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MULTI-INPUT PORTABLE POWER STATION DESIGN USING LITHIUM-ION BATTERY

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ABSTRACT

A portable power station is a power station that can be easily transported to meet the electricity needs of outbound activities, night-time fishing, merchants at night markets, and refugee tents. When natural disasters such as earthquakes, landslides, tsunamis, and floods occur, the electricity network and communication networks are disrupted, despite the urgent need for electricity to supply basic things at the disaster site, such as lighting, charging cellphones, and providing other electronic equipment. This study designed and implemented a portable power station using lithium-ion batteries as a source of electrical energy, with solar modules and the State Electricity Company (PLN) power grid for recharging the batteries. The research method is experimental quantitative, and the power station is intended to generate 300 Wh of electrical energy. Tests performed include: 1) The charging process uses a 1 x 50 Wp solar module and the PLN electricity network; 2). The process of discharging involves a 50-Watt ac-led lamp and a 4.000-mAh smartphone. As a result, the portable power station can function effectively, can provide electrical energy for one 50-watt ac-led lamp for t = 6.27 hours, and can recharge a smartphone six times. While the process of recharging using a solar module took t = 8 hours, it took t = 4 hours when using the State Electricity Company (PLN) power grid.

Keywords: portable power station, lithium-ion battery, solar module, PLN power grid.

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INTRODUCTION

Along with technological advances and advancements, the need for electrical energy sources that are flexible, portable, and compact is essential for outdoor activities (camping), buying and selling at night markets, activities in emergency tents, refugee areas, and locations that are still beyond the reach of the electric power grid. To meet these requirements, gasoline-powered portable power plants with varying electrical output capacities are typically employed (Ferrah *et al*., 2017). However, the use of portable gasoline-powered power plants still has disadvantages, such as the need for operational costs such as the purchase of gasoline, routine maintenance costs, and the replacement of spare parts; additionally, the operation can cause air pollution and noise pollution (Ramly *et al*., 2019).

The development of portable power plants from renewable energy sources such as sunlight is required to support the electrical energy needs of the community and provide options for the use of electrical energy that are environmentally friendly, pollution-free, have low maintenance costs, are abundantly available, and are modular so that the capacity of the electricity generated can be adapted to the load (Singh, 2013).

The multi-input portable power station is intended to facilitate temporary electrical energy needs in areas without a source of electrical energy or in refugee camps in areas affected by natural disasters. Utilizing a lithium-ion battery as a source of electrical energy that is arranged in series and parallel to produce an output voltage (DC) of 12 Volts connected to the battery management system (BMS). The use of lithium-ion batteries has advantages over deep cycle batteries (Valve Regulated Lead Acid / VRLA), including faster charging, high energy, and power density, long cycle time, smaller dimensions and lighter weight, and the ability to be entirely discharged (Chen *et al*., 2020), (Blomgren, 2017). Utilizing solar radiation, which is converted into direct current (DC) by the solar module by the battery voltage, the solar charging controller (SCC) regulates the charging and discharging processes. In addition, it is possible to recharge portable power stations through the PLN power grid.

LITERATURE REVIEW

In recent decades, the electric power system has undergone significant transformations. Where the demand for electrical energy can be met not only by fossil fuel power plants but also by non-fossil power plants like solar energy (Hayusman *et al*., 2018). Through solar modules, solar energy can be converted into direct current (DC) electrical energy for battery charging and discharging, which is regulated by solar charging controller (SCC) equipment. DC electrical energy produced by solar modules must first be converted using inverter equipment before it can be used to power alternating current (AC) electrical loads (Hayusman *et al*., 2021).

In recent years, numerous studies and applications of solar power plants as an alternative source of electrical energy have been conducted, such as a

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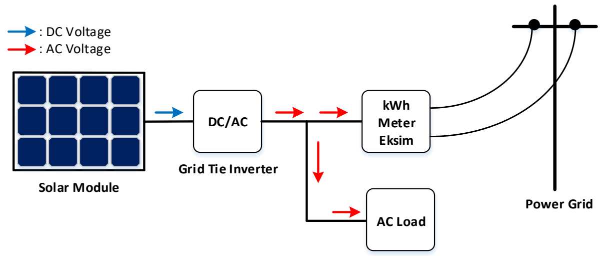
feasibility study for the construction of solar power plants in 58 remote villages in Pamekasan district, Madura Island, which requires a power supply of 24.935 MW at a total investment cost of Rp. 632.812.500.000. The installation of a centralized/communal system and a distributed installation (solar home system) where the installation plan was carried out by local geographical conditions (Quentara and Suryani, 2017). In addition, research was conducted on the factors that affect the efficiency and output power of solar modules installed in tropical regions, including the surface temperature of the solar module, shading effects, inverter efficiency, and the type of solar charger controller utilized (Dewi *et al.*, 2019). Integrating two types of power plants powered by solar and wind energy is also being studied to increase electrical energy production efficiency (Perdiansyah *et al.*, n.d.). Additionally, the research employs solar power plants to provide electrical energy as the driving force for water pumps in rice field irrigation. (Sastradiangga *et al.*, 2020).

Some research results still utilize electrical energy from a solar power plant that was permanently installed with a complex system, making its utilization extremely difficult to move from one location to another. Consequently, the need for electrical energy for activities outside the home or activities that are far from electrical energy sources (solar power plants) cannot be fulfilled.

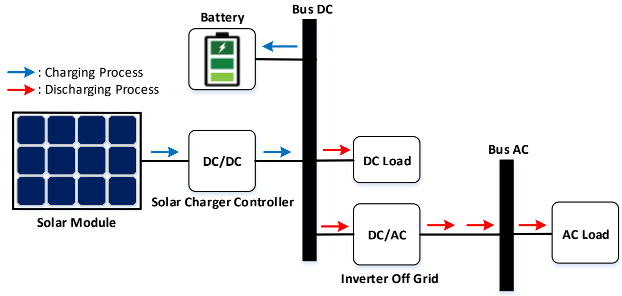
The portable power station that had been designed and researched are power stations that use solar modules with a capacity of 100 Wp for the battery recharging process, but the use of valve-regulated lead acid (VRLA) batteries has a weakness where the energy in the battery cannot be drained optimally because it can reduce battery life (Majid *et al.*, 2012), (Azhari Zakri *et al.*, 2021). In addition, there is no battery drain protection installed, so the energy taken from the portable power source can be drained, thereby shortening the battery's life cycle.

Solar Power Plant

Solar Power Plant is a type of new renewable energy generator that uses solar modules to convert sunlight into direct current (DC) electricity. There are two types of Solar Power Plant systems: off-grid systems and on-grid systems. The primary distinction between the two systems is that the on-grid solar power plant system can operate if it is connected to PLN electricity or if a PLN power grid is present. As depicted in Figure-1.a, this system can transmit excess (surplus) electrical power generated by solar modules via export-import kWh that can later be reused. Meanwhile, off-grid solar power plants are not connected to the PLN and still can operate independently. As shown in Figure-1b, the excess electrical power generated by the solar module when the sun is shining optimally is stored in the battery and reused when the sun is not shining optimally or at night.



(a)



(b)

Figure-1. Solar Power Plant Topology, (a) *on-grid* system, (b) *off-grid* system.

Lithium-Ion Battery

Lithium-ion batteries are a type of battery whose development is being increasingly applied to modern electronic devices, carpentry equipment, electric vehicles, and portable electrical energy storage (power bank). Lithium-ion batteries have a high energy density and life cycle, as well as smaller and lighter dimensions than lead acid (VRLA) batteries (Baccouche *et al.*, 2018). Lithium-ion batteries have the potential to be used as electrical energy storage for solar power plants, wind power plants, and other new renewable energy power plants due to these benefits (Nitta *et al.*, 2015).

The typical lithium-ion battery has an output voltage of Vdc = 3.6 Volts; to use it with equipment that requires a much higher input voltage, the battery must be connected in series to each cell so that the output voltage increases (Shams *et al.*, 2020). Due to a small imbalance of the cells during the charging and discharging processes, the problem of overcharging and over-discharging can occur in one or multiple series-connected cells. To prevent this, lithium-ion battery packs must be equipped with a battery management system (BMS) to enhance the performance and reliability of lithium-ion batteries (Gao *et al.*, 2017).

Figure-2 depicts the characteristics of the constant current and constant voltage (CC-constant voltage/CV) charging method. Because the charging conditions (undercharging and overcharging) have a significant impact on the lithium-ion battery's life cycle, the CC-CV method is typically used for the battery charging process. Where the battery is initially charged with a constant current until it reaches a predetermined maximum voltage, such as Vmax = 4.1 or 4.2 V. After the

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battery has been charged to 80%, the charging process switches to a constant voltage until the minimum current I_{min} is reached (0.1C). With the CC-CV charging method, the battery is charged by a current that decreases after the CC stage and before the CV stage. This is done to prevent the battery from being overcharged. (Tseng *et al*., 2009).

An example of determining the number and connection of lithium-ion batteries for a 12 V, 30 Ah output voltage. If the lithium-ion battery has a full charge voltage specification of 4.2 V and a capacity of 3000 mAh.

- Number of batteries in series:

Desired $V_{out}/V_{battery}$ (1)

- Number of parallelized batteries:

Desired Ah/Ah Battery (2)

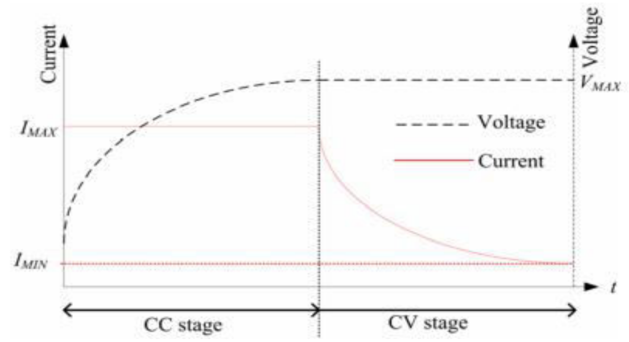

Figure-2. The stages of the lithium-ion battery charging process using the CC-CV method.

Multi Input Portable Power Station

Portable power stations are power plants that can be carried and moved from one location to another, have small dimensions, are lightweight, and require no special skills to operate. Solar modules and the existing electric power network (PLN power grid) will be used to charge lithium-ion batteries through the portable power station's dual inputs. Lithium-ion batteries are utilized in portable power stations due to their battery life cycle, energy density, power efficiency, dimensions, and lightweight.

Several mathematical equations can be used to calculate the need for portable multi-input power station components, namely (Hayusman and Hidayat, 2021):

- Electrical energy needs (Wh):

Power load (Watt) x operating duration (hour) (3)

- Solar module capacity (Watt-peak/Wp)

$$\frac{\text{Electrical energy consumption (Wh)}}{\text{Effective hours of sunshine (jam)}} \quad (4)$$

* The number of effective hours of sunlight is 4-5 hours.

- Inverter capacity (Watt)

Inverter capacity (Watt) > load capacity (Watts) to be supplied (5)

If the load you want to supply is an inductive type, it is recommended to use a pure sine wave inverter with a pure sinusoidal voltage wave.

- Battery capacity (Ah)

$$\frac{\text{Electrical energy consumption per day(Wh)}}{\text{Battery depth of discharge design (\%)}} \quad (6)$$

The depth of discharge battery/ DOD design is adjusted to the type of battery used by considering the battery life cycle.

MATERIALS AND METHODS

System Design

The system design in this study is to describe the process of designing a multi-input portable power plant from the beginning to the testing process. Several main things will be done in the design process, namely:

A. Portable power station design, which includes:
a) Lithium-ion battery capacity design.
b) Determination of the type and capacity of the solar module.
c) Determination of the type and capacity of the solar charger controller (SCC).
d) Determination of inverter type and capacity.
e) Determination of equipment of system and battery drain protection.
f) Control circuit and power generation circuit diagram.
B. Portable power generator box design, which includes:
a) Layout of each component.
b) Layout of reading and measuring equipment.

Figure-3 depicts a schematic diagram of a portable power station with multiple inputs. The source of power for both DC and AC loads is a 30 Ah lithium-ion battery. The direct voltage (DC) output is 12 Volts with a 2 A fuse for protection. The alternating voltage (AC) output is 220 V in the form of a pure sinusoidal wave, converted by a 300-Watt inverter with a 2 A fuse for protection. To preserve battery life, the battery draining process (discharging) is limited to 80% (depth of discharge/DOD). By pressing the S1 and S3 switches on the solar module, the process of recharging can be initiated. If the battery cannot be charged through the solar module, the S2 and S5 switches can be used to charge the battery through the PLN power grid. During charging via a solar module, the PLN electricity network, or when using a DC load output, the inverter can be deactivated by pressing the S1 switch so that it does not absorb electric current when the AC load output is not in use.

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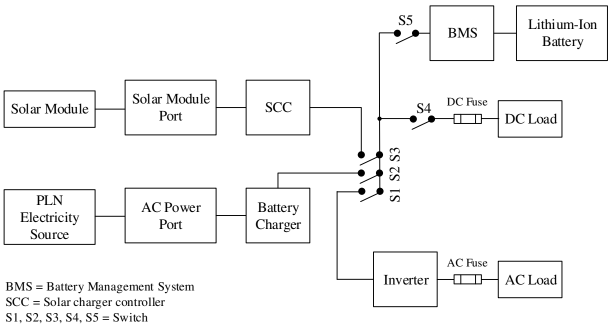

Figure-3. Schematic of a multi-input portable power station.

Research Stages

The research stage commences with a literature review concerning the process of generating portable electricity through solar modules and the PLN power grid, as well as the characteristics of lithium-ion batteries as a source of electrical energy that will be used to supply load demand (DC & AC). Determination of the capacity of the portable power station to be designed based on the planned load. 300 Wh of electrical energy is required for a portable power station that is capable of continuously supplying up to 50 Watts for up to 6 hours. Based on the electrical energy needs, the solar module capacity is calculated using the criteria for the amount of electrical energy (Wh) divided by the effective hours of sunlight, which are approximately 4-5 hours per day. The researcher then determines and calculates other components of the portable power station, including solar charger controllers, inverters, battery charging equipment (charging through the PLN power grid), and the number and arrangement of lithium-ion batteries. While the battery capacity can be determined by dividing the amount of electrical energy required (Wh) by the depth of discharge (DOD) design, which is 80%, the formula for calculating battery capacity is as follows: The next stage is to design a multi-input portable power station wiring diagram and layout of the main components and supporting components, such as digital multimeters, switches, fuses, PLN power grid input terminals, solar module input terminals, output terminals for AC loads and DC loads.

Further testing is performed based on the wiring diagram design after the installation, which includes: 1). Testing battery charging through solar modules; 2). Testing the charging of batteries via the PLN power grid; 3). Performing discharge tests with 1 x 50 Watts of ac led light load and 4). Using a 4000 mAh capacity mobile phone load to test battery discharge. The test results' data is then analyzed to conclude. Figure-4 depicts the research process in its entirety.

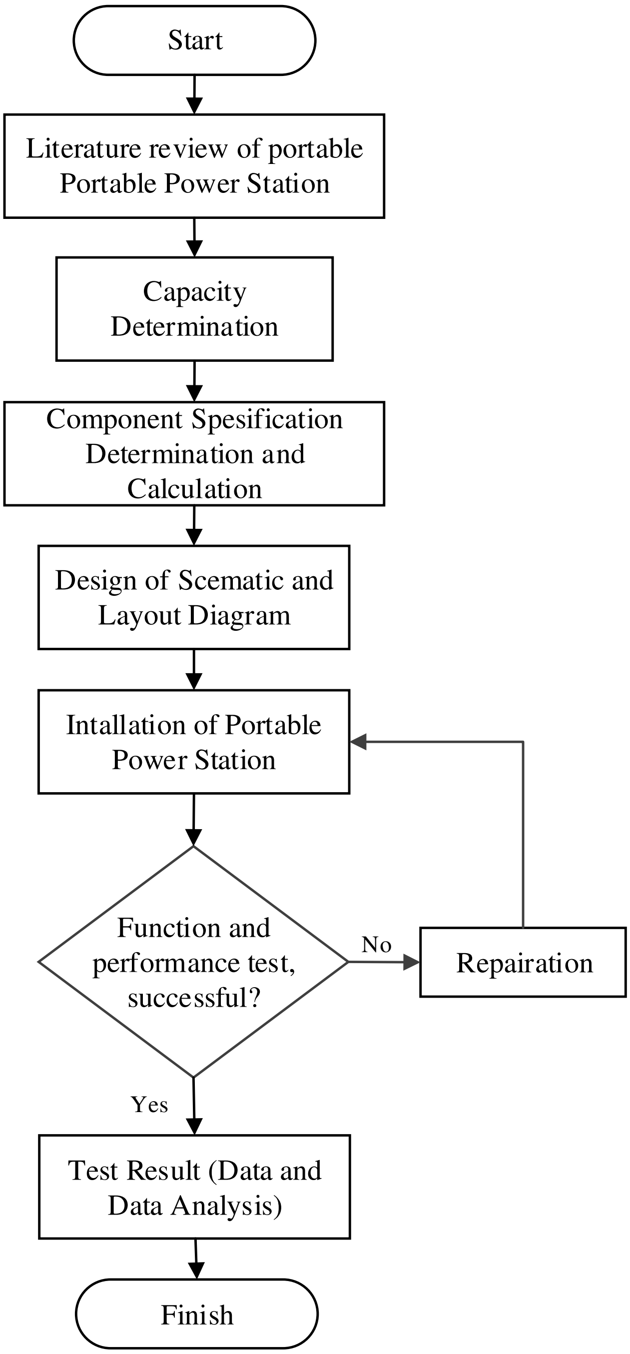

Figure-4. Research flow.

RESULTS AND DISCUSSIONS

Lithium-Ion Battery Pack Design

The design of this portable power station begins with the capacity of the temporary electrical energy source, which is 300 Wh with two types of output voltage, alternating voltage (Vac) 220 Volts and direct current voltage (Vdc) 12 Volts. In order to preserve battery life in portable power stations, the maximum depth of discharge is limited to 80% of the battery capacity. This portable power station's battery is a lithium-ion 18650 battery with a voltage range of 1 cell battery Vdc = 3.7-4.2 volts and a

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capacity of 3,000 mAh. With these specifications, the calculations below can be performed to produce an electrical energy source with a capacity of 300 Wh.

$$= \frac{\text{Energy Needs (Wh)}}{\text{Depth of Discharge (\%)}}$$
$$= \frac{300\ \text{Wh}}{0{,}8}$$
$$= 375\ \text{Wh}$$
$$= \frac{375\ \text{VAh}}{12\ \text{V}}$$
$$= 31{,}25\ \text{Ah or}$$
$$= 30\ \text{Ah}$$

Meanwhile, to calculate the number of battery cells in series and parallel, the calculation is as follows:

$$= \frac{\text{Battery pack voltage (V)}}{\text{1 cell battery voltage (V)}}$$
$$= \frac{12\ V}{4{,}2\ V}$$
$$= 2{,}8\ \text{equals 3 Series}$$
$$= \frac{\text{Battery pack capacity (Ah)}}{\text{1 cell battery capacity (Ah)}}$$
$$= \frac{30\ \text{Ah}}{3\ \text{Ah}}$$
$$= 10\ \text{Parallel}$$

So, for the battery circuit, a 3 series 10 parallel scheme is used, using a BMS with 3S 40 A specifications.

Portable Power Station Box Design

The layout of the components used to build a portable power station is shown in Figure-5 to Figure-9.

Figure-5. Front view.

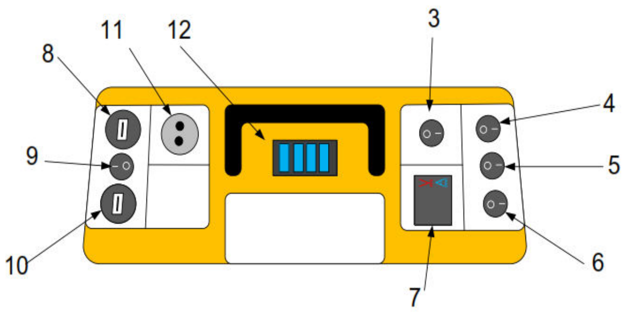

Figure-6. Top view.

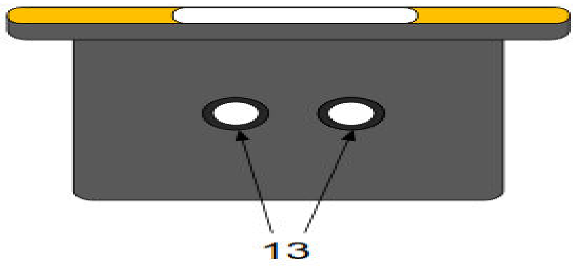

Figure-7. Side view.

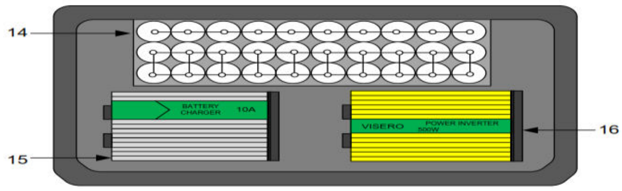

Figure-8. Bottom view.

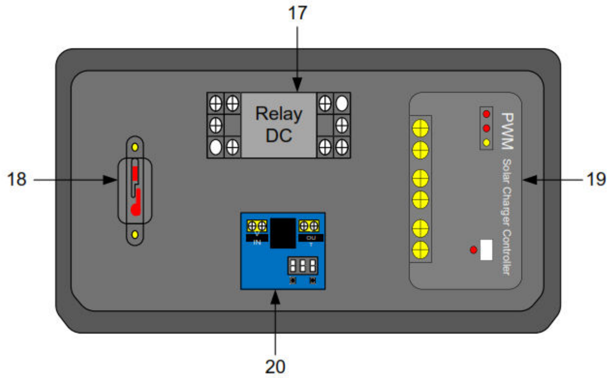

Figure-9. Top view.

Caption:
1. 12v dc output socket
2. on/off battery switch
3. 12v dc output socket
4. Socket connector mc4
5. Battery indicator
6. Lighting
7. Battery charger
8. 12 v 30 ah Battery pack lithium
9. 500 watts inverter
10. 12 v dc relay
11. 12 v 30 ah dc breaker
12. Low voltage disconnect (lvd)
13. Solar charge controller

Charging Test Using a Solar Module

Testing of the process of lithium-ion batteries charging for portable multi-input power stations using a solar module with a capacity of 50 WP polycrystalline cell type with detailed specifications is shown in Table-1.

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Table-1. Solar module data.

Brand	ST SOLAR
Cell type	Polycrystalline
Rated maximum power (Pmax)	50 Watt
Current at Pmax	2,81 A
Voltage at Pmax	17,8 V
Open Circuit Voltage (Voc)	21,8 V
Short Circuit Current (Isc)	3,05 A
Nominal operating cell temo	± 50^0C
Irradiance and cell	1000 W/m^2
Temperature	AM1.5 25^0C

Vdc = 11.6 Volts is the initial battery voltage before the charging process is initiated, as depicted in Figure-10. This rating represents the minimum portable generator battery voltage rating.

Figure-10. Voltage rating on the portable power station.

The charging process utilizing a solar module with a capacity of 1 x 50 Wp can generate an average current of Idc = 1.13 A, with a maximum current of Idc = 1.8 A being generated at 15.00 under sunny weather conditions. Charging the battery from the initial voltage condition of Vdc = 11.6 Volts to the fully charged condition (final voltage) of Vdc = 12.6 Volts with a duration t = 8 hours. The charging rate of the battery is dependent on the sun's brightness. If the solar module receives optimal solar radiation, the generated current and voltage will have a higher rating and the battery will charge more quickly. In contrast, if the weather is unfavorable due to cloudy conditions, the generated voltage and current will be low and the battery charging process will be diminished or slowed. The charging procedure is depicted in Table-2.

Table-2. The results of the charging test using solar module.

No	Time	Voltage (V)		Current (A)	Weather Conditions
		Solar Module	Battery		
1.	08.00	12	11,6	0,5	Cloudy
2.	09.00	11	11,6	0,3	Cloudy
3.	10.00	12	11,7	0,7	Cloudy
4.	11.00	12	11,8	1,2	Sunny
5.	12.00	13	11,9	1,1	Sunny
6.	13.00	13	12	1,5	Sunny
7.	14.00	13	12,2	1,6	Sunny
8.	15.00	13	12,4	1,8	Sunny
9.	16.00	13	12,6	1,5	Sunny

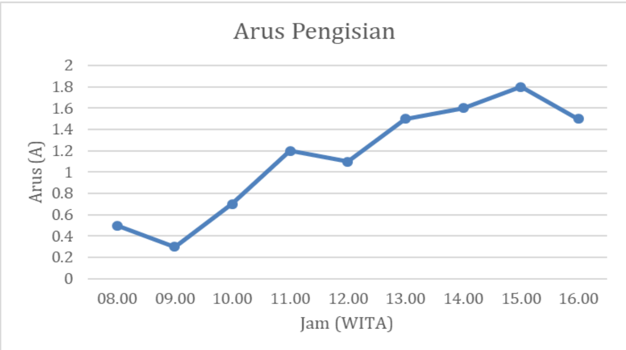

Figure-11. Graph of charging current using a solar module.

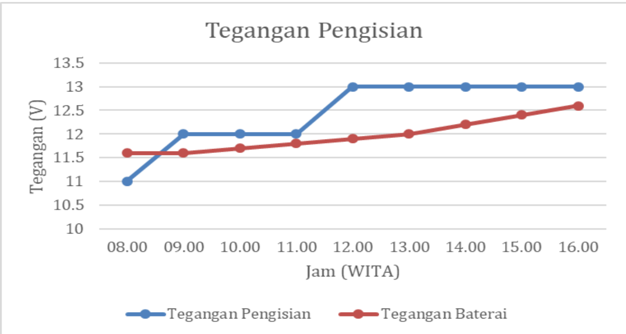

Figure-12. Graph of charging voltage using a solar module.

Testing Charging Using the PLN Power Grid

The process of charging a multi-input portable power station using a PLN power source and a 12 Vdc 10 A battery charger is tested. Based on calculations, the charging time is as follows:

$$\text{Charging duration} = \frac{\text{Battery capacity (Ah)}}{\text{Battery charger capacity (A)}}$$

$$= \frac{30\ \text{Ah}}{10\ \text{A}} = 3\ \text{hours}$$

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As shown in Table-3, the charging time was 3 hours from the initial battery voltage condition of Vdc = 11.6 Volts to the final battery voltage of Vdc = 12.6 Volts, with an average charging current of Idc = 7.8 A and a constant charging voltage of Vdc = 13 Volts.

Table-3. The results of the charging test using the PLN electricity source.

No	Time	Voltage (Volt)		Battery charger current (A)
		Battery charger	Battery	
1.	21.00	13	11,6	8
2.	22.00	13	11,9	8
3.	23.00	13	12,4	8
4.	00.00	13	12,6	7

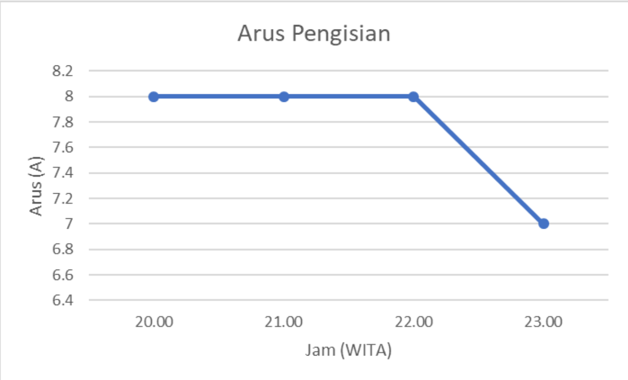

Figure-13. Graph of charging current using electricity source from PLN.

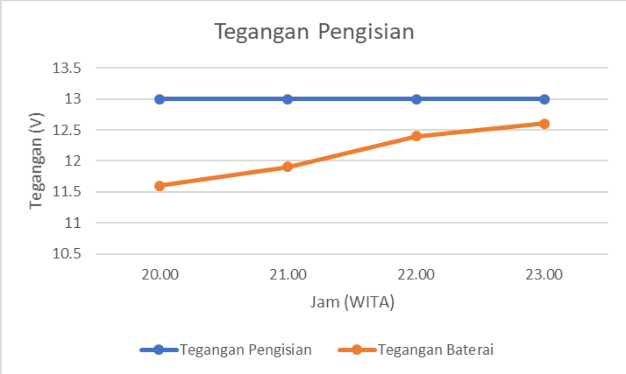

Figure-14. Graph of charging voltage using a power source from PLN.

Discharging Test Using a Lamp

Testing the discharge of a portable power station using a 50 Watt led lamp as an ac load was performed. As the test uses an ac load with an input voltage of 220 V, the output voltage of the portable power station's battery is first converted using an inverter from a direct voltage (Vdc) of 12 volts to an alternating voltage (Vac) of 220 volts.

As shown in the calculation below, based on the results of the calculation, this portable power station can supply 50-watt LED lamps for six hours.

Portable generator power supply duration:

$$= \frac{\text{Portable power station capacity (Wh)}}{\text{Lamp capacity (W)}}$$

$$= \frac{300\ \text{Wh}}{50\ \text{W}} = 6\ \text{hours}$$

The test results indicate that this portable power station can provide electricity for 6 hours and 27 minutes. The battery discharging time is affected by the load capacity used. The greater the load capacity supplied by the portable power station, the faster the testing or usage time. Figure-15 depicts the voltage rating of the battery, which decreases as the portable power station is utilized. This portable power station is designed so that the lowest voltage of the lithium-ion battery is maintained at a value of Vdc = 11.6 V using low voltage disconnect (lvd) equipment. This is done so that the lithium-ion battery used in the portable power station can last as long as specified by the manufacturer. Figure-16 demonstrates that the battery's current rating varies according to the state of the battery voltage, with an average output current of Idc = 1.3 amperes.

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Table-4. The results of the discharging test using a 50 Watt led lamp.

No	Time	Voltage (Volt)		Current (Amper)	
		Inverter	Battery	Battery	Inverter
1.	15.00	221	12,6	1,05	0,6
2.	16.00	220	12,3	1,32	0,7
3.	17.00	220	12,1	1,35	0,8
4.	18.00	220	11,8	1,34	0,7
5.	19.00	221	11,6	1,30	0,5
6.	20.00	220	11,6	1,29	0,5
7.	20.27	220	11,5	1,25	0,3

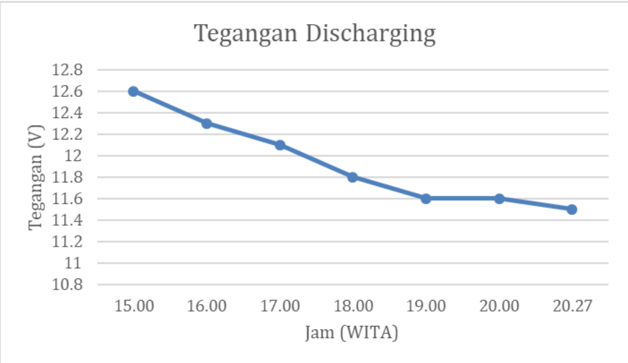

Figure-15. Graph of 50-watt led lamp discharging voltage.

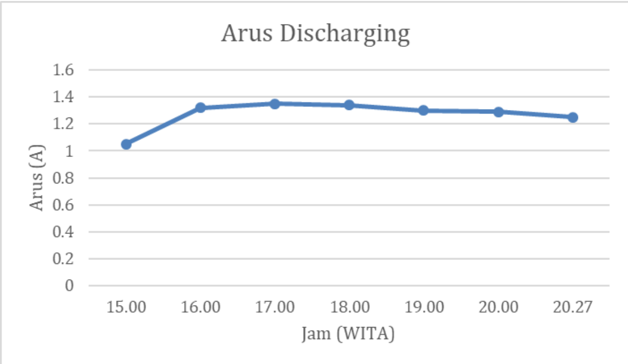

Figure-16. Graph of 50-watt led lamp discharging current.

Discharging Test Using a Smartphone

The next discharge test for the portable power station utilizes a cellphone with a battery capacity of 4000 mAh as the load. Based on the results of the tests, it was determined that mobile phones were charged six times with an average battery output current of Idc = 3.1 Amperes.

Table-5. The results of the discharging test through the cellphone charging process.

No	Charging frequency (times)	Voltage (Volt)		Current (Amper)	
		Inverter	Battery	Battery	Inverter
1.	1	222	12,6	3,05	0,8
2.	2	220	12,2	3,12	1,1
3.	3	220	12	3,08	0,7
4.	4	221	11,8	3,06	0,8
5.	5	220	11,6	3,08	0,8
6.	6	221	11,5	3,05	0,6

CONCLUSIONS

Using a solar module with a capacity of 50 Wp and an average charging current of 1.13 A, the time required to charge a portable power station is t = 8 hours, with an average charging current of Idc = 1.13 A. If the charging process uses the PLN power grid, it will take t = 4 hours with an average charging current of 7.75 A. While the time required to drain a portable power station from a full battery condition Vdc = 12.6 Volts to a battery voltage condition Vdc = 11.6 Volts with 1 led lamp ac 50 watts was t = 6.27 hours with an average discharge current of Idc = 1.29 A, it was possible to recharge a smartphone with a capacity of 4,000 mAh 6 times with an average discharge current of Idc = 3.07 A.

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