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Performance Ratio of Photovoltaic Energy Sources in the Application of E-bike Charging Station

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Abstract

The conversion of solar energy by the use of photovoltaic modules requires testing the performance of the conversion results to determine the efficiency and performance ratio, when unloaded and loaded. In the implementation of this photovoltaic energy source, the researcher aims to use the load of the e-bike at the e-bike charging station with a peak power capacity of 200 Wp photovoltaic and a battery storage capacity of 200 Ah 12 V. The test results obtained that photovoltaic energy provides 69% of the load power needs with a peak power of 98.67W at 12.25 WIB, while the battery supplies 31%, with a total PV energy of 0.68 kWh, and the performance ratio (PR) of the solar panels was obtained at 85.7%. The load of the bike itself absorbs 437.6 Wh of energy from SoC charging (62%-100%) with a charging duration of 3.42 hours, where the charging of the e-bike in planning requires 576 Wh of energy for 4.5 hours from the SoC (50%-100%).

Keywords : Performance Ratio, Photovoltaic Energy Source, Battery, E-bike Charging Station

1 Introduction

Renewable energy sources are primary energy sources produced from non-fossil natural energy or non-conventional energy. Renewable energy sources are generated from wind, water, geothermal, sunlight, biomass, seawater waves, and others. Renewable energy is present as an alternative to conventional energy. Various countries, including Indonesia, participate in the development and application of these energy sources, considering that Indonesia is a country with a tropical climate, of course, in summer the potential for sunlight is very large, and the potential for a wide water source is a very important and valuable advantage for the application of non-fossil energy [1]. Hybrid systems from renewable energy sources continue to be developed in the current era. The latest developments in the application of smartgrid systems (microgrids and nanogrids) the level of flexibility must be maintained and continuously improved [2]. So, to support this smartgrid system, the converter device is one of the important components to maintain the reliability of the system. The converter devices in power electronics are divided into several types, including: DC-DC converters (DC choppers), DC-AC converters (inverters), AC-DC converters (rectifiers), and AC-AC converters (cycloconverters).

Charging stations or charging stations for electric vehicles in operation require continuous energy to meet load needs at all times. So, a microgid topology in which the integrated system is renewable energy supported by the Battery Energy Storage System (BESS) as a proposal to meet the load requirements of the charging station concept [3], even according to [4] Charging stations for electric vehicles, which in total resources continue to come from renewable energy, are a mode of transportation that truly applies the concept of zero emissions. On the other hand, the concept of environmentally friendly electric bikes that use an off-grid charging system is preferred over an on-grid system, in this case because the off-Grid charging system has several advantages, including sustainability, ease of movement and installation, and independence from the power grid [5], [6], [7].

At [8], [9], [10], [11], the concept of charging and discharging electric vehicles can be categorized into several concepts, including: 1. Uncontrolled charging; 2. Delayed charging; 3. Average charging; 4. Intelligent charging; 5. Intelligent discharging. Talking about e-bike charging stations that use wind and photovoltaic energy [12], this study compares the application of energy source systems in coastal and terrestrial areas. Each energy source has a DC-DC converter, namely MPPT is used to stabilize voltage and current values, from the output of the MPPT the two energy sources are assembled in series so that the DC voltage system is applied to integrate wind and PV energy sources. The simulation results assume that the energy produced from hybrid energy is 27.08 kWh / day offshore and 22 kWh / day onshore.

The second research is titled modeling of standalone solar PV on an electric bike charging station, a system designed to charge electric bikes in workplaces such as schools, colleges, offices, etc. [6]. It can be seen from this work that electric bicycles have voltages of different configurations, namely 12 V, 24 V, and 36 V, which can be charged efficiently. In this charging station concept, charging to the storage battery uses a bidirectional method with a PI controller. The third research is titled e-bike charging station using photovoltaic (PV) with AC, DC charging, and contactless charging [4]. Charging electric vehicles with solar energy provides a sustainable means of transportation. Research in [13], shows the design of a solar powered e-bike charging station that provides AC, DC, and contactless e-bike charging. DC chargers allow DC charging directly on the e-bike from photovoltaic (PV) panel DC power without the need for an external AC charger adapter. In the case of contactless chargers, the bike can be charged without using any cables, providing maximum convenience to the user. Finally, the charging station has an integrated battery that allows both grid-connected and off-grid operations.

The micro-grids consist of energy conversion, energy storage, and energy consumption. The photovoltaic solar generation system is the main source to meet the energy needs of the load, the battery storage system integrated with solar panels becomes the second source to meet the energy needs of the load, to complement the energy source from the grid/PLN to the backup system in anticipation of the source of renewable energy. In the event of a disturbance, the system is based on the principle of the smart grid system considering the reliability of the system to meet the energy needs of the charge station load [14], [15]. The smartgrid system is equipped with system control to apply the working principle of the smartgrid works well and reliably, the monitoring system is planned to display the condition of the energy and power supplied to the load and display the energy and power absorbed by the load at the charging station. So when the monitoring system is installed accurately in its measurement, it will be easy to analyze the energy system from the solar energy source that has been produced by the photovoltaic module, and the energy balance system between the PV energy source, the battery storage system (BESS) and the e-bike charging load. Therefore, the ability of solar energy that has been produced by photovoltaic modules to the needs of charging e-bikes will be inferred from the value of the performance ratio (PR), when the condition is no-load with the condition being loaded. Thus, in the introduction of this study, the focus of this study is to find out the performance ratio of the energy system produced by photovoltaic energy for the use of e-bike charging load in the concept of e-bike charging stations.

2 Method

This research begins by finding the energy needs of the load that will be installed at the e-bike charging station, then the load needs have been obtained, then it continues with the determination of the main components of the photovoltaic system including the charge controller (MPPT / PWM), battery system, inverter, and charging system. The load requirements and its main components are continued with a PV installation simulation using an application owned by the meteorological agency, namely the Global Solar Atlas to determine the average solar irradiance per day, which is used as a reference for the efficiency of PV modules based on simulations, which is then also measured solar irradiation by converting the intensity of sunlight to solar irradiance using a lux measuring device meters, with these measurements, a conclusion will be produced while the efficiency of the PV energy source is in a no-load condition. When the energy source from the Sun by the PV module is attached to the battery and the e-bike charging is carried out, the load energy will be increased, so that the total value of the energy produced by the PV compared to the total load energy will be obtained by the performance ratio of the PV source system used in the application of the e-bike charging station. Where the greater the %PR value, the better the PV system works and vice versa.

2.1 Daily Load Needs at E-bike Charging Stations

Load data is obtained from the power specification on each load expressed in units (W), then the operating hours of load use. Then the total energy required by the load expressed in units (Wh) is obtained.

$$E_{Load}(kWh) = p_{load}(W)t(h) \tag{1}$$

E_{load} is the energy that is needed to carry a load every day. is the magnitude of the load power required, and is the length of time the load power is used.p_{load} t

Table 1: E-bike Specifications

E-bike Specifications	
Electric Motor Power	350 Watt
Mileage	42 Km/h
Battery Capacity	48 V 12 Ah
Rider Load	120 Kg
Control Charge	128 Watt

The power in the e-bike charge controller, so that the value of $p_{load} = 128$ (W), while the battery on the embedded e-bike uses the lead acid type battery so that the maximum % DoD (dept of discharge) is 50% x C_{bat} (Wh), so that the charging duration takes 4.5 hours from 50% - 100% SoC, so equation (2) the daily energy value needed to calculate the PV value used.

$$E_{Load}(kWh) = 128(W).4,5(h) = 576Wh = 0,576kWh \tag{2}$$

Table 2: Daily Energy Load

Load	Power	Charge Duration (SoC 50%)	Energy
E-bike	128 Watt	4,5 hours	576 Wh

In Table 2 The amount of energy required is as large as $E_{Load} = 576Wh$, with $SoCxC_bat(Wh)$ and $p_{load}(W) = 128W$, by equation the current that will be charged on the battery is 2.7A, with a duration of 4.5 hours of charging from 50% SoC- 100%.

2.2 Solar Module Peak Power Design (kWp)

The research was carried out on the page of the postgraduate building, so for solar irradiation taken from daily data in Malang City, data taken from the Solargis website, the average daily irradiance was obtained $5,02kWh/m^2$. Then the value is obtained in the equation below:

$$PowerPeek(Wp) = \frac{LoadDailyEnergy(kWh)Irradiance(\frac{kWh}{m^2})}{=} \frac{576Wh}{5,02(\frac{kWh}{m^2})} = 114,74Wp \tag{3}$$

the calculation of peak power is obtained, to add from the system loss plus 30% of the peak, then the peak power is obtained of 149 Wp, then the total solar module power needed is 200 Wp. For the number of solar modules that are charged as much as in the calculation below.114,74 Wp

$$NumberofModules = \frac{PowerPeek(Wp)}{WpSelectedModul} = \frac{200Wp}{100Wp} = 2modules \tag{4}$$

When the calculation of the required solar module is obtained, it continues to the type of solar module to be installed along with its specifications, in Table 3 is the specification of the solar module used in the photovoltaic system.

Table 3: Solar Module Specification

Specification of Solar Module	
Merk	Sunwatt
Type	Monocrystaline
Maximum Power at STC (Pmax)	100- 110 Watt
Short Circuit Current (Isc)	6,3A
Open Circuit voltage (Voc)	23 V
Max. Power Current (Imp)	5,8 A
Max. Power Voltage (Vmp)	17 V
Modul Efficiency	18,30%
Power Tolerance	0 ± 3%
Dimension	1160 x450x30 mm

2.3 Block Diagram of Photovoltaic System on E-bike Charging Station

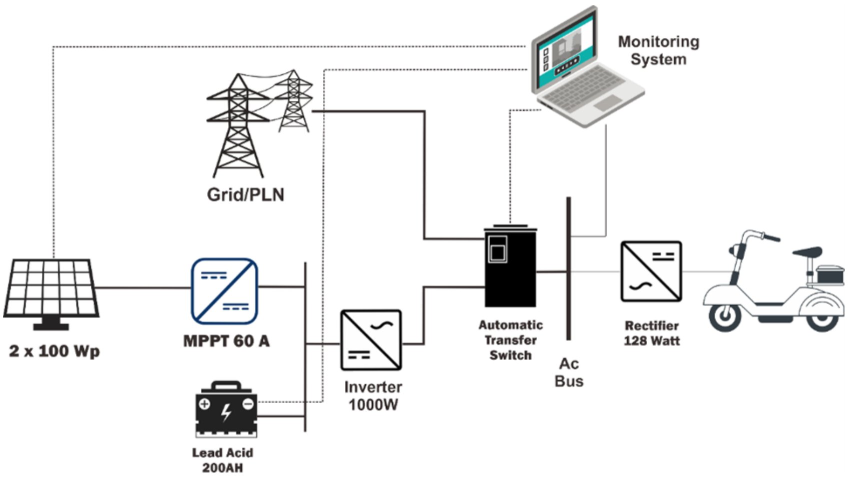

Figure 1: PV System of E-bike Charging Station Diagram Block

Based on Figure 1, the e-bike charging station consists of several main components consisting of 2 x100 Wp with a monocrystalline type open circuit voltage (Voc) of 22.4 V. Where the number of solar modules is taken from the calculation of the daily energy requirement of a load of 576 Wh and the average irradiation of sunlight in Malang City of 5.02 kWh/, the DC/DC converter uses a Powmr MPPT 60 A 13 V device as a tool to control the energy charging from photovoltaic to battery storage. The storage battery with Lead Acid type 12 V 100 AH is installed in parallel with the Kenika Inverter 12 V 1000 W. The system voltage of 12 Vdc is applied to the concept of this e-bike charging station. The inverter is arranged in parallel with the storage battery because when the energy of the photovoltaic is below the standard rating on the inverter, the battery will directly support the photovoltaic to supply energy to the load through the inverter. The design of the system at the electric bike charging station is equipped with a monitoring system that includes the value of power, voltage, and current produced by renewable energy sources and the grid, along with the energy consumption that has been absorbed by the electric bike load. The charge controller attached to the system operates at a voltage of 13 volts, with the type of MPPT used, the voltage generated by the PV will be stabilized at a voltage rating of 13volt by the MPPT device to charge energy to the storage battery and will directly supply energy to the e-bike load. The inverter output voltage in the form of AC voltage before reaching the load will be operated by the ATS system (Automatic Transfer Switch) as the main device in the control of the energy sources that will supply the load, where the ATS device is connected to two energy sources from renewable energy and the grid [16]. This ATS device will be the main subject of discussion in this paper. Basically, the ATS in this study is to maintain the potential of the PV energy supply against the electric bike loads, then basically the balance of the energy system in the PV in eqn (1), which of the solar iridiations captured by the solar modules generates PV power (P_{pv}), then MPPT directly controls the charging of the battery ($P_{bat)}$) dan When the e-bike load is attached (P_L), there will be a large power value [16], [17], [18].

$$P_{bat} = P_{pv} - P_L \quad (5)$$

2.4 PV Performance at No Load Conditions

Knowing the PV performance in a no-load condition aims to determine the efficiency of solar panels in absorbing solar energy into electrical energy, To find out the efficiency, a no-load experiment is needed to determine the value of the V_{oc} and I_{sc}, Irradiance measurements (Wh/m^2) are conducted to quantify solar energy, allowing for a comparison between the actual electrical energy output (E_{pv}) and the irradiance (Wh/m^2) obtained panel conversion efficiency value (module conversion efficiency) [19], [20], [21],[17]. In addition to the results of the field tests, the efficiency of the panels under the condition of STC (μ_{STC}) It can be calculated in Equation (9) following this: Maximum power in STC(P_{max})

$$P_{max} = V_{max}.i_{max} \quad (6)$$

Solar Panel Efficiency in STC (μ_{STC})

$$\mu_{STC} = (\frac{P_{max}}{A.1000})x100 \quad (7)$$

P_{max} is the peak power (Wp) produced by photovoltaic energy from the result of solar energy conversion is the product of the multiplication of V_{max} dengan I_{max}, These values are already contained in the specifications of solar modules. Then the performance testing of solar modules in the field can be calculated using the following equation:

$$H_{it}(\frac{kWh}{m^2}/day) = \int H_i dt \quad (8)$$

$$E_i(\frac{kWh}{m^2}/day) = H_{it}.A \quad (9)$$

H_{it} is the total solar irradiation during the test time ($\frac{kWh}{m^2}/day$), E_i It is the input energy obtained from the total solar irradiation rays during the test with the area of the solar panel and the determination of 60% of the solar energy that can be consumed by the solar module with the diffuse concept. For calculating the output energy (E_o) It can be calculated in the following equations:

$$V_{mp} = V_{(oc_measure)}.(\frac{V_{mp_spec}}{V_{oc_spec}}) \quad (10)$$

$$I_{mp} = I_{(sc_measure)}.(\frac{I_{mp_spec}}{I_{sc_spec}}) \quad (11)$$

After calculating the value V_{mp} and I_{mp} Specify the Fill Factor value (FF) and maximum power (P_m) In the following equation:

$$FF = \frac{(V_{mp}.I_{mp})}{(V_{(oc_measure)}.I_{(sc_measure)}} \quad (12)$$

$$P_m = V_{(oc_measure)}.I_{(sc_measure)}.FF \quad (13)$$

Fill Factor (FF) value and maximum power (P_m) has been determined, proceed to calculate the output energy (E_o) and PV efficiency (μ_{pv}) with the following equation,

$$E_o(kWh) = \int P_m dt \quad (14)$$

$$\mu_{pv}(\%) = \frac{E_o}{E_i}.100 \quad (15)$$

Information: V_{mp} = Maximum Voltage Rating Pv (V)
I_{mp} = Maximum Current Value Pv (A)
$V_{(oc_measure)}$ = Open Circuit PV Voltage Values based on Measurements (V)
$V_{(oc_spec)}$ = PV Open Circuit Voltage Ratings by nameplate (V)
$V_{(mp_spec)}$ = PV Maximum Voltage Rating based on nameplate (V)
$I_{(sc_measure)}$ = PV Short Circuit Current Values based on measurements (A)
$I_{(sc_spec)}$ = PV Short Circuit Current Values based on nameplate (A)
$I_{(mp_spec)}$ = PV Maximum Current Values based on nameplate (A)

2.5 PV Performance under Loading Conditions

After knowing the efficiency value of PV in its maximum condition, then this value will be a reference for PV efficiency in determining the Performance Ratio (PR), PR is a comparison between PV Energy when loading (E_{o1}) with total solar irradiation rays during testing with solar panel area and a determination of 60% of the solar energy that can be consumed by solar modules with diffuse concept, (E_i).So the following equation is obtained:

$$\%PR(PerfrormanaceRatio) = \frac{E_{o1}}{E_o}x100 \tag{16}$$

where, $E_o = E_i.\mu_{pv}$
This Performance Ratio is useful for finding out the performance of the PV system used, the higher the PR value, the better the performance of the solar panels used.

3 Results and Discussion

3.1 Efficiency of Solar Modules at No Load

The calculation was carried out after testing PV without load so that the open-circuit voltage value was obtained (V_{oc}), arus short circuit (I_{sc}), FF (Fill Factor) and irradiance $H_{it}(\frac{kWh}{m^2}/day)$. Solar irradiation testing is carried out by testing the value of sunlight intensity using a lux meter, which is then converted to irradiance $H_{it}(\frac{kWh}{m^2}/day)$.

$$Irradiance(\frac{Wh}{m^2}/day) = \frac{SunlightIntensity(Lux)}{100} \tag{17}$$

From the test results, the value was obtained from the calculation $H_{it}(\frac{kWh}{m^2}/day)$ and $E_o(Wh)$ in Table 4 below:

Table 4: No load PV Test Results

Time	$H_{it}(\frac{Wh}{1{,}1m^2}/day), h = 60T$	$E_o(Wh)$	$\mu_{pv}(\%)$
8:00:00	447,79	68,00	15,19%
9:00:00	708,58	100,87	14,24%
10:00:00	848,93	123,83	14,59%
11:00:00	878,81	128,55	14,63%
12:00:00	881,19	126,86	14,40%
13:00:00	817,30	110,26	13,49%
14:00:00	713,12	86,89	12,18%
15:00:00	259,97	34,70	13,35%
16:00:00	83,42	8,00	9,59%
17:00:00	41,80	3,68	8,80%
Total Energy (kWh)	5,68	0,79	13,94%

From the results of the above test with a solar module area of 1.1m2, a value was obtained,
Irradiance, $H_{it}(\frac{Wh}{1{,}1m^2}/day) = 5,68(\frac{Wh}{1{,}1m^2}/day)$
$E_o(Wh) = 0,79kWh/day$

So, to calculate the efficiency value of the solar module based on the no-load test that will be used on the PV in this charging station system, the following calculation is obtained, the calculations with no-load testing obtained a PV efficiency value of 13,94%.

$$\mu_{pv}(\%) = \frac{E_o}{E_i}.100 \tag{18}$$

Where,
$E_i(\frac{kWh}{m^2}/day), = H_{it}.A$
$\mu_{pv}(\%) = \frac{0{,}79}{(H_{it}.A)}$
$\mu_{pv}(\%) = \frac{0{,}79}{5{,}68} = 13,94\%$

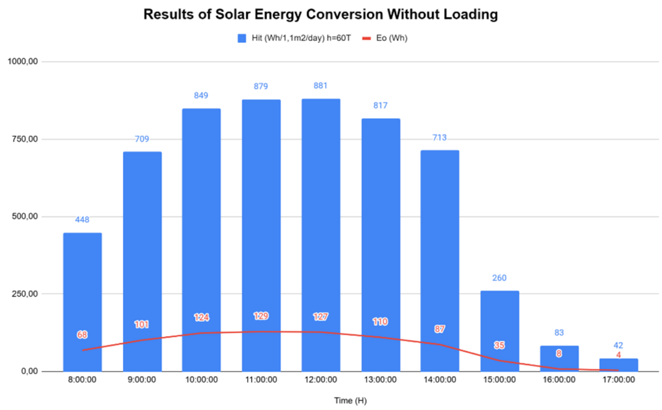

Figure 2: Solar Energy Conversion Without Load

Based on Figure 2, the maximum power of solar irradiance is 881 $(Wh/1,1m2/day)$ at 12.00 WIB with a test duration of 10 hours, while the maximum power $E_o(Wh)$ at 129Wh at 11.00 WIB.

3.2 Results of PV Mode Performance Testing and Analysis during E-bike Loading

In this subchapter, the analysis is carried out to explain the analysis of data related to PV performance at the time of loading where the energy produced by $PV(Epv)$ When loading (E_{o1}) will be compared with the PV output energy When no load Eo(Wh) so that the Performance Ratio (PR) value is obtained. Table 5 explains the results of the photovoltaic energy test (Epv) when loading (E_{o1}) and when the photovoltaic output energy is not loaded (E_o).

Table 5: PV Test Result during E-bike Loading

Time	$H_{it}(\frac{Wh}{1,1m^2}/day), h = 60T$	$E_{o1}(Wh)h = 60T$	$E_o(Wh)$	$\mu_{pv}(\%)$
8:00:00	447,79	41,35	68,00	15,19%
9:00:00	708,58	49,82	100,87	14,24%
10:00:00	848,93	56,29	123,83	14,59%
11:00:00	878,81	86,16	128,55	14,63%
12:00:00	881,19	91,16	126,86	14,40%
13:00:00	817,30	96,92	110,26	13,49%
14:00:00	713,12	92,97	86,89	12,18%
15:00:00	259,97	90,18	34,70	13,35%
16:00:00	83,42	51,40	8,00	9,59%
17:00:00	41,80	21,78	3,68	8,80%
Total (kWh)	5,68	0,68	0,79	13,94%
%PR		85.7%		

Based on Table 5, it can be explained by the calculation below:
$\%PR(PerfrormanceRatio) = \frac{E_{o1}}{E_i.\mu_{pv}}x100$
where
$E_i(\frac{kWh}{m^2}/day), = H_{it}.A$

$$\%PR(PerfrormanaceRatio) = \frac{0,68(kWh)}{5,68\frac{\frac{kWh}{1,1m2}}{day}x13,94\%}x100 = \frac{0,68}{0,79}x100 = 85,7\% \quad (19)$$

By testing the PV energy during loading (Eo1) by 0.68 KWh and the PV energy without loading of 0.79 KWh, the percentage value of the performance ratio (PR) of the solar panels is 85 7%. The higher the performance ratio (PR), the better the performance of the solar panel. A comparison graph of the Performance Ratio (PR) of solar panels can be seen in Figure 3

3.3 PV Energy Balance and Storage Battery Energy when Charging E-bike

Based on the performance of the photovoltaic system in Figure 4 when supplying the PV battery load and the e-bike, the average total power (P_pv) reaches 60W with a maximum power of 98.67W at 12.25 WIB. According to calculations related to the integration of photovoltaics with batteries, to find the value of energy supplied to the battery or load using the equation, $\frac{dE_{bat}}{dt} = P_{pv} - P_L$ so that when the value of (E_{bat}) positive values indicate the condition of battery charging, and vice versa when (E_{bat}) negative values indicate that the battery is discharging, backing up the solar panels to supply energy to the load of the e-bike. The performance of photovoltaic and battery production in supplying energy for charging e-bikes can be seen in Figure 5.

Table 6: Accumulated Usage E_{bat} and E_{pv} for Needs E_L

Time	$E_{pv}(Wh)h = 60T$	$E_{bat}(Wh)h = 60T$	$E_L(Wh)h = 60T$	
8:00:00	41,35	25,35	16,01	
9:00:00	49,82	19,03	30,79	
10:00:00	56,29	21,39	34,90	
11:00:00	86,16	8,35	77,82	
12:00:00	91,16	-72,16	163,32	
13:00:00	96,92	-73,85	170,77	E-bike charging
14:00:00	92,97	-77,32	170,29	SoC 62%-100%
15:00:00	90,18	-7,98	98,16	(437,76 Wh)
16:00:00	51,40	-25,68	77,08	h=3,42 hours
17:00:00	21,78	-15,18	36,96	
Total energy (kWh)	0,68	0,20	0,88	
Usage Percentage	69% (Pv)	31% (Battery)		

Based on Table 6, the accumulated photovoltaic energy supplied to the load is 69% of the total load energy (E_L), while the battery supplies the energy to the load by 31% of the total energy required in the load. For the load of the e-bike itself, it absorbs 437.6 Wh of energy from charging the SoC (62%-100%) with a charging duration of 3.42 hours, where charging the e-bike in planning requires 576 Wh of energy for 4.5 hours from the SoC (50%-100%).

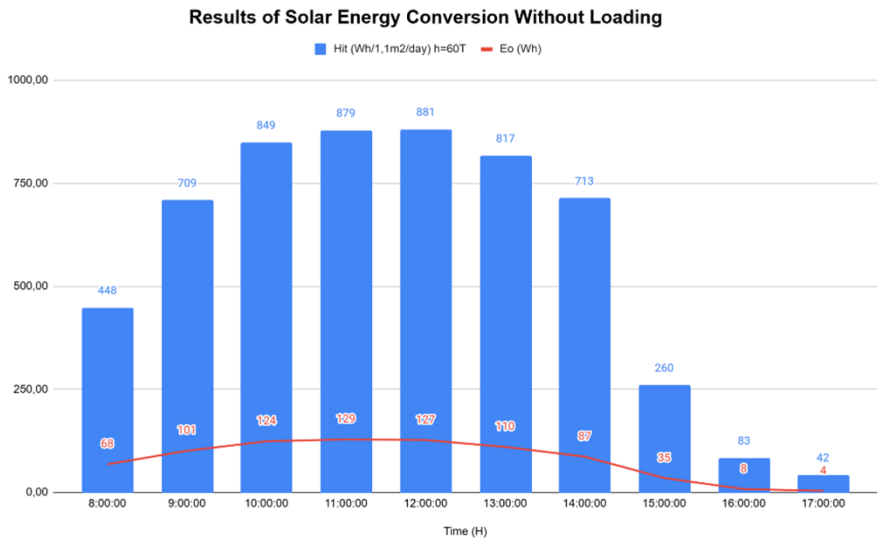

Figure 3: Ppv Test Results during Loading

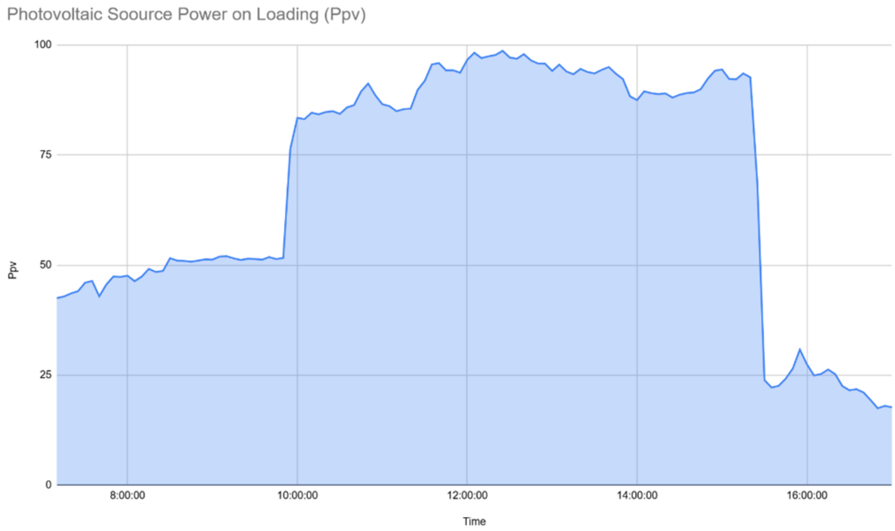

Figure 4: Test Results E_{bat}, E_{pv}, and E_L

By Figure 5 The battery is in charging condition for 4 hours from 07.00-11.00 WIB, after which the battery is in a discharging condition. This happens because at 12 noon the load of the e-bike requires energy (E_L) 163.32 Wh, while at the same time the PV energy E_{pv} 91.6 Wh, then the battery will back up the PV to supply energy to the load of (E_{bat}) $= 72, 16Wh$, this takes place at the time afterwards.

4 Conclusion

PV performance when supplying PV and e-bike battery loads reaches the average power (P_{pv}) by 60 watts with a peak power of 98.67 W at 12.20 WIB. For the energy produced by photovoltaics during testing (E_{o1}) by 0.68 kWh with an energy use that increased drastically at 11.00-15.30 WIB, there began to be a decrease in photovoltaic energy consumption after 15.30 WIB; this is, of course, due to the decrease in PV power capacity in the afternoon, and more load power is taken from storage batteries. The Performance Ratio (PR) of the photovoltaic system is 85. 7%, where the value of the energy produced by photovoltaics without load in the test is $E_o(Wh) = 0, 79kWh$, with a photovoltaic efficiency based on the testing of 23. 23%. So in general testing for 10 hours the battery was in a charging condition for 4 hours from 07.00-11.00 WIB, the battery was in a discharging condition at 11.00-17.00. by accumulating PV energy supplied to the load by 69% of the total load energy (E_L), Meanwhile, the battery supplies energy to the load by 31% of the total energy required at the load. For the load of the bike itself, it absorbs 437.6 Wh of energy from charging the SoC (62%-100%) with a charging duration of 3.42 hours, where charging the e-bike in planning requires 576 Wh of energy for 4.5 hours from the SoC (50%-100%).

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