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DESIGN AND DEVELOPMENT OF HYBRID SOLAR E-BIKE FOR SUSTAINABLE GREEN TRANSPORTATION

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Solar energy has great potential for utilization as an unlimited and alternative renewable energy source that can be stored in batteries and used to drive the BLDC motor on electric bicycles. The purpose of this study was to determine the charging efficiency of a 100 Wp solar panel mounted on an electric bicycle. A solar power meter was used to measure the solar radiation absorbed by the photovoltaic (PV) module, while sensors were used to measure the current and voltage (DC) output from the solar panels. The sensor signals were then processed by a microcontroller and displayed on an LCD screen, as well as recorded by an SD card data logger. The characteristics of the charging voltage were compared with and without the PV module. The results showed that at a solar radiation of 1008 W/m², the maximum voltage and current achieved were 17.49 V and 3.37 A, respectively. Under these conditions, the battery charging efficiency of a 100 Wp solar panel was 58.94%. A one-hour test with an average solar radiation of 976.3 W/m² showed that integrating a 100 Wp PV module increased the energy stored in the e-bike battery by 33.33%. Therefore, the hybrid solar e-bike concept has the potential to improve the performance of electric vehicles in the future.

Keywords: PV-module, e-bike, solar energy, hybrid, charging efficiency

1 INTRODUCTION

Indonesia benefits from excellent solar exposure due to its geographical location near the equator. Almost every area of Indonesia receives solar exposure from early morning to late afternoon [1,2]. Meanwhile, Indonesians' demand for transportation is increasing year after year. The majority of energy sources now in use are fossil fuels. As a result, efforts must be made to minimize and replace the usage of fossil fuels. Solar radiation energy is an alternative energy source that can be exploited [3]. The solar panel (PV module) consists of a series of solar cells (photovoltaic). It is a semiconductor-based device capable of converting electromagnetic energy from the sun into electricity [4,5]. Currently, solar panel manufacturing technology is improving in terms of materials, shapes, sizes, efficiencies and low prices [6].

Electric vehicles are an alternative mode of transportation that is environmentally friendly. In the future, it has the potential to replace conventional means of transportation, especially oil-fueled vehicles [7,8]. Several researchers have studied electric vehicles powered by solar energy in the last decade. The results show that solar electric vehicles have the potential as a sustainable mode of transportation in big cities [9,10]. The integration of photovoltaic (PV) with electric vehicles can reduce the peak load on the power grid while increasing the construction of PV power plants. The e-bike sharing model, which involves creating a solar charger station for charging electric bicycles, is a widely developed concept of an integrated solar electric vehicle [11]. In its development, the usage of PV Modules is also a source of battery charging, one of which is an electric bicycle battery. The charging of electric vehicles through the usage of PV systems is starting to get the attention of researchers, especially on the stability of battery charging systems. The research that has been done is to design, manufacture, and test the electric bicycle battery charging controller system [12–14]. Therefore, stand-alone solar PV systems for charging stations in public settings have become increasingly popular in recent years [15].

On the other hand, hybrid solar e-bike needs to be investigated, especially for electric bicycles. The design and performance of the hybrid solar e-bike need to be improved. It's to achieve an ergonomic and eye-catching appearance.The first vehicles with rooftop solar panels appeared, mostly in three or four-wheelers. Meanwhile, research and development of electric bicycles (two-wheel) with integrated solar modules by hybrid concept are rare [16-18]. The electric bicycle has various advantages in urban environments, including being faster, more practical, more comfortable, and can reduce congestion [19]. In addition, e-bikes are electric-powered bicycles that still have pedal assistance to help people cycle. So that E-bike owners can still use their bikes for recreation and exercise [20].

In this study, an electric bicycle was assembled with 100 Wp PV module. In addition, the charging characteristics of Solar PV on electric bicycle batteries will be investigated. In this regard, the voltage and current output of the PV Module will be monitored to determine the charging efficiency.The added value of this research is: (i) A solar e-bike with an easy and affordable design. (ii) The development of battery charging modules for low to high DC voltage, therefore allowing the use of PV panels with a small capacity (100-150 Wp). (iii) Data monitoring system installation on solar-powered e-bike.

2 MATERIALS AND METHODS

This research is true experimental research conducted outdoors. Voltage (*V*) and current *(I*) are the research's dependent variables. a time (*t*) and solar radiation (*G*) are the independent variables. The solar module used is a monocrystalline type with a capacity of 100 Wp, with specifications as shown in table 1.

Table 1. PV Module spesification [21]

Parameter	Value
Type	Monocrystalline
Peak power (P_{max})	100 W
Cell Efficiency	18.0 %
Max power (V_{mp})	17.8 V
Max power current (I_{mp})	5.62 A
Open circuit volt (V_{oc})	21.8 V
Short circuit current (I_{sc})	6.05 A

This PV Module is mounted on an electric bicycle using 36V/350 BLDC. The specifications of the battery used are VRLA 36V/12 Ah. Energy from the solar radiation is converted into electricity by PV Module. So that the output voltage and current of the PV module can be measured. Solar radiation was measured with the SM 206-Solar Power Meter. DS3231 RTC (Real Time Clock) module, ACS712 current sensor, and 0-50 VDC voltage sensor were used to measure real-time, current, and voltage of PV, respectively.

The microcontroller utilized in this study is the Arduino Uno R3 with the Atmega 328P-PU chip. A widely used microcontroller board for a diverse range of projects, the Arduino Uno R3 features the Atmega 328P-PU chip, a low-power, 8-bit microcontroller with 32 kb of flash memory, 2 kb of SRAM, and 1 kb of EEPROM. The chip has a clock speed of 16 MHz. Some common uses for the Arduino Uno R3 board include controlling LEDs, reading sensors, driving motors, creating interactive displays, and communicating with other devices [22]. Program creation is also carried out using the Arduino software application, also known as the Integrated Development Environment (IDE). This microcontroller system is responsible for changing the sensor's reading data, displaying it on the LCD, and storing it on the SD card data logger. Fig. 1 shows the devices settings installed for data measuring test on the hybrid solar e-bike. Moreover, also represent of scheme the battery charging method.

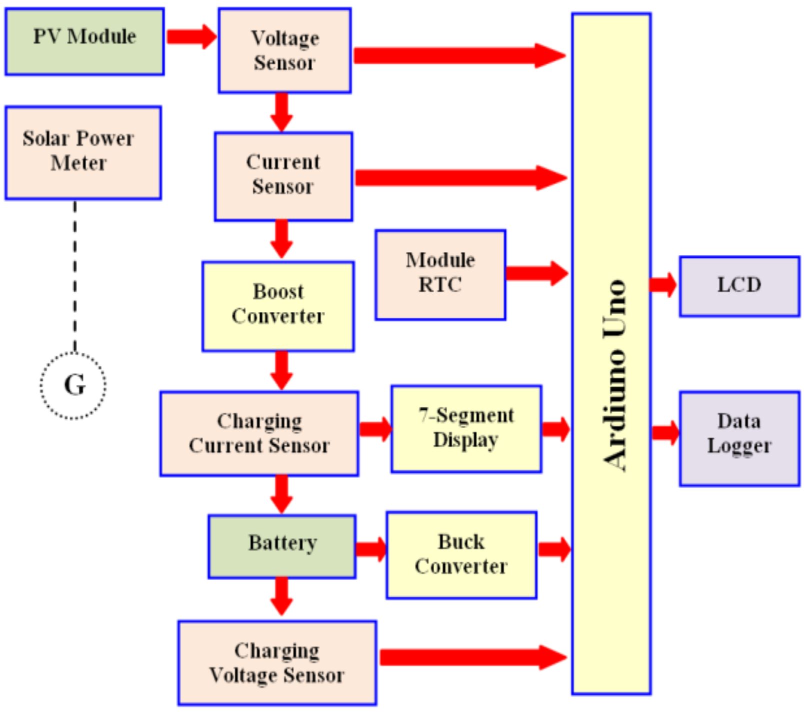


Fig. 1. Block diagram of the battery charging system for a solar e-bike

Fig. 2 depicts the solar panels and equipment installed on a solar-powered e-bike prototype (hybrid solar e-bike). The electric bicycle shown in Fig. 2 utilizes a BLDC 250W/36V motor. The battery is a VRLA (Valve Regulated Lead Acid) type with a capacity of 12V/12Ah, connected in series for a total voltage of 36V [23,24].

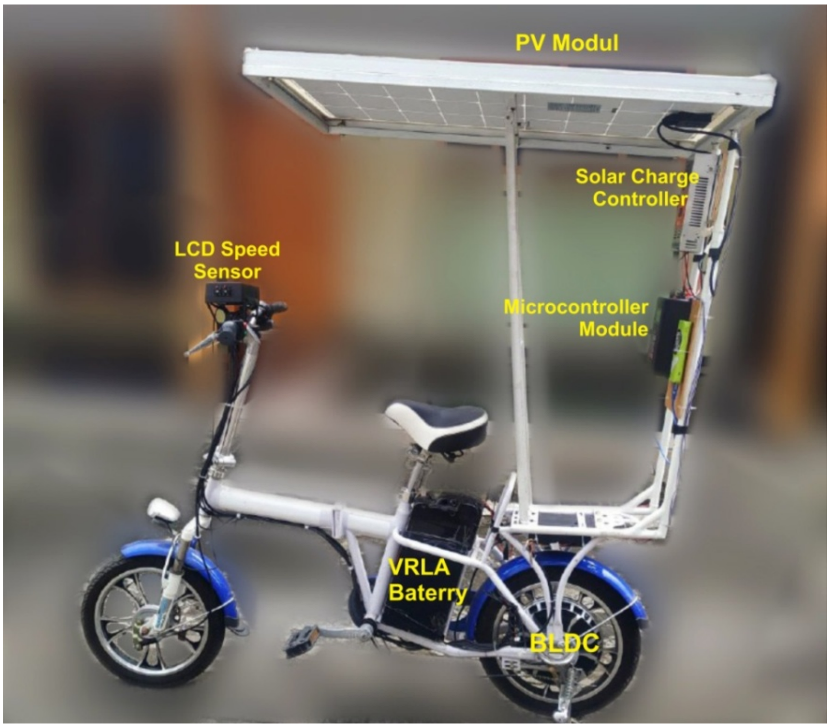
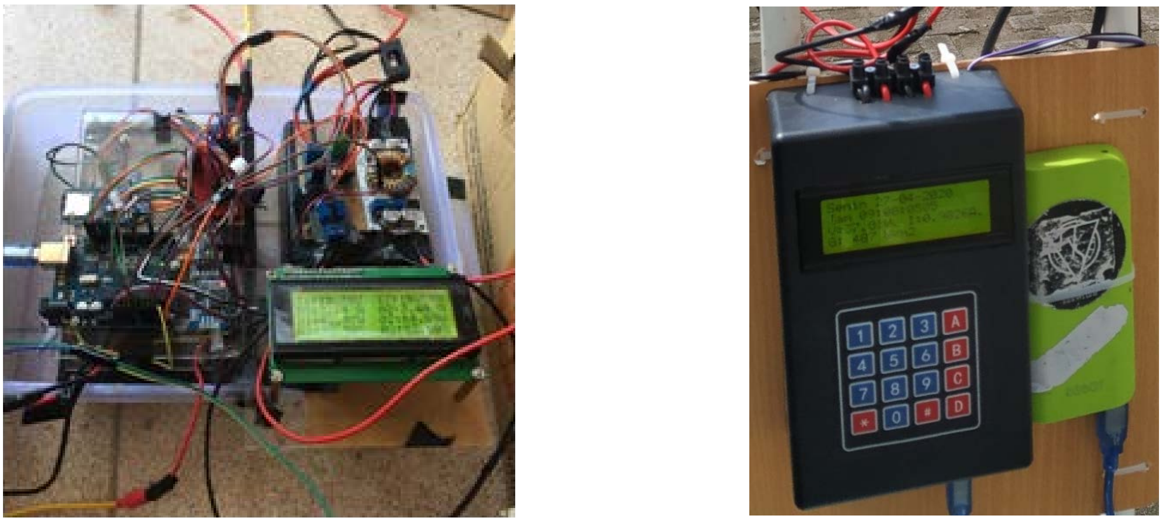


Fig. 2. The prototype of hybrid solar e-bike

The "Minimum Microcontroller System" is the instrument kit shown in Fig. 2. All installed components, including current sensor components, voltage sensors, RTC modules as timers, LCD as screen displays, and SD card data logger modules as data storage in the form of files, are used to create the minimum system.

Fig. 3 shows the assembly of these components into a single unit. As a result, this circuit functions as a system that reads and displays the voltage, current, and power produced by solar cells (PV modules).



a *b*

Fig. 3. The minimum microcontroller system: *a*–electronic device board; *b*–instrumentation kits position

Measurement of current and voltage from the PV module starts from 06:00 am until 05:00 pm (at local time). The hybrid solar e-bike is placed under the sun's rays, so that the electric bicycle battery can be charged (Fig. 5). The current and voltage of the PV Module will be read by the sensor and measured by the microcontroller in real-time. The data every second will be displayed on the LCD screen, and stored on the SD Card, simultaneously.

The performance of a PV Module on an electric bicycle is influenced by many factors including the type of panel, area, solar radiation, ambient temperature, weather, type of battery charger device and other factors [17]. The basic equations, which can be used as data analysis in this study are as follows,

– Maximum power of PV Module (Eq. 1):

$$P_{max} = V_{max} \times I_{max}, \tag{1}$$

Where; P_{max}, V_{max}, I_{max} are the maximum power, voltage and current, respectively (listed in the table 1).

– The Eficiency charging of PV module.

Furthermore, the results of field testing are used to determine the efficiency of the performance of the PV Module when charging the battery. The PV Module charging efficiency in this regard is the normalized power output efficiency, i.e., the ratio of the measured output power to the maximum power of the PV module. Thus, the normalized power output efficiency, η_{PV} in % is calculated using equation (2).

$$\eta_{PV} = \frac{P_{act}}{P_{max}} \times 100 \quad (2)$$

Where, P_{act} is the real output power of the PV module (Watt), which is obtained from the measurement.

– Battery charging time.

According to Shashank [18], the time required to charge an electric bicycle battery under ideal conditions can be calculated by the following equation (3).

$$T = \frac{V \times Ah}{P_{act}} \quad (3)$$

Where; T is charging time (hours), V is baterry voltage (Volt), and Ah is battery capacity in ampere hour.

3 RESULTS AND DISCUSSIONS

The data displayed in this study is the result of the average hourly measurement, as shown in Table 2 and Table 3. As a result of the data tabulation, a graph can be produced as shown in Fig. 4 to Fig. 8. Table 2 is the result of measuring data on solar radiation, voltage and output current from the PV module. Tests conducted from 06:00 am until 05:00 pm are the hourly average results.

Tabel 2. The PV output power and solar radiation

Local Time (hh:mm)	Solar Radiation (W/m^2)	Output Voltage (V)	Output Current (A)	PV Power (W)
06:00	59	7.01	0.16	1.12
07:00	179	7.22	0.47	3.39
08:00	582	7.48	2.70	20.20
09:00	699	9.32	3.11	28.99
10:00	779	12.72	3.22	40.96
11:00	938	15.67	3.29	51.55
12:00	974	16.38	3.32	54.38
13:00	1008	17.49	3.37	58.94
14:00	879	15.68	2.96	46.41
15:00	512	7.29	2.69	19.61
16:00	234	7.20	2.08	14.98
17:00	65	7.06	0.29	2.05

Table 2 above presents data collected using a solar power meter to measure solar radiation at hourly intervals over an 11-hour period. The voltage and current displayed are data from the PV module charging process on the battery. Based on equation 1, the charging power can be calculated and displayed.

A comparison of battery voltage characteristics without charging and with charging from the PV module is conducted to determine the effect of installing the PV module. Table 3 shows the comparison of battery voltage before and after the PV module is installed.

Tabel 3. Comparison of battery voltage on e-bike

	Without PV	With PV	
Duration (minute)	Baterry Voltage (Volt)	Baterry Voltage (Volt)	Solar Radiation (W/m^2)
0	36.40	36.40	854
5	36.20	36.40	863
10	36.10	36.30	873
15	36.00	36.10	965

	Without PV	With PV	
Duration (minute)	Baterry Voltage (Volt)	Baterry Voltage (Volt)	Solar Radiation (W/m^2)
20	35.80	36.00	960
25	35.70	35.90	975
30	35.50	35.80	990
35	35.40	35.70	1029
40	35.30	35.70	1042
45	35.20	35.60	1053
50	35.10	35.60	1023
55	35.10	35.50	1008
60	34.90	35.40	1057

The battery output voltage indicates the power consumption of the electric bicycle battery. This test was carried out by running an electric bicycle for one hour. So that the battery voltage drop can be measured every 5 minutes. Similarly, when a 100 Wp PV module is mounted on an electric bicycle. Fig. 4 shows the effect of solar radiation on the output voltage of the PV module.

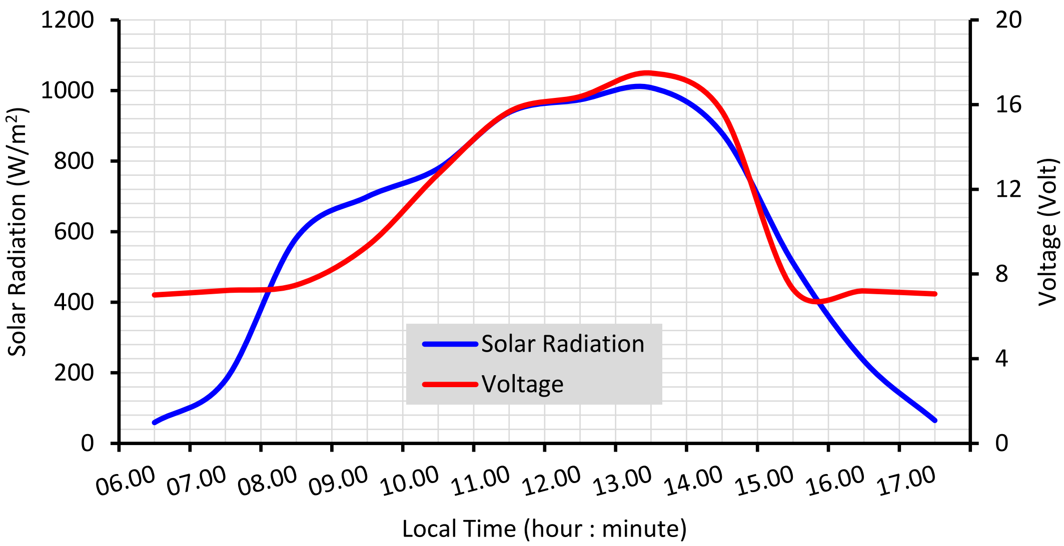


Fig. 4. The graph of solar radiation and output voltage of PV module at local time

A Fig. 4 shows that from 06:00 am until 01.00 pm, the level of solar radiation tends to increase because the weather conditions are clear day and the solar incidence angle is getting smaller. G = 1008 W/m^2 is the maximum solar radiation at 1:00 p.m. When the weather is sunny and the sun is perpendicular to the solar panel's surface. Furthermore, there is a decrease in solar radiation until the test is complete (05:00 pm). Meanwhile, the PV Module's output voltage pattern, from 08:00 am until 01:00 pm, tends to increase drastically along with increasing of solar radiation. So that at 01:00 pm is the peak voltage generated by 17.49 volts. The test results show that solar radiation affects the output voltage of the PV module. In addition, it can be shown that the effective use of hybrid solar e-bikes occurs at 09:00 am - 03:00 pm.

The same pattern is also shown in Fig. 5, the output current tends to increase following the increase in solar radiation.

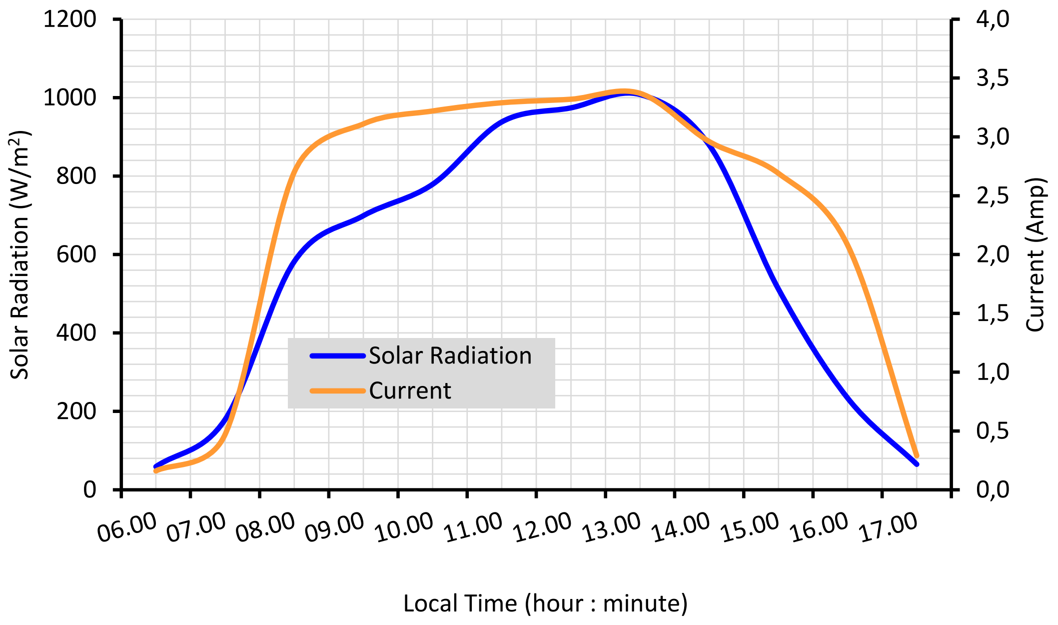


Fig. 5. The graph of solar radiation and output current of PV module at local time

The graph in Fig. 5 above shows that the peak of PV module output current occurs at 01:00 pm by 3.37 A. As described above, the output current pattern is similar to the PV module output voltage. However, this current pattern tends to be sensitive to sun rays. A Fig. 5 shows that output current tends to follow the pattern of solar radiation.

Based on the graphs and tables above, the peak of solar radiation is 1008 Watt/m^2 at 01:00 pm, and the lowest is 59 Watt/m^2 at 06:00 am. Meanwhile, the optimum solar radiation is 779 W/m^2, 938 W/m^2, 974 W/m^2, 1008 W/m^2, and 879 W/m^2 between 10:00 am and 02:00 pm. So that under these conditions, solar panels can optimally utilize solar radiation to charge electric bicycle batteries. Therefore, solar radiation has an impact on the current and voltage values generated by solar panels. When solar radiation is less than 779 W/m^2, PV module performance is low. A Fig. 6 shows the relationship between solar radiation and solar panel output power at local time.

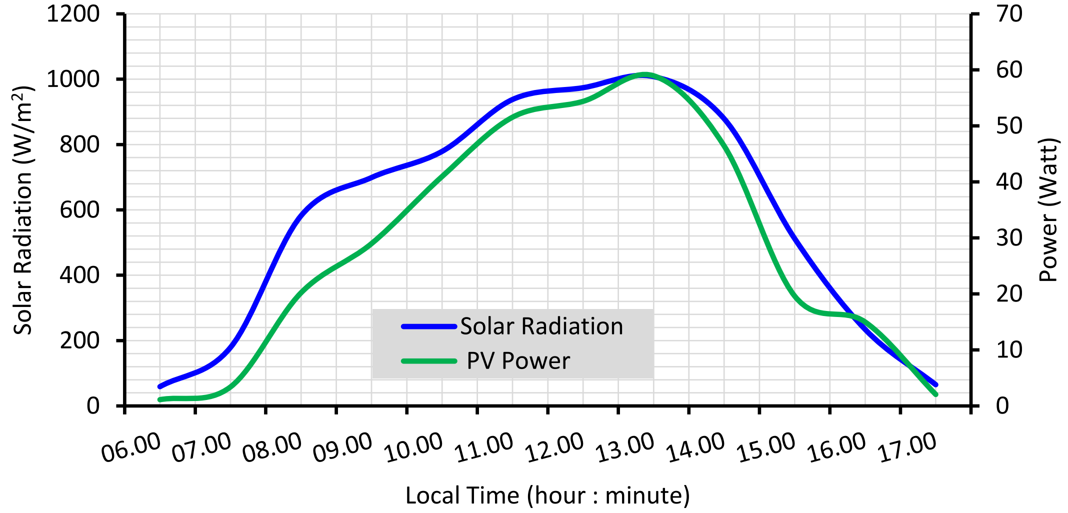


Fig. 6. The graph of solar radiation and output power of PV module at local time

The PV power is the result of the voltage value multiplied by the output current value of the solar panel (Equation 1). A Fig. 6 shows that the charging power generated by the solar panels is relatively low between 6:00 and 7:00 am, ranging from 1.89 to 3.21 Watts.

Furthermore, the charging power produced by the PV Module increased significantly between 07.00 and 11:00 a.m. It is due to an increase in solar radiation, which is followed by an increase in the PV Module's voltage and current. The graph shows peak charging power at 01:00 p.m. by 58.94 Watts. The charging power continues to decrease from 1:00 to 5:00 pm in tests. It's because the sun is moving continuously west and towards sunset at that moment, hence reducing the amount of solar radiation. A Fig. 7 shows the relationship between solar radiation with the current, voltage, and charging efficiency of a PV module.

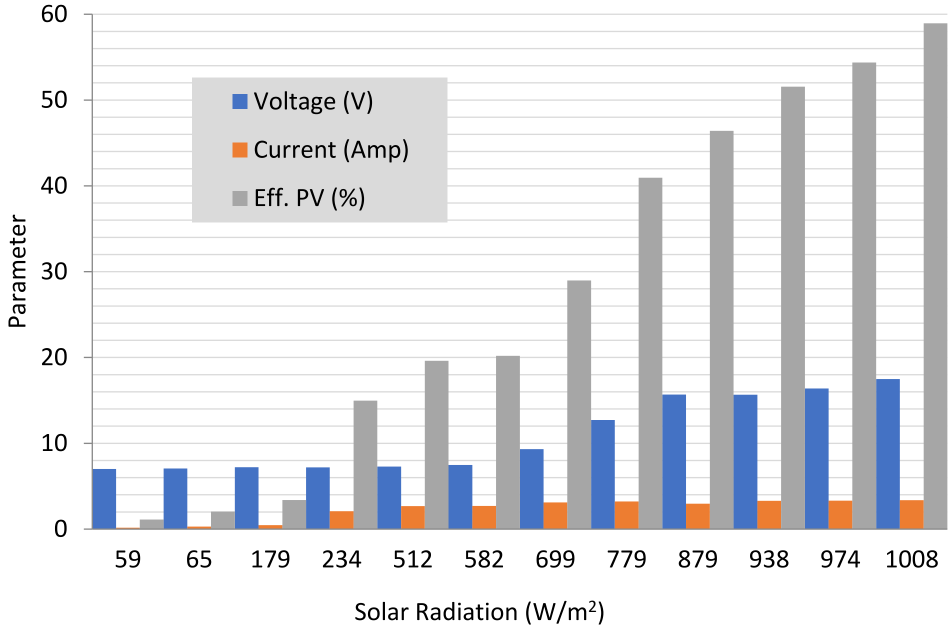


Fig. 7. Relationship solar radiation with current, voltage and charging efficiency of PV Module

Testing the output parameters (voltage and current) of a 100 Wp photovoltaic (PV) module shows that the output power of the PV module increases with increasing solar radiation. However, at peak solar radiation, the battery charging power is only 58.94 W. This indicates that the battery charging efficiency of a 100 Wp solar panel is 58.94%. The energy loss that occurs is about 41.06%. Several factors can cause a decrease in the efficiency of this PV module, as described at the beginning of this paper. In addition, the battery type, temperature and charger controller device need to be considered to be able to increase the power outputs [25].

Furthermore, the effect of adding PV panels to an electric bicycle is presented in Fig. 8 below. A Fig. 8 presents a comparison graph of the e-bike battery voltage drop between without charging and with charging for a period of 60 minutes. As can be seen from the graph, there is a significant difference in voltage drop between the two conditions. In addition, Fig. 8 can be used to demonstrate the impact of PV modules on the charging of electric bicycles.

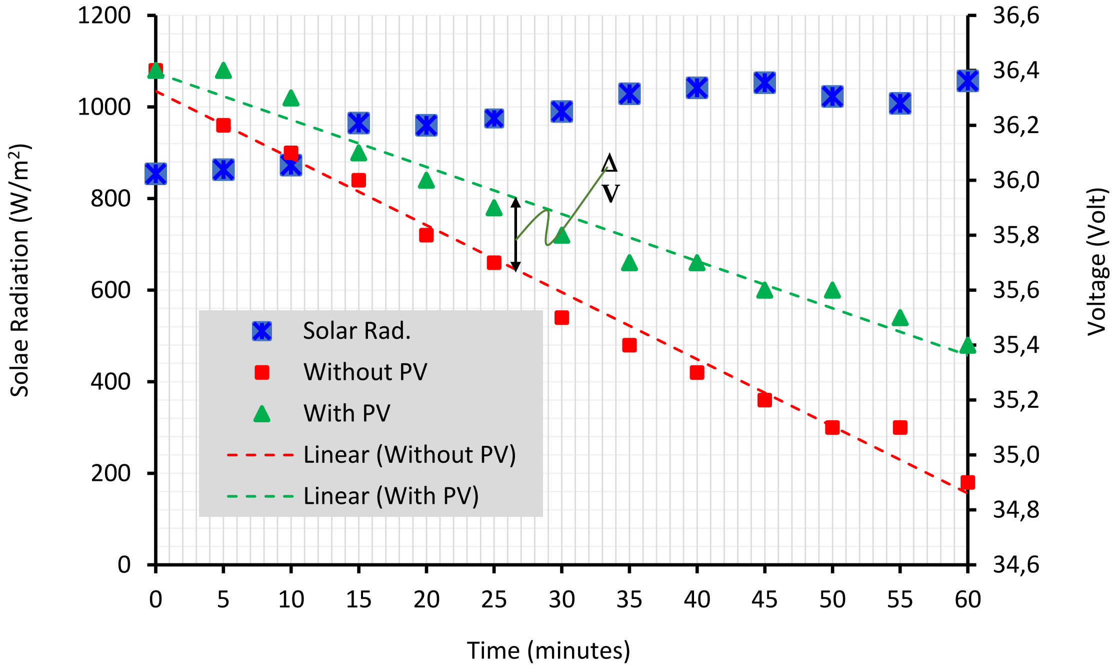


Fig. 8. The relationship of solar radiation to voltage deviation for one hour

The higher the slope of the line in Fig. 8, the better, indicating that the PV module can supply the energy consumed by the electric bicycle. It will need to be developed in the future to achieve this. The average difference in voltage drop between charging and without charging is 0.28 V over a period of 60 minutes. This difference is significant when considering the working range of the battery, which is defined as the voltage drop from its initial condition (36 V) to the point at which it can no longer be used (32 V). In this case, the working range of the battery is 4 V.

Meanwhile, the additional power percentage stored in the battery due to the mounting of the PV module be calculated by:

$$\%\Delta P = \frac{\Delta V_{(without\_PV)} - \Delta V_{(with\_PV)}}{\Delta V_{(without\_PV)}}, \quad (4)$$

$$\%\Delta P = \frac{\left[(36.40-34.90)-(36.40-35.40)\right]}{36.40-34.90},$$

$$\%\Delta P = 33.33\ \%.$$

Where; $\%\Delta P$ is the addditional power percentage, ΔV is the difference between the initial and final battery voltages. According to the results of this study, while 100 Wp-PV modules are installed on electric bicycles for one-hour testing at average solar radiation of 976.31 W/m^2, the battery stored power can be increased by 33.33 %.

4 CONCLUSIONS

Battery charging efficiency using a 100 Wp monocrystalline PV module can reach 58.94%. The PV module can increase the stored power in the battery by 33.33%, under an average solar radiation of 976.31 W/m^2. The use of PV modules can significantly expand the working range of batteries. By providing a continuous charging source, PV modules can help maintain battery voltage and reduce the rate of voltage drop. It's can lead to significant improvements in battery operating time and performance. Therefore, the hybrid solar e-bike concept has great potential for future development.

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