Pedal Energy – Photovoltaic (PV) Integration as an Environmentally Friendly Alternative Energy

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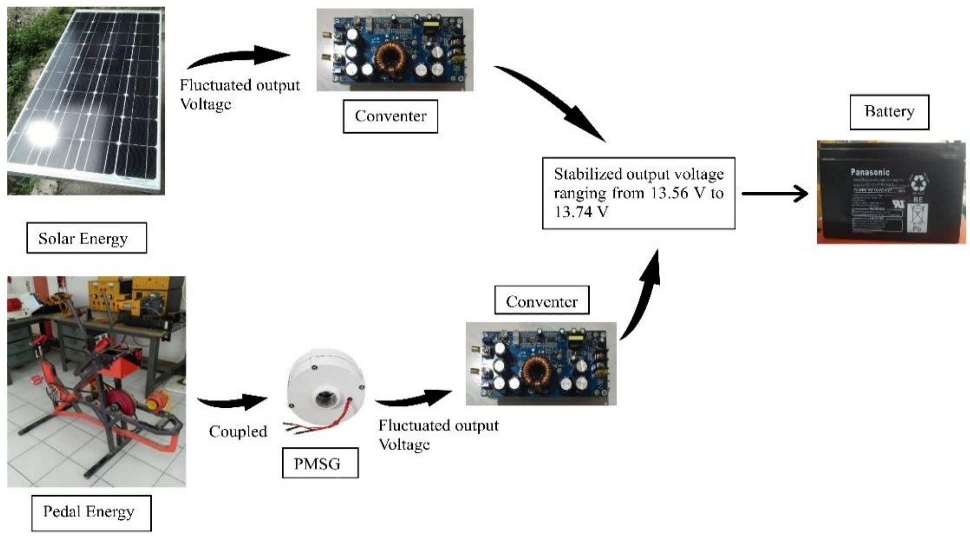

ABSTRACT: Photovoltaic is Renewable Energy (RE) sourced from the sun. Apart from PV, pedal power generation is also a form of RE that can be used as alternative electrical energy because humans generate this energy in the pedalling mechanism. Furthermore, single use of renewable energy has limited continuity in the load supply because it relies heavily on sources that are only available sometimes. As proposed in this research, integrating several renewable energies, such as PV and pedal energy, could be a solution. This pedal generator uses a static bicycle to produce electrical energy by utilizing the Permanent Magnet Synchronous Generator (PMSG) to convert pedal energy into electrical energy. The electrical energy produced by PV and static bicycle is stored in a battery. A constant DC voltage interfacing in an efficient battery energy storage system is needed. Buck DC-DC converters maintain constant voltage from PV and static bicycles. The results show that the converters can stabilize a voltage of 65-32 volts from the generator permanent magnet and 17.19-18.3 volts from the photovoltaic to a constant voltage of 13.8 Volts. In addition, the proposed system utilized INA219 sensors as a measuring system. The maximum sensor inaccuracy of voltage and current is 2.96% and 0.81%, respectively.

Keywords: current; integrated; pedal; photovoltaic; voltage.

تكامل طاقة الدواسات والخلايا الكهروضوئية كطاقة بديلة صديقة للبيئة

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الملخص: الملخص: الطاقة الكهروضوئية هي طاقة متجددة (RE) مصدرها الشمس. بالإضافة إلى الطاقة الكهروضوئية، يعد توليد الطاقة بواسطة الدواسات شكلًا آخر من أشكال الطاقة المتجددة التي يمكن استخدامها كطاقة كهربائية بديلة، حيث يتم إنتاج هذه الطاقة من خلال آلية التدوير. علاوة على ذلك، فإن استخدام مصدر واحد من الطاقة المتجددة يعاني من محدودية الاستمرارية في تزويد الأحمال بالطاقة بسبب اعتماده الكبير على مصادر تكون متوفرة أحيانًا فقط. وكما اقترح في هذا البحث، فإن دمج عدة مصادر للطاقة المتجددة، مثل الطاقة الكهروضوئية والطاقة الناتجة عن التدوير، يمكن أن يكون حلاً لهذه المشكلة. يستخدم مولد الدواسات في هذا البحث دراجة ثابتة لإنتاج الطاقة الكهربائية، مستفيدًا من مولد مغناطيسي متزامن دائم (PMSG) لتحويل طاقة التدوير إلى طاقة كهربائية. يتم تخزين الطاقة الكهربائية المنتجة من الألواح الكهروضوئية والدراجة الثابتة في بطارية. هناك حاجة إلى نظام تخزين طاقة بطارية يعتمد على جهد تيار مستمر ثابت وبكفاءة عالية. يحافظ محول التيار المستمر-المستمر (Buck DC-DC) على الجهد الثابت من الطاقة الكهروضوئية والدراجة الثابتة. أظهرت النتائج أن المحولات يمكنها تثبيت جهد يتراوح بين 65-32 فولت من المولد المغناطيسي الدائم و17.19-18.3 فولت من الطاقة الكهروضوئية إلى جهد ثابت يبلغ 13.8 فولت. بالإضافة إلى ذلك، استخدم النظام المقترح مستشعرات INA219 كنظام قياس. وقد بلغ الحد الأقصى لعدم دقة المستشعر في قياس الجهد والتيار 2.96٪ و0.81٪ على التوالي.

الكلمات المفتاحية: التيار؛ مدمج؛ الدواسة؛ الكهروضوئية؛ الجهد.

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1. INTRODUCTION

Currently, the world's primary energy source comes from fossil fuels, especially in rural development, where availability is increasingly scarce (Erdiwansyah et al., 2019). One of the uses of energy can be used to generate electricity (Park, 2017). The increase in electrical energy needs is directly proportional to the increase in human needs, resulting in the development of renewable energy as alternative energy continues to be developed and become important. The use of alternative energy not only addresses increasing human needs but also saves electricity costs (Ramaprabha et al., 2013). Renewable energy is increasingly considered an alternative to depleting fossil energy reserves and attracts attention (Milbrandt et al., 2014; Nematollahi et al., 2016).

However, the shortage of renewable energy, such as solar and wind energy, is generally unstable and intermittent. The instability and intermittent nature of individual renewable energy cause insufficient supply to the load continuously (Guo et al., 2018)(Albadi, 2019). In addition, the efficiency of a single renewable energy system is low compared with conventional energy.

Integrating various renewable energy sources is an excellent solution to overcome the instability and intermittency of single renewable energy. The integration is also known as hybrid renewable energy (RES) (Marchenko & Solomin, 2017). Moreover, RES is also used to increase the efficiency of a single renewable energy system. Several studies have been carried out regarding hybrid renewable energy, which can increase the efficiency of this single renewable energy (Balleh et al., 2016; Marchenko & Solomin, 2017; Mustofa et al., 2016). The combination of renewable energy hybrid systems depends on the need and availability of sources.

Several studies related to a hybrid of RES have been carried out. Solar and wind hybrids are very reliable hybrid systems due to complementary natural sources (Sinha & Chandel, 2015) (Kajela & Manshahia, 2017)(Balleh et al., 2016). Solar intensity is excellent when wind speed is low and, conversely, in seasons with poor wind resources when solar intensity is high (Hiendro et al., 2013). Solar and biomass are another renewable energy hybrid system (Balleh et al., 2016). The combination of renewable energy hybrid systems depends on the need and availability of sources.

Another form of renewable energy is human power, which is effort or energy produced by the human body. Human power can be a great source of clean energy for the environment as it does not require any fuel and thus does not cause any pollution to the environment. It is eco-friendly and can also be a great way to improve physical health and well-being. Human power can be used when there is no solar, wind, or water to generate power. Implementing human power has been widely applied in various aspects of human life, such as flashlight shaking, gym equipment, and hand-crank radios (Onyinye et al., 2021). These have also been discussed (Varsh & Healy, 2012).

One form of human power is pedal power, which includes bicycle power. This research will design a static bicycle integrated with a photovoltaic connected to storage and a battery. This research also pioneered rooftop PV combined with static bicycles as environmentally friendly alternative energy. The following section will discuss in more detail the renewable energy that will be integrated.

2. ALTERNATIVE ENERGIES

As previously mentioned, renewable energy is a popular alternative energy whose performance is increased through a hybrid system. Meanwhile, most renewable energy is a nature-dependent source that is not always available; human energy is available in large amounts. In this section, photovoltaic and pedal power generation will be briefly described.

2.1 Photovoltaic

Solar energy is one of the best renewable energies, and it has become a subject of interest in research studies. Photovoltaics (PV) is an increasingly popular solar energy utilization technology due to its low-carbon technology and reduced costs in installation investments.

Currently, PV is widely used because of some advantages: less maintenance, environmentally friendly, and no pollution or noise (Ramaprabha & Chitra, 2015). In addition, once the installation costs are covered, it is cheap and can produce energy throughout its lifetime for free. There are no moving parts in a solar cell; thus, it is impossible to damage it.

Nevertheless, PV depends on solar radiation that varies greatly, requires large amounts of land, and is low-efficient. The highest efficiency for silicon crystalline is about 25% (Saga, 2010).

Among the currently available renewable energies, PV and wind power show remarkable installation capacities (REN21, 2018). However, PV and wind power depend highly on environmental conditions (Hiendro et al., 2013).

2.1 Pedal power generation using a static bicycle

One type of human power is pedal power, which transfers energy from a human source using a foot pedal and a crank system (S. Sivasubramanian, M. Manikandan & Sabariraj, 2018). Pedal energy can pump the water from the well, irrigate the fields, and operate the washing machine.

Bicycles are one of the tools that implement energy pedals used as transportation facilities by people in villages (Megalingam et al., 2012). Aside from being a mode of transportation, cycling a bicycle is also a popular recreational activity. However, cycling a bicycle outdoors can cause injury (Silberman, 2013). Despite the injury, the density of motorized vehicles on the roads produces pollution, which exposes cyclists. As a result, indoor cycling using a static bicycle is an option. As a part of injuries, lack of free time has caused static bicycles to become famous.

Moreover, the static bicycle is not a new activity; currently, it is only used for health. The energy used to pedal the bicycle is wasted. The bicycle's rotation can be converted into electrical energy, so the energy used to pedal can be converted into electrical energy.

Converting rotation from pedal energy into electrical energy requires a generator. Electric power can be generated from pedal energy by implementing an alternator (Onyinye et al., 2021). As well as alternators, PMSG is a popular generator used in generating renewable energy due to brushless arrangement, self-started generator, simple operation, high efficiency, suitable for variable and constant speed prime mover (Iacchetti et al., 2015)(B Murali Krishna V, V Sandeep, 2021), also suitable for low speed, wide range variable speed, such as wind energy application (Sahin et al., 2017). The PMSG output is connected to a rectifier, of which a full bridge diode rectifier is an option to reduce costs and is followed by a DC-DC converter (Iacchetti et al., 2015). The output from the rectifier is stored in the battery for continuity to the load.

Three-phase PMSG attached to a diode bridge rectifier is connected to a constant DC voltage, and the steady state equivalent circuit can be seen in Figure 1.

The internal sinusoidal EMFs, Ek, represent the PMSG that can be expressed as follows:

$$e_k(t) = e_{pk}\sin\left(\omega t - (k-1)\frac{2}{3}\pi\right. \qquad (1)$$

The peak value of the e_{pk} formula is:

$$e_{pk} = \omega k_{\omega} N \varphi \qquad (2)$$

where kw is the winding factor for the fundamental harmonic, N is the number of turns in series per phase, ☐ the pole flux (peak value), and the stator angular frequency is directly proportional to the rotor speed.

3. METHODOLOGY

The methodology used in this work focused on developing pedal energy integrated with photovoltaics for harvesting electrical energy. The pedal energy used in this work is the static bicycle, in which the rotation is connected to a permanent magnet synchronous generator. The output of PMSG is connected to a buck DC-DC converter and the charging system, consisting of sensors, relays, and displays.

The design of static bicycle refers to (Dadang Hermanto et al., 2023), as shown in Figure 2. This design uses the car's alternator to convert the rotation produced by the pedal into electrical energy. The proposed static bicycle utilizes the same design by replacing the car's alternator with a permanent magnet synchronous generator. The specifications of the static bicycle by Dadang Hermanto et al. can be seen in Table 1.

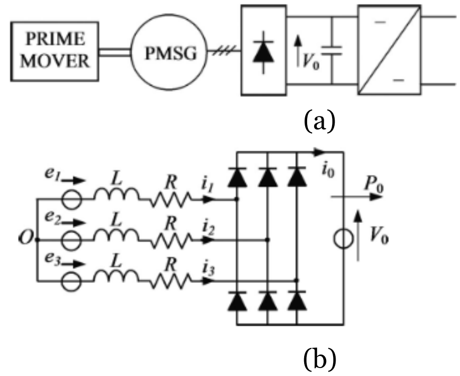

Figure 1. **(a)** Three-phase PMSG attached to a diode bridge rectifier connected to a constant DC voltage; and **(b)** the steady state equivalent of PMSG

Table 1. Specification of the static bicycle using the car's alternator

Parameter	Monocrystalline 80 Wp
Weight	45 kg
Length	125 cm
Width	80 cm
Height	150 cm
Output voltage	13 – 14 Volt

Figure 2. The static bicycle with a car alternator.

Figure 3. Monocrystalline PV 80 Wp.

Table 2. Specification of PV module

Type	Monocrystalline 80 Wp
Series Number	20-997
Irradiance	1000 W/m²
Dimension	1210*808*28 mm
P_M	80 W
V_{mp}	17.6 V
I_{mp}	4.55 A
V_{OC}	21.8 V
I_{SC}	5.23 A

Figure 4. Layout of both energy sources.

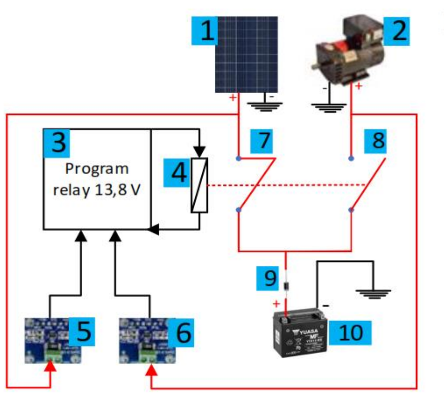

Figure 5. Hardware set up of the charging system.

Furthermore, the photovoltaic (PV) module type is monocrystalline with a capacity of 80 Wp, figure 3. The detailed specifications can be seen in Table 2.

The intermittency of integrated renewable energy sources fluctuates the energy output. Thus, a buck DC-DC converter is needed to maintain constant voltage output. The voltage output is 13.8 Volt. Selecting converter specifications is based on the amount of voltage to be input, which depends on the PV and PMSG voltage output. PV and the static bicycle are placed outside and indoors, respectively, as shown in Figure 4.

Before integrating the two renewable energy sources, the output voltage of each renewable energy source with and without a charging system was tested. As previously mentioned, the charging system consisted of sensors, relays, displays, and contacts. Sensors are set at 13.8 Volt to activate the relay. In addition, considering the sensor reading error (Wen et al., 2015), sensor accuracy is validated before use.

In addition, after integration, the two energy sources are set not to charge the battery simultaneously. Once the PV output voltage reaches 13.8 V, the relay connecting the PV to the battery is on, and the PMSG relay is off. The charging current flows only from the PV to the battery. Conversely, PMSG charges the battery when the output voltage is 13.8 Volt and PV is off. The not simultaneously charging battery mitigates the fluctuation voltage applied to the battery and maintains battery health. Figure 5 illustrates the hardware setup equipped with the charging system, and Figure 6 shows the working principle of the proposed system.

1) Photovoltaic (PV) 80 Wp
2) PMSG
3) Relay set at 13.8 V
4) Coil magnet
5) INA219 sensor for output voltage and current of PV
6) INA219 sensor for output voltage and current of PMSG
7) Normally closed (NC)
8) Normally open (NO)
9) Diode
10) Battery 12 Volt, 7.2 Ah, lead acid.

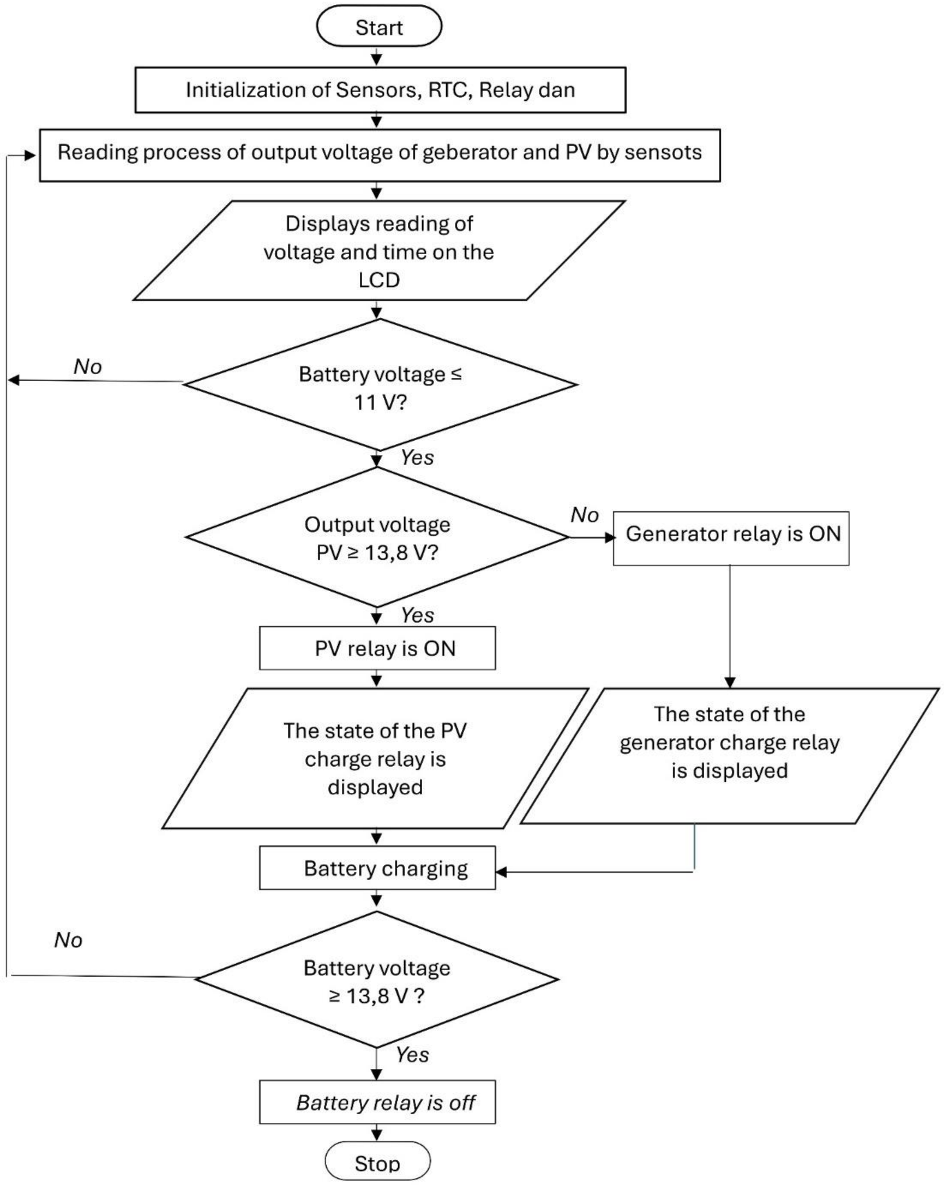

Figure 6. Flowchart of the principal workings of the proposed system.

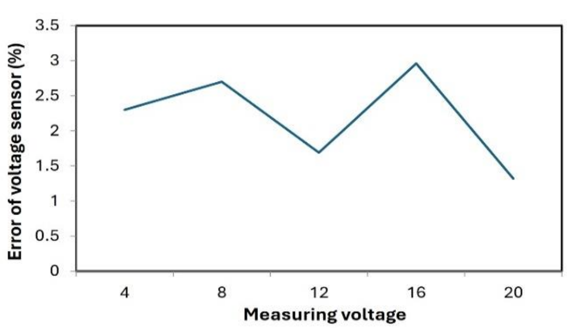

Figure 7. Validation of voltage sensor accuracy.

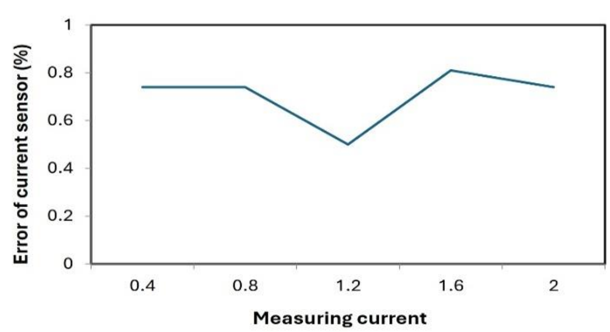

Figure 8. Validation of voltage sensor accuracy.

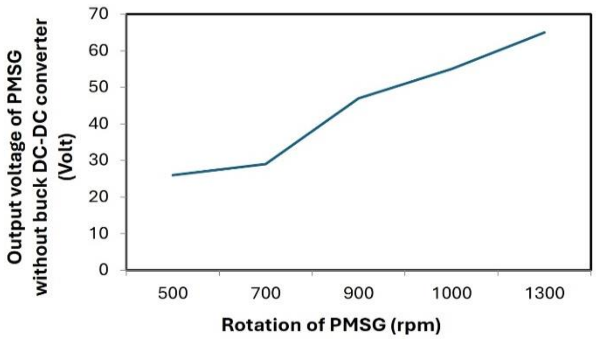

Figure 9. Output voltage of PMSG without converter vs rotation.

4. RESULT AND DISCUSSION

4.1 Validation Error of Sensors and Controller System

In determining the sensor performance, the validation of sensor accuracy is done. The validation shows that voltage errors range between 1.32 % and 2.96% for measuring voltage from 4 Volt to 20 Volt, as shown in Figure 7. The error of the current sensor is around 0.50 % - 0.81 %. The measurement error for the current sensor can be seen in Figure 8. The error measurement aligns with (Indrasari et al., 2019) research about a hybrid solar panel prototype with a PV-TEG module. The research utilizes the INA 219 sensor for measuring voltage and current. The maximum voltage and current error are 2.48% and 2.52%, respectively.

Figure 6 shows the overall principal working of the proposed system. The charging process starts when the battery sensor senses a voltage of less than 11 Volt and stops when the voltage is at 13.8 Volt, indicated by the indicator light turning on. In producing the pedal energy source, PMSG is connected to a buck DC-DC converter, of which the sensor reads the output voltage. PV is connected to a buck DC-DC converter and sensor, like pedal energy-producing energy. In the charging state, the reading of PV and PMSG sensors is input to the microcontroller, and the relay is activated. Relay flow the energy from the sources in which the voltage reaches 13.8 Volt to the battery. While the reading sensor of PV is 13.8 Volt, the energy will transfer from PV to the battery, and energy from pedal energy is off, and vice versa. The charging process stops once the battery sensor reads 13.8 Volt and inactivates the relay connected to the battery.

In this work, the charging battery was done for 30 minutes. The result shows that after charging the battery for the period, the voltage of the battery increased from 10.45 V to 11.94 V, with current charging decreasing from 826.6 mA to 195.4 mA.

4.2 The Output of Static Bicycle, PMSG, and, PV

PMSG is a generator that converts pedal energy to electrical energy used in the proposed system. To measure the voltage output of the PMSG, the bicycle is pedalled until the rotation coupled to the generator reaches 300, 500, 700, 900, 100, and 1300 rpm.

Measurement of PMSG output voltage to the rotation shows that rotational fluctuations change the voltage produced by the PMSG. The output voltage is directly proportional to the rotation, as Figure 9 shows the relationship related to the equation (2). Using a buck converter decreases and keeps the output voltage from 13.56 – 13.67 despite the setting of 13.8V, as shown in Figure 10. Reading deviation from the setting is caused by an error in the sensor reading.

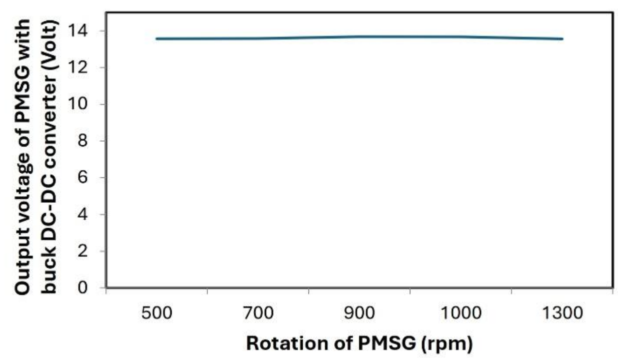

Figure 10. PMSG Output voltage with converter vs rotation.

The output voltage of PV depends on the solar intensity. The output voltages without the buck converter range from 17.37 – 18.3 V. These voltages are reduced and kept by the buck converter to around 13.7 Volt. The difference is approximately 0.1 V or 0.7% deviation from the setting value of 13.8 V. It can be seen in Table 4.

Table 4. Output voltage of PV

Solar intensity (W/m2)	Output voltage PV (Volt)	Output PV with buck converter (Volt)
503.7	17.44	13.71
821.8	17.52	13.7
1243.5	18.3	13.71
1237.5	18.11	13.71
1046.4	18.17	13.71
1158.2	17.91	13.7
846.8	17.37	13.7

4.3 The Output of the Proposed System

The energy from PV and pedal sources is stored in the battery. Thus, energy can be used even though the two renewable energy sources cannot produce energy. The charging process was described in the previous section. The system charges the battery changeably. Once PV charges the battery, PMSG is off, and vice versa. It can be seen in Figures 11 and 12. Measurements are carried out at 3-minute intervals between 10.07 am and 3.08 pm until the battery reaches a voltage of 13.8 volts.

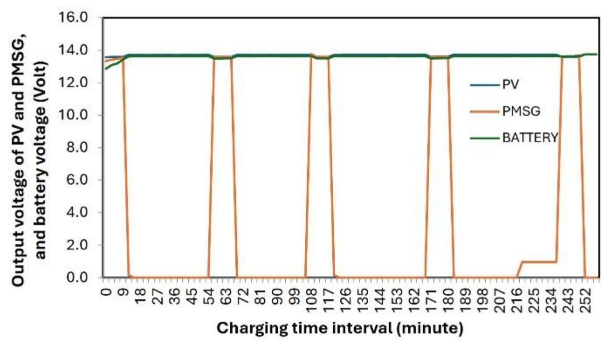

Figure. 11. Output voltage of PV and PMSG, as well as the battery voltage.

Figure 11 shows that PV produces a voltage relative constant ranging from 13.56 Volt to 13.74 Volt. That is influenced by measurements done when the solar source is available. On the other hand, the voltage produced by PMSG is not always available. Energy is not produced when the bicycle is not pedaled, so voltage is not produced.

Furthermore, Figure 12 shows that the battery charging current decreases to almost zero at the end of the measurement time. The decrease in the charging current is in line with the increase in battery voltage. At the beginning of the measurement, at 0 - 9 minutes, the charging current decreased significantly. The output voltage of both energy sources differs greatly from the battery voltage, which causes a significant decrease in charging current. As soon as the output voltage from the source is almost the same as the battery voltage, the charging current will be almost zero. It is shown in Figure 12.

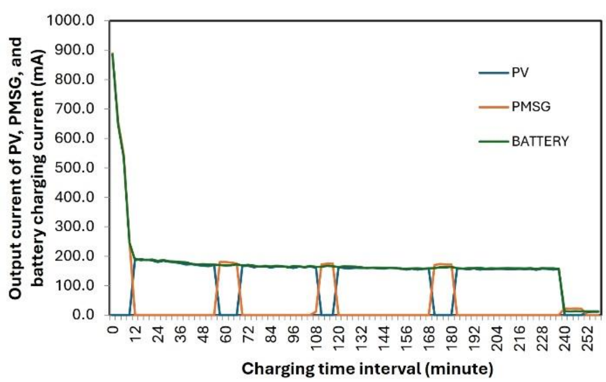

Figure. 12. Output current of PV and PMSG and the battery charging current.

5. CONCLUSION

This paper has carried out the integration of PV and pedal energy from a static bicycle. The results show that the two renewable energy sources can be integrated and become an alternative energy source to produce electrical energy. Intermittency from both sources can be further stabilized using a converter at around 13.8 Volt. A sharp decrease in average battery charging current occurs in minutes 0 - 9, caused by a significant increase in average voltage compared to other minutes. The average increase in battery charging current per minute, minutes 0 - 9, ranges from 0.1 - 0.25 mA, while the other minutes range from 0.0 - 0.04 mA. In addition, the trend.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding this article.

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