The Development of Brushless DC (BLDC) Motor as a Boost Converter on Solar Panel System

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Abstract. Electrical energy from solar panels can be used to supply electrical loads directly or stored in batteries. However, the produced electrical power is highly dependent on the absorption of solar energy. The sun's movement also causes variations in the absorption of solar energy by solar panels. This study was aimed to increase the output voltage of the solar panel by applying a Brushless Direct Current (BLDC) motor as a boost converter that could overcome the voltage drop due to variations in the absorption of sunlight intensity. The research method was carried out by developing a series of BLDC motors as an electrodynamic boost converter. Thus, the induced voltage generated by the stator coil when the rotor rotated could be used to increase the output voltage of the solar panel. The results showed that the BLDC motor was able to produce an induced voltage to increase the output voltage of the solar panel. That could continuously supply the electrical load and speed up storing electrical energy into the battery. This research can be used as an alternative source of electrical energy from the potential of solar energy as new renewable energy.

Keywords: boost converter, solar Panel, BLDC motor.

1 Introduction

Nowadays, solar panels are increasing as an alternative energy source by converting renewable energy from sunlight energy into electrical energy that can be used to meet electrical energy needs either directly or temporarily stored in batteries. The production price of solar panels is relatively affordable; thus, people are starting to switch to solar panels as an alternative environmentally-friendly electricity source.

The electrical energy produced by solar panels is highly dependent on the amount of direct sunlight energy absorption. Changes in the sun's position will also cause variations in the absorption of solar energy by solar panels. Optimal absorption of solar energy occurs when the sun's position is at its peak and perpendicular to the solar panel to produce maximum electrical energy. However, in general, the installation of solar panels is placed at a fixed angle so that the electrical energy produced is not maximum for each position of the sun.

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Several research results have carried out efforts to optimize the electrical energy produced by solar panels due to variations in the absorption of solar energy intensity. Tudorache and Kreindler[1] have used the solar tracker system, namely a sun position tracking system. The solar panel's position was in line with the sun, resulting in the electrical energy that could be maintained optimally. This method worked well when the weather conditions were sunny, thus the control system could track the position of the sun precisely. Conversely, when the weather conditions were cloudy, then the position of the sun was difficult to track by the light sensor correctly. In other studies, Fadhilah et al. [2] and Ahmad Faizal et al. [3] have optimized solar panel electrical energy using the Maximum Power Point Tracking (MPPT) method by finding the working point of voltage and current, VI from the solar panel curve, thus the maximum performance efficiency could be obtained. This method could overcome the effect of variations in the intensity of solar energy by adjusting a boost converter circuit. However, the regulation technique with a complex boost converter circuit in MPPT technology caused the manufacturing cost to be quite expensive. In the research by Sirait and Hendi [3] and Matalata[4], they have carried out a PWM control pulse control technique on a boost converter circuit by using a resistance change in the LDR (Light Dependent Resistor) light sensor, thus it could increase the solar panel output voltage at weak sunlight intensity. Mujadin and Rahmatia[5], in their research, have developed the Joule Thief as a boost converter circuit to increase the source voltage to light an LED (Light Emitting Diode). In other studies, Budiyanto and Fadliondi [6] and Bilal et al. [7] have made efforts to increase and efficiency of the solar panel output voltage by reflecting sunlight through a mirror. This method could increase the concentration of light on the surface of the solar panel. Thus, more electrons were generated and increased the output voltage.

To solve this problem, in this study, optimization of electrical energy produced by solar panels was carried out by developing a boost converter circuit with a different method from several previous studies. The difference lied in the working concept of the boost converter circuit, but its function was the same, to increase the output voltage of the solar panel. This study used an electromechanical type as the boost converter by utilizing the induced voltage generated by the stator coil of a Brushless DC (BLDC) motor when the rotor rotated. The induced voltage was used to increase the solar panel's output voltage, which decreased when the intensity of solar energy weakened. In this study, the regulation of the stability of the solar panel output voltage with a dynamic boost converter was carried out, thus it could store electrical energy into the battery continuously.

2 Research methods

This research is applied research that developed an electromechanical boost converter system based on a brushless dc motor (BLDC). The design of this research can be seen in Figure 1. The main point of this system was a BLDC type dc motor which has two stator coils. The output voltage from the solar panel could supply electricity directly through an inverter circuit or store electrical energy in the battery. In addition, the solar panel voltage could also be used to supply electricity to the BLDC motor through a voltage regulator as safety against overvoltage. A voltage sensor was used to monitor the output voltage value of the solar panel due to the influence of variations in the intensity of sunlight. This sensor adjusted the value of the Pulse Width Modulation (PWM) control signal used to control the MOSFET transistor component.

The system's working principle was that when the weather was sunny, where the sun shines brightly, the solar panels absorbed and converted sunlight energy into sufficient electrical energy to be stored in batteries or used directly through an inverter circuit. However, the sun's position was not always fixed, causing the absorption of solar energy in solar panels to become unstable. In return, it affected the amount of electrical energy produced. To overcome this issue, some of the solar panel electrical energy was used to turn on a BLDC motor to produce an additional voltage in the form of an induced voltage generated by the stator coil when the rotor rotated. With the addition of this induced voltage, the drop output voltage of the solar panel could be overcome so that the process of storing electrical energy into the battery could be carried out continuously.

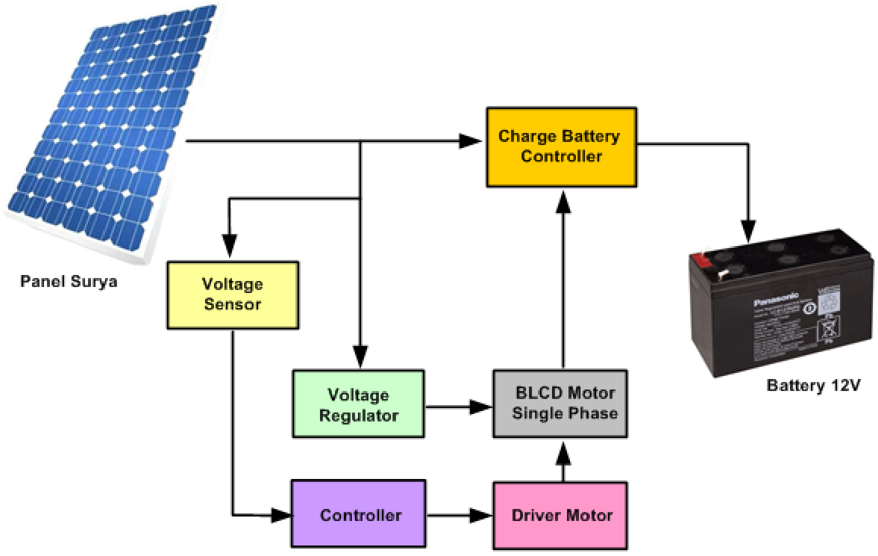
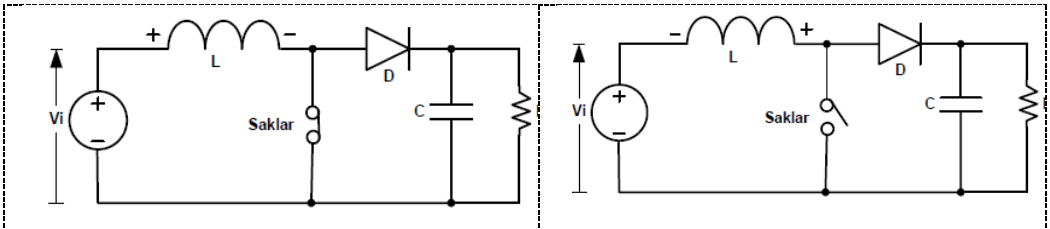


Fig. 1. Boost Converter system with BLDC motor.

2.1 Boost converter

Boost-converter is a converter circuit that increases the DC source voltage to a higher DC level [5]. A boost converter circuit overcame the need for a higher load voltage when compared to the source voltage. **Figure 2** describes the working principle of the boost converter circuit in two conditions, namely (a) the switch ON condition and (b) the switch OFF condition.



(a). Switch ON condition (b) Switch OFF condition

Fig. 2. The working principle of the boost converter circuit.

In **Figure 2**, it can be seen that the Boost converter has two modes of function depending on the position of the switch. In this case, the electronic switch was a transistor that generally used the MOSFET type, where the switch would open or close with a switch at high frequency. In **Figure 1(a)**, where the switch was closed (ON), the current flows through the inductor clockwise and the inductor converted the electric current into magnetic field energy and stores it in the inductor core. The length of the closed switch period could be expressed in Tons. In **Figure 1(b)**, where the switch was open (OFF), the magnetic field stored in the inductor could disappear, thus at both ends of the inductor produce an induced voltage with a polarity opposite to the polarity of the source voltage. The length of the closed switch period could be expressed by the Toff quantity. The combination of both the source voltage and the induced voltage resembled two voltages connected in series with a continuous voltage polarity so that the resulting voltage was higher than the source voltage.

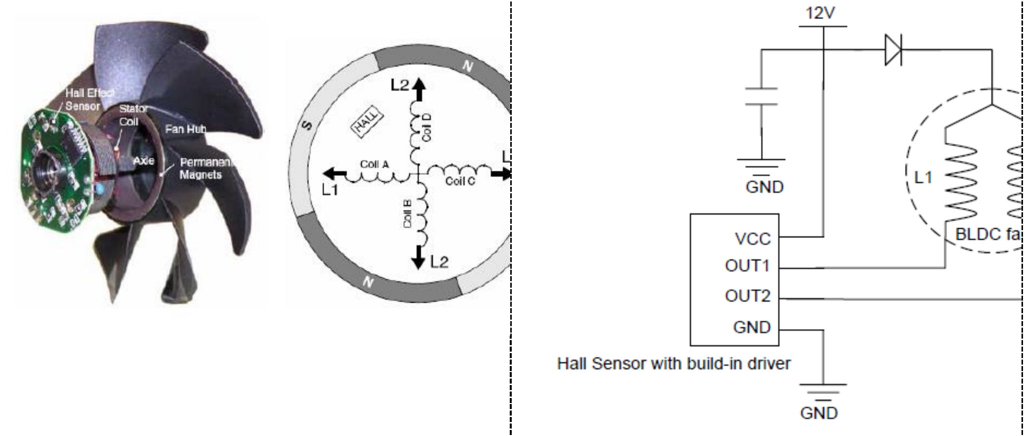
The magnitude of the output voltage resulting from the switching process in the boost converter circuit was determined by the ratio between the open switch time Toff and the closed switch time Ton expressed by the equation (1).

$$Vo=Ton/Toff \times Vs \,. \tag{1}$$

where :
Vo = output voltage (Volt) ; Vs = source voltage (Volts) ; Ton = closed switch period time (seconds) ;
Toff = open switch period time (seconds)

2.2 Brushless DC motor

A DC (Direct Current) motor is a direct current electric motor that converts electrical energy into mechanical energy/rotation. A Brushless DC motor is a direct current motor that does not have a commutator, thus no charcoal brush is needed to flow current in the stator coil [8]. BLDC motor is a type of synchronous motor where its working principle resembles a synchronous motor. The magnetic field generated by the stator coil has the same frequency as the rotor magnetic field so that its rotation does not produce slip. In this study, the type of BLDC motor used was a fan motor commonly used in computer power supplies. The construction of the BLDC motor from the computer fan can be seen in **Figure 3(a)**. The figure shows that the stator has two stator coils L1 and L2. These two coils have 180 degrees of opposite polarity. Between the two stator coils, a component functioned as a magnetic sensor, namely the hall effect sensor, as shown in **Figure 3(b)**. This sensor functioned to detect changes in the polarity of the magnetic poles when the rotor rotates [9]. This sensor has been integrated with two internal electronic switches to control the two switches for any changes in the magnetic poles of the rotor.



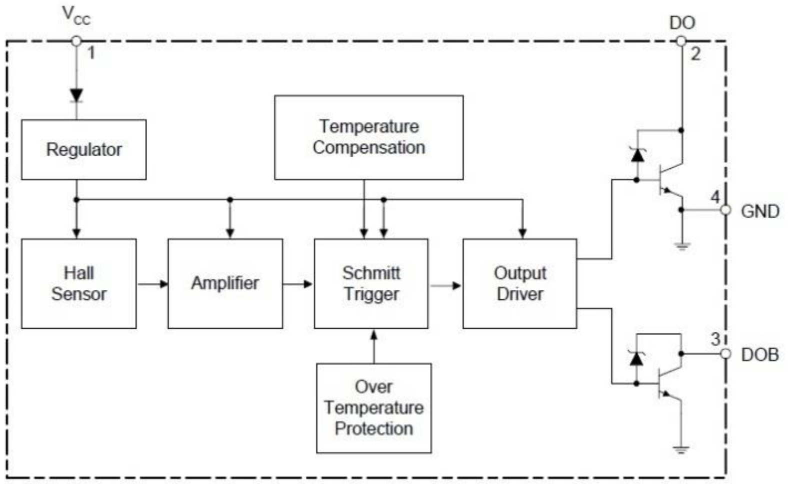
(a) Fan BLDC motor construction.

(b) Hall effect sensor circuit.

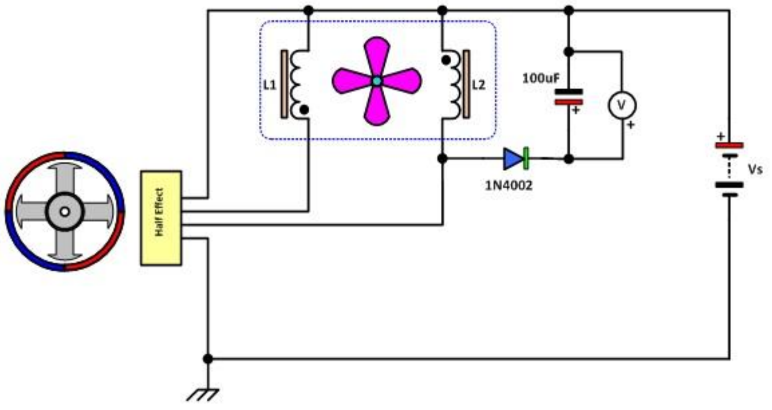
Fig. 3. The working principle of the boost converter circuit.

2.3 Electro-Motive Force (EMF) DC brushless motor

Figure 4(a) shows a block diagram of the Hall Effect sensor which controlled two transistors as the current controller of the two stator coils. These two transistors worked to disconnect and connect the electric current to the stator coil alternately according to the changes in the rotor's magnetic poles detected by the Hall Effect sensor when the rotor rotates. The transistor working process of this Hall sensor has the same performance as the switching performance in the boost converter circuit as shown in **Figure 2(a)** and **Figure 2(b)**. Thus, when the current stator coil was disconnected by one of the transistors from the Hall sensor, the coil would produce an induced voltage with the opposite voltage polarity. The polarity of this induced voltage would be connected in series with the polarity of the source voltage, which causes the reverse voltage arising at the collector-emitter terminal (Vce) of the Hall sensor transistor to increase when the induced voltage occurred. Therefore, the stator coil must be designed with a certain number of turns so that the induced voltage produced did not cause a breakdown voltage at the collector-emitter terminal of the transistor. A rectifier diode was placed in such a way that the transistor's collector terminal would operate when the transistor was not conducting and delivering the induced voltage back to the stator coil through a capacitor, as shown in **Figure 4(b)**. During the rotation, the induced voltage would be generated by the two stator coils whose magnitude was determined by the number of turns of the stator coil and the rotational speed of the rotor, which determined the magnitude of the change in the rotor magnetic flux and the magnitude of the change in coil current when the transistor changed to a non-conducting state. A capacitor was installed in series with the rectifier diode to determine the magnitude of the peak value of this induced voltage. The capacitor, in this case, functioned to store electrical energy from several cycles of induced voltage until it reached the peak voltage value.



(a) Hall effect sensor block diagram.



(b) EMF induced voltage test circuit.

Fig. 4. Induction voltage measurement.

Based on the Hall sensor datasheet [10], the maximum current capability of the two transistors was 350 mA. Since the value of the induced voltage was directly proportional to the change in the current of the stator coil, it was necessary to have a transistor capable of controlling a larger current to increase the value of the induced voltage. The stator coil must also be redesigned with a larger wire diameter than before to be able to carry a larger current. The current amplifier circuit design from the Hall sensor can be seen in **Figure 5**. In **Figure 5**, the two transistors T1 and T2 act as current amplifiers from the Hall sensor, which then controlled the two driving transistors, T3 and T4, to regulate the electric current in the stator coil. The Hall sensor would be more durable with this current amplifier circuit because it only controlled a small base current of transistors T1 and T2.

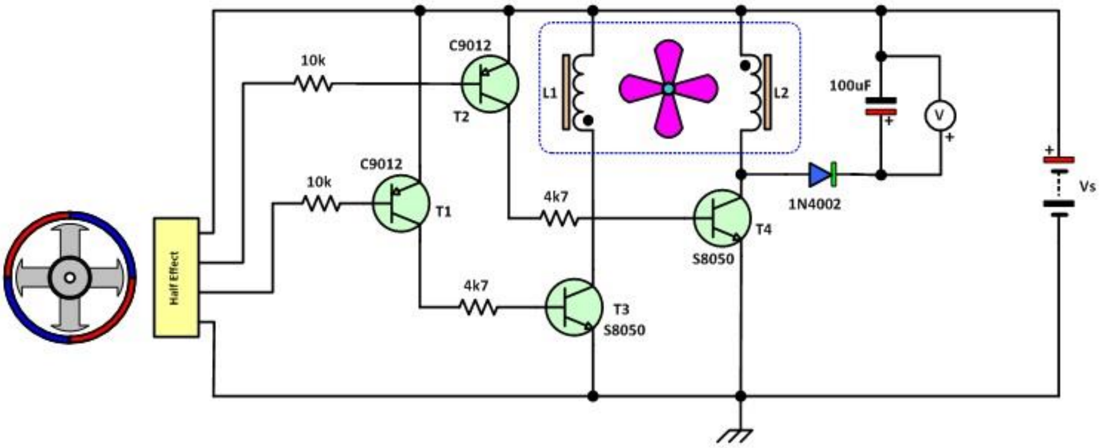


Fig. 5. Hall sensor current amplifier circuit.

2.4 Solar panel and BLDC motor

Figure 6 shows a combination of two voltage sources, namely the voltage source from the solar panel and the voltage source from the boost converter output generated by the BLDC motor. The solar panel voltage (PV) was connected to a regulator circuit which also acts as a battery charging circuit (Accu). This regulator produced a relatively constant voltage for variations in the output voltage value of the solar panel (PV) so that the battery charging process during sunny weather conditions became more stable.

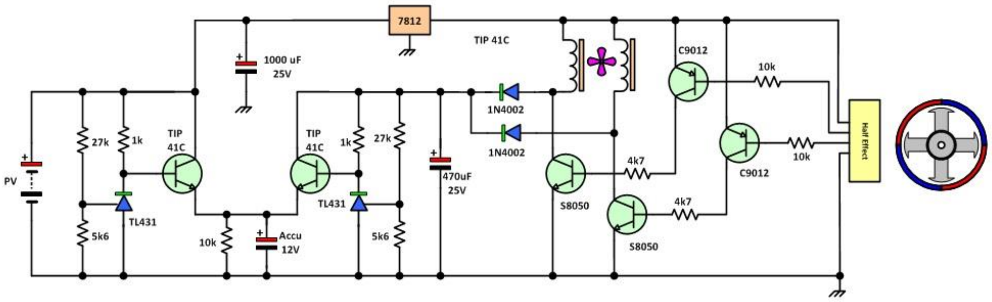


Fig. 6. Hall sensor current amplifier circuit.

In addition to the solar panel output voltage used for the battery charging process, some of the energy was used to supply voltage to the BLDC motor through a voltage regulator IC 7812, thus the BLDC motor could operate at normal working voltage. When the rotor of the BLDC motor rotated, the two stator coils would produce an induced voltage stored in a 470 uF capacitor after passing through two rectifier diodes. This induced voltage was passed to a regulator to obtain a stable voltage that provided a charging current to the battery along with the charging current from the solar panel. The two charging currents combine so that the charging current would be greater and the battery charging process time would be faster.

3 Results

This study used a solar panel with a power specification of 20 WP. The testing of solar panels in sunny weather conditions was carried out to determine the characteristics of the output voltage under no-load (VNL) and loaded (VL) conditions with a constant current of 0.5 Amperes. The results of the solar panel output voltage test are shown in Figure 7, with the observation time starting from the morning at 07.45 a.m to the afternoon at 05.00 p.m. From the graph of the output voltage of the solar panel, it can be seen that the optimal working area of the solar panel was capable of producing sufficient current and voltage for the battery charging process. It can be seen that the solar panel output voltage met the requirements in the battery charging process when the voltage was above the 15 Volt between 09.30 a.m to 03.30 p.m.

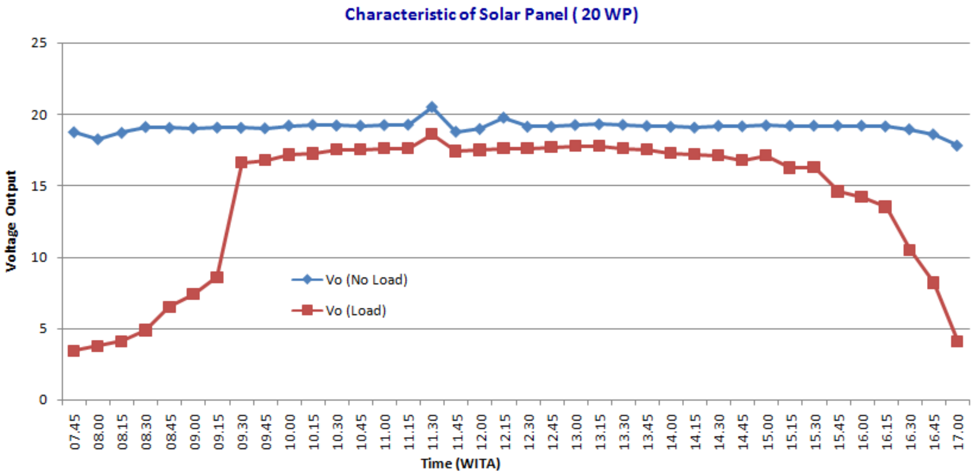


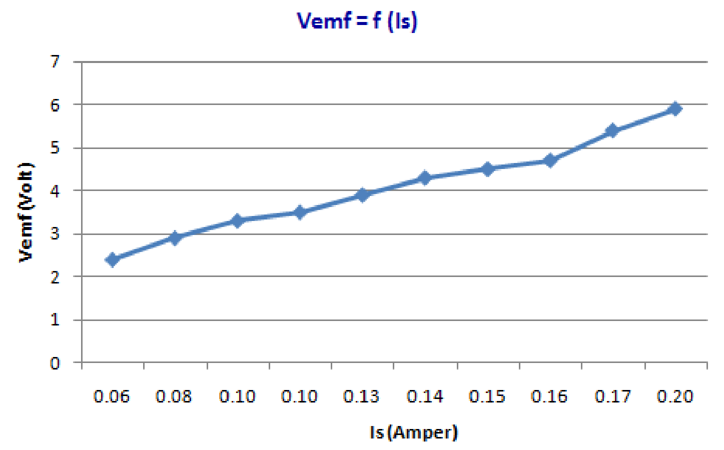
Fig. 7. The voltage characteristics of a 20 WP solar panel at a constant current load of 0.5 A.

The value of the output voltage of the solar panel, which was below 15 Volt under load conditions, indicated that the intensity of light hitting the surface of the solar panel was quite weak. This condition could occur in cloudy weather conditions, thus the voltage was not enough to carry out the process of charging the battery. This activity aimed to increase the output voltage of weak solar panels, thus the charging voltage on the battery remained stable.

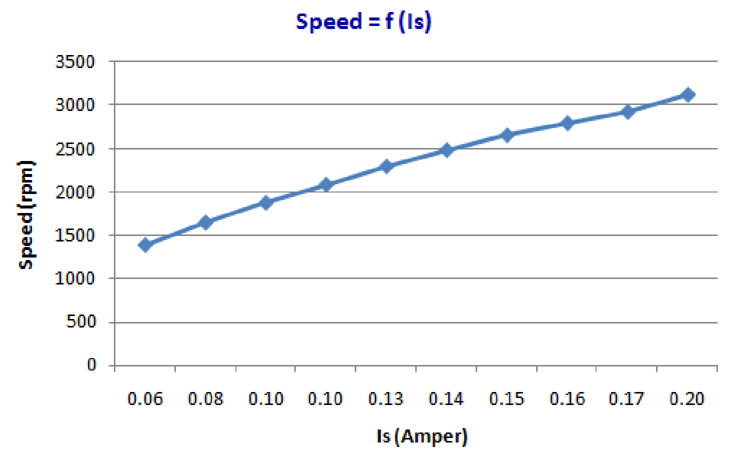
In the working principle of the boost converter, it is known that the induced voltage generated due to the disconnection process could provide additional voltage to the source voltage. Therefore, before the BLDC motor was used as a boost converter, it was necessary to test the stator coil induced voltage due to switching while the rotor was rotating. The measurement of the induced voltage (emf) of the BLDC motor was carried out based on a series of tests as shown in Figure 5, where the measurement results are shown in Table 1 below. Table 1 shows that the BLDC motor could work at a minimum limit of 4 Volts to 13 Volts. In the source voltage range, an induced voltage was obtained between 2.4 Volts to 5.9 Volts. The variation in the value of this induced voltage was directly proportional to the given source voltage so that it affected the current flowing into the stator coil. The greater the source voltage, the value of the current flowing would be greater from 0.06 Ampere to 0.20 Ampere, as shown in **Figure 8(a)**. In addition to the coil current factor, the induced voltage was also influenced by the rotor rotation speed factor, where the faster the rotation, the greater the induced voltage, as shown in **Figure 8(b)**.

Table 1. Induction voltage (EMF) BLDC motor 12V.

Vs (Volt)	Is (Amper)	Vemf (Volt)	Speed (rpm)
4	0.06	2.4	1380
5	0.08	2.9	1640
6	0.10	3.3	1870
7	0.10	3.5	2080
8	0.13	3.9	2290
9	0.14	4.3	2480
10	0.15	4.5	2650
11	0.16	4.7	2790
12	0.17	5.4	2920
13	0.20	5.9	3120



(a) Characteristics Vemf = f (Is).



(b) Characteristics Speed = f (Is).

Fig. 8. The characteristics of 12 V BLDC fan motor.

Based on the BLDC motor's induction voltage (emf) data in Table 1, this voltage would be connected in series with the source voltage (Vs) so that a voltage summation occurred, which produced an output voltage higher than the source voltage, as shown in Table 2 below. From Table 2, it can be analyzed that the value of the added voltage (Vboost) that met the requirements to be able to carry out the charging process to the battery was 14.5 Volts to 18.9 Volts at a Vs source voltage of 10 Volts to 13 Volts. This source voltage Vs represented the input voltage of the solar panel. This means that when the output voltage value of the solar panel was less than 15 Volts due to the weak light intensity received, the solar panel voltage would be increased by adding the induced voltage generated by the stator coil from the BLDC motor.

Table 2. BLDC motor boost voltage 12V.

Vs (Volt)	Vemf (Volt)	Vboost (Volt)
4	2.4	6.4
5	2.9	7.9
6	3.3	9.3
7	3.5	10.5
8	3.9	11.9
9	4.3	13.3
10	4.5	14.5
11	4.7	15.7
12	5.4	17.4
13	5.9	18.9

Figure 9 shows a graph of the relationship between the voltage generated (Vboost) by a BLDC motor in increasing the source voltage. It appears that the graph of the boost voltage was relatively linear in proportion to the change in the source voltage between 10 V to 13

Volts. From this data, it can be seen that the BLDC motor could produce an output voltage that was close to the output voltage of the solar panel. It could help the sustainability of the battery charging process when the solar panel output voltage was not sufficient to supply the battery due to the reception of weak light intensity.

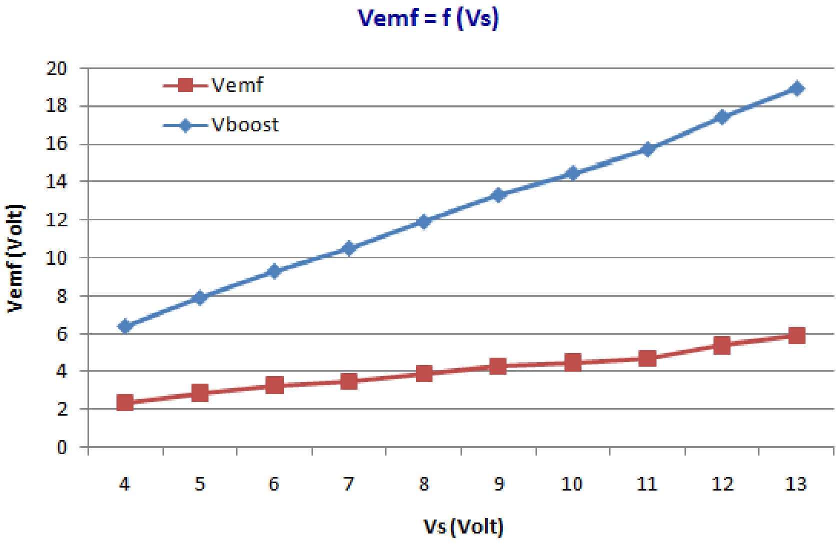


Fig. 9. BLDC motor boost converter voltage.

4 Conclusions

Based on the results of the development of the BLDC motor as a boost converter in the solar panel system, it can be concluded that the BLDC motor stator coil could produce sufficient induced voltage when the rotor rotates. It provides additional voltage to overcome the decrease in the output voltage of the solar panel when the reception of sunlight intensity was quite weak due to conditions of cloudy weather. With the ability of the BLDC motor to increase the source voltage, the BLDC motor acted as a boost converter with a switching operation based on the rotational speed of the rotor.

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