International Journal of Frontier Technology and Engineering (IJFTE)
Vol. 01, No. 01, December 2022, pp. 33-41

Battery charging control using photovoltaic with sepic converter

Ratna Ika Putri[1], Surya Nata[1], and Bambang Priyadi[1]

[1]*Electrical Department, State Polytechnic of Malang, Malang, Indonesia*

Corresponding Author: Ratna Ika Putri, ratna.ika@polinema.ac.id

Received Date: 13-10-2022 Revised Date: 13-11-2022 Accepted Date: 01-12-2022

Abstract

This article presents a battery charging design using photovoltaic with a septic converter. The use of batteries as energy storage is one way to ensure the availability of energy to the load and overcome the weaknesses of photovoltaic systems which depend on solar irradiation and temperature. when the solar irradiation is low, the battery can supply energy to the load. SEPIC converter is used to adjust the battery charging voltage requirements. The output voltage of the SEPIC converter is maintained constant by setting the duty cycle using a microcontroller. Based on the results of experimental testing, this PV system with a SEPIC converter can work well. Battery charging can be done optimally. This system is also equipped with automatic disconnection of the battery if the battery is fully charged so that the lifetime of the battery is maintained.

Keywords : Photovoltaic, Battery, Converter

1 Introduction

Electrical energy is a primary need to support everyday life. Currently, the use of renewable energy as a source of electrical energy is increasing to overcome the limitations of fossil energy. One of the renewable energies is solar energy which can be used as an option for electricity generation. Utilization of solar energy as a generator of electrical energy requires photovoltaic which will convert sunlight into electricity. Solar energy is very environmentally friendly and does not cause air pollution or noise pollution that can interfere with human activities [1][2]. However, the use of photovoltaics is highly dependent on solar irradiation and ambient temperature. The higher the solar irradiation, the greater the electrical energy generated.

The use of photovoltaics is highly dependent on solar irradiation and temperature, so to be able to supply the load continuously, a battery is needed as energy storage in the photovoltaic system. The battery is an important component in the PV system to ensure the availability of energy to the load. Charging lead acid batteries using a PV module with a buck converter has good performance. However, the use of batteries also has weaknesses, battery lifetime which depends on the charging and discharging settings of the battery[2]. Several studies have been conducted to regulate battery charging with this photovoltaic [3-6]. A photovoltaic cannot be connected directly to the load because the voltage generated does not meet the load requirements. Therefore, energy storage is needed, which can be in the form of a battery. Batteries as energy storage can store excess energy when solar irradiation is high and can supply loads when there is no sunlight.

Photovoltaic systems with batteries require a dc/dc converter to match the voltage requirements. The dc/dc converter is a circuit that plays an important role in a renewable energy system. Several types of converters have been studied for applications in renewable energy systems [7]. Therefore, it is necessary to design a converter that can convert an output voltage of a solar panel from a small voltage to a large voltage and also from a large voltage to a small voltage. One type of converter that can be used is the SEPIC Converter. SEPIC Converter is very effective for charging batteries with solar panels that can change the output voltage to greater than or less than the input voltage. The output of the SEPIC Converter is controlled by the duty cycle of the MOSFET control [8-9].

A SEPIC (Single-Ended Primary-Inductance Converter) converter is a type of DC-DC converter that is used to convert a high-voltage DC input to a lower-voltage DC output. It is often used in solar panel systems because it allows the solar panels to operate at a higher voltage than the battery bank, which can increase the efficiency of the system. In a solar panel system, the SEPIC converter is typically used to convert the high-voltage DC output of the solar panels to a lower voltage that is suitable for charging the battery bank. The SEPIC converter is able to maintain a constant output voltage, even if the input voltage or load changes, which makes it well-suited for use in a solar panel system where the input voltage can vary significantly due to changes in solar insolation or temperature. Overall, the use of a SEPIC converter in a solar panel system can help to improve the efficiency and performance of the system by allowing the solar panels to operate at their optimal voltage and by providing a stable and reliable source of power to the battery bank [10].

SEPIC converters are capable of operating in either up or down states and are widely used in battery-operated equipment by varying the duty cycle of the MOSFET gate signal. To get a stable voltage value, a control that can maintain the desired output voltage value is needed. Therefore, using a PID control method [11]. PID control can overcome a voltage drop, if there is one, in order to maintain the output voltage at the setpoint so that it can be utilized for the battery charging process.

2 Method

2.1 Battery Charging System

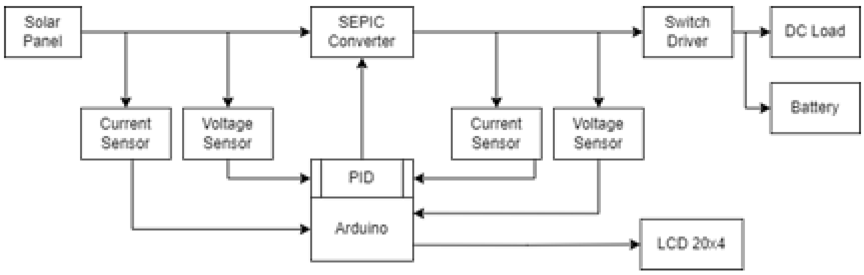

Figure 1: Battery Charging System

The working principle of this system is to utilize a 200 wp Photovoltaic, where the intensity of sunlight is converted into current and voltage will be used to charge the load, namely a 12 Volt battery. Due to the unstable current and voltage output from the Photovoltaic, depending on the intensity of the sun, to obtain maximum and stable power, a SEPIC Converter is designed with PID control using the Ziegler Nichols method. The PID control output is used to adjust the duty cycle value that must be given to the SEPIC Converter circuit, so that the voltage at the load can be maintained at 14 Volts. When the voltage generated from the Photovoltaic is smaller than the desired output, the SEPIC Converter will increase the duty cycle to increase the output according to the desired output. Likewise, when the output is more than the desired output, the SEPIC Converter will decrease the duty cycle so that the output drops according to the desired output. This system is equipped with an ACS712 current sensor and a voltage divider circuit used as a voltage sensor. The sensor reading results will be processed by Arduino NANO, where the output voltage reading results will be used as system feedback. The data will be displayed on the 20x4 LCD in the form of input voltage, input current, input power, output voltage, output current, output power, and power efficiency (η). The setpoint of this system is set at 14V and is set via arduino. Then, it will be processed by the Arduino NANO microcontroller which has been filled with the PID program. PID will generate a duty cycle from the PWM signal, and then the Arduino NANO microcontroller will put out the PWM signal to the driver circuit. Driver circuit will amplify the PWM signal received in order to trigger the MOSFET Gate on Sepic converter. Then, the MOSFET will work or activate switching according to the PWM output given and the SEPIC Converter will provide output to the system in the form of output voltage. Then, the output voltage will be read by a voltage sensor which will be used as feedback from the system which will be sent to the Arduino NANO microcontroller. The Arduino NANO microcontroller that receives the feedback results will process it by comparing the difference from the Setpoint with the feedback given by the voltage sensor (Error).

2.2 Electronic Design

2.2.1 LCD Circuit Design

LCD functions to display characters in the form of letters, numbers, or symbols which are responses / information from a system. In this study, the LCD is used to display the readings of the voltage divider sensor, current sensor, power converter, and efficiency converter. In the LCD design that is connected to the Arduino NANO, an I2C module which functions to save the use of PINs on the Arduino NANO is added, as shown in Figure 2.

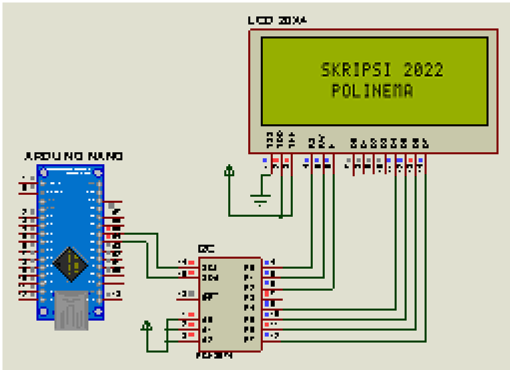

Figure 2: LCD 20x4 Circuit

2.2.2 Current Detector Design

Current detector is used to measure the Photovoltaic output current and the SEPIC converter output current. In this research, current detector uses ACS712, as shown on Figure 3. ACS712 is a current sensor that can be used to measure the current flowing through a conductor. It consists of a Hall effect sensor that produces a voltage output proportional to the strength of the magnetic field around the conductor. The ACS712 has a range of 5A, 20A, and 30A, which means it can measure currents up to 5A, 20A, or 30A depending on the version. It has a sensitivity of 185mV/A, which means that for every 1A of current flowing through the conductor, the ACS712 will produce a voltage output of 185mV. The ACS712 is often used in applications where it is necessary to measure current in a non-invasive way, such as in power monitoring systems or motor control systems. The Photovoltaic output current is a maximum of 5.56 Amperes and the SEPIC converter output current is a maximum of 5 Amperes.

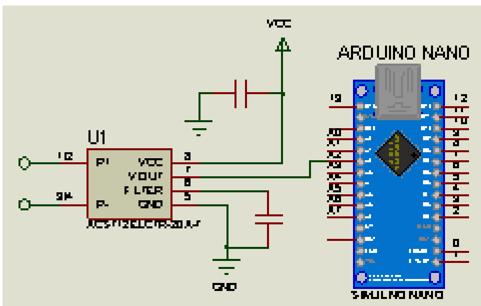

Figure 3: Current Detector Design

2.2.3 Voltage Detector Design

Voltage detector functions to measure the output voltage of the Photovoltaic and SEPIC converter. The output of the sensor is connected to the Analog pin of the Microcontroller. The voltage to be measured from the Photovoltaic has a voltage of 0 - 36 Volts and the output voltage from the converter has a voltage output of 0 - 18 Volts. The sensor output voltage connected to the Microcontroller has a voltage of 0 - 4.8 Volts. Voltage detector uses voltage divider circuit, as shown on Figure 4. Based on the voltage to be measured, the resistance value can be determined using the equation below

$$V_{out} = V_{in} \times \frac{R_2}{(R_1 + R_2)} \tag{1}$$

Based on the results of the above calculations, the voltage divider circuit obtained is R1 $10K\Omega$ and R2 $1K6\Omega$. Because the $1K6\Omega$ resistor is not available in the market, it is replaced with a $1K5\Omega$ resistor.

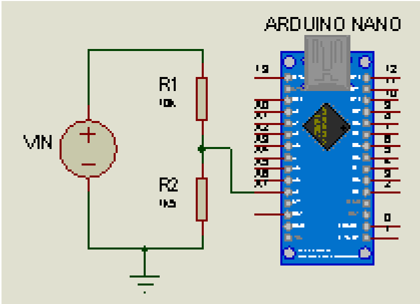

Figure 4: Input Voltage Sensor Circuit

2.2.4 Battery charger cut off circuit design

A battery charger is a device that supplies electrical energy to a rechargeable battery or battery pack to replenish its energy capacity and maintain its performance. The charger does this by applying a specific charging voltage and current to the battery, which causes a chemical reaction inside the battery that restores its stored chemical energy. There are several types of battery chargers, including:

1. Constant current charger: This type of charger supplies a constant charging current to the battery until it reaches a full charge, at which point the charger reduces the current to a trickle to maintain the battery at its full charge.
2. Constant voltage charger: This type of charger supplies a constant charging voltage to the battery until it reaches a full charge, at which point the charger reduces the voltage to a trickle to maintain the battery at its full charge.
3. Constant current-constant voltage (CC-CV) charger: This type of charger combines the constant current and constant voltage charging methods, and is often used to charge lithium-ion batteries. It begins by applying a constant current to the battery until it reaches a certain voltage, at which point it switches to a constant voltage charging mode to complete the charging process.
4. Pulse charger: This type of charger applies periodic bursts of current to the battery, which can help to reduce the amount of heat generated during the charging process and extend the life of the battery.

The design of the battery charger cut off circuit functions as a breaker of the current that enters the battery and will be diverted to the DC load, as shown on Figure 5. The way the auto cut off circuit works is when the voltage on the battery has reached the same as the Zener diode voltage, the Zener diode will trigger the SCR so that the relay will change its condition to Normally Open.

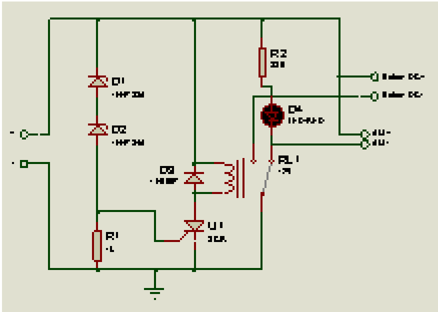

Figure 5: Battery charger cut off circuit

2.2.5 SEPIC Converter Design

A SEPIC (Single-Ended Primary Inductor Converter) is a type of DC-DC converter that is used to convert a DC input voltage to a higher or lower DC output voltage. It is a type of buck-boost converter, which means that it can operate in either buck mode (to reduce the input voltage) or boost mode (to increase the input voltage). The SEPIC converter consists of an inductor, a capacitor, and a switch (usually a MOSFET), as shown on Figure 6. The switch is used to control the flow of current through the inductor and capacitor, and the output voltage is regulated by adjusting the duty cycle of the switch.

During the charging phase of the SEPIC converter, the switch is turned on, and current flows through the inductor and charges the capacitor. When the switch is turned off, the stored energy in the capacitor is released and flows through the load, supplying power to the load. The output voltage is regulated by adjusting the duty cycle of the switch, which controls the amount of energy that is stored in the capacitor and released to the load. Overall, the SEPIC converter works by storing energy in the inductor and capacitor during the charging phase, and then releasing that energy to the load during the discharge phase. This allows it to efficiently convert a DC input voltage to a higher or lower DC output voltage, depending on the operating mode.

Designing the SEPIC Converter begins by calculating several related parameters, including the duty cycle range, inductor, coupling capacitor, and input capacitor which will be used to optimize the supply voltage entering the 14 Volt battery load.

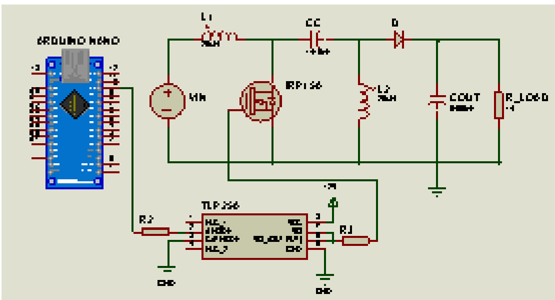

Figure 6: SEPIC Converter Circuit

Inductor and capacitor value can be determined by equation below

$$L1 = L2 = L = \frac{V_{in(min)}}{\Delta I_L x f_{sw}} x D_{max} \tag{2}$$

where f_{sw} is the switching frequency and D_{max} is the duty cycle when the V_{in} value is minimum.

$$I_{L1}(peak) = I_{out} x \frac{(V_{out} + V_D)}{V_{in(min)}} x(1 + \frac{40\%}{2}) \tag{3}$$

$$I_{L2}(peak) = 20x(1 + \frac{40\%}{2}) \tag{4}$$

$$I_{Cc}(rms) = I_{out}x\sqrt{\frac{V_{out}+V_D}{V_{in(min)}}} \tag{5}$$

While the V_{Cc} value can be calculated through the formula below:

$$\Delta V_{Cc} = \frac{I_{out}xD_{max}}{C_c x f_{sw}} \tag{6}$$

$$I_{Cout}(rms) = I_{out}x\sqrt{\frac{V_{out}+V_D}{V_{in(min)}}} \tag{7}$$

$$ESR\frac{V_{ripple}x0.5}{I_{L1(peak)}+I_{L2(peak)}} \tag{8}$$

3 Results and Discussion

The performance of the photovoltaic battery charger system was tested through laboratory experiments. Testing is carried out for each circuit that has been designed. In addition, testing of the entire series of the system was also carried out. Testing is carried out to determine the work capability of the voltage sensor before the sensor is used as a voltage measuring instrument in the SEPIC Converter circuit. Testing is carried out by passing the voltage from the DC voltage source, namely the power supply, into a voltage sensor circuit. The value read on the voltage sensor will then be compared with other voltage measuring instruments as shown on Figure 7. Based on the test results of the voltage detector, this circuit can work well with a measurement error of 1

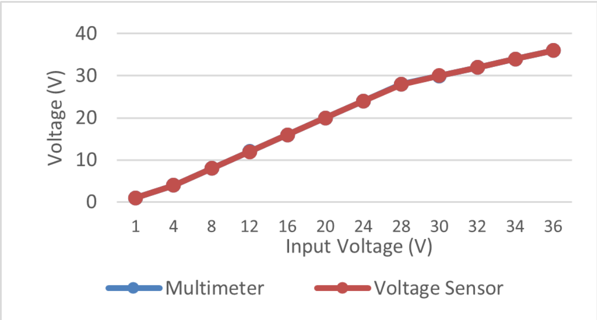

Figure 7: Voltage detector test result

Testing is carried out to determine the work capability of the ACS712 current sensor before the sensor is used as a current measuring instrument in the SEPIC Converter circuit. Testing is carried out by passing the current from the DC voltage source, namely the power supply, into a current sensor circuit that has been given a load. The value read on the current sensor will then be compared with other current measuring instruments.

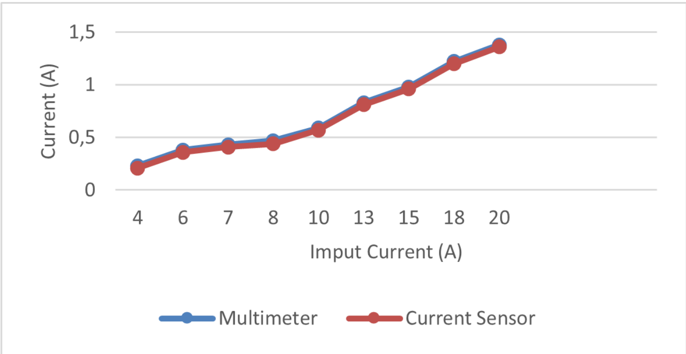

Figure 8: Current detector test result

The current sensor test results show that the 5A current sensor has an average error value of 1.8%. While the test results of the 20A current sensor have an average error value of 0.2%. From these two results, it can be said that both current sensors are accurate enough to be used.

The SEPIC converter is controlled using a PID controller to maintain an output voltage value of 14 Volts. A PID (Proportional Integral Derivative) controller is a type of control system that is used to control the output of a process or system by continuously calculating and adjusting the error between the desired output and the actual output. It is widely used in a variety of applications, including industrial control, aerospace, and automotive systems. The PID controller consists of three main components: the proportional, integral, and derivative terms. Each of these terms has a specific function in the control loop. The proportional term (P) compares the error between the desired output and the actual output, and adjusts the output in proportion to the error. This helps to bring the output closer to the desired value, but it can also lead to overshooting or oscillation if the error is large. The integral term (I) is used to eliminate steady-state error, which is the difference between the desired output and the actual output that remains even when the error is zero. The integral term sums the error over time, and adjusts the output to eliminate this error. The derivative term (D) is used to anticipate future errors and reduce the overshoot and oscillation that can be caused by the proportional term. It compares the rate of change of the error with respect to time, and adjusts the output accordingly. By combining these three terms, the PID controller can effectively control the output of a process or system and maintain it at a desired value.

In testing the SEPIC Converter without PID control using a rheostat load of 14Ω. By entering the value of Kp = 1, Ki = 0, and Kd = 0. To see the oscillation results using MATLAB software shown in Figure 9. The results obtained from SEPIC converter test without PID control do not reach the predetermined set point. In testing the SEPIC Converter with the PID method using a rheostat load of 14Ω. By entering the value of Kp = 0.6, Ki = 17.14, and Kd = 0.00525 obtained through the calculation of Ziegler Nichols II. To see the oscillation results using MATLAB software where the results are obtained in accordance with the setpoint of 14 Volts shown in Figure 10. Based on the test results with the PID controller, the output voltage response of the SEPIC converter produces a steady state error of 5%, a settling time of 7.15s and a maximum overshoot of 8.7%.

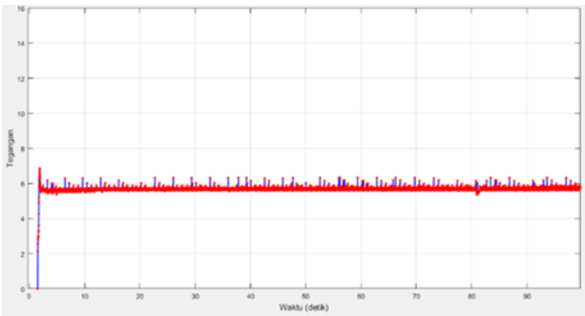

Figure 9: SEPIC Converter output voltage without PID Control with Rheostat Load

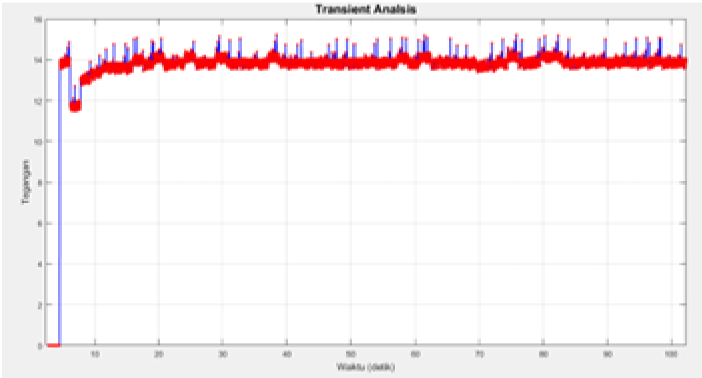

Figure 10: SEPIC Converter output voltage of PID Method with Rheostat Load

The purpose of testing the converter for battery charging is to find out whether the SEPIC converter can be done for battery charging. The equipment needed in this test is a solar panel and SEPIC converter with the load used is a 12V/7.5Ah battery. After testing the battery charging, the data obtained shown in the table 1. The battery charging process stops at 16:00 due to cloudy weather so that the solar panel does not receive good light intensity and the voltage coming out of the solar panel is very small.

Table 1: Testing Data of Sepic Converter For Charging 12V Battery Using PID Method

Time (Hour)	Solar Panel Voltage (V)	SEPIC Converter Output Voltage (V)	Battery Voltage (V)
14.00	25.02	14	11.90
14.30	25.10	14	11.94
15.00	25.00	14	11.97
15.30	25.10	14	12.07
16.00	25.00	14	12.16

4 Conclusion

The battery charging control system using photovoltaic with a sepic converter has been designed and tested experimentally. The system is designed using a microcontroller as a control unit for charging the battery. This system is also equipped with an automatic battery cut-off circuit that will disconnect the photovoltaic battery if the battery is fully charged. The battery charging voltage is maintained at a constant 14 V even though the solar intensity and the photovoltaic output voltage change. Based on the test results, the system can maintain a battery charging output voltage of 14V with a steady state error of 5%. By adding the PID method without control, it produces an error of 16%, settling time of 7.15 seconds, and overshoot of 8.7%. While the PID method with control values Kp=0.6, Ki=17.14, Kd=0.00525 can stabilize the output voltage in accordance with the setpoint of 14 Volts by varying the input voltage from the power supply.

References

[1] Debashish Mohapatra, Subhransu Padhee, Jhansirani Jena, "Design of Solar Powered Battery Charger: An Experimental Verification," R*enew. 2018 IEEE International Conference on Electrical, Electronics and Computer Science (SCEECS)*., Bhopal, India, 2018.

[2] Julio Lopez, Seleme I, "Robust Digital Control Strategy Based on Fuzzy Logic for a Solar Charger of VRLA Batteries," *Energies*, 14, 1001, 2021.

[3] Yasser.AbuEldahab a, NaggarH.Saad b, AbdalhalimZekry, "Enhancing the design of battery charging controllers for photovoltaic systems", *Renewable and Sustainable Energy Reviews*, v521.

[4] López, J.; Seleme, I.; Donoso, P.; Morais, L.; Cortizo, P.; Severo, M., "Digital control strategy for a buck converter operating as a battery charger for stand-alone photovoltaic systems", *Sol. Energy*, 140, 171–187, 2016.

[5] El-Khateb, A.; Rahim, N.; Selvaraj, J. "Cascaded DC-DC Converters as a Battery Charger and Maximum Power Point Tracker for PV Systems" in *Proceedings of the International Renewable and Sustainable Energy Conference (IRSEC)*, Ouarzazate, Morocco, 7–9 March 2013.

[6] T. T. Chen, M. Y. Hsiao, S. H. Tsai, and C. N. Lin, "Design of digital battery charger system based on PV-module," *IEEE Int. Conf. Fuzzy Syst.*, pp. 1860–1865, 2011, doi: 10.1109/FUZZY.2011.6007402.

[7] Mumtaz F, Yahaya N Y, Meraj S.T, Singh B, Kannan R, " Review on non-isolated DC-DC Converter and their control techniques for renewable energy applications" *Ain Shams Engineering Journal*, Volume 12, Issue 4, December 2021, Pages 3747-3763

[8] T. Bhavin, B. Patel, J. Desai, and K. Sonwane, "Analysis of SEPIC Converter," *Int. J. Eng. Dev. Res*, [8].vol. 6, no. 2, pp. 489–494, 2018.

[9] O. Kircioğlu, M. Ünlü, and S. Çamur, "Modeling and analysis of DC-DC SEPIC converter with coupled inductors," *2016 Int. Symp. Ind. Electron. INDEL 2016 - Proc.* 2016, doi: 10.1109/INDEL.2016.7797807.

[10] Ardi H, Ajami, "A. Study on a high voltage gain SEPIC-based DC-DC converter with a continuous input current for sustainable energy applications" *IEEE Trans Power Electron 2018*, 33(12):10403–9.

[11] S. I. Khather and M. A. Ibrahim, "Modeling and simulation of SEPIC controlled converter using PID controller," *Int. J. Power Electron. Drive Syst.*, vol. 11, no. 2, pp. 833–843, 2020, doi: 10.11591/ijpeds.v11.i2.pp833-843.