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Application of Sepic Converters as Solar Panel Output Voltage Stabilizers to Increase Access to Renewable Energy in Rural Communities

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Abstract: *The increasing demand for electricity in modern society necessitates innovative solutions, particularly in rural areas with limited access to reliable energy sources. Solar power, utilizing photovoltaic (PV) technology, has emerged as a sustainable energy solution. However, the challenge lies in ensuring that the voltage output from solar panels aligns with the requirements of energy storage systems, such as batteries. This research explores the application of a SEPIC converter as a voltage stabilizer for a 30W solar panel, aimed at improving the reliability of renewable energy in rural communities. In this study, two 30Wp polycrystalline solar panels are configured in series to generate a variable output voltage ranging from 5V to 17V. To charge a 24V battery, a SEPIC converter is employed to adjust the voltage, ensuring that it meets the battery's requirements. The converter's duty cycle, controlled by an Arduino Uno, regulates the voltage output. Testing reveals that the SEPIC converter successfully stabilizes the output voltage, with an average of 24.26V, meeting the desired set point. This solution provides a reliable and sustainable energy source for rural communities, promoting the use of renewable energy while addressing the voltage stability issue. The study highlights the practical application of the SEPIC converter in enhancing energy access and supporting community empowerment through renewable technology.*

Keyword*: Arduino, Battery, Solar Panel, SEPIC Converter.*

Introduction

Electricity is a fundamental resource in the modern era, serving the needs of individuals and industries alike. From lighting to complex machinery, electricity is essential in homes and businesses. The increasing demand for electricity, driven by population growth and industrial expansion, has intensified the consumption of non-renewable energy sources such as coal, oil, and natural gas (Budiharto, 2010). In Indonesia, for instance, the per capita electricity consumption in 2019 was recorded at 1.08 GWh (Central Statistics Agency, 2019). With the growing demand for energy, the exploitation of these finite resources is escalating. As a result, alternative energy sources such as solar, wind, tidal, and wave energy are being explored to provide a sustainable future (Nugraha, 2020).

Energy conversion is the process of transforming one form of energy into another that is more suitable for specific applications. For example, solar energy can be converted into electricity via photovoltaic (PV) systems. The PV system converts solar radiation into electrical energy through the photovoltaic effect (Trisna, 2020). Solar panels require batteries to store the DC energy generated, but the voltage output of solar panels may not directly match the battery voltage, creating a need for efficient charge control (Budianto, 2015). A solution to this is the use of a SEPIC converter, which can regulate the voltage to match battery requirements, ensuring optimal energy storage and efficiency.

The SEPIC converter, with its lower ripple level and ability to either increase or decrease the voltage, presents an advantage over other DC-DC converters like buck-boost converters (Anderson et al., 2017). This research focuses on utilizing the SEPIC converter in rural areas to improve renewable energy access, aligning with community empowerment goals through technological solutions (Chandra, 2019).

Methodology

1. Block Diagram of the Research

This research focuses on the application of a SEPIC converter as a voltage stabilizer for the output of a 30 WP solar panel. The solar panel's output voltage enters the SEPIC converter to charge a 24V battery. The process utilizes a DC output load. The solar panels used in this project are two 30Wp polycrystalline panels connected in series. The output voltage from these panels ranges from 5V to 17V, while a 24V input is required for charging the battery. Therefore, a SEPIC converter is employed to boost the voltage. The SEPIC converter controls the voltage based on the duty cycle, which is adjusted by an Arduino UNO R3 microcontroller.

The Arduino microcontroller is programmed to handle voltage drops and maintain the output voltage at a set point. A voltage sensor is installed to monitor the output voltage from the solar panel, SEPIC converter, and to provide input to the Arduino's ADC (Analog to Digital Converter). The block diagram for the entire research system is shown in Figure 1.

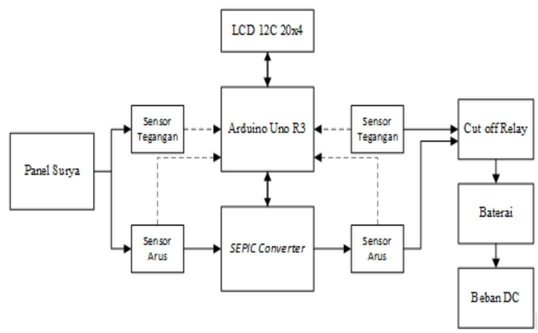

Figure 1. System Block Diagram

In the block diagram, solar energy is the power source. Voltage and current sensors are installed at the solar panel's output. The sensor data is processed by the Arduino UNO R3, with the results displayed on a 20x4 LCD screen. The output voltage from the solar panel is input to the SEPIC converter, which is controlled by Arduino to ensure the output voltage matches the battery's requirements. Additional sensors are used to measure the current and voltage at the SEPIC converter output. These readings are also displayed on the LCD screen. Finally, the output voltage of the SEPIC converter is connected to a cut-off relay, which serves as a protection mechanism to disconnect the battery charging process once the battery is fully charged.

2. SEPIC Converter Design

Based on the specifications of the 30 WP solar panel shown in Table 1, calculations were made to determine the values of each converter component.

Table 1. SEPIC Converter Parameters

Parameters	Value
Input Voltage	8 – 21 Volts
Output Voltage	14 Volts
Output Current	2 A
Switching Frequency	40 KHz

The following calculations were performed:

Duty Cycle Calculation

The duty cycle is calculated as:

$$D = \frac{(V_{out}+V_D)}{(V_{in}+V_{out}+V_D)}$$

For the maximum duty cycle:

$$D_{max} = \frac{(V_{out}+V_D)}{(V_{in(min)}+V_{out}+V_D)} = \frac{(24+0.7)}{(8+24+0.7)} = 0.75$$

For the minimum duty cycle:

$$D_{min} = \frac{(V_{out}+V_D)}{(V_{in(max)}+V_{out}+V_D)} = \frac{(24+0.7)}{(21+24+0.7)} = 0.59$$

Inductor Ripple Current

The ripple current on the inductor is calculated as:

$$\Delta I_L = I_{out} \times \frac{V_{out}}{V_{in(min)}} \times 40\%$$

$$\Delta I_L = 2 \times \frac{24}{8} \times 0.4 = 2.4\,A$$

Inductor Capacity

The inductor value is calculated as:

$$L = \frac{V_{in(min)} \times D_{max}}{\Delta I_L \times F}$$

$$L = \frac{8\times 0.75}{1.2\times 40000} = 0.000125H = 125\mu H$$

Capacitor Value

The capacitor is calculated as:

$$C = \frac{D}{R\times 0.01\times F}$$

$$C = \frac{0.75}{12\times 0.01\times 40000} = 0.000156F = 156\mu F$$

Diode Selection

The diode reverse voltage (V_RD) is calculated as:

$$V_R D = V_{in(max)} + V_{out(max)}$$

$$V_R D = 21 + 63 = 84\,V$$

For the capacitor, the highest value chosen was 220 μF. For the inductor, a value of 100 μH was selected as it is more readily available in the market, though the calculated value is 125 μH. The Arduino's PWM signal output is 5V DC, which is insufficient to drive the MOSFET switch, requiring a MOSFET driver. The MOSFET driver circuit uses an optocoupler (TLP250). The SEPIC converter topology is shown in Figure 2.

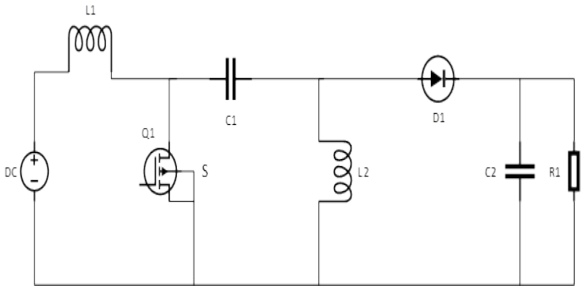

Figure 2. Topology SEPIC Converter

Results and Discussions

1. Solar Panel Characteristic Testing

In this stage, the solar panel was tested to evaluate its characteristics. The primary purpose of this testing was to determine the relationship between sunlight intensity, panel surface temperature, and the resulting output voltage. The solar panel used for this study is a 30 WP polycrystalline type. The measurement tools utilized include a lux meter to measure light intensity and a multimeter to record output voltage. The collected data is summarized in Table 2.

Table 2. Solar Panel Characteristic Testing

Testing Time	Light Intensity (Lux)	Solar Panel Surface Temperature (°C)	Output Voltage (V)
07.00	50100	29.1	18.77
08.00	889000	34.6	19.10
09.00	124600	39.7	19.35
10.00	171900	47.8	19.80
11.00	179400	48.5	19.88
12.00	167700	44.5	19.75
13.00	119900	32.7	18.9
14.00	73400	30.1	18.55
15.00	32200	29.9	18.01

The solar panel's characteristic graph, as derived from the test results, is illustrated in Figure 3.

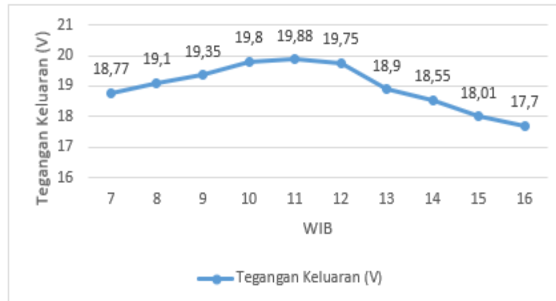

Figure 3. Solar Panel Characteristic Graph

2. SEPIC Converter Testing

The SEPIC converter was designed following the parameters calculated in the preliminary stages. The design includes various components calculated to meet the desired specifications, with a target output voltage of 24V. During testing, the converter was subjected to input voltages ranging from 16V to 21V, with a load resistance of 220 ohms. The goal was to confirm that the converter consistently produces the required 24V output. Table 3 provides the results.

Table 3. SEPIC Converter Testing

Duty Cycle (%)	Input Voltage (V)	Output Voltage (V)	Theoretical Output Voltage (V)	Error (%)
62	16.45	24.52	24.59	0.0028
58	16.89	24.47	24.36	0.0044
52	17.56	24.4	24.08	0.0132
51	17.78	24.43	24.19	0.0099
50	18.1	24,41	24.45	0.0016

46	18.63	24.48	24.38	0.0041
42	19.98	24.45	25.38	0.0360
34	20.45	24.4	24.5	0.0040
31	20.86	24.43	24.48	0.0020
29	21	24.42	24.31	0.0045

3. Testing Solar Panel with SEPIC Converter

The integration of the SEPIC converter with the solar panel was tested to measure its performance in charging a 24V battery system. The input and output voltages of the SEPIC converter were recorded, with results provided in Table 4.

Table 4. Testing Solar Panel with SEPIC Converter

Testing Time	Input Voltage (V)	Output Voltage (V)
08.00	19,78	24.23
09.00	19.7	24.31
10,00	19.83	24.41
11.00	20.12	24.58
12.00	19.94	24.43
13.00	19.68	24.33
14.00	19.56	24.27
15.00	19.22	24.21
16.00	18.71	24.19
17.00	14.1	24.12

The results from the solar panel and SEPIC converter testing indicate a direct correlation between light intensity and output voltage. As shown in Table 2, the highest light intensity recorded was 179,400 lux, producing an output voltage of 19.88V. The SEPIC converter testing yielded an average output voltage of 24.43V (Table 3), demonstrating its effectiveness in boosting and stabilizing the solar panel's output voltage. When integrated, the system achieved an average output of 24.26V (Table 4), confirming its ability to charge a 24V battery efficiently.

Conclusion

The SEPIC converter successfully achieved the target output voltage of 24V, as demonstrated by the consistent results from both standalone and integrated system testing. The results confirm that the system can effectively stabilize and boost the solar panel's output voltage to meet the requirements of charging a 24V battery. This system presents a reliable solution for enhancing renewable energy accessibility in rural areas, aligning with the goals of community service by improving energy infrastructure and sustainability.

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