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DESIGN OF MULTI INPUT SEPIC CONVERTER FOR WIND/ PV HYBRID ENERGY SYSTEM APPLICATION

Ratna Ika Putri, Muhammad Rifa'i, Ferdian Ronilaya, Ika Noer Syamsiana, and Septyana Riskitasari
Department of Electrical Engineering, State Polytechnic of Malang, Malang, Indonesia
E-Mail: ratna.ika@polinema.ac.id

ABSTRACT

An increase in the amount of electrical energy consumption in various sectors will have an impact on the depletion of different technological advancements that use electricity as their primary energy source. Of the various types of new renewable energy that have the potential to be developed, solar energy and wind energy have a high potential to be utilized as power plants. Meanwhile, the utilization of a new renewable energy generation system requires a power converter that functions to stabilize the output voltage and current values so that the power used to supply the load has good quality, optimum, and high efficiency. This article discusses the design of a multi-input Sepic converter circuit for wind turbines and photovoltaic hybrid energy systems. Sepic converter circuit is tested by simulation and experiment with frequency switching of 31 kHz. The prototype circuit is tested in the laboratory by adjusting the input voltage and duty cycle values. Based on the experiment results, the multi-input sepic converter has good performance with the highest output power of 130,634 watts.

Keywords: multi-Input sepic converter, wind power, photovoltaic, converter.

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INTRODUCTION

The increase in electrical energy consumption is also influenced by the development of various technological innovations that utilize electrical energy as its main energy source. The increasing consumption of electrical energy in Indonesia is inversely proportional to the number of fossil energy reserves that are dwindling. To overcome the energy crisis that has begun to occur, various developments in the application and renewable energy continue to be carried out. Another goal of developing Renewable Energy Sources (RESs) is also expected to be able to make a substantial contribution to energy efficiency and reduction of CO2 emissions to mitigate the negative consequences of climate change caused by the usage of fossil fuels which are still widely used for power generation [1]. Potential new renewable energy that can be utilized include geothermal, hydro, wind energy, solar energy, and bioenergy. From these various types of energy, the potential for solar energy and wind energy has great opportunities. However, the utilization of renewable energy sources, such as wind energy and solar heat as a source of electrical energy, has a weakness, namely dependence on weather conditions. Therefore, it is necessary to integrate with several renewable energy sources so that they can operate complementary to each other. In other words, the integration of several renewable energy sources results in a Hybrid Renewable Energy System (HRES) where solar energy sources are added to the wind energy system so that the sustainability of energy availability will remain even though wind energy is insufficient [2]. However, to be able to use it so that the power can supply the load, the solar and wind energy generator requires a converter that functions to optimize the output power generated by the generating system.

The converter is the most important part of a hybrid renewable energy system since it can control the output voltage even in unpredictable weather conditions. The power quality of a renewable energy system is highly dependent on the stable operation of the power converter and its control techniques. The boost converter is a device that is widely used in maximum power point tracking systems for solar energy generation. A boost converter with loop control is applied to keep the DC link voltage stable despite changes in the input voltage of the PV cell [3-4]. However, most of the use of conventional conversion and control techniques in renewable energy systems has various drawbacks. As a result, several research is being done right now on how to build DC-DC converters and efficient control methods for hybrid renewable energy systems [5].

DC-DC converters with an electronic architecture are more efficient than conventional power conversion methods. In hybrid PV and wind turbine systems that adopt the Perturb & Observe technique for maximum power extraction, the combined Sepic, Cuk, and Zeta converters were employed. Based on the simulation results, this topology has good performance and can produce stable energy [6]. The series of buck-boost converters connected in parallel has been tested on a hybrid energy system - battery using a fuzzy algorithm to adjust the controller. According to the results of the experiments, the output voltage can produce a fixed value and does not produce a ripple. By increasing the switching frequency, the converter system size can be reduced [7-8].

Of the various types of power converters that are widely used, such as Boost Converter, Buck Converter, Cuk Converter, Zeta Converter, and Sepic Converter. Of the various types of converters, the application of the Sepic converter is suitable for use in hybrid systems that can produce greater power and the Sepic which operates on CCM provides high efficiency in renewable energy applications [9-11]. Moradvour & Tavakoli [11] developed a Sepic converter coupled with an inductor for applications

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in renewable energy systems. This configuration provides the advantages of continuous input current, lower stress on switching components, and high power efficiency. Santos *et al* [12] developed a SEPIC topology with bridgeless isolation in order to increase the high power factor. To boost the power factor, this circuit is combined with a single-phase rectifier circuit with a sliding mode setting. Sabzali *et al* [13] integrated a SEPIC double boost converter (IDBS) for PV and fuel cell applications with switching control and two inductors. This topology can produce high voltage gain for alternative energy applications. Doshi & Harish [14] developed a Sepic converter for a wind solar hybrid system on a dc the microgrid system. Based on the outcomes of the simulation, this converter can operate at its best. Similarly, a Sepic and Cuk converter has been implemented in a wind-solar hybrid circuit [15]. For alternative energy applications, Sepic converters are used to increase high voltage gain and reduce voltage stress on the main switching components. The Sepic consists of two voltage multipliers, an inductor in this system. This circuit generates a steady input current that works well for applications for renewable energy. [16-18].

In this article, the construction of a multi-input Sepic converter will be made for a new renewable energy system with sources utilizing wind power and solar power. The design of the multi-input Sepic converter uses a Sepic converter circuit by combining two input sources from PMSG and Photovoltaic. The multi-input Sepic converter circuit simulation is carried out first using PSIM software to determine the performance of the designed converter, then experimental testing is carried out in the laboratory. The PWM test was performed in the experimental test, which functions for switching the multi-input Sepic converter circuit utilizing the Arduino Nano. Circuit performance testing is done by varying the value of the input voltage (PMSG and photovoltaic) and the value of the duty cycle.

SEPIC DESIGN FOR WIND/ PV HYBRID SYSTEM

Figure-1 shows a block diagram of a solar wind hybrid system using a Sepic converter. The wind turbine system consists of a PMSG and a 3-phase rectifier. The Sepic converter has two inputs connected to a 3-phase rectifier output and a Photovoltaic output. In the solar wind hybrid system, the duty cycle for the Sepic converter is controlled by the controller based on the output power of the PV and rectifier. The maximum rectifier output voltage is 100V, while the maximum PV output voltage is 36 V. And at the end of the system, the Sepic converter's output voltage is linked to the battery.

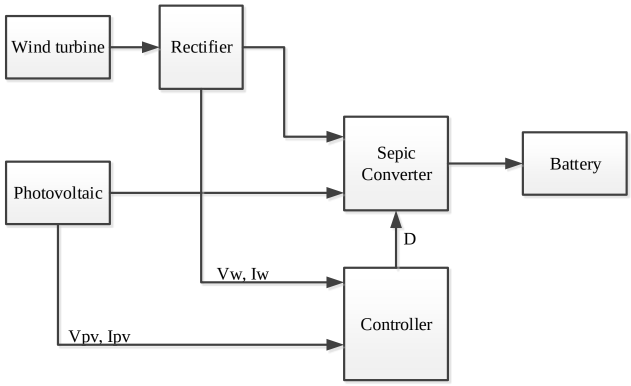

Figure-1. HRES solar wind using sepic converter.

Sepic converter for HRES, solar-wind consists of two Sepic circuits connected in parallel, as shown in Figure-2. The multi-input Sepic converter consists of two switching components S1 and S2, which will work based on the duty cycle received from the controller. The relationship between the output voltage (V_{OUT}), the input voltage (V_S), and the duty cycle (D) on the Sepic converter can be expressed by

$$D = \frac{V_{out}}{V_{Out}+V_S} \quad (1)$$

The inductor currents L_{1W} and L_{2W} in the Sepic converter connected to the rectifier circuit can be determined by

$$I_{L1W} = \frac{{V_{out}}^2}{V_S \, x \, R} \quad (2)$$

$$I_{L2W} = \frac{V_S \, x \, I_{L1}}{V_{out}} \quad (3)$$

The maximum output voltage of the rectifier is 100V, the L_{1W} inductor current on the WTS-connected Sepic converter (I_{L1W}) is 0.169 A, the L_{2W} inductor current (I_{L2W}) is 1.3A, and load resistance (R) is 400Ω. The value of the L_{1W} inductor could be calculated by

$$L_{1W} = \frac{V_S \, x \, D}{\Delta I_{L1W} \, x \, f} \quad (4)$$

The current ripple value of the L_{1W} inductor (ΔI_{L1W}) is 1 A, the minimum duty cycle is 0.1, and the switching frequency (f) is 31 kHz, so the L_{1W} value is 0.37 mH. While the value of the L_{2W} inductor may be calculated using

$$L_{2W} = \frac{V_S \, x \, D}{\Delta I_{L2W} x \, f} \quad (5)$$

The capacitor ripple voltage (ΔVc) is 0.01 V, and the capacitor value can be determined using the equation

$$C_{1W} = \frac{D}{R \, x \, f \, x \left({}^{\Delta V_C}/_{V_{Out}} \right)} \quad (6)$$

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With the output voltage connected to the battery and the switching frequency is 31 kHz, the C_{1W} and C_{2W} values are 482 µF.

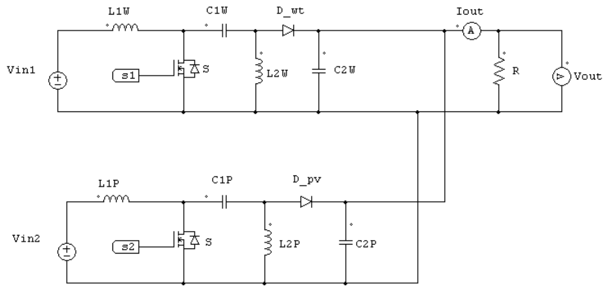

Figure-2. Circuit of Multi-Input SEPIC converter.

Similarly, the determination of the value of the inductor and capacitor in the Sepic converter circuit connected to the photovoltaic. The PV output voltage has an output range of up to 36 V with a maximum output power of 200 W. Using the switching frequency is 31 kHz, the inductor and capacitor parameters are obtained, as shown in Table-1.

Table-1. Parameter value of converter.

No.	Parameters	Wind Turbine	Photovoltaic
1.	Switching frequency	31 kHz	31 kHz
2.	Diode (D)	Schotty 20SQ045	Schotty 20SQ045
3.	Mosfet (S)	TLP 250	TLP 250
4.	Inductor (L_1)	3,711 x 10^{-4} H	3,081 x 10^{-4} H
5.	Inductor (L_2)	3,711 x 10^{-3} H	3,081 x 10^{-3} H
6.	Coupling Capasitor (C_1)	4,8244 x 10^{-4} F	1.112,57 x 10^{-6} F
7.	Output Capacitor (C_2)	4,8244 x 10^{-4} F	1.112,57 x 10^{-6} F

SIMULATION RESULTS AND DISCUSSIONS

Based on the component values that have been done, the Sepic converter circuit is simulated to display the performance of the circuit. Sepic, as shown in Figure-2, consists of two switching components driven by a PWM signal trigger circuit, as shown in Figure-3. The PWM signal trigger circuit generates a simulated cycle to control the switching components S1 and S2. The amount of the duty cycle value sent will determine the magnitude of the output voltage generated.

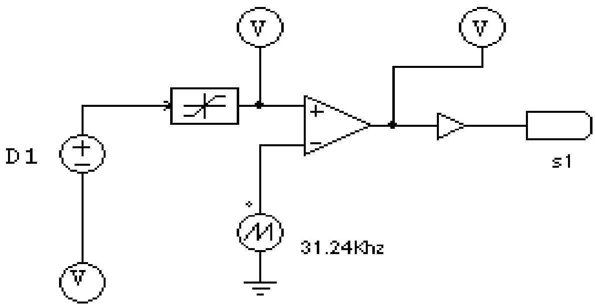

Figure-3. PWM signal trigger circuit.

Figure-2 is the main series of multi-input SEPIC converter simulations made on PSIM software, it has two SEPIC circuits that work to control the output voltage value from two separate energy sources, namely photovoltaic and wind turbines. The connection comes from the wind turbine (V_{IN1}) which can be set from 0-100 volts, while the input voltage comes from the photovoltaic (V_{IN2}) which can be set from 0-36 volts. In addition to the voltage values that can be varied in this multi-input SEPIC converter simulation, the duty cycle values that enter the two SEPIC circuits can also be adjusted in the range of 0.1 to 0.9 (10% - 90%).

The simulation is done by varying the value of V_{IN1}, V_{IN2}, and the values of the duty cycle, and then the output values of V_DC and I_DC generated by the multi-input SEPIC converter circuit are observed. Figure-4 shows the V_DC and I_DC signals from the multi-input SEPIC converter circuit when given a V_{IN1} of 10 V, V_{IN2} of 5 V, and a duty cycle of 10%. From the input combination, the resulting voltage is 4.8 V and the current is 0.96 A. Based on the simulation, the system response produces a high overshoot of up to 8.39 V at the voltage value and 1.67 A at the current value, then the output signal starts to stabilize after 0.22 seconds.

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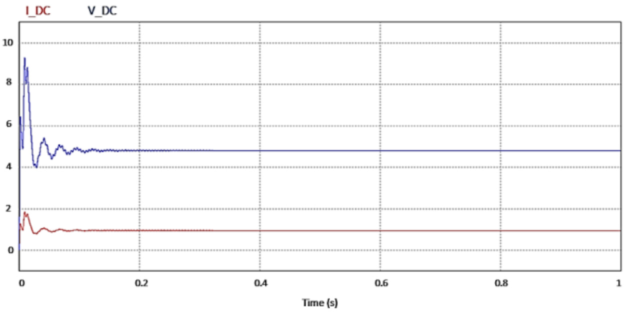

Figure-4. Output voltage and current.

To test the performance of the circuit, a test is performed by varying duty cycles at a specific input voltage. Figure-5 is a graph of the relationship between the output voltage and current when V_{IN1} is 25V, and V_{IN2} is 9V by varying the value of the duty cycle. The resulting output voltage and current depend on the given duty cycle. At the 50% duty cycle, the circuit produces an output power of 125 W. The greater the duty cycle, the greater the power generated. Figure-6 shows the output voltage of the multi-input Sepic converter with the input voltage V_{IN1} of 50 V, and V_{IN2} of 9 V by varying the duty cycle. The greater the input voltage, the greater the output power.

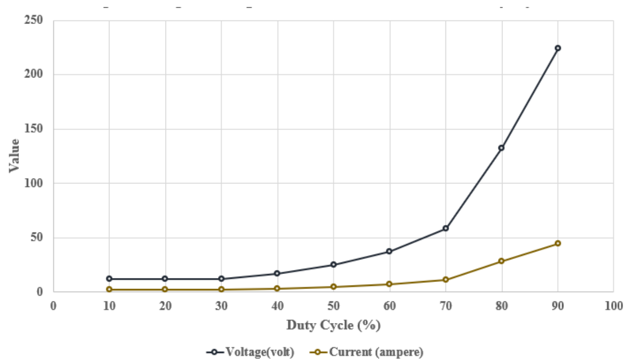

Figure-5. Output Voltage and Current with Variable Duty Cycle(V_{IN1} is 25 Volt and V_{IN2} is 9 Volt).

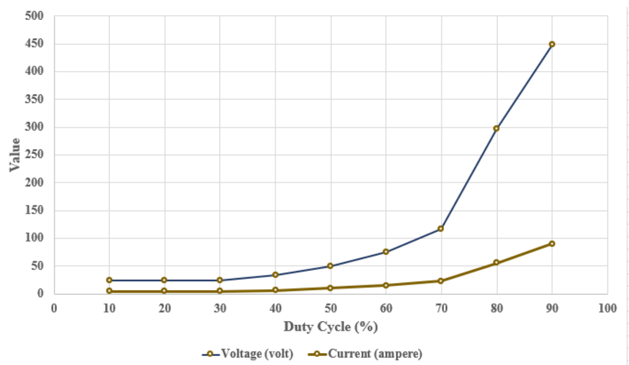

Figure-6. Output voltage and current with variable duty cycle (V_{IN1} is 50 Volt and V_{IN2} is 9 Volt).

HARDWARE EXPERIMENTAL RESULTS

A multi-input Sepic converter was constructed based on the modelling results, and experimental testing was performed as shown in Figure-7. The test is carried out by varying the two input voltages on the multi-input Sepic converter and changing the duty cycle. The controller generates the duty cycle of the PWM signal using an embedded system. Figure-8 shows the results of an oscilloscope measuring Pulse Width Modulation (PWM) signals generated by a controller with a duty cycle of 70%.

Figure-7. Experimental testing of multi-input sepic converter circuit.

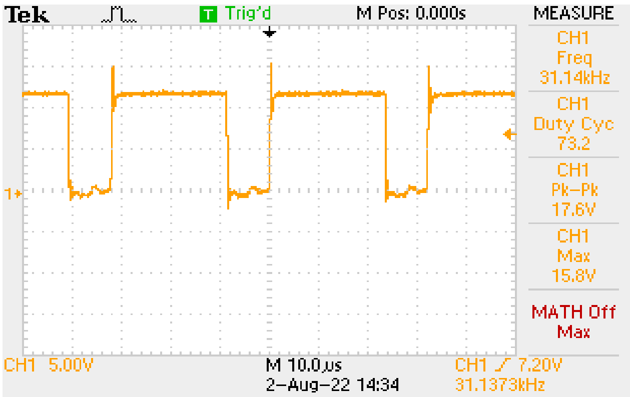

Figure-8. PWM signal with duty cycle 70%.

The test is done by adjusting the input voltage at V_{IN1}, V_{IN2}, and the duty cycle. The output voltage signal and output current of the multi-input Sepic converter circuit were observed through laboratory equipment. When the multi-input converter gets the input voltages V_{IN1} and V_{IN2} of 5 volts with a PWM signal with a 50% duty cycle, the resulting output voltage is 4.45V with an output current of 0.334A. Compared with the simulation results, when the duty cycle is 50%, the resulting output voltage has the same value as the input voltage. In the experimental results, the output voltage has an error of 0.55V.

While Figure-9 shows the experimental results of the multi-input SEPIC converter with V_{IN1} 5V and V_{IN2} 5V, where the duty cycle varies from 10% to 60%. Meanwhile, testing with a duty cycle value of 70% to 90% cannot be carried out due to the limited power supply which is only able to pass 3A current.

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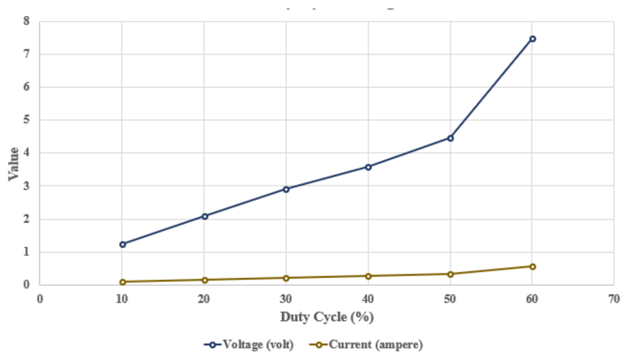

Figure-9. The Relationship of Output Voltage and Current with Duty Cycle Change.

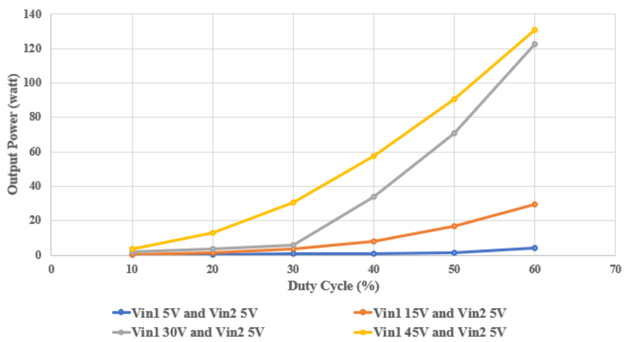

Figure-10. Output voltage with variations of duty cycle and input voltage.

Figure-10 shows the experimental results concerning the variation of the SEPIC converter's output power and duty cycle. Experiments were carried out with several variations of input voltage. The multi-input Sepic converter has a maximum output power of 130.634 watts.

CONCLUSIONS

This article has discussed the design of a multi-input SEPIC converter to optimize the performance of a hybrid renewable energy solar wind system. The multi-input SEPIC converter consists of two inputs and produces a voltage and current output that depends on the duty cycle. The input of the multi-input Sepic converter is linked to the wind turbine and PV system's circuit. Determination of the value of the parameters used in the multi-input SEPIC converter circuit is obtained through calculations based on the specifications of the capability of the energy source used. The performance test of the multi-input Sepic converter was made by simulation and experimentation. The multi-input SEPIC converter test is carried out by varying the value of the two input voltages and the value of the duty cycle. This system was tested at a switching frequency of 31 kHz and the variation of the duty cycle value is 10%-90%. Based on the test result, if the duty cycle is less than 50%, then V_{OUT} will be smaller than V_{IN}, if the duty cycle is equal to 50%, then V_{OUT} is equal to V_{IN}, and if the duty cycle is more than 50%, then the V_{OUT} will be bigger than V_{IN}. Based on experimental results, the multi-input Sepic converter circuit produces an output power of up to 130W. In the future result, this research will implement the adaptive P&O method to optimize the output power of the multi-input converter by setting the duty cycle.

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