Design of Sepic Converter for Renewable Energy System

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***Abstract*— The use of renewable energy is increasing to meet the need for electrical energy because the availability of fossil energy as fuel for electricity generation is running low. In addition, the use of renewable energy is environmentally friendly and pollution-free. The use of renewable energy systems requires a power converter that plays an important role to produce high power quality and efficiency. In this article, a Sepic converter circuit is designed for applications in photovoltaic systems. The Sepic converter performance is simulated using PSIM. In addition, the Sepic converter's hardware prototype was made and tested in a laboratory using an Arduino Uno microcontroller-based PWM generator. The duty cycle of the PWM signal, which is controlled by the microcontroller, determines how efficiently the Sepic converter performs. Based on the results of the simulation test and experiments on the plant, the designed Sepic converter can work well with a switching frequency of 31 kHz. It will provide an output voltage larger than the input voltage during a duty cycle over 50%.**

Keywords—Sepic converter, dc/dc converter, renewable energy

I. INTRODUCTION

The use of renewable energy is currently increasing in proportion to the limitations of fossil energy as fuel for electricity generation. Demand for electrical energy is projected to increase with an average growth of around 5.9% per year [1]. This condition causes an energy crisis in Indonesia so energy diversification by increasing the supply of new and renewable energy is needed to ensure energy availability. The development of renewable energy sources such as hydropower, geothermal, wind, solar, marine, and biomass has a lot of potentials if developed by Indonesia. Utilization of various types of renewable energy in the form of a photovoltaic, wind turbine, micro-hydro, and others requires a power converter to be used to adjust the input voltage in accordance with the application requirement. Power converters have already become a crucial component of power systems and driver engineering. Because it can stabilize the output voltage even in unpredictable weather conditions, the converter implementation is the most important part of the hybrid renewable energy system (HRES). The power quality of a renewable energy system is highly dependent on the power converter's stable operation and control techniques. However, the majority of conventional converters and control techniques used in HRES have a number of drawbacks. As a result, numerous studies on the design of DC-DC converters and effective control techniques for HRES have been conducted [2]-[6].

The use of electronic-based DC-DC converters will provide more efficient results than conventional power conversion techniques. Several types of converters have been researched and used in renewable energy systems, such as Buck converter, Boost Converter, Buck-Boost converter, and Sepic converter. A combined Sepic, Cuk, and Zeta converter have been used in hybrid PV systems and wind turbines that use maximum power extraction with the perturb & observe method. Based on the simulation results, this topology can produce stable energy and has good performance [7]. A sepic converter combined with a Cuk converter is used in hybrid wind/PV systems. Based on the simulation results, the converter can produce greater power efficiency [4], [8].

The use of a Sepic converter in a hybrid energy system has been simulated and proven to produce a good performance. The prototype of the circuit is designed using embedded systems [5]. The use of a Sepic converter that operates in CCM gives a high efficiency in renewable energy applications [6], [9], [10]. In addition, this converter is also suitable for multi-input converters that are applied in hybrid systems [11].

In this article, a Sepic converter will be designed for a renewable energy system whose performance will be tested through simulation and experiment. Simulation is carried out using PSIM, where the component parameters use values that are commonly used in the market and are adjusted to the hardware. Meanwhile, the hardware is tested in the laboratory using an Arduino Uno microcontroller as a PWM to drive the switching components on the Sepic converter. Testing the performance of the circuit is done by providing changes in the duty cycle of PWM pulse and input voltage. The simulation results will be compared with the experimental results.

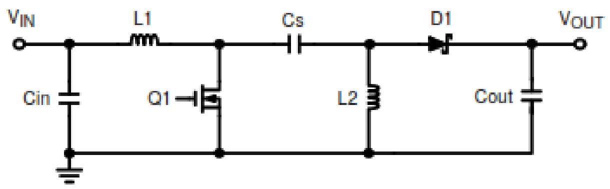
II. SEPIC CONVERTER

One type of converter, the sepic converter, would change the value of output voltage to be more or lower than the input voltage's value depending on the duty cycle (D) value that the circuit receives [12]. A Sepic converter is consisted of a switching component (Q1), two inductors, two capacitors, and a diode, as shown in Fig. 1(a). How the Sepic converter will work is dependent on the duty cycle which will determine the condition of the switch (Q1). There are two conditions in this converter, that is when Q1 is on or when Q1 is off, where the amount of energy exchanged is controlled by switch Q1 [3]. When switch Q1 is active, as shown in Fig. 1(b), the diode (D1) will be reverse biased so that current from the input will flow through inductors L1 and L2. This will increase current IL1 and voltage VL1 will approach the input voltage. The current in inductor L2 will become increasingly negative so that the voltage on L2 will approach the voltage on the capacitor (Cs). Energy and current that are stored in L2 will flow to the load.

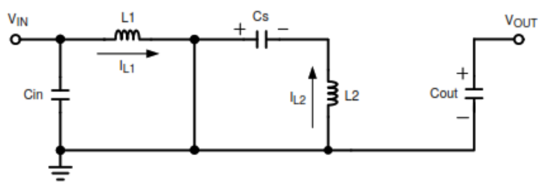
On the other hand, when switch Q1 is off, as shown in Fig. 1(c), the diode will be forward biased so that the current value in Cs will have the same value as the current L1 and the inductor's current IL2 will increase and then send power to the load. During this cycle, inductor L1 will charge capacitor Cs and power is sent to the load from inductors L1 and L2. Fig. 2 shows the inductor's current, capacitor, and switch Q1's conditions on the Sepic converter. The magnitude of the Sepic converter's output voltage can be expressed by (1).

$$V_{out} = \left(\frac{D}{1-D}\right)V_{in} \tag{1}$$

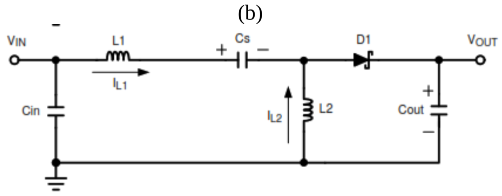
Where D is the duty cycle, V_{out} is the output voltage of the Sepic converter, and V_{in} is the input voltage of the Sepic converter.



(a)



(b)



(c)

Fig. 1. (a) Sepic Converter (b) During on Condition (c) During off Condition.

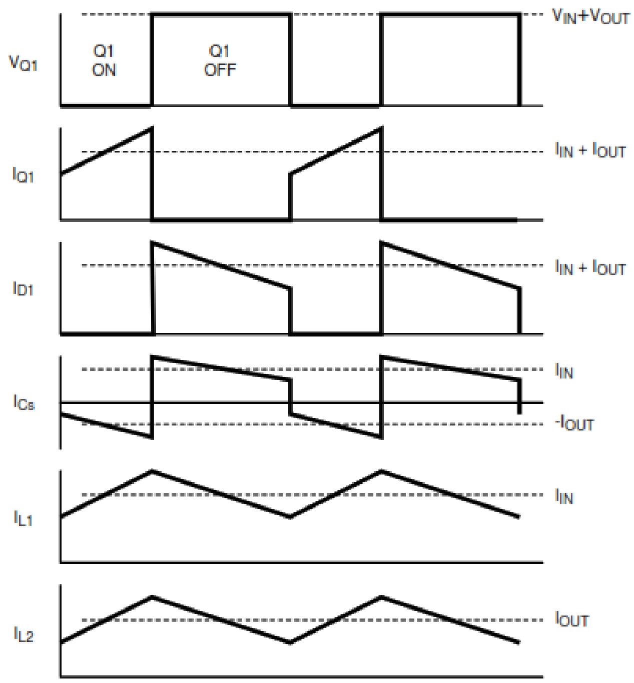


Fig. 2. Current inductor and capacitor in Sepic converter.

III. SEPIC CONVERTER DESIGN

In this paper, the output of the Sepic converter is connected to the load, and the input voltage of the Sepic converter is connected to the solar panel's output. Sepic converter operates in CCM. Maximum input voltage of the photovoltaic is 36 V, with the output voltage of the Sepic converter which will be connected to the resistive load.

- Inductor Selection

The value of the inductor is determined based on the peak to peak ripple current where ripple current in the inductor is limited to 25% of the input current (I_{in}) as shown in (2).

$$\Delta I_L = I_{in} \times 25\% = I_{out} \times \frac{V_{out}}{V_{in(\min)}} \times 25\% \tag{2}$$

With a maximum output current of 10 A, the peak-to-peak inductor current ripple (ΔI_L) is 6.5 A. The value of inductors can be calculated by (3).

$$L1 = L2 = L = \frac{V_{in(\min)}}{\Delta I_L \times f_{SW}} \times D_{\max} \tag{3}$$

Where the switching frequency (f_{SW}) is 31 kHz and the value of D_{max} at the minimum input voltage can be determined by (4).

$$D_{\max} = \frac{V_{out} + V_D}{V_{in(\min)} + V_{out} + V_D} \tag{4}$$

With a minimum input voltage ($V_{in(min)}$) of 5 V and a diode voltage (V_D) of 0.7, the maximum duty cycle (D_{max}) is 0.73. So that the value of the inductor L1 and L2 is 18 µH.

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The peak currents in the inductor ($IL_{1(peak)}$) and inductor 2 ($IL_{2(peak)}$) can be determined by (5) and (6).

$$I_{L1(peak)} = I_{out} \times \frac{V_{out}+V_D}{V_{in(\min)}} \times \left(1+\frac{25\%}{2}\right) \qquad (5)$$

$$I_{L2(peak)} = I_{out} \times \left(1+\frac{25\%}{2}\right) \qquad (6)$$

The Peak current in inductors L1 and L2 is 30.8 A and 11.25 A.

- Capacitor Selection

In a Sepic converter, there are coupling capacitors and output capacitors. Determination of the value of the C_C depends on the I_{RMS} and ripple voltage peak to peak capacitor. The I_{RMS} in the C_C called $I_{CC(rms)}$ is given by (7).

$$I_{CC(rms)} = I_{out} \times \sqrt{\frac{V_{out}+V_D}{V_{in(\min)}}} \qquad (7)$$

The ripple voltage in the coupling capacitor (ΔV_{Cc}) is given by (8).

$$\Delta V_{CC} = \frac{I_{out} \times D_{\max}}{C_C \times f_{SW}} \qquad (8)$$

With a capacitor's ripple voltage of 0.5 V, a coupling capacitor's value of 470 F can be determined. Parameters that have been calculated and adjusted to the existing market conditions are shown in Table I.

IV. Discussion and Result

A. Simulation Result

The designed Sepic converter was tested through simulation using PSIM as shown in Fig. 3. The duty cycle is generated by the PWM signal generator. Fig. 4 shows the V_{out} and I_{out} signal of the Sepic converter when it is given an V_{in} of 18 V and D of 60%. The resulting output voltage is 30 V. The V_{out} of the response has a fairly large overshot.

B. Hardware Experimental Result

A simulated sepic converter is created and tested experimentally in a laboratory. PWM pulses are generated by the Arduino Uno embedded system which will adjust the PWM pulse frequency and duty cycle. The Sepic converter is designed based on the parameters shown in Table I. Fig. 5 shows the experimental setup of the Sepic converter's circuit in the laboratory. IRF 150 is used as a switching component and the input voltage can be adjusted from 10 V – 36 V.

The switching frequency used in this circuit is 31 kHz and The duty cycle can be varied within a certain range of 10% - 90%. The resulting PWM output signal is shown in Fig. 6, while the output voltage of the Sepic converter is shown in Fig. 7.

TABLE I. Parameters of Sepic Converter

No.	Parameters	Value
1.	Switching frequency	31 KHz
2.	Diode (D)	20SQ045
3.	Mosfet (S)	IRF150
4.	Inductors (L1)	20 µH
5.	Inductors (L2)	20 µH
6.	Coupling Capacitor (Cc)	470 µF
7.	Output Capacitor (Cout)	4700 µF

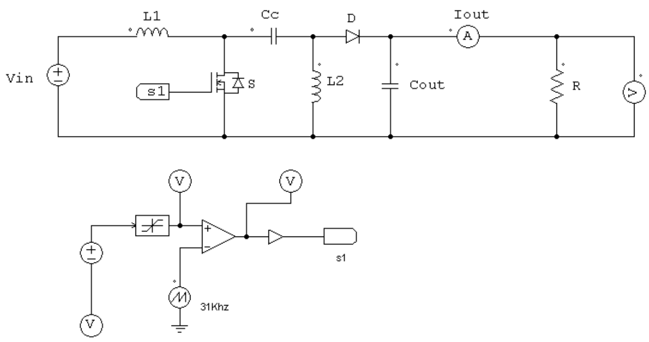


Fig. 3. Simulation of Sepic Converter.

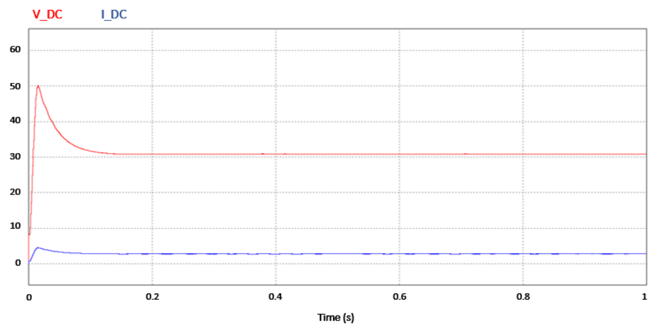
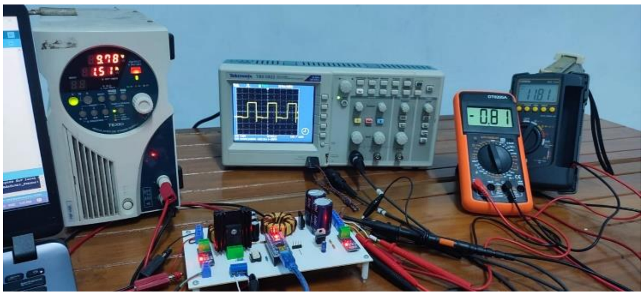


Fig. 4. Current and Voltage Output Signal when Vin 18 Volt and Duty Cycle 60%.

At an input voltage of 10 V with a duty cycle of 60% and a resistive load of 14 Ω, the Sepic converter will produce V_{out} of 15.89 V and I_{out} of 1.16 A. To test the circuit's performance, a test is carried out by providing several changes in the duty cycle at a certain input voltage. The values of the inductors and capacitors used are shown in Table I. Fig. 7 shows the output voltages produced experimentally and simulated with changes in the duty cycle at the input voltage of 10 V. The experimental results are close to the simulation output voltage's values. At a duty cycle below 50%, the output voltage is lower than 10 V and at a duty cycle above 50%, it produces a voltage higher than the input voltage. Based on (1), with a duty cycle of 60% and an input voltage of 10 V, it will produce an output voltage of 15 V. The experimental results with an input voltage of 10 V and a duty cycle of 60% produce an output voltage of 15.89 V, while the simulation results produce 16.5 V.

(a)



(b)

Fig. 5. (a) Sepic Converter Circuit, (b) Experimental Setup of Sepic Converter Circuit.

(a)

(b)

Fig. 6. (a) PWM Signal with Duty Cycle 20%, (b) PWM Signal with Duty Cycle 60%.

The sepic converter test is also carried out by providing a change in the input voltage within a range between 10 V to 32 V. Fig. 8 shows the experimental results in the form of changes in the output voltage from the experimental results against the duty cycle for several input voltages. The resulting output voltage for the input voltage variation is in accordance with the plan. The greater the input voltage and the duty cycle, the greater the output voltage.

Fig. 9 displays the experimental results in relation to variations in the Sepic converter's output power and duty cycle. At the input voltage of 32 V, the Sepic converter can produce output power above 100 W. The Sepic converter circuit has worked according to the plan and it can produce an output power of 100 W.

Fig. 7. Sepic Converter Output Voltage.

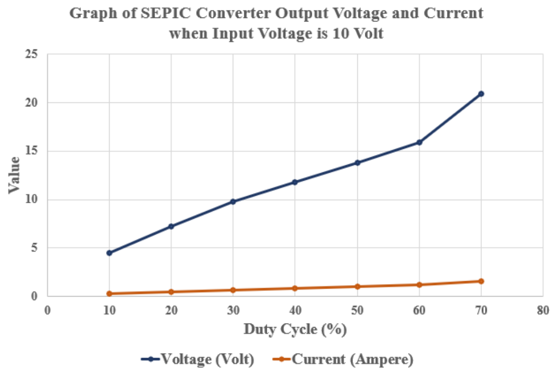


Fig. 8. Change of Output Voltage to Duty Cycle.

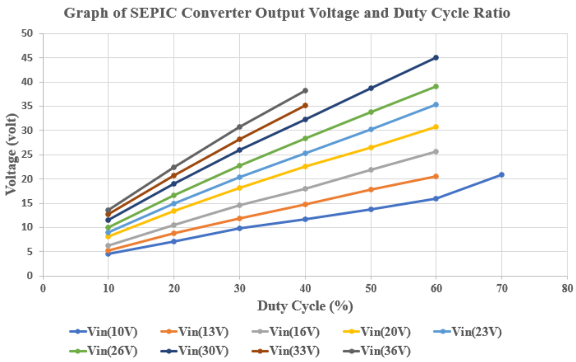


Fig. 9. Results of the Experiment with Various Input Voltages and Changing Output Voltage to Duty Cycle.

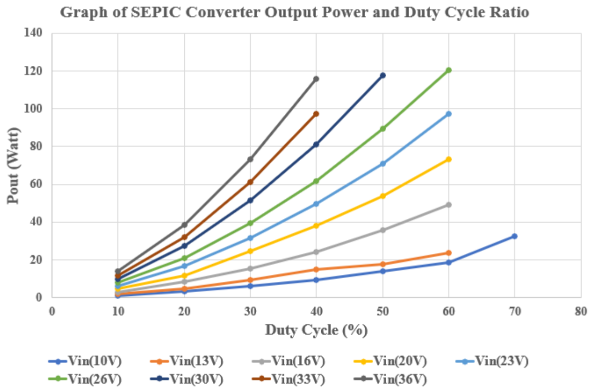


Fig. 10. Experiment Result of Output Power and Duty Cycle.

V. Conclusion

The Sepic converter design for applications in renewable energy systems has been described in this article. The determination of component parameters used is based on calculations and values of existing components. The Sepic converter performance testing is done by using simulation and testing in the laboratory for the prototype hardware made. By using PSIM, the Sepic converter is simulated and the hardware prototype is made to be driven by a microcontroller as a PWM generator. The duty cycle given to the switching component determines the Sepic converter's output voltage. If the duty cycle is less than 50%, the output voltage is less than the input voltage; whereas if the duty cycle is more than 50%, the output voltage will be greater than the input voltage. In the hardware prototype, the duty cycle is regulated through the embedded system microcontroller which produces a PWM signal with a switching frequency of 31 kHz. Based on the simulation and experimental results, the Sepic converter works well and can produce the highest output power of 100 W. The resulting voltage depends on the given duty cycle. In future research, control of Sepic converter for renewable energy system will be designed to increase systems efficiency.

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