Design of Sepic Converter for 3 Phase Inverter Input with PI Control Method

Mohammad Erik Echsony[1], Ikhsan Rizki Ramadhan[2], R. Akbar Nur Apriyanto[3], Rahayu Mekar Bisono[4], Adiratna Ciptaningrum[5], Darma Arif Wicaksono[6], R. Gaguk Pratama Yudha[7], Ibra Satriatama[8], Ananda Khoirunisa Putri[9]
[1,2,3,4,5,6,7,8,9]Politeknik Negeri Madiun, Madiun, Jawa Timur, Indonesia
*Corresponding Author Email: [2]iksanrizki1155@gmail.com

Abstract**—***The development of technology and the increasing demand for renewable energy have driven extensive research, particularly in the field of power conversion. However, most conventional step-up DC converters face limitations in achievable output voltage levels and suboptimal efficiency. DC-DC converter technology emerges as a solution that enables voltage conversion at different DC levels. In various applications such as electric vehicles and renewable energy systems, DC converters with significant voltage step-up capability are required without compromising efficiency. In this research, a SEPIC converter based on a Proportional-Integral (PI) control system was designed according to precise calculations and has successfully increased the voltage by up to four times with an average efficiency of 71% at specific duty cycle values. To improve output voltage regulation, the PI controller method, integrating control parameters (Kp = 0.8515) and (Ki = 0.003), which allowed the converter to increase input voltage (Vin: 72 Volts) to an output voltage (Vout: 311 Volts). This also reduced overshoot by up to 90% during the transient phase toward steady state without sacrificing efficiency. The designed SEPIC converter is expected to meet the energy demands of renewable energy applications.*

Keywords**—** *Sepic Converter, DC-DC converter technology, Proportional Integral (PI), Duty cycle.*

I. Introduction

The use of natural resources, especially fuel oil, has a negative impact on the environment such as air and noise pollution. If this increase in fossil fuel consumption is not accompanied by an acceleration of fossil fuel production, Indonesia risks experiencing a shortage of fuel oil. Oil production in Indonesia was around 686,000 barrels per day in January 2021. Pollution from exhaust gases is one example of environmental damage generated by the use of motor vehicles. Motor vehicle emissions have various chemical compounds such as CO, NOx, SOx, HF that pollute the environment, bringing negative impacts on the environment and health.[1]

The development of technology and the increasing need for renewable energy have encouraged research, especially in the field of electric-based vehicles. In the development of electric vehicles, there are many components that need to be developed, especially in the field of power conversion. DC-DC Converter technology comes as a solution that allows DC voltage conversion at different levels. In various applications such as electric vehicles, renewable electrical energy, DC converters are needed with significant voltage step-up capability without losing efficiency. However, most conventional step-up DC converters have limitations on the output voltage values that can be achieved as well as sub-optimal efficiency.

Single Ended Primary Inductor Converter is a type of DC-DC boost converter that can operate as a step-up mode. In step-up mode the SEPIC converter topology can increase the voltage up to 4 times with a Duty Cycle of 80%.[2]

Based on this background, the author takes the research title "Design of Sepic Converter for 3 phase inverter input with Proportional integral (PI) Control Method". As a solution to meet the increasing need for renewable energy in the field of power conversion. In this study with 72Vdc/10A input will be (Step-Up) through Sepic converter to reach a voltage of 311Vdc/12Ah or 4 times with Duty Cycle reaching 80% using the Proportional integral (PI) controller method. The application of this Converter is expected to be able to answer the needs of renewable energy in various applications that require more efficient and optimal voltage conversion.

II. Methodologies

SEPIC Converter (Single-Ended Primary Inductance Converter) is a type of DC-DC converter that can function as increasing the voltage of the input voltage. The polarity between the input and output voltage is the same. SEPIC converters can also operate on continuous and discontinuous.

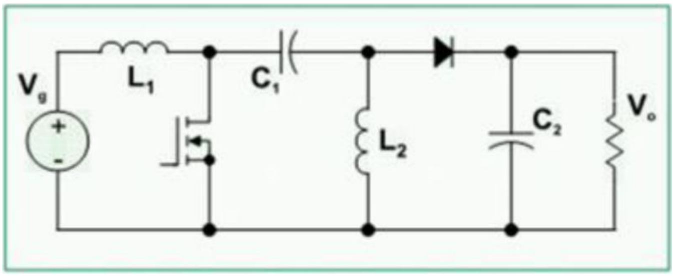

Figure 2. 1 Reaction Response Orde 2 [3]

In the Sepic Converter circuit there are several components and their functions are different. Sepic Converter has a work cycle in the Sepic converter circuit. In the Sepic Converter circuit components have the following functions:

A. Inductor Design

In the Sepic converter circuit, two inductors have a function to store energy in the form of a magnetic field when

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current flows into the inductor. The stored energy is released when switching in the off state, thus helping in the regulation of the voltage to be achieved. In the Sepic Converter circuit to calculate the inductance value in the Sepic Circuit. There is an equation for Inductor design as follows:

a) Current Ripple Inductor

$$\Delta IL = Iin \times 20\% = 10 \times 20\% = 2A$$

b) Value Inductor

$$\Delta IL = \frac{Vin \times D}{L \times fs}$$

$$2A = \frac{72V \times 0{,}81}{L \times 100Khz}$$

$$L = \frac{72V \times 0{,}81}{2 \times 100Khz}$$

$$L = 291{,}6\ \mu H$$

c) Inductor Maximum Current

$$Imax = Iin + \frac{\Delta IL}{2}$$

$$Imax1 = 10 + \frac{2}{2} = 11\ A$$

$$Imax2 = 11 + \frac{2}{2} = 12\ A$$

d) Inductor RMS Current

$$ILrms = \sqrt{{I_{in}}^2 + \left(\frac{\Delta IL/2}{\sqrt{3}}\right)}$$

$$ILrms1 = \sqrt{10^2 + \left(\frac{2/2}{\sqrt{3}}\right)} = \sqrt{10^2 + 0{,}577} = 10{,}02\ A$$

$$ILrms2 = \sqrt{12^2 + \left(\frac{2/2}{\sqrt{3}}\right)} = \sqrt{12^2 + 0{,}577} = 12{,}02\ A$$

e) Number of Inductor turns

$$N = \frac{L \times I_{max}}{B_{max} \times A_c} \times 10^6$$

$$N1 = \frac{291{,}6 \times 10^{-6} \times 11}{0{,}25 \times 3{,}28 \times 10^{-4}} = 39{,}1$$

$$N2 = \frac{291{,}6 \times 10^{-6} \times 12}{0{,}25 \times 3{,}28 \times 10^{-4}} = 42{,}5$$

f) Length Inductor wire diameter 1

$$I_{SPLIT} = \frac{IL_1 rms}{split} = \frac{10{,}2}{9} = 1{,}11\ A$$

$$Q_w = \frac{I_{SPLIT}}{j} = \frac{1{,}11}{4{,}5} = 2{,}2267 mm^2$$

$$D_w = \sqrt{\frac{4}{\pi} \times Q_w} = \sqrt{\frac{4}{3{,}14} \times 2{,}2267 mm^2} = 1{,}6836\ mm$$

$$\Sigma = (N \times Around\ Bobin \times \Sigma I_{SPLIT}) \times 150\%$$

$$\Sigma = (39{,}11 \times 3{,}14 \times 2{,}6 \times 10^{-2} \times 9) \times 150\%$$

$$= 43{,}10\ m$$

g) Length Inductor wire diameter 2

$$I_{SPLIT} = \frac{IL_1 rms}{split} = \frac{12{,}2}{10} = 1{,}202\ A$$

$$Q_w = \frac{I_{SPLIT}}{j} = \frac{1{,}202}{4{,}5} = 0{,}267 mm^2$$

$$D_w = \sqrt{\frac{4}{\pi} \times Q_w} = \sqrt{\frac{4}{3{,}14} \times 0{,}267} = 0{,}58\ mm$$

$$\Sigma = (N \times Around\ Bobin \times \Sigma I_{SPLIT}) \times 150\%$$

$$\Sigma = (42{,}5 \times 3{,}14 \times 2{,}6 \times 10^{-2} \times 9) \times 150\%$$

$$= 52{,}02\ m$$

h) Thick Airgap

$$I_g = \frac{\mu_O \times L \times i^2{}_{max} \times 10^4}{B^2{}_{max} \times A_c}$$

$$I_g1 = \frac{4\pi \times (10^{-7}) \times 291{,}6 \times 11^2 \times 10^{-7}}{(0{,}25)^2 \times 328} = 2{,}16\ mm$$

$$I_g2 = \frac{4\pi \times (10^{-7}) \times 291{,}6 \times 12^2 \times 10^{-7}}{(0{,}25)^2 \times 328} = 2{,}57\ mm$$

B. Capacitor

Capacitor is an electrically passive two-terminal component used to store energy in an electric field. Basically, a capacitor consists of two electrical conductors separated by an insulator. In the Sepic converter circuit, there are two capacitors that function to connect two inductors that are large enough to store and release energy without causing significant ripple [4]. To calculate the Capistor value of the Sepic Converter on the Sepic Circuit. There is a capacitor value equation as follows:

$$\Delta Vo = 0{,}1\% \times Vo$$
$$= 0{,}1\% \times 311$$
$$= 0{,}311\,V$$
$$\Delta Vo = \frac{V_{out} \times D}{R \times C \times f_s}$$
$$0{,}311 = \frac{311 \times 0{,}81}{25{,}9 \times C \times 100Khz}$$
$$C = \frac{311 \times 0{,}81}{25{,}9 \times 0{,}311 \times 100Khz}$$
$$C1, C2 = 312{,}73\ \mu F$$

C. Resistor

Resistor is a passive electrical two-terminal component that serves to inhibit the amount of electric current flowing in the electrical / electronic circuit. The current through the resistor is in direct proportion to the voltage at the terminals of the resistor. Thus, the ratio of the voltage applied at the terminals of the resistor to the intensity of the current through the circuit is called resistance. This relationship is represented by Ohm's law. The unit of resistance of a resistor is ohm [4]. In determining the resistance value, the equation is obtained as follows:

$$R = \frac{V_O}{I_O}$$
$$R = \frac{311}{12}$$
$$R = 25{,}9\Omega$$

D. MOSFET

MOSFET (Metal Oxide Semiconductor Field Effect Transistor) is intended for switching with a large current capacity. There are two types of MOSFET, namely MOSFET type n and type p. MOSFET has three legs, namely gate, drain and source legs. The following figure 3 is a picture of the n-type and p-type MOSFET symbols. [3]

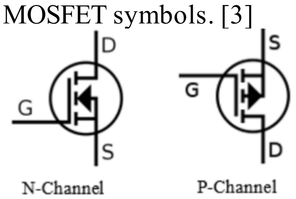

Figure 2. 2 Symbol of n- and p-channel MOSFET [3]

E. Dioda

In a Sepic Converter circuit the diode provides a current flow path when the switch (MOSFET) is in the off state. This allows the energy stored in the inductor to be released to the load or stored in the output capacitor. By providing a path for reverse current to flow, the diode prevents overvoltage that can occur when the switch changes from the "on" to the "off" state. Output diode determination should be chosen to cope with both peak current and reverse voltage. In SEPIC, the diode peak current is equal to the IQ1 peak current.[3]

F. PWM (Pulse Width Modulation)

PWM signals are signals that operate at frequency. to control the output voltage in order to achieve optimal performance efficiency the role of Duty Cycle is very important. Duty Cycle is the fraction of a period in which a signal or system is active. Duty cycle is generally expressed as a percentage or ratio. Period is the time it takes for a signal to complete an on-off cycle. Duty Cycle is a working factor on the switch, the output voltage can be changed by varying the Duty Cycle value on the switch. [3]. to achieve optimal performance efficiency. To determine the variation of the value of the switch, the following equation is obtained :

$$D = \frac{V_O}{V_O + V_I}$$
$$D = \frac{311{,}13}{311{,}13 + 72}$$
$$D = 0{,}81$$

G. PI (Proportional integral)

PI (Proportional integral) controller is a mechanism for close loops that is widely used in industrial processes. This PI controller algorithm is a combination of two separate types of parameters, namely proportional constants and integral constants. [5]

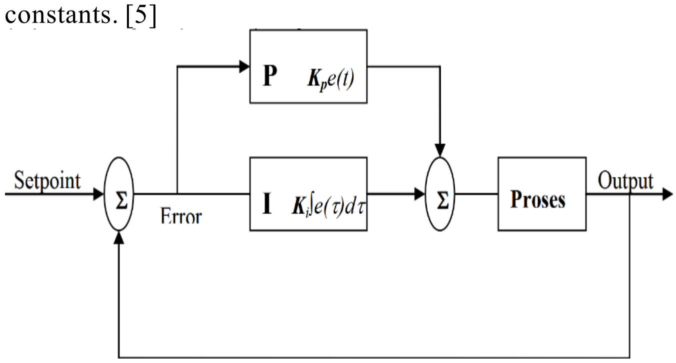

Figure 2. 3 Controller Block Diagram of PI Controller [5]

To speed up the reaction of a system and eliminate controller offset with proportional control added with integral controller the relationship is u(t) as the output of the controller and e(t) is the error signal. [6].

III. Results and Analysis

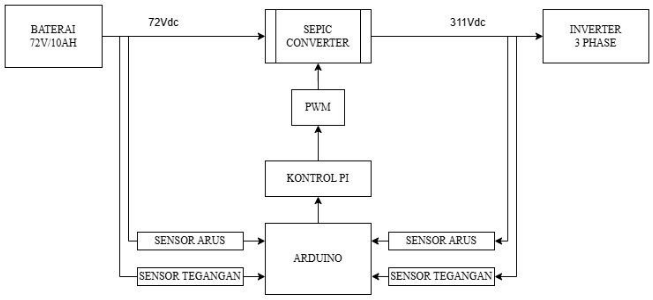

Figure 3. 1 Block Diagram

In Figure 3.1 The power source used in this study uses a battery as a supply for the Sepic converter for the power conversion process. The battery that will be used is a VRLA (Valve-Regulated Lead Acid) battery. Then, SEPIC Converter (Single Ended Primary Inductor Converter) is a type of power converter that can convert 72vdc input voltage to 311vdc output voltage with good and optimal efficiency. The control system used in this study uses the Proportional integral (PI)

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method. Serves to regulate the stability of the output voltage to achieve the expected voltage efficiency. This control system was chosen because it can control the Duty Cycle and can control the output voltage precisely and maintain stability in the output voltage of the Sepic Converter. to achieve optimal performance efficiency. The inverter functions to receive loading voltage output from the Sepic converter will be converted from 311vdc voltage to 3 phase AC voltage to be distributed to the device.

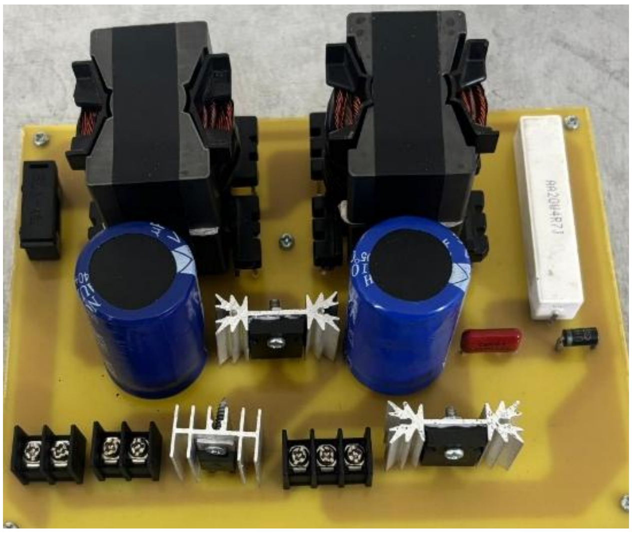

Figure 3. 2 Sepic Converter circuit

A. Open loop system septic converter testing

Testing sepic converter will be done Opeen Loop system with 72 Volt input to find out the system can work properly as shown in Figure 3.3

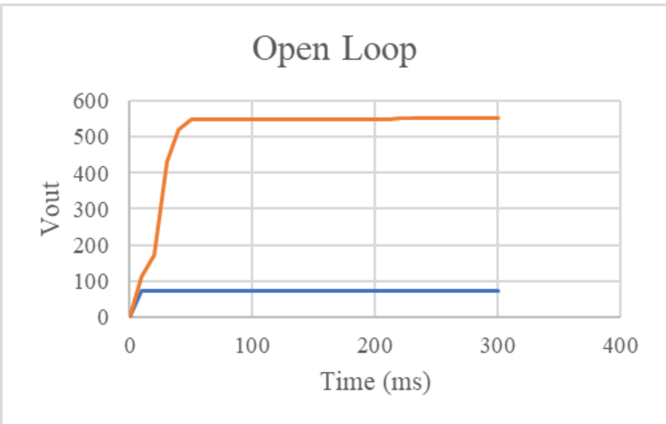

Figure 3. 3 Graphic Open loop

In Figure 3.3, the results obtained at 10 ms, the output voltage is at 110.9 V and then experiences Overshoot within 30 ms, the Vout value experiences a very high overshoot until it reaches 430.2 V. This value far exceeds the expected set point value. This value far exceeds the expected set point value. Then at a voltage value range of 60 ms to 300 ms the overshoot continues to increase slowly ranging from 547.9 to 554.1 V. In the Open Loop system the voltage cannot reach the set point 311, the voltage experiences a fairly high steady state error.

B. Testing Sepic converter with Load

Testing Sepic converter will be given a Duty cycle value of 0.5 with a maximum input voltage of 72 Volts and later the output of the Sepic converter will be connected to a 24 Volt DC lamp load which we series 14 lamps with a total load of 336 Volts to determine the output voltage.

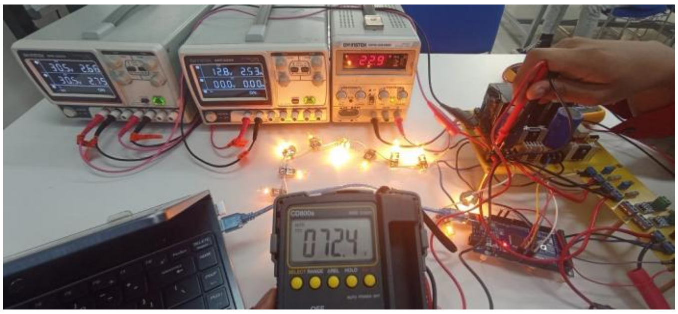

Figure 3. 4 Testing Sepic converter with load

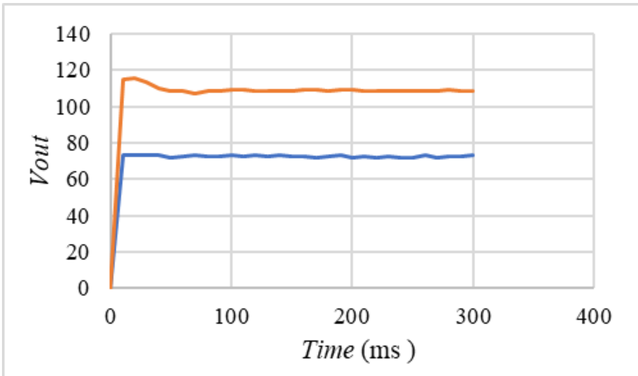

Figure 3. 5 Graphic Sepic converter with Duty Cycle 0,5

TABLE 3. 1 Sepic Converter Power Efficiency

Vin	*Vout*	*Iin*	*Iout*	*Pin*	*Pout*	*n (%)*
72.2V	108.2	2.75	2.58	198,55	279,1	71%

Based on the test results data listed in Table 3.1 shows that the Sepic converter that has been designed can work well. At Duty Cycle 0.5 with 72Volt input, it is able to increase the voltage to 115Volt at the beginning of operation then the voltage can stabilize at 108 Volts as shown in the voltage graph in Figure 3.5 and in Table 3.1 Sepic converter has a pretty good performance with an efficiency value of 71%.

C. Closed Loop System Sepic Converter Testing

In testing the sepic converter using PI control will be given a voltage input of 72 Volts with a Setpoint of 311 Volts. Testing sepic converter using PI control will be carried out Close loop system to determine the stability and performance of the PI control system is able to achieve the expected Set point.

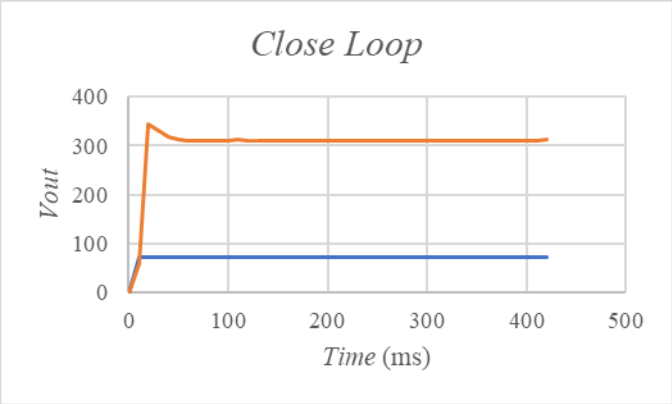

Figure 3. 6 Graphic *Close loop*

From the results of testing the Sepic converter with the Open loop system shown in Figure 3.6 graph, the voltage results experienced a high overshoot required a control system to control the voltage in accordance with the expected set point. Then the results obtained in Figure 3.6 testing in the Close loop system with parameter values KP = 0.05815, and KI = 0.003, at the beginning of operation the system can reach the setpoint at 50ms and the voltage stabilizes at the set point 311Volt able to reduce overshoot. PI control is able to maintain voltage stability and is able to reduce the occurrence of overshoot in the converter. PI control has been able to control the voltage by increasing the voltage quickly and still maintaining stability in the voltage according to the expected set point.

IV. Conclusions

After going through several processes of planning, making, testing tools, and taking data obtained from testing the Sepic converter tool, conclusions can be drawn, including :

1) Sepic converter is in accordance with the calculation and design of the tool. Able to work well with a Duty Cycle value of 0.5. After testing with a load, the Sepic Converter has very good Power Efficiency with an average of 71%.
2) Sepic converter has not been able to reach 311 with Duty Cycle 0.8 using a load due to limitations in input using a power supply has limitations in the value of current only reaching 3A. This test has not actually used a 72 Volt 10Ah battery.
3) R PI control response to control Sepic converter is able to reduce overshoot is able to reach the set point with time in (50ms) and is able to maintain a relatively stable output level of 311V.

Thus it can be concluded that the PI controller system on the Sepic converter that has been designed in accordance with the initial calculations is able to work well and has a very good efficiency in running the system.

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