Design SEPIC Converter for Battery Charging Using Solar Panel

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Abstract. Indonesia is a tropical country and has a great potential in alternative source of solar energy. Solar energy is friendly for environmentally because it does not make pollution and is renewable energy. Using solar energy can reduce fossil energy which is this energy can’t be renewed and if used continuously it will be used up. Sunlight is solar energy that can convert the light energy into electrical energy by using solar panels. This paper presents details the design of the SEPIC Converter to Supply Electrical Energy to a Smart Lamp with Solar Energy. Sunlight energy is not always in maximum condition, so to maximize the power produced by solar panels are needed a control system to maximize the output power of converter. This experiment use 2 solar panels, each of 100 WP and arranged in parallel. The control system use PI control. The function is to generate the output voltage for battery charging. Time response of PI control is 0.6 s to according to the set point value of 14 volt for battery charging with the battery capacity is 20 Ah 12 volt. Cohen Coon method is used to find the PI control parameter. So using PI control with Cohen Coon method can make battery charging according to the set point even though solar panels has shading.

1. Introduction

Electricity is an important energy for daily life. Electric energy is relying with fossil energy, whereas the existence of fossil energy is become smaller as electric demand increases due to people’s lifestyles that are wasteful of electrical energy. Since 1991, Indonesia’s oil production has decreasing. To solve these problems, Indonesia advanced and explored alternative energy source of renewable energy. One of them is solar energy [1-3].

The weakness of the solar energy is the energy only produced from solar radiation, so at night the solar energy is not generated, therefore is needed a battery to store the energy produced during at the irradiation process. So at night we can use electricity stored in batteries [1], [4-5]. The power generated from solar panels is often unstable value due to changes of intensity of sunlight caused by erratic weather, therefore a DC-DC SEPIC converter is used with an algorithm using PI control to set the duty cycle value PI controller is a control methods used to produce a constant output [5], [7-9]. Each of advantages and disadvantages of each controller P and I can cover each other by combining the two in parallel into a proportional plus integral controller. The elements of the P and I controllers respectively aim to accelerate the response of a system and get rid of the offsets. To find the parameter of PI control in this paper using Cohen Coon method [10]. SEPIC converter can convert DC to DC voltage bigger or smaller than the input voltage without reversing polarity.

2. Design System

Converter with the name of SEPIC (Single Ended Primary Inductor Converter) converter is a derivative topology from the buck-boost converter, both of these converters can generate output voltages that can be larger or smaller than the input voltage but the polarity of buck-boost converter output voltage is inverse, while SEPIC without reversing the polarity, other than that adding capacitors and inductors to the SEPIC converter can cut down the value of the output ripple [11-15]. The design of proposed SEPIC converter was shown in Figure 1.
Figure 1. The Proposed SEPIC Converter

Figure 1 explained that the SEPIC converter is getting an input voltage from the solar panel that will be used for battery charging. The output voltage of the SEPIC converter will be regulated using STM32F40VG microcontroller to match the battery charging process. In microcontroller will set the duty cycle of SEPIC converter with a PI control algorithm.

A. Planning of SEPIC Converter

In this paper have planned SEPIC converter with the voltage of output is 14 volt. SEPIC converter can generate output voltage which one can be bigger or smaller than input voltage but without reversing polarity [16]. Kirchhoff’s Voltage Law around the path containing $V_s$, $L_1$, $C_1$, and $L_2$ gives,

$$-V_s + V_{L1} + V_{C1} - V_{L2} = 0$$

(1)

At the closing of switch, the diode will be off and Figure 2b shows the circuit. The cross voltage $L_1$ for the $DT$ interval is,

$$V_{L1} = V_s$$

(2)

At the opening of the switch, the diode will be on and Figure 2c shows the circuit. KVL on the outer lane is

$$-V_s + V_{L1} + V_{C1} + V_0 = 0$$

(3)
Figure 2. (a) Circuit of SEPIC; (b) Circuit of SEPIC at closing switch and diode off; (c) Circuit of SEPIC at opening switch and diode on

At interval \((1 - D)T\). Because for periodic operation the average voltage transverse an inductor is zero, the equation becomes,

\[
V_s(DT) - V_o(1 - D)T = 0
\]  

(4)

Where the duty cycle of ratio the switch is D, the result is

\[
D = \frac{V_o}{V_o + V_s}
\]  

(5)

The equation of CUK converter and buck-boost converter are similar to this equation. A capability to have a voltage output larger or lower than input voltage without reversing the polarity made this converter applicable for various appliances. The equation of current source can be examination by,

\[
I_{L1} = I_T = \frac{V_{ol0}}{V_s} = \frac{V_o^2}{V_{SR}}
\]  

(6)

Figure 3 shows the current waveform. In Figure 3c apply Kirchhoff’s Law of KVL, it is assumed is no rippling voltage on the capacitor, express an opening of switch the voltage going through is \(V_s + V_o\). 
From Figure 3b, diode is off and maximum reverse voltage is $V_s + V_o$. $C_2$, Diodes and load resistors are part of the output side is equal with boost converter, to determine the output of ripple voltage is,

$$
\Delta V_o = \Delta V_{cs2} = \frac{V_o D}{R \cdot C_2 \cdot f} \quad \text{(7)}
$$

Then $C_2$ is,

$$
C_2 = \frac{D}{R (\Delta V_{o} / V_o) f} \quad \text{(8)}
$$

To determine the variation of voltage in $C_1$ on the figure of the circuit when the switch is closed. The reciprocal of the capacitor current is $i_{c2}$, which has reversely been searched to have an $I_o$ average value. The equation is,

$$
\Delta V_{C1} = \frac{\Delta Q_{c1}}{C} = \frac{i_o \Delta t}{C} = \frac{I_o DT}{C} \quad \text{(9)}
$$

So $C_1$ is,

$$
C_1 = \frac{D}{R (\Delta V_{c1} / V_o) f} \quad \text{(10)}
$$

![Figure 3. SEPIC converter current. (a) L1; (b) L2; (c) C1; (d) C2; (e) switch; (f) diode](image)

**B. Design PI Controller**

Cohen Coon method is used to improve the oscillation method by using the quarter amplitude decay method. Quarter amplitude decay is defined as the transient response which is the amplitude at the first period has a ratio of a quarter (1/4). The proportional Kp controller is tuned until it is obtained quarter amplitude decay response, the period when this response is called Tp and Ti parameters and Td is calculated from the combination of Kp with Tp. In Table I explain the parameter tuning using Cohen Coon method.
### Table 1. Parameter Tuning Using Cohen-Coon Method

| Controller Type | Kp | Ti | Td |
|-----------------|----|----|----|
| P               | \( \frac{1}{R} \left( \frac{T}{L} \right) \left( 1 + \frac{1}{3} \frac{L}{T} \right) \) | - | - |
| PI              | \( \frac{1}{R} \left( \frac{T}{L} \right) \left( 0.9 + \frac{1}{12} \frac{L}{T} \right) \frac{9 + 20 \left( \frac{T}{L} \right)}{30 + 3 \left( \frac{T}{L} \right) \left( \frac{L}{T} \right)} \) | - | - |

The SEPIC converter is simulated using an open loop and the K parameter is 0.97 and the open loop transfer function (OLTF) generate an equation \( \frac{0.97}{0.0325+1} \). After determine the K parameter and OLTF equation, it can determine the parameters of Kp, Ki, and close loop transfer function (CLTF). By using the Cohen Coon method, the Kp value is 5.155 and the Ki value is 32.21. For the close loop transfer function (CLTF) is \( \frac{1}{0.325+1} \).

### 3. Result and Discussion

In this section, we will discuss the results of testing of the SEPIC converter with open loop and close loop systems.

#### A. SEPIC Converter Testing in an Open Loop Transfer Function System (OLTF)

In this open loop transfer function (OLTF) test the value varied are duty cycle value and irradiation disorders. In Figure. 4 is shown a simulation circuit of SEPIC converter with an open loop transfer function (OLTF) system using PSIM software.

![Simulation Circuit of SEPIC Converter with an Open Loop Transfer Function (OLTF) System](image)

**Figure 4.** Simulation Circuit of SEPIC Converter with an Open Loop Transfer Function (OLTF) System

After simulating, the simulation result will be shown in Table 2.

### Table 2. Open Loop Simulation Result

| Duty Cycle (%) | V Input (V) | I Input (A) | V Output (V) | I Output (A) |
|----------------|------------|-------------|--------------|--------------|
| 20.00          | 21.01      | 0.12        | 5.25         | 1.20         |
| 25.00          | 20.94      | 0.32        | 6.97         | 1.59         |
| 30.00          | 20.83      | 0.62        | 8.93         | 2.04         |
| 35.00          | 20.67      | 1.08        | 11.13        | 2.54         |
| 40.00          | 20.44      | 1.74        | 13.6         | 3.11         |
| 45.00          | 20.36      | 1.96        | 14.32        | 3.27         |
From the result of the open loop transfer function (OLTF) simulation it can be seen that the output voltage can be greater or lower than the input voltage by setting the value of duty cycle. The graph of the simulation result of a SEPIC converter with an open loop system shown in Figure 5.

![Simulation Result of a SEPIC Converter with an Open Loop Transfer Function (OLTF) System](image1)

**Figure 5.** Simulation Result of a SEPIC Converter with an Open Loop Transfer Function (OLTF) System

In Figure 5, SEPIC converter with open loop system and the output voltage is 14.32 V with the duty cycle is 45%. But converter with open loop system have not produced according to set point.

In the second test will simulate the SEPIC converter by giving interference to the irradiation of the solar panel. Figure 6 show the graph of the simulation result of a SEPIC converter by giving interference to the irradiation of the solar panel in an open loop system.

![Result of Simulation with Interference to the Irradiation with Open Loop System](image2)

**Figure 6.** Result of Simulation with Interference to the Irradiation with Open Loop System
The result of Figure 6 can be seen that the output voltage is 14.32 V but has decreased and there are ripples. This happens because the solar panels are given interference with irradiation with the value is 250 W/m².

B. SEPIC Converter Testing in a Close Loop System

In this close loop transfer function (CLTF) system there are two types of testing, there are STC condition test on the solar panel and solar panel test with giving a disturbance in the value of irradiation. In Figure 7 is shown a simulation circuit of SEPIC converter with a close loop transfer function (CLTF) system using PSIM software. In the SEPIC converter design with a close loop system using Kp value of 5.155 and Ki value of 32.21. The desired set point value is 14 volts. First test is solar panel in STC condition.

![Simulation Circuit of SEPIC Converter with a Close Loop Transfer Function (CLTF) System](image)

**Figure 7.** Simulation Circuit of SEPIC Converter with a Close Loop Transfer Function (CLTF) System

After simulating, the simulation result will be shown in Figure 8.

![Simulation Result of a SEPIC Converter with a Close Loop System](image)

**Figure 8.** Simulation Result of a SEPIC Converter with a Close Loop System

Figure 8 is shown that the output voltage has reached the set point with a value 14 volt for battery charging. In this simulation using 2 solar panels with the value are 100 WP. The output voltage waveform in Figure 8 shows that the wave has a perfect shape because the solar panel is in the STC condition.
In second test the solar panel will giving a disturbance to the irradiation value, so for a moment the value of irradiations drops. The result of the simulation wave can be seen in Figure 9.

![Simulation Result with Interference to the Irradiation with Close Loop System](image)

Figure 9. Simulation Result with Interference to the Irradiation with Close Loop System

In figure 9 shown that the value output voltage of SEPIC converter with close loop system is 14 V and have increase about 14.6 V. the result is different from SEPIC converter with open loop system because there is PI control to decrease the error signal.

### 4. Conclusion

After simulate of SEPIC converter with open loop and close loop systems, the output voltage waveform are different. At open loop system with changing the duty cycle value, shown that the duty cycle value is take effect for output voltage of SEPIC converter, the simulation result shown at Table II, when the value is 20% for duty cycle the value is 5.25 V for output voltage and when the value is 55% for duty cycle the value is 22.31 V for output voltage. The simulate result of the output voltage reached the set point value of 14 V, but there is a ripple and unstable output voltage. In the second test is giving a disturbance to the solar panel so at the moment the value of irradiation is drop and makes the output voltage waveform not perfect, because of ripple and the voltage is drop until 5 V, and at two seconds the waveform back to the normal form. In close loop system, the first test is solar panel in STC condition with the irradiation value is 1000W/m² and the temperature is 25°C. Result of close loop system is the output voltage reach the set point value of 14 V with the response time is 0.6 s, there is no ripple and the output voltage is stable. At the second test is giving a disturbance to the solar panel as same as at open loop system, so that the irradiation value is drop. The result of the simulation is the output voltage is drop until 13.5 V at 1.5 s and increasing until 15.6 V at 1.8 s. The output voltage wave in normal condition when the response time at 2 s, so the output voltage reach to the set point value of 14 V.

### 5. References

[1] Mochamad Abdul Mughis, Indhana Sudiharto, Indra Ferdiansyah, Diah Septi Yanaratri, *Design and Implementation of Partial M-Type Zero Voltage Resonant Circuit Interleaved Bidirectional DC-DC Converter (Energy Storage and Load Sharing)*, Departemen Elektro, Politeknik Elektronika Negeri Surabaya, IEEE 2018
[2] Luki Septya M, Indhana Sudiharto, Syechu Dwitya N, Ony Asrarul Qudsi, Epyk Sunarno, *Design And Implementation Soft-Switching MPPT SEPIC Converter Using P&O Algorithm*, Electrical Engineering Department Politeknik Elektronika Negeri Surabaya, Indonesia E3S Web of Conferences 43, 01010, 2018

[3] Indra Ferdiansyah, Era Purwanto, Indhana Sudiharto, Epyk Sunarno, Syechu Dwitya Nugraha, Ony Asrarul Qudsi, Lucky Pradigta Setya Raharja, Mohamad Abdul Mughis, Ipensisus Tua Simorangkir, *Application of Interleaved Bidirectional Converter on Pond Aerators with Electricity Sources from Solar Panels*, Departemen Elektro, Politeknik Elektronika Negeri Surabaya, ICECOS 2019

[4] Epyk Sunarno, Indhana Sudiharto, Indra Ferdiansyah, Syechu Dwitya Nugraha, Ony Asrarul Qudsi, Mahbub Gusti Muhammad, *Design of Single Phase Full Bridge Inverter for Uninterruptible Power Supply (UPS)*, Departemen Elektro, Politeknik Elektronika Negeri Surabaya, 978-1-7281-3018-7, 2019

[5] Sutedjo, Indra Ferdiansyah, Ony Asrarul Qudsi, Fandi Setiawan, *Design of Battery Charging System as Supply of Rice Thresholds in Tractor*, Departemen Elektro, Politeknik Elektronika Negeri Surabaya, IEEE 978-1-7281-3018-7

[6] Eddy Sulistyono, Sutedjo, Syechu Dwitya Nugraha, Epyk Sunarno, Ony Asrarul Qudsi, Indhana Sudiharto, *Desain dan Implementasi Tapped Inductor Buck Converter dengan Metode Kontrol PI pada Rumah Mandiri*, Departemen Elektro, Politeknik Elektronika Negeri Surabaya, Prosiding Seminar Nasional Teknologi Elektro Terapan, Vol.01 No.01, ISSN: 2581-0049, 2017

[7] Sarutibhat Poluthai and Nirudh Jirasuwankul, *Modified High Step-up Non-isolated Single Ended Primary Inductor Converter (SEPIC) For PV Applications*, Department of Electrical Engineering, Faculty of Engineering King Mongkut’s Institute of Technology Ladkrabang Bangkok, Thailand, IEECON 2018

[8] A. Kalaiavani and Dr. S. K. Nandha Kumar, *Modified High Step-up Non-isolated Single Ended Primary Inductor Converter (SEPIC) For PV Applications*, PSNA College of Engineering & Technology, Dindigul, National Power Engineering Conference (NPEC), 2018

[9] Indhana Sudiharto, Farid Dwi Murdianto, Epyk Sunarno, Desy Nanda Kurniasari, *Robustness Analysis of PI Controller to Constant Output Power with Dynamic Load Condition in DC Nanogrid System*, Electronic Engineering Polytechnic Institute of Surabaya, 3rd International Conference on Information Technology, Information Systems and Electrical Engineering (ICITISEE)2018

[10] Ahmad Aftas Azman, Mohd Hezri Rahiman, Nurul Nadia Mohammad, Mohd Hezri Marzaki, Mohd Nasir Taib, Mohd Fozi Ali, *Modeling and Comparative Study of PID Ziegler Nichols (ZN) and Cohen Coon (CC) tuning method for Multi-Tube Aluminium Sulphate Water Filter (MTAS)*, Universiti Teknologi MARA, Malaysia, IEEE 2017 2nd International Conference on Automatic Control and Intelligent Systems (I2CACIS 2017)

[11] Nentaweyilwatda Goshwe and Gyang John Dung, *Implementation of Sepic DC-DC Voltage Converter Using Voltage Mode And Proportional Integral Controller*, American Journal of Engineering Research (AJER), Vol. 7, Issue-9, pp-01-07, 2018

[12] Mahajan Sagar Bhaskar Rishi M. Kulkarni, Kohkade Anita, Chandodkar Pooja, *Non Isolated Switched Inductor SEPIC Converter Topologies For Photovoltaic Boost Applications*, Department of Electrical and Electronics Engineering Marathwada Institute of Technology, Aurangabad, India, International Conference on Circuit, Power and Computing Technologies (ICCPPCT) 2016

[13] Charles Muranda, Emre Ozsoy, Sanjeevikumar Padmanaban, Vilian Fedak, Vigna K.
Ramachandaramurthy, Mahajan Sagar Bhaskara, *Modified SEPIC DC-to-DC Boost Converter with High Output-Gain Configuration for Renewable Applications*, Department of Electrical and Electronics Science, University of Johannesburg, Auckland Park, South Africa IEEE 2017

[14] Baocheng Wang, Wei Tang, *A Novel SEPIC-Based Z-Source Inverter*, Department of Electrical Engineering, Yanshan University, Qinhuangdao, China, IEEE 2018

[15] Mriduwani Verma, S.Shiv Kumar, *Hardware Design of SEPIC Converter and its Analysis*, Department of Electrical & Electronics Engineering Birla Institute of Technology, Mesra IEEE 2018 International Conference on Current Trends toward Converging Technologies, Coimbatore, India

[16] Daniel W. Hart *Power Electronics*, The McGraw-Hill Companies, Inc., 2011