SEPIC converter with coupled inductor using Fuzzy Logic controller to optimized battery charging process

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Abstract. Population of human is growth up but fossil energy as main fuel for generate electricity sources become less and less, so it’s needed renewable energy such as solar energy is suitable in Indonesia’s climate. Solar energy as a source of electrical energy can be done using photovoltaic. Photovoltaic can be used directly or indirectly. Result energy from indirectly photovoltaic is stored first in the battery. On the other hand, output voltage of photovoltaic is not stable, if used for charging a battery, it will not reach the set point charging. To stabilize the output voltage of a photovoltaic can use converter such as SEPIC Converter with Coupled Inductor. Simulation the SEPIC Converter with coupled inductor as a Battery Charger using Fuzzy Logic Control can stabilize the output voltage so that the battery charging runs well. Fuzzy logic control is used to control the generation of PWM to produce a constant output voltage.

1. Introduction
The high rate of growth of the population of Indonesia causes electricity’s demand is increase every year. Solar energy as an alternative source of electrical energy can be done using photovoltaic. Electrical energy produced by solar panels is useful for supplying dc (direct current) loads directly or stored in a battery (accumulator).

The output photovoltaic depends on irradiation (W/m²) and temperature itself, it can be maximum output, if the irradiation is 1000W/m² and the temperature of surface’s photovoltaic is 25°C[1-3], so this is not suitable to charging battery directly[4-5]. Battery has voltage and current requirement value which is use to charge. the charging current should be 10% to 30% of battery capacity (Ah) and the charging voltage should be set at 2.3V to 2.4V per 2V cells. If the current is below the minimum charging requirements, the charging time will be longer than originally, and if the voltage is below the minimum value, the battery cannot be charged, and the battery can be a supplier, but if both the charging current value and the charging voltage is excessive will reduce the lifetime of battery.

This problems requires a converter that can reduce and increase the voltage like a sepic converter with a coupled inductor and to stabilize the charging voltage can use fuzzy logic control.
2. System Description

In general, the system to be made is a solar panel used by a SEPIC converter coupled inductor to charge 2 12V / 45Ah batteries which are connected in series, because the voltage source changes, the fuzzy logic control will control the voltage so that the constant 26.4V of the battery voltage.

![Figure 1. Block diagram system](image)

The working principle of the system created is the voltage input of a coupled inductor sepic converter is 20-50 volts. Voltage sensor located on the side of the input converter and output converter is used for sensing the ARM STM32F7 microcontroller, then the data will be processed as a reference for the duty cycle control. The current sensor on the output side of converter. It used to monitor the value of the output current converter. The output voltage connects with ADC microcontroller. Then the signal will be used as a reference for the duty cycle control using the fuzzy logic control method. It produces the constant voltage.

3. Methodology

This system consists of several series and components which will be integrated and can be operated according based on the purpose of making the tool that are; Coupled Inductor SEPIC Converter, two batteries 24 V/45 Ah, design and program of fuzzy logic controller.

3.1. SEPIC Converter

A power converter called Single Ended Primary Inductace Converter (SEPIC) can produce an output voltage that can be higher or lower than the input but without changing the polarity. To get the relationship between input and output voltage, the assumptions made:

1. Both inductors are very large and the current inside is constant,
2. Both capacitors are very large and the voltage between them is constant.
3. This circuit operates in a steady-state operation, which means that the voltage and current waveforms are periodic.
4. For duty ratio D, switches are closed when DT and open when (1-D) T.

The inductor current and capacitor boundary voltage are removed to investigate current and voltage fluctuations. The inductor current is assumed to work continuously in this analysis[6-7]. The average inductor voltage is zero and the average capacitor current is zero for steady-state operations.

Kirchoff’s Voltage Law (KVL) on lines Vs, L1, C1 and L2

\[-V_s + V_{l1} + V_{c1} - V_{l2} = 0\]  \hspace{1cm} (2.1)

If it follows the assumption of the average voltage of the inductor, then

\[-V_s + 0 + V_{c1} - 0 = 0\]  \hspace{1cm} (2.2)
The voltage on capacitor C1 is

\[ V_{C1} = V_s \]  

(2.3)

When the switch is closed, the diode will be off and the circuit is shown in Figure 2.6 (b). The voltage across L1 for interfacial DT is

\[ V_{L1} = V_s \]  

(2.4)

When the switch is open, the diode will be on and the circuit is shown in Figure 2.6 (c). KVL in the outer lane is

\[ -V_s + V_{L1} + V_{C1} + V_O = 0 \]  

(2.5)

The voltage assumption of C1 capacitors remains constant at the average voltage Vs

\[ -V_s + V_{L1} + V_s + V_O = 0 \] atau,  

(2.6)

\[ V_{L1} = -V_O \]  

(2.7)

Figure 2. (a) SEPIC series; (b) SEPIC circuit when the switch is closed and diode off; (c) The SEPIC circuit when the switch is open and the diode is on

3.2 SEPIC Converter with Coupled Inductor

In the conventional SEPIC converter topology there are two inductors which are rolled at different. The two inductors can be rolled at the same core so that they can be referred to as SEPIC converters with coupled inductors [8-9]. The voltage through two inductors in the SEPIC converter has the same value as the voltage flowing in the SEPIC converter with coupled inductors. This happens because two inductors can be coupled to the same core without the effect of DC voltage conversion. The total magnetization current in the coupled inductor is the sum of the currents in each inductor[10-12].

If there are two inductors placed at the same core, then there is an effect to reduce the current ripple on the input side or on the output side depending on how to design the SEPIC converter circuit. Using the same core, there will be a flux effect between the L1 inductor and the L2 inductor[13-15]. Based on Figure 2.4, it can be interpreted that if there is a current flowing in the L1 inductor, flux will flow in
the iron core inside the core. This flux will induce the L2 inductor so that there will be an influence from the magnetization inductor[16-18]. Parameter of converter shown in Table 1.

![Figure 3. Series of SEPIC Converter Coupled Inductor Simulation](image)

3.3 Fuzzy Logic Controller
Fuzzy logic, is an increase of boolean logic that deals with the concept of partial truth. Classical logic states that everything can be expressed in binary terms (0 or 1, yes or no), fuzzy logic replaces the boolean truth with the level of truth. Fuzzy logic allows membership values between 0 and 1. This system using fuzzy logic controller to control output voltage converter to be constant. Figure 4 shows the flowchart of FLC and figure 5 and shows the input of FLC are voltage error, Δerror, and figure 6 output FLC is duty cycle which is changed the output voltage converter.

![Figure 4. Flowchart of Fuzzy Logic Control system](image)
### Table 1. Parameter of converter

| Parameter                  | Symbol | Value | Units |
|----------------------------|--------|-------|-------|
| Input Voltage              | $V_{in}$ | 20    | Volt  |
| Output Voltage             | $V_o$  | 26.4  | Volt  |
| Input Power                | $P_{in}$ | 200   | Watt  |
| Frequency Switching        | $f$    | 100   | KHz   |
| Input Current Ripple       | $\Delta_i_1$ | 10    | %     |
| Output Current Ripple      | $\Delta_i_2$ | 11    | %     |
| Voltage Ripple             | $\Delta_v_o$ | 0.1   | %     |
| Input Inductor             | $L_1$  | 62.4  | uH    |
| Output Inductor            | $L_2$  | 61.92 | uH    |
| Magnetisation of Inductor  | $L_m$  | 61.92 | uH    |
| Load                       | $R$    | 3.4848| Ω     |
| Transferred Capacitor      | $C_1$  | 2.16  | mF    |
| Filter Capacitor           | $C_2$  | 1.63  | mF    |

**Figure 5.** Output Fuzzy Logic Controller (duty cycle)

The output of Fuzzy Logic Controller has seventh member function which are NB, NM, NS, Z, PS, PM, PM and the amplitude is 0 until 1 because this is range of duty cycle.

### 4. Simulation Result and Discussions

Result Output Voltage of Coupled Inductor SEPIC Converter wave without control shown in Figure 6, Simulation Circuit of Coupled Inductor SEPIC Converter without control shown in Figure 7, Simulation Circuit of Coupled Inductor SEPIC Converter with Fuzzy Logic control, shown in Figure 8 and Output Voltage of Coupled Inductor SEPIC Converter wave with Fuzzy Logic Control show in Figure 9.

**Figure 6.** Result Output Voltage of Coupled Inductor SEPIC Converter wave without control
Figure 7. Simulation Circuit of Coupled Inductor SEPIC Converter without control

Figure 8. Simulation Circuit of Coupled Inductor SEPIC Converter with Fuzzy Logic control

Figure 9. Output Voltage of Coupled Inductor SEPIC Converter wave with Fuzzy Logic Control
5. Conclusions
In this paper, the system helps to control output voltage of charging with constant voltage. So the charging voltage stays stable and suitable with battery condition with 110 percent from 24Volts battery is 26.4Volts. So the charging voltage will not overvoltages and then damage life time battery or batteries. Beside that, if the input of converter is photo voltaic can reduces PLN consumption and reduces used foil.

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