Solar power based positive output super-lift Luo converter using fuzzy logic controller

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Abstract. Photovoltaic (PV) power generation is employed to meet the increasing demand for energy and of cleaner form. Though renewable and high energy using PV can be produced, they have certain disadvantages. PV cells have a low voltage (approx. 0.5V) rating and they have to be connected in series when higher voltage is required. These cells when connected in series should have identical electrical characteristics to avoid ripples in the output voltage and current, but it is not possible practically. To avoid this miss-match, converter circuits are employed. The major drawbacks in most power converters are reduced voltage gain and their tendency to generate harmonics in the supply system and the load circuit. To overcome these limitations, a positive output super-lift Luo converter is designed. A Positive Output Super Lift Luo converter (POSLC) is a powerful DC-DC converter where the voltage is converted from positive source voltage to positive load voltage as it produces positive voltages of comparatively higher ranges than those of conventional types. The super-lift technique also overcomes the effect of parasitic elements and thus minimizing the ripples in the output voltage and current. In addition to this, the voltage build-up can be achieved by implementing the super-lift technique where the output voltage rises in geometric progression with increased voltage transfer gain and high power density. In this paper fuzzy control is used to produce better-controlled voltage and a more refined output. The performance of POSLC with and without implementation of fuzzy control has been successfully simulated and verified using MATLAB/SIMULINK as well simulation model also developed and analyzed with Proteus package.

Keywords: DC – DC converter, High gain, POSLC, Fuzzy Logic Control

1. Introduction

In recent trends, in various industries, DC-DC conversion plays a significant role for various applications and there are various types of DC-DC conversion techniques to improve the voltage gain as well as efficiency [1]. In DC-DC conversion step-up chopper boosts the output voltage whereas step down chopper bucks the output voltage. Due to a lot of research in DC-DC conversion more topologies developed, generally, these topologies are categorized into with and without transformer. The transformerless DC-DC conversion has led to a reduction in the size, weight, cost and losses [2]-[5]. There are many voltage building techniques adopted in conversion stages, namely, voltage lift technique and super- lift technique in the case of Luo DC – DC converters. Luo converters developed from the fundamental DC – DC converter which has a simple and cheap topology as well provide high voltage gain, better efficiency and lowest ripple at the output. In the voltage lift technique, the output voltage is increased step by step in arithmetic progression. However, in the super-lift technique, the output voltage increases geometrically. Two types of super-
Positive Output Super-lift Luo Converter (POSLC) and Negative Output Super-lift Luo Converter (NOSLC).

This paper deals with different performances of POSLC that build up the input voltage to much higher levels compared to that of other voltage building techniques [5]. Basically, in POSLC, the output DC voltage is increased step by step in geometric progression. Positive Output Super-lift Luo Converter is constructed to overcome the major drawbacks of conventional power electronic converters such as reduced DC voltage gain, harmonics, and low power factor. In POSLC, much higher voltage ranges can be obtained at a lower gain value of about 0.8. In addition to this, ripple content in the output voltage and current can be reduced and thus higher efficiency can be achieved at the output [6]. Low switching loss, large DC gain, continuous input current and higher power density are its other advantages.

In general PI, PD and PID controllers are predominantly used to obtain the precise output voltage in DC – DC conversion but in recent trends, Fuzzy Logic Controllers successfully adopted closed loop control of the conversion stage, and this method implemented in this paper to provide the output feedback to regulate the output voltage as expected.

2. Operation of POSLC

The simulation circuit diagram of the POSLC is given in Fig.1. The circuit consists of a MOSFET switch S, Inductor L1, Diodes D1 and D2, capacitors C1 and C2, and a load resistance R. The other circuit components are Pulse generator, input DC voltage V and Scope output. POSLC produces the particular output voltage for input by introducing pulse width modulation techniques accordingly [7].

![Figure 1. Circuit Diagram of POSLC](image)

The design values for the proposed positive output super lift Luo converter [8] are derived based on the considerations as follows:

The input voltage ($V_\text{in}$) to the POSLC is given as 12V which is provided by a constant DC source. The output voltage ($V_\text{o}$) for the load resistance $R$ of 100Ω is obtained as 36V.

The formula for transfer gain ($K$) is expressed as,

$$
\frac{V_\text{o}}{V_\text{in}} = \frac{(2-K)}{(1-K)}
$$

Rewritten as,

$$
V_\text{o} - V_\text{in} = 2V_\text{in} - V_\text{in}K
$$

$$
V_\text{in}K - V_\text{o}K = 2V_\text{in} - V_\text{o}
$$

Thus,

$$
K = \frac{2V_\text{in} - V_\text{o}}{V_\text{in} - V_\text{o}}
$$

$$
K = \frac{(2 \times 12) - 36}{12 - 36}
$$

$$
K = 0.5 \approx 50\%
$$

The output current $I_\text{o}$ is obtained from Ohm’s law as,

$$
V_\text{o} = I_\text{o}R
$$
Rearranged as,

\[ I_o = \frac{V_o}{R} \]

\[ I_o = \frac{36}{100} = 0.36A \]

Then, using

Input power = Output power

\[ V_{in}I_{in} = V_oI_o \]

The value of \( I_{in} \) is obtained as,

\[ 12I_{in} = 36 \times 0.36 \]

\[ I_{in} = 1.08A \]

Let us assume that 5% of ripples in the output current, then the value of \( \Delta i_0 = 5\% \text{ of } I_{in} \)

\[ = 0.05 \times 1.08\Delta i_0 = 0.054 \]

The value of inductor \( L_1 \) is calculated using the formula,

\[ \Delta i_{11} = \frac{V_o - 2V_{in}}{L_1} (1 - K)T \]

\[ L_1 = \frac{V_o - 2V_{in}}{\Delta i_{11}} \frac{(1 - K)}{f} \]

\[ L_1 = \frac{36 - 2(12)}{0.054} \frac{(1 - 0.5)}{50000} \]

\[ L_1 = 2.22 \text{ mH} \]

Let 5% of ripple content in the output voltage,

\[ \Delta V_o = 5\% \text{ of } V_o \]

\[ \Delta V_o = 0.05 \times 36 \]

\[ \Delta V_o = 1.8 \]

The formula to find the value of capacitance \( C_2 \) is,

\[ \Delta V_o = \frac{(1 - K)V_o}{fC_2} \frac{1}{R} \]

Rearranged as,

\[ C_2 = \frac{(1 - K)V_o}{f\Delta V_o} \frac{1}{R} \]

\[ C_2 = \frac{(1 - 0.5)36}{50000 \times 1.8 \times 100} \]

\[ C_2 = 2 \times 10^{-6}F \]

The values of both the capacitances \( C_1 \) and \( C_2 \) are equal,

\[ C_2 = C_1 \]

Therefore, \( C_1 = 2 \times 10^{-6}F \)

Simulations have been done using the parameters shown in Table 1 and the performance of the POSLC analyzed.
Table 1. Design Values for Positive Output Super-Lift Luo Converter

| Parameters | POSLC |
|------------|-------|
| $V_{in}$   | 12V   |
| $V_o$      | 36V   |
| $L_1$      | $2.22 \times 10^{-3}$H |
| $C_1$      | $2 \times 10^{-6}$F |
| $C_2$      | $2 \times 10^{-6}$F |
| $R$        | 100Ω  |
| $K$        | 0.5   |

3. Open Loop Configuration

The open loop configuration technique for the POSLC has been constructed in the Simulink model without any feedback controller by using a fixed DC source and PV as input. The open loop system with DC input is shown in Figure 2. POSLC produces the particular output voltage for input by introducing pulse width modulation techniques accordingly.

![Figure 2. Open Loop System of POSLC with DC source](image)

The POSLC is given with a constant input voltage of 12V, 50% duty cycle and switching frequency of 50kHz. The scope output for the open loop system with a fixed DC source is shown in Figure 3.

![Figure 3. Output Voltage of POSLC for Open Loop with DC source](image)
4. Closed Loop Configuration

The closed loop system is defined as the control action that eliminates the shortcomings of the open loop system thereby improving the overall performance of POSLC and has several benefits. This system consists of feedback that provides the switching gate pulses to MOSFET switch S. In the closed loop control of POSLC, the simulation circuit diagram is designed with the same circuit parameters along with the feedback system. The simulation of the POSLC converter with gain as the feedback controller is done. Simulation for the closed loop system is shown below in Figure 6.

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**Figure 4.** Open Loop System of POSLC with PV source

**Figure 5.** Closed loop control of POSLC with DC source

**Figure 6.** Output Voltage of Closed Loop POSLC with DC source
From Figure 7 and 9, we can infer that the errors between input and output have been reduced and the disturbances are also reduced to a greater extent compared to the open loop system.

5. Fuzzy Logic Control
To obtain further precise and accurate output values, fuzzy logic (FL) control is employed. Fuzzy control systems analyze the analog input values and express them in logical variables, entirely different from digital logic. Here, the membership function is defined as a matter of degree where it is a curve drawn for input and output that depicts the point in the input space mapped to the membership value using Mamdani’s fuzzy inference method [9]-[11]. The input variable given to the controller is error voltage ($e$) and the output variable is duty ratio ($K$) that defines the duty cycle. The offline implementation is employed where the lookup table is constructed based on the set of all the possible combinations of input variables and output variables. The table contains the duty ratio ($K$) according to the input entries ($V_{ref}$, $V_o$, Error). Using the lookup table, a set of rules is designed. There are several approaches for designing the rules, here; the IF-THEN system of rules is taken as the logical interpretation of fuzzy control.

The input variable is divided into nine groups namely: NVB (Negative Very Big), NB (Negative Big), NM (Negative Medium), NS (Negative Small), Zero (Z), PS (Positive Small), PM (Positive Medium), PB (Positive Big), PVB (Positive Very Big). In the same way, the output variables are given with the same names [12]. Having developed the set of
rules and the membership function, the controlled voltage, and improved output performances have been determined using the fuzzy logic control system [13].

Figure 9. Fuzzy Control of POSLC with DC Source

Figure 10. Output Voltage of Fuzzy Controlled POSLC with DC source

Figure 11. PV Based Fuzzy Control of POSLC
Figure 12. PV Output Voltage fuzzy controlled POSLC
Using these fuzzy rules, the output obtained from simulating is shown in Figure 11 and Figure 13. The membership function plots for both input and output variables are depicted as below:

Figure 13. Ruler view: Membership function plot of error [e]

Figure 14. Ruler view: Membership function plot of gain [K]
Table 2. FIS Editor Values

| V_{ref} | V_0  | Error | K    | FIS Editor values |
|---------|------|-------|------|------------------|
| 36      | 31   | 5     | 0.3684 | 0.33             |
| 36      | 32   | 4     | 0.4   | 0.353            |
| 36      | 33   | 3     | 0.4285 | 0.386           |
| 36      | 34   | 2     | 0.4545 | 0.431           |
| 36      | 35   | 1     | 0.4782 | 0.467           |
| 36      | 36   | 0     | 0.5   | 0.5              |
| 36      | 37   | -1    | 0.52  | 0.5              |
| 36      | 38   | -2    | 0.5384 | 0.5          |
| 36      | 39   | -3    | 0.5555 | 0.5          |
| 36      | 40   | -4    | 0.5714 | 0.533        |
| 36      | 41   | -5    | 0.5862 | 0.565        |
| 36      | 42   | -6    | 0.6   | 0.6             |
| 36      | 43   | -7    | 0.6129 | 0.602        |

Table 2 shows the various values of output voltage for different values of FIS along with the duty cycle.

6. IMPLEMENTATION IN PROTEUS

The Positive Output Super-lift Luo Converter for the open loop is simulated in Proteus Software to know about the real-time implementation. From the below figure 16, it is seen that the DC supply for the POSLC circuit is given by the ARDUINO UNO board which is an open-source electronics board based on easy-to-use hardware and software. The output of the circuit can be seen in Digital Oscilloscope.

![Figure 15. Open loop simulation of POSLC in Proteus](image-url)
The above figures 17, 18 and 19 shows the Pulse Width Modulation (PWM) to the MOSFET switch, output voltage ($V_o$) for the load and output current ($I_o$) respectively for the Positive Output Super-lift Luo Converter for open loop system.
Figure 19. Closed loop simulation of POSLC in Proteus

The above figure 20 shows the Positive Output Super-lift Luo Converter for closed loop is simulated in Proteus software to obtain the required output voltage.

Figure 20. Proteus 1st stage output of POSLC for closed loop system

Figure 21. Proteus 2nd stage output of POSLC for closed loop system

The above figures 21 and 22 show the Pulse Width Modulation (PWM) to the MOSFET switch, output voltage (V_o) for the load, and output current (I_o) respectively for the Positive Output Super-lift Luo Converter for closed loop system.
7. Conclusion
In this paper, the simulation of open loop, closed loop and fuzzy control of the Positive Output Super-lift Converter has been successfully executed in MATLAB/SIMULINK and also the circuit model that is simulated and verified in the Proteus environment. The voltage required from the solar supply is obtained from the solar cells by connecting the cells in a series and parallel combinations. The simulation of the POSLC is done for:

- Open loop
- Closed loop with Proportional gain
- Closed loop with Fuzzy Logic Controller

For various values of duty cycle output voltages measured as well the error at the output side is reduced. By using the fuzzy logic control in the closed loop provide precise and accurate voltage control, high voltage gain and therefore better output efficiency can be achieved better than the conventional converters. Fuzzy logic control-based closed loop control of positive output super lift Luo converter has been simulated and verified.

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