Comparison of Performance Measures for PV based Super-Lift Luo-Converter using Hybrid Controller with Conventional Controller

T. V. Narmadha1*, J. Velu2 and T. D. Sudhakar1

1Department of EEE, St Joseph’s College of Engineering, Chennai - 600119, Tamil Nadu, India; nar_velu@yahoo.co.in, t.d.sudhakar@gmail.com
2Anugraha Power Systems, Chennai - 600097, Tamil Nadu, India; veluash15@gmail.com

Abstract

Objectives: The paper presents design and analyze of PV based Super-lift Luo converter with different controllers in the modern technology of DC-DC converter. Methods: The Luo converter provides output voltage which is positive from positive source voltage. By using this converter power density obtained is high with less ripple content in voltage and current profile. It is proven from the Mathematical modeling that the output voltage increases in geometric progression, thereby efficiency of the converter increases. The controller parameters in PI controller are tuned using Ziegler Nichols tuning algorithm. The paper proposes a design of hybrid controller which gives good transient performance compared with conventional PI controller. Findings: Using Simulink the proposed converter with its control circuit is implemented. The main advantage of this proposed converter based on photo voltaic system is that it produces voltages increasing in geometric progression. The converter has proved to be robustness around the operating point. In various operating condition, the dynamic performance with input voltage variations and load fluctuation is good. The simulation performance closely coincides with the theoretical analysis. The settling time and overshoot obtained using hybrid controller is compared with fuzzy controller and conventional controller and it is proven that hybrid controller has good dynamic performance. The real time implementation with solar PV cell is also carried out. Applications/Improvements: The converter finds wide application in switch mode power supply and speed control of DC motors.

Keywords: Fuzzy Logic Controller, Peak Overshoot, Photo Voltaic (PV) Cells, PI Controller, Settling Time, Super Lift Converter

1. Introduction

One of the main renewable energy resources is solar energy. It mainly depends on changing sunlight and atmospheric conditions. The solar panel output is unstable and the variation in voltage is quite large. This may lead to have adverse effects on DC loads or utility. To overcome this problem, a good and stable control module is necessary. To obtain a high efficient output voltage using solar panel a DC-DC converters1–3 were used. Several ongoing research works are carried in DC-DC converters4–5 to increase the power density and the output voltage. Due to the effect of dependent elements a simple boost converter cannot provide the voltage to higher level. In recent past years; there are many number of networks of DC-DC converters6. The proposed Converter has very high voltage transfer gain increasing in geometric progression7,8 which makes highly popular. High power density with very low ripple in voltage and current, high efficiency and simple structure9 of this converter finds wide application in industry. Hence, in this work FLC is designed for Positive output Super Lift Luo-Converter. Figure 1 shows the block diagram of closed-loop control to desired target using soft computing technique to obtain the desired output voltage as shown in in Figure 1.

*Author for correspondence
2. Mathematical Modelling of Super Lift Luo Converter

In electronic circuit design Voltage Lift (VL) technique finds wide application. The DC-DC converter suffers in output voltage and efficiency due to the presence of dependent elements. In addition, the output voltage boost up in arithmetic progression. The voltage transfer gain is more is the main merits of proposed converter with increased output voltage\(^1\), thereby increasing the converter efficiency and power density. This converter minimizes the ripple content in voltage and current. Figure 2 shows the proposed Converter. Figure 3 and Figure 4 shows the equivalent circuits representation during switch ON and switch OFF period respectively\(^11\).

From Figure 2, when switch S is in ON, \(C_1\) is charged to \(V_{in}\). Inductor \(L\) is in parallel with capacitor \(C_1\), current \(I_{L1}\) will increase with voltage \(V_{in}kt\) and the change in current is \(\Delta I\).

\[
\Delta I = \frac{V_{in}kt}{L} \tag{1}
\]

From Figure 4 with switch S in off condition, the voltage across L is \((V_a - 2V_{in})(1-kt)\) and the change in current is \(\Delta I\).

\[
\Delta I = \frac{(V_a - 2V_{in})(1-kt)}{L} \tag{2}
\]

So, current \(I_{L1}\) will decrease. The switch-on period is assumed as \(kT\) and switch-off period is \((1-k)T\). Equating Equations (1) and (2) the following equation is obtained.

\[
V_{in}kT + (V_a - 2V_{in})(1-k)T = 0 \tag{3}
\]

Output voltage is calculated from Equation (4)

\[
V_a = \frac{2-k}{1-k}V_{in} \tag{4}
\]

So the voltage transfer gain is given in Equation (5)

\[
G = \frac{V_a}{V_{in}} = \frac{2-k}{1-k} \tag{5}
\]

where \(k\) - conduction duty ratio.
By varying the ON period of duty ratio \( k \), the output voltage will change. The output voltage is dependent on \( k \) as given in Equation (4).

### 3. Design Procedure of Pi Controller

The controller parameters \( K_p \) and \( T_i \) are designed using Ziegler – Nichols tuning method. The step test is obtained to the given transfer function\(^{12-14} \) of POSLLC given by the Equation (6). By state space averaging method the transfer function is obtained.

\[
TF = \frac{sL(D-2) + RD(1-D)^2}{(1-D)^2 [s^2RCL + sL + R(1-D)^2]}
\]

(6)

From the step response of POSLLC delay time \( L = 0.0167 \)s and time constant \( T = 0.0222 \)s is obtained as in Figure 5. The values of \( K_p = 2.89 \) and \( T_i = 53.59 \) is obtained as per the Table 1.

### 4. Design of Fuzzy Logic Controller

Fuzzy control is a soft controlling technique based on vagueness. A fuzzy controller as the inputs containing information about the system to be controlled and an output that is the manipulated variable\(^{15,16} \). The input and output values are crisp values\(^{17} \). The measured values from the system is the input variable of a fuzzy controller. This could be either system output or system states or control errors obtained from the set-point and controlled variables.

#### 4.1 Inputs and Output Identification

The inputs to fuzzy controller are error \( e \) (\( V_{ref} - V_o \)) and change in error \( ce \), \( V_{ref} \) is the desired output voltage and \( V_o \) is the actual output voltage\(^{18} \). The controller output is duty ratio for controlling\(^{19} \) MOSFET switch.

#### 4.2 Fuzzification

Fuzzification is the process of transforming crisp values into grades of membership for linguistic terms of fuzzy sets. The inputs domain is divided into several membership values using Mamdani type and triangular membership function chosen for simplicity as shown in Figure 6. Here, five linguistic variables for error \( e \) and rate of error \( de \) are considered for this system.

#### 4.3 Rule Base

The rules linking inputs and output are based on the understanding of the system behavior\(^{20} \) is given in Table 2. Generally the rules are formed based on “if and then…. “ AND operator is used for combining the inputs\(^{21} \).

The formation of Rule Table is based on the following criteria:

- If voltage at the output is far away with respect to reference point, then variation in duty cycle must be large.
- If voltage at the output is closer to reference point, then fine variation in duty cycle is sufficient.
The successful soft computing techniques finds wide range of control applications is fuzzy logic\textsuperscript{23}. This Fuzzy logic with PI controller, to build a hybrid fuzzy self-tuning controllers, has a more robust control\textsuperscript{24}. The output voltage of super lift Luo converter using fuzzy self-tuning PI is given in Table 3. The fuzzy rules update gains parameters Kp and Ki of PI controller based on quantitative knowledge and experience. The proposed method makes suitable to work with systems having model uncertainties.

### 6. Simulation Results

The Matlab/Simulink model of POSLLC is depicted in Figure 7 and parameters of POSLLC are given in Table 4. Figure 8 shows the open loop simulation of proposed converter. The pulse generator with 50% duty ratio is used to turn ON the MOSFET switch and the output voltage is obtained. It has small overshoot and settles very fast. The closed loop response with PI controller is given in Figure 9. The output voltage has lot of ripples and settles at 0.0030 seconds.

#### Table 4. List of parameters used in posllc

| Parameter Name         | Symbol | Value    |
|------------------------|--------|----------|
| Input Voltage          | $V_{in}$ | 12V      |
| Output Voltage         | $V_o$  | 36V      |
| Inductor               | $L_1$  | 100μH    |
| Capacitor              | $C_1,C_2$ | 30μF |
| Nominal Switching Frequency | $F_s$       | 100kHz   |
| Load Resistance        | $R$    | 50Ω      |
| Output Power           | $P_o$  | 25.92W   |
| Input Power            | $P_m$  | 28.236W  |
| Input Current          | $I_n$  | 2.353A   |
| Efficiency             | $\eta$ | 91.79%   |
| Range of Duty Cycle    | $d$    | 0.3 to 0.9 |
| Desired Duty Cycle     | $d$    | 0.5      |

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### 4.4 Defuzzification

Getting back a crisp number from a fuzzy set is known as defuzzification. After collecting the results a defuzified value of duty cycle is obtained by center of gravity defuzzification method to compute duty ratio.

#### Table 2. Rule table

| e/Δe  | VH | H  | N  | L  | VL |
|-------|----|----|----|----|----|
| VH    | VH | VH | VH | VH | VH |
| H     | VH | VH | H  | L  | VL |
| N     | VH | H  | N  | L  | VL |
| L     | VH | N  | L  | VL | VL |
| VL    | VH | VL | VL | VL | VL |

- If voltage at the output is near to reference point and varying rapidly, then duty cycle is maintained constant to avoid overshoot.
- If reference point is reached and voltage is still varying, then duty cycle must be slightly varied.
- If reference point is reached and output is steady, then duty cycle remains without change.
- If voltage at the output is above the set point, then sign of variation in duty cycle must be negative and vice versa.

### 5. Design of Fuzzy Tuned PI Controller

In electrical drives the most common controller used is PI controller. It finds wide application because of simple design of controller parameters and it is the basis for all other controllers. This controller performs well for some operating condition. Since it has fixed gain it may not perform well when the processes are complex, time dependent with non linearity and have model uncertainties\textsuperscript{22}.
Figure 10 shows the closed loop simulation of the proposed converter with fuzzy controller. The controller output provides the desired duty ratio to switch the MOSFET. The voltage at the output has overshoot of 48% and settles very fast at 0.0025 seconds.

Figure 11 shows the comparison of conventional and proposed voltages without load disturbance. The output voltage of conventional (PI) system has lot of ripples when compared with proposed fuzzy system and has small overshoot of 48% when compared with conventional system which has 85% overshoot.

Figure 12 shows the conventional system with load. Here the load disturbance is initiated at 0.02 seconds and it is made to occur for every 0.01 seconds to check the dynamic performance. It is found that the settling time after the disturbance is more and it has ripples in the response.

Figure 13 shows the proposed system with load disturbance. Here the load disturbance is initiated at 0.02 seconds and it is made to occur for every 0.01 seconds to check the dynamic performance. It is found that the settling time after the disturbance is less with good dynamic behavior.

Figure 14 shows the comparison of conventional and fuzzy system with load disturbance. The load disturbance is given at 0.02 sec for both conventional and proposed system. It is found that settling time for the Fuzzy system is very less when compared to conventional system. The operation of the fuzzy system at the time of transients is smooth compared to conventional system. Fuzzy system shows good dynamic behavior when compared with conventional system.

Figure 15 shows closed loop simulation of proposed super lift Luo converter using Fuzzy tuned PI controller. The controller output fed to PI controller and it provides the desired duty ratio to switch the MOSFET. The output
voltage has small overshoot of 46% and it settles very fast at 0.0018 seconds.

Figures 16, 17 and Table 5 shows the comparison of conventional and Fuzzy tuned PI output voltage. The output voltage of conventional (PI) system has lot of ripples when compared with proposed fuzzy tuned PI system and has small overshoot of 46% when compared with conventional system also settles very fast and the output voltage also improved to 36 V.

The real time implementation of proposed luo converter is shown in Figure 18. Figure 19 shows the hardware circuit of converter. Figure 20 shows the power supply, driver and the PIC microcontroller circuit.

Figure 21 shows the 100 KHz pulse with 50% duty cycle generated from the controller which acts as gating pulse for the converter with on time of 5.0 µs. Table 6 shows the specification of the solar panel used in hardware implementation. Figure 22 shows the input voltage to the super lift luo converter from PV panel. Figure 23 shows output voltage of 36.6 volts from the POSLC converter. Real time Implementation quantitative analysis results are tabulated in Table 7.
Table 6. Solar panel specifications

| Parameter                        | Value  |
|----------------------------------|--------|
| Maximum power Pm                 | 40Wp   |
| Open circuit voltage             | 21.7 V |
| Short circuit current            | 2.37 A |
| Rated voltage                    | 18.0 V |
| Rated current                    | 2.23 A |
| Max. System voltage              | 600 V  |

Table 7. Hardware results of the converter

| Parameters                                      | Results Of Positive Output Superlift Luo Converter |
|-------------------------------------------------|---------------------------------------------------|
| Input Voltage                                   | 12V                                               |
| Output Voltage                                  | 36.6V                                             |

Figure 19. Super lift Luo converter.

Figure 20. Controller and driver circuit.

Figure 21. PWM pulse from PIC.

Figure 22. Input voltages from PV panel.

Figure 23. Output voltage from converter.

Table 5. Comparison of performance measures for various controllers

| Type of Controller | Input Voltage(V) | Theoretical Output Voltage(V) | Simulated Output Voltage(V) | Peak Overshoot(%) | Settling Time(S) |
|--------------------|------------------|--------------------------------|------------------------------|-------------------|------------------|
| Open loop          | 12               | 36                             | 33.8                         | 48                | 0.0030           |
| PI                 | 12               | 36                             | 34.9                         | 85                | 0.0046           |
| Fuzzy logic        | 12               | 36                             | 33.8                         | 48                | 0.0025           |
| Fuzzy tuned PI     | 12               | 36                             | 36                           | 46                | 0.0018           |
7. Conclusion

The simulation results conclude the output from the proposed system has a good voltage profile and the system stability is good at various operating conditions. The capability of Fuzzy tuned PI controller converter’s output voltage is most proper than conventional controller on system fluctuations. Also, the designing of conventional PI controller parameters are very hard than fuzzy controller.

8. Reference

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