Indian Journal of Science and Technology, *Vol 9(29), DOI: 10.17485/ijst/2016/v9i29/89937, August 2016*

ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

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

T. V. Narmadha[1*], J. Velu[2] and T. D. Sudhakar[1]

[1]Department of EEE, St Joseph's College of Engineering, Chennai - 600119, Tamil Nadu, India; nar_velu@yahoo.co.in, t.d.sudhakar@gmail.com

[2]Anugraha 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 converters[1–3] were used. Several ongoing research works are carried in DC-DC converters[4,5] 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 converters[6]. The proposed Converter has very high voltage transfer gain increasing in geometric progression[7,8] which makes highly popular. High power density with very low ripple in voltage and current, high efficiency and simple structure[9] 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*

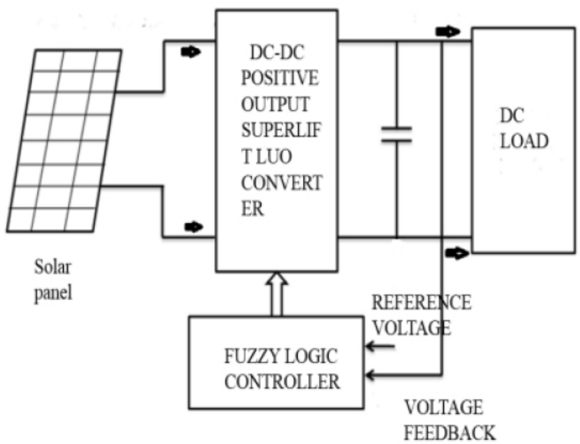

Figure 1. Block diagram representation of POSLC LC.

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[10], 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 Vin. Inductor L is in parallel with capacitor C_1, current I_{L1} will increase with voltage Vin kt and the change in current is ΔI.

$$\Delta I = \frac{V_{in}kt}{L} \quad (1)$$

From Figure 4 with switch S in off condition, the voltage across L is (Va -2Vin)(1-kt) and the change in current is ΔI.

$$\Delta I = \frac{(V_o - 2V_{in})(1-kT)}{L} \quad (2)$$

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

$$V_{in}kT + (V_o - 2V_{in})(1-k)T = 0 \quad (3)$$

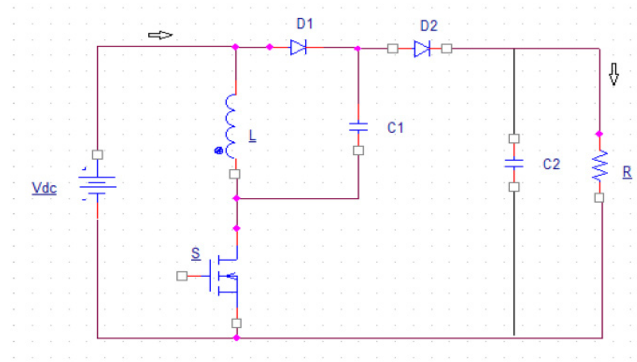

Figure 2. Proposed POSLC circuit.

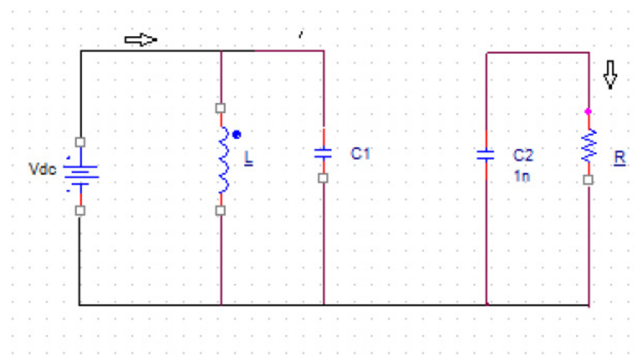

Figure 3. Equivalent circuit representation during switch-on period.

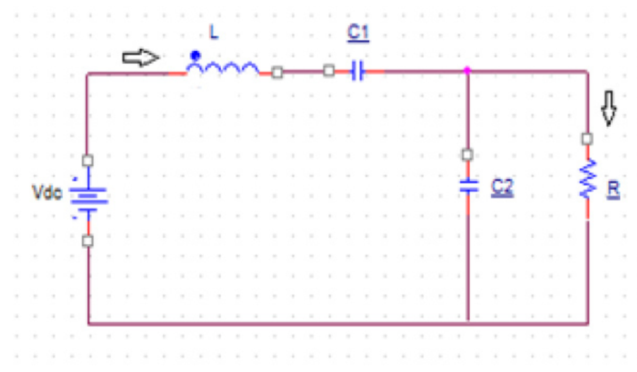

Figure 4. Equivalent circuit representation during switch-off period.

Output voltage is calculated from Equation (4)

$$V_o = \frac{2-k}{1-k} = V_{in} \quad (4)$$

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

$$G = \frac{V_o}{V_{in}} = \frac{2-k}{1-k} \quad (5)$$

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 *Kp* and *Ti* 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.

$$TF = \frac{sL(D-2)+RD(1-D)^2}{(1-D)^2\left[s^2RCL+sL+R(1-D)^2\right]} \quad (6)$$

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

4. Design of Fuzzy Logic Controller

Fuzzy control is a soft controlling technique based on vaguness. A fuzzy controller as the inputs containing information about the system to be controlled and an

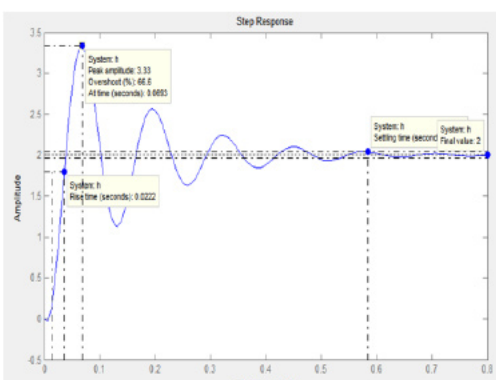

Figure 5. Step response.

Table 1. Ziegler nichols tuning method

Type of Controller	K_p	T_i	T_d
P	T/L	∞	0
PI	0.9T/L	L/0.3	0
PID	1.2T/L	2L	0.5L

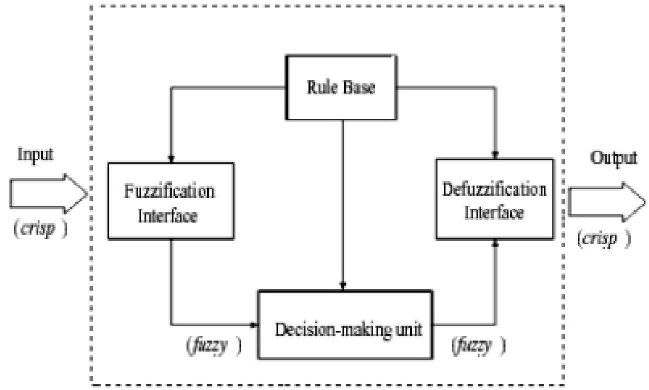

Figure 6. Block diagram of fuzzy controller.

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 (Vref-Vo) and change in error ce, Vref is the desired output voltage and Vo 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.

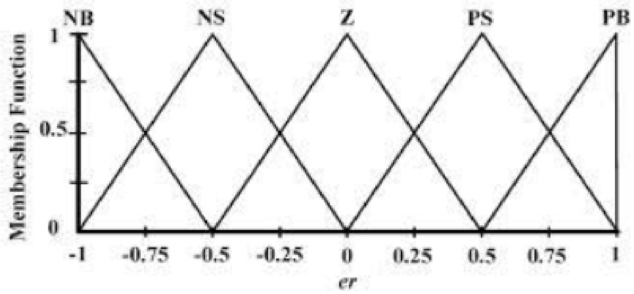

Figure 7. Membership functions for error and change in error.

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.

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.

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[22].

The successful soft computing techniques finds wide range of control applications is fuzzy logic[23]. This Fuzzy logic with PI controller, to build a hybrid fuzzy self-tuning controllers, has a more robust control[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 3. Rule table for fuzzy pi controller

e/Δe	VLL	LL	N	HH	VHH
VLL	VLL	VLL	VLL	VLL	VLL
LL	VLL	LL	LL	LL	VLL
N	LL	LL	N	HH	HH
HH	HH	HH	HH	HH	HH
VHH	VHH	VHH	VHH	VHH	VHH

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_{in}	28.236W
Input Current	I_{in}	2.353A
Efficiency	η	91.79%
Range of Duty Cycle	d	0.3 to 0.9
Desired Duty Cycle	d	0.5

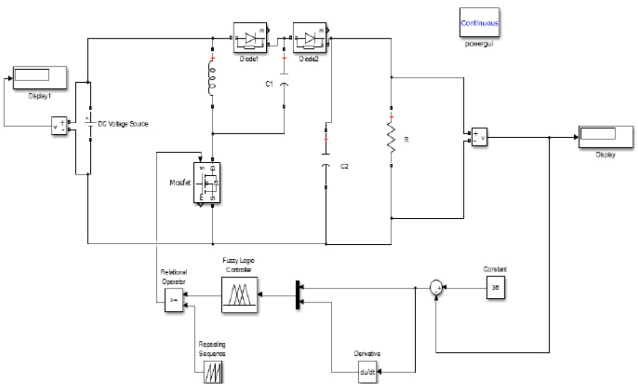

Figure 8. Simulink model of POSLLC.

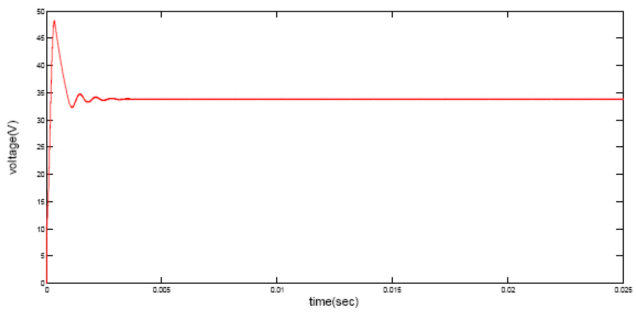

Figure 9. Open loop simulation of POSLLC.

Figure 10 shows the closed loop simulation of 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 0.02seconds and it is made to occur for every 0.01seconds 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.

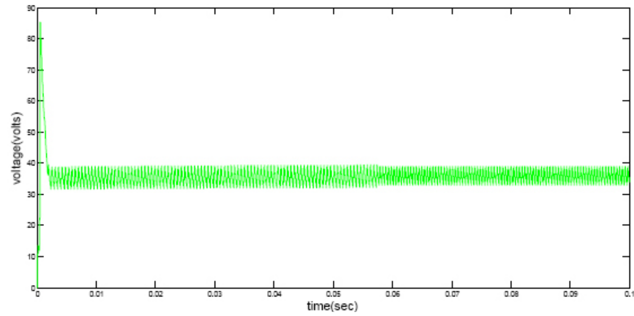

Figure 10. Closed loop simulation with PI control.

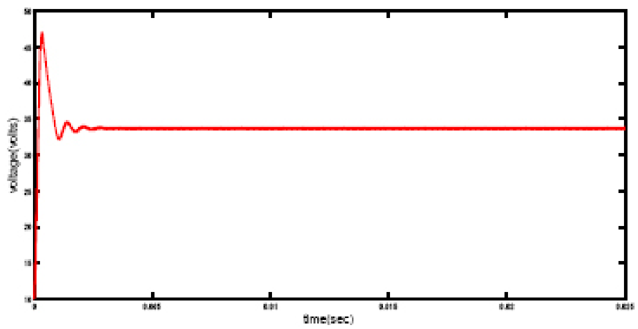

Figure 11. Closed loop simulation with fuzzy control.

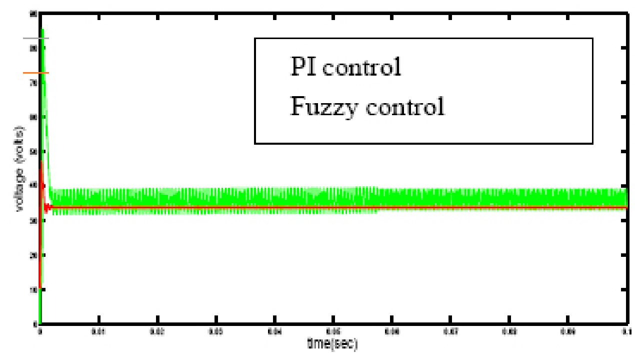

Figure 12. Comparison of PI and fuzzy control.

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 0f 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.

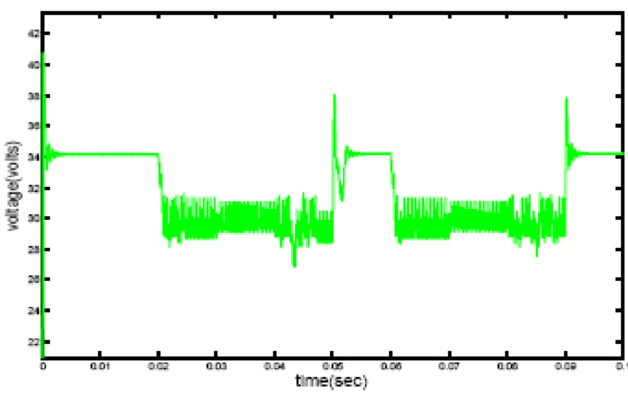

Figure 13. Conventional system with load disturbance.

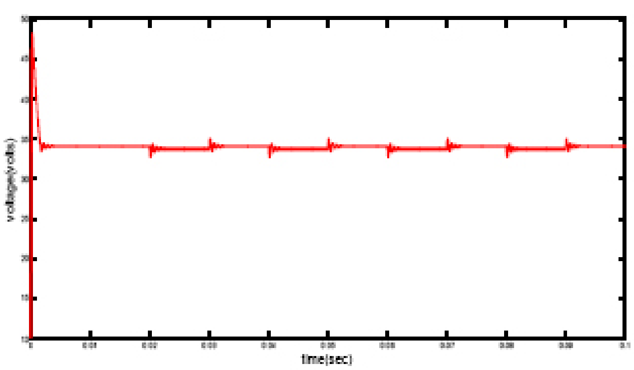

Figure 14. Fuzzy systems with load disturbance.

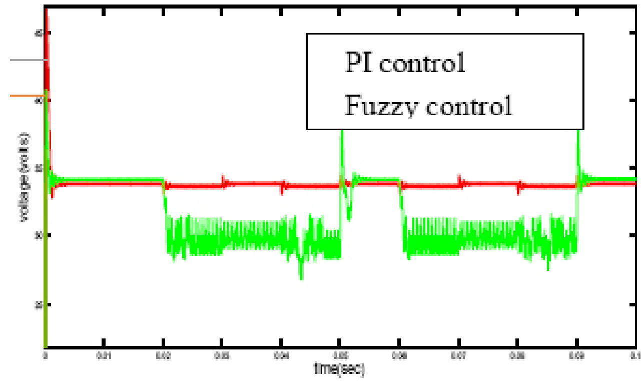

Figure 15. Comparison of conventional and fuzzy system with load disturbance.

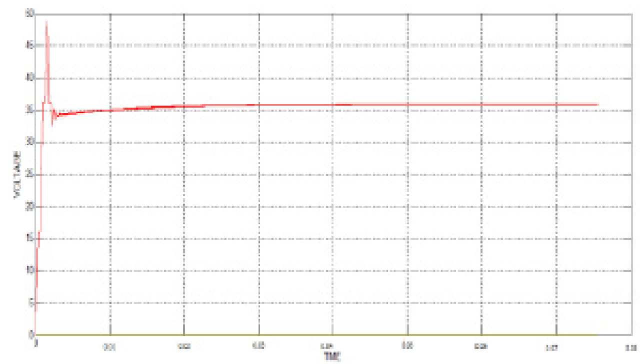

Figure 16. Closed loop simulation with fuzzy PI control.

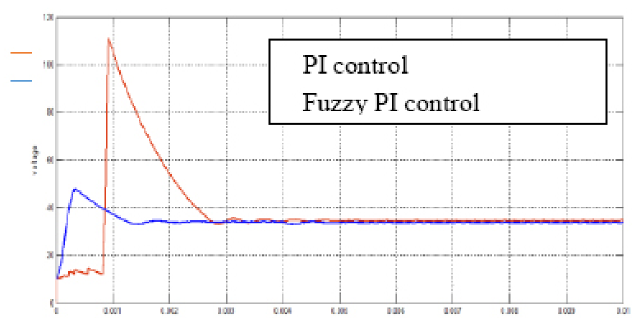

Figure 17. Comparison of conventional and fuzzy tuned PI system.

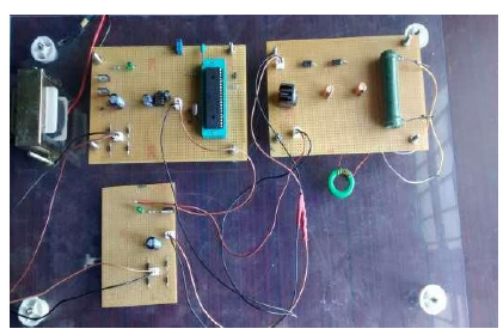

Figure 18. Overall hardware of POSLC.

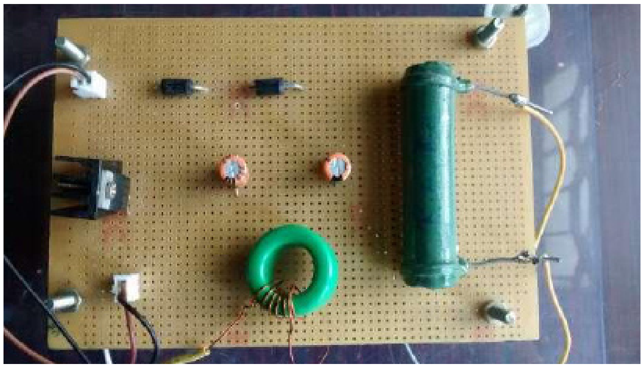

Figure 19. Super lift Luo converter.

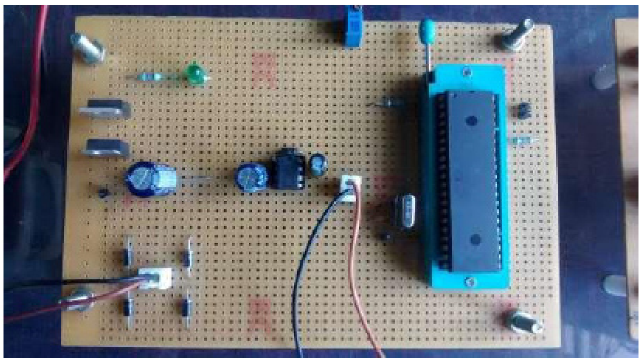

Figure 20. Controller and driver circuit.

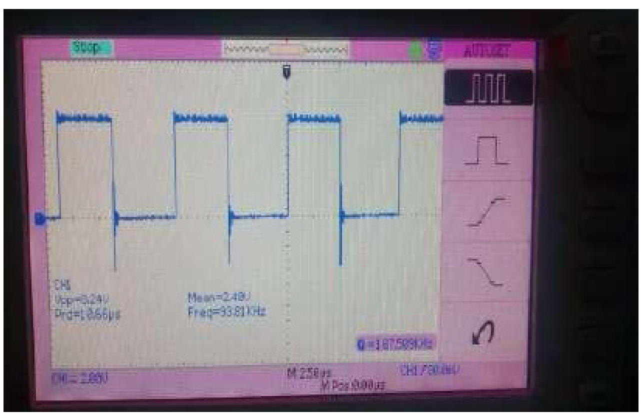

Figure 21. PWM pulse from PIC.

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

Table 6. Solar panel specifications

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 22. Input voltages from PV panel.

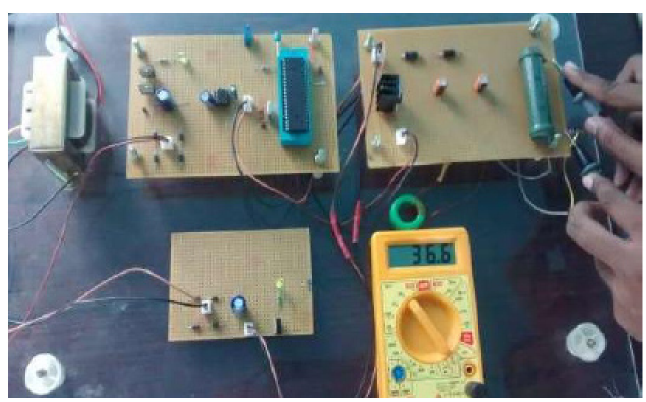

Figure 23. Output voltage from converter.

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

1. Shan Z-L. Investigation of a super-lift luo-converter used in solar panel system. China International Conference on Electricity Distribution. 2012 Sep; 1–4.
2. Bharathi ML, Kirubakaran D. Comparative study on solar powered interleaved boost converter. Indian Journal of Science and Technology. 2015 Feb; 8(3):270–9.
3. Reddy PRK, Kumar SG, Sandeep K, Arun N. LMI control of conventional boost converter. Indian Journal of Science and Technology. 2015 Jan; 8(S2):50–2.
4. Rashid MH. Power electronics: Circuits, devices and applications. 3rd ed. New Delhi: Pearson Education, PHI; 2004.
5. Rohini G, Jamuna V. Dynamic analysis of positive output super lift converter. 2012 IEEE International Conference on Power Electronics Drives and Energy Systems (PEDES); 2012.
6. Luo FL,Ye H. Advanced DC/DC converters. Boca Raton. FL, USA: CRC Press; 2004.
7. LUO FL, Luo converters – Voltage lift technique. Proceedings of the IEEE Power Electronics Special Conference IEEE-PESC'98; Fukuoka, Japan. 1998. p. 1783–9.
8. Shan Z-L, Liu S, Luo FL. Investigation of a super-lift luo-converter used in solar panel system. 2012 China International Conference on Electricity Distribution; 2012.
9. Luo FL, Ye H. Positive output super lift converters. IEEE Transaction on Power Electronics. 2003; 18(1):105–13.
10. Rohini G, Jamuna V. Dynamic analysis of positive output super lift converter. IEEE International Conference on Power Electronics. 2012 Dec; p. 1–5.
11. Luo. Split-capacitor and split-inductor techniques and their application in positive-output super-lift luo converters. Industrial Electronics, 2012.
12. Elangovan K. Design and simulation of PI control for paralleled positive output elementary luo converters for distributed power supplies. 2006 IEEE Power India Conference; 2006.
13. Ogata K. Modern control engineering. 5th ed. New Delhi: Pearson Education. PHI; 2012.
14. Comines P, Munro N. PID controllers: Recent tuning methods and design to specification. IEEE Proc Control Theory Application. 2001; 149(1):46–53.
15. Ma G-F. A nonlinear controller design based on the interpolation chart. 2006 SICE-ICASE International Joint Conference; 2006 Oct.
16. Ross T. Fuzzy logic with engineering applications. 3rd ed.
17. Vijayarajeswaran R. TMS320F2407 DSP based fuzzy logic controller for negative output luo re-lift converter: Design, simulation and experimental evaluation. 2005 International Conference on Power Electronics and Drives Systems; 2005.
18. Padmaloshani P. Development of neuro controller for negative output self-lift luo converter. 2006 1st IEEE Conference on Industrial Electronics and Applications; 2006 May.
19. Vijayarajeswaran R. TMS320F2407 DSP Based Fuzzy Logic Controller for Negative Output Luo Re-Lift Converter: Design, Simulation and Experimental Evaluation",2005 International Conference on Power Electronics and Drives Systems, 2005.
20. Anbumalar S. Development of fuzzy logic control for paralleled positive output elementary luo Converters. 2006 1st IEEE Conference on Industrial Electronics and Applications; 2006 May.
21. Baghramian A, Eshyani HG. Fuzzy controller of luo converter for controlling of DC motors speed. 4th Annual International Power Electronics Drive Systems and Technologies Conference; 2013.
22. Abdessemed R. A fuzzy self-tuning PI controller for speed control of induction motor drive. Proceedings of 2003 IEEE Conference on Control Applications CCA; 2003.
23. Kumar BM. Ravi G, Chakrabarti R. Hybrid speed control of sensorless brushless DC motor with fuzzy-based estimation. IUP Journal of Electrical and Electronics Engineering. 2011; 4(2);21–41.
24. Namnabat M, Poodeh MB, Eshtehardiha S. Comparison the control methods in improvement the performance of the DC-DC Converter. The 7th International Conference on Power Electronics; 2007 Oct. p. 246–51.