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Investigation of Power Quality Improvement in Super Lift Luo Converter

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ABSTRACT

This paper presents the improved single phase AC-DC super lift Luo converter for enhancing quality of power by mitigating the issues. The proposed converter is used for output voltage control, power factor improvement and reduced source current harmonics at supply side. The main intention of this work is to design appropriate closed loop controllers for this AC-DC super lift Luo converter to achieve unity power factor in the source end. The designed control system comprises of two control loops, voltage control in outer loop and the current controller is devised in the inner loop. Fuzzy controller is used for current controller whereas PI controller as voltage controller. In the MATLAB/SIMULINK platform, simulation of the proposed AC-DC super lift Luo converter is done. It is clear from the simulation results that PI integrated fuzzy controller for voltage and control is proven to be better than classical PI with hysteresis controllers. The proposed system is able to achieve high input power factor along with supply current harmonic distortions of less than 5%.

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1. INTRODUCTION

The AC-DC power converter grabs the attention, since it meets the commercial requirements in precise manner. But with deviation in the source parameters by the use of power converters may results in potential power quality problems. Among various power quality issues the harmonic distortions are considered to be one of the most important reasons for the power quality problems. On account of reducing the price of the AC to DC conversion system, diode bridge rectifier along with a capacitor is commonly employed in classic methods. But the main drawbacks of the conventional systems are low power factor, high harmonic distortions, voltage distortion and low efficiency [1]-[3]. To prevail over these shortcomings, single phase rectifier with boost topology is adopted. In comparison to bridge rectifiers, the boost topology offers reduced supply current harmonics, improved input power factor and reduced filter requirements [4]. Even though, it offers lot of advantages it has its own drawback of high switching loss thereby efficiency gets lowered. To overcome these drawbacks, buck-boost converters, SEPIC, CUK converters are used along with the AC-DC rectifier [5]-[8]. Bridgeless topology was introduced in conventional topologies instead of rectifier circuitry to reduce the conduction losses [9]-[11] and a single stage dual-purpose inverter was proposed to improve control reliability and to improve power factor [12]. Though, these topologies operates with minimized conduction losses, there occurs switching losses due to increased number of components. And also the voltage transfer gain is low and ripple content in output voltage is high. So the single phase AC-DC super lift Luo converter is proposed here. Due to the inherent response, super lift Luo converter is most commonly preferred. High voltage gain converters employ voltage lifting technique thereby the output voltage is being increased in an arithmetic progression [13]-[16]. However in super lift technique, the gain ratio increases in geometric progression on stage-by-stage. But their circuits are quite complex to design. To overcome the above mentioned drawback, elementary super lift Luo converter with positive output is used [17]-[19].

The main purpose of the proposed system is to design a single phase AC-DC super lift Luo converter offering high input power factor with reduced THD even under source and load variations. To achieve this PI-fuzzy current controllers for voltage and current control are adapted in this paper, since conventional PI current controller requires an accurate and precise mathematical modelling and it ineffective during parameter variation, nonlinearity, load disturbance, etc.,[20]-[24], and whereas hysteresis controller will limit the error value only to certain limits [25]-[26]. The fuzzy current controller gives very fast response and improves the reliability of the system [27]-[29]. To evaluate the performance of the proposed system, the obtained simulation results are compared with the conventional PI-PI controller, PI-Hysteresis controller. The proposed system can be used in various electrical drive applications, battery charging and electric vehicle applications, etc.

2. AC-DC SUPER LIFT LUO CONVERTER

Figure 1 represents the circuit model of single phase AC-DC super lift Luo converter. The proposed system is designed and their performances are analyzed for wide range of variation in load and supply voltage.

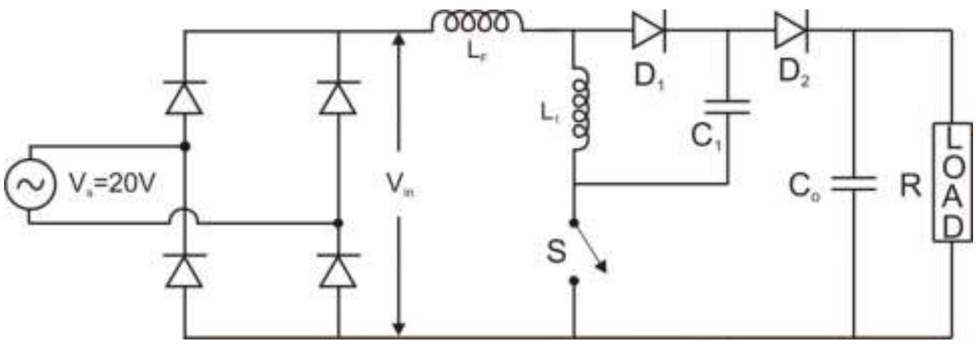


Figure 1. Single phase AC-DC super lift Luo converter

2.1 Modes of Operation

Based on the switching action, there are two modes of operation of super lift Luo converter. Two modes are explained.

2.1.1 Mode 1

Figure 2 represents the mode 1 operation where the switch (S) is being turned 'ON'. Capacitor (C_1) gets charged to V_s during this mode. The inductor current i_{L_1} rises with respect to supply voltage V_s. The input current i_s will be equal to $i_{L_1} + i_{c_1}$ .The characteristic equation during mode 1 operation.

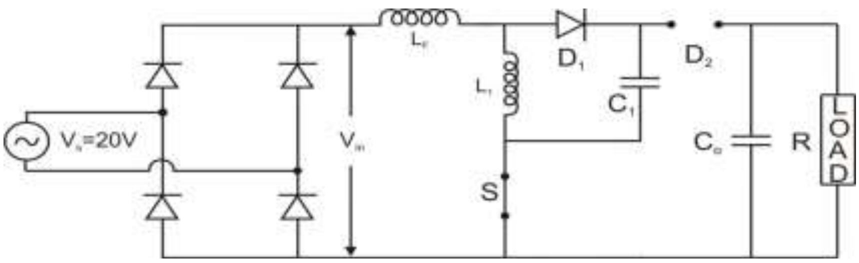


Figure 2. Mode 1 operation

$$\left|v_s\right| = L\frac{di}{dt} = V_{c_1} \tag{1}$$

$$C_o\frac{dv_o}{dt} + \frac{v_o}{R} = 0 \tag{2}$$

2.1.2. Mode 2

Figure 3 explains the second mode of operation of single phase AC – DC super lift Luo converter. In this mode, the switch (S) is being turned 'OFF' with the diode D_2 under forward bias and diode D_1 under reverse bias. The input current will be equal to $i_{L_1}\left(=i_{c_0}\right)$ during mode 2 operation. During off-time of the switch,

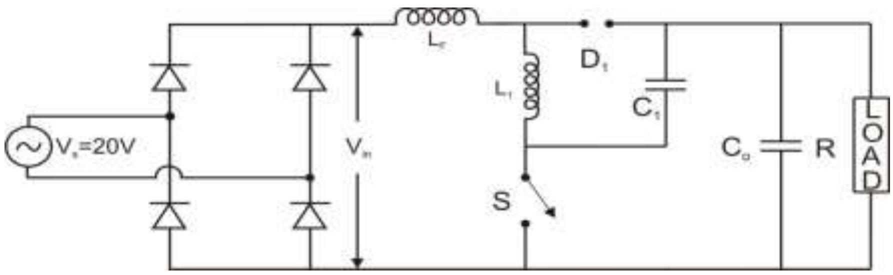


Figure 3. Mode 2 operation

$$\left|v_s\right| = L\frac{di}{dt} + V_{c_1} + V_o \tag{3}$$

$$C_o\frac{dv_o}{dt} + \frac{v_o}{R} = i_{L_1} \tag{4}$$

3. MODELING OF THE PROPOSED CONVERTER

The inductor voltage will get decreases to a voltage of $-\left(V_o - 2V_{in}\right)$, during switch S under open condition. Therefore, the inductor L_1 can be represented as,

$$L_1 = \frac{v_o - 2v_{in}}{\Delta I_L f} \tag{5}$$

The capacitor value can be calculated by the formula given below,

$$C_1 = C_o = \frac{\left(1-D\right)V_o}{fR\Delta V_o} \tag{6}$$

Output voltage can be obtained from,

$$V_o = \frac{2-D}{1-D}V_{in} \tag{7}$$

where D - duty cycle, V_o - output voltage, V_{in} is the voltage across the diode bridge rectifier, ΔI_L - inductor current ripple, f - switching frequency, ΔV_0 is the ripple voltage, R is the load resistance. By using the design equations the values of circuit components are calculated and it is listed in Table 1.

Table 1. Design Parameters

Parameter	Specification
Input line voltage (V_s)	20 V
Output DC voltage(V_o)	48 V
Rated power(P_o)	100 W
Switching frequency (f)	10 kHz
Line frequency(F)	50 Hz
Inductor (L_f)	1.4 mH
Inductor (L_1)	1.6 mH
Capacitance C_1= C_o	2200 µF

Representation of transfer function of super lift Luo converter,

$$\frac{v_o}{v_s}=\frac{K}{1+s\frac{L_1}{R}+s^2L_1C_1} \quad (8)$$

where $K=\frac{2-D}{1-D}$

By substituting the values designed in the Equation (8) we get,

$$\frac{v_o}{v_s}=\frac{2.6949}{1+6.08\times10^{-3}s+2.8\times10^{-6}s^2} \quad (9)$$

4. BLOCK DIAGRAM OF CONTROL CIRCUIT

The control layout of the single phase AC-DC super lift Luo converter is shown in Figure 4. The proposed system consists of AC-DC super lift Luo converter, voltage and current controller, power estimator and phase lock loop. Error in output voltage as obtained from the comparison of actual converter output and reference output voltage is given to the voltage controller. Then, output signal from the power estimator block and the control signal from the voltage controller are summed up. The obtained value is then multiplied with the PLL output to get reference current. Sensed inductor current is then compared with the generated reference current and the error current signal is fed it into the inner current loop.

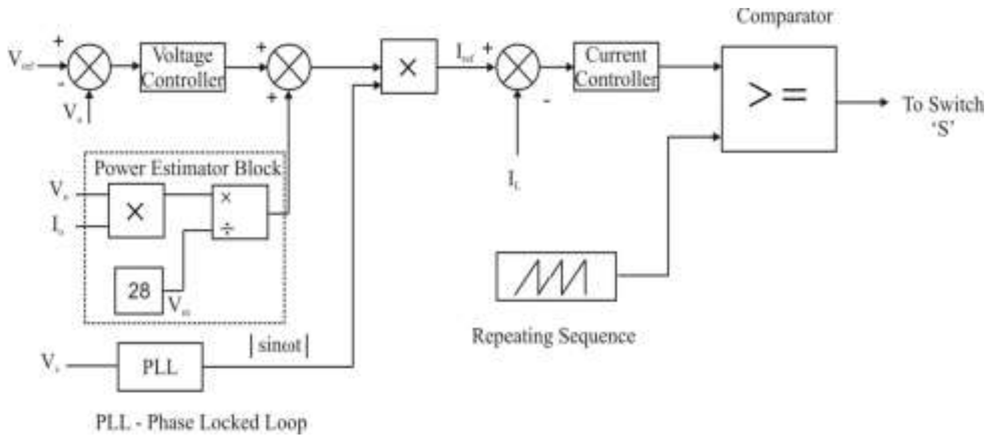


Figure 4. Schematic representation of control circuit for proposed single phase AC-DC super lift Luo converter

4.1. PI Controller Design

PI controller is used in the outer voltage loop. With the help of proportional gain (K_p) and integral gain (K_i), the error signal can be reduced near to zero. Steady state error is eliminated by K_i and rise time can be reduced by K_p. K_p, K_i values are obtained by automatic tuning method are 0.015, 3.7 respectively.

4.2. Hysteresis Current Controller Design

Hysteresis current controller is used in the inner loop. Hysteresis current controller limits the current signal around the dead band and paves way to reduce the error value. Hysteresis controller produces signal in accordance with the limit of error signal. Whenever the error signal rises from minimum I_l to maximum I_l the switch will get turned ON and the switch gets turned OFF during the fall period. The hysteresis bandwidth can be determined from the formula.

$$\beta=\frac{\left(V_{in}-L_1\times\omega\times i_{ref}\right)\times\left(V_o+V_{in}-\left(L_1\times\omega\times i_{ref}\right)\right)}{L_1\times V_o\times f_s} \quad (10)$$

where,

V_{in} is the voltage across the diode bridge rectifier
L_1 is the value of the inductor
ω is the angular frequency
i_{ref} is the reference inductor current
V_o is the output voltage
β is the hysteresis bandwidth

By using equation (10), it is found that the value of hysteresis bandwidth β is 0.21. The hysteresis current controller with its inherent simplicity paves a way to design a system that provide regulated output voltage and low distorted input current waveforms.

4.3. Design Of Fuzzy Current Controller

For the proposed system, the optimized result is obtained by implementing Fuzzy in the inner current control loop. The fuzzy logic controller is gaining attention because it provides good support in converting both the heuristic knowledge about the process and control mechanism which into numerical algorithms (i.e., FLC replicates the human logic to take decision).

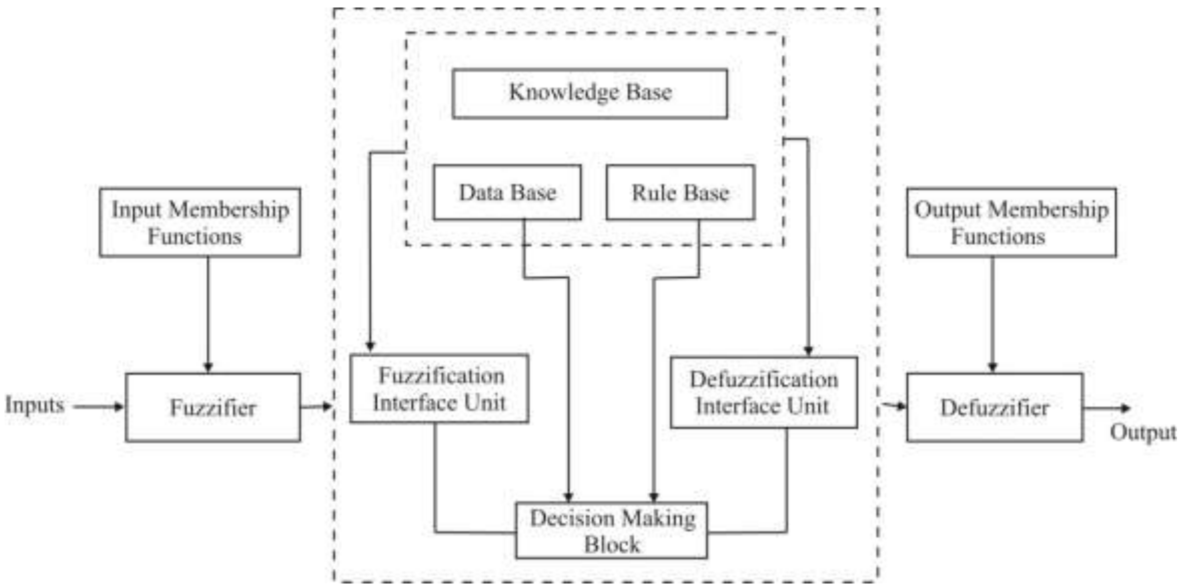


Figure 5. Fuzzy inference system

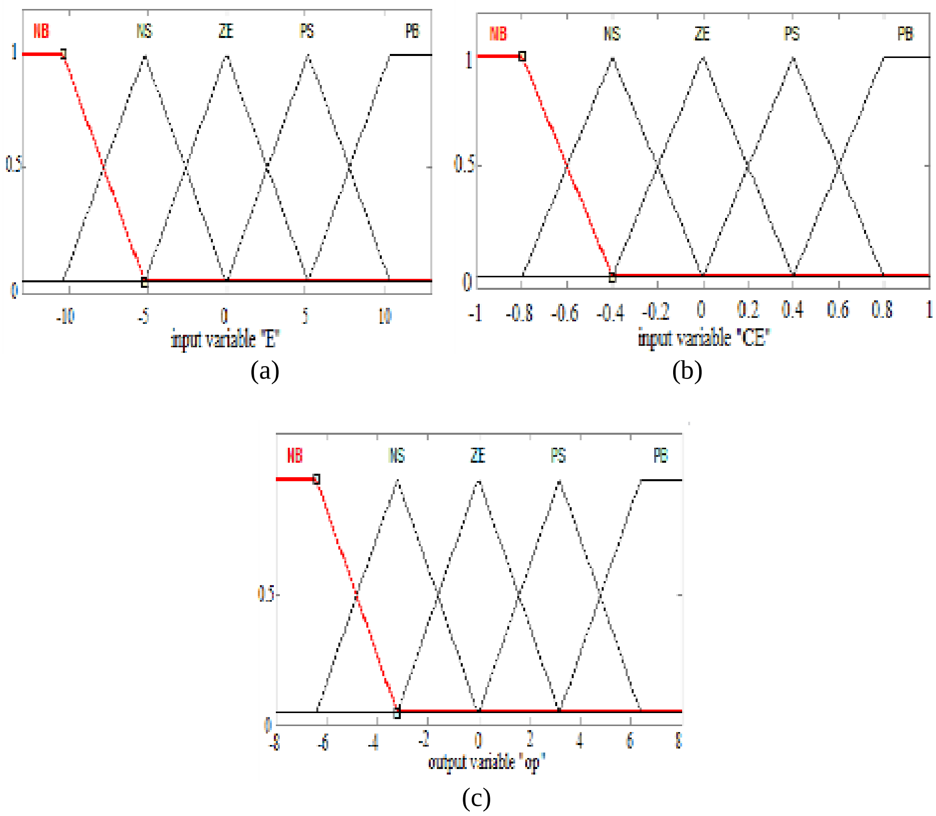


Figure 6. Membership functions for (a) input (output voltage error), (b) input 1 (derivative error signal), (c) output (manipulated output signal)

Fuzzy rules (5×5) are given in Table 2. The input parameters (output voltage error & derivative error signal) and the output parameter (manipulated output signal) are helpful in designing fuzzy logic controller. Figure 7 shows the surface view of fuzzy current controller for the proposed system.

Table 2. Fuzzy control rules

E \ CE	NB	NS	ZE	PS	PB
NB	NB	NB	NS	ZE	PS
NS	NB	NS	NS	ZE	PS
ZE	NS	NS	ZE	PS	PB
PS	PS	ZE	PS	PS	PB
PB	PB	PS	PS	PB	PB

NB- Negative Big, NS-Negative Small, ZE-Zero, PS-Positive Small, PB-Positive Big.

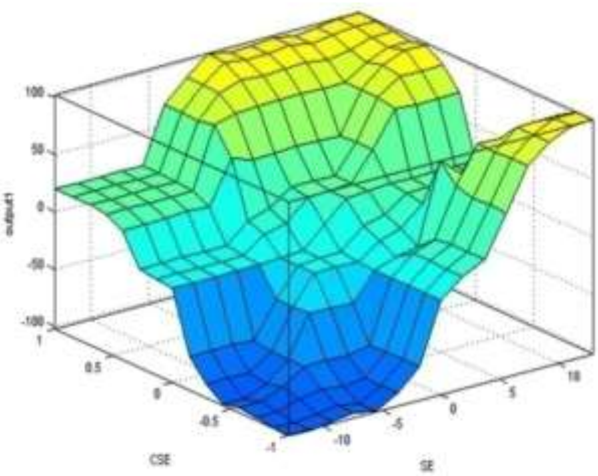


Figure 7. Control surface of fuzzy current controller

5. SIMULATION AND RESULTS

The simulation of the proposed system is carried out by using MATLAB package. Figure 8 depicts the simulation diagram of single phase AC-DC super lift Luo converter and Figure 9 explains the fuzzy subsystem used.

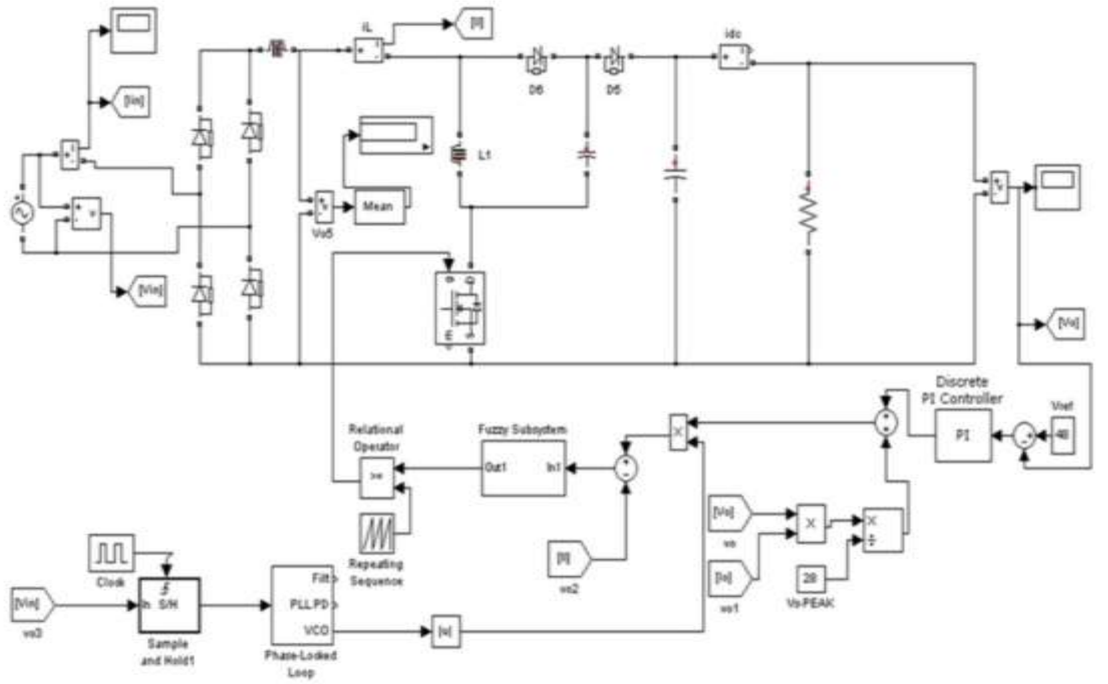


Figure 8. Simulation of single phase AC-DC super-lift Luo converter

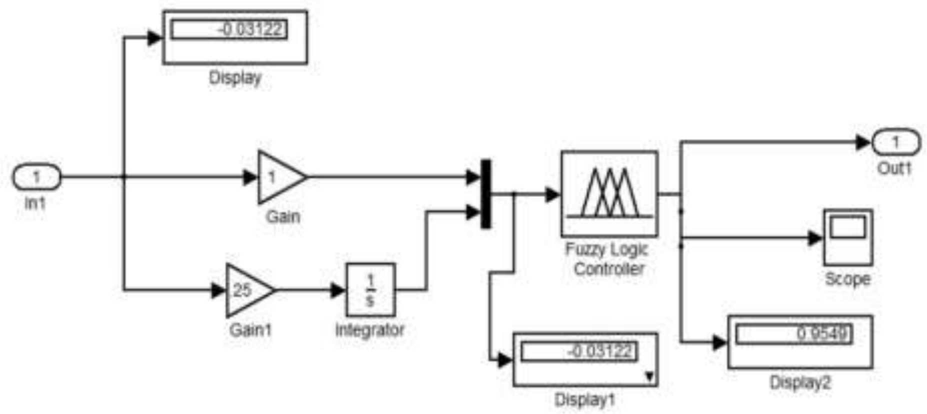
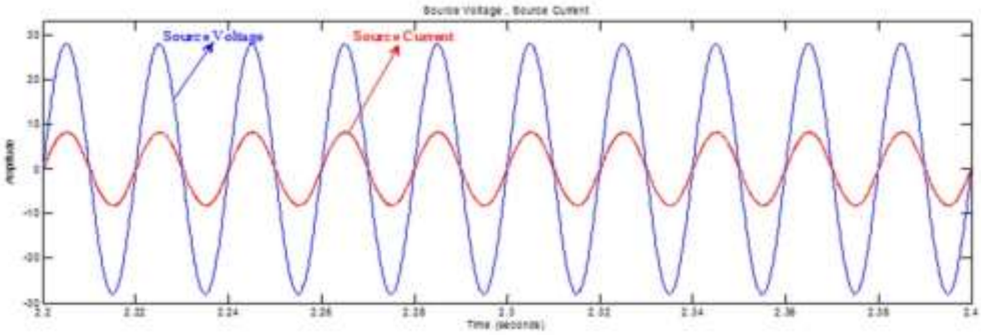
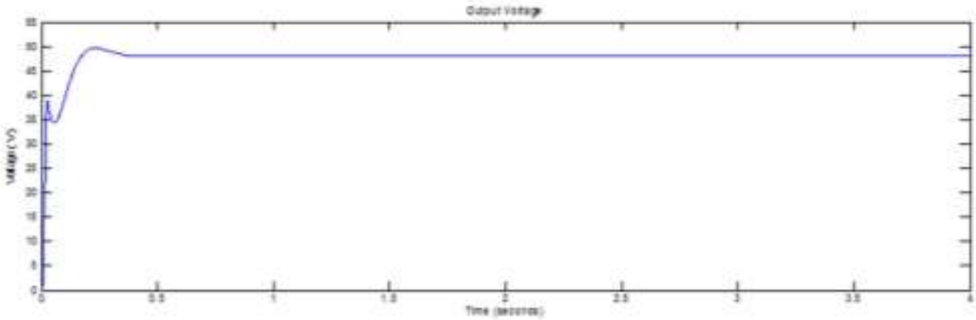


Figure 9. Sub system of fuzzy current controller

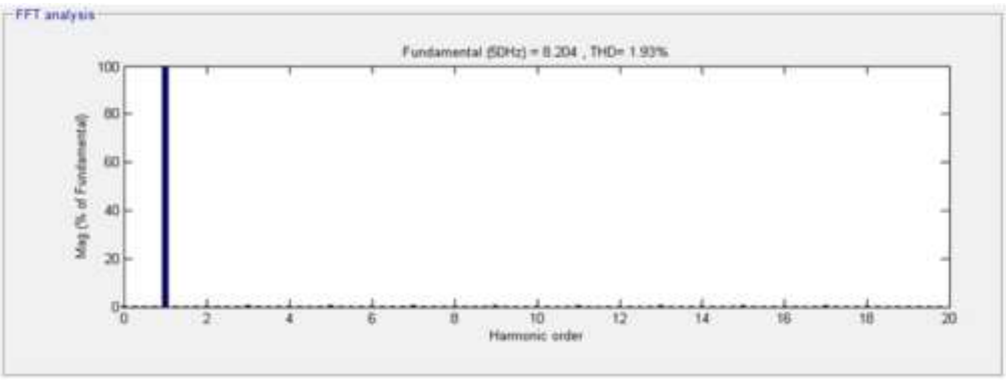
Figure 10 (a) depicts the waveform of input voltage and current and from the waveform it is evident that distortions in the source side parameters are too low. The output voltage waveform of single phase AC-DC super lift Luo converter is shown in Figure 10 (b). The FFT spectrum of the proposed system under rated constraints is found to be 1.93% and it is shown in Figure 10(c).



(a)



(b)



(c)

Figure 10. (a) Source voltage and source current waveforms, (b) Output voltage waveform, (c) FFT analysis under rated constraints

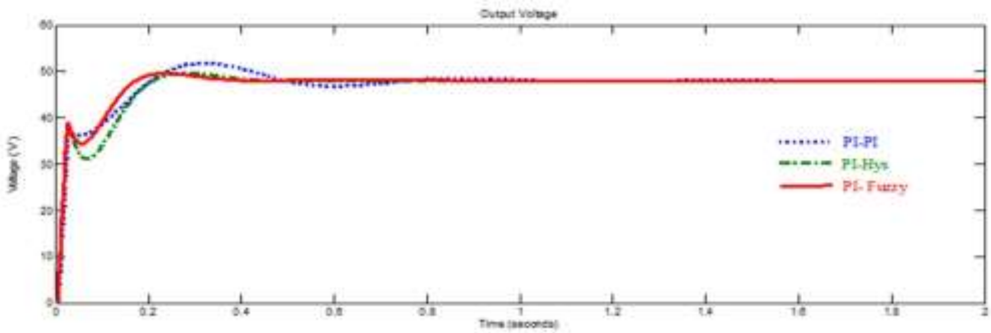


Figure 11. Comparative results of output voltage waveform under rated constraints

To evaluate the performance of the proposed system, the results obtained from PI – Fuzzy controller are compared with PI-PI and PI-Hysteresis controller combinations. The comparative results of various controllers are showcased in Figure 11. The comparison of output voltage waveform clearly reveals that, for PI-PI controller overshoot value is 8.12%, whereas in PI-Hysteresis it is in the order of 3.12% and with PI-Fuzzy it is reduced further to 2.58%. PI-Fuzzy controller produces the optimized result with faster response, quick settling time and with very low harmonic content of 1.93%. The detailed comparisons of the PI-PI, PI-Hysteresis and PI-Fuzzy are tabulated in Table 3 and Table 4.

Table 3. Performance analysis of single phase AC-DC super lift Luo converter under load variation

Load (%)	Output voltage (V)	Power factor at supply side			Total Harmonic Distortions of supply current (%)		
		PI-PI	PI-Hysteresis	PI-Fuzzy	PI-PI	PI-Hysteresis	PI-Fuzzy
100	48	0.9991	0.9994	0.9996	3.92	2.72	1.93
80	48	0 9987	0.9993	0.9995	4.98	3.12	2.04
60	48	0.9979	0.9992	0.9993	6.73	3.52	2.00
40	48	0.9954	0.9990	0.9991	9.12	4.38	2.26
20	48	0.9853	0.9981	0.9986	17.02	4.30	3.84

Table 4. Performance analysis of Single phase AC-DC super lift Luo converter under supply voltage variation

Supply voltage (V)	Power factor at supply side			Total Harmonic Distortions of supply current (%)		
	PI-PI	PI-Hysteresis	PI-Fuzzy	PI-PI	PI-Hysteresis	PI-Fuzzy
15	0.9963	0.9966	0.9973	6.78	6.60	4.84
20	0.9991	0.9995	0.9995	3.92	2.72	1.93
25	0.9986	0.9991	0.9997	4.99	2.53	1.72
30	0.9976	0.9990	0.9996	7.21	2.86	1.99
35	0.9956	0.9986	0.9996	10.5	3.14	2.40

Table 3 depicts the functional analysis of AC-DC super lift Luo converter under various load condition. From the analysis, it is evident that output voltage is regulated and maintained constant at 48 V, with power factor at supply side nearer to unity and source current harmonics is lies less than 5% during wide variation of load. Table 4 shows the performance comparison of single phase AC-DC super lift Luo converter during change in supply voltage both below and above the rated condition (20V). This proposed ac-dc super lift Luo converter is compared with other conventional power factor correction converters. It is shown in Table 5. This proposed converter gives better power quality improvement.

Table 5. Comparision

Converters	THD%	Power Factor
Boost converter [26]	2.10	0.9970
Buck Boost converter [7]	9.64	0.9648
Cuk converter [6]	2.22	0.9994
Bridgeless Cuk converter [9]	3.38	0.9993
Proposed converter	1.93	0.9996

7 CONCLUSION

The proposed system is explored to meet the power quality constraints by incorporating PI and fuzzy controllers for voltage and current control. The simulation of closed loop control of single phase AC-DC super lift Luo converter is carried out in MATLAB/SIMULINK platform. The behavior of the proposed system in comparison to the PI – PI and PI - Hysteresis controller, it is noted that the source current harmonics is 1.93% and power factor at supply side is almost unity. Wide range of load variation and change in supply voltage does not affect the system performance which proves the controller's sustainability.

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