International Journal on Future Revolution in Computer Science & Communication Engineering
Volume: 4 Issue: 12
ISSN: 2454-4248
32 – 36

Design of a PI Controller for Negative Output 1 & 3 -lift Main Series Switched Capacitor Push Pull Luo Converter

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Abstract— Classic converters like DC-DC converters are having the passive components such as switches, diodes, capacitors and inductors that are combined. By this size of the converter will be large and power density will be low. Power density of the converter can be increased by micro power consumption technique. Voltage-lift technique is the best technique to design circuits in electronics. For more power density, compact size and gain switched capacitors can be used and incorporated into the IC having lesser EMI. This work provide the performance evaluation of PI controller for Negative output push-pull switched capacitor DC-DC 1 lift and 3 lift Luo converter and also performance evaluation of chosen converter with PI controller. Mat lab and Simulink based simulation is carried out under line and load disturbances for performance evaluation.

Keywords- *PI controller; Luo Converter; Matlab.*

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I. Introduction

DC-DC Converters provides the conversion of unregulated Dc voltage to regulated DC voltage and also conversion of various voltage levels to power. These converters can be applied in the equipment's of computer peripherals, regulation of buses and isolation, in industrial applications [1]. SC's requires huge amount of capacitors and works in on-off state to get high output voltages. These converters works in 4 quadrants with constant frequency. Thus change in the duty ratio of the switches results in the output voltage. This is called PWM technique. The combined voltage-lift technique and SC's can be used in the design of Negative output (NO) multiple-lift push-pull switched capacitor (SC) Luo converter with increased gain and power density, compact size, less EMI and high efficiency [1]. There are converters with large output voltage and small ripples. But Luo converters provide non-linear characteristics. Along with PI controller voltage input is regulated by varying the converters duty ratio.

II. MAIN SERIES 1-LIFT CIRCUIT

The circuit possessing on and off period for Negative output multiplelift main series elementary switched capacitor push pull Luo DC-DC converter is shown in [1] Fig.1. This circuit is having two switches namely S (main switch) and S1 (slave switch), two diodes and two capacitors. During the switch off period (1-K)T, C2 charges to 2Vin and during switch on period KT, C1 charges to Vin. Consider R as resistive load, Vo and Vin are output and input voltages respectively. Input and output currents denoted as Iin and Io respectively. S1 and S are connected in the configuration of push pull. So the voltage drop across both period is same as the input voltage and shown in eqn.1 & 2.

$$V_o = V_{in}. \quad (1)$$

$$V_o = V_{in} - V_d \quad (2)$$

Where Vd represents the voltage drop across diode cum switches and table 1 gives the circuit parameters.

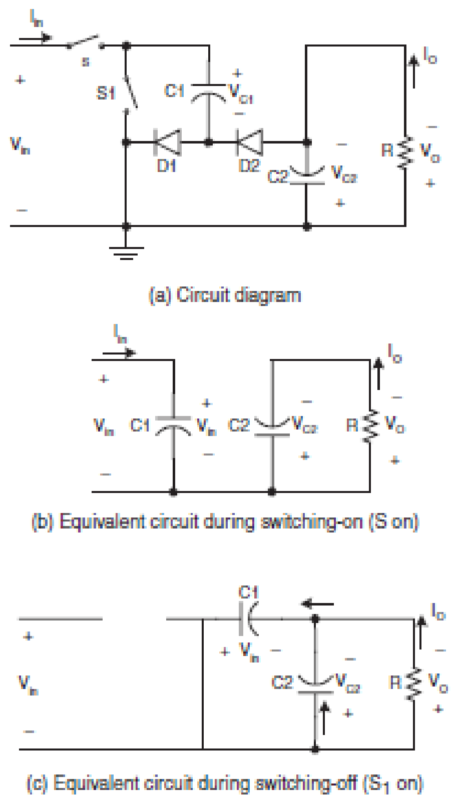

Figure.1 Negative output Main series elementary push pull Switched capacitor Luo converter

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III. MAIN SERIES 3-LIFT CIRCUIT

3-Lift circuit is taken from 1 lift circuit along with the addition of one more slave switch (S2) (Here n = 2) two capacitors (C3, C4) and three diodes (D3, D4 and D5). The circuit schematic and equivalent circuit when switch is ON and OFF is displayed in Figure 1.

The Master Switch S and Slave Switches (S1, S2) operate in Push-Pull state (ON-OFF state). When Master Switch (S) is ON and Slave Switches (S1, S2) are OFF, capacitor C1 charges to Vin and C3 charges to V1. When Master Switch (S) is OFF and Slave Switches (S1, S2) are ON, capacitor C2 charges to V1 = 2Vin – ΔV1 and C4 charges to Vo = 2V1 – ΔV2. Voltage Output is the difference between voltage across the capacitor C4 and C1 as below in equation

Vo = 2V1- ΔV2 –Vin

By simplifying for Vo, voltage output obtains to be three times the voltage input

i.e., Vo = 3Vin - 2ΔV2-ΔV2

By taking into account voltage drop across switches and diodes, voltage output will be less than 3Vin

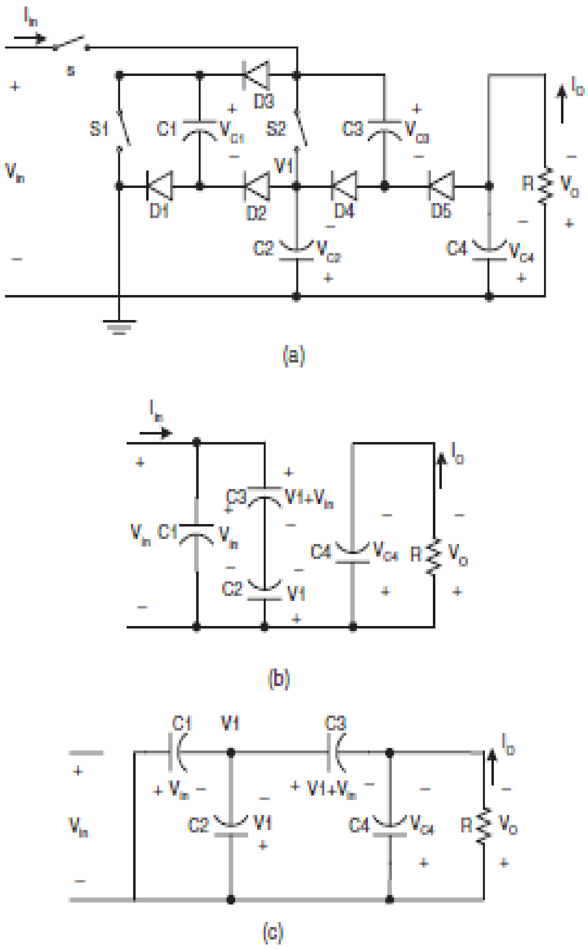

Figure. 2 (a) Schematic circuit of 3lift, (b) Equivalent circuit when switch S is ON, (c) Equivalent circuit when switch S is OFF

TABLE 1
1 LIFT LUO CONVERTER CIRCUIT PARAMETERS

Parameters	Values
Capacitors C_1, C_2	1μf
Range of load (R)	1KΩ
Input voltage V_I	20 volts
Switching frequency f_s	10KHz
Range of duty ratio (d)	0.1-0.9
Output voltage V_O	-20 volts

TABLE 2
3-LIFT LUO CONVERTER CIRCUIT PARAMETERS

Parameters	Values
Capacitors C_1, C_2	1μf
Range of load (R)	1KΩ
Input voltage V_I	10 volts
Switching frequency f_s	10KHz
Range of duty ratio (d)	0.1-0.9
Output voltage V_O	-30 volts

IV. ANALYSIS OF PI CONTROLLER DESIGN

The chosen converter has been modeled and simulated using MATLAB/SIMULINK Power System Block set. Fig.2 shows the S shaped curve and Fig. 2(a) shows the block diagram of Positive output main series 8-Lift Luo converter using Proportional Integral (PI) controller. This controller [6][7] sets proportional gain (Kp), integral time (Ti) are aimed using ZN tuning technique [11][12] by implementing the step test to the state space averaged model, of the chosen converter. The time constant and delay time (Td) is calculated by creating a tangent line at the inflection point at S-shaped curve [3][5], finding the tangent line convergent point. PI control is implemented using control system toolbox and table shows the ZN tuning rules.

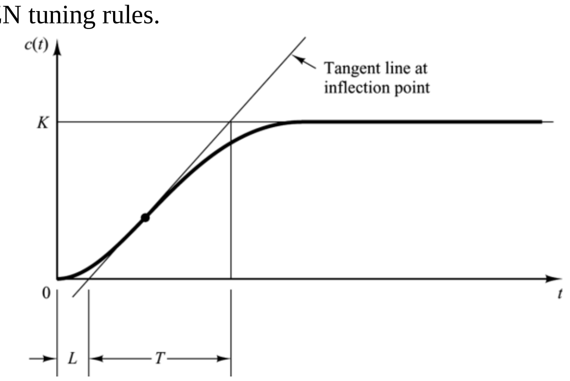

Figure.3 S Shaped response curve

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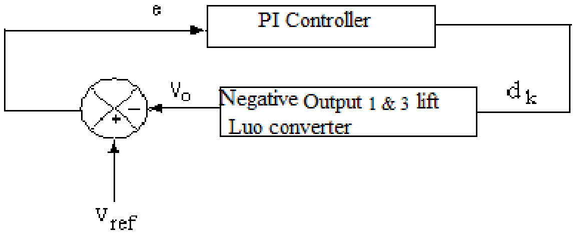

Figure.4 Block diagram of Negative output main series 1 & 3-Lift Luo converter using PI controller

TABLE 3
ZIEGLER-NICHOLS TUNING RULES

Type of Controller	K_p	T_i	T_d
P	$\frac{T}{L}$	∞	0
PI	$0.9\frac{T}{L}$	$\frac{L}{0.3}$	0
PID	$1.2\frac{T}{L}$	$2L$	$0.5L$

V. SIMULATION RESULTS

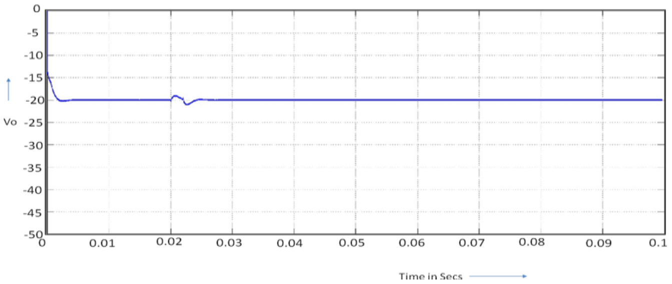

Figure.5 (a) +20% supply disturbances of input 20V

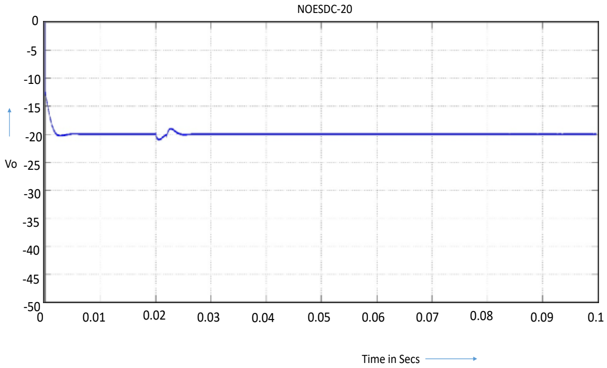

Figure.5(b) -20% supply disturbances of input 20V

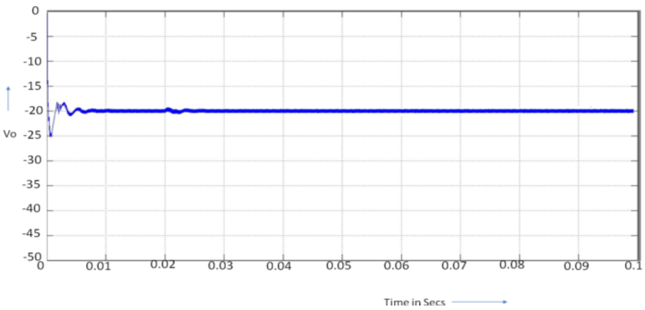

Figure.5(c) +20% load disturbances of load 1000Ω

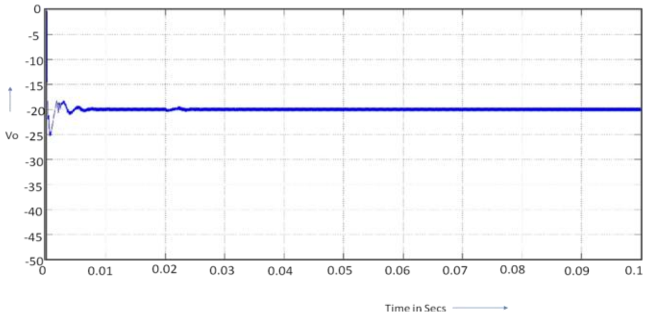

Figure.5 (d) -20% load disturbances of load 1000Ω

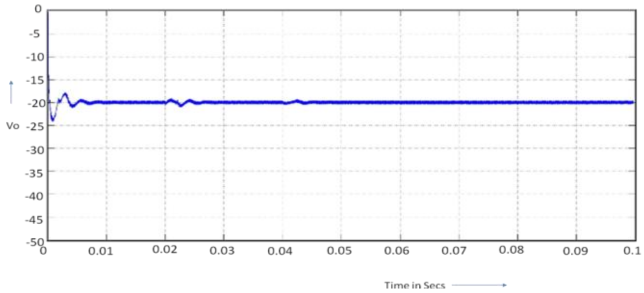

Figure.5(e) -20% line disturbance of input 20V and +20%Load disturbances of load 1000 Ω.

Simulation analysis of load regulation and line regulation of the 1 lift Luo converter was done to estimate the controller behaviour. Converter voltage output for step change in voltage input of 18V to 20V (disturbance in supply by -20%), which results in settling time of 6ms and peak overshoot of 10% is as shown in Fig. 5(b) [1]. Converter voltage output for step change in voltage input of 20V to 22V (disturbance in supply by +20%), which results in settling time of 7ms and peak overshoot of 10% is as shown in Fig. 5(a). Converter voltage output for step change in load by 800Ω to 1000Ω (disturbance in load by -20%), which results in settling time of 5ms and peak overshoot of 5% is as shown in Fig. 5(d). Converter voltage output for step change in load by 1000Ω to 1200Ω (disturbance in load by +20%), which results in settling time of 7ms and peak overshoot of 10% is as shown in Fig. 5(c). Fig. 5(e) shows -20% supply disturbances of 20V and +20% load disturbance of 1000Ω.

TABLE 4

START-UP RESPONSE FOR 1 LIFT CIRCUIT

Parameters	***Startup Transient***
Rise Time (ms)	2
Setteling Time(ms)	8

TABLE 5

ANALYSIS OF PI CONTROLLER WITH DISTURBANCE IN SUPPLY

Parameters	***Supply decreases 20%***	***Supply increases 20%***
Peak overshoot %	10	10
Settling Time(ms)	6	7

TABLE 6

ANALYSIS OF PI CONTROLLER WITH DISTURBANCE IN LOAD

Name of the Parameters	***Load decreases 20%***	***Load increases 20%***
Peak overshoot %	5	10
Settling Time(ms)	5	7

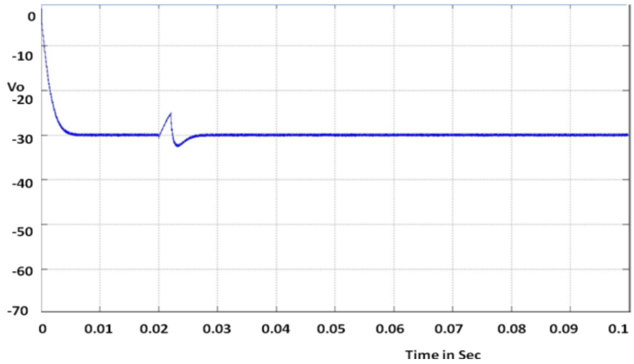

Figure.6 (a) +20% supply disturbances of input 10V

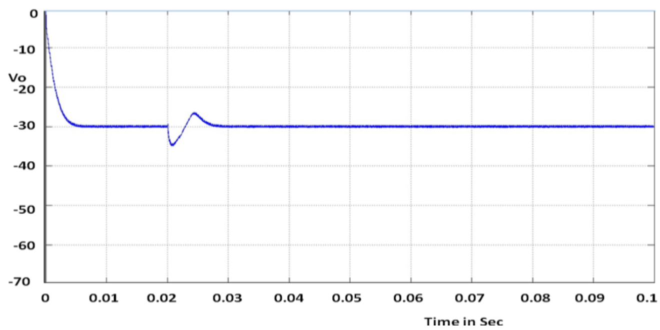

Figure. 6(b) -20% supply disturbances of of input 10V

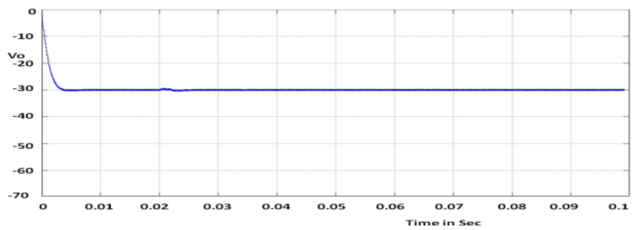

Figure.6(c) +20% load disturbances of load 1000Ω

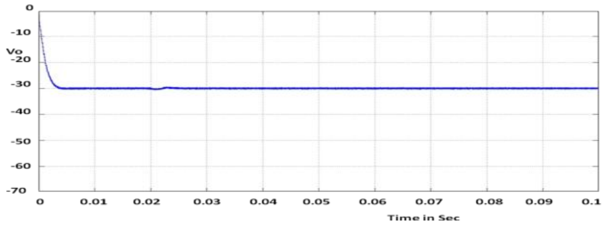

Figure.6(d) -20% load disturbances of load 1000Ω

TABLE 7

START-UP RESPONSE FOR 3 LIFT CIRCUIT

Parameters	***Startup Transient***
Setteling Time(ms)	8
Peak Overshoot	0

TABLE 8
ANALYSIS OF PI CONTROLLER WITH DISTURBANCE IN SUPPLY

Parameters	***Supply decreases 20%***	***Supply increases 20%***
Peak overshoot %	20	16
Settling Time(ms)	8	7

TABLE 9
ANALYSIS OF PI CONTROLLER WITH DISTURBANCE IN LOAD

Name of the Parameters	***Load decreases 20%***	***Load increases 20%***
Peak overshoot %	5	3
Settling Time(ms)	4	6

Simulation analysis of load regulation and line regulation of the above mentioned converter was done to estimate the controller behaviour. Converter voltage output for step change in voltage input of 8V to 10V (disturbance in supply by -20%), which results in settling time of 7ms and peak overshoot of 16% is as shown in Fig. 6(a) [1]. Converter voltage output for step change in voltage input of 10V to 12V (disturbance in supply by +20%), which results in settling time of 8ms and peak overshoot of 20% is as shown in Fig. 6(b). Converter voltage output for step change in load by 800Ω to 1000Ω (disturbance in load by -20%), which results in settling time of 6ms and peak overshoot of 6% is as shown in Fig. 6(c). Converter voltage output for step change in load by 1000Ω to 1200Ω (disturbance in load by +20%), which results in settling time of 6ms and peak overshoot of 3% is as shown in Fig. 6(d).

VI. CONCLUSION

The multiple-lift main series elementary Negative output switched capacitor push pull Luo converters provide transform to load voltage from supply voltage [1]. Transient response of 1 lift and 3 lift circuit is show in Table 4 & 7 and Analysis of PI controller for line and load disturbances for 2 & 1 lift circuit is shown in Table 5, 6, 8 & 9. Results of simulation of Fuzzy controller analyze that it has better ability to overhead rejection compared to other intelligent controller for line as well as load variations. Sharing the current properly in FLC gives regulated voltage output. PI controller thus developed verifies the results effectively [11].

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