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Pi And Fuzzy Logic Controlled Multiple Lift-Push-Pull Switched Capacitor Luo Converter

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ABSTRACT

This study shows a simulation using PI and fuzzy logic controllers for a newly constructed elementary P/O push-pull switched capacitor Luo converter circuit. This incorporates both voltage lift and switched-capacitor technology. Power electronic converters' dynamic behavior becomes quite non-linear due to their time-varying and switching nature. Fuzzy logic controllers can be utilized as feedforward controllers for power electronic converters because conventional controllers are unable to provide high dynamic performance. By taking repeated measurements of the converter output voltage at specific points during a conduction period, the Control algorithm is created in this study to ensure tracking of the reference voltage and rejection of system disturbances. The main aim is a simulation of PI and Fuzzy logic controls using MATLAB/ Simulink software to evaluate the controller's performances. The simulation results show Fuzzy controller performs effectively for the preferred converter.

Keywords: DC-DC Converter; Luo Converter; PI controller.

1. INTRODUCTION

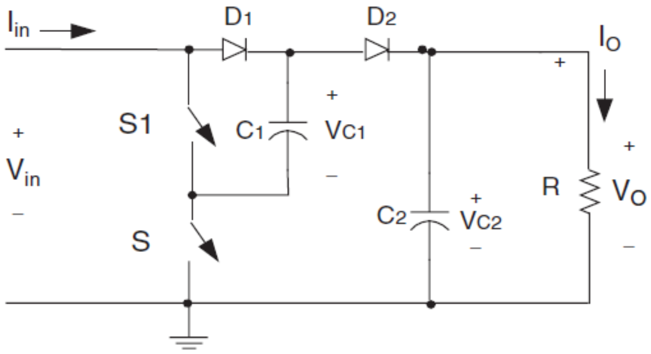
Since it is necessary to obtain a high power density, high voltage transfer gain, and high power efficiency, DC-DC conversion technology has risen recently. The positive input source voltage is converted to positive and negative output voltages via dual-output DC-DC converters. They consist of two conversion routes, one of which is positive and the other of which is negative. Particularly needed in industrial applications and computer peripheral circuits such as operational amplifiers, computer peripheral power supplies, differential servo motor drives, and some proportional voltage medical equipment are these mirror symmetrical double-output voltages. Operating the DC-DC converters as closed-loop systems is important to set the output voltage of the converters independent of load changes and supply disruptions. When using pulse-width modulation control, the output voltage of DC-DC converters is regulated by adjusting the duty cycle of the electronic switch while maintaining a constant operating frequency [1-6]. These converters typically feature complicated non-linear models with issues with parameter variation. The output potential of reverse self-lift positive output Luo converters under supply and load disturbances is calculated in this paper using a PI controller. To assess the performance of the controllers, load and line regulation tests are run. The findings are discussed and assessed.

2. P/O PUSH-PULL SWITCHED CAPACITOR LUO CONVERTER

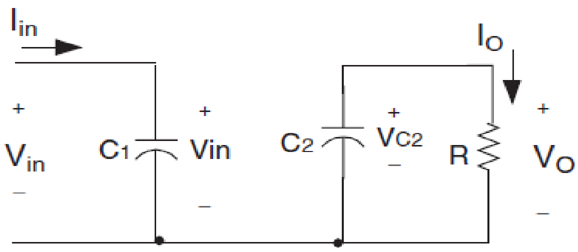
The switched capacitor's size is reduced since it may be integrated into the power integrated circuit (IC) chip. A DC/DC converter with a small size, high power density, high voltage transfer gain, high power efficiency, and low EMI is produced by combining the switched-capacitor and voltage lift techniques. With a conduction duty cycle of k = 0.5, switched-capacitor (SC) converters can operate in the push-pull mode. Each circuit consists of a single main switch (S) and numerous slave switches (i = 1, 2, 3,..., n). The number n is called the stage number. The main switch S is on and slaves off during the switch-on period kT, and S is off and slaves on during the switch-off period (1 – k)T. The load is resistive load R. Input voltage and current are V_{in} and I_{in}, and output voltage and current are V_O and I_O.

2.1 Elementary Circuit of P/O Push-Pull SC Luo Converter

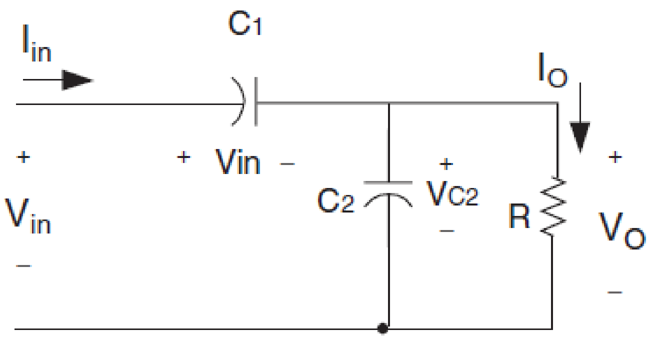
The elementary circuit and its equivalent circuits during Switch-on and switch-off are shown in Fig.1. Two switches S and S_1 operate in the push-pull state [7-11].



(a) Circuit diagram



(b) Equivalent circuit during S on



(c) Equivalent circuit during S_1 on

Fig.1: Elementary circuit and its equivalent circuits during Switch-on and switch-off

The voltage across capacitor C_1 is charged to V_{in} during switch on. The voltage across capacitor C_2 is charged to $V_O = 2V_{in}$ during the switch-off. Therefore, the output voltage is,

$$V_O = 2V_{in} \tag{1}$$

Considering the voltage drops across the diodes and switches, we combine all values in a figure of ΔV_1. The real output voltage is

$$\begin{aligned} V_o &= 2V_{in} - \Delta V_1 \\ &= 2V_{in} - (V_{D1} + V_s + V_{S1} + V_{D2}) \\ &= 2V_{in} - (2V_s + 2V_d) \end{aligned} \quad (2)$$

3. DESIGN OF CONVENTIONAL CONTROLLER

Process control applications have been using PI controllers for many years in the industrial sector. Their widespread acceptance can be attributed to their straightforward designs, good performance, low percentage overshoot, and short settling times for sluggish process plants. The three linked parameters have a distinct physical meaning, making the PI controllers' relative usability their most praised feature. This allows the operators to tune them by using trial and error as well, and in any case, many tuning rules have been devised.

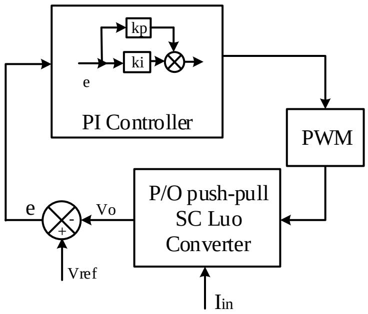


Fig.2: Structure of PI controller

Despite the success of all the currently available strategies for PI controller parameter tweaking, extensive research is still being done to increase system control quality and performance. A general closed-loop feedback system is a PI controller. To adjust the process, a corrective signal is derived from the error between a measured process variable and the desired setpoint. This signal is finally fed back to the input side. The PI controller's differential equation is as follows,

$$u(t) = K_p e(t) + T_i \int_o^t e_p(t)dt \quad (3)$$

To define the PID controller algorithm, the three times functions are weighted, with the three different weights being: The area under the error time curve up to the present point, which accounts for the extent of the reaction to the rate of change of the error with time, is used to decide the reaction while KP (Proportional Gain) defines the influence of the present error value on the control mechanism [12]. Figure 2 depicts the PI controller's structural layout. PI controller configuration Using the Ziegler-Nichols tuning technique, Kp and Ti are created based on the converter's open loop step responses under the aforementioned loads. Controller tuning involves the selection of the best values of Kp and Ti. This is often a subjective procedure and is certainly process-dependent. Kp= 0.205, Ti =0.000025 in this work.

4. DESIGN OF FUZZY LOGIC CONTROLLER

The fuzzy control provides a formal methodology for representing, manipulating, and implementing a human's heuristic knowledge about how to control a system.

The fuzzy controller has the following main components

- The "rule-base" holds the knowledge, in the form of a set of rules, of how best to control the system.
- The inference mechanism evaluates which control rules are relevant at the current time and then decides what the input to the plant should be.

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- The fuzzification interface simply modifies the inputs so that they can be interpreted and compared to the rules in the rule base.
- The defuzzification interface converts the conclusions reached by the inference mechanism into the inputs to the plant.

For the design of fuzzy logic controller, the following design steps are to be followed:

- Choice of state and control variables
- Select the inference method.
- Fuzzification. Process of making a crisp quantity fuzzy
- Design the knowledge base.
- Select the defuzzification method.
- Test and tuning.
- Produce a Lookup table.

The derivation of fuzzy control rules is based on the following criteria:

- When the output of the converter is far from the set point, the change of duty cycle must be large to bring the output to the set point quickly.
- When the output of the converter is approaching the set point, a small change of duty cycle is necessary.
- When the output of the converter is near the set point and is approaching it rapidly, the duty cycle must be kept constant to prevent overshoot.
- When the set point is reached, and the output is still changing, the duty cycle must be modified a little bit to prevent the output from moving away.
- When the set point is reached, and the output is steady, the duty cycle remains unchanged.
- When the output is above the set point, the sign of a change of duty cycle must be negative and vice versa.

Fuzzy memberships NL, NM, NS, ZE, PS, PM, and PL are defined as negative large, negative medium, negative small, zero, positive small, positive medium, and positive significant. Fig.3 shows the basic structure of a fuzzy logic controller. The main building units of FLC are a fuzzification unit, a fuzzy logic reasoning unit, a knowledge base, and a defuzzification unit. Defuzzification is the process of converting inferred fuzzy control actions into crisp control actions.

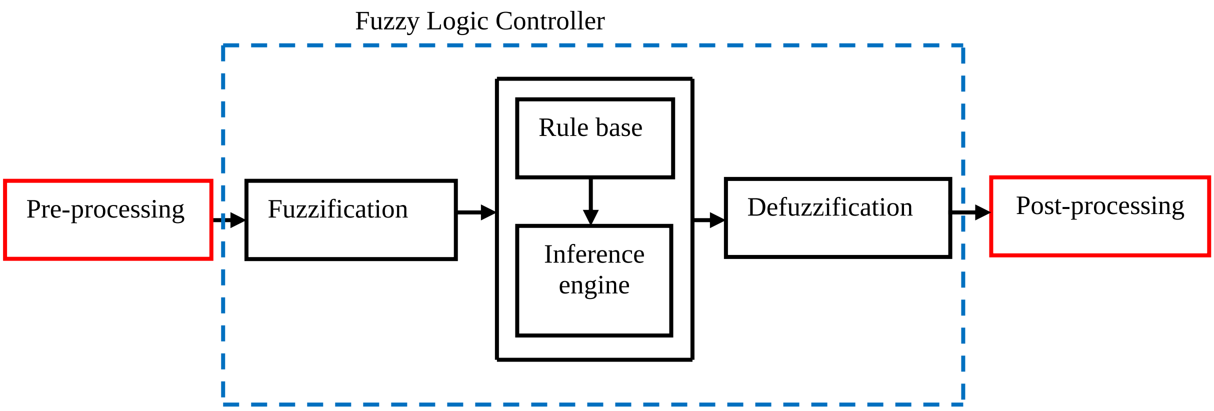


Fig.3. Basic structure of fuzzy logic controller

A fuzzy Logic Controller (FLC) constitutes a way of converting linguistic control strategy into an automatic action by generating a rule base that controls the behavior of the system. Fuzzy control is a control method based on fuzzy logic. Fuzzy logic provides a remarkably simple way to draw definite conclusions from vague, ambiguous, or imprecise information. FLC has some advantages compared to other classical controllers such as simplicity of control, low cost, and the possibility to design without knowing the exact mathematical model of the process. FLC for chosen Luo converters is shown in Fig. 4.

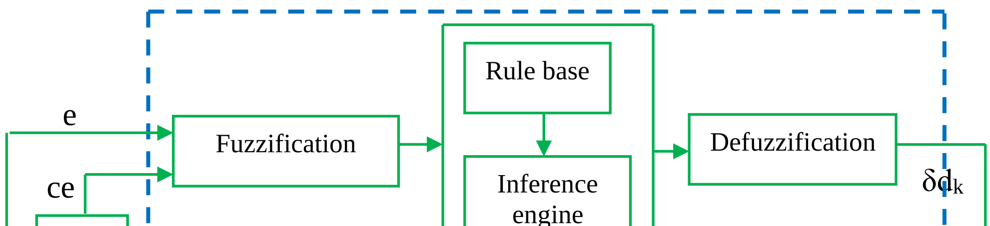


Fig.4 Fuzzy logic controller for Luo converter

Fuzzy logic incorporates an alternative way of thinking which allows modeling complex systems using a higher level of abstraction originating from knowledge and experience. Fuzzy logic can be described simply as “computing words rather than numbers” or “control with sentences rather than equations.”

5. SIMULATION RESULTS

Fig.3 shows the closed loop Simulink diagram of the Elementary Circuit of the P/O Push-Pull SC Luo Converter. The proposed system analysis has been done with R load. The circuit specifications are shown in Table 1.

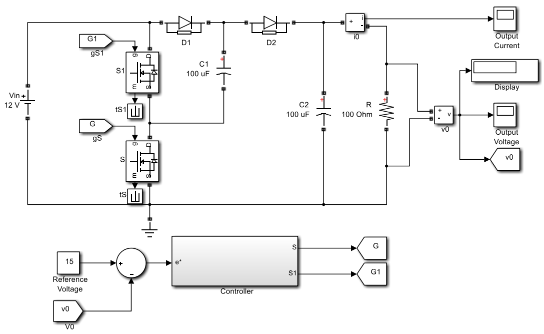


Fig. 5 Closed Loop Simulink of Elementary Circuit of P/O Push-Pull SC Luo Converter

TABLE I: Specification of circuit parameters

Parameters	Specification
Input voltage	12V
Output voltage	15 V
Load resistance	100 Ω
Switching frequency	20KHZ
Capacitance (C & C_1)	100 µF
Duty Range	0.05 to 0.95

PI Controller	**Fuzzy Logic Controller**

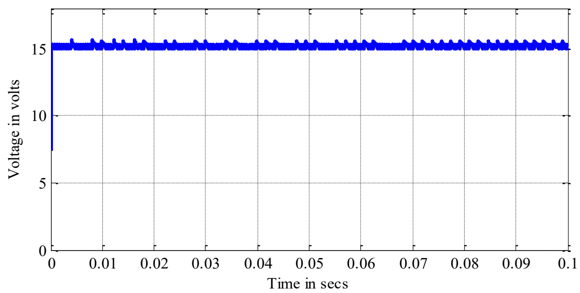


Fig.6. Simulated start-up of the output voltage with set point 15V and nominal load 100Ω

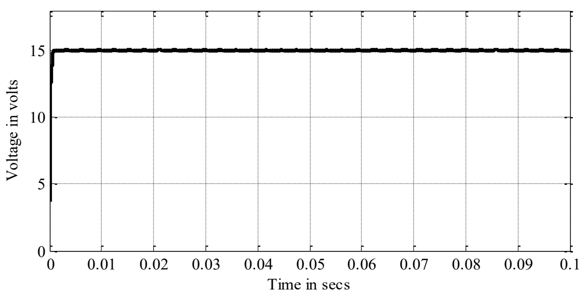


Fig.16. Simulated start-up of the output voltage with set point 15V and nominal load 100Ω

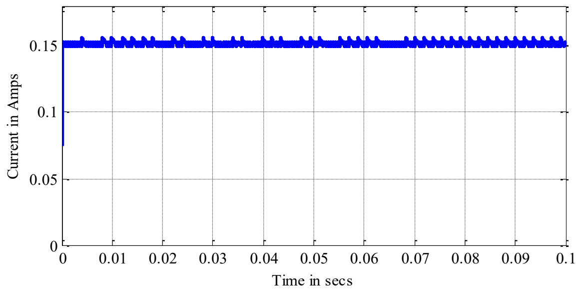


Fig.7. Simulated start-up of the output current with set point 15V and nominal load 100Ω

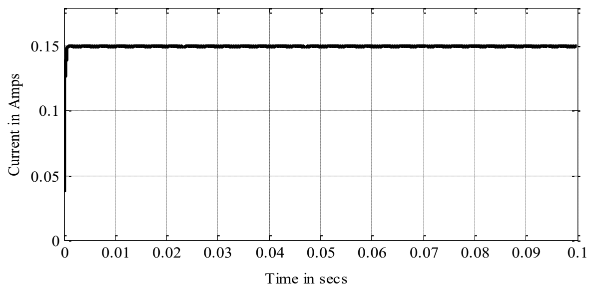


Fig.17. Simulated start-up of the output voltage with set point 15V and nominal load 100Ω

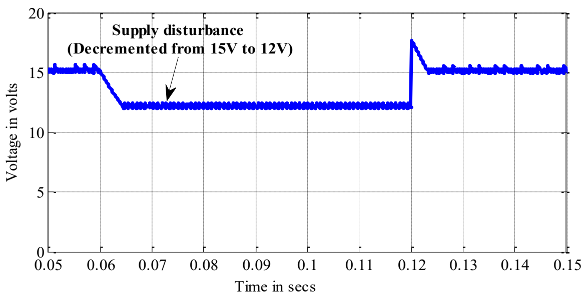


Fig.8. Simulated output voltage with line disturbances (15V-12V-15V) under nominal load 100 Ω

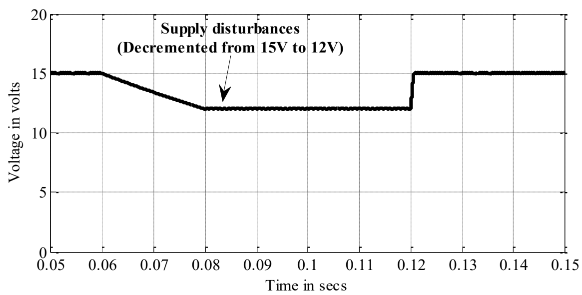


Fig.18. Simulated output voltage with line disturbances (15V-12V-15V) under nominal load 100 Ω

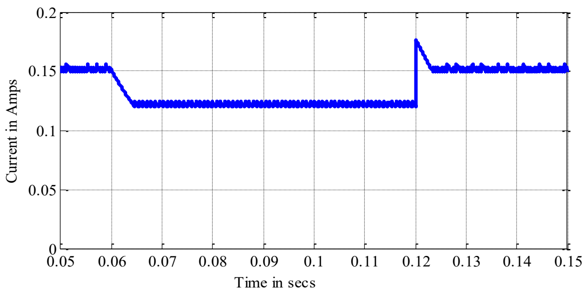


Fig.9. Simulated output current with line disturbances

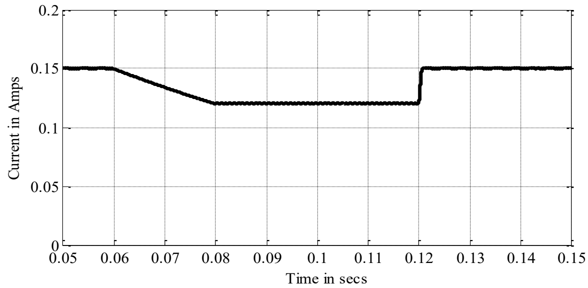


Fig.19. Simulated output current with line disturbances (15V-12V-15V) under nominal load 100

(15V-12V-15V) under nominal load 100 Ω

Ω

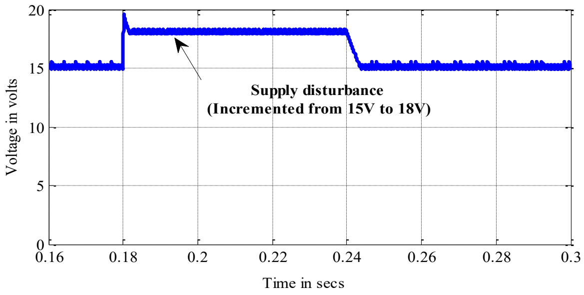


Fig.10. Simulated output voltage with line disturbances (15V-18V-15V) under nominal load 100 Ω

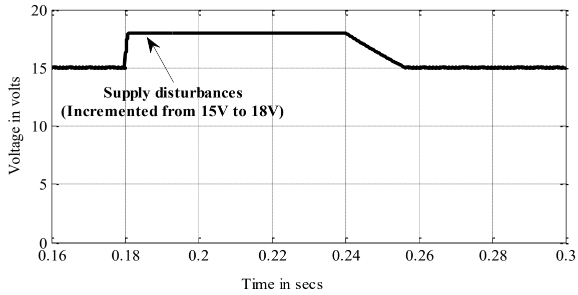


Fig.20. Simulated output voltage with line disturbances (15V-18V-15V) under nominal load 100 Ω

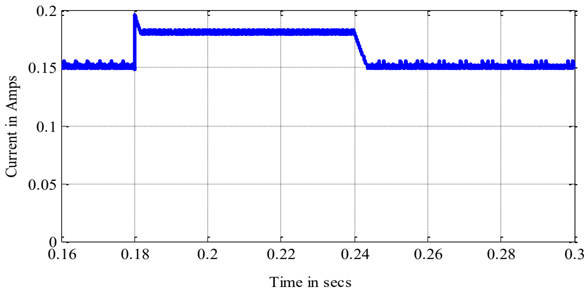


Fig.11. Simulated output current with line disturbances (15V-18V-15V) under nominal load 100 Ω

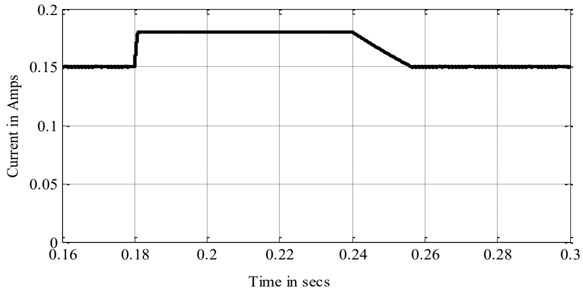


Fig.21. Simulated output current with line disturbances (15V-18V-15V) under nominal load 100 Ω

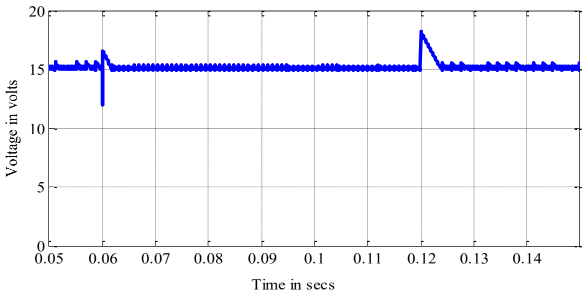


Fig.12. Simulated output voltage with load disturbances (100Ω –90 Ω -100Ω)

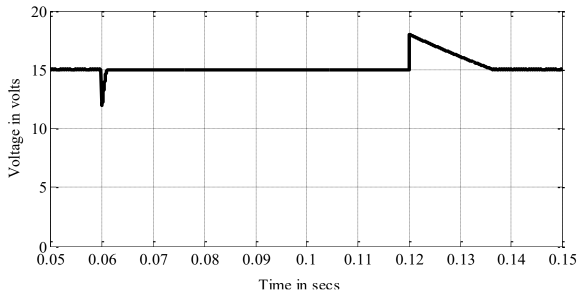
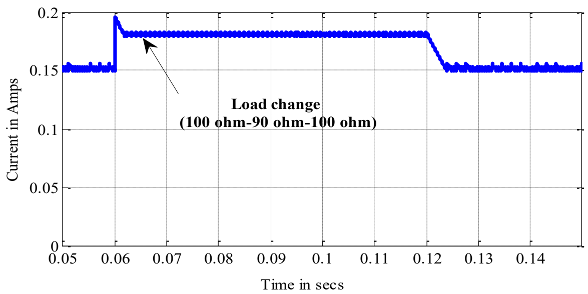


Fig.22. Simulated output voltage with load disturbances (100Ω –90 Ω -100Ω)



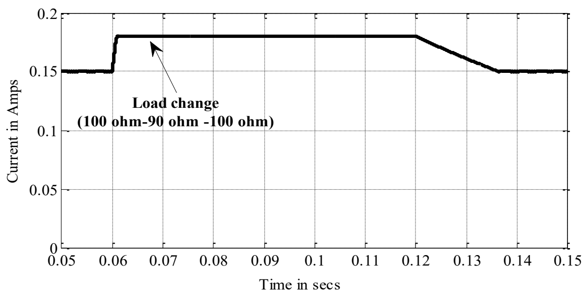


Fig.13. Simulated output current with load disturbances (100Ω –90 Ω -100Ω)

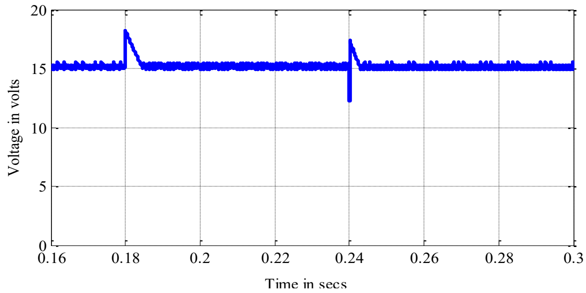


Fig.14. Simulated output voltage with load disturbances (100Ω –110 Ω -100Ω)

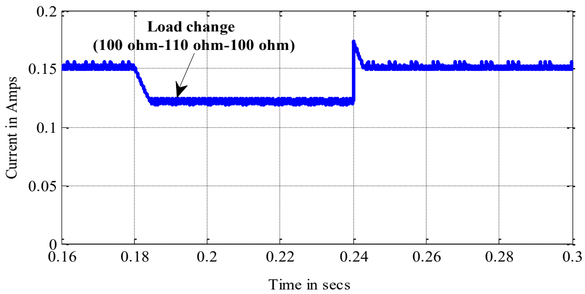


Fig.15. Simulated output current with load disturbances (100Ω –110 Ω -100Ω)

Fig.23. Simulated output current with load disturbances (100Ω –90 Ω -100Ω)

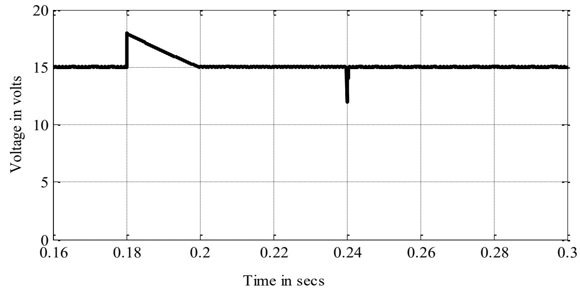


Fig.24. Simulated output voltage with load disturbances (100Ω –110 Ω -100Ω)

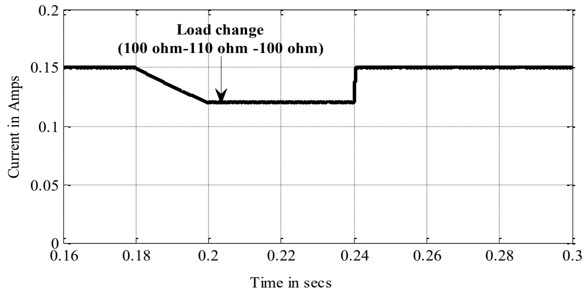


Fig.25. Simulated output current with load disturbances (100Ω –110 Ω -100Ω)

The regulatory responses obtained by simulation using Matlab software with PI and fuzzy controller undersupply and load disturbances of the proposed Elementary Circuit of P/O Push-Pull SC Luo Converter are presented in this section. Figs.6 and 7 show the simulated start-up of the output voltage and current waveform with set point 15V and nominal load 100Ω implemented with PI controller. Figs.16 and 17 show the simulated start-up of the output voltage and current waveform with set point 15V and nominal load 100Ω carried out with fuzzy logic controller. From the start-up transient waveform of both PI controllers, it is observed that the fuzzy logic controller produced the response with less settling time and without any shoot compared with PI. Figs. 8 and 9 show the simulated output voltage and current waveform with line disturbances (15V-12V-15V) under nominal load 100 Ω with a PI controller. Figs.18 and 19 show the simulated output voltage and current waveform with line disturbances (15V-12V-15V) under nominal load 100 Ω with the fuzzy logic controller. Similarly, Figs. 10 and 11 show the simulated output voltage and current waveform with line disturbances (15V-18V-15V) under a nominal load of 100 Ω with a PI controller. Figs.20 and 21 show the simulated output voltage and current waveform with line disturbances (15V-18V-15V) under nominal load 100 Ω with fuzzy logic controller. From the observation of line disturbances for both the PI and fuzzy logic controller, the fuzzy logic controller response is superior to the PI controller. The settling time and disturbances are much less in the response of fuzzy logic control. Figs.12 and 13 show the simulated output voltage and current with load disturbances (100Ω –90 Ω -100Ω) with PI controller and Figs. 22 and 23 show the simulated output voltage and current with load disturbances (100Ω –90 Ω -100Ω) with the fuzzy logic controller. Similarly, Figs.14 and 15 show the simulated output voltage and current with load disturbances (100Ω –110 Ω -100Ω) with PI controller, and Figs.24 and 25 show the simulated output voltage and current with load disturbances (100Ω –110 Ω -100Ω) with the fuzzy logic controller. From the observation of load responses of PI and fuzzy logic controllers, the PI controller produced an excellent result which is near to the fuzzy controller, but the noise of the waveforms is high in the PI controller compared to the fuzzy controller. The overall performance evaluation of the proposed Elementary Circuit of Positive Output Push-Pull Switched Capacitor Luo Converter with the implementation of PI controller and Fuzzy Logic Controllers is shown in Table 3, and the graphical representation of the performance evaluation of the same is shown in Fig. 26.

Table. 3 Performance evaluation of controller for Elementary Circuit of P/O Push-Pull SC Luo Converter using MATLAB

Controller	Start-up transient			Servo Response				Regulatory Response			
				Supply change (15V-12V-15V)		Supply change (15V-18V-15V)		Load change (100Ω-90Ω-100Ω)		Load change (100Ω-110Ω-100Ω)	
	Peak overshoot	Rise time (ms)	Settling time (ms)	Peak overshoot	Settling time (ms)	under shoot	Settling time (ms)	Peak overshoot	Settling time (ms)	under shoot	Settling time (ms)
PI	-	-	1.5	-	5.7	7.94	3.0	10	3.6	20	7.5
Fuzzy	-	5.0	0.9	-	0.5	-	1.8	-	2.4	-	1.5

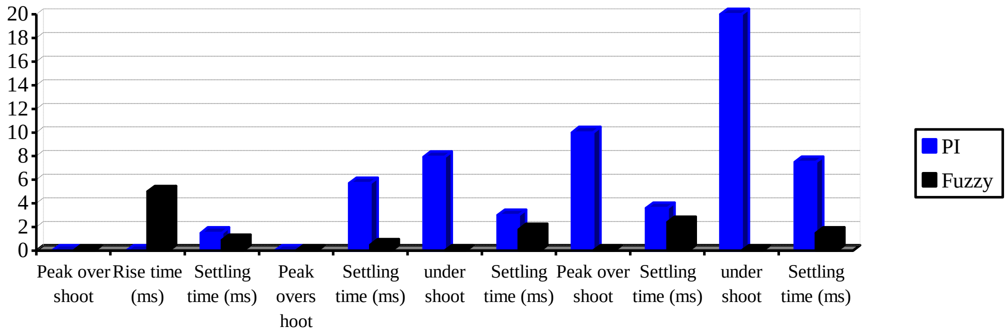


Fig. 26 Graphical representation of performance evaluation of controllers for Elementary Circuit of P/O Push-Pull SC Luo Converter using MATLAB

6. CONCLUSION

This paper implemented the advanced voltage lift technique to be successfully applied in the Elementary Circuit of P/O Push-Pull SC Luo Converter design and feedback with PI and fuzzy controller. Carefully selecting the parameters we obtain the required output voltages from a positive input source. From the performance evaluation fuzzy controller has better performance than PI for line and load disturbances. These results validate the effectiveness of the developed fuzzy control and establish the superiority of the proposed fuzzy controller.

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