Kufa Journal of Engineering
Vol. 17, No. 1, January 2026, P.P. 544-557
Article history: Received 25 February 2025, last revised 19 May 2025, accepted 28 May 2025

A MODIFIED DESIGN OF SELF-LIFT NEGATIVE OUTPUT LUO DC-DC CONVERTER BASED ON INDUCTIVE AND HYBRID SWITCHING CELLS

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https://doi.org/10.30572/2018/KJE/170131

ABSTRACT

The DC-DC converters are essential to the operation of renewable energy systems because they implement conversions for changing input voltage levels to fixed output levels of voltage. In this paper, we propose adopting a Self-Lift Negative Output Luo DC-DC Converter (SLNOLC), which implements two more configurations – an inductive switching cell and a hybrid switching cell – to increase the voltage gain and efficiency of the converter while reducing component fatigue and ripple. The first design implements an inductive boosting cell, which improves gain by reconfiguring the energy transfer path, while the second design enhances performance even further with the addition of a hybrid inductor-capacitor cell. The proposed converters deliver output voltages of –48V to –60V at 12V input voltage, with pump efficiencies of up to 97 percent. Through continuous conduction mode (CCM), a dynamic response PI controller delivers output stability and fast adjustment within set response values. Simulations done in MATLAB/Simulink demonstrate the superior performance of the proposed designs, validating their use in low-voltage and high-efficiency environments for renewable energy systems.

KEYWORDS

DC–DC Converter, Self-lift, Negative Luo Converter, PI Controller, Hybrid cell, Inductive cell.

1. INTRODUCTION

DC-DC converters are essential components in current electronic and energy systems such as laptops, communication devices, LED lights, electric cars, and even in renewable energy technologies like solar power systems (Aberoumandazar and Shahir, 2021;Shahir and Babaei, 2017;Maheri, Shahir and Babaei, 2020). These converters are usually divided into two classes: isolated and non-isolated converters. Non-isolated converters, for example, are known to have greater efficiency and a more compact size. However, they tend to have circuitry that is more complicated than their isolated counterparts (Farakhor, Abapour and Sabahi, 2019;Shanthi, Prabha and Sundaramoorthy, 2021). A noteworthy non-isolated converter is the Luo converter, which is well known for its negative output feature along with its high voltage gain and small output ripple(Sweatha, Baskaran and Duraipandy, 2023). Luo converters, and especially self-lift topologies, utilize the voltage-lift technique to boost output voltage without additional stress from switching. Because of this, they are highly suited for applications where control of electromagnetic interference (EMI), high power density, and low ripple are essential (Devi, Abirami and Banu, 2018;Cocor et al., 2015;Shahir, Babaei and Aberoumandazar, 2021). One variant of Luo converters, the Self-Lift Negative Output Luo Converter (SLNOLC), to be precise, is made with the intention of negative output regulation with a positive input voltage (Devi, Abirami and Banu, 2018). This is done by incorporating diodes and capacitors as passive enhancers. Prior works have made several augmentations on SLNOLC to amplify gain and efficiency. For instance, (Hussein, Motlak and Hussein, 2022) fabricated a hybrid switching cell with an inductor pair, a capacitor, and two diodes, which greatly improved voltage gain. Also,(Sri Revathi, Joseph Samuel and Mahalingam, 2023) introduced a coupled inductor topology with the intention of reducing component stress while increasing output voltage. But, with these positives, it does have drawbacks where most works focus on a single enhancement technique and haven't undergone rigorous comparison simulations or design standards for consistent conditions. Unlike others, this study uniquely investigates two configurations of the Self-Lift Negative Output Luo Converter (SLNOLC). This study aims to investigate SLNOLC configurations: one sub-model with a switched inductor cell to increase power transfer and voltage gain, the other hybrid inductor-capacitor switching cell to reduce ripple and increase the boost effect. Both configurations were realized in MATLAB/Simulink, where a Proportional-Integral (PI) controller was used to control the output under Continuous Conduction Mode (CCM). Recent contributions have highlighted the application of optimization algorithms in tuning PI/PID controllers for electric motors (Jaber, 2025). The results obtained from the simulation are evaluated from the standpoint of voltage gain, ripple reduction, efficiency of conversion, and dynamic response, and special focus is placed on their applicability for systems powered by renewable energy and for electric vehicles.

2. METHODOLOGY

This part demonstrates the design and operating principles of three Self-Lift Negative Output Luo Converters (SLNOLC): the basic topology, one modified with a switched inductor cell, and another altered one incorporating a hybrid inductor-capacitor switching cell. All of the converters are evaluated under Continuous Conduction Mode (CCM). Their circuit parameters are designed for maximum efficiency and better voltage gain, as shown in Fig. 1.

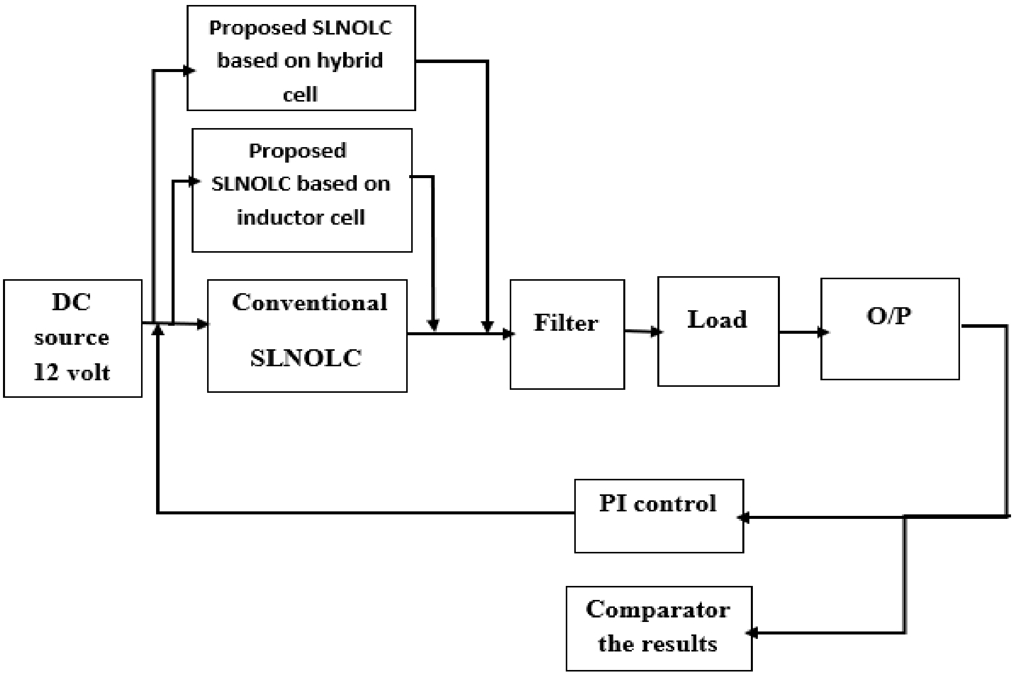
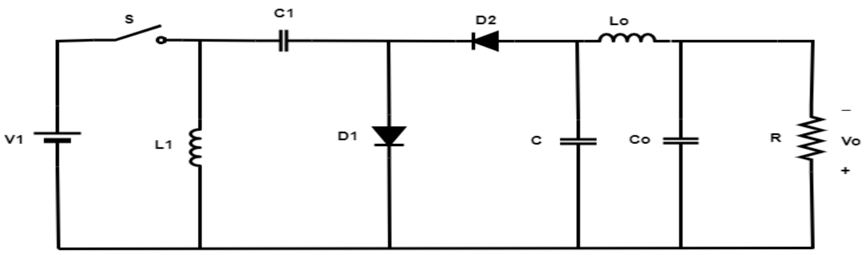


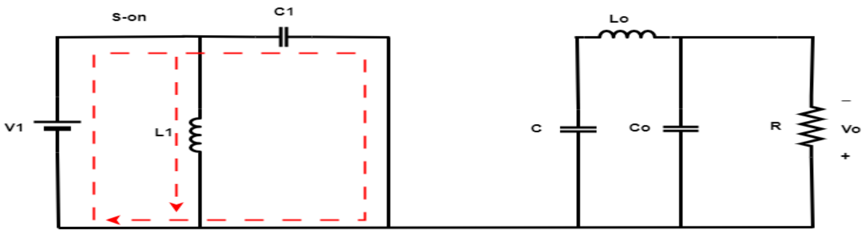
Fig. 1: Design of the proposed SLNOLC based on inductive and hybrid switching cells

2.1. Elementary SLNOLC

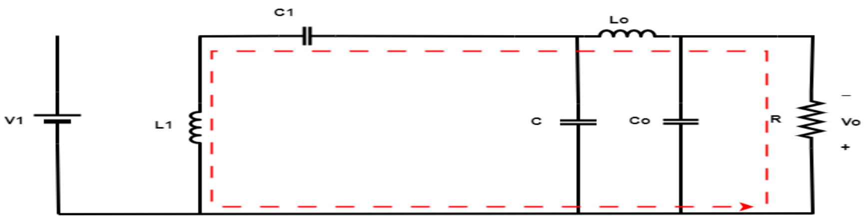
The elementary form of the Self-Lift Negative Output Luo Converter (SLNOLC) is designed to convert a positive input voltage into a negative output voltage using the voltage-lift technique. This topology is particularly effective in low-voltage electronic systems requiring efficient DC–DC conversion with minimal ripple. As shown in Fig.2, the circuit consists of a single MOSFET switch, two inductors (L1 and L2), three capacitors (C1, C, and Co), two diodes (D1 and D2), and a resistive load (R) (Devi, Abirami and Banu, 2018;Ganesh et al., 2024). During operation, energy is transferred from the input source to the load through a combination of charging and discharging processes involving the inductors and capacitors. The voltage-lift mechanism employed in this converter increases the output voltage above the input level while inverting its polarity. This elementary structure serves as the reference model for evaluating the performance improvements introduced by the proposed modifications.



(a)



(b) S-ON



(C) S-OFF

Fig 2: (a)self-lift N/O Luo converter. (b) The equivalent circuit during switch-on. (c) The equivalent circuit during switch-off.

The output voltage, output current, voltage gain, on-time duration, and off-time duration were calculated as follows (Devi, Abirami and Banu, 2018):

$$v_0 = \frac{-1}{(1-D)} v_1 \quad (1)$$

$$I_0 = -(1-D)I_1 \quad (2)$$

$$G = \frac{-1}{(1-D)} \quad (3)$$

$$ton = DT \quad (4)$$

$$t_{off} = (1-D)T \quad (5)$$

2.2. Modification of SLNOLC using a switched inductor cell

In order to reduce switching stress and enhance the voltage gain, a cell with a switched inductor was incorporated within the SLNOLC topology, known for boosting the step-up ratio by reconfiguring the connections of the inductors and diodes. This architecture allows for parallel charging and serial discharging of inductors, leading to a greater voltage conversion range (Pola et al., 2022). In this design, the inductor L1 in the original SLNOLC was replaced with a switched inductor module made of two inductors (L1, L2) and three diodes. According to Fig.3, the modified converter maintains the negative output characteristic while improving voltage gain. The control of switching is performed in two fundamental modes: ON-State (S Closed): In this state, D5 is reverse-biased, and D4 is forward-biased. Capacitors, together with the inductors L1 and L2, get charged by the input voltage in the forward path through the closed switch. OFF-State (S Open): D1, D3, and D4 are reverse-bias, and the inductors discharge serially via D5 to the capacitive elements and the load. This increases the output voltage since the energy stored in L1 and L2 is transferred in an additive manner. D5 diode's function is crucial because, by blocking the reverse current, it allows the output capacitor (Co) to keep its energy during switching intervals. This approach of energy transfer by charging and discharging through several stages enhances the voltage at the output level beyond the elementary SLNOLC. These results are in line with the hypothesis proposed in prior studies that such changes would increase the efficiency and lower the voltage stress on the semiconductor devices (Sri Revathi, Joseph Samuel and Mahalingam, 2023). The theoretical analysis based on the Volt-Second Balance Principle validates that including a switched inductor module is beneficial in greatly increasing the output voltage conversion ratio. To achieve symmetrical current sharing and reduce the ripple to a minimum, L1 and L2 inductors with equal values of inductance were chosen. This design is compliant with the Continuous Conduction Mode (CCM) where current is always united throughout the switching cycle. Fig.4 shows the MATLAB/Simulink implementation of this configuration with a PI controller.

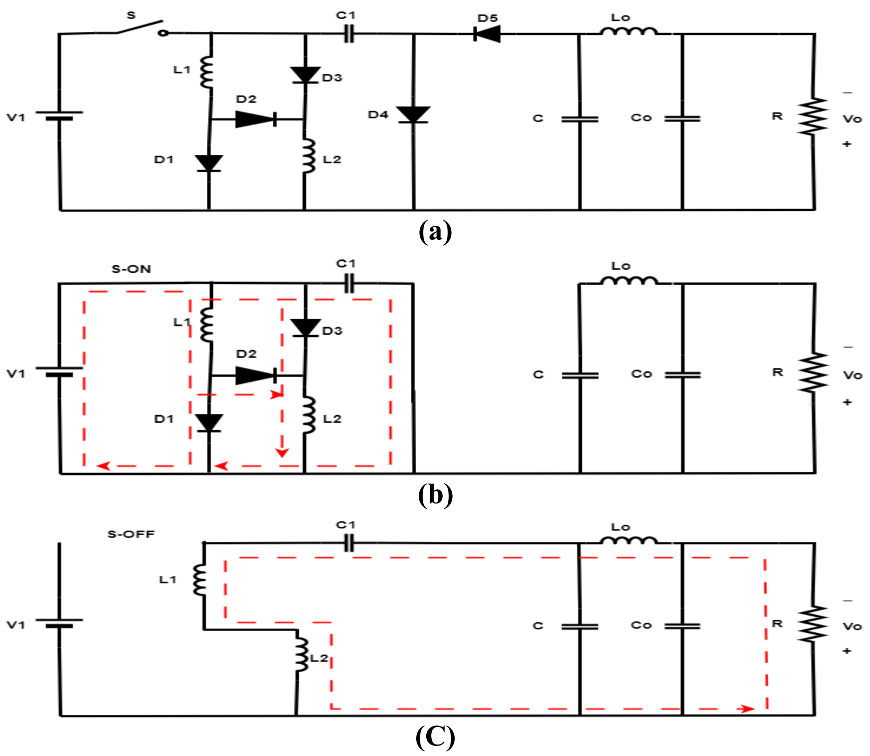


Fig. 3. (a) Modified SLNOLC based on an Inductor cell. (b) The equivalent circuit during switch-on. (c) The equivalent circuit during switch-off.

2.3. Mathematical modeling CCM of the modified SLNOLC based on a switched inductor cell

Mode 1: (0-DT): The switch is turned on, derived based on circuit analysis.

$$v_{in} = v_{L_1} = v_{L_2} = v_{C_1} \tag{6}$$

$$v_{L_1} = v_{L_2} \tag{7}$$

To minimize ripple, L1 and L2 should have equal values.

$$v_{in} = v_L \tag{8}$$

Mode 2: (DT-(1-D) T): When the switch is turned off,

$$v_0 + v_{c_1} - v_{L_1} - v_{L_2} = 0 \tag{9}$$

$$v_L = \frac{v_0 + v_{in}}{2} \tag{10}$$

$$v_0 = v_{Co} = v_c \tag{11}$$

Based on the Volt-Second balance principle,

$$v_{L(on)}DT+V_{L}(off)(1-D)T=0 \tag{12}$$

$$vo = \frac{-(1 + D)}{(1 - D)} v_{in} \tag{13}$$

From the volt-second balance rule (Erickson and Maksimovic, 2007) Eq.13 captures the output voltage of the SLNOLC with a switched inductor cell. The complete parameter values are summarized in Table 1, depicting the simulation setup.

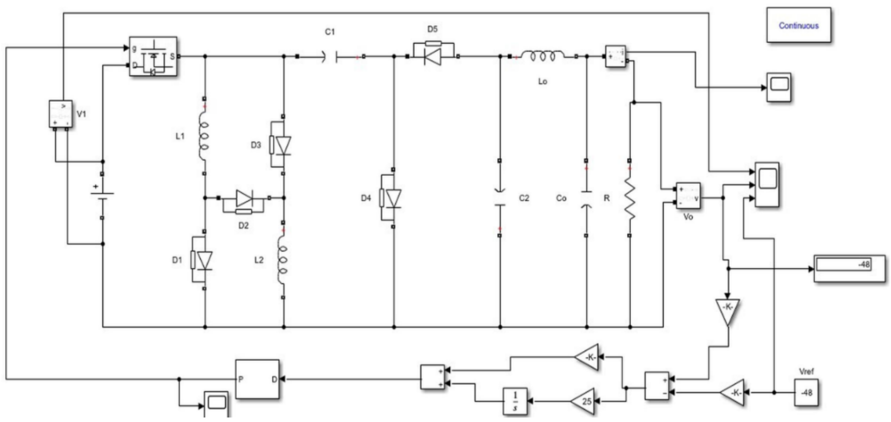


Fig. 4. MATLAB simulation of modified SLNOLC based on a switched inductor cell and PI control

2.4. Modified SLNOLC based on a switching-hybrid inductor-capacitor cell

To further improve the voltage gain while also decreasing ripple, a hybrid switching cell was integrated with the SLNOLC. This configuration features two inductors (L1, L2), two additional diodes (D3, D4), along with a second capacitor (C2), leading to better results at low duty cycle ranges. When in the ON state, D3 and D4 diodes are also turned on, so that L1 and L2, C1 and C2 are charged in parallel from the input source, therefore allowing the five units to be charged in parallel. When the unit is in the OFF state, the energy that has been stored previously is dumped to the output through a filter series shunt path. This change of energy from parallel to series results in a much higher output voltage than the classical systems use.

Moreover, the hybrid base with these properties effectively reduces ripple, switching stress, and EMI, hence improving the efficiency overall (Hussein, Motlak and Hussein, 2022). The voltage gain, which can be derived from volt-second and charge balance principles, is able to achieve a maximum of five times the input value. For symmetry of current as well as stability of the system, equal values for L1 and L2 are set. System stability and current symmetry are maintained with equal values for L1 and L2. Such hybrid enhancement and control approaches correspond with past works on PI-based controllers on solar-powered DC systems, where strong voltage regulation and converter dynamic responses are of primary importance (Al-Jabari,et al., 2022;Hadi et al., 2024). Fast response and system stability were performed using a PI controller and tuned in MATLAB/Simulink simulation, displaying a fast dynamic response and low settling time with an acceptable overshoot. Simulation results and operational modes are captured in Fig.5 and 6, and Table 2 provides the parameter values for all units.

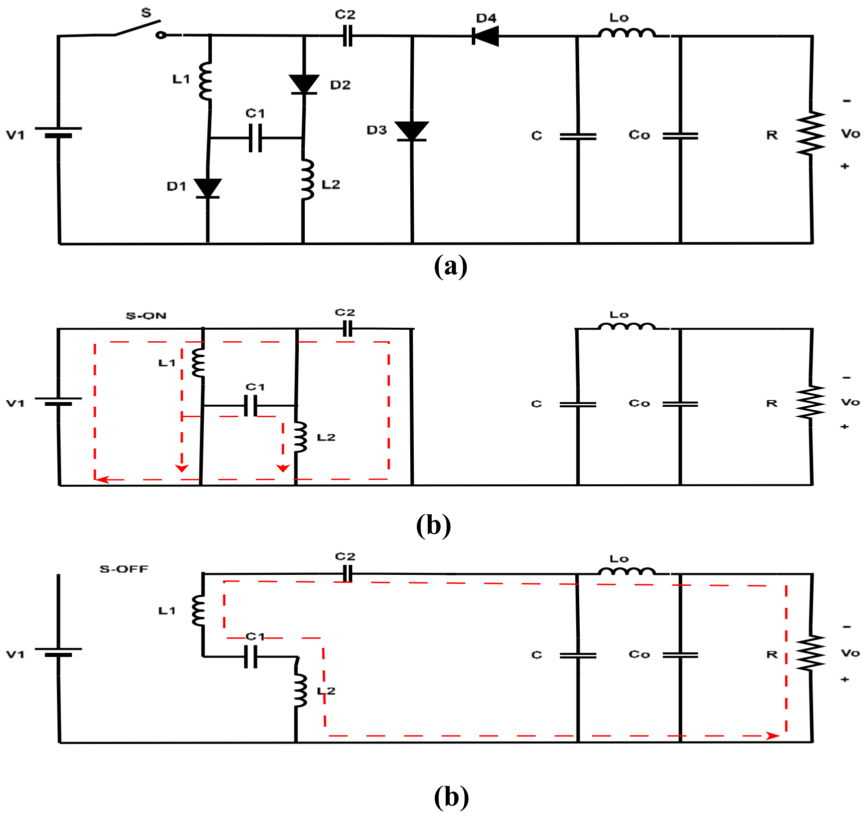


Fig. 5. (a) A modified SLNOLC based on a Hybrid cell. (b) The equivalent circuit during switch-on. (c) The equivalent circuit during switch-off.

2.5. Mathematical modeling of CCM of modified SLNOLC based on a hybrid cell

Mode 1: (0-DT): When the switch is turned on, derived based on circuit analysis

$$v_{in} = v_{L_1} = v_{L_2} = v_{C_1} = v_{C_2} \quad (14)$$

$$v_{L_1} = v_{L_2} \quad (15)$$

$$v_{C_1} = v_{C_2} \quad (16)$$

To minimize ripple, L1 and L2 should have equal values.

$$v_{in} = v_L \tag{17}$$

$$v_L = L\frac{\Delta I}{DT} \tag{18}$$

Mode 2: (DT-(1-D) T): When the switch is turned off,

$$v_o + v_{c_2} - v_{L_1} + vc_1 - v_{L_2} = 0 \tag{19}$$

$$v_{c_1} = v_{c_2} = v_{in} \tag{20}$$

$$v_{L_1} = v_{L_2} = v_L \tag{21}$$

$$v_L = \frac{v_0 + 2v_{in}}{2} \tag{22}$$

According to the Volt-Second balance principle,

$$v_{L(on)DT + V_L(off)(1-D)T=0} \tag{23}$$

$$v_0 = \frac{-2}{(1-D)}V_{in} \tag{24}$$

simulated using MATLAB Simulink, and Table 2 provides the parameter values for all units.

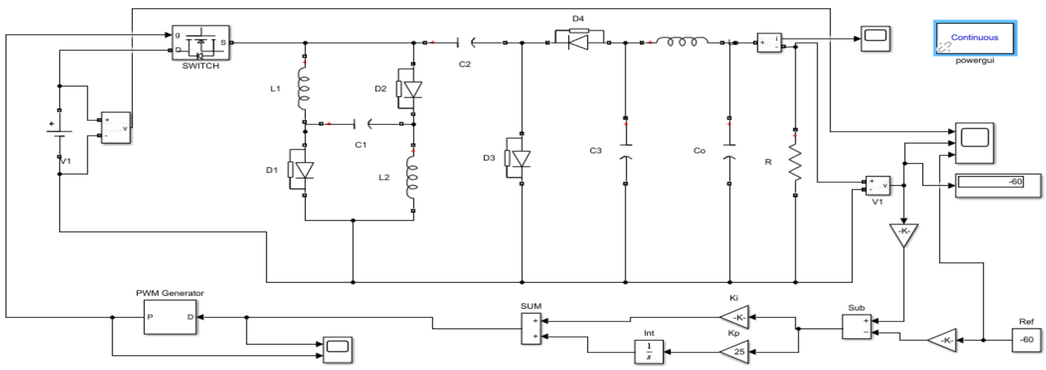


Fig 6. MATLAB simulation of Modified SLNOLC with a switching hybrid inductor-capacitor cell and PI controller.

2.6. Design element

The design equations are important to ensure the operation of the modified SLNOLC in the CCM case (Cocor et al., 2015). In designing, losses are negligible because it's very small

$$I_0 = \frac{v_0}{R} \tag{25}$$

$$I_L = \frac{1}{1-D}I_0 \tag{26}$$

$$\zeta_L = \frac{\Delta I}{2I_L} \tag{27}$$

$$C_0 = \frac{D}{2Rf\epsilon_0} \tag{28}$$

$$L_1 = \frac{v_{in}D}{f\Delta I} \tag{29}$$

$$c_1 = \frac{v_0}{fR\Delta vc_1} \tag{30}$$

Δl= ripple if current inductor boosting (L1) (0.2-0.4). ϵ_0 = Ripple is recommended at 0.05 or less. vc_1 = Ripple of voltage is 5%. ζ_L = variation ripple we can choose = 0.2.

3. RESULTS AND DISCUSSION

3.1. Simulation results of the modified SLNOLC based on an inductor switching cell

Fig.7 shows the duty cycle signal, which manifests as an ideal square wave, thus confirming the robust performance of the control circuit.

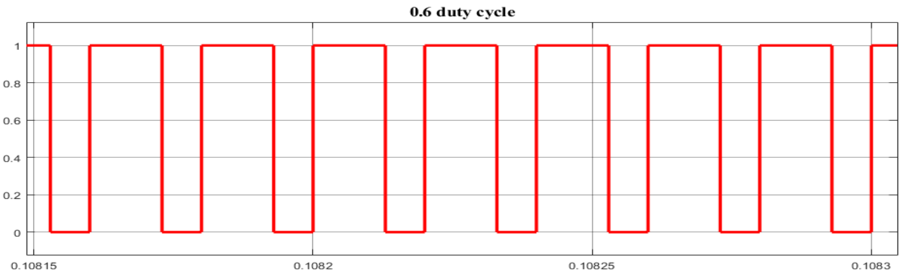


Fig.7. Simulation control signal (duty cycle).

Fig. 8 presents the input voltage signal, output voltage, and reference voltage, whose readings confirm that the proposed control circuit and the modified converter can track the reference voltage effectively and with low ripple. Fig. 9 shows the output current signal with a lower current ripple, while Table 1 displays the PI control parameter values (kp and ki). Iterative tuning was used to determine the controller values Kp=0.05 and Ki=25 to guarantee low overshoot and quick dynamic response, and the design values for the inductors and capacitors for the modified SLNOLC DC-DC converter. Fig.10: presents the simulated output voltage waveform of the hybrid SLNOLC. It demonstrates a low ripple level, confirming the enhanced voltage regulation and filtering performance of the proposed hybrid design

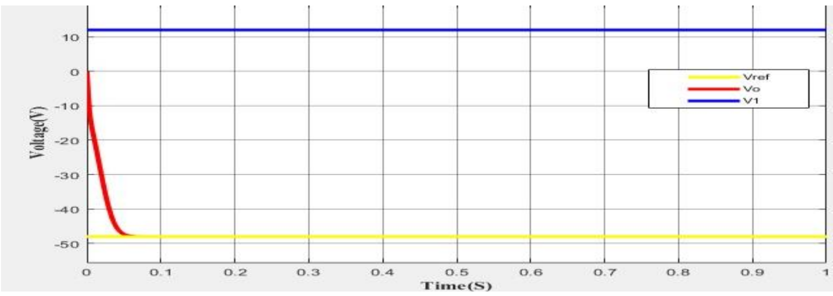


Fig.8. Input, output, and required voltage (Vref) signals.

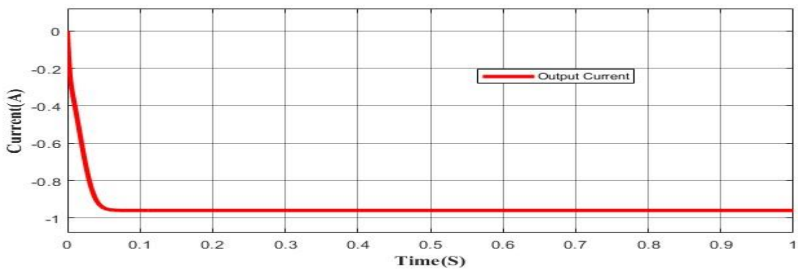


Fig. 9. Output current signal

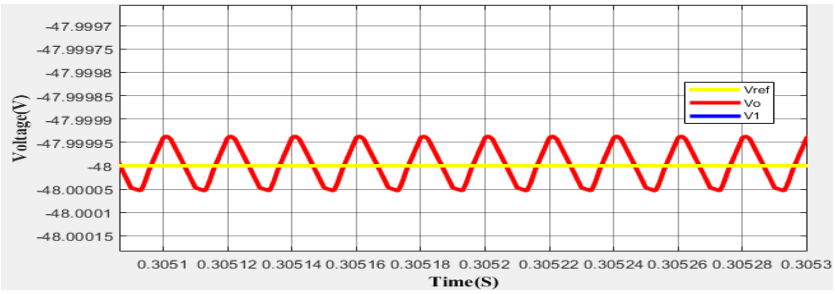


Fig 10. Output ripple voltage signal

Table 1. Circuit parameters of modified SLNOLC based on an Inductor switching cell.

Components	Symbol	Value	Unit
Voltage output	Vo	-48	volt
Voltage input	Vin	12	volt
Inductors	L1, L2, Lo	0.271,0.271,0.16	mH
Capacitors	C1, C	548.57	µF
Capacitor output	Co	10	µF
Switching frequency	f	50000	HZ
Duty cycle	D	0.6	
Load resistance	R	50	Ohm
Efficiency	η	94.14%	
Output current	Io	-0.96	A
Gain	G	4	
Proportional gain	Kp	0.05	
Integral gain	Ki	25	

Iterative tuning in MATLAB/Simulink helped the PI controller gains (Kp = 0.05, Ki = 25) to be chosen, thereby guaranteeing system stability and fast response. These parameters produced a settling time of less than 0.01 seconds and a step response of less than 5% overshoot. Although traditional techniques like Ziegler–Nichols were taken into account, iterative refining resolved the converter's nonlinear behavior better.

3.2. Simulation results of the modified SLNOLC based on a hybrid Inductor-Capacitor Switching Cell

In Fig.11, it can be seen that the input, output, and reference voltage signals are well aligned, which confirms effective tracking with minimal ripple under the proposed control strategy. The output current signal, as illustrated in Fig.12, also exhibits near-zero ripple. A summary of the design parameters for inductors, capacitors, and the PI controller gains Kp, Ki of this modified SLNOLC is provided in Table 2.

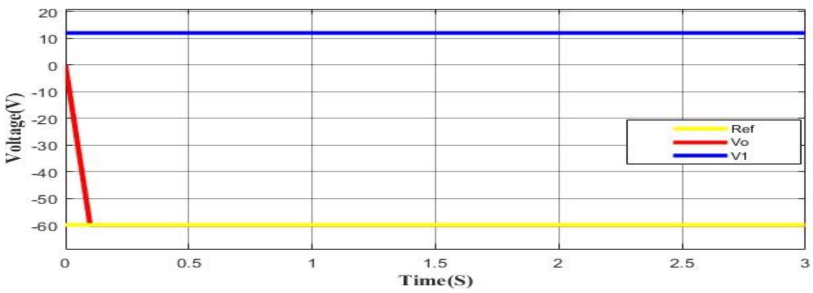


Fig.11. Signals of self-lift input, output, and reference voltage of modified SLNOLC based on a hybrid switching cell.

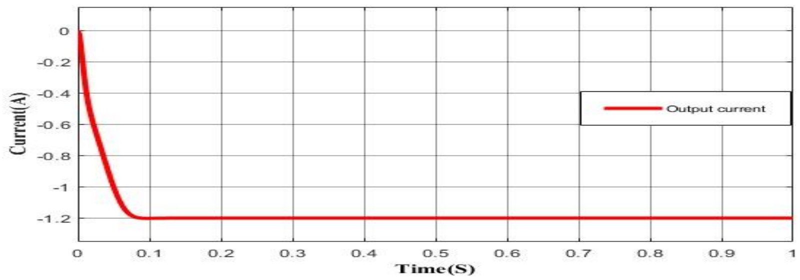


Fig.12. Output current signals of modified SLNOLC based on a hybrid switching cell.

Table 2. Circuit parameters of the modified SLNOLC based on a hybrid switching cell.

I	Parameter	Symbol	Value	Unit
1	Voltage output	Vo	-60	volt
2	Voltage input	Vin	12	volt
3	Inductors	L1, L2, Lo	0.3,0.3,0.2	mH
4	Capacitors	C1, C2, C	30	µF
5	Capacitor output	Co	10	µF
6	Switching frequency	f	50000	HZ
7	Duty cycle	D	0.6	
8	Load resistance	R	50	Ohm
9	Efficiency	η	97%	
10	Output current	Io	-1.2	A
11	Gain	G	5	
12	Proportional gain	Kp	0.05	
13	Integral gain	Ki	25	

Table 3. Comparison between the elementary and modified SLNOLC circuits.

Attributes	**Elementary SLNOLC**	**Modified SLNOLC based on inductor cell**	**Modified SLNOLC based on a hybrid cell**
Voltage gain expression	$\frac{-1}{(1-D)}$	$\frac{-(1+D)}{(1-D)}$	$\frac{-2}{(1-D)}$
Voltage gain	2.5	4	5
Voltage output	-30	-48	-60
Current output	-0.6	-0.96	-1.2
No. of switch	1	1	1
Number of diodes	2	5	4
Number of inductors	2	3	3
Number of capacitors	3	3	4
High/Low side gate driver	High	High	High
Common ground	yes	yes	yes
Efficiency	90%	94.14%	97%

The modifications under consideration not only improve the SLNOLC's system performance but also solve practical implementation problems related to size and efficiency in power conversion. Its lower number of control switches, increased efficiency (up to 97%), and drastic gain enhancement make the converter appropriate for contemporary energy systems, particularly those with low component stress and stable voltage feedback control like solar charging stations and electric propulsion systems.

4. CONCLUSIONS

The Simulation carried out demonstrates that the usage of inductive and hybrid switching cells together increases the performance of the SLNOLC, when compared to its previous form, SLNOLC, significantly. The important results are as follows:

1- Attributed to greater energy redistribution and decreased losses, the hybrid SLNOLC surpassed the inductive version by reaching a voltage gain of −60 V and an efficiency of 97% at a 12 V input, therefore minimizing component stress and increasing system dependability.

2-The application of the PI controller allowed for the fast dynamic response and stable regulation for the output under different levels of load and input while ensuring that disturbances are minimized throughout and do not affect the output voltage.

3- In general, the designed system provides better gain, efficiency, and ripple suppression, making it more usable and highly reliable in systems like electric vehicles and renewable energy systems. Future research may examine hardware implementation to confirm the resilience and practical viability of the suggested configurations, even if the current study is restricted to simulation.

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