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RESEARCH ARTICLE - ENGINEERING

Efficient Design, Analysis and Implementation of Super-Lift LUO Converter for Standalone PV Applications

Zainab A. Ghafour[1*], Ahmed R. Ajel[1], Naseer M. Yasin[1], Noaman Mohammad Noaman[2]

[1] Electrical Engineering Technical College, Middle Technical University, Baghdad, Iraq

[2] College of Engineering, University of Technology Bahrain, Bahrain

[*] Corresponding author E-mail: eng.zainab777@gmail.com

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Abstract

Positive-output super-lift Luo converters (POSLCs) with low switching losses are the subject of this paper's analysis, design, and regulation. Due to their ability to boost voltage at higher levels, converter switching devices are rarely put under extreme voltage conditions. The input voltage to an active switching device is typically lower than the output voltage. This means that low-quality components are used to build the converter. The proposed conversion can be a good choice in PV micro converter applications requiring high voltage gain. The continuous conduction mode of the converter and its underlying operating principle and steady-state analysis are described. The converter's basic principle is demonstrated by constructing a working hardware prototype, which is tested in the lab. The outcomes demonstrate the benefits of employing an Arduino for voltage control. It has also been found that the converter achieves maximum efficiency of 95.3% at full load. The results were confirmed using MATLAB / Simulink in POSLC design with MPPT which is in agreement with the experimental results.

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Keywords: POSL Converter; MPPT; P&O; Photovoltaic; Standalone PV System.

1. Introduction

Power supplies are required in medical devices, telecommunication networks, computer peripherals, data transmission equipment in robot systems, power systems using renewable energy, … etc. [1-3]. All benefit from the rapid evolution of dc-dc conversion topologies in recent years. As the output voltage is increased geometrically through the stages of a dc-dc converter's operation, the super lift approach has seen widespread use [4]. The (POSLC) was developed to achieve a similar effect with minimum complexity.

The output voltage of POSLC is higher than that of conventional boost converters, and it also features high gain, high efficiency, good performance, and small output ripples in voltage and current [5-8]. The nonlinear models used by POSLC are often somewhat complicated, with widely varying parameters. There is a pressing need to investigate the best approach to controlling such topologies for potential implementation down the road. Consequently, a POSLC is the focus of this article's analysis. The two most common approaches to modeling dc-dc converters are the switching signal flow graph (SFG) and the state space averaging [9-11]. While the equations derived using the SFG method are straightforward, the method's lack of dynamic detail results from the modeling technique in averaging the high-frequency components Which will render the controller unsuitable for large-signal dynamic control. In [12], it was stated that a dc-dc converter's performance might be improved by using a sliding mode controller with a changeable structure.

However, it only functions optimally under certain conditions and cannot provide the same dynamic reaction as a switching converter in a saturated zone. Due to the low solar voltage and the fact that converters are very efficient, DC converters are important in applications involving renewable energy. Of all the DC-DC converter topologies available, the Luo converters are among the most efficient at converting power. No ripple step-up LUO converters are developed using Super-Lift (SL) and Voltage-Lift (VL) technologies to improve power efficiency and voltage gain. Many researchers have addressed the increase in low voltage in DC-DC converters and obtaining the highest efficiency from solar cells to increase profit while reducing costs and increasing efficiency [13-15]. The Luo converter types have been discussed in [16, 17]. Luo converter is used in renewable energy applications in[18, 19]. Presented POSLC was introduced with different control methods in [20-22]. In the previous works mentioned, the high step-up converter (POSLC) was used with different control methods but did not calculate the voltage stress across the switches and diodes, while in this work (POSLC) is used to increase the output voltage of DC-DC with calculating the voltage stress equations for the active elements were calculated by simulation and practically through the experimental process on the devices.

In some cases, the PV module must be connected directly to its dc-dc converter, which necessitates a high step-up capability due to the input voltage of 18.5 V.

Nomenclature & Symbols

PV	Photovoltaic	I_{sh}	Short Circuit Current
PWM	Pulse Width Modulator	V_{oc}	Open Circuit Voltage
MPPT	Maximum Power Point Tracking	Io	Saturation Current of PV
P&O	Perturb and Observe	Rsh	Equivalent Parallel Resistance of PV
DC	Direct Current	Rs	Equivalent Series Resistance of PV
SL	Super-Lift	Δ_{iL}	Peak-to-Peak Inductor Current Variation
VL	Voltage-Lift	Δ_{VC}	Peak-to-Peak Capacitor Voltage Variation
POSLC	Positive Output Super-Lift Luo Converter	ΔVo	Peak-to-Peak Output Voltage Variation
SFG	Signal Flow Graph	Id	Current of the Diode
KVL	Kirchhoff's Voltage Law	D	Duty Cycle
F	Frequency		

The primary function of the dc-dc converter is to maintain a constant voltage of 400 V on the module. Therefore, a remarkable step-up skill is required. High-step-up POSL dc/dc converters based on maximum power point tracking are proposed in this paper. The proposed converter is effective in many contexts, including PV (photovoltaic) systems. In comparison to conventional boost converters, the proposed converter boasts several desirable characteristics, such as a high step-up capacity, low voltage stress on active devices, and respectable efficiency.

2. Design the Proposed POSLC with the PV & MPPT Strategy

The proposed system consists of a POSLC, which is one of the high-lift converters of the DC source, the DC source is a solar panel with a capacity of 150W, Fig. 1 shows the proposed converter with PV & MPPT controller.

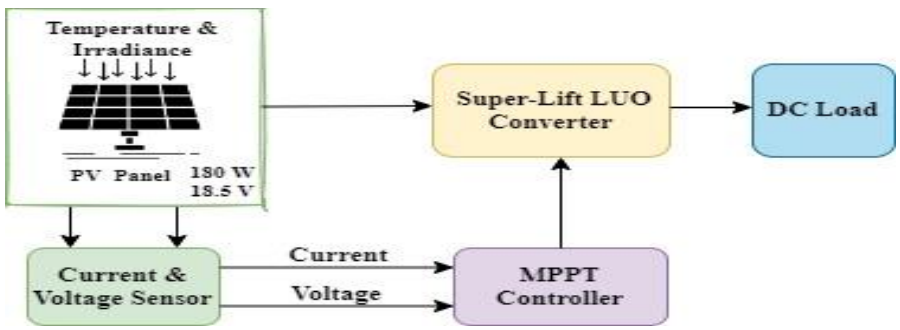

Fig. 1. The proposed system diagram [10]

2.1. PV modelling system

The photovoltaic cell modelling of a single diode offers an efficient trade-off between accuracy and simplicity. Solar cell modeling is based on the mathematical expression for its equivalent circuit, the most widely used model in photovoltaic cell modeling is the single diode, as represented in Fig. 2, A photovoltaic cell can be represented by its most elementary form, which consists of a current source, a diode, and a resistor connected in parallel and exhibiting a small leakage in the parallel resistance path, measured in Rsh. The module's losses are represented by the series resistance Rs and the parallel resistance Rsh, and the current flowing through the resistance Rsh is denoted by Ish. Before connecting the nonlinear system elements, I and V, the values of Io, Iph, Rs, and Rsh must be known [23, 24].

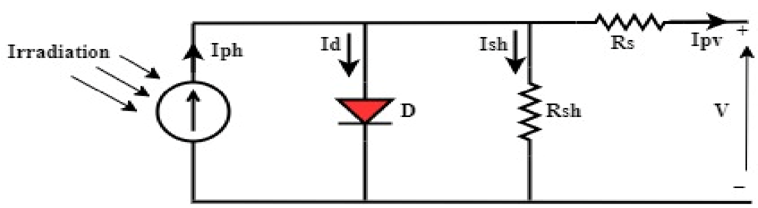

Fig. 2. PV Cell Circuit Diagram [23]

2.2. Positive Output Super-Lift Luo converter

One variety of DC-DC converters boosts the output voltage by increasing the input voltage at a low current. The Luo converter is created following operational requirements. The POSLC maintains the same polarity while increasing the positive source voltage output to the load. A switch (MOSFET), an inductor (L1), capacitors (C1, C2), and two diodes (D1) make up each simple circuit. The resistive load (RL), switching frequency (f), and duty cycle (D) are all represented as shown in Fig. 3 (a), the main aim of this converter is to increase the output voltage and efficiency and achieve high reliability compared with the traditional boost converter.

The operation of this converter is divided into two modes:

2.2.1. Mode I

When the switch (S) is turned ON, the inductor (L1) and capacitor (C1) are connected in parallel with the voltage source (Vin) through the diode (D1) for charging the capacitors and inductors. The diodes (D1) are forward-biased, and the output diode (DO) is reverse-biased, as illustrated in Fig. 3 (b). Also, in this period, the output capacitor (CO) discharges its stored energy to the load.

2.2.2. Mode II

When the switch (S) is turned OFF, the inductor (L1) and capacitor (C1) are connected in series with the voltage source (Vin) through the output diode (DO) to discharge the stored energy to charge the output capacitor (CO) and provide energy to the load. The diode (D1) is reverse-biased, and the output diode (DO) is forward-biased, as depicted in Fig. 3 (c) [8, 25].

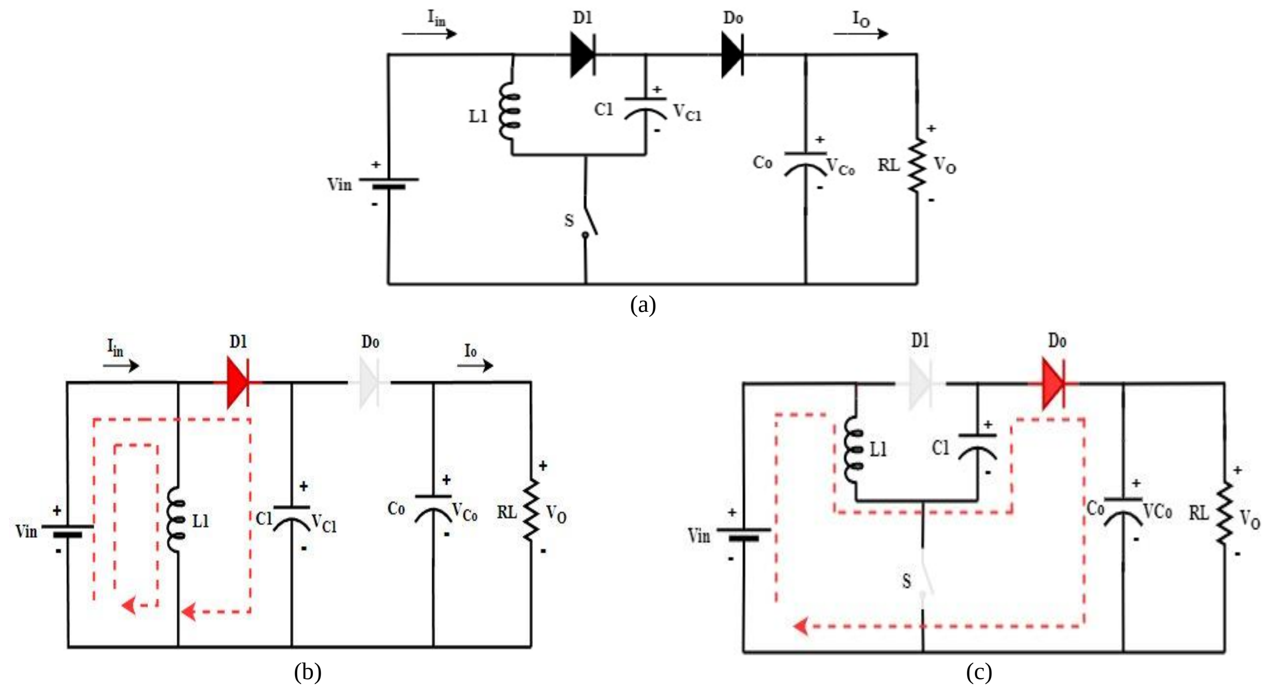

Fig. 3. (a) The circuit diagram of POSLC, (b) Switch ON, and (c) Switch OFF [8]

a- The values of components are determined by the equations below by applying Kirchhoff's Voltage Law (KVL):

The value of the inductor L1 is determined by equation,

$$\Delta i_L 1 = \frac{V_o - 2V_{in}}{L_1}(1 - D)T \tag{1}$$

$$L1 = \frac{V_o - 2V_{in}}{\Delta i_L 1}\frac{(1-D)}{f} \tag{2}$$

By utilizing the equation, the value of Super-Lift capacitor C1 is determined,

$$C_1 = \frac{I_{in}(1-D)}{(2-D)f_s\,\Delta VC_1} \tag{3}$$

The following is the equation to determine the output capacitance Co,

$$\Delta V_o = \frac{(1-D)}{f\,Co}\frac{V_o}{R} \tag{4}$$

The expression for transfer gain (G) in the equation is,

$$G = \frac{V_O}{V_{in}} = \frac{(2-D)}{(1-D)} \tag{5}$$

$$V_O = \frac{(2-D)}{(1-D)}Vin \tag{6}$$

b- Voltage stress is determined across diodes and the MOSFET switch:

During the ON switch, the output diode can be defined by the equations as:

$$V_{in} - V_{DO} - V_O = 0 \tag{7}$$

$$V_{DO} = -(V_O - V_{in}) \tag{8}$$

During the OFF switch, the voltage stress across D1 is:

$$V_{in} - V_{D1} - V_O = 0 \tag{9}$$

$$V_{D1} = -(V_O - V_{in}) = V_{DO} \tag{10}$$

According to the KVL, the voltage stress across the MOSFET switch is:

$$V_S + V_{C1} - V_O = 0 \tag{11}$$

Where $V_C = V_{in}$

$$V_S = V_O - V_{in} \quad (12)$$

2.3. Maximum power point tracking (MPPT)

An electronic system that continuously monitors all power points and optimizes the solar panels' output is necessary to make the most of the PV modules' energy output. To guarantee maximum load capacity despite the ever-shifting weather, PV modules must be operated at their maximum power point. MPPT is used with a mechanical tracking system, and MPPT cannot be considered mechanical.

Also important are MPPT controllers with DC-DC converters for duty cycle modulation. The converter typically generates a signal voltage and duty cycle that serve as inputs to the PWM generator. The purpose of this is to generate switching pulses for the converter. In order to significantly improve the tracking of the maximum power point, a PI controller based on dp /dv has been proposed in this work.

Since MPP does not have a fixed point, it moves around the curve (P-V) when temperature and light intensity change, so MPP will change as environmental conditions change. The fundamental goal of MPPT is to increase solar panel efficiency by obtaining the maximum amount of energy from photovoltaic cells by matching source resistance to load resistance. MPPT employs several algorithms to do calculations by reading the voltages and currents of the solar panel and then extracting the maximum energy. Perturb, and observation (P&O) technique is commonly used because of its simplicity [26-28].

2.3.1. Perturb and observe (P&O) method

The perturb and observe method is commonly used to regulate MPPT. Its low cost, ease of implementation, few parameters, and potential for improvement make it a strong candidate for widespread use.

Research into the relationship between PV modules' output power and voltage forms the basis of this method. P&O algorithm is used to monitor the solar array's output power and disturbance (increase or decrease). The concept of the P&O method is to modify the operating voltage or the photovoltaic current to obtain maximum power. The system oscillates about the MPP once the MPP is reached. The perturbation step size should be lowered to reduce the oscillation. If the operational point is not MPP, the work cycle will shift to an enormous step. the flowchart for implementing the P&O algorithm is shown in Fig. 4.

The voltage and current of the actual PV array are measured first. After that point, we can calculate the true power output of the PV module by multiplying voltage by current. [29, 30].

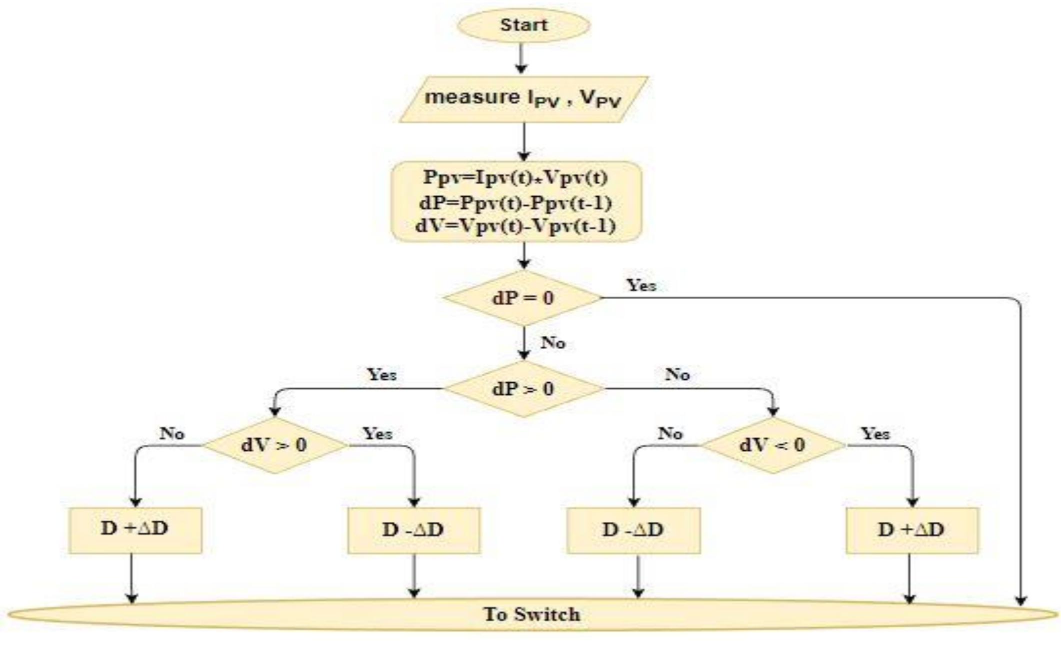

Fig. 4. The P&O algorithm flowchart [29]

3. Design Simulation and hardware of proposed system

Figure 1 depicts the layout for the proposed PV system. Table 1 displays the photovoltaic panel's technical specifications, in the simulation model, the parameters of the proposed system are listed in Table 2. parameters POSLC is designed according to the above equations. The results of the proposed work were obtained by executing a simulation of the system using MATLAB 2018 / Simulink software. Fig. 5 shows the Simulink of POSLC. The hardware system is composed of a solar panel 150W, Arduino for "implementing the MPPT controller", Current sensor, Voltage sensor, Capacitors, inductors, diodes, MOSFET, and Resistor for "building the DC/DC Converter", Resistive load, Printed circuit board (P, can be seen in Fig. 6. In this application, the LUO converter utilizes a MOSFET switch. The MOSFET is managed using an Arduino NANO. Though the MOSFET can produce a PWM pulse with a voltage of 5 volts, it requires a gate driver circuit to turn on. This is achieved by employing the TLP350 gate drive, which protects the microcontroller from high-side reverse current, then, current and voltage sensor is needed to measure the PV system's voltage and current, with the information then being sent to Arduino, which serves as the MPPT.

4. Experimental Results

The converter receives 18.5 V of input voltage and produces 55.5 V at 50% duty cycle. Fig. 7 displays experimental and simulated values for the instantaneous voltage and current at the POSLC's P&O output (a-c). The output voltage ripple for the average switching frequency of 20 kHz is seen in the figure to be very minimal, about 0.2V. At the same time, Fig. 8(a and c) show the simulation and hardware for the voltage across the passive element, which is the inductor and capacitor. In addition, the peak-to-peak inductor ripple current is 0.47 A/0.21 A, which is indicated in Fig. 8 (b). Additionally, it shows that the inductor current for the POSLC should always be continuous and not reach zero. It can be evident from Fig. 8 (a) that the inductor and capacitor are charged in Vin and discharged by also Vin, which proves the theoretical analysis.

In order to show the voltage stress across the MOSFET, Fig. 9 (a, b, and c) show the simulation and hardware waveforms of voltage across MOSFET and the duty cycle, respectively. The theoretical results of voltage stress across MOSFET are equal to 37 V by using equation 12 above $V_o - V_{in}(55.5 - 18.5)$. It can show from this figure that the simulation results and hardware are matching with the theoretical calculation and analysis.

Finally, the voltage stress across the semiconductor devices is demonstrated in Fig. 10 (a, b and c). The voltage stress across the diodes (d1 and do) in equations above (8 and 10) is equal to - ($V_o - V_{in}$)it is equal to 37 V. it can be seen that the waveforms also match the calculation results. The hardware efficiency is equal to 95.3%.

Table 1. PV panel specifications

Parameter	Value
Maximum Peak Voltage (V_{mp})	18.55 V
Maximum Peak Current (I_{mp})	8.25 A
Open Circuit Voltage (V_{OC})	22.20 V
Short Circuit Voltage (I_{SC})	8.81 A
Maximum Power (P_m)	150 W
Number of cells	36

Table 2. Parameters of the proposed system

Parameter	Value
Input voltage (Vin)	18.5 V
Output voltage (Vo)	55.5 V
Maximum output power (Po)	150 W
Switching frequency (fs)	20 kHz
Duty cycle (D)	0.5
Capacitors C_1=C_2	100 µF,400 V
Inductors L1	0.67 µH, 5A
Diodes D_1, D_0 (RURG 5060)	50 A, 600 V
Switch MOSFET (IRFP 460)	40A, 600V
TLP 350 drive	1.5A, 30V
Load Resistance	330 Ω

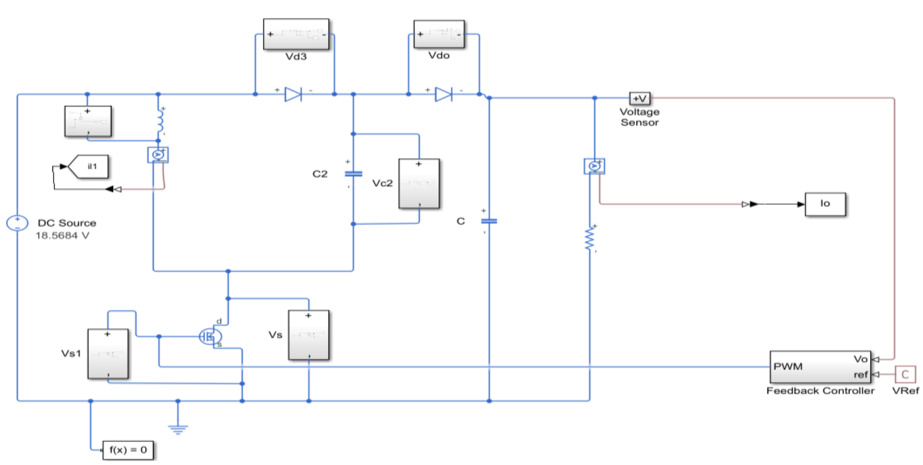

Fig. 5. Simulink model of POSLC

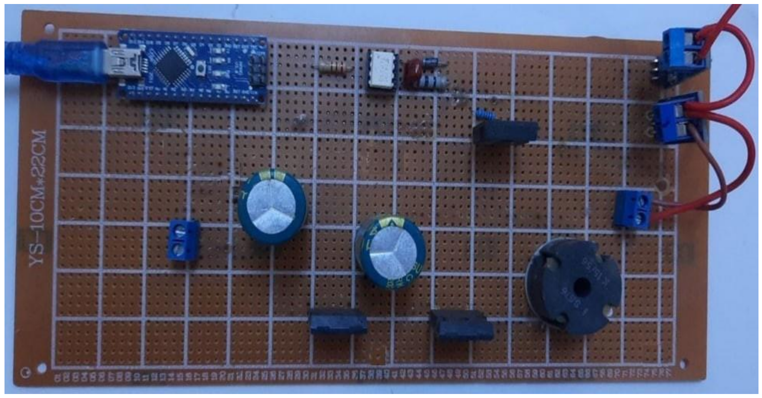

Fig. 6. Hardware prototype of POSLC

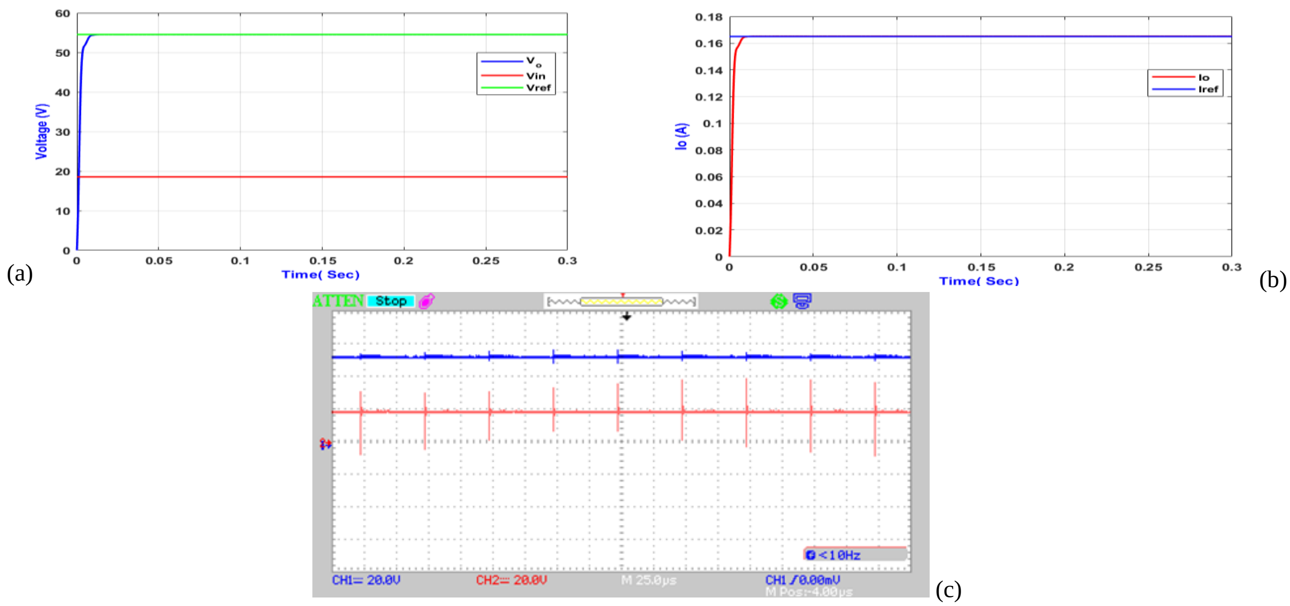

Fig. 7. (a) Simulation of input and output voltage, (b) Output current response, and (c) Hardware output and input voltage

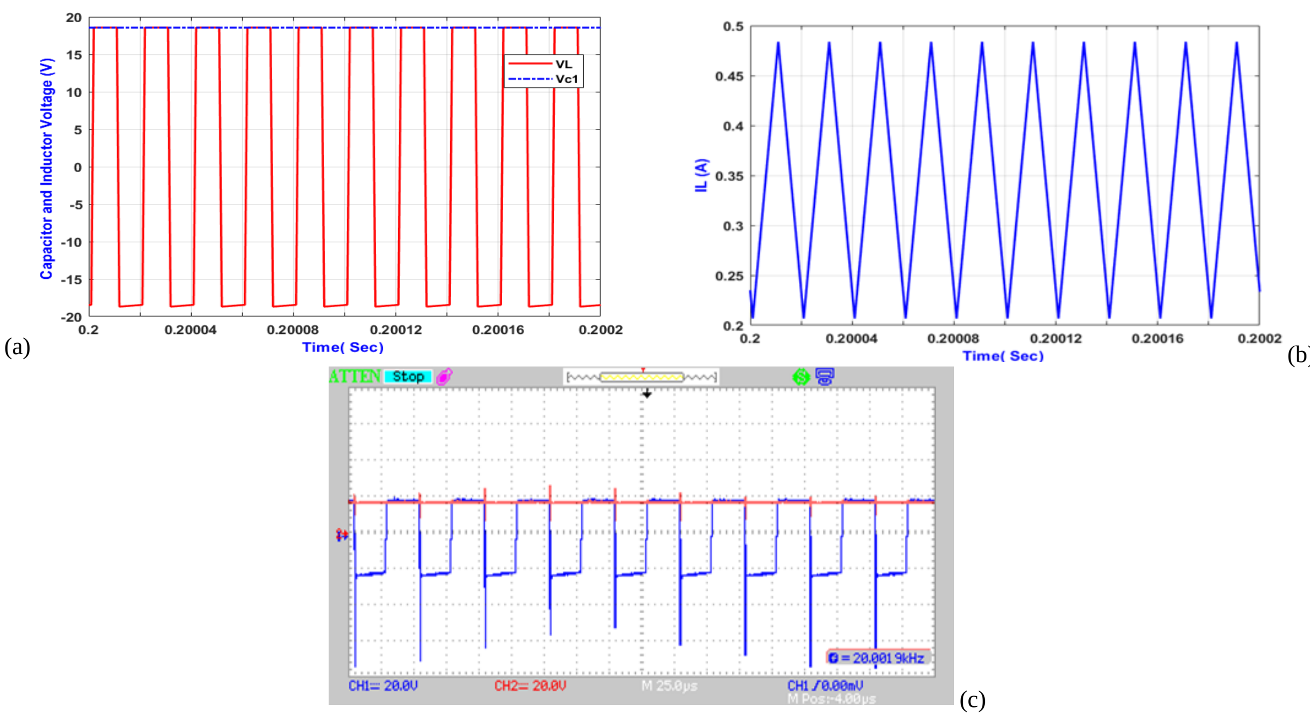

Fig. 8. (a) Simulation voltage across inductor and capacitor, (b) Inductor current, and (c) Hardware voltage across inductor and capacitor

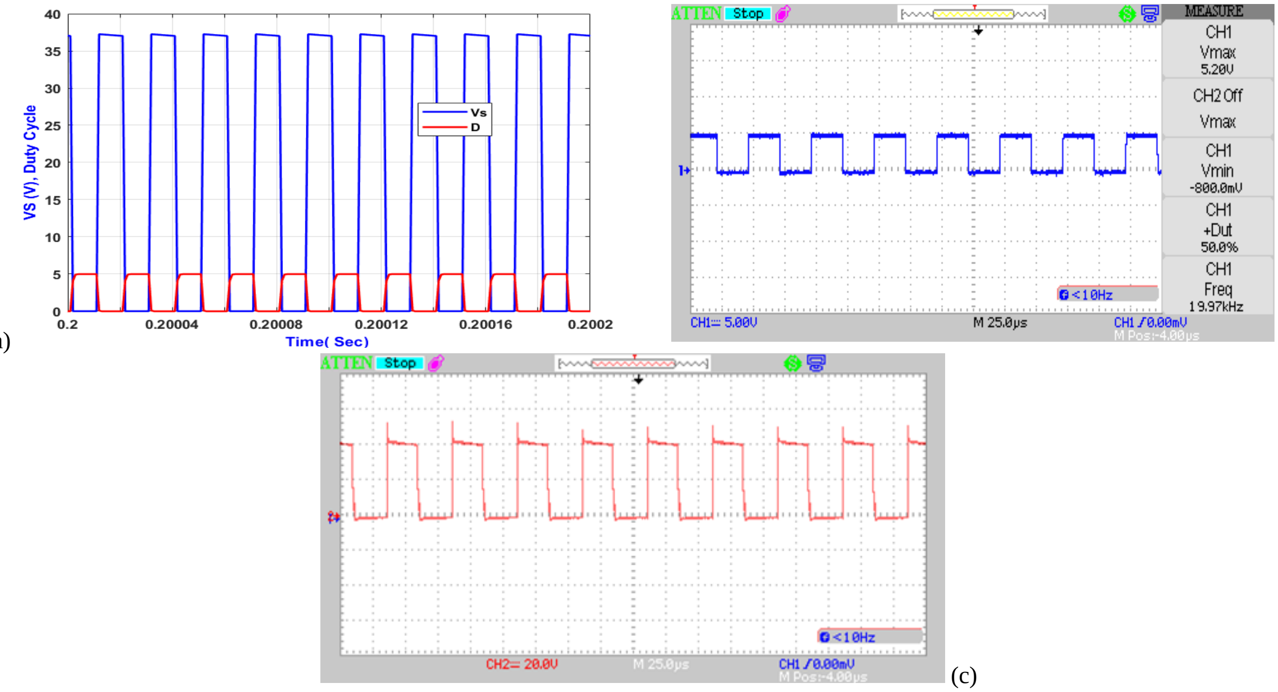

Fig. 9. a) Simulation voltage across MOSFET switch and duty cycle, b) Hardware duty cycle, c) Hardware voltage across MOSFET switch

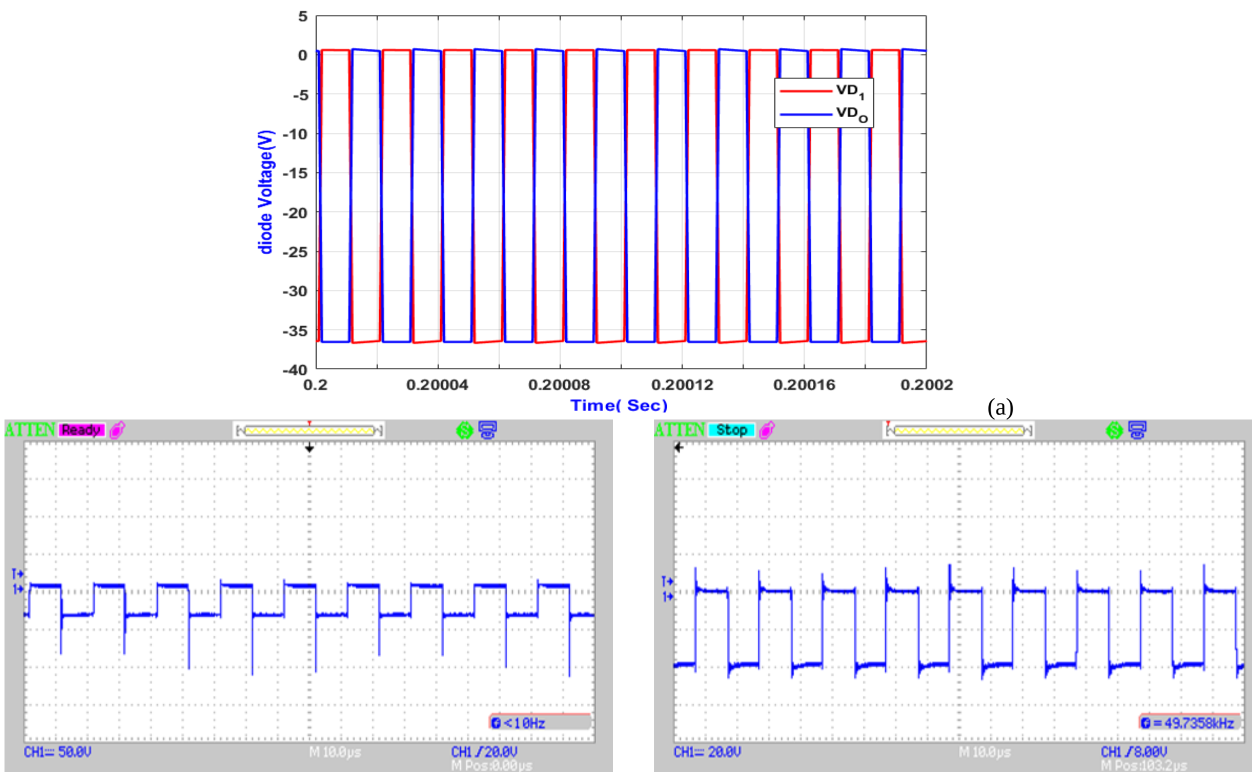

Fig. 10. (a) Simulation voltage across diodes (Vd1, and Vdo), (b) and (c) Hardware voltage across diodes (Vd1, and Vdo)

5. Conclusions

This work aims to design a POSLC configuration. It is seen from the outcomes that the converter results are capable of high voltage gain and featured high current output. Additionally, the MPPT algorithm is used to interact with PV, and track the peak energy of the PV. The easy structure of the circuit used one inductor, one switch, two capacitors, and two diodes. Theoretical and practical analysis of the converter's performance uncovered moderate efficiency, low voltage and current stress, and high voltage gain. The LUO converter transforms the unregulated voltage into a controlled voltage; the suggested DC/DC converter is therefore suitable for PV systems. And because of the low voltage stress on the active elements, which leads to decreased heating and the prolongation of the life of the circuit, can be used elements at a low cost. The theoretical and simulation analysis and converter results were consistent with the experimental findings.

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