A Novel Switched-Inductor Type Modified LUO Converter for Solar-PV Powered Water Pumping System

1. Aseela Sweatha , 2. Dr. Balasubramanian Baskaran ,
3. Dr. Periyasamy Duraipandy

[1]*Research Scholar, Department of Electrical and Electronics Engineering, Annamalai University, Chidambaram, Tamilnadu, India, Email:* sweatha.electrical@gmail.com
[2]*Professor, Department of Electrical and Electronics Engineering, Annamalai University, Chidambaram, Tamilnadu, India,*
Email: baskarancdm@gmail.com
[3]*Associate Professor, Department of Electrical and Electronics Engineering, J. B. Institute of Engineering and Technology, Hyderabad, Telangana, India,*
E-mail: Vai_2k4@yahoo.co.in

Abstract

The continuing depletion of traditional energy sources, along with their environmental implications, has sparked increasing interest in a variety of Renewable-Energy Sources (RES)-based water-pumping systems. Solar-PV is the most promising and feasible renewable energy source for water-pumping applications and it is simply placed on a building's roof. The available solar-PV energy is incorporated into the AC electric motor using a front-end DC-DC boost converter architecture. Modified DC-DC boost converters for solar-PV supplied water-pumping systems are distinguished by their efficient operation, stable performance, high boost competency, and continuous input current. This paper presents a complete examination of basic and modified LUO DC-DC boost converters, including operational characteristics and voltage-boosting techniques. Among the many DC-DC converter topologies, a new Switched-Inductor type Modified LUO converter has been developed for a solar-PV driven water pumping system. The suggested SI-MLUO converter has a simple construction that provides high voltage gain with low leakage currents, low current ripples, decreased voltage spikes, low dv/dt stress, and good efficiency compared to numerous standard DC-DC converters. The operating modes and performance of the proposed SI-MLUO converter topology are confirmed using the Matlab/Simulink tool, and the simulation results are evaluated against traditional topologies.

Keywords: *Modified DC-DC Boost Converters, Modified LUO Converter, Switched-Inductor Module, Solar-PV System, Voltage-Lifting Technique, Water Pumping Application*

1. Introduction

Water resources are essential for humankind for drinking, irrigation, and food production. Water becomes more important than ever as the population grows. In recent times, the primary source of energy for raising water from rivers, canals, and ponds has become increasingly important. Traditionally, water lifting or pumping systems are driven by fossil fuels such as diesel, petrol and kerosene [1], which increase CO2 emissions, raise fuel costs, have an impact on the environment and have low operational efficiency, among other things. Renewable Energy Sources (RES) are making sincere efforts throughout the world to promote social-economic and sustainable development. Solar Photovoltaics are the most practical and promising method of energy production in areas where the utility grid is absent. In this situation, solar-PV energy-powered pumping systems are more cost-effective, environmentally friendly, require no fuel, and may generate 35% to 40% more power than standard diesel-powered pumping systems [2]-[4]. Fig.1 depicts the block diagram of a solar-PV-fed water pumping system. Solar-PV-powered pumping systems require practical power-electronic converters to convert available solar-PV energy into high-voltage DC output to drive the electric motor [5]. Advances in power converters make it easier to condition, convert, and regulate the output voltage with specific characteristics for driving any load device. In this sense, a DC-DC converter is the most crucial element in a solar-PV powered pumping system that delivers different output voltage [6].

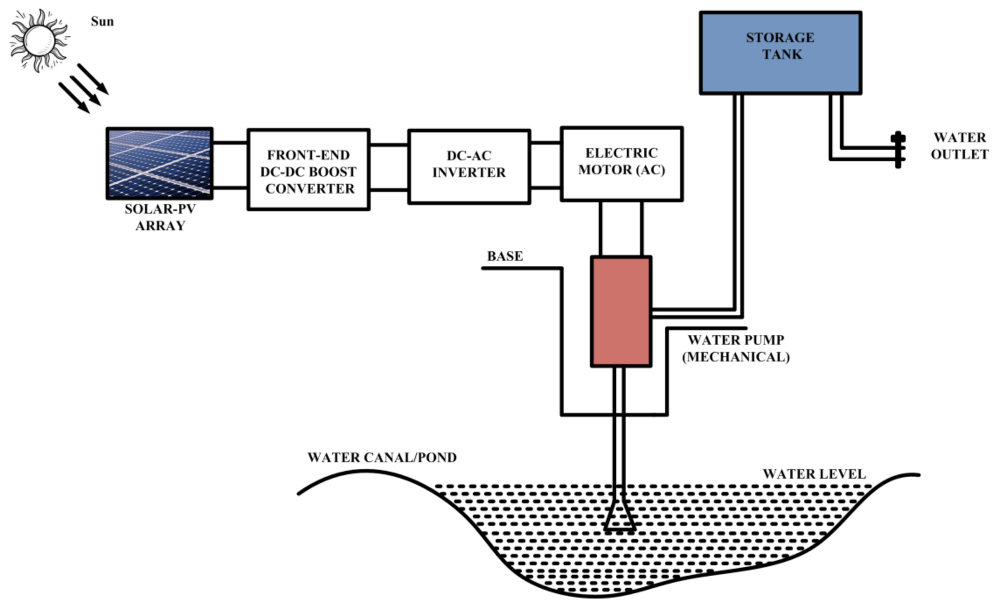


Fig.1 Schematic Model of Solar-PV Fed Water Pumping System

The DC-DC converter converts low DC voltage into high DC output voltage by momentarily storing energy and delivering it to the load terminals with increased competence. Some well-known fundamental DC-DC converters are boost converters [7], CUK, SEPIC, LUO type converters [8], and so on. These basic DC-DC converters are improper since they are mostly used at high duty ratios to produce higher voltage levels. In recent years, new DC-DC boost topologies have been investigated to obtain better voltage gain by modernizing the fundamental DC-DC converter architecture using voltage multipliers or sub-module circuits. This method presents the features, technical analysis, benefits, and drawbacks of basic and contemporary DC-DC converter topologies for solar-PV driven water pumping systems [9]. The high-voltage boost capability [10] is provided by employing switched inductors that may operate in either Discontinuous Conduction Mode (DCM) or Continuous Conduction Mode (CCM) conditions. In reality, the functioning of the converter in CCM is more crucial since it achieves a large voltage gain at the load terminals while minimizing current ripple. Coupled inductors and/or high-frequency transformers can be used to achieve high boost competence, but they need enormous windings, high leakage inductance, and a complicated construction, which leads to increased dv/dt stress, among other things.

According to multiple literature evaluations, researched converter topologies are unsuitable for this application for a variety of reasons, including the need for additional switching components, increased dv/dt stress, complicated design, high switching loss, and decreased efficiency [11], [12]. The fundamental challenge with typical topologies is linked inductors. Multi-winding transformers may be used, but [13], they have high leakage inductance due to strong current waves, are more complicated to design, and require a large number of windings to provide significant voltage gain. The proposed solution, an imaginative notion of modified LUO converter topology, has been designed to solve the aforementioned disadvantages by applying switched-inductors to increase the voltage gain at the load terminal. A unique Switched-Inductor type Modified LUO converter (SI-MLUO) has been presented for a solar-PV powered water pumping system. The proposed SI-MLUO converter outperforms traditional DC-DC converters in terms of voltage gain, simplicity, low leakage currents, low current ripples, decreased voltage spikes, low dv/dt stress, and high efficiency. The operation and performance of the proposed SI-MLUO converter architecture are confirmed using the Matlab/Simulink tool, and the simulation results are evaluated against standard topologies.

2. SEVERAL LUO TYPE DC-DC BOOST CONVERTERS

A DC-DC boost converter is a type of power electronic converter that transforms unregulated low DC voltage to regulated high DC voltage at load terminals while maintaining a unique voltage gain. In general, simple DC-DC boost converters are divided into two types: switched and linear. Linear converters are inexpensive, widely available, and suitable for low-power applications. Switched type converters are well-known for their simplicity and ability to handle high power applications. In recent years, numerous DC-DC converter topologies have been investigated to achieve high voltage gain by altering the design of a basic DC-DC converter topology that includes a sub-module cell or voltage multiplication circuits [14].

In this approach, a thorough analysis of basic and modified LUO type DC-DC boost converters is provided and recognized for water-pumping systems with simple design, high power capability, and dependable performance. The LUO is a non-isolated type converter [15], [16] that conducts boost operations and transforms low voltage DC into high voltage DC at output terminals. It performed very well with a simple circuit design when compared to other basic DC-DC converters. It is made up of two inductors Ls1, Ls2, one diode D1, two capacitors Cs1, Cs2, and a single MOSFET switch Ss1 to drive the resistive R-load Rs1, respectively. Fig.2 shows the schematic diagram of a basic LUO DC-DC converter. The voltage-lifting approach is the most effective strategy to improve circuit characteristics.

These are a set of innovative boost converter topologies designed using various circuit designs to achieve low ripple content and high voltage gain in both current and voltage wave forms. Voltage-lifting circuits include elementary positive-output and negative-output LUO converter topologies, as well as self-lift positive-output and negative-output LUO converter topologies, as described in [17], [18]. These lifting converters provide high voltage gain with reduced ripple content, as well as higher power density, a simpler construction, and excellent efficiency. These voltage-lifting converters are widely employed in switched-mode circuits, mid-range industrial, and residential applications. Fig.3 shows a schematic representation of several voltage-lifting LUO DC-DC boost converters.

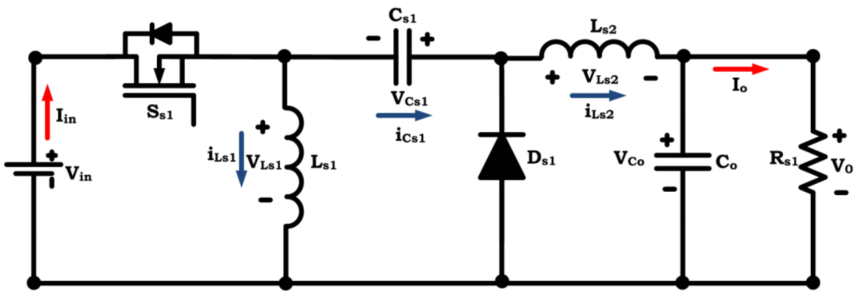


Fig.2 Schematic Diagram of Basic LUO Converter

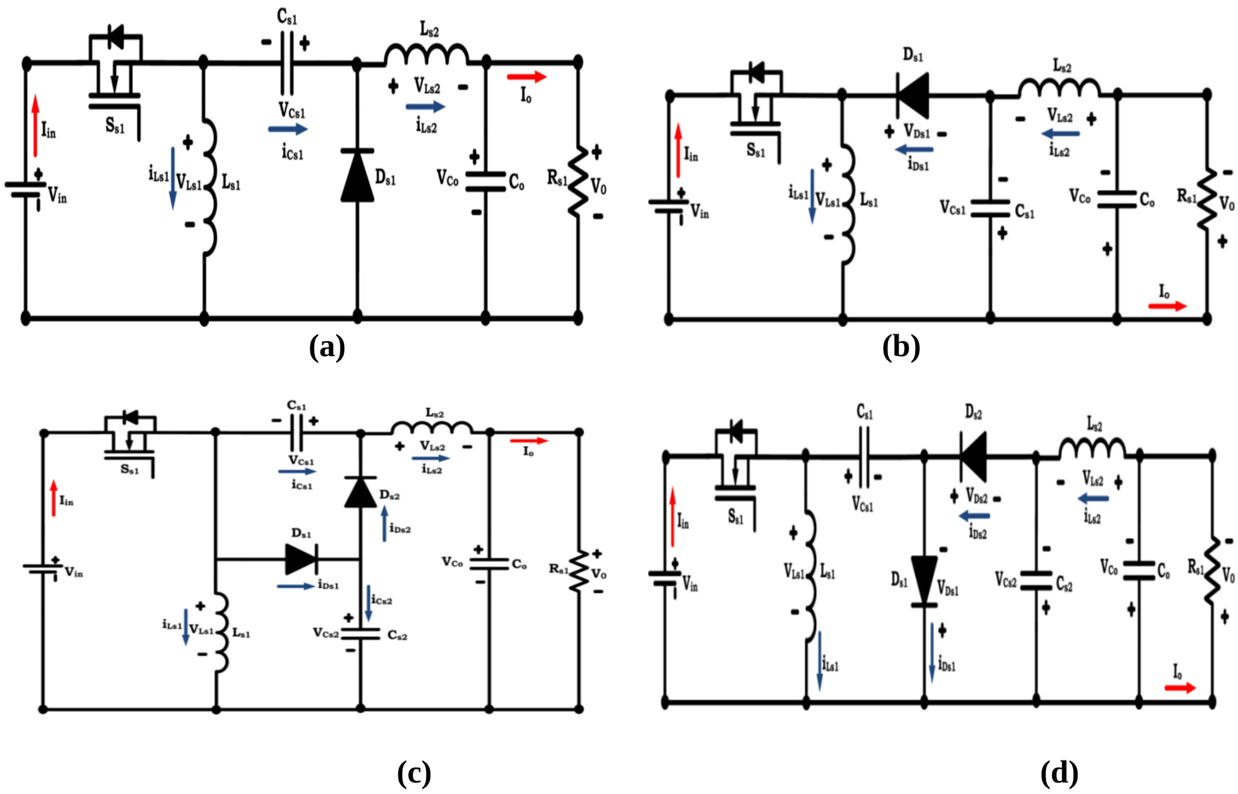


Fig.3 Various LUO DC-DC Boost Converters (a) Elementary Positive-Output LUO Converter, (b) Elementary Negative-Output LUO Converter, (c) Self-Lifting Positive-Output LUO Converter, (d) Self-Lifting Negative-Output LUO Converter

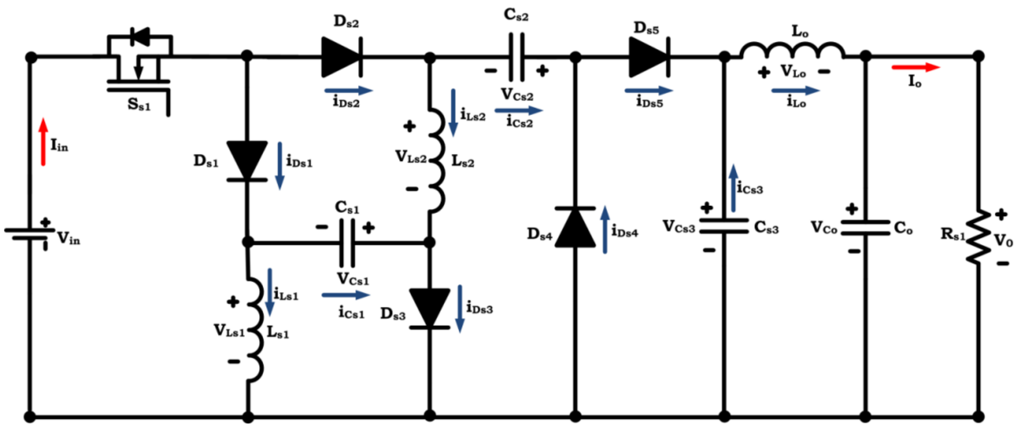


Fig.4 Modified Re-Lift Positive-Output LUO DC-DC Boost Converter

The modified self-lift positive-output LUO converter is designed to provide high voltage gain by combining the elementary and self-lift PO-LUO converter topologies [19]. This improved LUO converter uses a mix of capacitors and inductors to generate high voltage DC from low input DC voltage, resulting in doubled voltage gain. The primary benefits of a modified-LUO converter are double-voltage gain with low duty ratios, low voltage and current ripples, minimal dv/dt stress and EMI loss, and high efficiency. The main module is made up of a single inductor L0, a single diode Ds5, two capacitors Cs3 and Co, and a single MOSFET switch Ss1 that drives the resistive R-load Rs1. The voltage-lifting module is made up of two inductors (Ls1, Ls2), four diodes (Ds1, Ds2, Ds3, Ds4), and two capacitors (Cs1, Cs2). The operational modes and steady-state analysis of the modified-re-lift positive-output LUO DC-DC converter are described in [20]. Fig.4 shows the schematic design of a modified re-lift positive-output LUO DC-DC boost converter.

3. DESIGN & OPERATION OF PROPOSED SI-MLUO DC-DC CONVERTER TOPOLOGY

The proposed SI-MLUO converter falls within the non-isolated converter group; it converts low voltage to high voltage while maintaining a constant DC voltage at the load terminals. The proposed SI-MLUO converter is based on a basic LUO converter, with the primary inductor replaced with a single switched-inductor cell with a decreased rating. In reality, switched-inductor cells decrease leakage currents, have minimal spikes at switches, and offer significant benefits such as a simple construction, good voltage gain at low duty ratios, continuous input current, low dv/dt switch stress, and high efficiency. The high voltage boosting capacity of the proposed SI-MLUO converter is achieved by employing low switching elements and SI cells; it may operate in Continuous or Discontinuous Conduction Modes (CCM/DCM), with aero current function in DCM mode. In actuality, the functioning of the SI-MLUO converter is more important in CCM due to the load's dependency on voltage boost capabilities. High current ripples, greater voltage spikes, and low efficiency are the main concerns encountered in DCM operation.

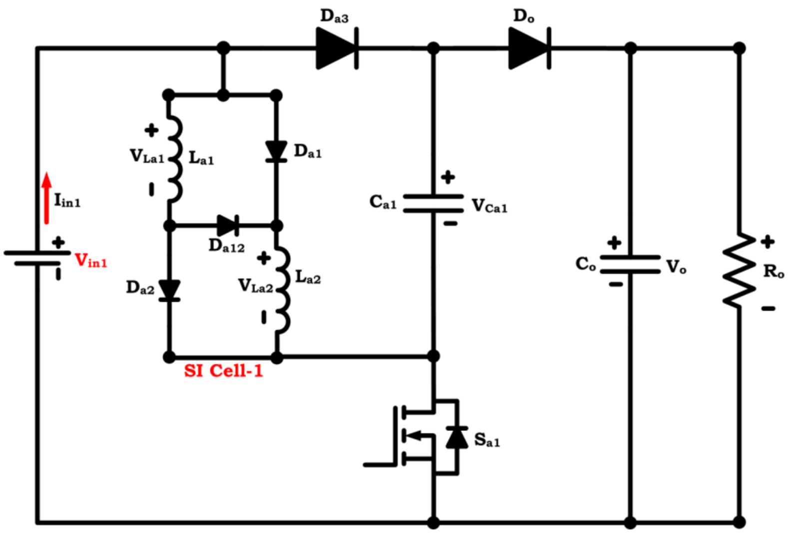


Fig.5 Schematic Diagram of Proposed SI-MLUO Converter Topology

The schematic diagram of the proposed SI-MLUO converter is depicted in Fig.5. It comprises of one MOSFET switch Sa1, one switched inductor cell dubbed SI cell-1, one boosting capacitor Ca1, one clamping diode Da3, one output capacitor Co, and one output diode Do, all of which power the resistive load Ro. The SI cell-1 consists of two inductors, La1 and La2, and three diodes, Da1, Da2, and Da12. The suggested converter architecture is normally powered by Vin1's input DC voltage and generates high voltage gain and constant output voltage Vo at the load terminals. The high voltage at the load terminal is generated by symmetrically energizing the appropriate inductors in the SI cell and boost capacitor by sequential switching of switch Sa1 using output diode Do and output capacitor Co. The operating modes and steady-state analysis of the proposed SI-MLUO converter architecture are clearly stated as follows:

Mode-I (t_0-t_1): During this operating mode-I, the switch Sa1 is turned on by sending gate-pulses generated by gate-drive circuitry. The input DC voltage Vin1 powers the boost capacitor Ca1 while simultaneously charging the inductors in SI cells La1, La2 via SI-cell diodes Da1, Da2, respectively. It has conserved some energy using the parallel charging approach on switch Sa1. The voltage across two inductors in the SI cell of La1, La2 is VLa1, VLa2, which is equal to Vin1's input DC voltage. Although the input DC current Iin1 flows continuously towards the boost capacitor and inductors of the SI cells Ca1, La1, and La2, the current flow in the capacitor and SI-cell inductors is iCa1, iLa1, and iLa2, which increases linearly. So, the input DC current does not flow to the resistive load because the output diode Do is reverse-biased as a result of the switch Sa1 being in the conduction area. Thus, the output capacitor Co supplies continuous energy to the load Ro while keeping the output voltage Vo constant until the switch Sa1 enters the non-conduction state. Fig.6 (a) depicts the proposed SI-MLUO converter's working mode I.

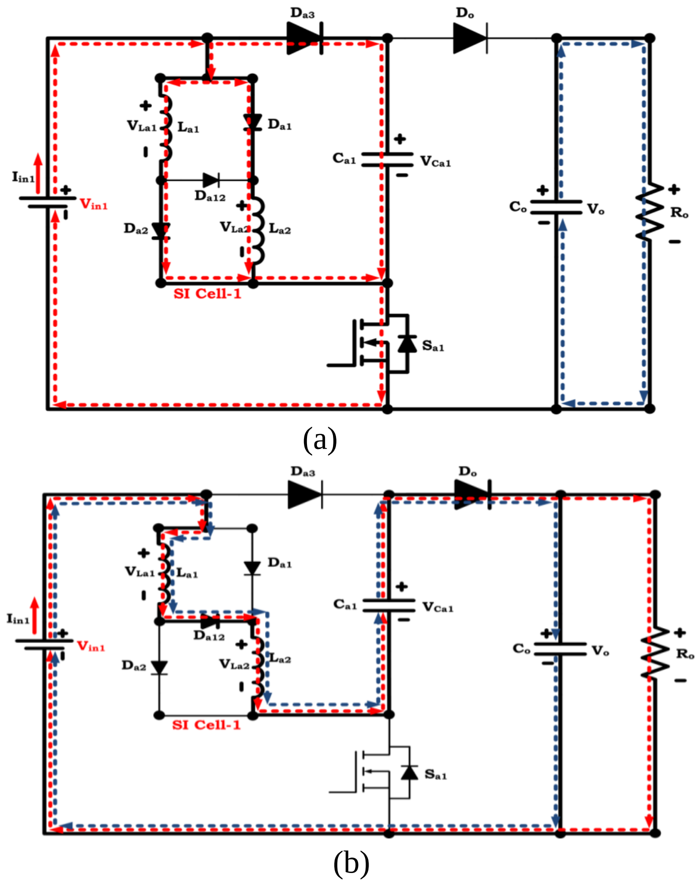


Fig.6 Operating Modes of Proposed SI-MLUO Converter, (a) Mode-I and (b) Mode-II

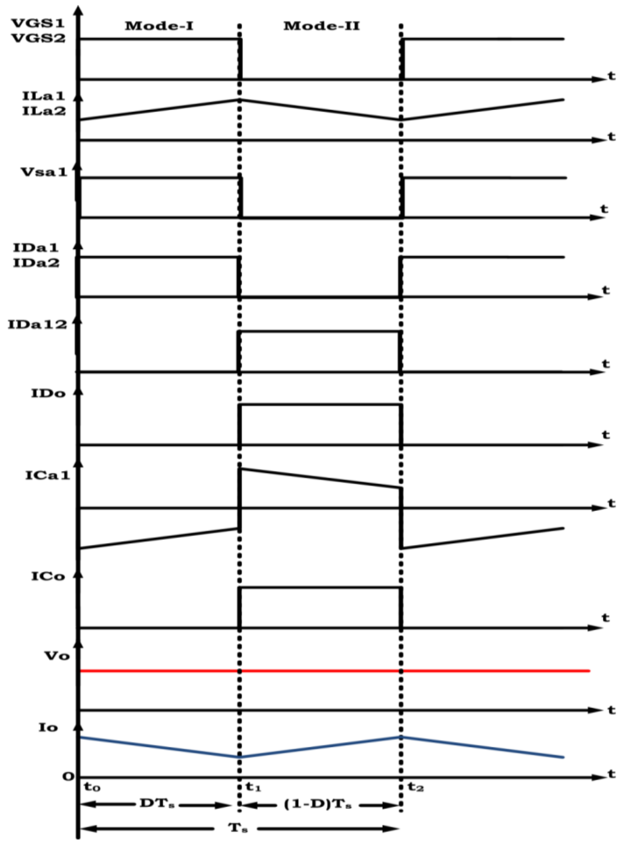


Fig.7 Typical Waveforms

Mode-II (t_1-t_2): During this operating mode-II, the switch Sa1 is turned off by terminating the gate-pulses generated by the gate-drive circuit. The energy stored in the SI cell-1 inductors La1, La2, and boost capacitor Ca1 is then de-energized via the Da12 diode and the Do output diode. It provided energy to a resistive load using the serial discharging technique with an input voltage of Vin1. As a result, the voltage across two inductors in the SI cell of La1, La2 is -VLa1, -VLa2, which equals the boost capacitor voltage of VC1. Although the load current IO flows constantly towards the boost capacitors and inductors of the SI cells Ca1, La1, and La2, it decreases linearly and transfers energy to the load and output DC capacitor Co. As a result, the current flows continuously to the resistive load since the output diode Do is forward biased and the switch Sa1 is in the non-conduction area, resulting in a significant voltage gain at the load terminals. Thus, the switched inductors and boost capacitor give continuous energy to the load Ro while maintaining a constant output voltage Vo until switch Sa1 enters the conduction state. Fig.6(b) depicts the proposed SI-MLUO converter's working mode II. The typical waveforms of the proposed SI-MLUO converter are illustrated in Fig.7.

The average voltage induced in the switched-inductors is expressed as follows:

$$V_{La1} = V_{La2} = 0 \quad (1)$$

During Mode-I (Sa1 ON, ton=DT), the amount of voltage generated and current that flows in the switched inductors are expressed as,

$$V_{La1} = V_{La2} = V_{in1} \quad (2)$$

$$V_{Ca1} = V_{in1} \quad (3)$$

$$I_{La1}(t) = I_{La2}(t) = \frac{V_{in1}}{L} \quad (4)$$

During Mode-II (Sa1 OFF, ton=(1-D)T), the amount of voltage generated and current that flows in the load terminals are expressed as,

$$V_{in1} - V_{La1} - V_{La2} + V_{Ca1} - V_O = 0 \quad (5)$$

According from the switch-off duration, the voltages that are induced are represented as,

$$V_{La1} = V_{La2} = \frac{3V_{in1} - V_O}{2} \quad (6)$$

According to the volt-sec balancing principle between the switched inductors La1 and La2, which is represented as,

$$V_{in1}DT + \frac{3V_{in1} - V_O}{2}\,(1-D)T = 0 \quad (7)$$

Therefore, the relationship for voltage gain ratio may be written as follows:

$$\frac{V_O}{V_{in1}} = \frac{4-D}{1-D} \quad (8)$$

Eqn. (9) expresses the final voltage gain (VGCCM) as follows:

$$VG_{CCM}\,(boost) = \frac{V_o}{V_{in}} = \frac{4-D}{1-D} \quad (9)$$

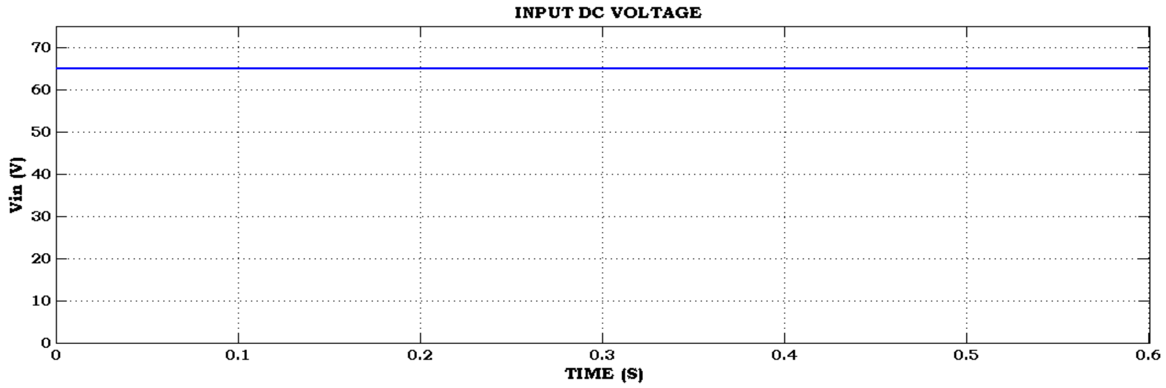
4. MATLAB/SIMULINK RESULTS

The performance of the suggested SI-MLUO converter architecture is checked using the Matlab/Simulink tool, and the simulation results are confirmed against traditional topologies. The Matlab/Simulink design requirements for the proposed SI-MLUO converter topology are shown in Table. I.

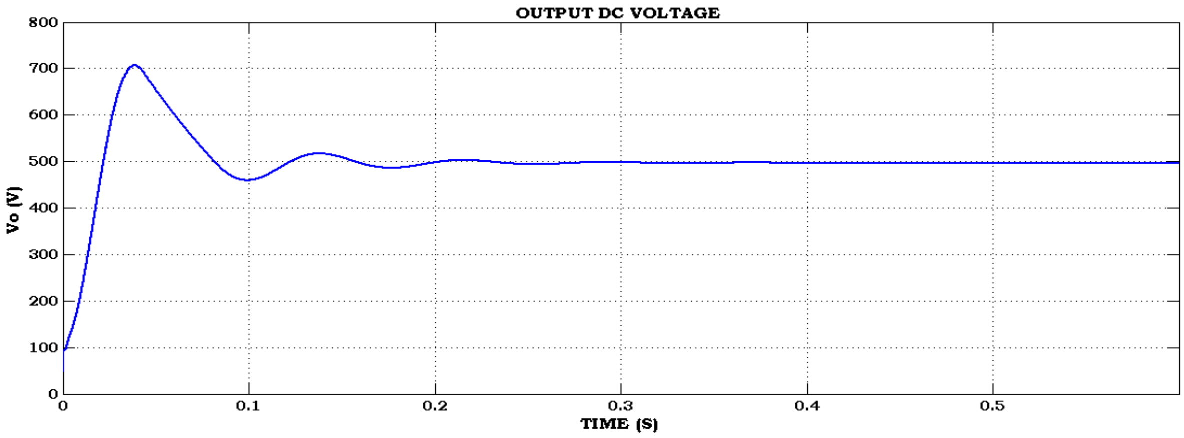
Table. I Design Specifications

S.No	Design Specifications	Values
1	DC Input Voltage	V_{in1}=65V
2	DC Output Voltage & Power	V_o=500V, P_o-1 KW
3	Switched Inductors	L_{a1}=L_{a2} =10 mH
4	Output & Boost Capacitor	C_o=15μF, C_b=470μF
5	Switching Frequency & Duty Ratio	F_s=50KHz, D-55%
6	Resistive Load	R_L=250Ω

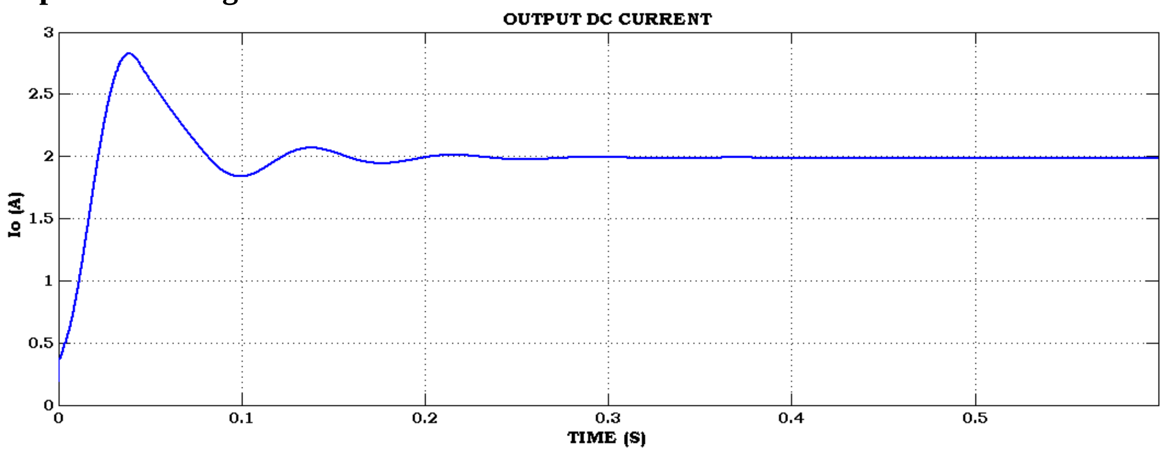
4.1 Performance of Proposed SI-MLUO Converter Topology



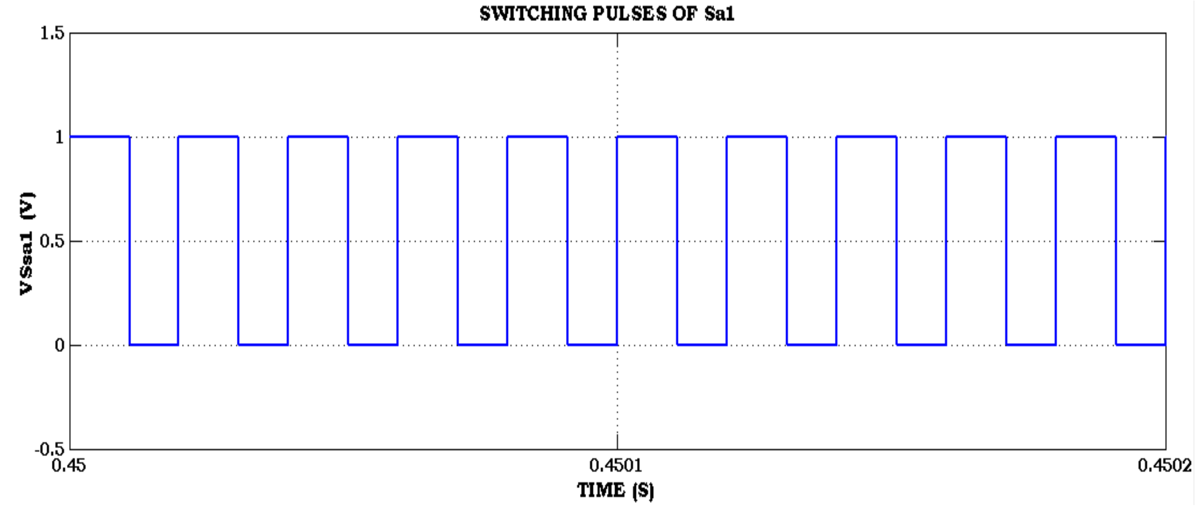
(a) Input DC Voltage



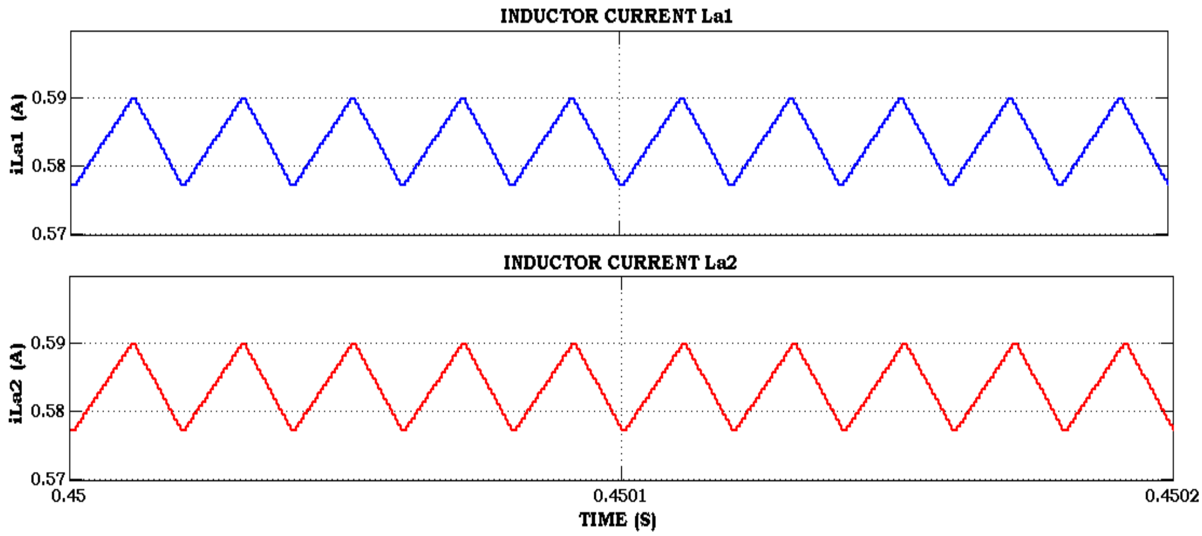
(b) Output DC Voltage



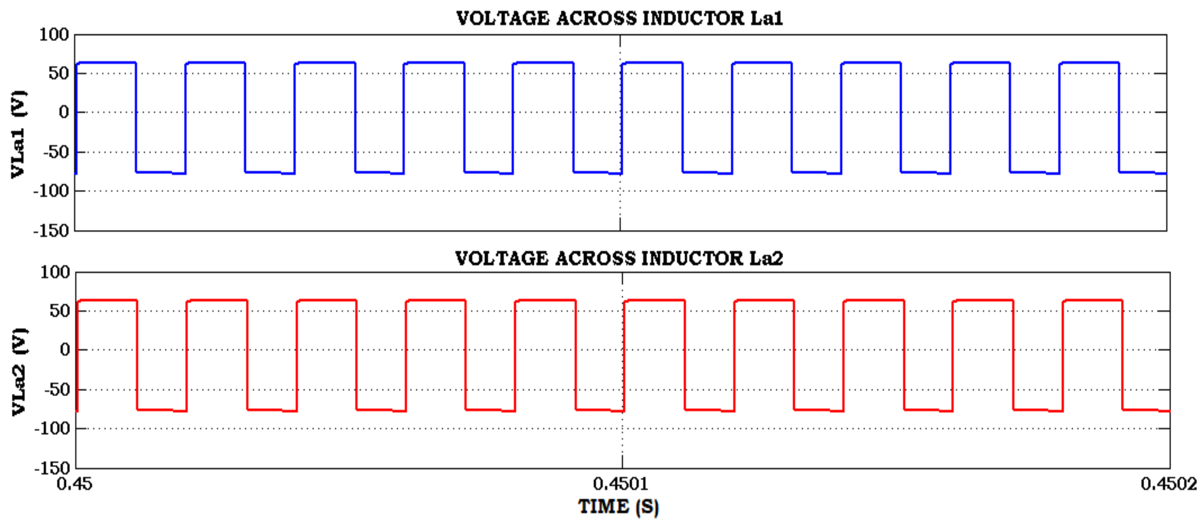
(c) Output DC Current



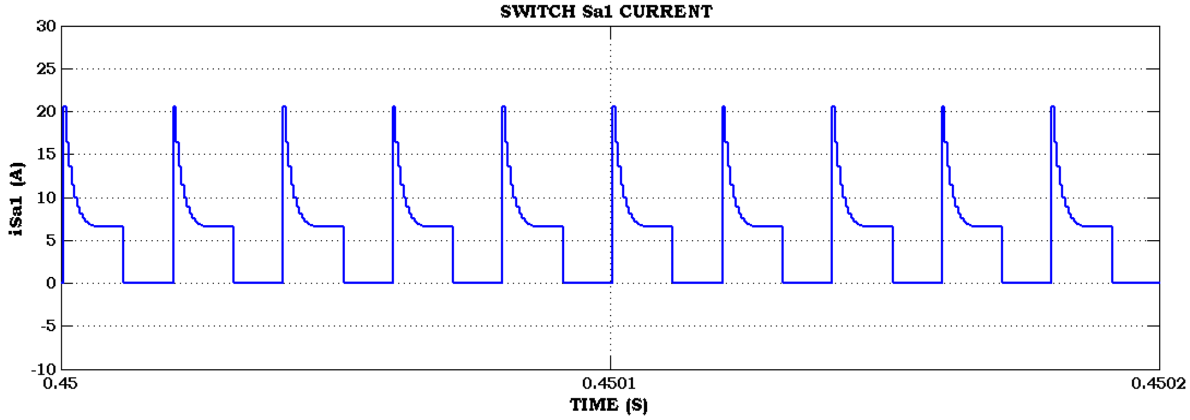
(d) Switching/ Gate Pulses of Switch S_{a1}



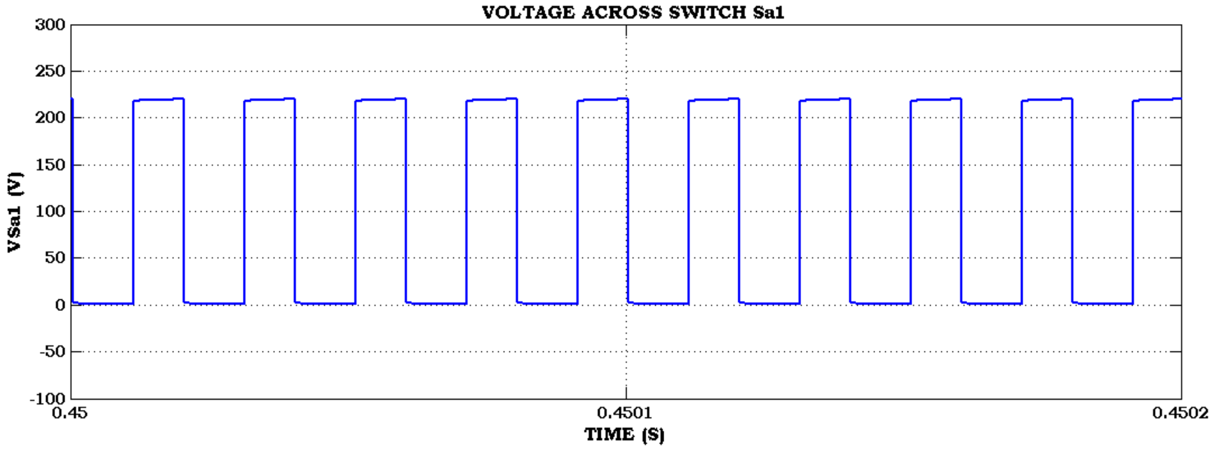
(e) Inductor Currents of L_{a1}, L_{a2}



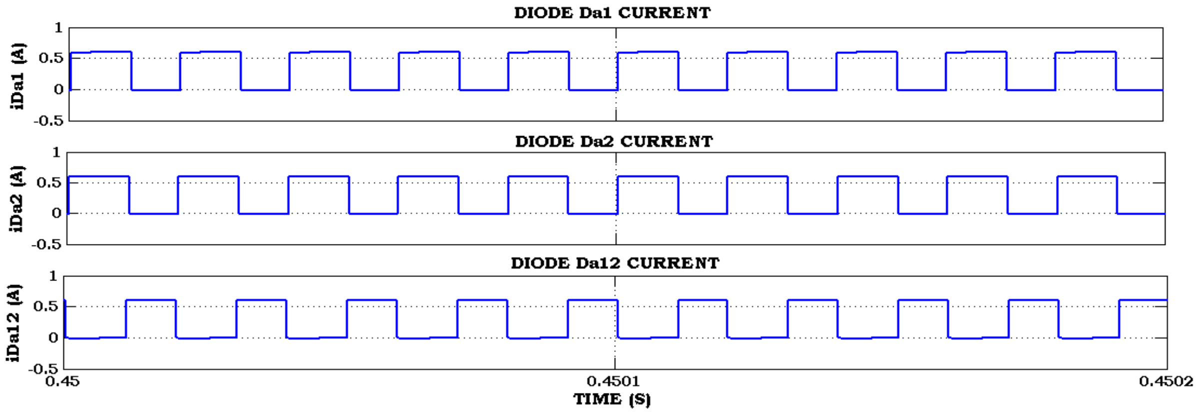
(f) Voltage across Inductors L_{a1}, L_{a2}



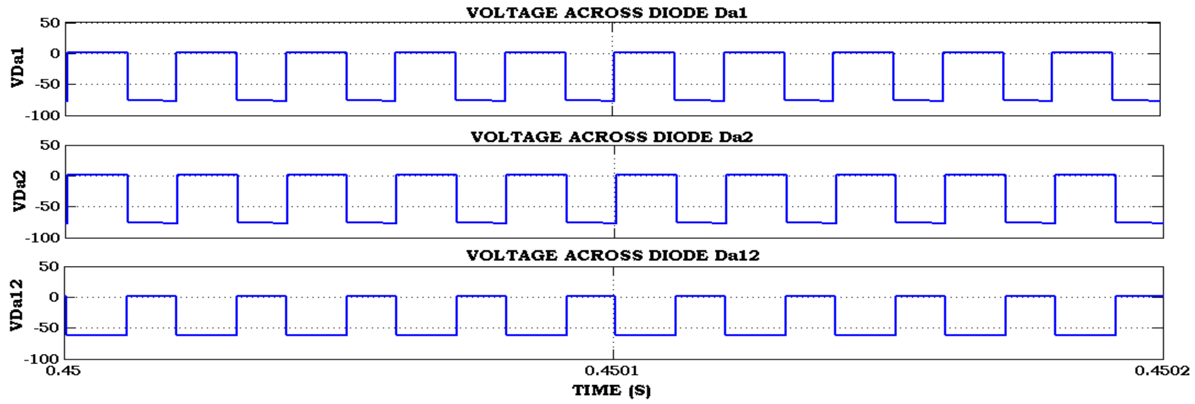
(g) Switch S_{a1} Current



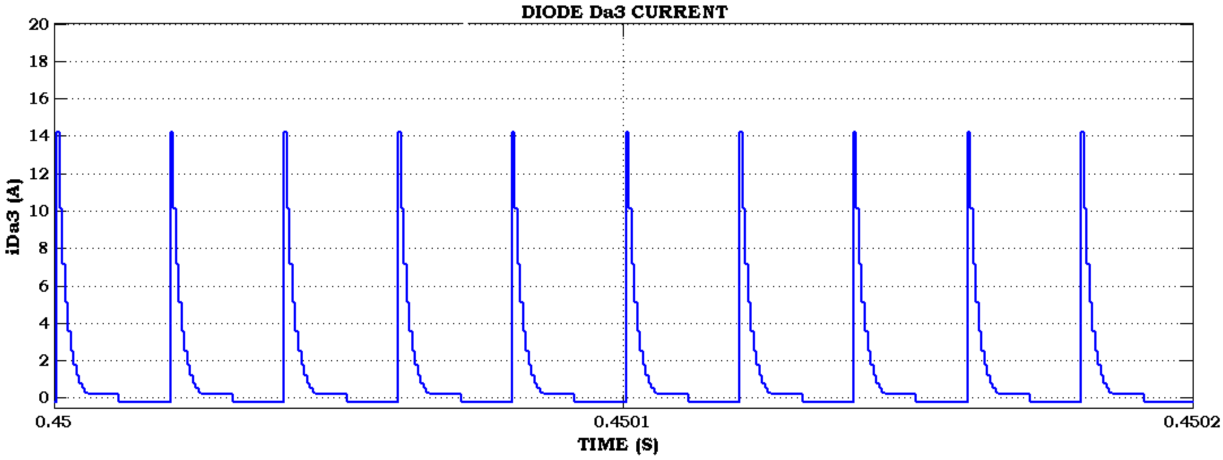
(h) Voltage across Switch S_{a1}



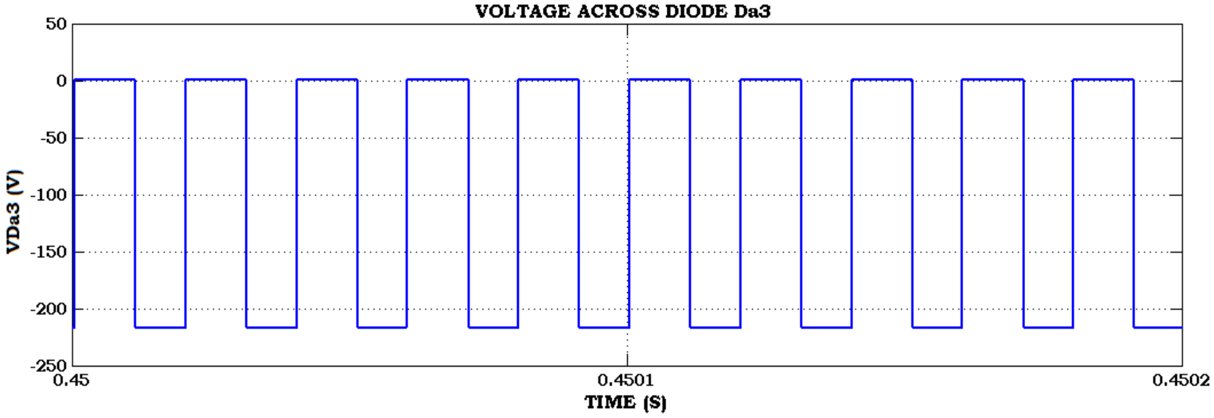
(i) Diode D_{a1}, D_{a2} and D_{a12} Currents



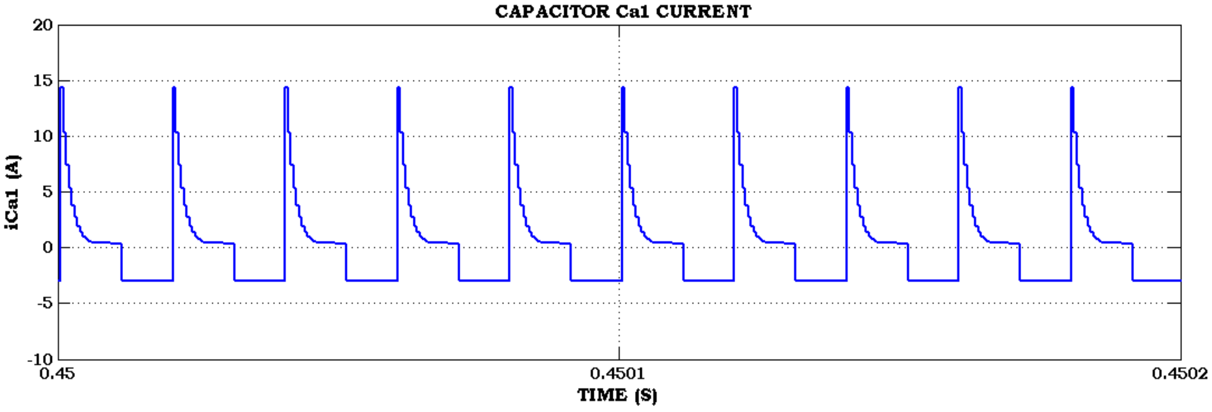
(j) Voltage across Diodes D_{a1}, D_{a2} and D_{a12}



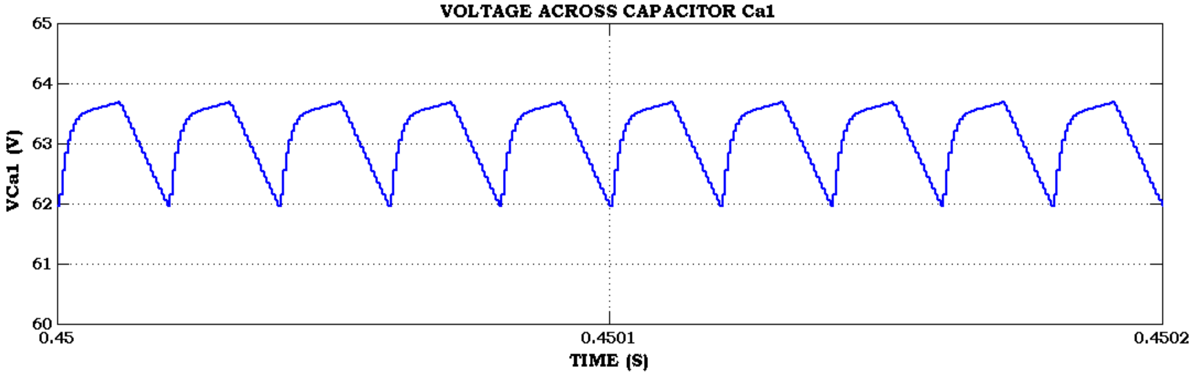
(k) Diode D_{a3} Current



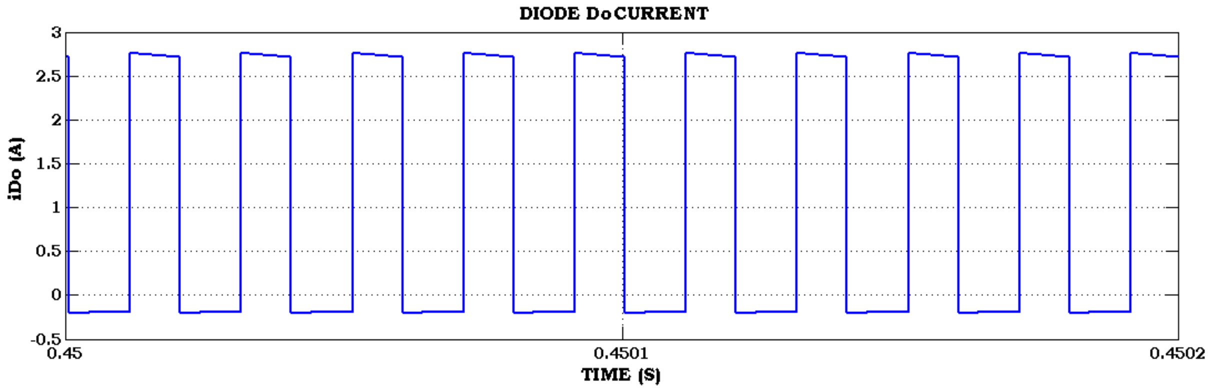
(l) Voltage across Diode D_{a3}



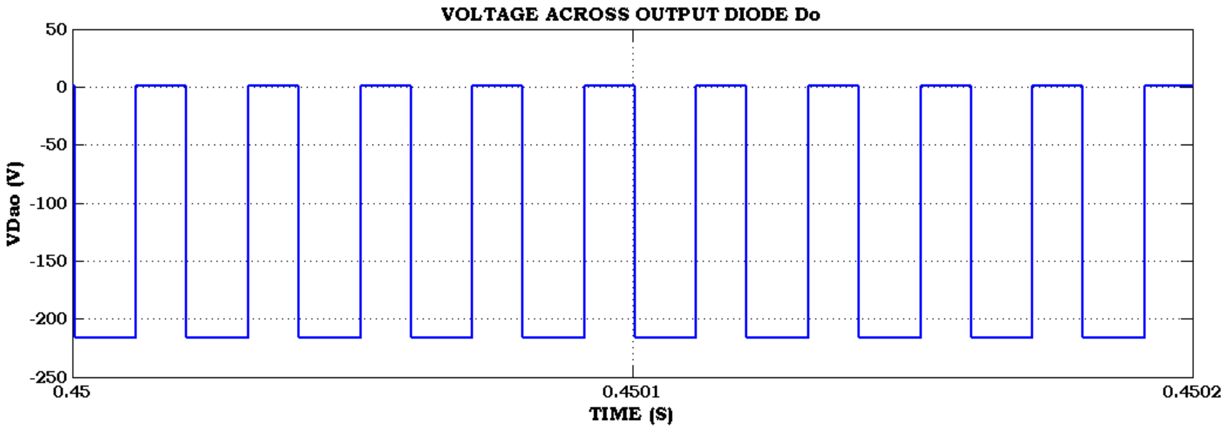
(m)Capacitor C_{a1} Current



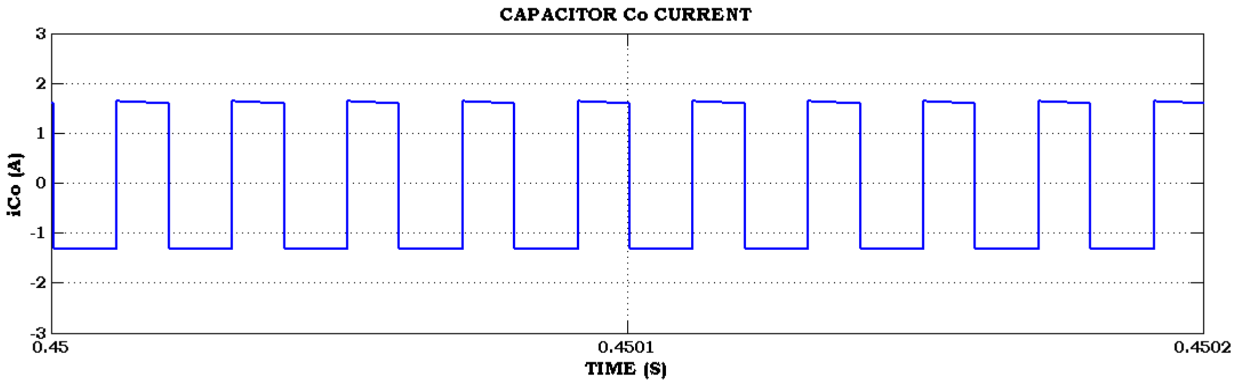
(n) Voltage across Capacitor C_{a1}



(o) Diode D_O Current



(p) Voltage across Diode D_O



(q) Capacitor C_O Current

Fig.8 Simulink Results of Proposed SI-MLUO Converter Topology

The simulation results for the proposed SI-MLUO converter architecture are displayed in Fig. 8. The proposed SI-MLUO converter architecture is powered by input DC voltage Vin1-65V to charge the switched inductors and achieve the requisite voltage at the load terminals, as shown in Fig. 8 (a). It provides the requisite load voltage of 500V and a load current of 2A to drive the resistive load, as seen in Figs. 8 (b), (c). The switching pulses of switch Sa1 are determined by a switching frequency of 50 KHz, as seen in Fig.8 (d). The switched-inductors La1, La2 of SI-Cell are charged by switching the switch Sa1 by gate-pulses, and then both inductors are charged linearly in a positive-slope area with a typical current iLa1, iLa2 of 0.59A and voltage across the inductor VLa1, VLa2 of 60A, as illustrated in Fig. 8 (e, f). In mode-I, the switch Sa1 is to be continued; the voltage that exists across the switch is zero, and the greatest possible current flow during Sa1 switch-on is 21A. Similarly, in mode-II, the switch Sa1 is not to be executed, resulting in zero current flow and some voltage across switch Sa1 during the OFF-state, i.e., 220V, as illustrated in Fig.8 (g), (h). In mode-I, the diodes Da1, Da2 are in forward bias and Da12 are in reverse bias, so the mean flow of current of the diodes throughout these modes is 0.55A, 0.55A, 0.6A, and some voltage appears across the diodes is -75A, -75A, and -60A, accordingly, as shown in Fig.8 (i), (j).

The diodes Da3 are forward biased in mode I and reverse biased in mode II, thus the average current flow through the diode throughout these modes is 14A and the voltage appeared across the diode is -220A, as shown in Fig.8 (k), (l). The boost capacitor Ca1 is in forward bias during mode-I and reverse bias in mode-II, therefore the average current flow through the capacitor throughout these modes is 14A, and the voltage across the diode is 64A, as shown in Fig.8 (m), (n). The diode DO is reverse-biased during mode-I and forward-biased during mode-II, therefore the average current flow through the output diode during these modes is 2.7A and the voltage appeared across the diode during these modes is -220V, as illustrated in Fig.8 (o), (p).

Furthermore, the highest current flow via the output capacitor during various working modes is 1.8A, as illustrated in Fig. 8 (q). Table II shows a comparison of voltage gain (MCCM) vs. duty ratio (D) in conventional and suggested SI-MLUO DC-DC boost converter topologies. The proposed SI-MLUO converter topology has a higher voltage gain than the different traditional basic and modified DC-DC converters. Table III shows a comparison of semiconductor devices and energy storage devices in standard and suggested SI-MLUO converter topologies. Compared to typical basic and modified DC-DC converters, the proposed SI-MLUO converter architecture requires fewer semiconductors and energy storage devices.

Table.II Comparison of Voltage Gain (M_{CCM}) vs. Duty ratio (D)

Type of Converter	**Voltage Gain (M_{CCM})**	**Duty Ratio (D)**								
		0.1	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
Basic LUO Converter [17]	$V_0 = \frac{D}{(1-D)} V_{in}$	0.11	0.25	0.42	0.66	1	1.5	2.33	4	9
Elementary Positive-Output LUO Converter [18]	$V_0 = \frac{D}{(1-D)} V_{in}$	0.11	0.25	0.42	0.66	1	1.5	2.33	4	9
Elementary Negative-Output LUO Converter	$V_0 = \frac{D}{(1-D)} V_{in}$	0.11	0.25	0.42	0.66	1	1.5	2.33	4	9

[19]										
Self-Lifting Positive-Output LUO Converter [20]	$V_0 = \frac{1}{(1-D)} V_{in}$	1.11	1.25	1.42	1.66	2	2.5	3.33	5	10
Self-Lifting Negative-Output LUO Converter [20]	$V_0 = \frac{1}{(1-D)} V_{in}$	1.11	1.25	1.42	1.66	2	2.5	3.33	5	10
Modified Re-lift Positive-Output LUO Converter [21]	$V_0 = \frac{2}{(1-D)} V_{in}$	2.22	2.5	2.85	3.33	4	5	6.66	10	20
Proposed SI-MLUO Converter	$V_0 = \frac{4-D}{(1-D)} V_{in}$	4.33	4.75	5.28	6	7	8.5	11	16	31

Table.III Comparison of Semiconductor Devices and Energy Storage Devices in Basic and Proposed SI-MLUO Converter Topologies

Converter Topology	**Output Gain**	**No. of Semi-Conductor Device**		**No. of Energy Storage Devices**	
		Diodes	**Switches**	**Capacitors**	**Inductors**
Basic LUO Converter [17]	$V_0 = \frac{D}{(1-D)} V_{in}$	1	1	2	2
Modified Re-lift Positive-Output LUO Converter [21]	$V_0 = \frac{2}{(1-D)} V_{in}$	5	1	4	3
Proposed SI-MLUO Converter	$V_0 = \frac{4-D}{(1-D)} V_{in}$	4	1	2	2

5. CONCLUSION

The current research advancement in high-boosting competency of basic and modified DC-DC converters is primarily driven by high-power handling capability, high-efficiency operation, cheap cost, low-complexity design, and dependable performance. In this approach, innovative DC-DC boost converters, frequently combining voltage-lifting methods, will emerge to improve the performance of solar-PV fueled water-pumping systems. This paper proposes a unique modified LUO converter based on switched-inductor cells, which is ideally suited for a solar-PV powered pumping system. The SI-MLUO is the most important converter architecture for converting high voltage gain at load terminals while using fewer switching devices and energy storage components. Compared to traditional basic and modified DC-DC converters described in the literature, the suggested SI-MLUO converter requires just one switch, four diodes, one SI cell, and two capacitors. The suggested SI-MLUO converter topology achieves roughly 8 times the gain voltage of the input DC voltage when run with a duty ratio of D-0.55, with a computed efficiency of 92.5%. Furthermore, the suggested SI-MLUO converter has been recognized for its benefits, including low leakage currents, low spikes, continuous input current, and so on.

References

[1]. *E. C. Carmo, V. C. Onofri and V. F. Mendes, "Analysis of water pumps start powered by diesel generator,"* 2018 Simposio Brasileiro de Sistemas Eletricos (SBSE), *2018, pp. 1-6, doi: 10.1109/SBSE.2018.8395779.*

[2]. *G. Zheng and Q. Huang, "Energy Optimization Study of Rural Deep Well Two-Stage Water Supply Pumping Station," in* IEEE Transactions on Control Systems Technology*, vol. 24, no. 4, pp. 1308-1316, July 2016, doi: 10.1109/TCST.2015.2498140.*

[3]. *B. S. Pali and S. Vadhera, "Renewable energy systems for generating electric power: A review,"* 2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*, 2016, pp. 1-6, doi: 10.1109/ICPEICES.2016.7853703.*

[4]. *P. Benalcázar, J. Lara and M. Samper, "Distributed Photovoltaic Generation in Ecuador: Economic Analysis and Incentives Mechanisms," in* IEEE Latin America Transactions*, vol. 18, no. 03, pp. 564-572, March 2020, doi: 10.1109/TLA.2020.9082728.*

[5]. *S. Pant and R. P. Saini, "Solar Water Pumping System Modelling and Analysis using MATLAB/Simulink,"* 2020 IEEE Students Conference on Engineering & Systems (SCES)*, 2020, pp. 1-6, doi: 10.1109/SCES50439.2020.9236716.*

[6]. *M. Forouzesh, Y. P. Siwakoti, S. A. Gorji, F. Blaabjerg and B. Lehman, "Step-Up DC–DC Converters: A Comprehensive Review of Voltage-Boosting Techniques, Topologies, and Applications," in* IEEE Transactions on Power Electronics*, vol. 32, no. 12, pp. 9143-9178, Dec. 2017, doi: 10.1109/TPEL.2017.2652318.*

[7]. *N. Swaminathan and Y. Cao, "An Overview of High-Conversion High-Voltage DC–DC Converters for Electrified Aviation Power Distribution System," in* IEEE Transactions on Transportation Electrification*, vol. 6, no. 4, pp. 1740-1754, Dec. 2020, doi: 10.1109/TTE.2020.3009152.*

[8]. *Deepak, R. K. Pachauri and Y. K. Chauhan, "Modeling and simulation analysis of PV fed Cuk, Sepic, Zeta and Luo DC-DC converter,"* 2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*, Delhi, India, 2016, pp. 1-6, doi: 10.1109/ICPEICES.2016.7853596.*

[9]. *A. Sweatha, B. Baskaran and P. Duraipandy, "An Extensive Review of DC-DC Converter Topologies for Water-Pumping Application,"* 2022 International Conference on Innovations in Science and Technology for Sustainable Development (ICISTSD)*, Kollam, India, 2022, pp. 151-156, doi: 10.1109/ICISTSD55159.2022.10010591.*

[10]. *K. V. Krishna Varma, A. Ramkumar and K. Rajesh, "Grid Integrated Eco-Friendly Pumping System for Active PFC Using Interleaved Boost Converter (IBC) Topology,"* 2019 IEEE International Conference on Clean Energy and Energy Efficient Electronics Circuit for Sustainable Development (INCCES)*, 2019, pp. 1-9, doi: 10.1109/INCCES47820.2019.9167711.*

[11]. *Jalla Upendar, Sangem Ravi Kumar, Sapavath Sreenu, Bogimi Sirisha, "Implementation and study of fuzzy based KY boost converter for electric vehicle charging", International Journal of Applied Power Engineering (IJAPE), Vol. 11, No. 1, March 2022, pp. 98-108, doi: 10.11591/ijape.v11.i1.pp98-108*

[12]. *Asapu Siva, Vanitha Rajendran, "A novel auxiliary unit based high gain DC-DC converter for solar PV system with MPPT control", International Journal of Power Electronics and Drive Systems (IJPEDS), Vol. 13, No. 4, December 2022, pp. 2386~2395, DOI: 10.11591/ijpeds.v13.i4.pp2386-2395*

[13]. *A. Sanam, L. S. Rao, R. Kommineni, S. Shaik, V. Regulagadda and G. s. Doddi, "A Solar-PV/BESS Powered Multi-Input DC-DC Boost Converter Fed BLDC Motor Drive," 2022 International Conference on Intelligent Controller and Computing for Smart Power (ICICCSP), Hyderabad, India, 2022, pp. 1-6, doi: 10.1109/ICICCSP53532.2022.*

[14]. *M. Meraj, M. S. Bhaskar, A. Iqbal, N. Al-Emadi and S. Rahman, "Interleaved Multilevel Boost Converter With Minimal Voltage Multiplier Components for High-Voltage Step-Up Applications," in* IEEE Transactions on Power Electronics*, vol. 35, no. 12, pp. 12816-12833, Dec. 2020, doi: 10.1109/TPEL.2020.2992602.*

[15]. *R. Abid, F. Masmoudi and N. Derbel, "Comparative study of the performances of the DC/DC luo-converter in photovoltaic applications,"* 2017 International Conference on Smart, Monitored and Controlled Cities (SM2C)*, 2017, pp. 117-122, doi: 10.1109/SM2C.2017.8071831.*

[16]. *K. Deepa, M. F. Baig, P. Mohith and A. V. Abhinav, "Dynamic analysis of LUO converter with all parasitics,"* 2017 International Conference on Trends in Electronics and Informatics (ICEI)*, 2017, pp. 1024-1028, doi: 10.1109/ICOEI.2017.8300862.*

[17]. *P. Anbarasan, M. Venmathi, M. Vijayaragavan and V. Krishnakumar, "Performance Enhancement of Grid Integrated Photovoltaic System Using Luo Converter," in* IEEE Canadian Journal of Electrical and Computer Engineering*, vol. 45, no. 3, pp. 293-302, Summer 2022, doi: 10.1109/ICJECE.2022.3178696.*

[18]. *C. Pansare, S. K. Sharma, C. Jain and R. Saxena, "Analysis of a modified positive output Luo converter and its application to solar PV system,"* 2017 IEEE Industry Applications Society Annual Meeting*, 2017, pp. 1-6, doi: 10.1109/IAS.2017.8101849.*

[19]. *Sapavath Sreenu, Jalla Upendar, Bogimi Sirisha, "Analysis of switched impedance source/quasi-impedance source DC-DC converters for photovoltaic system", International Journal of Applied Power Engineering (IJAPE), Vol. 11, No. 1, March 2022, pp. 14-24, doi:10.11591/ijape.v11.i1.pp14-24*

[20]. *Edara Sreelatha, AlagappanPandian, Mohana Sundaram Kuppusamy, "A novel topology for single-inductor single input triple output DC-DC power converter", International Journal of Power Electronics and Drive Systems(IJPEDS), Vol. 14, No. 1, March 2023, pp. 304-310, doi:10.11591/ijpeds.v14.i1.pp304-310*

[21]. *J. D. Navamani, A. Geetha, D. Almakhles, A. Lavanya and J. S. M. Ali, "Modified LUO High Gain DC-DC Converter With Minimal Capacitor Stress for Electric Vehicle Application," in* IEEE Access*, vol. 9, pp. 122335-122350, 2021, doi: 10.1109/ACCESS.2021.3109273.*