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A Comprehensive Research Review of LUO Type DC-DC Boost Converters for Water-Pumping Application

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Abstract : The fundamental DC-DC boost converter has the drawbacks of low voltage gain ratio followed by discontinuous output current. May the reverse recovery problem rises as a disaster for the output diode along with harming the power switch. Also the stress of voltage is significantly high in respect with the output voltage. Therefore, a new topology of high gain non-isolated DC-DC boost converter is proposed in this paper. A unique framework of DC-DC boost converters with efficient operation, reliable performance, high boost competency, continuous input current is regarded as modified DC-DC boost converters for solar-PV fed water-pumping system. In this work, a comprehensive review on basic LUO and modified LUO DC-DC boost converters are presented with operating features and voltage-boosting methods. Finally, the comprehensive review of basic and modified LUO dc-dc boost converters and its operating features are presented.

Index Terms* - *DC-DC Boost Converters, LUO Converter, Modified LUO Converters, Solar-PV System, Water Pumping Application

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I. INTRODUCTION

Water resources are essential for humankind since they are used for drinking, irrigation, and the production of healthy food. Water has become more important than ever before as population expansion has raised the need for it. In recent days, the source of energy for raising water from rivers, canals, and ponds has become increasingly important. Traditionally, water lifting or pumping systems have been driven by fossil fuels such as diesel, petrol and kerosene [1], which raise CO2 emissions, fuel costs, environmental impact, and low operational efficiency, among other things.

Renewable Energy Sources (RES) are actively pursuing social-economic and sustainable development across the world. Solar-Photovoltaics are the most viable and suggested form of energy generation locally when the utility-grid is missing. In this situation, solar-PV energy driven pumping systems are more cost effective, environmentally benign, have no fuel costs, and may create 25% to 40% more power than standard diesel-powered pumping systems [2]-[4].

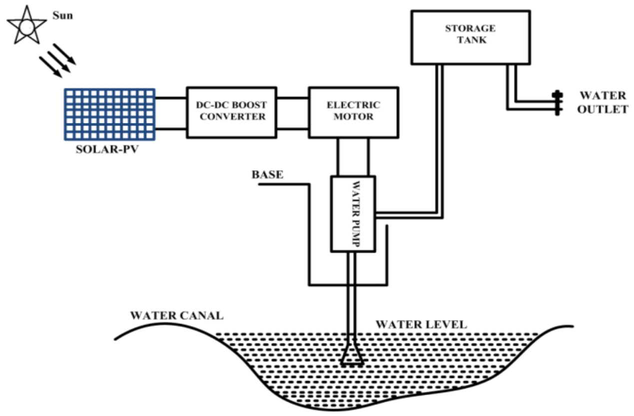


Fig.1 Block Diagram of Solar-PV Fed Water Pumping System

The block diagram of solar-PV fed water pumping system is depicted in Fig.1. The solar-PV powered pumping systems require feasible power-electronic converters for converting the available solar-PV energy into high-voltage DC output to drive the electric motor [5]. The advances in power converters easing the conditioning, conversion and controlling the output voltage with definite characteristics to drive the any load apparatus. In this regard, a DC-DC converter is most significant device in solar-PV powered pumping system for delivering distinct output voltage [6].

The DC-DC converter transforms the low DC voltage into high DC output voltage by storing the energy temporarily and delivered to load terminals with boost competency. Such type of energy storage can occurs either in capacitors or inductors by switching the MOSFET switches in a certain switching sequence. The high-voltage boost competency [7] is enabled by using switched inductors can function either in Dis-Continuous Conduction Mode (DCM) or Continuous Conduction Mode (CCM) operating conditions. In fact, the operation of converter in CCM is more significant owing to attain high voltage gain at load terminals with low current ripples. For attaining high boost competency, coupled inductors and/or high-frequency transformers can be employed but it needs massive windings, high leakage inductance, complex structure leads to more dv/dt stress, etc. In this work, various basic and modified LUO type DC-DC converters are reviewed to obtain high-boosting capability with low switching elements, reliable operation and non-presence of high-frequency transformers and coupled inductors for developing significant solar-PV powered pumping system.

II. Various LUO Type Family Converters

A DC-DC boost converter is a power-electronic converter that transforms unregulated low DC voltage at load terminals into regulated high DC voltage with unique voltage gain. In general, basic DC-DC boost converters are divided into switched and linear types; linear type converters are less expensive, more widespread, and suitable for low-power applications. Switched type converters are noticeable, simple, and capable of handling high power applications. In reality, these switched converters are classified into two types: isolated and non-isolated DC-DC converters [8].

The isolated type DC-DC converters come up with vibrant dielectric isolation and no electrical contact between the input ports to output ports. The ports of this isolated DC-DC converters are linked with coupled inductors or high-frequency transformers with equal or un-equal turn ratios. It comprises of high insulation barrier between the ports and can be developed as negative or positive output at load terminals [9], [10]. On other side, the non-isolated type DC-DC converters come up with no dielectric isolation between front-end and output terminals or ports. It have electrical contact between the ports like regular DC-DC converters and highly suggested for several applications like standalone systems, grid connected systems, electric-vehicles, traction and aircraft, so on.

The non-isolated type DC-DC converters are more efficient and complex circuit design [11], [12]. But, non-isolated type converters are low-weighted and low size compared to isolated type converters because non-presence of transformer. Some of the familiar non-isolated type converters are boost, buck-boost, buck, CUK, SEPIC, LUO, etc. But, the basic converters are not suitable due to operate in high duty ratios for obtaining boost voltage. In recent days, several DC-DC converter topologies are explored to obtain high-voltage gain by modifying the design of basic DC-DC converter topology either including the sub-module cell or voltage multiplying circuits. In this way, a comprehensive study on basic and modified LUO family DC-DC boost converters are presented and recognized for water-pumping system.

The LUO is the non-isolated type converter [13], [14]; it performs boost operations and converts low voltage DC into high voltage DC at output terminals functioned very effectively with simple circuit design compared to other basic DC-DC converters. It consists of two inductors L_{s1}, L_{s2}, one diode D_1, two capacitors C_{s1}, C_{s2} and single MOSFET switch S_{s1} to drive the resistive R-load R_{s1}, respectively. The schematic diagram of basic LUO DC-DC converter is shown in Fig.2. The voltage-lifting technique is the most significant way to enhance the circuit features.

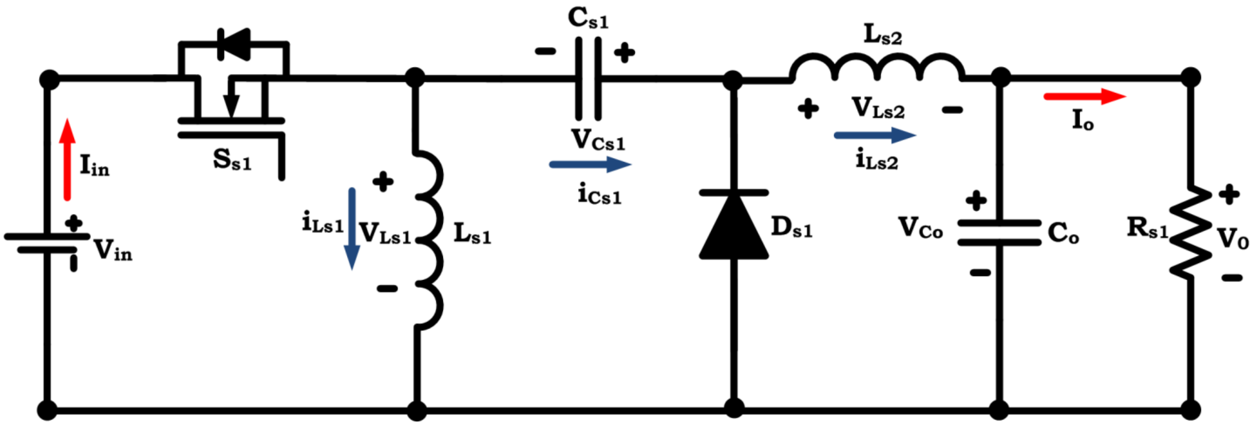
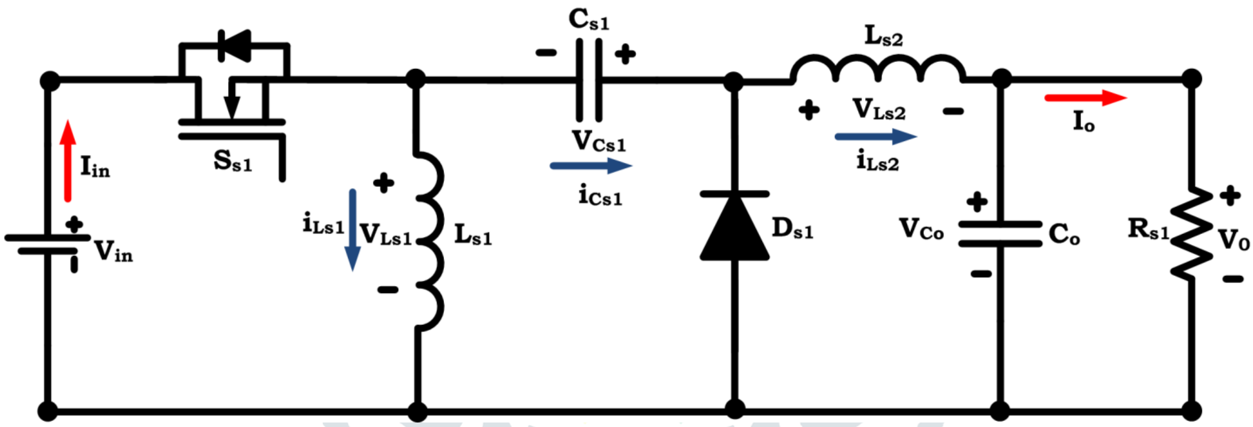
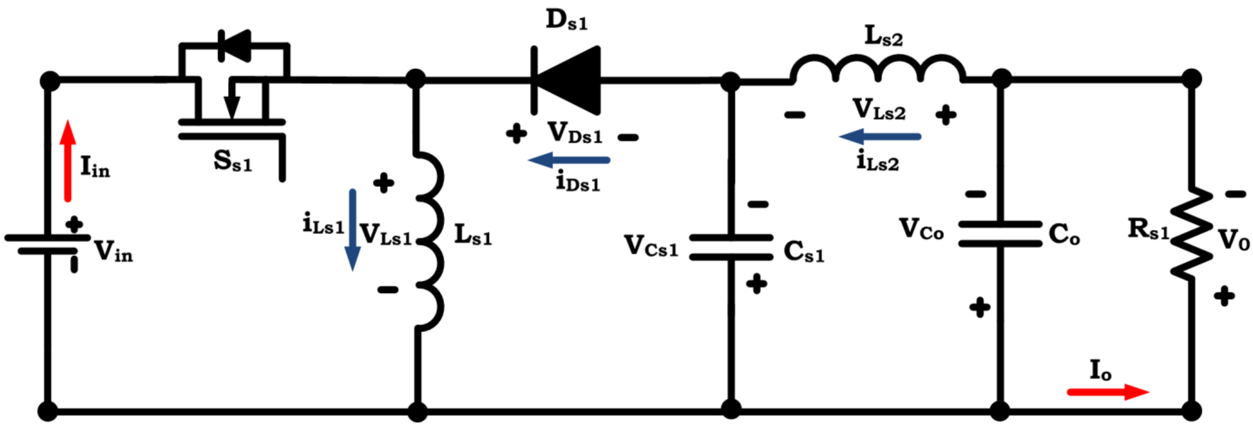


Fig.2 Schematic Diagram of Basic LUO Converter

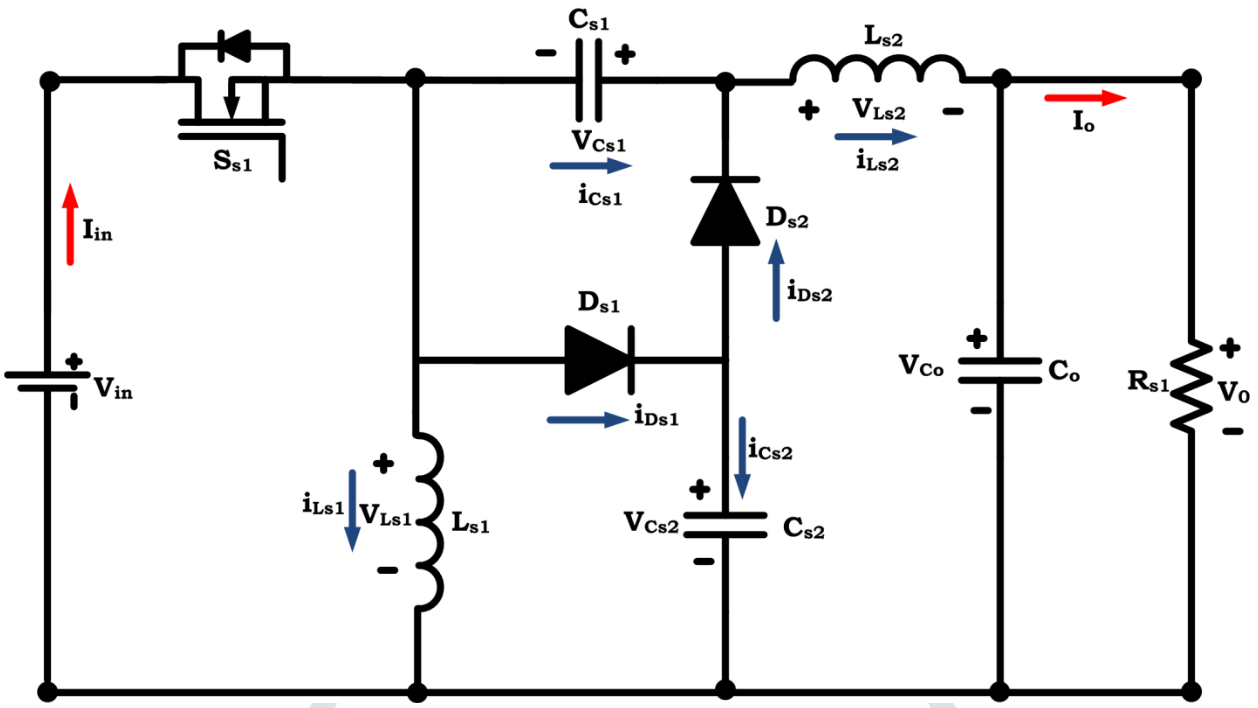
These are the series of novel boost converter topologies, developed based on various circuit configurations for obtaining low ripple content and high voltage gain in both current and voltage wave shapes. Some of the voltage-lifting circuits are elementary positive-output and negative-output LUO converter topologies, self-lift positive-output and negative-output LUO converter topologies are presented in [15], [16]. These lifting converters furnish the high voltage gain with low ripple content along with greater power density, simple structure and high efficiency. These voltage lifting converters are broadly used in switched-mode circuits, mid-range industrial and domestic applications. The schematic diagram of various voltage-lifting LUO DC-DC boost converters is shown in Fig.3. The modified self-lift positive-output LUO converter is developed based on combination of elementary and self-lift PO-LUO converter topologies for obtaining high voltage gain [17]. This modified LUO converter utilizes the combination of capacitors and inductors to lift the high voltage DC from low input DC voltage obtained as doubled voltage gain.



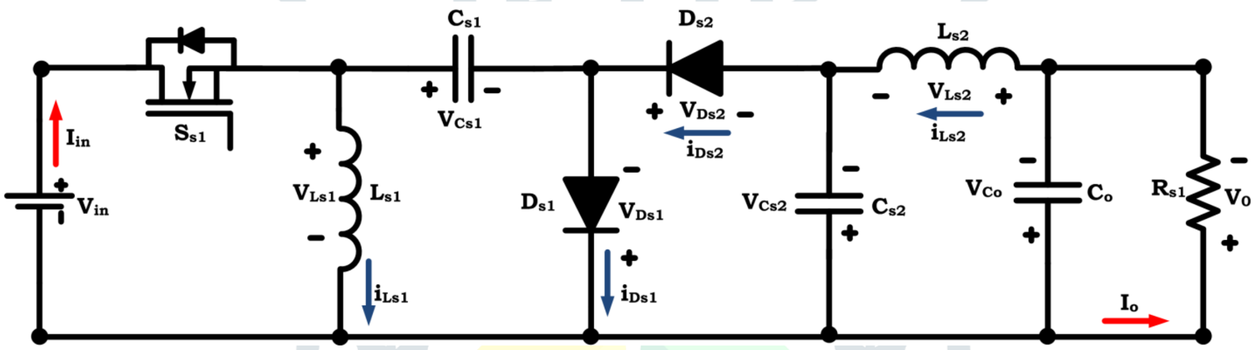
(a) Elementary Positive-Output LUO Converter



(b) Elementary Negative-Output LUO Converter



(c) Self-Lifting Positive-Output LUO Converter



(d) Self-Lifting Negative-Output LUO Converter

Fig.3 Schematic Diagram of Various Voltage-Lifting LUO DC-DC Boost Converters

The key advantages of modified-LUO converter is double-voltage gain with low duty ratio's, low voltage and current ripples, low dv/dt stress and EMI loss, high efficiency. The main module consists of single inductor L_0, single diode D_{s5}, two capacitors C_{s3}, C_o and single MOSFET switch S_{s1} to drive the resistive R-load R_{s1}, respectively. The voltage-lifting module consists of two inductors L_{s1}, L_{s2}, four diodes D_{s1}, D_{s2}, D_{s3}, D_{s4} and two capacitors C_{s1}, C_{s2}, respectively. The operating modes and steady-state analysis of modified-re-lift positive-output LUO DC-DC converter is presented in [18]. The schematic diagram of modified re-lift positive-output LUO DC-DC boost converter is shown in Fig.8. The comprehensive summary of basic and modified dc-dc boost converters is illustrated in Table. 1. The voltage gain (M_{CCM}) vs. Duty ratio (D) comparison of basic and modified DC-DC boost converters is illustrated in Table.2. Among various LUO type converters, the modified re-lift positive-output LUO converter obtains high voltage gain with high power-handling capability, reliable performance and also more efficient performance over the various basic and modified DC-DC boost converters. It does not require any coupled inductors and high-frequency transformers for obtaining doubled-voltage gain. But it requires more switching devices and passive elements for boosting the high-voltage at load terminals. To overcome these issues, a novel modified mega-lift LUO converter has been proposed in future by using reduced-switching devices with triple or high voltage gain.

Table.1 Comprehensive Summary of Basic and Modified DC-DC Boost Converters

Converter Topology	Output Gain	No. of Semi-Conductors		No. of Passive Devices		Features
		Switches	Diodes	Inductors	Capacitors	
Basic LUO Converter [13]	$V_0 = \frac{D}{(1-D)} V_{in}$	1	1	2	2	• Simple Boosting Circuit • Fast response • High boost capability with voltage-lifting techniques • Low current ripples
Elementary Positive-Output LUO Converter [14]	$V_0 = \frac{D}{(1-D)} V_{in}$	1	1	2	2	• Wide Operation range • Simple Circuit design • High efficiency

						• Low current ripples
Elementary Negative-Output LUO Converter [15]	$V_0 = \frac{D}{(1-D)} V_{in}$	1	1	2	2	• Inverted output voltage • High boost capability
Self-Lifting Positive-Output LUO Converter [16]	$V_0 = \frac{1}{(1-D)} V_{in}$	1	2	2	3	• Non-inverted output voltage • High boosting competency • Low duty ratio • High efficiency
Self-Lifting Negative-Output LUO Converter [17]	$V_0 = \frac{1}{(1-D)} V_{in}$	1	2	2	3	• Inverted output voltage • High boosting competency • Suitable for high voltage and current applications
Modified Re-lift Positive-Output LUO Converter [18]	$V_0 = \frac{2}{(1-D)} V_{in}$	1	5	3	4	• Doubled voltage gain • Non-inverted output voltage • High power-handling capability • Easy to integrate • Boosting the very low input voltage

Table.2 Voltage Gain (M_{CCM}) vs. Duty ratio (D) Comparison of Basic and Modified DC-DC Boost Converters

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 [13]	$V_0 = \frac{D}{(1-D)} V_{in}$	0.11	0.25	0.42	0.66	1	1.5	2.33	4	9
Elementary Positive-Output LUO Converter [14]	$V_0 = \frac{D}{(1-D)} V_{in}$	0.11	0.25	0.42	0.66	1	1.5	2.33	4	9
Elementary Negative-Output LUO Converter [15]	$V_0 = \frac{D}{(1-D)} V_{in}$	0.11	0.25	0.42	0.66	1	1.5	2.33	4	9
Self-Lifting Positive-Output LUO Converter [16]	$V_0 = \frac{1}{(1-D)} V_{in}$	1.11	1.25	1.42	1.66	2	2.5	3.33	5	10
Self-Lifting Negative-Output LUO Converter [17]	$V_0 = \frac{1}{(1-D)} V_{in}$	1.11	1.25	1.42	1.66	2	2.5	3.33	5	10
Modified Re-lift Positive-Output LUO Converter [18]	$V_0 = \frac{2}{(1-D)} V_{in}$	2.22	2.5	2.85	3.33	4	5	6.66	10	20

III. Conclusion

The current research advancement in high-boosting competency of basic and modified LUO DC-DC converters is driven by important primary factors such as high-power handling capability, high-efficiency operation, cheap cost, low complexity design, and dependable performance. This perspective aids in the speedy selection of a LUO DC-DC boost converter for water-pumping applications with unique choices. Every boost converter has distinct characteristics, and a single DC-DC converter is adequate for all applications. As a result, innovative basic and modified LUO DC-DC boost converters, frequently combining voltage-lifting methods, will emerge to improve the performance of solar-PV powered water-pumping applications.

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