Development of Solar Dc Home System using Modified LUO Converter

Saradha Devi R, Mrudhulaa P. V, Priyadharshini K, Seyezhai R, Mrudula Vempati

Abstract: ***Photovoltaic energy generation is considered to be one of the most promising sources of renewable green energy because it is clean, inexhaustible and requires less maintenance. However, the efficiency and gain obtained from PV systems are not satisfactory. The output of a single PV cell is about 0.6V and hence high gain dc-dc converters are required to step up the voltage. Solar energy for off-grid power sources is preferred to be the best solution for rural households, which don't have an uninterrupted power supply, across India. PV power generation for DC appliances will prove to be beneficial as the DC-AC conversion is eliminated. This paper discusses three topologies of DC-DC converters that act as an interface between PV and the load. The topologies investigated in this paper include Boost, Luo, and Luo-buck converters. The configuration of these converters is studied and simulated in MATLAB/SIMULINK. The operative parameters such as conversion gain, output voltage ripple, output current ripple, stress across the semiconductor devices and input current ripple are computed and the results are compared. From the results, it is found that the Luo-Buck DC-DC converter results in better performance compared to the other two topologies. The theoretical results are verified in simulation.***

Keywords: PV; Boost, Luo; Luo-Buck; DC-DC Converters; Ripple; Stress.

I. INTRODUCTION

Clean and ceaseless electrical energy is the most vital and indispensable requirement of mankind in daily life. Today, many of the energy conversion systems are dependent on fuel reserves. In recent years, due to the increase in world's population, there is a rapid decline in fuel reserves. Moreover, their negative impact caused by those conventional fuels to our environment has increased the demand for using alternate sources of energy. This situation has driven us to make use of an efficient and environmental-friendly source of energy. Nowadays, the focus has shifted to optimizing the usage of solar PV panels to achieve higher efficiency.

Manuscript published on 30 October 2018.
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Significant developments have also been achieved in studies conducted in the field of dissemination of renewable energy sources over the last two decades. Since most of the consumer loads and storage elements use DC supply, DC-DC converters are highly being used. In this paper, three different converters i.e., Boost Converter, Luo Converter and Luo-Buck Converters have been studied independently for PV applications. In the case of boost converters, the output voltage that is higher than input voltage can be obtained and the input current is continuous which means it is easy to filter and meet electromagnetic interference requirements. The disadvantage with this converter is that a large output capacitor is required to reduce ripple voltage as the output current is pulsating and moreover, the converters cannot be operated at extreme duty ratios to achieve a higher gain. The Luo converters perform DC-DC increasing conversion with high power density, high efficiency, and cheap topology when compared to boost converters. But the limitation with this converter is that the output current obtained is very less, which makes the Luo converter inefficient. In order to improve its performance, a buck converter is coupled with it. Hence the Luo-buck combined topology will improve the necessary parameters which make the conventional Luo converter efficient.

The objective of the paper is to propose a suitable DC-DC converter for output voltage ripple reduction along with high current in PV applications. Simulation studies of the above-mentioned topologies are carried out in MATLAB SIMULINK. Thus, it can be stated that the Luo-Buck converter is most preferably used in solar DC home applications. The required topology is thus chosen and interfaced with the solar panel and the results are verified.

II. TOPOLOGIES OF DC-DC CONVERTERS

A circuit that converts one level of the Direct current source to another level is called DC-DC Converter. These converters mainly deal with controlling the average output voltage to the desired voltage value. Some of the applications of DC-DC converters include laptop computers, switched mode regulators and cellular phones. The different topologies of DC-DC converters are discussed below and their output current and output voltage ripples are calculated.

2.1. Boost Converter

A boost converter is a conventional DC-DC converter that gives an output voltage that is greater than the input voltage. It employs an inductor, a capacitor and a MOSFET switch along with a freewheeling diode. There are two modes of operation, i.e. when the switch is closed and when the switch is open.

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The boosting of voltage happens due to the inductor being charged when the switch is closed. When the switch is open, the voltage across the load will be the sum of the source voltage and the voltage across the inductor. The level of boost is determined by the duty cycle, D.

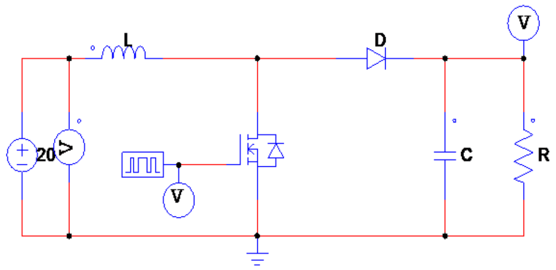

Fig. 1 Circuit Diagram of a Boost Converter

The converter operates in two modes of operation [1]

Mode 1 operation: When switch S is closed, the inductor gets charged due to the input voltage and stores the energy. The circuit diagram of mode 1 operation is shown in Fig.2. In this mode inductor current increase linearly. The diode blocks the current flowing and therefore the load current remains constant which is being supplied due to the discharging of the capacitor.

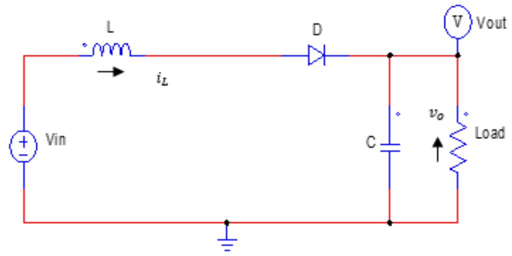

Fig. 2. Mode 1. Operation of the Boost Converter

Mode 2 operation: When the switch S is open, the diode becomes forward biased. The circuit diagram of mode 1 operation is shown in Fig.3.The energy stored in the inductor changes its polarity to discharge through the diode and charge through the capacitor. Now, the capacitor supplies voltage to load. The load current remains constant throughout the operation.

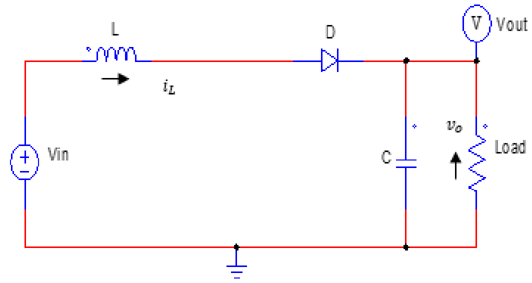

Fig 3. Mode 2. Operation of the Boost Converter

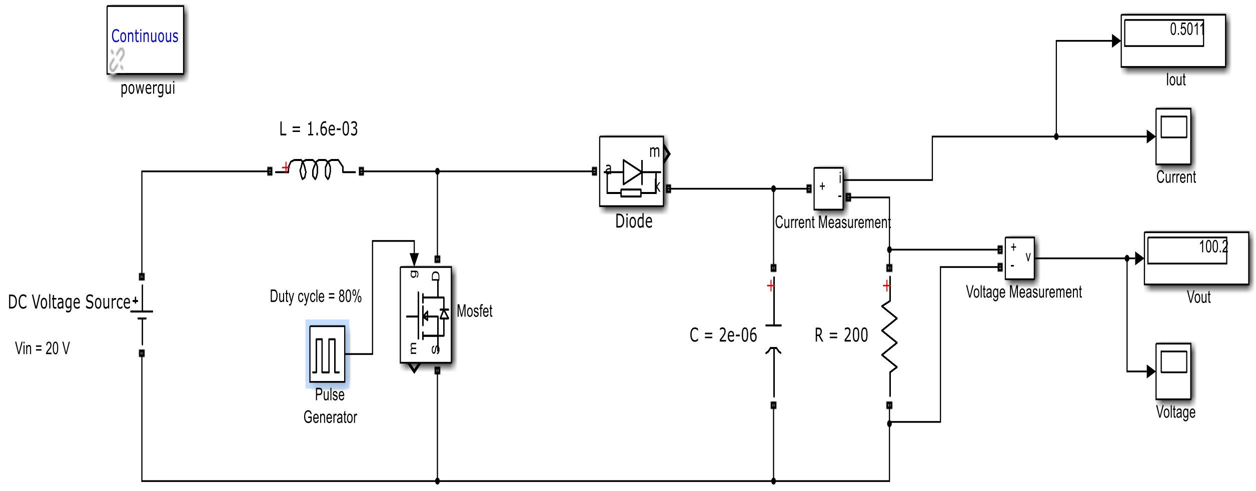

Fig 4. Simulation of the Boost Converter

Design equations:

The output voltage as a function of the duty cycle and the input voltage is given by,

$$V_{out} = V_{in} * \frac{1}{1-D} \text{ V} \qquad (1)$$

Where D is the duty cycle, V_{in} is the input voltage and V_{out} is the output voltage.

The capacitance C is given by the formula,

$$C = \frac{(I_o * D)}{f \Delta V_{out}} \text{ Farad} \qquad (2)$$

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Where I_o is the output current and

ΔV_{out} is the output voltage ripple The inductance L is given by

$$L = \frac{(V_{in} * D)}{f\ \Delta I_o}\ \text{Henry} \qquad (3)$$

Where ΔI_o is the inductor ripple current and f-switching frequency

Table 1. The Design Specification for a Boost Converter

PARAMETERS	VALUES
Input voltage	20 V
Duty cycle	80%
Inductor	1.6 mH
Capacitor	2 µF
Resistive load	200 Ω
Switching frequency	50kHz

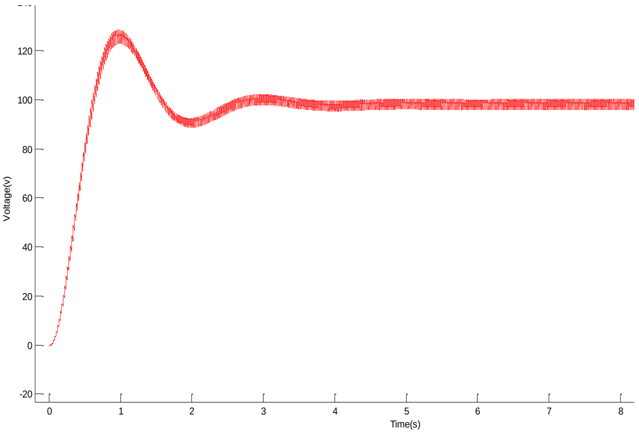

Fig. 5 Simulation Waveform of the Output Voltage of the Boost converter

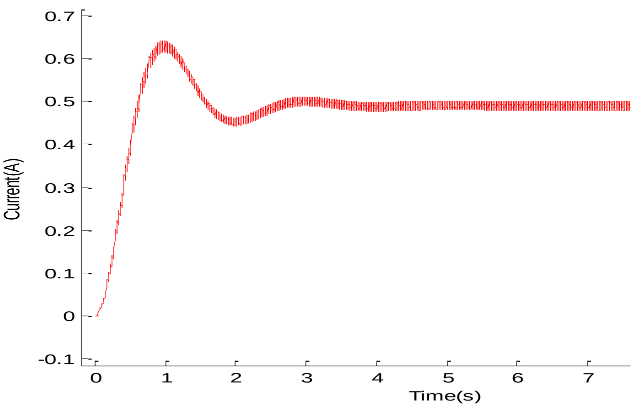

Fig. 6 Simulation Waveform of the Current of the Boost Converter

From fig.5, it is inferred that the output voltage of the Boost converter is 100V for 20V input voltage and from fig.6 the output current is 0.5A. All the simulations are done with an 80% duty cycle.

2.2. Super lift LUO DC-DC Converter:

The difference between Luo and other conventional DC-DC converters is that the voltage is boosted in a geometric progression in case of the Luo converters [2-4]. The topology that is analyzed in the following section is the elementary circuit of "positive output Super lift Luo boost converter". During the steady state operation, the capacitor is charged to the input voltage, and the current through the inductor proportionately increases when the switch is ON.

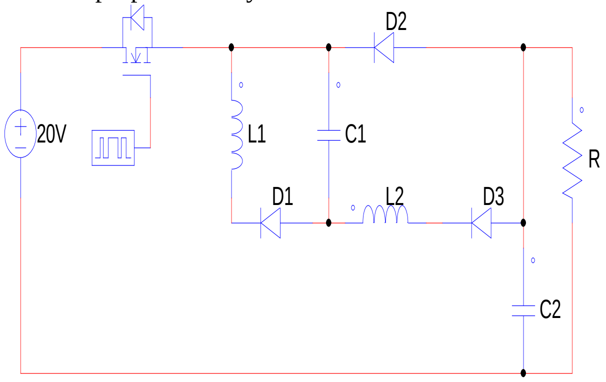

Fig.7 Circuit of LUO Converter

Modes of operation of Luo:

This converter usually works in continuous conduction mode and the output terminal voltage is usually positive. When the switch is in the ON state, the input voltage is directly transmitted to the inductor L and capacitor C_1, both of which are charged. The circuit diagram of modes of operation is shown in Fig.6. and Fig.7.Capacitor C_2 supplies the load and the inductor current increases. Freewheeling Diode D_1 is in operation. When the switch is in the OFF state, the current through the inductor decreases, and capacitor C_2 charges. Freewheeling Diode D_2 is in operation.

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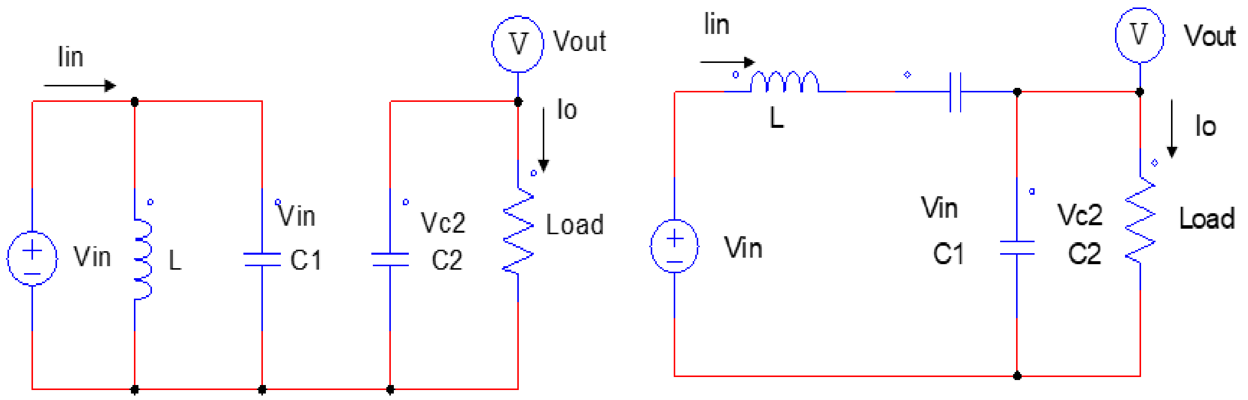

Fig. 8. (a) Mode 1 Operation of the Super Lift Luo converter, (b) Mode 2 Operation

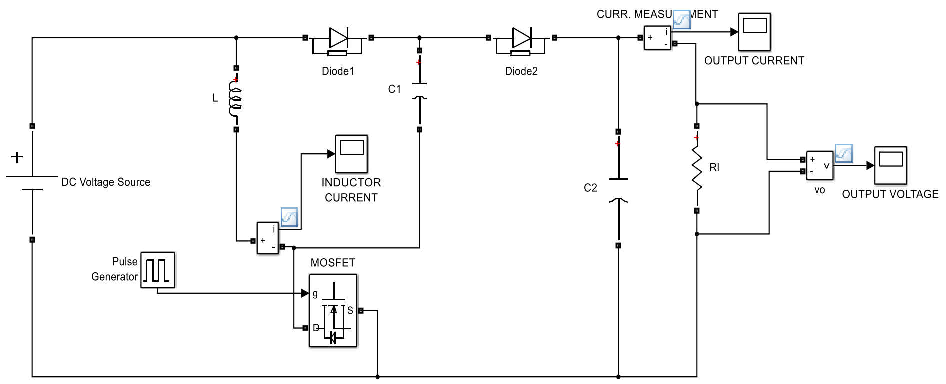

Fig.9 Simulation of LUO Converter

Design equations:

The output voltage as a function of the input voltage is given by:

$$V_{out} = V_{in} * \frac{2-D}{1-D} \quad \text{volts} \qquad (4)$$

Where V_{in} is the input voltage, V_{out} is the output voltage and D is the duty cycle.

The capacitances C_1 and C_2 are given by the same formula,

$$C = 25 * \frac{1-D}{R * fs} \text{ Farad} \qquad (5)$$

Where f_s is the switching frequency and *R* is the Resistance.

The inductance L is given by,

$$L_1 = \frac{(V_o - 2V_{in} * (1-D))}{f_s * \Delta I} \text{ Henry} \qquad (6)$$

Where ΔI is the ripple current through the inductor, which is given by,

$$\Delta I = 0.4 * I$$

The ripple in the output voltage is measured from the graph. It is ideally within 4% of the output voltage.

Table 2. Design Specification for LUO Converter

PARAMETERS	VALUES
Input voltage	20 V
Duty cycle	80%
Inductor	13.46 mH
Capacitor	0.347 µF
Resistive load	200 Ω
Switching frequency	50kHz

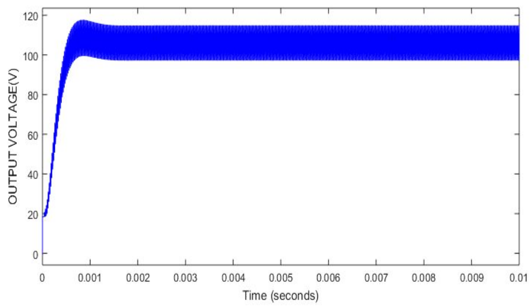

Fig.10 Simulation waveform of the output voltage of the Luo converter

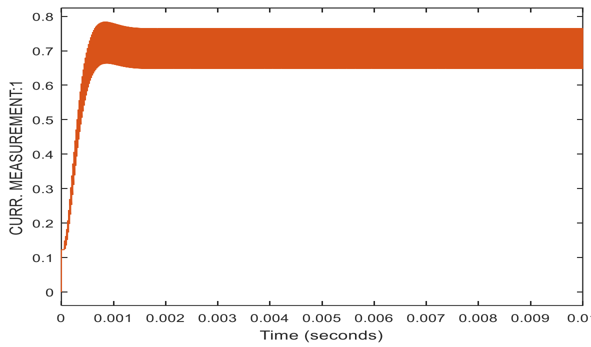

Fig.11 Simulation Waveform of the Output Current of Luo Converter

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From fig.10, it is inferred that the output voltage of the Luo converter is 107.6V for a 20V input voltage and from fig.11 the output current is 0.35A.

2.3. Modified Luo Topology (Luo-buck):

In the case of Luo DC-DC converter, it is observed that the output current is very low, which is not useful in practical applications (E.g., charging a battery or powering multiple devices). It is well known that a Buck DC-DC converter (which is used to step down voltage) gives a high value of output current; hence by cascading the Luo and Buck converters, we can gain a stepped-up voltage without significant reduction in the current. The output of the Luo converter is given as input to the Buck converter [5-6]. The duty cycles of the converters are chosen in such a way that the overall output of the topology is higher than the input voltage.

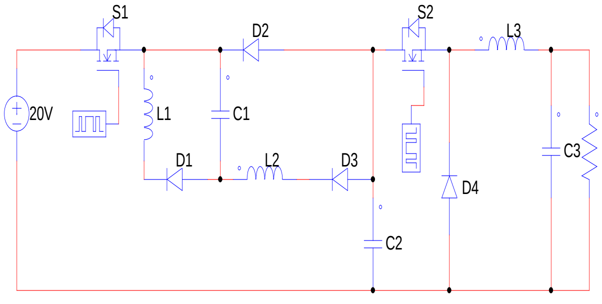

Fig.12 The Circuit of Luo Converter

Working:

The modification to the Luo converter is done to increase the output current so it can be used for the charging of batteries, and for supplying loads. The modification is a Luo converter cascaded with a buck converter. A traditional Buck converter results in a stepped down voltage and an increased current. This particular characteristic is employed in tandem with the voltage lifting properties of the Luo converter to result in an output terminal voltage where both the current and voltage are high. When the voltage is applied to the input terminals of the Luo converter, it is boosted and appears across the output terminals. The duty cycle of the switch S_1 is chosen such that the voltage at the output terminals of the Luo converter is much higher than necessary. This output voltage is then fed to the input terminals of the Buck converter, which results in a decreased output voltage, but with higher current gain. The duty cycle of switch S_2 is chosen so that the resulting output voltage is at the required level.

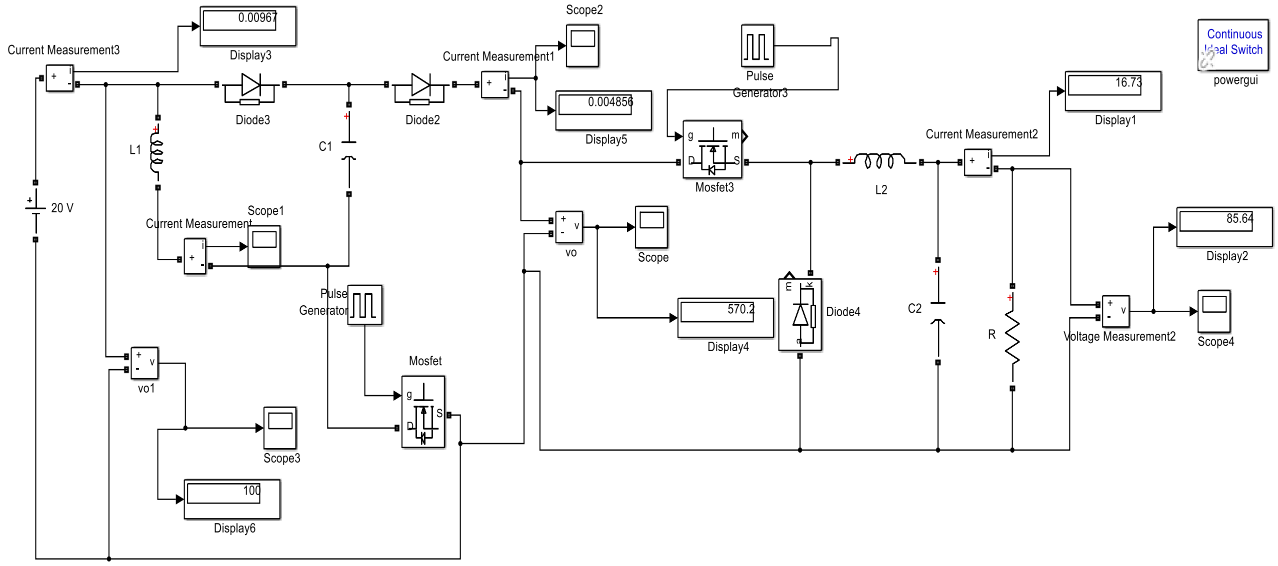

Fig.13 Simulation of Modified Luo Converter

Design equations:

Buck:

Output voltage,

$$V_{out} = V_{in} * D \text{ volts} \quad (7)$$

Where V_{in} is the input voltage, V_{out} is the output voltage and D is the duty cycle.

Inductance,

$$L_2 = \frac{(V_o * (1 - D))}{f_s * \Delta I} \text{Henry} \quad (8)$$

Where f_s is the switching frequency, ΔI is the ripple current through the inductor.

Capacitance,

$$C_2 = \frac{V_o * (1 - D)}{8 * f_s^2 * \Delta V * L_2} \text{ Farad} \quad (9)$$

ΔV is the ripple voltage through the capacitor.

Where,

$$\Delta V = 2\ \% \text{ of } V_o$$

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Table 3. The Design Specification for Luo-Buck Converter

PARAMETERS	VALUES
Input voltage	20 V
Duty cycle	80%
Inductor L_1	13.46 mH
Inductor L_2	0.0051mH
Capacitor C_1	0.347 µF
Capacitor C_2	98.03uF
Resistive load	200 Ω
Switching frequency	50kHz

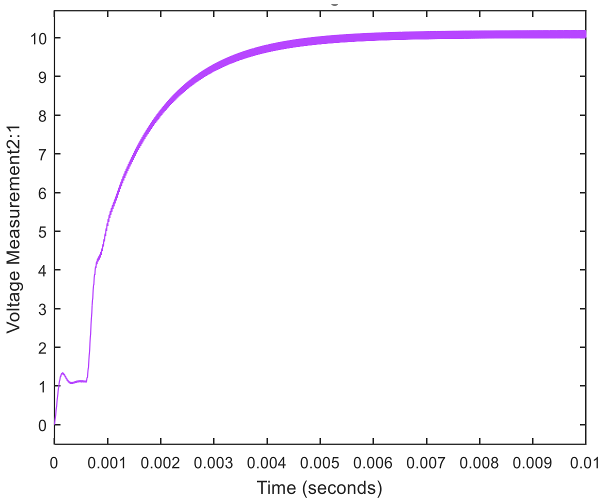

Fig. 14 Output Voltage Waveform for Luo-Buck Converter

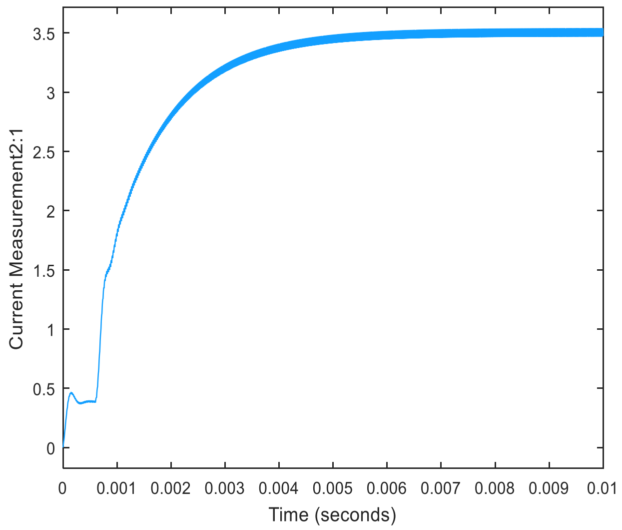

Fig. 15 Output Current Waveform for Luo-Buck Converter

From fig.14, it is inferred that the output voltage of Luo-Buck converter is 16.01V for 20V input voltage and from fig.15 the output current is 3.12A.

III. SIMULATION AND ANALYSIS OF DIFFERENT DC-DC CONVERTERS

3.1. Voltage Ripple

From the output voltage waveforms of different DC-DC converters, the voltage ripples are calculated. From fig.5, it is inferred that the output voltage ripple for Boost converter is 0.0319V. Fig.10 shows the ripple voltage for Luo converter as. Fig.14 gives the ripple voltage for Luo-Buck converter as 0.0106.

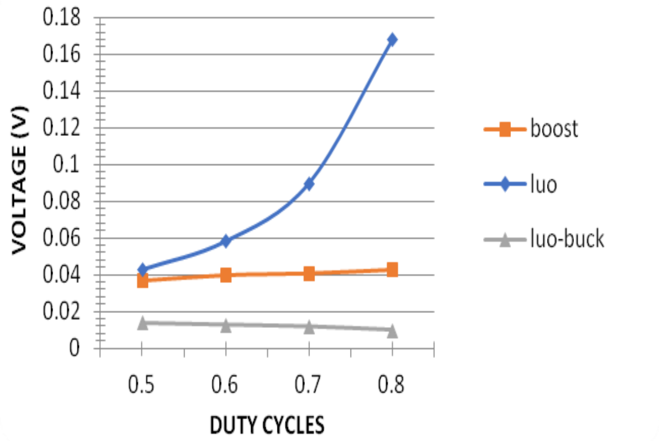

Fig. 16 Output Voltage ripple

Fig.16 depicts the variation of ripple voltages with respect to varying duty cycles for different DC-DC converters. The Luo-Buck converter exhibits a less voltage ripple in comparison with other converters.

3.2. Current Ripple

From the output voltage waveforms of different DC-DC converters, the voltage ripples are calculated. From fig.5, it is inferred that the output voltage ripple for Boost converter is 0.2A.Fig.10 shows the ripple voltage for Luo converter as 0.18A. Fig.14 gives the ripple voltage for Luo-Buck converter as 0.0118A.

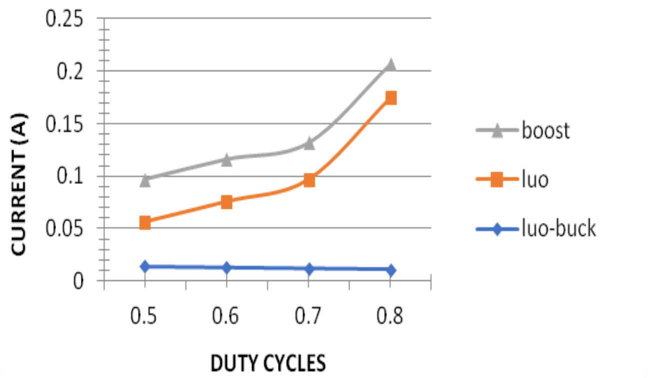

Fig. 17 Output Current Ripple

Fig.17 depicts the variation of ripple currents with respect to varying duty cycles for different DC-DC converters. The Luo-Buck converter exhibits a less output current ripple in comparison with other converters.

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3.3. Voltage and Current Stress:

Table 4. Voltage and Current stress of Boost Converter

Topology	PARAMETERS	VALUES
Boost DC-DC Converter	Voltage stress	101V
	Current stress	1.01 A
Luo Converter	Voltage stress	12.58 V
	Current stress	0.1258A
Luo Buck Converter Luo side	Voltage stress	112V
	Current stress	216mA
Buck side	Voltage stress	119.9V
	Current stress	4.435A

3.4. Input Current Ripple

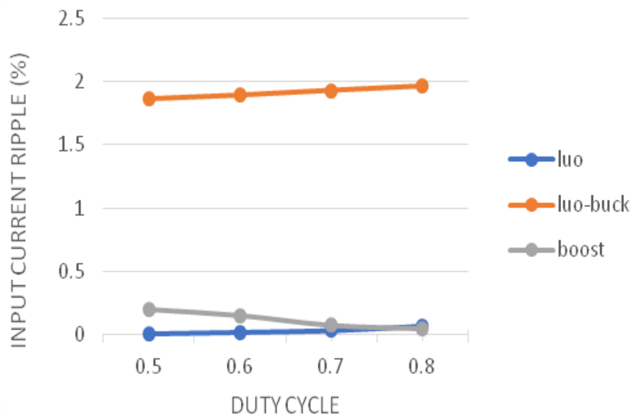

Fig. 18 Input Current Ripple for Converters

Fig.18 shows the variation of input ripple currents with respect to varying duty cycles for different DC-DC converters. The Luo-Buck converter exhibits the highest input current ripple in comparison with other converters.

IV. INTERFACING WITH PV PANEL

The PV panel was modeled [7] using MATLAB/SIMULINK. The Luo-Buck converter is interfaced with this PV model as shown in fig.18 and is simulated to obtain the results. The output voltage and current waveforms are shown in figure 19 and figure 20.

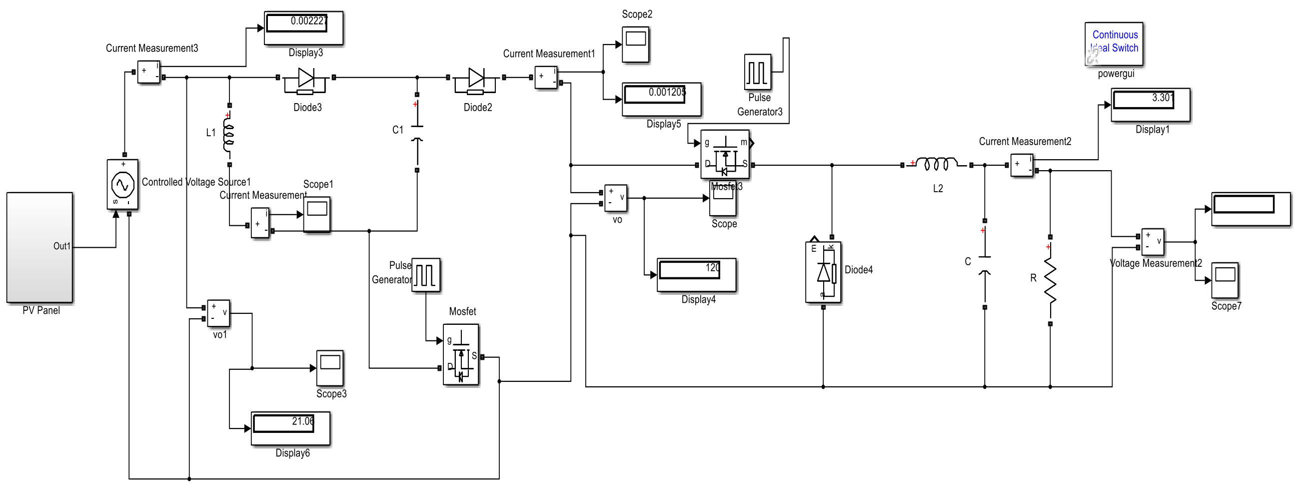

Fig. 19 Simulation of Luo-Buck Converter Interfaced with PV

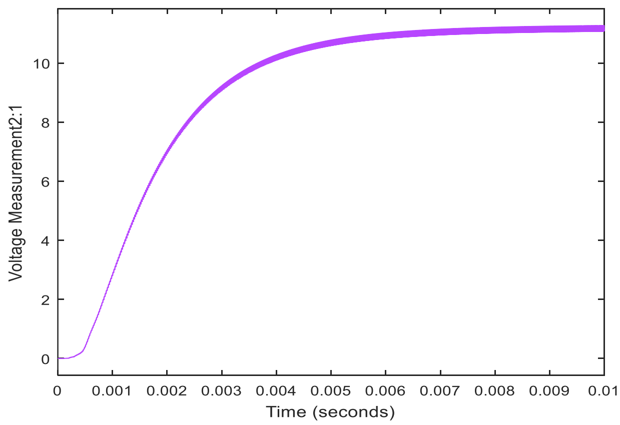

Fig. 20 Output Voltage Waveform of Luo-Buck Converter Interfaced with PV

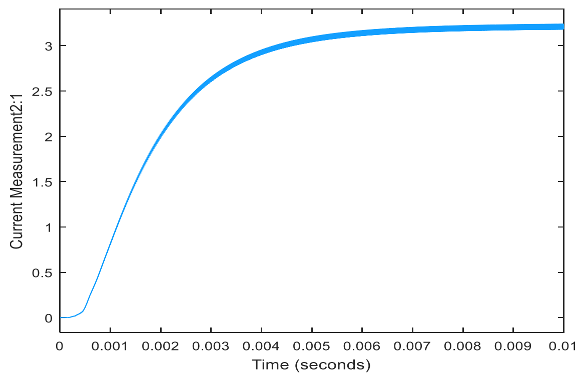

Fig. 21 Output Current Waveform of Luo-Buck Converter Interfaced with PV

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Table 7. Simulation Results of Luo-Buck Converter Interfaced with PV

PARAMETERS	VALUES
Output Voltage	11.01V
Output current ripple	2.03%
Output voltage ripple	1.88%
Input Current ripple	1.967 A

V. CONCLUSION

In this paper, three DC-DC converters- Boost converter, Luo converter and Luo-Buck converter were analysed using SIMULINK/MATLAB. The consolidated results show that the proposed Luo-Buck converter offers less output voltage ripple and output current ripple, which is desirable for our intended solar DC home application. In this application, apart from supplying the loads, the battery has to be charged simultaneously which needs sufficient current from the output. This criterion is met by the proposed Luo-Buck topology and hence proves to be the best for the standalone PV application.

ACKNOWLEDGMENTS

Our first and foremost thanks to the almighty for his everlasting love showered upon us throughout this endeavor. We express our sincere gratitude to our beloved professor Dr. R. Seyezhai, Associate professor, EEE department of SSN College of Engineering, who guided and supported us to consummate this research work and also for being an inspiring source. Whose enthusiasm in research cheered us in following her path. We thank SSN Institutions for providing the facilities to carry out this work.

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