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. 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. 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.
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The level of boost is determined by the duty cycle, D.

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. 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

Design equations:

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

\[ V_{\text{out}} = V_{\text{in}} \cdot \frac{D}{1-D} \quad (1) \]

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

The capacitance \( C \) is given by the formula,

\[ C = \frac{(I_o + D)}{f \Delta I_o} \quad \text{Farad} \quad (2) \]

Where \( I_o \) is the output current and \( \Delta V_{\text{out}} \) is the output voltage ripple. The inductance \( L \) is given by

\[ L = \frac{(V_{\text{in}} + D)}{f \Delta I_o} \quad \text{Henry} \quad (3) \]

Where \( \Delta I_o \) is the inductor ripple current and \( f \)-switching frequency.

Fig 4. Simulation of the Boost Converter

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Table 1. The Design Specification for a Boost Converter

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage</td>
<td>20 V</td>
</tr>
<tr>
<td>Duty cycle</td>
<td>80%</td>
</tr>
<tr>
<td>Inductor</td>
<td>1.6 mH</td>
</tr>
<tr>
<td>Capacitor</td>
<td>2 µF</td>
</tr>
<tr>
<td>Resistive load</td>
<td>200 Ω</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>50kHz</td>
</tr>
</tbody>
</table>

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. 5 Simulation Waveform of the Output Voltage of the Boost converter](image)

![Fig. 6 Simulation Waveform of the Current of the Boost Converter](image)

![Fig. 7 Circuit of LUO Converter](image)

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 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.

![Fig. 8. (a) Mode 1 Operation of the Super Lift Luo converter, (b) Mode 2 Operation](image)
Design equations:
The output voltage as a function of the input voltage is given by:

\[ V_{\text{out}} = V_{\text{in}} \cdot \frac{2 - D}{1 - D} \text{ volts} \]  \hspace{1cm} (4)

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

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

\[ C = 25 \cdot \frac{1 - D}{R \cdot f_s} \text{ Farad} \]  \hspace{1cm} (5)

Where \( f_s \) is the switching frequency and \( R \) is the resistance.

The inductance \( L \) is given by,

\[ L = \frac{(V_0 - 2V_{\text{in}} \cdot (1 - D))}{f_s \cdot \Delta I} \text{ Henry} \]  \hspace{1cm} (6)

Where \( \Delta I \) is the ripple current through the inductor, which is given by,

\[ \Delta I = 0.4 \cdot I \]

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

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage</td>
<td>20 V</td>
</tr>
<tr>
<td>Duty cycle</td>
<td>80%</td>
</tr>
<tr>
<td>Inductor</td>
<td>13.46 mH</td>
</tr>
<tr>
<td>Capacitor</td>
<td>0.347 µF</td>
</tr>
<tr>
<td>Resistive load</td>
<td>200 Ω</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>50kHz</td>
</tr>
</tbody>
</table>

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 higher 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.

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.

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

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

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):
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Fig.12 The Circuit of Luo Converter
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.

**Design equations:**

**Buck:**

Output voltage,

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

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

Inductance,

$$L_1 = \frac{V_0 \times (1 - D)}{f_s \times \Delta I} \, \text{Henry} \quad (8)$$

Where $f_s$ is the switching frequency, $\Delta I$ is the ripple current through the inductor.

Capacitance,

$$C_2 = \frac{V_0 \times (1 - D)}{8 \times f_s^2 \times \Delta V \times L_2} \, \text{Farad} \quad (9)$$

$\Delta V$ is the ripple voltage through the capacitor.

Where,

$$\Delta V = 2 \% \, \text{of} \, V_0$$

**Table 3. The Design Specification for Luo-Buck Converter**

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage</td>
<td>20 V</td>
</tr>
<tr>
<td>Duty cycle</td>
<td>80%</td>
</tr>
<tr>
<td>Inductor $L_1$</td>
<td>13.46 mH</td>
</tr>
</tbody>
</table>

![Fig.13 Simulation of Modified Luo Converter]

**Fig. 14 Output Voltage Waveform for Luo-Buck Converter**
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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.

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.

3.3. Voltage and Current Stress:
Table 4. Voltage and Current stress of Boost Converter

<table>
<thead>
<tr>
<th>Topology</th>
<th>PARAMETERS</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boost DC-DC</td>
<td>Voltage stress</td>
<td>101V</td>
</tr>
<tr>
<td></td>
<td>Current stress</td>
<td>1.01 A</td>
</tr>
<tr>
<td>Luo Converter</td>
<td>Voltage stress</td>
<td>12.58 V</td>
</tr>
<tr>
<td></td>
<td>Current stress</td>
<td>0.1258 A</td>
</tr>
<tr>
<td>Luo Buck Converter</td>
<td>Voltage stress</td>
<td>112V</td>
</tr>
<tr>
<td>Luo side</td>
<td>Current stress</td>
<td>216mA</td>
</tr>
<tr>
<td>Buck side</td>
<td>Voltage stress</td>
<td>119.9V</td>
</tr>
<tr>
<td></td>
<td>Current stress</td>
<td>4.435A</td>
</tr>
</tbody>
</table>

3.4. Input Current Ripple
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.

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

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Voltage</td>
<td>11.01V</td>
</tr>
<tr>
<td>Output current ripple</td>
<td>2.03%</td>
</tr>
<tr>
<td>Output voltage ripple</td>
<td>1.88%</td>
</tr>
<tr>
<td>Input Current ripple</td>
<td>1.967 A</td>
</tr>
</tbody>
</table>

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.

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