Simulation and Implementation of High Gain DC-DC Converter for PV Applications

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Abstract

This paper investigates a high gain DC-DC converter with low ripple content employing coupled inductor for PV applications. It is highly preferable in boosting low PV panel voltage to high voltage. The efficiency of the proposed converter is high and it is cost effective as it is basically a transformer less topology. The proposed topology is designed and implemented with multiple maxima search MPPT algorithm interfaced with PV. Simulation studies of the converter and PV modeling with MPPT are carried out in MATLAB/SIMULINK. A hardware prototype is built to validate the simulation results.

Key Words: Coupled inductor, Voltage gain, transformer less topology.
1 Introduction

In recent days, high gain converter plays a dominate role in case of renewable energy resources. It has numerous advantage such as low ripple content and high efficiency and hence finds application in solar system, UPS and automobile applications. The recent change in the environmental conditions such as global warming and increased electricity demand led to generation of electricity from renewable energy resources (1). In that, solar energy has emerged to meet the electricity demand to give a feasible solution to the above mentioned problem. Therefore, the DC/DC converters play an important role for solar PV system. In addition, the design of high power DC-DC converters and their controller plays an important role to regulate the output voltage.

To meet the existing power demand, PV power generation has become increasingly important as it is a clean energy source due to its environmentally friendly nature and practically unlimited source. Without any mechanical effort, solar panel delivers electrical energy when required number of cells connected in series and parallel (2). The great challenge of working with solar panel is its cost and efficiency. One best way to reduce the cost of PV panel (installation, generation and marketing) is to buy the solar panel with low efficiency. And to increase the efficiency of PV panel is to improve the efficiency of maximum power point tracking (MPPT) algorithm. In the literature, many power point tracking techniques has been explored to overcome the drawbacks of low conversion efficiency of PV panel (3 & 4). This paper focuses on multiple maxima search MPPT algorithm to track the maximum operation point (OP) from multiple maxima points. During partial shading condition, conventional algorithm fails to track global maximum point. To overcome this, many MPPT algorithms is emerged and the survey shows that multiple maxima search MPPT algorithm works well during partial shading condition. It tracks as well as controls the pulse pattern of the converter switch (5).

Mostly, boost converter is chosen for high output voltage range, but the conventional boost converter suffers from high output voltage ripple and low voltage gain. There are two types of converter: non-isolated and isolated converters, it is proven that the non-isolated can be more efficient than the isolated ones. The different
non-isolated dc-dc converters topologies are: classical boost, modified boost, high gain boost, cascade, interleaved boost, high gain interleaved boost and classic boost converter. For high voltage conversion ratio, traditional boost converter is not preferable since the conversion ratio of output voltage is limited to 5 times of the input voltage. Hence, high gain DC-DC boost converter is proposed. In this topology, the input inductor is replaced by coupled inductor to overcome problems such as high reverse recovery current, turn on and turn off losses, the leakage current and current stress in switching devices. High conversion gain is obtained at low value of duty ratio.

The paper is organized as: Section II discusses about the proposed high gain DC-DC converter, Section III focuses on the simulation results, Section IV depicts the hardware results and section V finally concludes the paper.

2 HIGH GAIN DC-DC BOOST CONVERTER

The circuit diagram of high gain converter is shown in Fig.1.

With the primary of the coupled inductor, current limiting inductor, two diodes and capacitor is connected to reduce the voltage stress across the switch. Moreover, LC filter is connected with coupled inductor to reduce the output voltage ripple. By varying the
turns ratio of coupled inductor, high gain can be achieved in this topology. The voltage gain of the converter is given by

\[ V_0 = \frac{n \times V_s}{1 - D} \] (1)

Where 'n' is the turns ratio, 'D' is the duty cycle and 'V_s' is the input voltage.

The pulses are generated to the converter by employing PWM technique, where a triangle waveform is used as a carrier wave and DC as the reference as shown in Fig.2.

![Fig.2. PWM signal for the DC-DC converter](image)

3 SIMULATION RESULTS

The high gain DC-DC boost converter is modeled and interfaced with PV panel with multiple maxima search MPPT algorithm is shown in Fig.3.

![Fig.3. Simulink diagram of high gain DC-DC boost converter](image)
Fig. 4 shows the output voltage boosted to 500V for an input of 21V. The voltage across the diode, voltage across the inductor, voltage stress across the switch and inductor current is shown in Fig. 5 - Fig. 8.

**Fig. 5. Diode voltage**

**Fig. 6. Voltage across the inductor**
The inductor current shape and voltage across the device depicted in Fig.7 & 8, proves that current ripple and stress across the device is low.

From the simulation results, the performance analysis of proposed converter is done and compared with conventional boost converter, the results shows that the proposed converter has 2% output voltage ripple, 2.4% output current ripple and voltage gain of 24 whereas traditional boost converter has 25 % output voltage ripple, 25% output current ripple and voltage gain of 15. And it is proven that the high gain boost converter with coupled inductor has low voltage ripple, low current ripple and high voltage gain compared to traditional boost converter.

The converter switching loss is calculated using the equation (2)

\[ P_{sw} = \frac{1}{2} \times |V| \times |I| \times (t_{on} + t_{off}) \times f_{sw} \quad (2) \]
The switching loss calculated is about 2.187W and diode loss is 6.561W and the total loss is about 10.61W. The efficiency of the proposed high gain DC-DC boost converter with coupled inductor is 80%.

Fig. 9. Duty ratio (D) Vs Voltage gain

Fig. 10. Duty ratio (D) Vs Voltage ripple (V)
Fig. 11 shows the variation of voltage gain, voltage ripple and current ripple with different values of duty ratio. It is proven that the proposed high gain converter has high voltage gain, lower voltage ripple and lower current ripple compared to traditional boost converter.

### 4 HARDWARE RESULTS

Practically, the VI and PV characteristics are observed for the 40W solar panel and the characteristics are shown in Fig. 12. The pulse for the proposed converter is generated using FPGA SPARTAN 3E.

Fig. 12. VI and PV characteristics of 40W panel wit \( \text{Voc} = 21.4 \text{V} \) and \( \text{Isc} = 2.48 \)
In Fig. 13, the triangular carrier wave is generated using SPARTAN 3E XILINX tools and compared with constant. The program is burned to the FPGA Processor and given to the optocoupler board. The generated pulse pattern for high gain converter is shown in Fig. 14.

Fig. 13. Pulse generation for high gain DC-DC boost converter

The parameters used for the prototype of the high gain DC-DC boost converter is listed in table - I.

**TABLE I : Specifications of high gain boost converter**

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>RATING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Power</td>
<td>300W</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>218V</td>
</tr>
<tr>
<td>Coupled Inductor</td>
<td>25.3H</td>
</tr>
<tr>
<td>Capacity</td>
<td>5.1µF</td>
</tr>
<tr>
<td>Inductor</td>
<td>270 µH</td>
</tr>
<tr>
<td>Resistor</td>
<td>400 Ω</td>
</tr>
</tbody>
</table>

A prototype model of high gain DC-DC boost converter is developed with input voltage of 6.3V and it is boosted to 218V is shown in Fig. 15.
In Fig. 16, the proposed boost converter is interfaced with PV panel through 12V, 6A charge controller with input voltage of 12V is boosted to 214V.
Fig. 17 shows that the high gain converter has 0.8% ripple content which validates the simulation results.

5 CONCLUSION

This paper has explored the significance of high gain DC-DC converter for PV applications. From the simulation results, it is noted that this topology has resulted in high voltage gain, reduced ripple compared to the classical boost converter. Further, a hardware prototype has been built and pulses have been generated using FPGA. The output voltage ripple have been measured using PQ analyzer and the results have been validated. Therefore, the proposed high gain converter will be highly beneficial for PV applications.

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References


