High Gain DC-DC Converter Using Coupled Inductor and Voltage Doubler

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**ABSTRACT**

The output voltage obtained from renewable energy sources is low and needs to be stepped up by an order of 20 for practical usage or grid integration. This emphasizes the need for high gain DC-DC converters. The proposed DC-DC converter topology combines the simple boost converter and a coupled inductor with voltage double stages to provide high voltage gain. The main advantages of this topology are continuous input current, large conversion ratio without extreme duty. The proposed converter is simulated and the waveforms obtained. The experimental setup will be taken up as future work.

**Keywords:** Boost Converter, Coupled Inductor, Non-Isolated, Photovoltaic.

1. **INTRODUCTION**

The advent of renewable energy sources like solar and wind based system as clean and viable alternatives to conventional sources such as fossil fuel based energy generation, demands high gain DC-DC converters to step up the voltage significantly to be used either practically as a domestic stand-alone system or for connection to the grid. Initially cascaded and interleaved boost converters (IBC) were used to obtain the required high gain [3]-[4]. These converters however faced inherent problems of high ripple current and high power losses. This prevented higher efficiency at a higher gain when using these topologies. Isolated topologies using transformers or coupled inductors with suitable turns-ratio were used to achieve the required voltage gain. When using transformers the losses are a function of switching frequency, this in turn puts an upper limit on the operating frequency of the converter. Also this increases the size of the converter besides making the converter heavier and costlier. The high current flowing through the boost inductor also imposes large voltage stress across the devices.

For efficient utilization of renewable energy, compact non-isolated converters are required. Coupled inductors were used in conjunction with switched capacitors in [2]. The main disadvantage of this topology is that many numbers of components were used. In [1] and [8], coupled inductor was used in conjunction with a voltage multiplier cell. Switched inductor and switched capacitor based topologies were used to reduce the switch stress in [9]. The concept of multi-level based DC-DC power conversion proves to be a suitable non-isolated alternative solution to obtain the required high voltage gain and high power level[10]-[12]. The main advantage of multilevel conversion is that only low voltage level devices are required as each device only block one voltage level. The advantage of multi-level conversion can further be extended by including a coupled inductor into the converter. This provides further control over the gain. The presence of the coupled inductor in addition to the voltage multiplier reduces the duty cycle required to achieve a particular gain.
In this paper, a DC-DC converter using coupled inductor and switched capacitor is presented. This combines the boost converter, the coupled inductor and switched capacitor function to provide the require output voltage at the desired power level is proposed. The proposed topology is a single switch design, employing one coupled inductor and (2N-1) capacitors and (2N-1) diodes for an N stage voltage multiplier. The output voltage can be further increase by adding more voltage doubler stages. The main advantages of this topology are (i) High gain without transformers; (ii) single switch topology; (iii) Continuous input current; (iv) easily expanded to give higher gain. The operating principle along with the design details and simulation results are presented in the following sections.

2. CIRCUIT DESCRIPTION

2.1 Power Circuit

The power circuit diagram depicted in Fig1. It is a conventional Boost converter which employs a coupled inductor and switched capacitor function to achieve higher output voltage. The circuit shows a 3-level multi-level boost converter with coupled inductor.

2.2 Modes of Operation

The operation of the circuit can be divided into two major parts- one when switch M1 is closed and when M1 is open. The events that take place during the two modes are described as follows:

In mode 1, Switch M1 is turned ON and the Inductor L1 charges from the voltage source Vdc. The voltage induced in the inductor L1 causes an induced voltage in the inductor L2. This induced secondary voltage charges capacitor C4 through C2 and. Similarly, capacitors C4 and C6 are charged together through C2, C3 and L2.

In Mode 2, Switch M2 is turned OFF and the voltage across inductor L1 forward biases diode D1 and the inductor current charges C1 through D1. The change in voltage polarity of inductor L2 switches the diodes D2-D6. On the secondary side, with the polarity of the voltage across L2 reversed, the diode D2 is forward biased and the inductor current L2 charges C2. With D4 conducting, the voltage across L2 and C4 clamps across C2 and C3 through D4. Similarly the voltage across L2, C4 and C6 clamps across C2, C3 and C5 through D6.

As seen from the power circuit diagram and operating modes, diodes D3 and D5 operate complementary to D2, D4 and D6 and D1 is conducting throughout Mode 2.

2.3 DESIGN DETAILS

The conventional boost converter provides the basis for the design of the passive elements present in the power converter. The voltage gain of the conventional, simple boost converter is given by:

\[ M = \frac{1}{1 - D} \]  

(1)
Where ‘D’ is the duty ratio of the boost converter. The voltage gain of the conventional flyback converter is given by:

\[ M = \frac{L_2}{L_1} \]  

(2)

Where ‘L1’ is the inductance of the primary and ‘L2’ is the inductance of the secondary.

For the current converter topology, the voltage gain expression can be given by:

\[ M = \left( \frac{1}{1 - D} + \frac{L_2}{L_1} \right) \times N \]  

(3)

Where ‘N’ is the number of levels on the voltage multiplier stage.

The design specifications are input voltage = 24 V, output voltage = 430 V, output power = 600 W and switching frequency = 50 kHz. To determine the values in the voltage gain equation, we first fix the least flexible parameter, namely, turns ratio. Boost converters operating at lower levels or with lower turns ratio need to increase their duty ratio to get the required gain. This is practically not possible. Hence the required gain is achieved by increasing the number of levels.

It is proposed to operate at a duty cycle of 0.5 with 3 levels and a turns-ratio of 3.96. This provides ample turn off time for the power device and avoids excessive voltage stresses and flexibility to obtain additional gain if required.

The value of inductance chosen is 26.5µH in the primary and 415 µH in the secondary and 100µF capacitors are used.

3. SIMULATION RESULTS

The proposed converter with the designed values is simulated in PSpice. The gate pulse output current, output voltage and output power waveforms are shown in Fig.5. For a duty cycle of 0.5, the required output voltage is obtained at the required output power. Further, the voltage distribution across the capacitors C1, C2, C3 and C5 shows that the converter performs satisfactorily. The voltage distribution across the capacitors is shown in Fig.6. The gate pulse and the current through the two inductors are shown in Fig.7. The linear increase and decrease of primary inductor current during presence and absence of gate pulse, and vice-versa for secondary inductor can be clearly observed. Further, the ripple current magnitude is also within specified limits. This confirms the design aspects of the converter. Fig.8 shows the switch voltage and current stress. It is observed that the voltage stress across the device is 70V which is expected for 24V input and 430V output.
Figure 3. Operating Circuit(s) when the Switch is OFF.

Figure 4. Voltage Gain Plot

Figure 5. Gate Pulse, Output Current and Output Voltage Waveforms.

Figure 6. Capacitor Voltage Distribution

Figure 7. Gate Pulse and Inductor Current Waveform
4. CONCLUSION

The proposed converter has been designed and simulated. The converter employs one coupled inductor and a three stage voltage multiplier in conjunction with the conventional boost converter which is operated at a duty cycle of 0.5. A voltage gain of 17.92 was obtained without using both a transformer or causing excessive device voltage and current stresses. The converter was designed to supply a load at 430V at 600W. The performance of the proposed converter is confirmed from the output waveforms obtained from the simulation. Experimental verification of the converter is underway.

REFERENCES