A Boost Converter for High Voltage Applications using Three State Switching Cell

Saravanan P*  
HOD/EEE&Jay shriram group of institutions

PonGomathic C  
PG Scholar (EEE)&Jay shriram group of institutions

Abstract—This paper presents the modulation of a DC-DC non-isolated boost converter supply as a source to double half bridge inverter. The system is constituted by two active switches, two diodes and two coupled inductors. The literature review presents the advantages and disadvantages of other step-up converters. In this the converter operates in overlapping mode with duty cycle higher than 0.5 which is in continuous conduction region. The intrinsic characteristics of the switch MOSFET here produces low input current ripple, steps up the input voltage, and provides the implementation in high voltage application. The boost converter is based on three state switching cell. The output of the system can be given any high voltage and high current applications. Other than the mathematical analysis and theoretical calculations, an experimental prototype of 1kw can be carried out.

Keywords—Boost converter, step-up dc-dc converters, three state switching cell (3SSC), double half bridge inverter, continuous conduction mode

I. INTRODUCTION

Step-up converters are widely used in modern technologies as sources to many industrial drives. In industrial drives to supply the source of a dc drive systems which require high voltage. When a high voltage is demanded at industries, it is useful when the demand can be met by a small input voltage supplied by either photovoltaic panels, batteries, fuel cells, or other sources. Whatever may be the source but it is necessary to maintain the gain and ripple at a proper rate.

Mainly dc-dc converters include pulse width modulated (PWM) converters currently. These converters produce power supplies for a large variety of systems in electronics, telecommunications, dc motor drives, satellites, utilization of the solar energy and also for other types of power converters.

The main evolution of power converter was necessary for the increase in demand for the variety of applications. From these the buck-boost converters mainly based on Pulse Width Modulation (PWM) techniques using switching principle evolved.

In order to obtain the above high voltage, conventional boost converter is not adequate because to get high duty cycle the main switch needs to be turned on for a prolonged time which causes conduction loss. A well-known concept of cascading which operates in continuous conduction mode (CCM) can also be done in order to get a high voltage but cascading increases the complexity and reduces the efficiency.

Many modifications have been made in modern times to make these conventional boost converters useful for the voltage step up applications. These topologies vary and make themselves suitable and evolve to meet the requirements of the duty cycle. The hard switching conventional converters present low power density but with the use of filters they increase the switching losses. This conventional boost converter with two inductor and auxiliary transformer increase the efficiency but the switching losses in the inductor causes the failure of the system, as the system needs to be turned off for a period of time.

A high voltage gain with the use of switches though the efficiency can be compromised with less on resistance by losses due to leakage inductance is achieved by flyback or SEPIC converters where there is magnetically coupled inductance. The overlap of voltage and current during commutation can be reduced to avoid the switching losses. An addition of auxiliary switches in the circuit causes complication in the power and control strategy. This can be overcome by using passive lossless snubber since they reduce EMI electromagnetic interference and switching loss but they cause a main disadvantage of not supporting the entire load range.

An effort in improving the ZVS zero voltage switching technique is carried out. Though they reduce the complication in the switching losses, for higher voltage application they cause large EMI electromagnetic interference filter and energy storage inductor.

A resonant converters increases the voltage gain by increasing and adjusting the turns ratio of a high frequency transformer. But these are applicable for low power rated devices not for high power application because of high circulating energy due to LC resonant tank.

Now it is necessary to bring forth the concept of 3SSC. This three state switching cell is normally used for high voltage application. 2SSC is normally called cell type B. They can be used in high current applications. A 3SSC is made up of a 2 state pulse width modulation cells (2SSC) which are connected by a centre tap transformer making it as a dc-dc converter. This is called cell type B. Here the centre tap transformer is considered ideal with unity turns ratio where the primary and secondary windings are replaced with the magnetizing inductances.

The characteristics of the isolated converter are similar to push converter. The advantages of 3SSC are as follows: here we utilize only one winding of the transformer which has the dc current blocking capacitor in series to avoid the
saturation problem in transformer, reduced magnetic cores and less copper losses are involved in transformer assembly; low commutation losses are achieved by low leakage inductance.

This paper presents high voltage gain and high current application based on the diodes and capacitor designs. This converter operates in non-overlapping mode with duty cycle less than 0.5 and overlapping mode with duty cycle greater than 0.5. But it is known that with duty cycle less than 0.5 causes magnetic induction issues and poor performance of the transformer. Here the voltage gain can be increased by adjusting the turns ratio. Thus we get a stable voltage which can be provided to a Neutral Point Clamped (NPC), half bridge and double half bridge inverters.

![Diagram of DC-DC Boost Converter](image)

**Fig. 1.** DC-dc boost converter using the 3SSC supplying a double half bridge inverter.

### II. PROPOSED DC-DC BOOST CONVERTER

#### A. Qualitative Analysis

A converter has the following elements: input voltage $V_{in}$, inductor $L_1$, transformer $T$, switches $S_1$ and $S_2$, rectifier diodes $D_1$, $D_2$, $D_3$, $D_4$, $D_5$ and $D_6$ and capacitors $C_1$, $C_2$, $C_3$, $C_4$ and $C_5$ and output capacitors $C_{o1}$ and $C_{o2}$ are electrolytic capacitors.

The current flow through the inductance determines the operating stages. Although the converter can operate in different modes such as overlapping mode with continuous and discontinuous conduction and non-overlapping mode with continuous and discontinuous conduction mode but here for high current and high voltage application we choose continuous conduction mode in overlapping mode with duty cycle greater than 0.5.

The equivalent circuit of the converter with a switching cycle is shown in the fig 2 with all operations and their waveforms are shown in fig 3.

**First stage** $[t_0, t_1]$ Fig.2(a): The switch $S1$ and $S2$ are turned on. The diodes $D_1$, $D_2$, $D_3$, $D_4$, $D_5$ and $D_6$ are reverse biased. The current through the inductor $L_1$ increases linearly and energy is stored as magnetic field. In order to minimise the loss of current flow through winding $P1$ and switch $S1$ and the remaining current through $P2$ and $S2$. When this stage finishes $S1$ is turned OFF while $S2$ is still kept on.

$$\frac{dL_1}{dt} = \frac{V_{in}}{L_1} = 0$$

Besides, the time interval that defines the stage depends on the duty cycle $D$ as

$$t_2 - t_1 = \frac{L_1}{5} (2 \cdot D - 1)$$

---

© 2014, IJIRAE- All Rights Reserved
Second stage $[t_1, t_2]$ Fig. 2(b): At $t = t_1$, Switch S1 is turned off where as S2 is still kept on. The magnetic flux is kept continuous due to the voltage in the inductor $L_1$. The voltage in $S1$ and $C_1$ are equal. The diodes $D_1$, $D_4$ and $D_6$ remain reverse biased where as the diodes $D_2$, $D_3$ and $D_5$ are forward biased. The current through the inductor $L_1$ decreases linearly which flows through the primary windings $L_{p1}$ and $L_{p2}$. The energy from inductor and source is transferred to auxiliary capacitor $C_1$, $C_2$, $C_3$, $C_{o1}$ and $C_{o2}$.

\[ \frac{d\phi_1}{dt} + \frac{v_{L1}}{z_{L1}} - v_{Is} = 0 \]  

(3)

The time interval is

\[ t_2 - t_1 = T_s \cdot (1 - D) \]  

(4)

Third Stage $[t_2, t_3]$ Fig. 2(c) At $t = t_2$, Switch S1 and S2 is turned on. The diodes $D_1$, $D_2$, $D_3$, $D_4$, $D_5$ and $D_6$ are reverse biased. This is similar to the first stage. This continuous till switch S2 is turned OFF. The equations are same as first stage as (1) and (2).

Fourth stage $[t_3, t_4]$ Fig. 2(d): Switch S1 is still kept on while S2 is turned OFF. The voltage in the inductor is inverted which makes the magnetic flux continuous. This stage is similar to second stage. The equations are same as second stage as (3) and (4).

B. Static Gain

During one switching period $T_s$ the voltage across the inductor $L_1$ ($V_{L1}$) is null.

\[ V_{L1_{(avg)}} = 2 \frac{1}{T_s} \left[ \int_{t_1}^{t_2} v_{Is} \, dt + \int_{t_2}^{t_3} (v_{Is} - v_{I_2}) \, dt \right] = 0 \]  

(5)

where $V_{L1_{p}}$ is maximum voltage in the primary windings.

Substituting (2), (4) in (5). We get

\[ V_{Is} \left[ \frac{L_2}{2} (\alpha U - 1) \right] = V_{L2} \left[ (1 - \alpha) - V_{Is} \left( \alpha (1 - U) \right) \right] \]  

(6)
The waveforms based on these calculations are shown as follows.

Then the maximum voltage across the primary winding is:

\[ V_{Lp}(\text{max}) = V_{2p2(\text{max})} = \frac{V_{2a}}{2} = \frac{V_{2a}}{2j} \]  

(7)

The voltage capacitor \( C_i \) is determined by (8). Besides, the voltage across a generic capacitor is defined by (9).

\[ V_{Cj}(\text{max}) = 2 \cdot V_{2p}(\text{max}) = \frac{V_{2a}}{2} \]  

(8)

\[ V_{Cj}(\text{max}) = V_{Cj}(\text{max}) = \frac{V_{2a}}{2} \]  

(9)

The following ratio is also valid:

\[ \alpha_j = \frac{N_j}{N_p} \]  

(10)

Where \( j \) is the number of secondary windings here it is two. Besides, the dimensionless quantity \( \alpha_j \) represents the ratio between the number of turns for a given secondary winding \( j \) represented as \( N_j \) and the number of turns for the primary winding \( N_p \).

The output voltage \( V_{out} \) corresponds to the sum of the voltages across the capacitors:

\[ V_{out} = \frac{V_{2a}}{2} \cdot \left( 1 + 2 \cdot \alpha \right) \]  

(11)

Where \( \alpha \) is defined as the (10) for a single secondary winding. Considering a generic converter with \( n \) for which several values of \( \alpha_j \) exists, the output voltage can be defined as:

\[ V_{out} = \frac{V_{2a}}{2} \cdot \left( 1 + \Sigma_{j=1}^{n} \alpha_j \right) \]  

(12)

Finally, the static gain expression can be defined from (12) as:

\[ G_j = \frac{V_{out}}{V_{2a}} = \frac{1}{L \cdot D} \cdot \left( 1 + \Sigma_{j=1}^{n} \alpha_j \right) \]  

(13)

According to (13), the static gain can be increased by adjusting the turns ratio, the number of secondary windings, or even both of the parameters simultaneously.

III. EXPERIMENTAL RESULTS

An experimental prototype can be developed to verify this theoretical values based on the design specified earlier. The waveforms based on these calculations are shown as follows.
Here we require an output of 300V or 440V which supplies a double half-bridge inverter or other dc-ac stage. When a classical boost converter is employed only a poor efficiency can be obtained. But this basic boost converter is the basic for non isolated topology, where the gain an be increased as necessary. The waveforms are shown below.

A reduced ripple with good current sharing among the windings are observed in the primary winding of the transformer as shown in the fig 4,5 and 6.

Fig. 4. Voltage waveforms of primary winding \( L_{p1} \) and \( L_{p2} \).

Fig. 5. Current waveform of primary winding \( L_{p1} \).

Fig. 6. Current waveform of primary winding \( L_{p2} \).

Fig. 7. Voltage waveform of diode \( D_5 \).

Fig. 8. Voltage waveform of diode \( D_6 \).
A MOSFET with reduced on state resistance because only half of the output voltage is passed by the switch S1 as shown in the fig 9 and 10.

### TABLE I

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated output power</td>
<td>$P_{out}=1000$ W</td>
</tr>
<tr>
<td>Rated load</td>
<td>$R_{o1}=R_{o2}=320\Omega$</td>
</tr>
<tr>
<td>Input voltage</td>
<td>$V_{in}=42$ V</td>
</tr>
<tr>
<td>Output voltage</td>
<td>$V_{out}=440$ V</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>$f_s=25$ kHz</td>
</tr>
<tr>
<td>Ripple current through inductor $L_1$</td>
<td>$\Delta I_{L1(max)}=20% I_{L1(avg)}$</td>
</tr>
<tr>
<td>Ripple voltage across auxiliary and output capacitors</td>
<td>$\Delta V_{C1...C5}=\Delta V_{c01}=\Delta V_{c02}=1% V_0$</td>
</tr>
<tr>
<td>Expected theoretical efficiency</td>
<td>$\eta=93%$</td>
</tr>
<tr>
<td>Number of secondary windings</td>
<td>$j=2$</td>
</tr>
<tr>
<td>Turn ratio of the transformers</td>
<td>$a_{j}=a_{a}=1$</td>
</tr>
</tbody>
</table>

**Designed Elements**

| Inductor                               | $L_1=60\mu$H                      |
| Main switches                          | MOSFET IRFP4227PBF                |
| Diodes $D_1, D_6$                      | Ultrafast diode HFA15PB60         |
| Capacitor $C_1...C_6$                  | $C_1=2\mu$F, polyester, 400V      |
| Output capacitors $C_{o1}$ and $C_{o2}$| $C_{o1}=C_{o2}=470$µF, electrolytic, 450V |

The fig 7 and 8 are the waveforms of the diodes in the boost converter. This is similar to the theoretical waveform in the fig 3.

The 3SSC mentioned is derived from the push-pull converter, which works in NOM and OM of the switches. They produce high power, high current operations which are designed for twice the switching frequency.

Non isolated converters are often preferred than isolated topologies in various applications such as VMCs, which is made up of diodes and capacitors to increase the static gain. In these all the parameters depend directly on the duty cycle and number of cells. In case when high static gain is required the component count has to be increased, this in turn increases the conduction losses by decreasing the efficiency.

Thus the proposed converter does not include VMCs and here the static gain is dependent on the turns ration between the primary and secondary windings, number of secondary winding and duty cycle. By increasing the number of secondary windings and turns ratio, the voltage stress across these switches can be reduced, which is the main advantages of 3SSC topology. This topology can be used when high voltage gain is required so that dc-dc converter can supply the half-bridge, double half-bridge, NPC inverter.
III. CONCLUSION

This paper presents a boost converter using 3SSC which supplies the double half-bridge inverter. The boost converter provides the necessary supply to the inverter. This system is also adequate for several applications mainly high voltage applications, photovoltaic system, UPS, inverter, industrial DC drives, etc. The experimental prototype has been implemented and evaluated. The behaviour is similar to the proposed theoretical system. The efficiency of 92% can be obtained over an entire load range, since only a part of the energy is processed through active switches, while the remaining part is directly fed to the load without being processed by these switches i.e. energy is delivered through the passive components such as diodes and the transformer windings. These are due to the use of 3SSC which causes low conduction loss. A proper design procedure has been obtained from the qualitative analyses of the converter. The behaviour of the converter is similar to the theoretical prototype.

REFERENCES


BIOGRAPHIES

Dr.P.Saravanan is presently working as Associate Professor in department of Electrical and Electronics Engineering, Jay Shriram Group of Institutions, Tiruppur Tamilnadu, India. He completed his doctorate degree in Anna University Chennai. Presently he is guiding many UG and PG scholars. He has published papers in both national and International conferences/journals. His research areas and field of Interests include power electronics, process control and power system.

PonGomathi C is currently pursuing Post Graduate degree under the department of Electrical and Electronics Engineering in Power Electronics and Drives, Jay Shriram Group of Institutions, Tiruppur Tamilnadu, India. She completed her under graduate degree in department of Electrical and Electronics Engineering, Dr. Mahalingam College of Engineering and Technology, Pollachi Tamilnadu, India. Her areas of interest are power electronics and control systems.