A Buck-Boost AC-AC Converter
Topology Eliminating Commutation Problem with Multiple Mode of Operations

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Abstract:
AC - AC power conversions were traditionally done by using thyristor power controllers, phase angle control or by integral cycle control, but had low PF and other disadvantages. Variable voltage, variable frequency high power conversions are nowadays use DC link and Matrix converters, with higher efficiency and better regulation. But in situations where only voltage regulation is required and the circuit need to be simple and less complicated, directed PWM AC-AC converters are more preferred, due to reduced size and components. This project presents the design and simulation of a new type of AC-AC converter which can operate as traditional non-inverting buck and boost converters, and inverting buck-boost converter as well. This converter uses six unidirectional current flowing and bidirectional voltage blocking switches, implemented by six reverse blocking IGBTs or series MOSFET-diode pairs, two input and output filter capacitors, and one inductor. It has no shoot-through problem of voltage source (or capacitor) even when all switches are turned-on and therefore; PWM dead times are not needed resulting in high quality waveforms, and solves the commutation problem without using bulky and lossy RC snubbers or dedicated soft-commutation strategies. It has smaller switching losses because; only two switches out of six are switched at high frequency during each half cycle of input voltage, and it can use power MOSFETs as body diode never conducts, making it immune from MOSFET failure risk.

Keywords- PWM AC-AC Converters, Inverting Buck Boost Converter, Non Inverting Buck Boost Converter, THD

1. INTRODUCTION

Traditionally in industry, the ac-ac power conversions are performed by using ac thyristor power controllers, which use the phase angle or integral cycle control on input ac voltage, to get the desired output ac voltage. However, the obvious disadvantages of ac thyristor controllers such as low power factor, large total harmonic distortion in source current and lower efficiency, have limited their use [3]. For ac-ac power conversions with variable frequency and voltage, the use of indirect ac-ac converters with de-link and matrix converters have been advanced because they can obtain better power factor and efficiency, and smaller filter requirements. However, for applications in which only voltage regulation is needed, the direct PWM ac-ac converters All of these direct PWM AC - AC converters in are obtained from their dc-dc counterparts, where all the unidirectional switches are replaced with bidirectional devices. However, each topology has its own limitations; the buck type ac-ac converter, can only step-down the input voltage while boost type can only step-up the input voltage. The buck-boost and Cuk topology can both step-up and step-down the input voltage, however, the phase angle is reversed. Moreover, both topologies have disadvantage of higher voltage stress across switches, and there are discontinuous input and output currents in case of the buck-boost converter. The Cuk topology can overcome the currents discontinuity but at the cost of additional passive components; increasing the size and cost of converter and decreasing the efficiency. All of the direct PWM ac-ac converters have a common commutation problem, which occurs because compared to the ideal situation in which the complementary.
A. **AC–AC Converter**

This section Figure 3.1 shows the circuit topology of the AC-AC converter consisting of six unidirectional current flowing bidirectional voltage blocking switches $S_1 - S_6$, one inductor $L$, and two input and output filter capacitors $C_{in}$ and $C_o$. The six unidirectional current switches can be realized by series combination of power MOSFETs with external fast recovery diodes, as shown in Figure 3.1. In this figure, body diodes of MOSFETs are not shown as they never conduct, and thus, their poor reverse recovery problem is eliminated. For high power applications, it can either use six reverse blocking IGBTs (RB-IGBTs), or six IGBTs (without body diode) with external fast recovery diodes in series. This converter can operate as traditional non-inverting buck and boost converters with voltage gain of $D$ and $1/(1-D)$, respectively, and also as inverting buck-boost converter with voltage gain of $(D/(1-D))$. By using only six switches, it can combine the functionality of eight switches non-inverting buck-boost converter shown in Fig. 1.1 and four switches inverting buck-boost converter shown in Fig. 1.2. Therefore, it can be used as non-inverting buck-boost converter to replace the traditional inverting buck-boost converter in various ac-ac conversion applications. For its as DVR, the non-inverting buck-boost mode can be used to compensate voltage sags (which occurs more often), and inverting buck-boost mode for voltage swells (which occurs less often). The current and voltage stresses of the components in the converter are calculated and in this section, the design parameters of inductor and switches will be determined based on maximum values of their stresses for its operation.

B. **Non Inverting Buck Mode**
Operating principle
The PWM switching sequence of the converter during non-inverting buck mode operation and key waveforms are shown in Figure 4. The modes of operations include:

a. Positive Cycle
Figure 5 shows operation circuit Positive half of input ac voltage \((v_{in} > 0)\), switches \(S1, S3, S6\) are always turn on and \(S4, S5\) are always turn off, while switch \(S2\) is switched at high frequency. Fig. 3.3 shows the equivalent circuits of the proposed converter for \(v_{in} > 0\).

For \(v_{in} < 0\), switches \(S2, S4, S5\) are always turn on while switches \(S3, S6\) are always turn off, and \(S1\) becomes high frequency switch. The operation for \(v_{in} = 0\) is same as explained for \(v_{in} < 0\), with only difference is that now the switch \(S1\) performs same as \(S2\) (for \(v_{in} > 0\)), and vice-versa. The equivalent circuits during this negative half-cycle are shown in Fig. 6 (a) and (b). By applying volt-sec balance condition on inductor \(L\) from above equations, the gain in this buck mode is given by
\[
\frac{V_o}{V_i} = D
\]
It can be concluded that the voltage gain of the proposed ac-ac converter in this operation mode is same as that of non-inverting buck ac-ac converter.

C. Non Inverting Boost Mode
The switching sequence of the converter during non-inverting boost mode operation and key waveforms are shown in below figure 7.

For \(v_{in} < 0\), switches \(S2, S4, S5\) are always turn on while switches \(S3, S6\) are always turn off, and \(S1\) becomes high frequency switch. The operation for \(v_{in} = 0\) is same as explained for \(v_{in} < 0\), with only difference is that now the switch \(S1\) performs same as \(S2\) (for \(v_{in} > 0\)), and vice-versa. The equivalent circuits during this negative half-cycle are shown in Fig. 6 (a) and (b). By applying volt-sec balance condition on inductor \(L\) from above equations, the gain in this boost mode is given by
\[
\frac{V_o}{V_i} = D
\]
It can be concluded that the voltage gain of the proposed ac-ac converter in this operation mode is same as that of non-inverting buck ac-ac converter.
inverse output voltage $v_o$ across it. Therefore, no current flows through switch S6 during this interval, as shown in Fig. 8(a). Applying KVL, we get

$$V_L = V_{in} - V_o$$

During (1-D)T interval as shown in Fig. 3.6(b), switch S5 is turned off while S6 conducts in this interval as its series diode becomes forward biased due to freewheeling action of inductor L current. Energy stored in inductor is released to load in this interval.

Applying KVL yields,

$$V_L = V_{in} - V_o$$

Figure 8: Operation during positive half of input ac voltage (a) During (D) (b) During (1-D)

b. Negative Half Cycle

For $V_{in} < 0$, switches S1, S4, S6 are always turn on while switches S2, S3, are always turn off, and S6 becomes high frequency switch. The operation for $V_{in} < 0$ is same as explained for $V_{in} > 0$, with only difference is that now the operation of switch S6 is same as that of S5 (for $V_{in} > 0$), and vice-versa. The equivalent circuits during this half-cycle are shown in Fig. 3.7(a) and (b). By applying volt-sec balance condition on inductor L from above Equations, the voltage gain in this boost mode is given by

$$\frac{V_o}{V_{in}} = \frac{1}{1-D}$$

It can be concluded that the voltage gain of the proposed ac-ac converter in this operation mode is same as that of non-inverting boost ac-ac converter.

### III. SIMULATION RESULTS

The simulation was done in MATLAB/SIMULINK 2014a. The simulation model and result for the two stage configuration is shown. A constant output voltage of 110 V is maintained for input voltages in each configuration. Simulation is done for an input voltage of 70 V for boost operation and 152 V for Buck and Buck-Boost operations, with switching frequency of converter $f_s = 50$ KHz and PWM frequency chosen is 25 KHz. Generation of switching signals involves switching pulses for converter switches S1 to S6. For each configuration, the switching pulses for switches changes according to the configuration requirement. The PWM switching frequency is chosen to be 25 KHz for PWM Switched Switches and 50 Hz for other 4 switches.

Table 2: Simulation Parameters

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<th>COMPONENTS</th>
<th>SPECIFICATION</th>
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<tr>
<td>Input Voltage, $V_{in}$</td>
<td>70Vrms</td>
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<td>Output Power</td>
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<td>Switching Frequency</td>
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<td>Input Inductor, $L$</td>
<td>800 µH</td>
</tr>
<tr>
<td>Input Capacitor, $C_i$</td>
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<tr>
<td>Output Capacitor, $C_o$</td>
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Table 3: Prototype Parameters

<table>
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<tr>
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<td>Input Voltage, $V_{in}$</td>
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<tr>
<td>Output Power</td>
<td>300 W</td>
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<tr>
<td>Switching Frequency</td>
<td>25KHz</td>
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<tr>
<td>Input Inductor, $L$</td>
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<tr>
<td>Input Capacitor, $C_i$</td>
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<tr>
<td>Output Capacitor, $C_o$</td>
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<td>MOSFET (ST-60)</td>
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<tr>
<td>Diode (DS-40)</td>
<td>96V45A</td>
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</tbody>
</table>

Figure 8: Gate signal to converter switches (a) S1 S3 (b) S2 S4 (c) S5 (d) S6
IV. EXPERIMENTAL RESULTS

Prototype with reduced voltage had been developed. For Boost converter mode an input voltage of 12 V is given with a duty ratio of 42% and with a switching frequency of 25 KHz for S₅ & S₆ and other switches S₁- S₄ at 50hz and for buck converter mode an input voltage of 12 V is given with a duty ratio of 72% and with a switching frequency of 25 KHz for S₁ & S₂ and other switches S₃- S₆ at 50hz

The switching pulses were developed using PIC 16F877A and driver IC used is TLP250. An output voltage of about 18 V and 9 V was obtained. Table 3 shows the prototype parameters used for experimental verification. Experimentally obtained value is 12.18 V which is nearly equals to the calculated value.
V. CONCLUSION

This paper is based on the development and analysis of the multiple mode operations in a AC-AC Converter topology. Compared with popularly used other converters, this topology has less high frequency active switches. Six switch converter circuit with reduced stress, less component count and high gain is proposed for multiple mode operations. For an input voltage of 12 V, output voltages for boost, buck modes and buck boost mode can be obtained. A closed-loop control of converter session can be done to maintain constant voltage at the output of the converter. A prototype converter section is tested and results are experimentally verified. Future scope involves increasing the modes included in converter with less complexity in control.

VI. ACKNOWLEDGMENT

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REFERENCES