Simulation of boost AC-AC converter using single-phase matrix converter

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ABSTRACT
Generally, AC-AC converters are implemented using thyristors. These converters generate harmonics and have a low power factor. To eliminate these problems matrix converters (MC) are become used as AC-AC converter. Matrix converters have the capability of being used as frequency changer, rectifier, inverter and chopper. In this work, it is proposed to achieve the desired output of AC-AC Boost converter using single phase matrix converter (SPMC). The operation of single-phase AC-AC boost converter using MC is studied in this paper. The output voltage of this boost converter is higher than the AC input supply voltage. insulated gate bipolar transistors (IGBTs) are used as the switching elements in the SPMC power circuit. Sinusoidal Pulse width modulation (SPWM) technique is applied to generate switching signals to obtain the output voltage. The model of the matrix converter is constructed in MATLAB/Simulink programming software package. The behavior of SPMC is simulated with various switching frequencies. The simulation results together with harmonic spectrum and total harmonic distortion (THD) values are presented. Successful operation of boost SPMC is achieved.

1. INTRODUCTION
Some industrial applications require an AC-AC conversion. AC voltage controllers with thyristors were performed this AC-AC conversion. This type of circuits distorts voltage and current waveform and have a low power factor. Therefore, power factor correction and harmonic reduction are necessary for these voltage regulators. To overcome these problems matrix converters has taken place of the AC voltage controllers. In a matrix converter (MC) circuit there are input and output lines. Matrix converter consists of bidirectional switches arranged in matrix form, connected between input and output lines. The switches in the converter circuit are both capable of conducting current in both directions that is bidirectional and capable of blocking voltage. Many research works have been done on SPMC implementation [4]-[9], [14]-[16].
Matrix converters can produce an output with variable voltages and frequencies. Various circuit topologies such as frequency changer, rectifier, inverter and chopper can be constructed with the MC with simple structure and high reliability. Because the boost MC is poorly studied in the literature, it is aimed to emphasize the boost characteristics of the matrix converter. Therefore, in this study, a single-phase boost AC-AC matrix converter is studied which has a higher output voltage than a low input voltage. Insulated gate bipolar transistors (IGBTs) are used as switching elements in the SPMC circuit. The output voltage is obtained through duty cycle control of switching device using the sinusoidal pulse width modulation (SPWM) technique. A resistive load is used with an LC filter for removing ripples at the load. An inductance is connected in series with the input supply for boost operation. A model of SPMC for boost AC-AC operation is developed in Simulink. The validation of the model is performed through simulations. The model is tested with different switching frequencies. The simulation results show the successful boost operation of SPMC.

2. SINGLE PHASE BOOST AC-AC MATRIX CONVERTER

One of the practical problems faced in the implementation of MC is commutation. Due to having no freewheel paths, the safe transfer of the current between the switches is difficult. The switching has to be so done as to maintain continuous load current and prevent short circuit. The commutation of current can generate over voltages that can disturb the semiconductor switches. For inductive loads, at the switch turn off instants there need to be an alternative current flow path that avoids over voltages. For this, four bidirectional switches in which current flow in both directions are used in the SPMC circuit as in Figure 1. An antiparallel IGBT and diode pairs, as represented in Figure 2, is connected to obtain the bidirectional switches. Diodes are used to add reverse blocking capability to bidirectional switches.

![Figure 1. Single phase matrix converter](image1)

![Figure 2. A bidirectional switch](image2)

The studied converter circuit topology is given in Figure 3. A load is connected to the output of the converter. This load comprises a resistive load and an LC filter. An inductor L is connected in series with the supply to provide boost operation.
3. SINUSOIDAL PWM

Due to its simplicity, SPWM is one of the most common used methods in power electronic circuits for digitally control of the switching commutation [17]. This modulation technique has advantages of reduced filtering requirements, less mathematical calculations, and high transmitted of effective power. In SPWM method, which is presented in Figure 4, basically, a high frequency sawtooth shaped carrier signal, \( V_c \), is compared with a sinusoidal reference signal, \( V_r \), with the desired frequency. The switching times are determined by the intersect points of the reference and carrier waves [6]-[13].

The modulation scheme uses the SPWM technique to obtain a signal which resembles of the reference sinusoidal signal. That is, the produced signal implicitly includes the amplitude and frequency information of the modulating wave. SPWM scheme block diagram is given in Figure 5.

The ratio of magnitude of the reference wave (\( V_r \)) to the magnitude of the carrier wave (\( V_c \)) is defined as the modulation index (\( M_i \)). Generally, the carrier signal \( V_c \) has a fixed amplitude. The output voltage can be changed by controlling the \( M_i \) [18].
4. SPMC MODES

SPMC has different topologies and operation modes depending on commutation scheme. These modes of SPMC are chopper, buck, boost, rectifier, rectifier with power factor correction and cycloconverter.

One of the operation mode of the matrix converters is AC-AC converter or cycloconverter. In this mode, the matrix converter is used to obtain AC voltage with variable amplitude and frequency without DC link. The control system is used to produce SPWM patterns to control the power switches.

4.1. Boost AC-AC operation

The boost AC-AC converter has four operation modes as shown in Figure 6. Two of the operation modes occur in the first half period and the other two operation modes occur in the next half period. The current flow for commutation switches is represented by bold line and the control (SPWM) switch is represented by the dotted line.

Mode 1 is the charging operation mode and starts when both switches S1a and S3a are closed. The input current through the inductor rises.

Mode 2 is the discharging operation mode. This mode starts when switches S1a and S4a are closed while S3a is open. The current flowing through S3a in mode 1 is transferred to the load in mode 2. The inductor current decreases till S3a has turned on again. The load receives the stored energy of the inductor L.

The other two modes have the same operation during the next half period.

Figure 6. Boost AC-AC converter topology: (a) Positive cycle, (b) Negative cycle
5. MODELING AND SIMULATION RESULTS

The boost SPMC is modeled using MATLAB/Simulink. The converter circuit parameters are listed in Table 1. The Simulink model of boost AC-AC converter with SPMC and switching signal production are shown in Figure 7 and Figure 8 respectively. The comparison of the sinusoidal reference wave with the triangular carrier wave produces the PWM signals. The triangular carrier wave is produced with the “Repeating Sequence” block of the Simulink.

Table 1. Parameters of SPMC

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage</td>
<td>15 Vp</td>
</tr>
<tr>
<td>Boost Inductor</td>
<td>20 mH</td>
</tr>
<tr>
<td>Load Resistor</td>
<td>50 Ω</td>
</tr>
<tr>
<td>LC Filter</td>
<td>5 mH, 570 µF</td>
</tr>
</tbody>
</table>

The switching scheme for SPMC as a boost AC-AC converter, as explained in section iv, is listed in Table 2 and the switching algorithm is given by Figure 9 for 50 Hz operation.

Table 2. Switching strategy

<table>
<thead>
<tr>
<th>Switches</th>
<th>S1a</th>
<th>S1b</th>
<th>S2a</th>
<th>S2b</th>
<th>S3a</th>
<th>S3b</th>
<th>S4a</th>
<th>S4b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive Cycle</td>
<td>Mode1</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>Mode2</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
</tr>
<tr>
<td>Negative Cycle</td>
<td>Mode3</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>Mode4</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
</tr>
</tbody>
</table>
The boost SPMC model is simulated with the parameters listed in Table 1. Figure 10 and Figure 11 present the obtained output voltages with switching frequency of 5 KHz and 10 KHz respectively. The modulation index, $m_i$, for each simulation, is set to 0.5. 15 V peak input voltage is used in the simulations. The produced output voltage is 46.33 V peak for switching frequency of 5 KHz and 51.1 V peak for switching frequency of 10 KHz.

Figure 9. Switching algorithm of AC-AC boost SPMC

Figure 10. SPMC output voltage with switching frequency $f_c=5$ KHz

Figure 11. SPMC output voltage with switching frequency $f_c=10$ KHz
Figure 12(a) and 12(b) represent the spectrum analysis for measuring THD of output voltage for switching frequencies 5 KHz and 10 KHz respectively. It can be seen in the simulations presented, increasing the carrier wave frequency, increases the output voltage. The simulations show that the output voltage is about 3 times higher than that of the input. The total harmonic distortions (THD) are 3.56 % and 3.71 % for 5 KHz and 10 KHz switching frequencies respectively. The total harmonic distortion calculated for the simulations presented stays within the standards. The IEEE standard for THD is 5 % [19], [20].

![Harmonic spectrum of output voltage](image)

Figure 12. Harmonic spectrum of output voltage: (a) fc=5 KHz, (b) fc=10 KHz

6. CONCLUSION

A study of boost AC-AC converter using SPMC is studied in this paper. The system is implemented in MATLAB/Simulink environment. The converter circuit is constructed using IGBT and diode pairs which are so connected to allow bidirectional current flow. The system is simulated with different switching frequencies. The simulation results have shown that the boost AC-AC converter with SPMC produce higher AC output voltage from a given AC supply voltage. It has been observed from the simulation results that changing the modulation index has no effect on the value of output voltage.

REFERENCES


BIOGRAPHIES OF AUTHORS

Zeynep Bala Duranay was born in 1985; received the BSc in Electrical and Electronics Engineering from the Faculty of Engineering, University of Firat, Turkey, in 2009; she received MSc from Gazi University, Turkey, in 2013 and PhD in 2017 from the Firat University, Turkey. Now she is assistant professor in Firat University, Technology Faculty. Her research interests are ac drivers, dc-dc converters and renewable energies.

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