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Simplified 1-Φ Matrix Converter as a Direct AC-AC Converter

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Abstract

This paper is concerned on implementation of Single Phase Matrix Converter (SPMC) as a direct AC- AC converter subjected to passive load conditions. In this paper, the switching spikes that could develop due to the presence of inductive load can be eliminated by providing a current path. The output voltage is synthesized using well-known sinusoidal pulse width modulation (SPWM) technique. The SPMC circuit requires four bidirectional switches which are capable of blocking both forward and reverse voltage, conducting current in both the directions. The feasibility of proposed topology is verified by using MATLAB SIMULINK and the results of the study are presented.

Keywords: Single Phase Matrix Converter (SPMC), Sinusoidal Pulse Width Modulation (SPWM), Insulated Gate Bipolar Transistor (IGBT), Direct AC-AC Converter, Commutation Strategies

Introduction

In the recent past, matrix converters have marked their presence as an advanced circuit topology that could perform a direct AC-AC power conversion employing nine bidirectional switches. It is a modern power conversion topology, that was first proposed by Gyugyi [1] in 1976, followed by Alesina and Venturini in1980 [2, 3], representing the circuit as a matrix of bi-directional power switches. It is a force commutated converter which uses an array of controlled bidirectional switches as the main power elements to create a variable output voltage system with unrestricted frequency.

There is presently considerable interest in matrix converter technology both in academic and industrial community [4]. One of the key benefits claimed for the matrix approach is the possibility of greater power density due to the absence of a DC link [5] in direct AC conversion. Matrix converter has been known to offer an "all silicon" solution for

AC-AC conversion, removing the need for reactive energy storage components used in conventional rectifier-inverter based system. In addition, matrix converter is able to operate in all the four quadrants of operation. These features make the matrix converter a suitable alternative to the traditional voltage source inverter [6]. Furthermore, it has the advantage of bidirectional power flow, high reliability and compact design. In comparison with conventional AC/DC/AC (rectifier-inverter) converter, it has the following merits:

1. No large energy storage components, such as large DC capacitors or inductors, are needed. As a result, a large capacity and compact converter system can be designed.
2. Four-quadrant operation is straightforward, by controlling the switching devices appropriately, both output voltage and input current are sinusoidal with only harmonics around or above switching frequency.
3. Clean input power characteristics with high input power factor.
4. Increased power density with the possibility of operating at high temperatures.

These ideal advantages can be fulfilled by matrix converter, and this is the reason for the tremendous interest in the topology.

The single-phase matrix converter (SPMC) has subsequently been investigated and has shown increased potential for use in converter designs. By manipulating its bi-directional switches additional new features could be designed and realized. The SPMC was first realized by Zuckerberger et al [7] in 1997 with other works on AC-AC [8], DC-DC [9], DC-AC [10] and more recently the AC-DC [11] operation.

The problem of commutation in SPMC occurs when inductive load is present due to the absence of freewheeling paths as available in other traditional converter topologies. The use of PWM type of switching algorithm in SPMC will result with possible switching spikes being developed during switch turn-off or during commutation. The main purpose of this paper is to describe successful implementation of the SPMC performing all the basic functions of a direct AC-AC converter. The SPMC had been designed and realized by synthesizing the output using the well-known SPWM technique [12]. The gate pulses for the switches are maintained in such a way that the switching spikes are avoided.

II. AC-AC CONVERTER

A conventional rectifier-inverter system that could perform frequency conversion can be depicted as shown in Fig.1, where the use of storage device for the DC link is necessary for operation. A direct AC-AC converter on the other hand converts a fixed frequency, fixed voltage input into a variable frequency, variable voltage output without the use of intermediate storage device. The basic AC-AC energy conversion described has three possible operations, namely; a) AC voltage controller, b) reduced frequency operation, c) increased frequency operation.

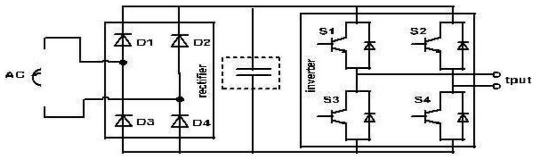


Fig. 1 Conventional rectifier-inverter AC-AC converter

III. SINGLE-PHASE MATRIX CONVERTER DESIGN

The matrix converter is a force commutated converter which uses an array of controlled bidirectional switches as the main power elements to create a variable output voltage system with unrestricted frequency. It does not have any dc-link circuit and does not need any large energy storage elements. The key element in a matrix converter is the fully controlled four-quadrant bidirectional switch, which allows high frequency operation.

The SPMC is presented in Fig. 2 V_{in} is the input voltage and V_{out} is the output voltage. It comprises of four bidirectional switches S_1-S_4.

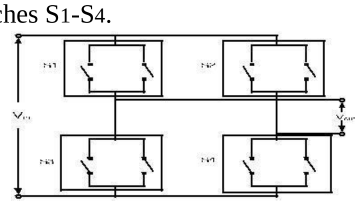


Fig. 2 Single phase matrix converter scheme

IV. BI-DIRECTIONAL SWITCH

The matrix converter requires a bidirectional switch which is capable of blocking both forward and reverse voltage, conducting current in both the directions. The common emitter bidirectional switch cell arrangement consists of two diodes and two IGBTs connected in anti parallel as shown in Fig. 3. The diodes are included to provide the reverse blocking capability.

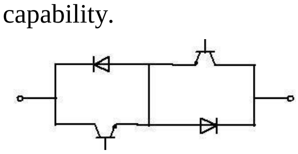


Fig. 3 Bidirectional switch

V. SWITCHING STRATEGIES

Driver circuits are designed to generate the SPWM patterns that are used to control the power switches, comprising IGBTs in the SPMC circuit.

The switching strategies for a 100 Hz output voltage and 50 Hz input voltage are explained as follows:

In this paper, the operation of the converter for the second cycle of input voltage is presented, so that how the current in the previous cycle can be reduced to zero can be well understood. The time period of input supply voltage is divided into four time intervals as shown below.

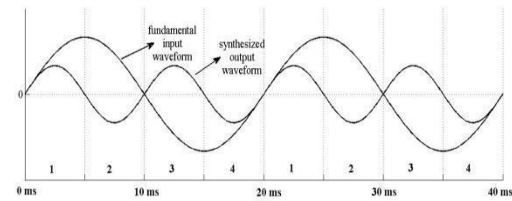


Fig. 4 Waveforms to indicate time intervals

In the first time interval, before inverting the current which was flowing in the previous cycle (of input voltage), we have to reduce it to zero so as to avoid voltage spikes that will result due to stored energy in inductive load. For providing path for the current to decay, the switching sequence and the operation of the circuit will be as shown in Fig. 5

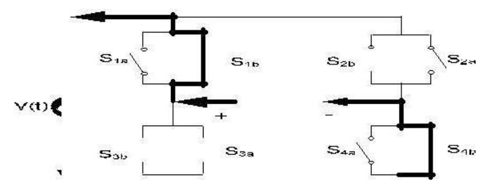


Fig. 5 Providing path for the current to decay in the 1^{st} interval

After the current reduces to zero, the current will invert and starts increasing in the direction as shown in Fig. 6

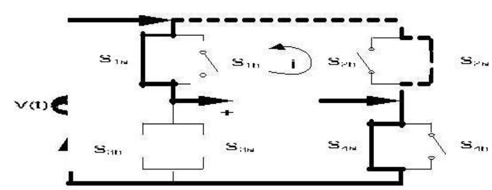


Fig. 6 Inverting and increasing the current in the 1^{st} interval

The SPWM gate pulses are produced by comparing a carrier wave (triangular wave of 2 KHz) with a reference wave (sine wave of 100Hz)

As SPWM gate pulses are applied to the switch S_{4a}, to avoid switching spikes due to inductive load gate pulse will be applied to switch S_{2a} .

Fig. 7 shows the waveforms of current through the switches S_{4a} and S_{2a} respectively in the 1^{st} interval

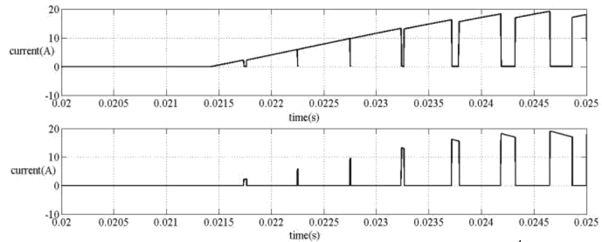


Fig. 7 Current through switches S_{4a}, S_{2a} respectively in 1st interval

In the second interval, for providing the path for the current of the first interval to decay, the switching sequence will be as shown in Fig. 8

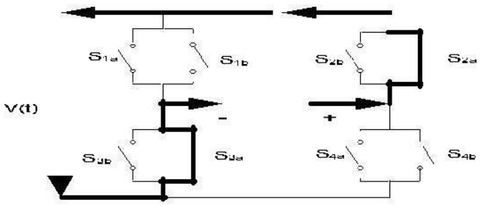


Fig. 8 Providing path for the current to decay in 2nd interval

After current is reduced to zero, the current will invert and increase in the direction as shown in Fig. 9 (gate pulse will be applied to switch S_{1b} to avoid switching spikes)

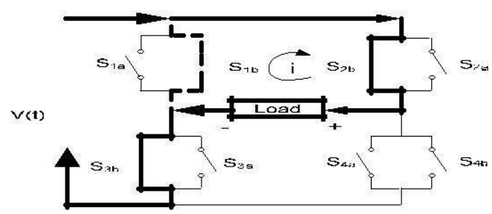


Fig. 9 Inverting and increasing current in 2nd interval

In the third interval, by providing a path, the current will decay to zero as shown in Fig. 10

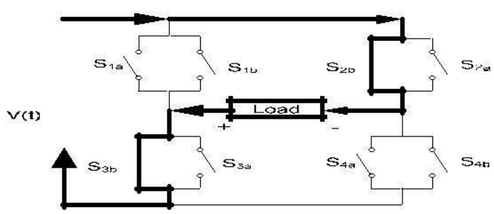


Fig. 10 Providing path for the current to decay in 3rd interval

The current will increase in the inverted direction as shown in Fig. 11

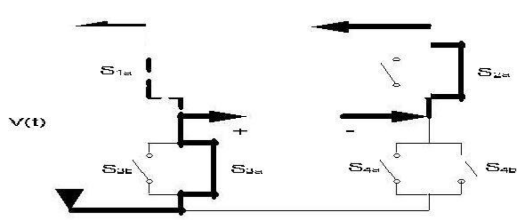


Fig. 11 Inverting and increasing current in 3rd interval

In the fourth interval, a path will be provided for the current to decay as shown in Fig. 12

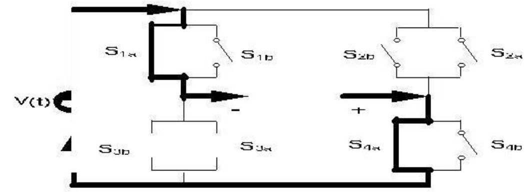


Fig. 12 Providing path for the current to decay in 4th interval

After current zero, current will increase in the inverted direction as shown in Fig. 13

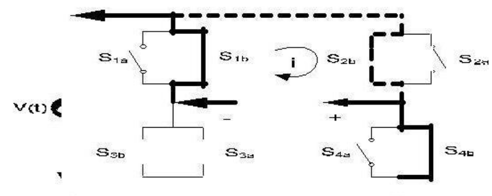
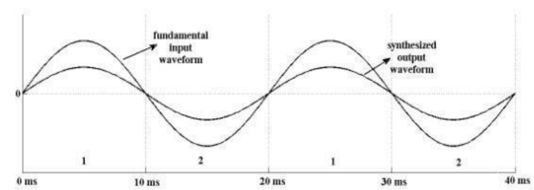


Fig. 13 Inverting and increasing current in 4th interval

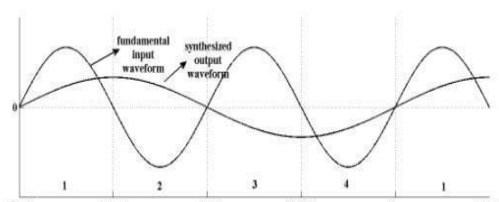
TABLE 1. SEQUENCE OF SWITCHING CONTROL

Input frequency	Output frequency	Time interval	PWM switch	Switches to which gate pulses are applied
50 Hz	100 Hz	1	S_{4a}	S_{1a},S_{1b},S_{4a},S_{4b},S_{2a}
		2	S_{3b}	S_{2a},S_{2b},S_{3a},S_{3b},S_{1b}
		3	S_{3a}	S_{2a},S_{2b},S_{3a},S_{3b},S_{1a}
		4	S_{4b}	S_{1a},S_{1b},S_{4a},S_{4b},S_{2b}
	50Hz	1	S_{4a}	S_{1a},S_{1b},S_{4a},S_{4b},S_{2a}
		2	S_{4b}	S_{1a},S_{1b},S_{4a},S_{4b},S_{2b}
	25Hz	1	S_{4a}	S_{1a},S_{1b},S_{4a},S_{4b},S_{2a}
		2	S_{3a}	S_{1a},S_{2a},S_{3a}
		3	S_{3b}	S_{2a},S_{2b},S_{3a},S_{3b},S_{1b}
		4	S_{4b}	S_{1b},S_{2b},S_{4b}

The waveforms explaining about the time intervals for output frequencies of 50 Hz and 25 Hz are shown in Fig. 14



(a)



(b)

Fig. 14 Waveforms explaining about time interval for output frequency of (a) 50 Hz (b) 25 Hz

VI. SIMULATION RESULTS

Simulation parameters	
Input supply voltage	221 V rms
Load resistance R	10 Ω
Load inductance L	0.0184H

By applying proper gating signals to switches the voltage spikes can be avoided. If the proper gating signals are not applied then the voltage spikes across load will be as shown in Fig. 15

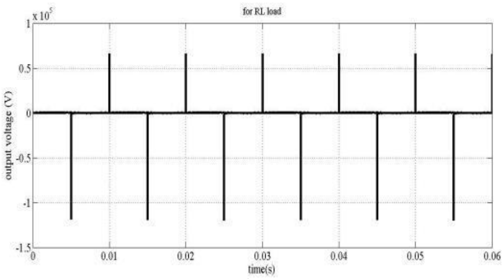
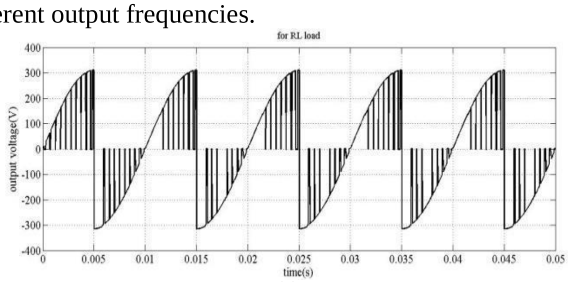
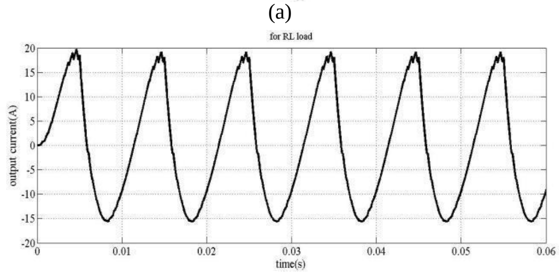


Fig. 15 Output voltage waveform across RL load at 100Hz

Proper gating signals are applied to the switches to avoid voltage spikes and the simulation results are shown below for different output frequencies.

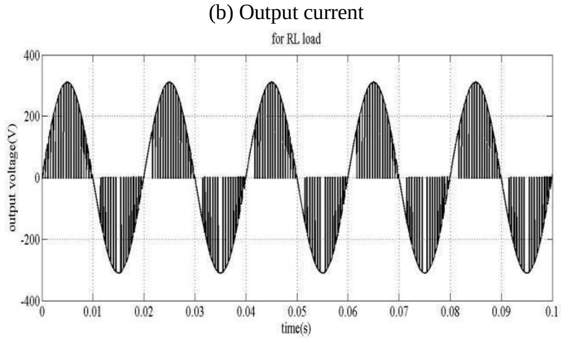


(a)

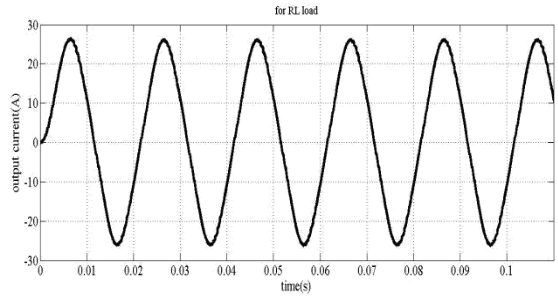


(b)

Fig. 16 Waveforms for RL load at 100Hz (a) Output voltage (b) Output current

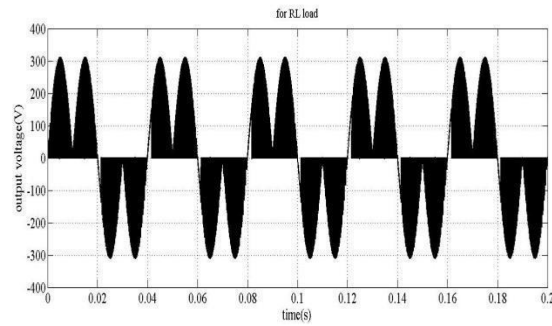


(a)

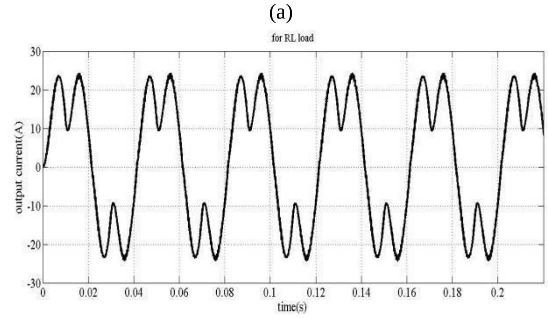


(b)

Fig. 17 Waveforms for RL load at 50Hz (a) Output voltage (b) Output current



(a)



(b)

Fig. 18 Waveforms for RL load at 25 Hz (a) Output voltage (b) Output current

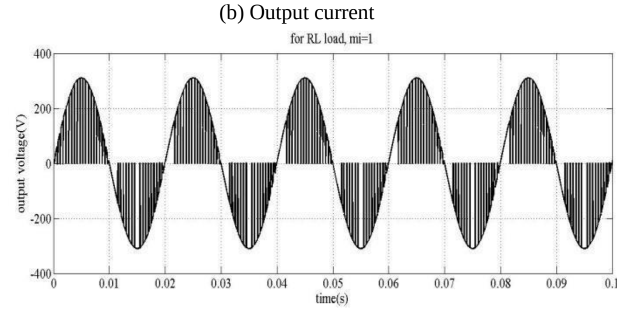


Fig. 19 Output voltage waveform across RL load at 50 Hz, with modulation index, m_i =1

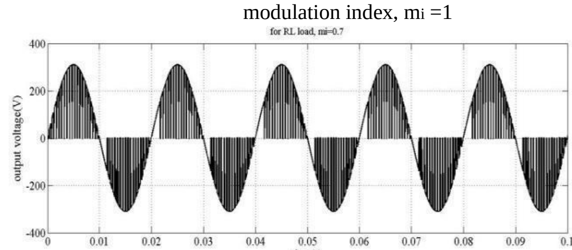


Fig. 20 Output voltage waveform across RL load at 50 Hz, with modulation index, m_i=0.7

VII. CONCLUSION

In this paper, a single-phase matrix converter as a direct AC-AC voltage controller with passive load condition is presented. Simulation results of the SPMC illustrates that it is feasible to realize the converter in the various basic AC-AC conversions that includes: AC voltage controller, step-up frequency changer and step-down frequency changer. The gate pulses for the switches are maintained in such a way that the switching spikes are avoided.

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