Chapter 2
Application of Sinusoidal Pulse Width Modulation Based Matrix Converter as Revolutionized Power Electronic Converter

K. Vijayakumar, R. Sundar Raj and S. Kannan

Abstract This Paper presents the application of Single Phase Matrix converter as a Cycloconverter and Cycloinverter. Sinusoidal Pulse Width Modulation (SPWM) technique is used to generate control pulses for the Matrix Converter switches to produce output. The switching sequences for the Matrix Converter to operate as Cycloconverter and Cycloinverter are presented and evaluated using MATLAB/ Simulink. The simulation results prove Single Phase Matrix Converter functionality as several power electronics converters by switching sequence via SPWM technique.

Keywords SPWM · Matrix converter · Cycloconverter

2.1 Introduction

Nowadays power electronics converters are used in many applications such as Industrial, Medical and Railways etc. Optimization of power electronic system design and operation is important to hold the growing need for energy efficiency in portable electric devices and respond to their increasing functional features. These features stipulate extra electric power while the devices must be reduced in size and weight. Power electronics converters like Rectifier and Inverters are used in various commercial and industrial applications. Inverters are used widely in many applications in which the required voltage is AC in nature. But still in most of the electrical drive system DC voltage is required due to ease of speed control in all the four quadrants. So rectifier find its part in which the voltage generated is DC. Power electronics converter also plays a major applicable role in DC motor drive con-

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trolling the speed in both forward and reverse direction by controlling the current in both the directions as well [1]. The Matrix Converter is a smart topology of power converter for direct power supply application with absence of electrolytic capacitors, potentiality of increasing power density, reduced size, weight and good input power quality [2]. An improved control structure for single phase Matrix Converter such that it can be used for different applications, is proposed in this paper. Development of control signals through Sinusoidal Pulse Width Modulation is presented and the Matrix Converter is evaluated for its operation based on switching sequence.

2.2 Single Phase Matrix Converter Topology

The circuit topology consists of four bi-directional IGBT switches which are configured in anti-parallel Common Emitter (CE) configuration. Matrix Converter in the three-phase variant is extensively researched at the same time as the single phase Matrix Converter had very little attention while offering the possibility of a very wide application. Single phase matrix converter was first released by Zuckerberger in 1997 as the direct single phase AC-AC converter [3]. The Single phase Matrix Converter can perform all the function of a generalized single phase power electronics converter only by varying the input parameters though having possibilities of single phase to three phase conversion in Matrix Converters [4]. The Matrix converter in single phase configuration is shown in Fig. 2.1. It consists of matrix of switches with two IGBTs connected back to back in CE configuration. The input to the Matrix Converter may be AC or DC depending on which the converter operation is made. The load is connected to supply directly through Matrix converter topology without any DC link (reactive energy storage elements). The output from the Matrix Converter is obtained by toggling of switches with control signals developed via SPWM. It is to ensure that the switches do not short-circuit voltage sources and open-circuit current sources [5].

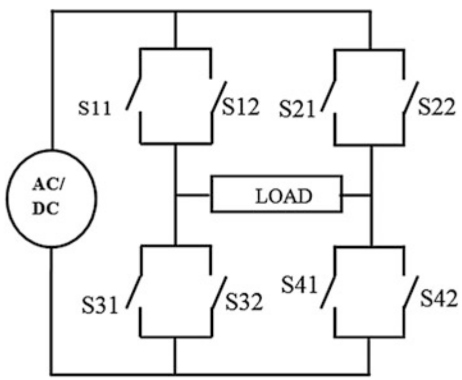

Fig. 2.1 Single phase matrix converter topology

2.3 Proposed Functionality of Matrix Converter

Figure 2.2 represents the functional block diagram in which the following operations possibilities could be elucidated as follows.

2.3.1 Matrix Converter Applicable as a Cycloconverter

The input supply to the Matrix Converter is chosen as AC for its operation as a Cycloconverter. In this condition if the related switches of the Matrix converter are toggled with control signals, then the Matrix converter will generate AC, which is called as Cycloconverter (AC-AC). For Cycloconverter mode of operation, the output frequency obtained is given by, $f_o = f_{in}/N_r$, Where, f_o = Output frequency, f_{in} = Input frequency and N_r = Real number. Here the desired output from the Matrix Converter could be used for variable frequency applications of AC drives and AC load purpose. The control signals when given to the switches S11, S41 & S22, S32 of the pair, positive load voltage is obtained across the load for the positive and negative cycles of the input AC voltage. Similarly when the switches S21, S31 & S12, S42 of the pair are toggled, negative load voltage is obtained across the load for the positive and negative cycles of the input voltage thus giving off the Cycloconverter function.

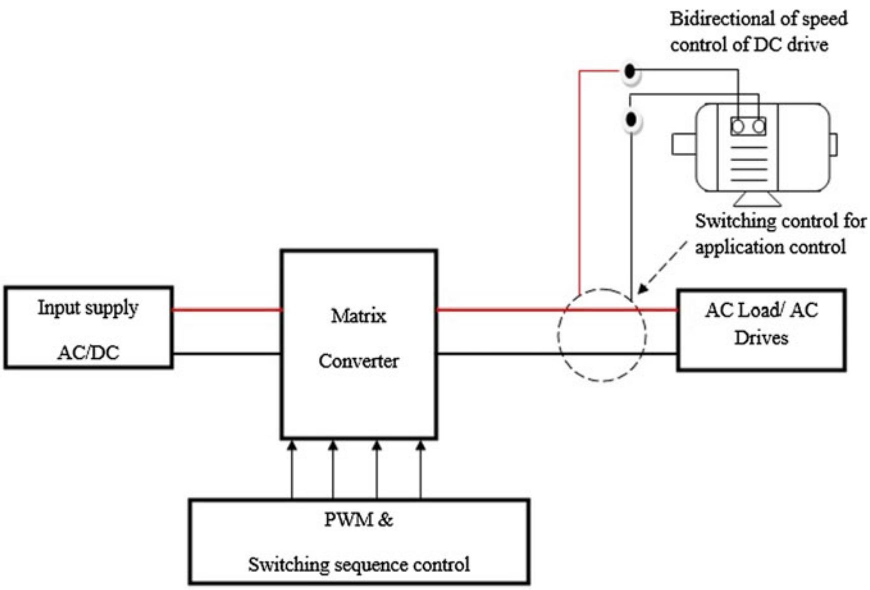

Fig. 2.2 Functional block diagram of matrix converter

2.3.2 Matrix Converter Applicable as a Cycloinverter

Similarly, if the Matrix converter is chosen with input supply AC, it operates as Cycloinverter in which the output frequency f_o will be $f_o = f_{in} \times N_r$, Where, f_o = Output frequency, f_{in} = Input frequency and N_r = Real number. In this condition if the related switches of the Matrix converter are toggled, it will generate AC, which is called as AC-AC Cycloinverter.

2.3.3 Matrix Converter Applicable as a Dual Converter, Rectifier and Inverter

With appropriate switch control for selecting application, the Matrix converter could be reliably used for bi-directional speed control of DC drive as in dual converter. The DC motor could be run in the positive direction by the toggling of switches S11 & S41 for the positive half cycle of the input AC voltage and S22 & S32 for the negative cycle of the input. For the DC motor to run in the reverse direction, the switches S21 & S31 and S12 & S42 are toggled with control signals for the positive and negative cycles of the AC input respectively. Similarly, the Matrix Converter could also be made applicable as Rectifier and Inverter [6].

2.4 Sinusoidal Pulse Width Modulation Technique

Sinusoidal Pulse Width Modulation (SPWM) technique is one of the simplest carrier-based modulation methods for the control of Matrix Converters. The SPWM is a familiar shaping technique in the field of Power Electronics where a high-frequency triangular carrier signal is compared with a sinusoidal reference signal. The main advantage of carrier based SPWM is that the complexity is very low and the dynamic response is also good for Matrix Converters [7]. The number of pulses per cycle is being decided by ratio of the triangular carrier frequency to that of modulating sinusoidal frequency. Modulation ratio (M_R) is given by the relation,

$$M_R = \frac{\text{Frequency of Carrier Waveform}}{\text{Frequency of the Modulating Waveform}} \tag{2.1}$$

M_R is related to the harmonic frequency and the harmonics are normally located at:

$$f = kM_R(f_m) \tag{2.2}$$

where f_m is the frequency of the modulating signal and k is an integer (1, 2, 3…)

Modulation index (M_I) is given by the ratio of Amplitude of modulating reference waveform to that of the Amplitude of carrier waveform and is denoted by,

$$M_I = A_r/A_c \tag{2.3}$$

where A_r is the reference amplitude and A_c the carrier amplitude

M_I is related to the fundamental (sine wave) output voltage magnitude. If M_I is high, then the sine wave output is high and vice versa.

When $0 < M_I < 1$, the linear relationship holds: $V_1 = M_I V_{in}$, where V_1, V_{in} are fundamental of the output voltage and input voltage, respectively.

2.5 Simulation Model

The simulation is carried out using MATLAB/Simulink and the implementation of SPWM is presented in Fig. 2.3. Here the triangular carrier signal of the switching frequency is compared with the sinusoidal reference signal and the control signals (pulses) are obtained for the positive and negative cycles of the sequence. The simulation output of SPWM is shown in Fig. 2.4.

The Cycloconverter operation is implemented using MATLAB/Simulink and is shown in Fig. 2.5. The operation of the Matrix Converter as Cycloconverter for positive output load voltage is obtained by the conduction of the switches S11, S41 for the positive half cycle of the AC input, and S22 & S32 for the negative half cycle of the input and similarly S21, S31, & S12, S42 for the negative output load

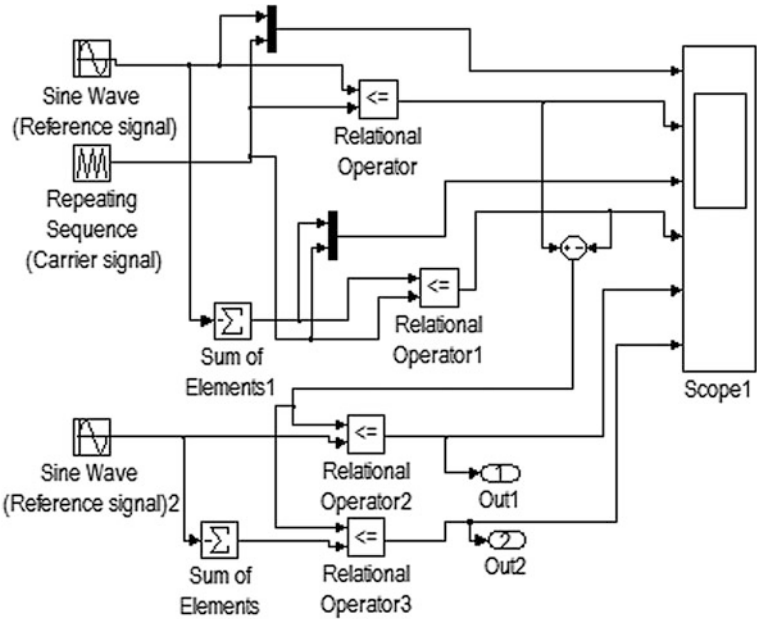

Fig. 2.3 SPWM implementation in MATLAB/Simulink

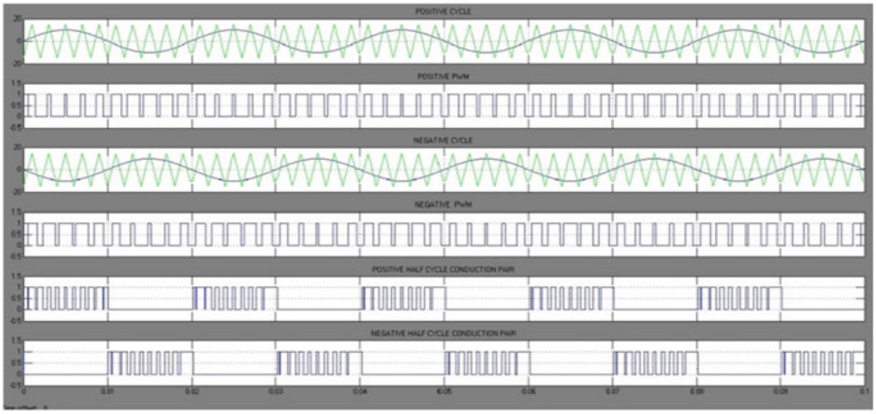

Fig. 2.4 SPWM output in MATLAB/Simulink

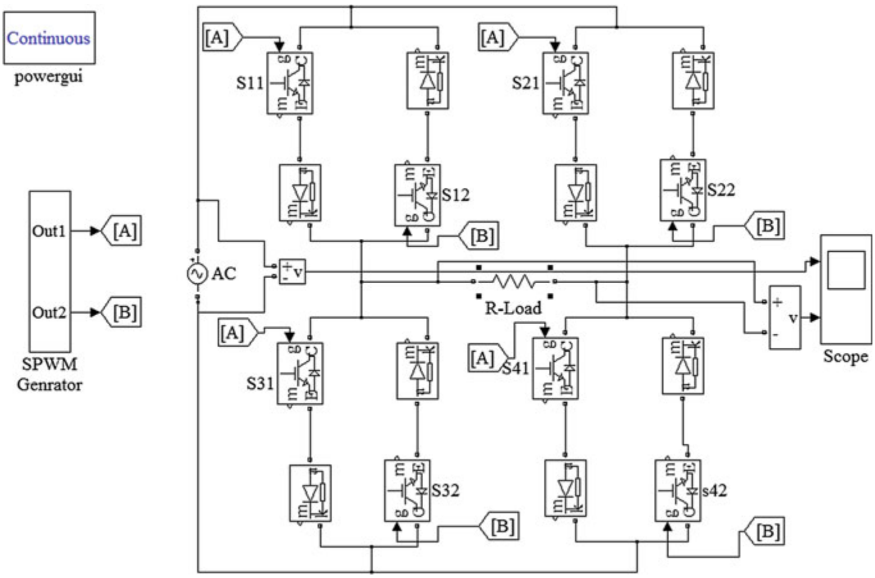

Fig. 2.5 Cycloconverter implementation in MATLAB/Simulink

voltage. For Cycloconverter mode of operation, the output frequency obtained is given by, $f_o = f_{in}/N_r$, Where, f_o = Output frequency, f_{in} = Input frequency and N_r = Real number. The operation of Matrix Converter as Cycloconverter could be easily understandable from the following simulation circuit and output.

An AC output voltage of 325 V peak and 50 Hz is obtained for the input voltage and switching frequency of 325 V DC and 5 kHz respectively for a resistive load of

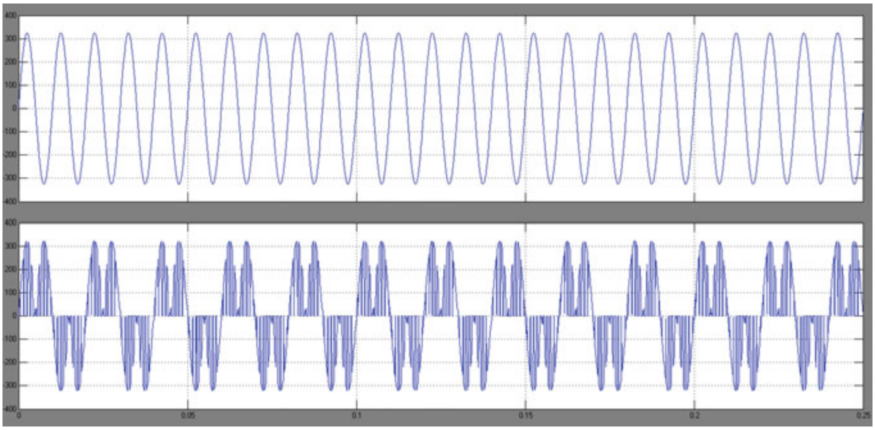

Fig. 2.6 Simulation output of Cycloconverter (100 Hz input voltage vs. 50 Hz output voltage)

50 Ω. The control signals are given by the SPWM technique as mentioned in Chap. 4. The simulation output is shown in Fig. 2.6.

Similarly, the Cycloinverter is implemented using MATLAB/Simulink. The operation as Cycloinverter is obtained by the conduction of switches S11, S41, S21, & S31 for the positive half cycle of the input and S22, S32, S12 and S42 for the negative half cycle of the input in which the output frequency f_o will be $f_o = f_{in} \times N_r$, Where, f_o = Output frequency, f_{in} = Input frequency and N_r = Real number. The output frequency of the Matrix Converter when working as Cycloinverter will be of the necessary value depending on the developed SPWM cycle frequency in which the output frequency is 100 Hz for an input of 50 Hz AC supply as shown in Fig. 2.7.

The Matrix Converter is implemented as dual-converter in MATLAB/Simulink with AC as supply input to the converter. When the control signals are given to the

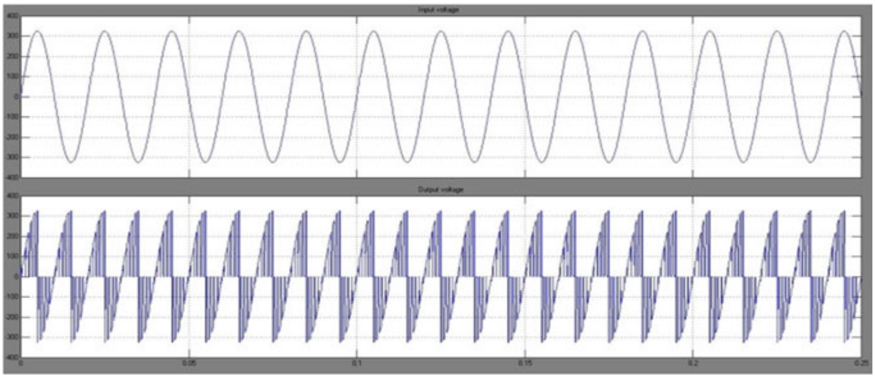

Fig. 2.7 Simulation output of Cycloinverter (50 Hz input voltage vs. 100 Hz output voltage)

Table 2.1 Matrix converter switching sequence and modes of operation

Supply sequence	Switching sequence	Mode of operation	Utility
Positive	S11 S41 & S22 S32	Cycloconverter operation	AC load/AC drive
Negative	S21 S31 & S12 S42		
Positive	S11 S41 & S21 S31	Cycloinverter operation	AC load/AC drive
Negative	S12 S42 & S22 S32		

switches S11 & S41 for the positive half cycle of the input AC voltage and S22 & S32 for the negative cycle of the input, the DC output is obtained in the positive potential. This positive load voltage serves running the DC motor in forward direction. The speed control is achieved by a change in the Modulation index M_I as given in Eq. 2.3 Similarly for the DC motor to run in the reverse direction the switches S21 & S31 and S12 & S42 are toggled with control pulses through SPWM for the positive and negative cycles of the AC input respectively. With a change in the Modulation index M_I, the speed is also controlled in the reverse direction of the DC motor. The operation of Matrix Converter as rectifier (switching states) is similar to the operation of dual-converter in obtaining positive load voltage. The switching states are presented in Table 2.1.

2.6 Conclusion

Generally the operation of converters and maintenance needs expertise and skilled manpower. But as proposed in this paper generalized functionality of Matrix Converter reduces the need for new converter hardware. The use of a Matrix Converter in the future reduces the need for learning many varying converter topologies. The Single phase Matrix Converter can perform all the functions of a generalized single phase power electronics converter only by changing the input parameters though having possibilities of single phase to three phase conversion in Matrix Converters.

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