State of the art of three phase to three phase Matrix Converter for Motor Drive

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Abstract— Matrix Converters (MC) have attracted increasing interest in recent years for industrial drive applications. Matrix converter does not require a dc link which has made it possible to reduce the size of converters by eliminating the use of energy storage elements. This paper focuses on the control of matrix converter from the perspective of converter switching functions which will find application in many power electronic systems like frequency converters, four-quadrant AC drives, wind electric generator etc. The advantages of space vector pulse width modulation (SVPWM) were identified and thus concluded that this method can be used as an optimized method for the control of matrix converter in various applications.

Key words: Matrix Converter (MC), Space vector pulse width modulation (SVPWM), Input filter, Clamp circuit

I. INTRODUCTION

In the past few decades, the modern high frequency switched mode converters employing fast power devices such as Insulated Gate Bipolar Transistors (IGBTs) have seen an evolution from the classical low switching frequency converters employing thyristors. This evolution has encouraged the interest of researchers to work on the existing technologies to make more efficient energy converters. High frequency switching has made it possible to reduce the size of converters by using smaller energy storage elements.

AC-AC converters are classified as indirect converters and direct converters. In indirect converters there exist a dc link which first converts AC to DC and then this DC is converted back to AC. Direct converter directly converts AC to AC and therefore it does not require a dc link. Matrix Converters are direct converters. This converter topology will play a large role in the application of industrial AC drives.

The principle of matrix converter was first proposed in 1976 by Gyugyi. In 1980, Venturini and Alesina published their work in which they presented the power circuit of the converter as a matrix of bidirectional power switches and they introduced the name “matrix converter”. The main feature of matrix converter is the fully controlled four-quadrant bidirectional switch which allows high frequency operation.

Research work is being done for the improvement in the control techniques for matrix converters. These modulation techniques are used to change the voltage transfer ratio of matrix converter. Using these modulation techniques, the output voltage is controlled by chopping the input voltage at proper instants and by constructing an output voltage waveform of desired amplitude and frequency.

Matrix converter find application in adjustable speed drives. They are more suited for constant power loads such as Induction motor or Permanent Magnet Synchronous Motor (PMSM).The paper presents a theoretical review on the Space vector modulation technique and its applicability to matrix converter.

II. MATRIX CONVERTER

A. Theory:

A three phase to three phase matrix converter consists of nine bidirectional switches that allow any output phase to be connected to any input phase. The input terminals of the converter are connected to a three phase voltage fed system while the output terminals are connected to a three phase current fed system. With the nine bidirectional switches, the matrix converter can have 512 different switching combinations. But the choice of switching states is based on two rules

- Input phases should never be short circuited as it is being supplied by a voltage source
- Output phases should never be open circuited due to the presence of inductive loads as the load current should not be interrupted

Based on these two rules only 27 switching combinations are permitted. Fig.1. shows a three phase to three phase matrix converter topology and the 27 switching combinations are shown in Table I. The table contains three group of switching combinations. In the first group there are six combinations in which each output phase is connected to a different input phase. In the second group there are 18 combinations in which two output phases are shorted. In the third group there are three combinations in which all the three output phases are shorted.

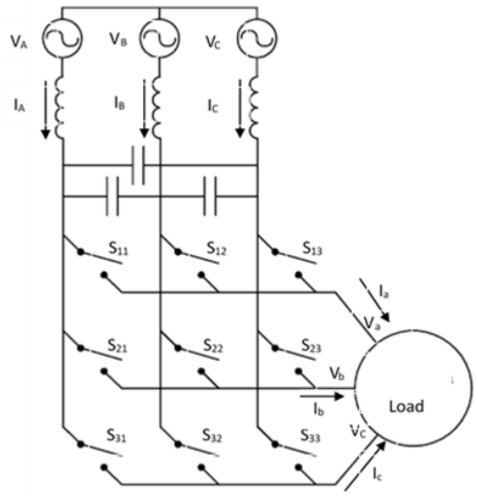

Fig. 1: Three phase to three phase matrix converter topology

B. Advantages and Limitations:

Matrix converter has several advantages over conventional AC-DC-AC converter. They are:

- Sinusoidal input and output waveforms
- Power flow is bidirectional

- Energy storage requirement is less
- Four quadrant operation is possible
- Longer operating life

Also it has several limitations as listed below

- Its input to output voltage transfer ratio is limited to 0.87
- It requires more number of semiconductor devices
- It is sensitive to disturbances
- Its control techniques are complex

Group	Vectors	a	b	c	Output Voltages			Input Currents			ON Switches		
					V_{ab}	V_{bc}	V_{ca}	I_A	I_B	I_C			
	1	A	B	C	VAB	V_{BC}	V_{CA}	I_a	I_b	I_c	S_{11}	S_{22}	S_{33}
	2	A	C	B	$-V_{CA}$	$-V_{BC}$	$-V_{AB}$	I_a	I_c	I_b	S_{11}	S_{23}	S_{32}
I	3	B	A	C	$-V_{AB}$	$-V_{CA}$	$-V_{BC}$	I_b	I_a	I_c	S_{12}	S_{21}	S_{33}
	4	B	C	A	V_{BC}	V_{CA}	V_{AB}	I_c	I_a	I_b	S_{12}	S_{23}	S_{31}
	5	C	A	B	V_{CA}	V_{AB}	V_{BC}	I_b	I_c	I_a	S_{13}	S_{21}	S_{32}
	6	C	B	A	$-V_{BC}$	$-V_{AB}$	$-V_{CA}$	I_c	I_b	I_a	S_{13}	S_{22}	S_{31}
	+1	A	C	C	$-V_{CA}$	0	V_{CA}	I_a	0	$-I_a$	S_{11}	S_{22}	S_{32}
	-1	B	C	C	V_{BC}	0	$-V_{BC}$	0	I_a	$-I_a$	S_{12}	S_{21}	S_{31}
II-A	+2	B	A	A	$-V_{AB}$	0	V_{AB}	$-I_a$	I_a	0	S_{12}	S_{23}	S_{33}
	-2	C	A	A	V_{CA}	0	$-V_{CA}$	$-I_a$	0	I_a	S_{13}	S_{22}	S_{32}
	+3	C	B	B	$-V_{BC}$	0	V_{BC}	0	$-I_a$	I_a	S_{13}	S_{21}	S_{31}
	-3	A	B	B	V_{AB}	0	$-V_{AB}$	I_a	$-I_a$	0	S_{11}	S_{23}	S_{33}
	+4	C	A	C	V_{CA}	$-V_{CA}$	0	I_b	0	$-I_b$	S_{12}	S_{21}	S_{32}
	-4	C	B	C	$-V_{BC}$	V_{BC}	0	0	I_b	$-I_b$	S_{11}	S_{22}	S_{31}
II-B	+5	A	B	A	V_{AB}	$-V_{AB}$	0	$-I_b$	I_b	0	S_{13}	S_{22}	S_{33}
	-5	A	C	A	$-V_{CA}$	V_{CA}	0	$-I_b$	0	I_b	S_{12}	S_{23}	S_{32}
	+6	B	C	B	V_{BC}	$-V_{BC}$	0	0	$-I_b$	I_b	S_{11}	S_{23}	S_{31}
	-6	B	A	B	$-V_{AB}$	V_{AB}	0	I_b	$-I_b$	0	S_{13}	S_{21}	S_{33}
	+7	C	C	A	0	V_{CA}	$-V_{CA}$	I_c	0	$-I_c$	S_{12}	S_{22}	S_{31}
	-7	C	C	B	0	$-V_{BC}$	V_{BC}	0	I_c	$-I_c$	S_{11}	S_{21}	S_{32}
II-C	+8	A	A	B	0	V_{AB}	$-V_{AB}$	$-I_c$	I_c	0	S_{13}	S_{23}	S_{32}
	-8	A	A	C	0	$-V_{CA}$	V_{CA}	$-I_c$	0	I_c	S_{12}	S_{22}	S_{32}
	+9	B	B	C	0	V_{BC}	$-V_{BC}$	0	$-I_c$	I_c	S_{11}	S_{21}	S_{33}
	-9	B	B	A	0	$-V_{AB}$	V_{AB}	I_c	$-I_c$	0	S_{13}	S_{23}	S_{31}
	0A	A	A	A	0	0	0	0	0	0	S_{11}	S_{21}	S_{31}
III	0B	B	B	B	0	0	0	0	0	0	S_{12}	S_{22}	S_{32}
	0C	C	C	C	0	0	0	0	0	0	S_{13}	S_{23}	S_{33}

Table 1: 27 Switching combinations of three phase to three phase Matrix Converter

C. Block Diagram:

Fig.2. shows the diagram of a Matrix Converter Drive which includes an input filter, clamp circuit and a load such as an induction motor. The input filter is required for reducing the harmonics generated by the converters. The clamp circuit is provided to protect the matrix converter from the overvoltage experienced both at the input side as well as output side. Overvoltage at the input side may be caused due to the supply side perturbations and that at the output side may be produced whenever an emergency shutdown of the converter takes place. The clamp circuit is made up of one or two capacitors connected to all input and all output lines through two diode rectifier bridges. It acts as a freewheeling path for the load current and thereby de-energizing the load. Matrix converter may require two types of shutdown namely controlled shutdown and emergency shutdown. Controlled shutdown is initiated by the user making the load current to zero by slowly reducing the power to the load to zero. Fault conditions causes emergency shutdown of the converter which interrupts the load current. But due to the presence of inductive load this interruption should not take place as it may cause inductive kick voltage. So a protective circuitry should be provided in order to discharge this current safely as the matrix converter does not have a natural freew

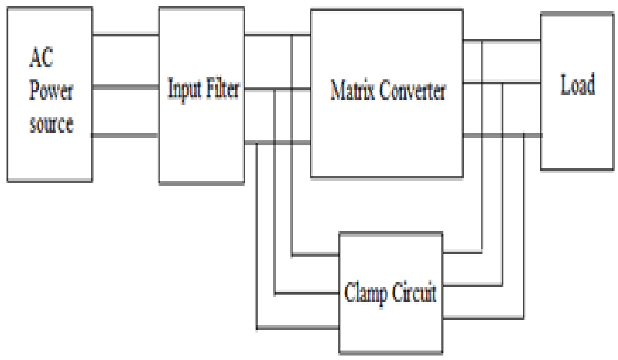

Fig. 2: Block Diagram of Matrix Converter Drive

III. Modulation Techniques

A. Alesina-Venturini Method:

It is the first control method developed for matrix converter. But it has a disadvantage that its voltage transfer ratio is limited to 0.5. Also for controlling the input power factor the knowledge of output power factor is required.

B. Space Vector Modulation Technique:

This method has several advantages such as generation of output voltage of desired amplitude and frequency at the converter output, sinusoidal input currents with unity power factor operation at input for all loads; its maximum voltage transfer is 0.866. It can be applied to output voltage and input current control. By using this method, the synthesis of output voltage is done by time averaging of the selected vectors from a set of converter output vectors in each sampling period.

IV. Implementation of Space Vector Pulse Width Modulation

The space vector modulation process consists of two parts: switching vector selection and computation of vector time interval.

A. Switching Vector Selection:

Table I shows all the different switching vectors for output voltages and input currents. The vectors in group I do not occupy a fixed position in space. So it cannot be used for the synthesis of the desired output voltage and input current space vectors. For the synthesis of the desired output voltage and input current space vectors, the vectors from group II and group III are utilized which occupy fixed position in space. There are 18 active vectors in group II and are obtained when two phases are connected to the same input line and third to a different input line. The magnitudes of the active vectors are functions of input line voltages and output line currents. There are three zero vectors in group III and the vectors have zero magnitude. Zero vectors are obtained when all the three output phases are shorted and connected to the same input phase.

B. Computation of Vector Time Interval:

In SVM, during each sampling period, the reference output voltage vector is expressed as a weighted average combination of the four active vectors and one zero vector. If V_1, V_2, V_3 and V_4 are the active voltage vectors and V_0 the zero voltage vector then

$$Vref.Ts= V1T1+V2T2+V3T3+V4T4+V0T0 \quad (1.1)$$

Where T_1, T_2, T_3, T_4 and T_0 are the time durations of application of V_1, V_2, V_3 ,V_4 and V_0 respectively.

If I_1, I_2, I_3 and I_4 are the active current vectors and I_0 the zero current vector then

$$Iref.Ts = I1T1+I2T2+I3T3+I4T4+I0T0 \quad (1.2)$$

$$T_0=T_s-(T_1+T_2+T_3+T_4) \quad (1.3)$$

Where T_1, T_2, T_3, T_4 and T_0 are the time durations of application of I_1, I_2, I_3 , I_4 and I_0 respectively. By resolving equations (1.1) and (1.2) along mutually perpendicular α - β axes, T_1, T_2, T_3, and T_4 can be determined and from equation (1.3), T_0 can be determined.

The knowledge of both the input current and output voltage vector are required for performing SVPWM. It is possible to find out different combinations of input current and output voltage vectors. Fig.3. shows the output voltage sectors and the input current sectors. When the output voltage vector is in a particular sector, the input current vector moves through all the six sectors.

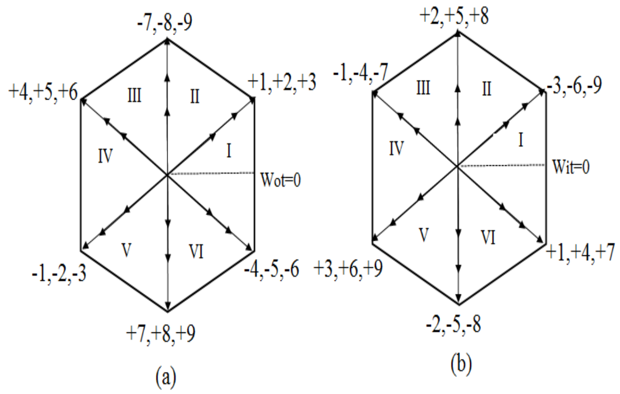

Fig. 3: (A) Output Voltage Sector (B) Input Current Sector

In each sampling duration, there are five vectors to be switched (four active vectors and a zero vector). Table II shows the switching sequence for different combinations. To reduce the switching losses in the converter, the selection of sequence should be such that the transition from one switch combination to another in the sequence should cause only one switch position change.

Sector				Vectors to be switched
V_o	I_o	V_o	I_o	
1	1	4	1	+1 -4 +6 -3 0A
1	2	4	2	+6 -3 +2 -5 0C
1	3	4	3	+2 -5 +4 -1 0B
1	4	4	4	+4 -1 +3 -6 0A
1	5	4	5	+3 -6 +5 -2 0C
1	6	4	6	+5 -2 +1 -4 0B
2	1	5	1	+1 -7 +9 -3 0A
2	2	5	2	+9 -3 +2 -8 0C
2	3	5	3	+2 -8 +7 -1 0B
2	4	5	4	+7 -1 +3 -9 0A
2	5	5	5	+3 -9 +8 -2 0C
2	6	5	6	+8 -2 +1 -7 0B
3	1	6	1	+4 -7 +9 -6 0A
3	2	6	2	+9 -6 +5 -8 0C
3	3	6	3	+5 -8 +7 -4 0B
3	4	6	4	+7 -4 +6 -9 0A
3	5	6	5	+6 -9 +8 -5 0C
3	6	6	6	+8 -5 +4 -7 0B

Table 2: Switching sequence for different combinations

V. Conclusion

In this paper, a study has been done on the main characteristics of three phase to three phase matrix converter. The principle of operation, advantages and disadvantages of matrix converter has been discussed. There are different control techniques for matrix converter. It can be analyzed that SVPWM has several advantages over other methods. So it can be concluded that by using SVPWM, performance of matrix converter can be improved.

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