A Review on Matrix Converter Topologies for Adjustable Speed Drives

Maheswari K.T. , Bharanikumar R. , Bhuvaneswari S.

Abstract: A detailed review on matrix converter circuits for adjustable speed drive applications has been presented in this paper. The power converter that is made up of a group of nine switches used to link three phase ac source to the load is called AC to AC Matrix Converter. Matrix Converter is capable to transform input with constant amplitude and frequency to three phase output with variable amplitude and variable frequency, as it is able to produce any frequency at the output as integer multiple of input. The attractive characteristics of Direct matrix converter are intrinsic four quadrant operation, high power factor at the input side, no intermediate capacitor, high regenerative capability, increased power density, light weight and reliable. However, some of the striking feature of these converters has been under research for the last few decades. The use of various topologies of matrix converter, and its PWM methods to get desired performance in adjustable speed drives have been discussed in this paper.

Index Terms: Direct matrix Converter, Four Quadrant Operation, PWM Methods, Regenerative Capability

I. INTRODUCTION

In recent years, the application of variable speed drives in industrial and commercial facilities has been increased greatly. Hence, the need for ac-ac conversion that converts three phase input to the three phase load, becomes essential in order to get variable frequency, amplitude and phase for several applications. The ac to ac converters receive power from the input source and distribute it to the three phase output with desired voltage and frequency. To enrich the characteristics, efficiency and the consistency of the systems, various power converter circuits are presented nowadays. In [1]-[2] the author discussed about the maximum voltage transformation ratio of direct AC-AC pulse-width- modulated converters. An inherent limit, independent of the control strategy, was found. To achieve maximum output capacity with some interesting features, a appropriate innovative converter control algorithm was presented. Lastly, the chance to establish control strategy for matrix converter by using feedback methods was deliberated, and a feedback-based modulation strategy for the converter was also explained.

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Maheswari K.T., Department of EEE, Bannari Amman Institute of Technology, Sthyamangalam,Tamilnadu,India.

Bharanikumar R., Department of EEE, Bannari Amman Institute of Technology, Sthyamangalam,Tamilnadu,India

Bhuvaneswari S., Department of EEE, Bannari Amman Institute of Technology, Sthyamangalam,Tamilnadu,India.

The paper [3] explains the progress and growth of this type of power converter with a thorough historic background. The most important a control strategies and modulation methods developed so far, has been discussed briefly. The modern methods are developed and employed to resolve the existing commutation problem. The implementation of arrays of nine switches able to conduct in both directions, integrated in a single module is being used. At last, this paper presents about the problems like protection at high voltage condition, use of filters and fault ride-through capability.In [4]-[5], the concept of three phase alternating current to alternating current converter system has been presented. In this paper a renowned, intermediate dc link converter system has been presented in order to implement ac-ac converter. The Direct matrix converters are finally controlled with space vector modulation methods. A momentary suggestion of AC to AC converter is shown and a novel unidirectional MC with three level is explained. The proposed converter obviously shows the acquaintances of proposed power converter that straightly results in the flexibility of the PWM control techniques. A novel type of power converter topology is presented in [6]-[7]. This converter is capable of converting input ac supply to output AC power through direct conversion and, it eliminates the usage of any input filters or intermediate DC link capacitors except for some small snubber elements. The proposed converter requires only insulated gate bipolar transistors in distinction to Matrix converters which in turn is made up of bidirectional switches. The current waveform at the input side of the suggested converter topology is equivalent to that of the diode rectifier with intermediate dc link inductor and it has unity input displacement power factor.In [8], the protection issues related to matrix converter has been presented. Conventionally the PWM based voltage source inverters are used to control the induction motors. A best alternate is the matrix converter, which is made up of nine bidirectional switches. The benefits of this converter include bidirectional power flow and sinusoidal input current. As the bidirectional switch is not available, this becomes the main drawback of the system. The two way conduction switch can be implemented by linking two power switches along with diodes.

A significant matter is the protection of the matrix converter, and this paper presents two novel protection circuits for matrix converters with a reduced number of components.

The paper is organized as follows: section II presents the classification of Matrix converter, section III presents the topologies of Matrix Converter; section IV gives the fundamental operation and Mathematical equations of Matrix Converter, section V shows the applications of Matrix Converter and section VI gives the conclusion.

II. CLASSIFICATION OF MATRIX CONVERTER

Among all power electronics converters, the two level diode rectifiers followed by voltage source inverters are most prevalent recently. A power converter that converts the dc input voltage into ac output voltage is called Voltage Source Inverter (VSI). In 1920, the concept of direct frequency conversion was initially presented. Generally, direct three phase ac to ac converters can be categorized in two different clusters. The Power Electronic circuits having input supply frequency higher than the functional output frequencies can be combined in the first group.

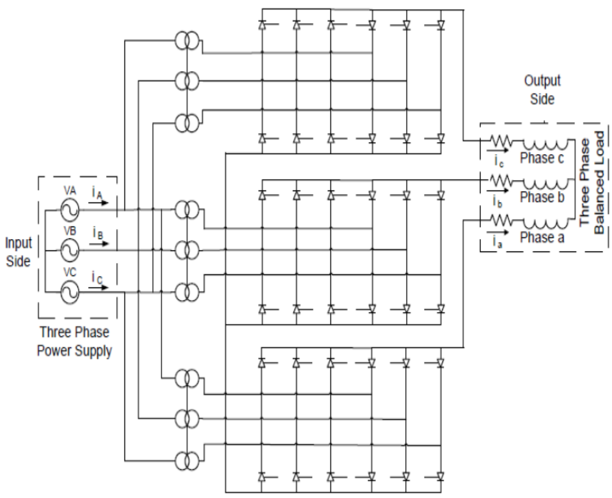

Fig.1 3 Phase to 3 Phase Cycloconverter

This variety of circuit was termed cycloconverter. The function of the cycloconverter is to convert the incoming alternating current voltage waveform to the output voltage waveform with low frequency. The first cycloconverter with semiconductor was established in 1960s, after the invention of thyristor. The 3 phase to 3 phase thyristor based cycloconverter is shown in Fig.1. These types of converters are frequently used in three phase ac-ac conversions.

In utmost applications of power systems, the cycloconverters are generally used to convert the voltage at the input side with fixed voltage and frequency into the output waveform with variable voltage and frequency. The output voltage and current of cyclo-converter are very much distorted and also power factor of the input voltage is low. However, if the number of switching devices is increased, the quality of the output voltage waveforms can also be enhanced. Furthermore, as the normal loads unable to bear the distorted output voltage waveform generated due to maximum input to output frequency ratios [9], its frequency at the output is also ordinarily restricted to partial frequency of supply voltage at the input side. Hence, the advantages of cycloconverter could be the robustness of thyristors and low losses. After considering all the above mentioned factors above, because of its limited output frequencies and deprived harmonic performance, the chance of using cycloconverters for low and medium power level converters becomes very less. However, cycloconverter can be seen as an ideal solution for high power levels due to the low losses and robustness. The converters used in electrical drives can be classified as shown in Fig.2.

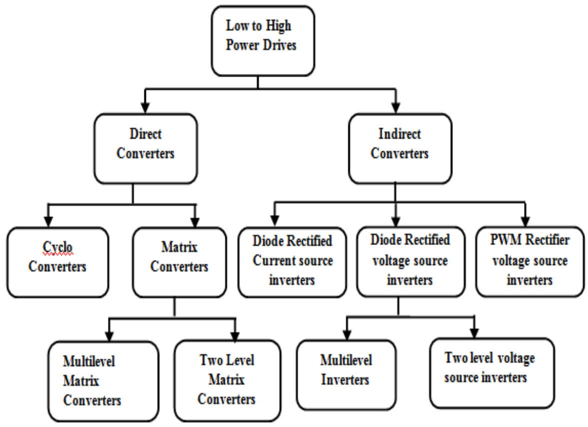

Fig.2 Classification of converters used in Electrical Drives.

III. MATRIX CONVERTER TOPOLOGIES

The matrix converters are categorized as two types [10] such as the direct matrix converter and indirect matrix converter that include intermediate dc link modules in between the input and output ac voltages.

A. Direct Matrix Converter

The additional direct ac power converters are the matrix converter (MC). The conventional matrix converter is made up of nine switches that connect each input phase to each output phases. With proper switching pattern, the output voltage control, current, phase angle and input power factor can be obtained. Fig. 3 shows the elementary circuit of direct matrix converter.

The most promising characteristics of MC are that it does not have any limitations on the output frequencies [11]. The input power from the input voltage source to the output three phase loads can be transferred directly, with the elimination of inductors and capacitors at the dc link as shown in Fig.3.4. Thus, it affords three phase ac to three phase ac single stage conversion. Furthermore, the size and volume of the converter can be mostly lessened by using direct matrix converter.

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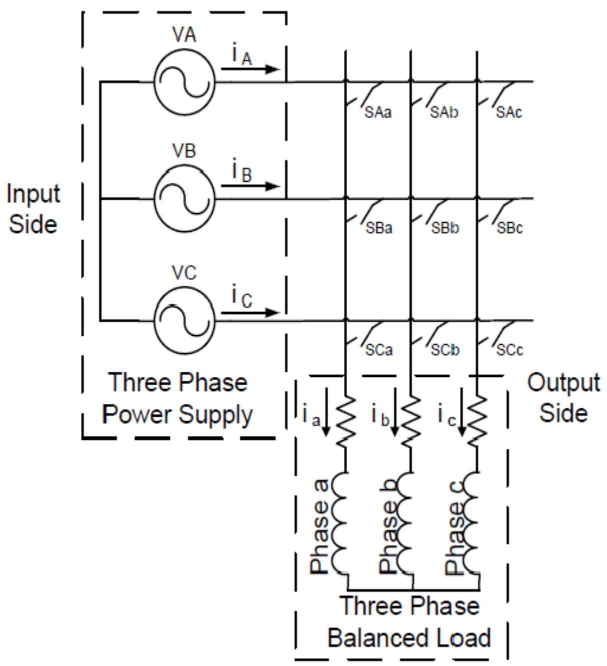

Fig.3 Basic DMC circuit

Thus, this type of converters can be preferred in applications which do not require more number of passive components.

B. Indirect Matrix Converter

Fig.4 shows the basic taditional matrix converters. The improved topology called Indirect Matrix converter is established on the concept of virtual direct current link which is used to control the Matrix Converter. Hence, there is no energy storing element between the input and output side. The advantages of Indirect Matrix Converter compared to direct Matrix Converter is that the commutation problem of power switches was solved and all the switches are switched ON and OFF at zero current [12].

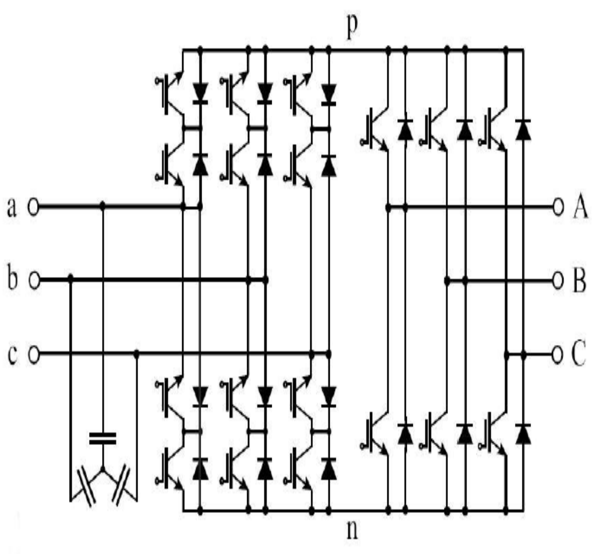

Fig. 4 Basic Conventional Indirect Matrix converter.

Even though both matrix converters shows dissimilarities in circuit configuration, modulation techniques, efficiency and complexity, they also afford similar characteristics such as sinusoidal input as well as output currents and power flow at both directions with the similar number of power semiconductor switches.

IV. FUNDAMENTAL OPERATION OF DIRECT MATRIX CONVERTER

The matrix converter is an array of a x b power switches which are bidirectional, that connects input source to the output load. In general, the direct matrix converter is fed by conventional VSI and hence, there is no possibility to allow short circuit for input terminals. Also, due to the inductive nature of the load, the output phase would not be open circuited [13]. Fig. 5 presents the pulse pattern of Matrix converters,

The switching function in Eq (1) and Eq (2) can be defined as follows,

$$S_{Kj}(t) = \begin{cases} 0\,, Switch\ S_{Kj}\ is\ open \\ 1\,, Switch\ S_{Kj}\ is\ closed \end{cases}$$

$$K = \{A, B, C\}\ and\ j = \{a, b, c\} \qquad (1)$$

The above constraint can be given as,

$$\sum m_{Ka}(t) = \sum m_{Kb}(t) = \sum m_{Kc}(t) = 1$$
$$Where\ K = A, B, C \qquad (2)$$

With these constraints, 27 possible switching states are allowed in 3x 3 matrix converter.

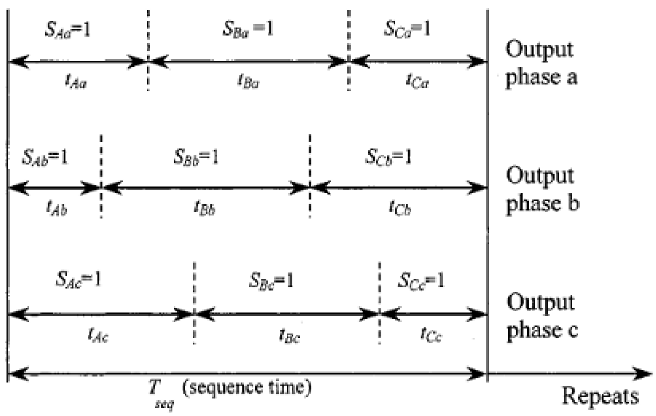

Fig.5 Switching pattern of Matrix Converter

The correlation between load and input voltage can be given as,

$$\begin{bmatrix} V_a(t) \\ V_b(t) \\ V_c(t) \end{bmatrix} = \begin{bmatrix} S_{Aa}(t) & S_{Ba}(t) & S_{Ca}(t) \\ S_{Ab}(t) & S_{Bb}(t) & S_{Cb}(t) \\ S_{Ac}(t) & S_{Bc}(t) & S_{Cc}(t) \end{bmatrix} \begin{bmatrix} V_A(t) \\ V_B(t) \\ V_C(t) \end{bmatrix} \qquad (3)$$

In the same manner, the following correlations is valid for input and output currents,

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$$\begin{bmatrix} i_A(t) \\ i_B(t) \\ i_C(t) \end{bmatrix} = \begin{bmatrix} S_{Aa}(t) & S_{Ba}(t) & S_{Ca}(t) \\ S_{Ab}(t) & S_{Bb}(t) & S_{Cb}(t) \\ S_{Ac}(t) & S_{Bc}(t) & S_{Cc}(t) \end{bmatrix} \begin{bmatrix} i_a(t) \\ i_b(t) \\ i_c(t) \end{bmatrix}$$

(4)

I. MODULATION METHODS FOR MATRIX CONVERTER

To control the Matrix Converter very significant solution, could obtained by using PWM control strategies, which is conventionally used for voltage source inverters. The two important modulation methods developed so far for Matrix Converter are conventional carrier modulation and modified space vector PWM techniques [14]. The carrier based PWM is the easiest method whereas very elegant method is the space vector PWM modulation.

A. Carrier PWM Method

The main advantage of PWM based control strategies is that it maintains power factor as one at the input side so as to normalize the output voltage. Furthermore to produce the required pulses for the power switches, the CBPWM technique which is a sinusoidal PWM technique, is used where high frequency triangle carrier signals are associated with the reference signal. In this technique, from the logical table the switching pulses are generated. If the limitations of Table I, are not fulfilled, the value assigned for the logical variable is 0. However, PWM method explained so far is limited to unity power Factor operation.

TABLE I
Input Voltage States of PWM Methods

Condition	Value
$V_A>V_B$	$X_A=1$
$V_B>V_C$	$X_B=1$
$V_C>V_A$	$X_C=1$

B. Space Vector PWM Method

SVPWM method is based on the continuous depiction of input and output voltage and currents [15]. Only 21 switching states among 27 possible states are used in SVM algorithm. Fig. shows the 18 switching pattern which determines the space vector for both input side and output side.

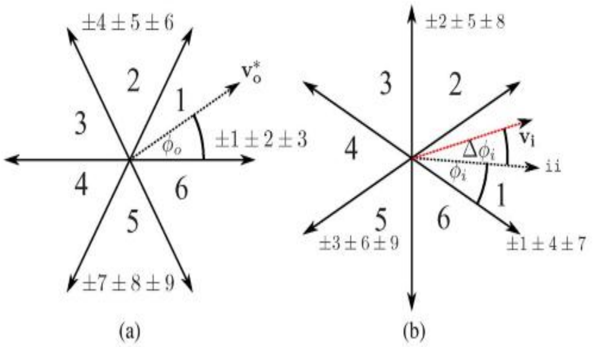

Fig. 6 (a) Voltage vectors (b) Current Vector of SVPWM Method.

VI. APPLICATIONS OF MATRIX CONVERTER

The direct matrix converter is a most important converter topology with characteristics such as simple and compressed power circuit, able to generate output voltage with variable amplitude and frequency, elimination of dc link capacitor, regeneration ability and sinusoidal source and load currents. The important applications of ac-ac Matrix Converter include field oriented control, wind energy conversion system with SCIG and doubly- fed induction generator. Several researches are going on to use auxiliary drive system in diesel locomotives. Currently, many papers are exploring the application of MC in aircrafts. Already, the problems in implementing a matrix converter have been solved and the step towards the commercialization has also been initiated. However, when compared to VSIs, the characteristics and equations of Matrix converter need to be improved more to exhibit good performance.

VII. CONCLUSION

In this paper a review on different topologies of matrix converter for adjustable speed drives has been done. Comparative analysis has been carried out among the diverse literature available in the field of matrix converter. The review concludes that there is an extensive development of Matrix Converter in terms of topology, modulation methods and applications to enhance the characteristics of MC for various applications. The topology with specific characteristics can be chosen for particular applications from analyzing the results of the paper. Hence, it has been concluded from the review that the matrix converter topologies is applicable to vast applications inorder to obtain desire amplitude and frequency from three phase input.

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AUTHORS PROFILE

Maheswari .K.T was born in Tamilnadu India, on Dec 20, 1980. She received her B.E Degree in Electrical and Electronics Engineering from Erode Sengunthar Engineering College, Erode, Bharathiyar University. She received her M.E Power Electronics and Drives from Bannari Amman Institute of Technology, affiliated to Anna University, Chennai in 2010. She has 9 yrs of teaching experience. Currently she is working as Assistant Professor in EEE department, Bannari Amman Institute of Technology, Sathya mangalam, TamilNadu, India. Her field of interest includes Power Converters for Renewable Energy Sources.

Author-2 Photo

Bharanikumar.R was born in Tamilnadu, India, on May 30, 1977. He received the B.E degree in Electrical and Electronics Engineering from Bharathiar University, in 1998. He received his M.E Power Electronics and Drives from College of Engineering Guindy Anna University in 2002. He has 19 yrs of teaching experience. Currently he is working as Professor in EEE department, Bannari Amman Institute of Technology, Sathyamangalam, TamilNadu, India. Currently he is doing research in the field of power converter for special machines; vector controlled based synchronous machine drives, converters for wind energy conversion systems.

Bhuvaneswari .S was born in Tamilnadu India, on Aug, 1985. She received her B.E Degree in Electrical and Electronics Engineering from V.L.B Janakiammal college of Engineering and Technology, Kovaipudur, Anna University and She received her M.E Degree in Electrical Machines from PSG college of Technology, Coimbatore, Anna University. Currently she is pursuing PhD in Electrical Engineering at Bannari Amman Institute of Technology. Her field of interest includes Electrical Machines and Renewable Energy Sources.