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Study of Matrix Converter for Motor Application: A Review

Ms. Puja Chauhan[1], Dr.P.V. Thakre[2]

[1]Research student, Electrical Engg, SSBT COET, Jalgaon, Maharashtra, India
[2]Professor, Electrical Engg, SSBT COET, Jalgaon, Maharashtra, India

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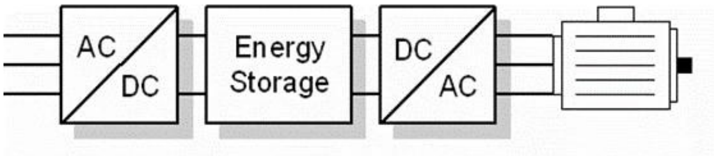
Abstract-This paper addressed to the working principle & application of Matrix converter for improving the performance of induction motor. The matrix converter is an array of controlled semiconductor switches that connects directly to the three phase source to the three phase load. Matrix Converters can directly convert an ac power supply of fixed voltage into an ac voltage of variable amplitude and frequency. Matrix Converter is a single stage converter. The matrix converters have following advantages over conventional converters with low volume, sinusoidal input current, bidirectional power flow, minimize the lower order harmonics and lack of bulky reactive elements. All this reasons causes the development of matrix converter. Based on the control techniques used in the matrix converter, the performance varies this is used for speed control of induction motor. So this paper analyzing the performance of matrix converter with three different modulation techniques like PWM, SVPWM, SPWM. The basic principle and switching sequence of those modulation techniques are presented during this paper

Key Words: Matrix Converter, Pulse Width Modulation (PWM), Space Vector Pulse Width Modulation (SVPWM), Sinusoidal Pulse Width Modulation(SPWM), AC-AC Converter.

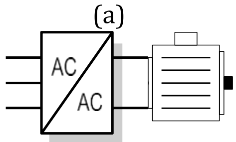
1. INTRODUCTION

Han Ju Cha in his paper "Analysis and Design of Matrix Converter for Adjustable Speed Driven and Distributed Power Sources"[1] explained many parts of a commercial application request ac/ac power conversion and ac/ac converters take power from one ac system and deliver it to different with waveforms of various amplitude, frequency, or phase. The ac/ac converters are commonly classified into indirect converter which utilizes a dc link between the 2 ac systems and direct converter that gives direct conversion. Indirect converter consists of two converter stages and energy storage element, which convert input ac to dc then reconverting dc back to output ac with variable amplitude and frequency as shown in Fig. (a). The operation of those converter stages is decoupled on an instant basis by means of energy storage element and controlled independently, because the average energy flow is equal. So, the instantaneous power flow doesn't need to equal the instantaneous power output. The difference between the instantaneous input and output power must be absorbed or delivered by an energy storage element within the converter. The energy storage element are often either a capacitor or an inductor.

However, the energy storage element isn't needed indirect converter as shown in Fig. (b) [2]. Generally, direct converter are often identified as three distinct topological approaches. The primary and simplest topology are often used to change the amplitude of an ac waveform. It's referred to as an ac controller and functions by simply chopping symmetric notches out of the input waveform. The second are often utilized if the output frequency is far less than the input source frequency. This topology is named a cycloconverter, and it approximates the specified output waveform by synthesizing it from pieces of the input waveform.



(a)



(b)

Fig.1. Ac/ac converter (a) indirect ac/ac converter (b) direct ac/ac converter

The last is matrix converter and it's most versatile with none limits on the output frequency and amplitude. It replaces the multiple conversion stages and therefore the intermediate energy storage element by single power conversion stage, and uses a matrix of semiconductor bidirectional switches, with a switch connected between each input terminal to each output terminal.

O. Hemakesavulu, T. Brahmanandav Reddy in their paper "Modeling and Simulation of Matrix Converter Using Space Vector PWM Technique" [3] analyses the performance of matrix converter. They states that matrix converter has advantages over conventional converters with low volume, sinusoidal input current, bidirectional power flow, minimizing of lower order harmonics and lack of bulky reactive elements. Supported the matrix converter, the performance varies. By analyzing the performance of matrix converter with two different modulation techniques like PWM and SVPWM, the output voltage, output current waveforms and THD spectrum of switching waveforms connected to RL load also are analyzed by using Matlab/Simulink software.

2.THREE PHASE MATRIXCONVERTER

With this general arrangement of switches, the power flow through the converter may reverse. Because of the absence of any energy storage element, the instantaneous power input must be adequate to the power output, assuming idealized zero-loss switches

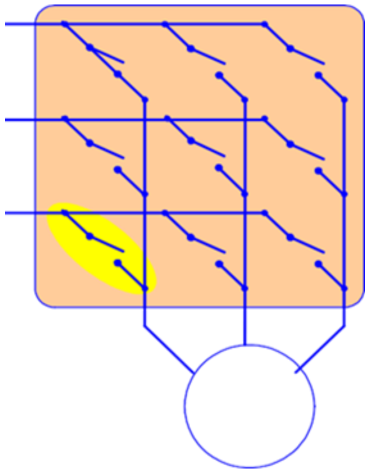


Fig. 2. Three phase matrix converter

However, the reactive power input doesn't need to equal the reactive power output. It can be said again that the phase angle between the voltages and currents at the input can be controlled and does not have to be the same as at the output. Also, the form as well as the frequency at the two sides are independent, in other words, the input could also be three- phase ac and the output is dc, or may be both dc, or may be both ac [2]. Therefore, the matrix converter topology is promising for universal power conversion such as: ac to dc, dc to ac, dc to dc or ac to ac.

The matrix converter has several advantages over traditional rectifier-inverter type power frequency converters.

• It provides sinusoidal input and output waveforms, with minimal higher order harmonics and no sub harmonics.

• It's inherent bi-directional energy flow capability, the input power factor are often fully controlled.

•New power devices (e.g silicon carbide) will increase the attractiveness of matrix converter.

•Modulation control of matrix converter is not difficult.

• Last but not least, it's minimal energy storage requirements, which urge to get rid of bulky and lifetime-limited energy-storing capacitors. The matrix converter has also some disadvantages over traditional rectifier-inverter type power frequency converters.

• First of all it has a maximum input output voltage transfer ratio limited to ≡ 87 % for sinusoidal input and output waveforms.

• It requires more semiconductor devices than conventional AC-AC indirect power frequency converter, since no monolithic bi-directional switches exist and consequently discrete unidirectional devices, variously arranged, need to be used for each bi-directional switch.

• Finally, it's particularly sensitive to the disturbances of the input voltage system. [4], [5] With nine bi-directional switches the matrix converter can theoretically assume 512 (29) different switching states combinations. But not all of them can be usefully employed. Regardless to the control method used, the selection of the matrix converter switching states combinations to be used must suits two basic rules, which are-

• The converter is supplied by a voltage source and typically feeds an inductive load.

• The input phases should never be short-circuited and the output currents should not be interrupted.

From a practical point of view these rules imply that one and just one bi-directional switch per output phase must be switched on at any instant. By this constraint, during a three phase to three phase matrix converter 27 are the permitted switching combinations[6].

3.CONTROL TECHNIQUES OF MATRICCONVERTER

3.1. Pulse Width Modulation Technique

Because of advances in solid state power devices based converters are becoming most widely used in drives PWM[7] inverters make it possible to control both the frequency and magnitude of the voltage and current applied to drive motor. The energy that a PWM converter delivers to a motor is controlled by PWM signals applied to the gates of power switches. Different PWM techniques are existing, that are Sinusoidal PWM, Hysteresis PWM and the relatively new Space-Vector PWM. These techniques are commonly used for the control of ac induction, Brushless Direct Current (BLDC) and Switched Reluctance (SR) motors. As a result, PWM converter powered motor drives offer better efficiency and better performance compared to fixed frequency motor drives.

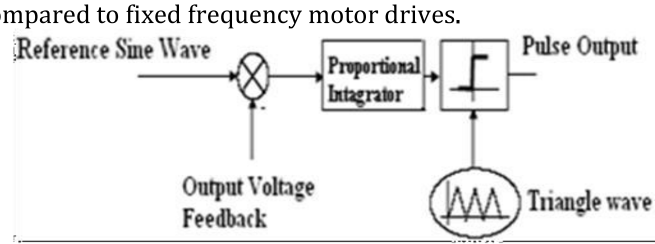


Fig. 3: PWM Pulse Generation Circuit

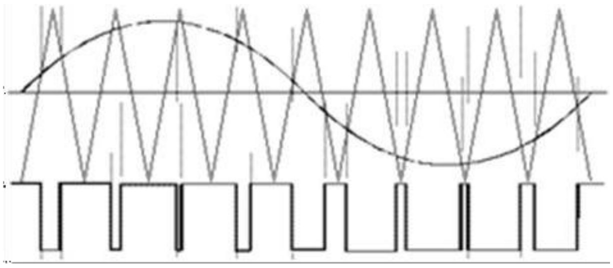


Fig.4: PWM Triggered Pulse Pattern for Power Devices

The generation of PWM pulse requires reference sine and triangular wave. The reference sine wave is compared with the feedback from the output voltage, is amplified and integrated as shown in figure 3. This signal is then compared with a generated triangular wave. The rectangular wave is the result of this comparison. As the sine wave is reaching its peak, the pulses get wider as show in figure 4. It is clearly visible that the duty cycle of the rectangular wave is varying consistent with the momentary value of the specified output voltage. The result is that the effective value of the rectangular wave is the same as that of the output voltage. This pulse is employed to modify switch ON or OFF the power switches. The width of the pulse or duty cycle are often varied by varying the frequency of the reference wave.

3.2. Space Vector Pulse Width Modulation

The concept of space vector is secured from the rotating field of AC machine. In this technique the three phase quantities can be transformed into two phase quantities during a d-q frame. The d, q components are found by Park transform, where the entire power, as well as the impedance, remains unchanged. The magnitude of every active vector (V1toV6) is 2/3 Vdc (dc bus voltage).

Fig. 5: SVPWM Pulse Generation

From reference[8] SVPWM based converters supplies the AC machine with the desired phase voltages. The space vector modulation concept is employed to calculate the duty cycle of the switches which is imperative implementation of digital control theory of PWM modulators. The space vector pulse width modulation technique has the subsequent advantages in comparison to the conventional PWM technique.

A. Maximum output voltage is15.5%greater,

B. The number of switching required is about30%less

The modulating signal is generated by injecting selected harmonics to the sine wave. This results in flat-topped waveform and reduces the amount of over modulation. It provides a better fundamental amplitude and low distortion of the output voltage. The modulating signal is usually composed of fundamental plus harmonics.

The concept of space vector is obtained from the rotating field of ac machine which is used for modulating the converter output voltage. In this modulation technique the three phase quantities are often transformed to their equivalent two phase quantity either in synchronously rotating frame or stationary d-qframe. From this two phase component, the reference vector magnitude can be found and used for modulating the converter output. SVM treats the sinusoidal voltage as a constant amplitude vector rotating at constant frequency. This technique approximates the reference voltage Vref by a mixture of the eight switching patterns(V0toV7).There presentation of rotating vector in complex plane is as shown in figure

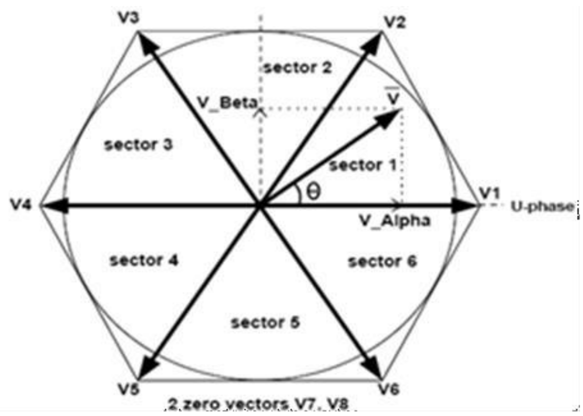


Fig. 6: Representation of Rotating Vector in Complex Plane

The Pulse Width modulation technique empowers to obtain three phase system voltages, which can be applied to the controlled output. Space Vector Modulation(SVM) principle is different from other PWM processes. The implementation of SVM process in digital systems requires less operation time with less program memory. The SVM algorithm is based on the principle of the space vector u*, which narrate all three output voltages ua, ub and uc:

$$u^* = 2/3. (ua + a . ub + a2 .uc) \qquad (1)$$

Where a = -1/2 + j.V3/2

We can differentiate six sectors limited by eight discrete vectors u0…..u7, which correspond to the 23 = 8 possible switching states of the power switches of the inverter. The amplitude of u0 and u7 equals to 0. The other vectors u1….u6 have the same amplitude with 60 degrees shifted. The space vector u* and also the output voltages ua, ub and uc can be varied by varying the relative on-switching time Tc of the different vectors and is defined as:

ua = Re (u*)

ub = Re (u*. a-1)

uc = Re (u*.a-2) (2)

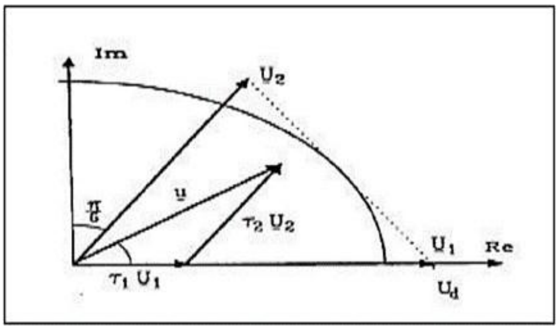


Fig. 7: Switching Sequence of output voltage space vector in SVPWM technique.

During a switching period Tc and considering for example the first sector, the vectors u0, u1 and u2 will be switched on alternatively represented in dq plane indicate real and imaginary axes. SVPWM focus to approximate the reference voltage $Vref$from the switching sequences. The desirable phase shift between input current and voltage are provided by selected vectors that are stationary that needs a selection of switching vectors and calculation of the vector time intervals are required in the modulation process. Zero vectors and active vectors are the vectors presented in the SVPWM. Implementation of the SVPWM can be made by calculatingVd,Vq,$Vref$, and angle (α) as Schemes 50 well as the time intervals, duty cycles dY,$d\delta$,$d0$ and switching time of each IGBT switches ($S1$, $S2$, $S3$, $S7$, $S8$, $S9$)

3.3. Sinusoidal Pulse Width Modulation Technique

Sinusoidal Pulse Width Modulation (SPWM) technique is one among the only simpler carrier-based modulation methods for the control of Matrix Converters. The SPWM is a familiar shaping technique in the field of Power Electronics where high frequency triangular carrier signal is compared with a sinusoidal reference signal. The main advantage of carrier based SPWM is that the complexity is extremely low and the dynamic response is additionally good for Matrix Converters explained in reference paper “A Review of control & modulation methods for matrix converters”, by rodriguez J, Riverab M, Kolar JW, Wheelar PW[9]. The number of pulses per cycle is being decided by ratio of the triangular carrier frequency to modulating sinusoidal frequency. Modulation ratio (MR) is given by the relation,

MR = Frequency of Carrier Waveform / Frequency of the Modulating Waveform

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

f=KMR(fm) (3)

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

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

MI=Ar/Ac (4)

Where Ar is reference amplitude and Ac is carrier amplitude MI is said to the fundamental (sine wave) output voltage magnitude.

If MI is high, then sine wave output is high and the other way around.

When 0 < MI < 1, the linear relationship holds: V1 = MIVin, where V1, Vin are fundamental of the output voltage and input voltage, respectively.

4. INDUCTION MOTORDRIVE

T.Matsuo, S.Bernet, R.S.Cooby& T.A.Lipo in his paper" Application of the Matrix Converter to Induction Motor Drives"[10]explained a three phase to three phase, ac to ac matrix converter basically consists of a 3x3 switch matrix. The 9 bidirectional voltage blocking, current conducting switches are arranged so that any input phase can be connected to any output phase at anytime. The 3x3 switch matrix can be arranged in the form of Fig. 8 for purpose of analysis. Since an inductive load is assumed, the voltage sources of the input must be created by placing capacitors (filter) from line to line across the converter input phases. Figure 8 also includes the impedance of the main power source, that is, the leakage inductance 1, and the resistance r. In principle, for a given set of input three phase voltages, any desired set of output voltages can then be synthesized by suitably toggling the matrix switches. Figure 8 also shows how a back to back arrangement of IGBTs may be used to implement the required bi-directional switch. The two diodes are used to provide the reverse voltage blocking capability. The diodes are also effectively placed in parallel with the IGBT by use of the short at the mid-point of the two branches. The total number of sets of an IGBT and a diode that are required to implement the matrix converter of Fig.8 is 18. This arrangement is preferable to the analogous configurations without a short at the mid-point as they prevent a possible avalanche breakdown of the IGBTs during the interruption of the reverse current. Furthermore, because the common collector arrangement requires the minimum number of isolated gate drives, that is 6, this switch configuration is the cheapest and also technically preferable implementation of all back-to-back configurations on the basis of conventional IGBTs. A comparison of the number of the required semiconductors shows that the matrix converter needs 6 IGBTs and 6 diodes more than the comparable PWM dc-voltage-link converter if the configuration shown in Fig.8 isused. Inspite of the different numbers of required semiconductors, a detailed investigation of the switch ratings reported in this paper demonstrates that the installed total switch power of both circuits is generally the same due to the possible reduction of the current ratings of the switches in the matrix converter by one third.

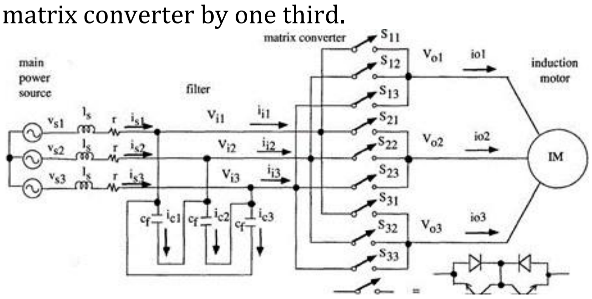


Fig.8.three phase ac-ac matrix converter

The expense of semiconductors can be reduced even more if one uses the capability of NPT-IGBTs to block both forward and reverse voltages [11]. The elimination of the series diodes and the possible reduction of the current ratings of the IGBTs could significantly reduce the installed total switch power of the matrix converter compared to that of the dc voltage link converter.

Figure 9 shows a drive configuration for a field oriented control of an induction motor which is driven by a three phase to three phase matrix converter. By means of an incremental encoder or resolver, the angular position of the rotor 0, is established. The angular position of the slip e, which is calculated in the field oriented control module, is added to the angular position of the rotor 0, to form the angular position of the stator MMF 0, These sinusoidal components are used to refer those physical stator currents from the physical (stationary) reference frame to the synchronously rotating(d-q)axes. The encoder is also used to measure speed. The voltage command signals from the field oriented controller are fed into the matrix converter block, where the matrix converter generates three phase PWM voltage pulses to drive the induction motor. The 3 phase to 3 phase matrix converter is completed by filters at the input side. The output side filters can generally be omitted in motor drive applications, where the stator winding inductances of the motor work as the filters. One important role of the filters at input side is to keep the input voltage from changing significantly during each PWM cycle.

Another important role is to absorb harmonic currents, which are generated by matrix converters, to prevent unwanted harmonic currents from flowing into ac main supplies and to satisfy any power quality regulation applicable. A simple filter configuration was examined, as shown in Fig. 8, where a capacitor is connected between each line to line at the matrix converter input.

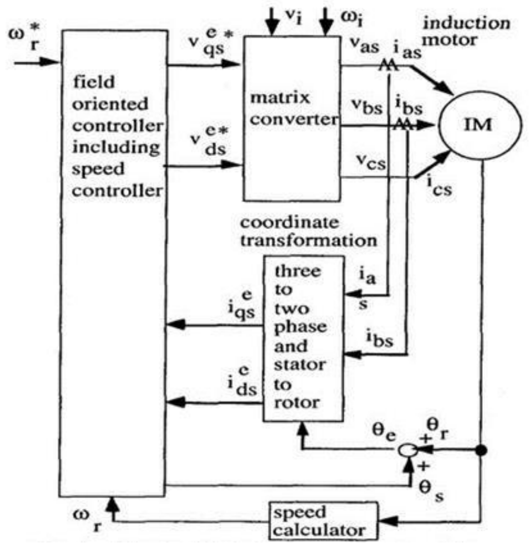


Fig.9.matrix converter induction motor drive

5.APPLICATION OF MATRIXCONVERTER

5.1. Integrated motordrives

1. DC linkcapacitor
2. Voltage ratio not alimitation

5.2. Industrialapplications

1. Lifts &Hoists
2. Powerdensity
3. Regeneration

5.3. Aerospace

1. Powerdensity
2. Temperaturetolerance

5.4. Electric militaryvehicles

1. Weight &volume
2. Bi-directional powerflow.

6. CONCLUSION

A brief review of matrix converter for motor application explained in this paper .The Matrix Converter is most versatile without any limits on the output frequency & amplitude. It replaces the multiple conversion stages & the intermediate energy storage element by single power conversion stage, & uses matrix of semiconductor bidirectional switches PWM, SVPWM, SPWM techniques were analysed in detail. The pulses obtained from various schemes are used to control the output parameters of the matrix converter to convert a given three phase input voltage into a three phase output voltage of a desired frequency and magnitude. . Because of this advantages matrix converter is more suitable to control parameters of machines.

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