Comparative study of indirect space vector and venturini modulation for matrix converter fed induction motor

M P Jati*, E Purwanto, and B Sumantri

Electrical Engineering Department, Politeknik Elektronika Negeri Surabaya, Surabaya, Indonesia

*Email: mentaripj@gmail.com

Abstract. This paper discusses the comparison method between two type modulations of direct matrix converter system with three-phase induction motor load. Matrix converter has accepted considerable interest as an alternative to conventional ac-dc-ac PWM (Pulse Width Modulation) converters in ac-ac conversion, especially for no-load induction motor drive. However, it is not convenient to control the matrix converter. The important point of the matrix converter is the modulation technique that has two different techniques in Venturini and indirect space vector modulation (ISVM). These methods are compared and analysed in the total harmonic distortion of output and input to find better performance for induction motor drive. Simulated input and output parameters of the matrix converter are presented using MATLAB/Simulink software for both modulation techniques. The result reveals smaller total harmonic distortion in ISVM than Venturini modulation for matrix converter.

1. Introduction

An AC-AC converters have explained by many studies about unity power factors, efficiency, compactness, and lifetime is a matrix converter [1]. Matrix converter is a single-stage converter that has an array of m-to-n two-way switches that directly connect the phase-m input voltage source to the n-phase load without the need for energy storage elements [2]. On the other hand, the most widely used electric motor is an induction motor with consideration of several factors [3], [4]. Although having advantages in several factors discussed earlier, induction motors also have a few disadvantages, such as high losses, low power factor and low efficiency [3]–[5]. In general, to control the speed of a three-phase induction motor can be done by changing the input voltage or frequency using a conventional converter. The frequency control of the electric drive by reducing the coefficient of harmonics is the solution to improve the quality of voltage output [6]. PWM from conventional converters in the form of inverters can increase reactive power when torque decreases and affects motor efficiency. Therefore, it is very important to take into account the effects of losses due to the PWM produced by the inverter in designing the motor [4]. Induction motor drive has become a necessity with developed to the direction of high power and speed.

Nevertheless, the matrix converter has a more complicated control technique. The acceptable method developed for the matrix converter is well-known for the Venturini modulation. In addition, the most preferred modulation for matrix converters is Space Vector Modulation (SVM) because the harmonic performance is better using a different switching method concept [7]. The matrix converter satisfies the four quadrants of motor operation while not producing higher harmonics at the three-phase system input.
and output. The circuit is capable of bidirectional power flow and generates sinusoidal input current [8]. Matrix converter, with all the advantages, is applied as an induction motor drive using modulation techniques. This paper presented the comparison of matrix converter modulation applied as an induction motor drive to get better performance that yields a smaller total harmonic distortion. Due to the fact that total harmonic distortion of drive converter effect for motor losses.

2. Methods
Matrix converter is direct ac-ac converter with adjustable output frequency and change in amplitude over a wide range that replaces the multiple stages of conversion and energy storage elements with a single stage power conversion and uses m-phase source times n-phase load of a bidirectional semiconductor switch as shown in Figure 1. The three-phase input matrix converter with three-phase induction motor load has nine bidirectional switches [9], [10].

![Figure 1. Three-phase matrix converter.](image)

The appearance of bidirectional switch makes the converter operates more resilient in all four quadrants of the motor drive [11]. In the matrix converter, there are a few modulation strategies that Venturini modulation and SVM. The principle of Venturini modulation can be explained initially using three phase input and single phase output. Only one of the three switches is turned on at any given time, and this confirms that the input of the matrix converter is not short-circuited while a continuous current is supplied to the load [12], [13]. The three phase output voltages can be expressed in the following matrix form:

\[
\begin{bmatrix}
V_a(t) \\
V_b(t) \\
V_c(t)
\end{bmatrix} =
\begin{bmatrix}
V_{im}\cos(\omega_0 t) \\
V_{im}\cos\left(\omega_0 t - \frac{2\pi}{3}\right) \\
V_{im}\cos\left(\omega_0 t + \frac{2\pi}{3}\right)
\end{bmatrix}
\]

\[
\begin{bmatrix}
V_o(t)
\end{bmatrix} = [M(t)] [V_i(t)]
\]

Then,

\[
\begin{bmatrix}
V_A(t) \\
V_B(t) \\
V_C(t)
\end{bmatrix} =
\begin{bmatrix}
V_{om}\cos(\omega_0 t + \theta_0) \\
V_{om}\cos\left(\omega_0 t + \theta_0 - \frac{2\pi}{3}\right) \\
V_{om}\cos\left(\omega_0 t + \theta_0 + \frac{2\pi}{3}\right)
\end{bmatrix}
\]

\[
\begin{bmatrix}
I_o(t)
\end{bmatrix} = [M^T(t)] [I_o(t)]
\]

\[
M(t) =
\begin{bmatrix}
m_{11}(t) & m_{12}(t) & m_{13}(t) \\
m_{21}(t) & m_{22}(t) & m_{23}(t) \\
m_{31}(t) & m_{32}(t) & m_{33}(t)
\end{bmatrix}
\]

Where \(M(t)\) is the index modulation matrix. It is elements \(m_{ij}(t)\), i, j = 1, 2, 3, represent duty cycle \(t_{ij}\) are called modulation functions.
\[ m_{ij} = \frac{1}{3} \left[ 1 + 2q \cos\left(\omega_i t - (j - 1) \frac{2\pi}{3}\right) x \left[ \cos\left(\omega_i t(i - 1) \frac{2\pi}{3}\right) + \frac{1}{2\sqrt{3}} \cos(3\omega_i t) - \frac{1}{3} \cos(3\omega_i t) \right] \right] - \frac{2a}{3\sqrt{3}} \cos\left(4\omega_i t - (j - 1) \frac{2\pi}{3}\right) - \cos\left(2\omega_i t - (1 - j) \frac{2\pi}{3}\right) \] (6)

While \( q = \frac{v_o}{v_i} \) is an input-to-output phase transfer ratio. However, output voltage with frequency variation conceives a continuous cycle and it is determined by the input voltage and modulation matrix calculation.

Space vector modulation (SVM), another matrix converter modulation method, is a control technique that has been widely used in speed drive regulation. The SVM technique is based on instantaneous vector space representations of sources and / or voltages and / or currents in an electronic power converter. The SVM is probably the most used modulation strategy for the matrix converter [14]. On the other hand, the indirect space vector modulation (ISVM) where matrix converter was referred to an equivalent circuit combining current source rectifier and voltage source inverter connected through virtual dc link as shown in Figure 2. The possible states of switches and vector spaces of the corresponding voltage and current is based on 27 switching combination [15].

Input side filter is an important requirement of the matrix converter topology to improve the input current wave due to switching frequency. In consideration of cost and weight, single-phase LC filter topology has been found as the most effective and efficient [16]. This paper does not delve further into the design of the input filter.

![Figure 2: The equivalent circuit for indirect topology](image)

From the rectifying and inverting switching combination selected sets, the \( V_a \) and \( V_b \) is applied to the first current vector \( I_\gamma \), \( V_a - I_\gamma \) pair and \( V_b - I_\gamma \) pair is created, the duty cycle of new vectors as defined in (21) – (24).

\[
d_{a\gamma} = m_\gamma \sin\left(\frac{\pi}{3} - \theta_\gamma\right) \sin\left(\frac{\pi}{3} - \theta_c\right) = \frac{T_{\alpha\gamma}}{T_s} \tag{7}
\]

\[
d_{a\delta} = m_\gamma \sin\left(\frac{\pi}{3} - \theta_\gamma\right) \sin(\theta_c) = \frac{T_{\alpha\delta}}{T_s} \tag{8}
\]

\[
d_{b\gamma} = m_\gamma \sin(\theta_\gamma) \sin\left(\frac{\pi}{3} - \theta_c\right) = \frac{T_{\beta\gamma}}{T_s} \tag{9}
\]

\[
d_{b\delta} = m_\gamma \sin(\theta_\gamma) \sin(\theta_c) = \frac{T_{\beta\delta}}{T_s} \tag{10}
\]

3. Result and Discussion

The simulation has been done to compare the modulation of matrix converter fed 5.4HP induction motor load. In the input side, a filter is used as a matrix converter for the smoother waveform. The system parameters are presented in Table 1. For the same comparison, these results are evaluated under the same conditions for input filter values, input power supply, and no-load induction motor output. Because of uncertain current and voltage value in drive application, it must get more attention to be analyzed especially for induction motor drive.
The first simulation is tried in various voltage transfer ratio (q) to know Total Harmonic Distortion (THD) each modulation technique. Table 2 shows the result of Venturini modulation and ISVM. Between q 0.4 – 0.866, Venturini modulation has a high-frequency input component when voltage transfer ratio is close to maximum that results THD equals 195.54%.

Based on equation 6, the modulation function is used to control the switching matrix converter that yields input and output with sinusoidal waveform. The output voltage with variable frequency is generated by the desired output voltage that occurs during a continuous cycle. Obviously, this condition affects the voltage transfer ratio in Venturini modulation equal to 0.5 that has the best result with smaller THD than another.

Matrix converter can adjust output in variable amplitude and frequency. However, output amplitude defined from the voltage transfer ratio (q). The simulation result of the matrix converter using ISVM is shown in Table 4 for various q. In maximum q equals to 0.866, ISVM yields THD input equals 24.9%. The best result of THD is obtained when using Venturini modulation with q= 0.5 while ISVM with q= 0.866. The output voltage of THD comparison between Venturini and ISVM is shown clearly in Figure 7 that ISVM has more stable THD in all q range than Venturini modulation. Figure 8 shows the simulation model in Matlab Simulink.

Table 1. Power circuit parameters.

| Parameter              | Value |
|------------------------|-------|
| Input voltage          | 311v  |
| Input frequency        | 50Hz  |
| Switching frequency    | 6kHz  |
| Input filter capacitance | 20uF |
| Input filter inductance | 1.26mH |
| 3 phase induction motor | 5.4HP |

Table 2. Venturini modulation and ISVM with various voltage transfer ratio.

| q  | Venturini | ISVM | rpm |
|----|-----------|------|-----|
|    | Lin       | Vout | Lin | Vout | Lin | Vout | Lin | Vout | Lin | Vout |
| 0.866 | 21.32 | 195.54 | 442 | 52.59 | 1.867 | 24.9 | 462 | 2.64 | 1500 |
| 0.8  | 13.12 | 308.67 | 420.4 | 51.06 | 1.89 | 28.73 | 439.9 | 4.05 | 1498 |
| 0.7  | 5.012 | 690.86 | 381.4 | 45.03 | 1.966 | 33.06 | 392 | 5.36 | 1494.5 |
| 0.6  | 2.03 | 133.5 | 323.8 | 5.01 | 1.998 | 18.58 | 338.9 | 5.24 | 1491 |
| 0.5  | 2.039 | 32.28 | 269.8 | 2.18 | 2.013 | 16.16 | 285.7 | 5.83 | 1486.5 |
| 0.4  | 3.492 | 33.99 | 215.1 | 5.39 | 2.912 | 41.83 | 230 | 5.99 | 1478 |
Figure 3. THD comparison between venturini modulation (VM) and ISVM.

The comparison of the two modulation performance with no load induction motor is shown in Table 3 for various speed demands. On the other hand, speed variation can be done by changing the output frequency. Speed variation in the induction motor affect the value of THD. Tests on the voltage transfer ratio are used to vary the output voltage amplitude. At the same low, mid and high speed, the Venturini modulation produces a lower voltage amplitude than ISVM. When q is set to maximum, the Venturini modulation yields THD input and output are higher than ISVM. Because the system using ISVM can apply the higher q so it can be applied to wider range voltage load. The speed drive method using a matrix converter for an induction motor will be studied in the future.

Table 3. Modulation strategies with various motor speed

| q   | Venturini Vout | THD  | ISVM Vout | THD  | rpm  |
|-----|----------------|------|-----------|------|------|
| 0.5 | 269.8          | 2.18 | 0.866     | 462  | 1490 | High |
| 0.5 | 269.6          | 5.13 | 0.866     | 470.8| 3.87 | Mid  |
| 0.5 | 272.8          | 5.66 | 0.866     | 470.2| 6.95 | Low  |

Figure 4 shows the simulation for matrix converter while Figure 5 - 8 show the results for input and output waveforms. The figures show that sinusoidal waveform input voltage in both modulation techniques. Also, the output current waveform in Figure 6 and 8 are sinusoidal. On the other hand, the output voltage waveform in Venturini modulation has more distortion than ISVM.

Figure 4. Simulation for matrix converter.
4. Conclusion
This paper presents the matrix converter for the no-load induction motor drive. The performance of the modulation matrix converter has been compared between Venturini and Indirect Space Vector modulation to investigate the better performance for motor drive. Both technique modulation matrix converter has been using the same parameter. The MATLAB/SIMULINK software has been used to simulate both modulations. Simulation results prove that the matrix converter with ISVM as an induction motor drive has shown a better THD in output voltage and input current with maximum voltage transfer ratio than in Venturini modulation.

References
[1] A. C. and K. B. B. Hamane, M. L. Doumbia, “Comparative Analysis of PI and Fuzzy Logic Controllers for Matrix Converter,” 2014 Ninth Int. Conf. Ecol. Veh. Renew. Energies, 2014.
[2] P. W. Wheeler, “Matrix Converters: A Technology Review,” IEEE Trans. Ind. Electron., vol. 49, no. 1, pp. 1–5, 2014.
[3] J. R. Riba, C. López-Torres, L. Romeral, and A. Garcia, “Rare-earth-free propulsion motors for electric vehicles: A technology review,” Renew. Sustain. Energy Rev., vol. 57, pp. 367–379, 2016.
[4] J. J. Lee, Y. K. Kim, H. Nam, K. H. Ha, J. P. Hong, and D. H. Hwang, “Loss distribution of three-phase induction motor fed by pulsewidth-modulated inverter,” IEEE Trans. Magn., vol. 40, no. 2 II, pp. 762–765, 2004.
[5] M. A. Hannan, J. A. Ali, A. Mohamed, and A. Hussain, “Optimization techniques to enhance the performance of induction motor drives: A review,” Renew. Sustain. Energy Rev., vol. 81, no. September 2016, pp. 1611–1626, 2018.
[6] A. V. Bondarev, S. V. Fedorov, and E. A. Muravyova, “Control Systems with Pulse Width Modulation in Matrix Converters,” IOP Conf. Ser. Mater. Sci. Eng., 2018.
[7] Z. Malekjamshidi, M. Jafari, and J. Zhu, “Analysis and comparison of direct matrix converters controlled by space vector and Venturini modulations,” Proc. Int. Conf. Power Electron. Drive Syst., vol. 2015-August, no. June, pp. 635–639, 2015.
[8] H. Altun and S. Sunter, “Matrix converter induction motor drive: modeling, simulation and
control,” *Electr. Eng.*, pp. 25–33, 2003.

[9] S. M. Dabour and E. M. Rashad, “Analysis and implementation of space vector modulated three-phase matrix converter,” *IET Power Electron.*, vol. 5, no. April, pp. 1374–1378, 2012.

[10] R. B. Roy, J. Cros, E. Basher, and S. M. B. Taslim, “Fuzzy logic based matrix converter controlled induction motor drive,” *5th IEEE Reg. 10 Humanit. Technol. Conf. 2017, R10-HTC 2017*, vol. 2018-Janua, pp. 489–493, 2018.

[11] S. Halder, A. Agrawal, P. Agarwal, S. P. Srivastava, and S. Das, “Matrix converter fed PMSM drive with maximum torque per ampere control,” *1st IEEE Int. Conf. Power Electron. Intell. Control Energy Syst. ICPEICES 2016*, pp. 1–4, 2017.

[12] W. Shepherd and L. Zhang, *Power Converter Circuits*. Marcel Dekker, 2004.

[13] E. Purwanto, F. D. Murdianto, G. Basuki, D. W. Herlambang, and M. P. Jati, “Venturini Modulation Based Matrix Converter Controlled Induction Motor Drive,” in *IEEE International Electronics Symposium on Engineering Technology and Applications (IES-ETA)*, 2019.

[14] H. J. Cha, “Analysis and Design of Matrix Converters for Adjustable Speed Drives and Distributed Power Sources,” Texas A&M University, 2004.

[15] E. Purwanto, F. D. Murdianto, D. W. Herlambang, G. Basuki, and M. P. Jati, “Three-Phase Direct Matrix Converter With Space Vector Modulation for Induction Motor Drive,” in *IEEE International Conference on Applied Information Technology and Innovation (ICAITI)*, 2019.

[16] A. Dasgupta and P. Sensarma, *Design and Control of Matrix Converters*. springer, 2017.