# Performance Analysis of a Matrix Converter under unbalanced Load

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**Abstract—** Matrix converter is a kind of power converter, which is different from traditional conventional or multi-level converters because it can directly perform a power conversion without intermediate capacitors. The typical design of a matrix converter includes nine switches. It allows a bi-directional power conversion between the grid and the load and through control of the switching matrix, the amplitude and frequency of the output voltage can also be controlled. The aim of this study is to design a matrix converter using SVM method and test its performance on RL load under distorted input voltage. The simulation results at the level of currents and voltages at the output are presented and discussed. The second objective of this research is to design a fuzzy logic controller to control the RL load currents in the different conditions.

**Keywords:** Matrix converter; SVM; Fuzzy logic, high quality, performances.

## 1. Introduction

The matrix converter (MC) is a direct frequency converter. It generates three-phase AC voltages variable in amplitude and frequency from AC voltages constant at its input. A continuous intermediate DC capacitor voltage is not necessary [1, 2]. The matrix converter is a single stage (AC/AC) converter which has an array of 3×3 bidirectional switches to connect, directly an input voltage ($V_{abc}$) to an Output voltage ($V_{ABC}$), as shown in the diagram in figure 1.

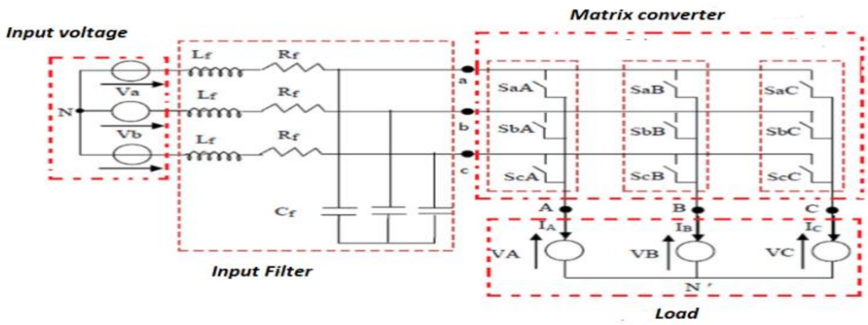



Figure 1 Topology Circuit of Matrix converter

This type of converter has several advantages compared to the traditional conventional, it's a direct frequency converter, the continuous intermediate circuit characterizing conventional converters is not necessary. The passive energy storage elements that form the intermediate circuit are eliminated. It is thus possible to considerably reduce the construction effort and the volume of the converter. However, the main disadvantage is that it generates large harmonic currents at the input as well as harmonic voltages at the output which cannot be eliminated easily by filters. This problem was solved by Venturini in 1980 who proposed a new algorithm with PWM control. This algorithm makes it possible to have sinusoidal input currents and output voltages. The disadvantage of this algorithm is that the output voltage ratio is limited to 0.5. In 1989, Venturini published a mathematical demonstration concerning the improvement of the voltage transfer ratio after modifying the original algorithm [3-5]. The input passive filter is used to eliminate harmonics distortion and to improve input voltage and currents waveforms [6-8]. The problem of controlling the matrix converter is to find the pulse sequences so that the moving averages of the phase voltages at the output are sinusoidal modulated. The amplitude and frequency of the fundamental wave of the voltages must be variable. Space vector modulation (SVM) is very often used in variable output frequency. The objective of this control strategy is to synthesize the output voltages by input voltages and the input currents by output currents [9-10]. In this study, we will present a detailed study of the matrix converter concerning its constitution and its principle of operation as well as its representation. We have realized some simulation tests under different conditions. Fuzzy logic controller is to regulate the transfer ratio voltage for different values, which performs close loop control of the output current waveforms. The proposed system is verified by both simulation results.

## 2. Theory of matrix converter

The balanced input voltages are expressed by the following equations:

$$v_{ABC}(t) = \begin{cases} v(t) = v_{im}\cos(\omega_i t) \\ v(t) = v_{im}\cos(\omega_i t - \frac{2\pi}{3}) \\ v(t) = v_{im}\cos(\omega_i t - \frac{4\pi}{3}) \end{cases} \qquad (1)$$

On the other hand, the balanced three-phase input currents are expressed by the following expression:

$$i_{ABC}(t) = \begin{cases} i(t) = i_{im}\cos(\omega_i t + \varphi_i) \\ i(t) = i_{im}\cos(\omega_i t - \frac{2\pi}{3} + \varphi_i) \\ i(t) = i_{im}\cos(\omega_i t - \frac{4\pi}{3} + \varphi_i) \end{cases} \qquad (2)$$

q(k) : is the transfer ratio voltage between the output voltage and the input voltage is given by [11-12, 13]:

$$q(k) = \frac{|V_o|}{|V_i|} \qquad (3)$$

The balanced three-phase output voltages can be expressed by the following equations:

$$v_{abc}(t) = q \cdot \begin{cases} v\ (t) = v_{im}\cos(\omega_O t) \\ v(t) = v_{im}\cos(\omega_O t - \frac{2\pi}{3}) \\ v(t) = v_{im}\cos(\omega_O t - \frac{4\pi}{3}) \end{cases} \qquad (4)$$

Where, the balanced three-phase input currents are given by :

$$i_{abc}(t) = q \cdot \cos(\varphi_0). \begin{cases} i_{im}\cos(\omega_O t + \varphi_O) \\ i_{im}\cos(\omega_O t - \frac{2\pi}{3} + \varphi_O) \\ i_{im}\cos(\omega_O t - \frac{4\pi}{3} + \varphi_O) \end{cases} \qquad (5)$$

## 3. SVM technique

The space vector modulation based on the three phase input current and output voltages as given as :

$$\boldsymbol{\overrightarrow{V_o} = V_o \cdot e^{j\alpha_o \cdot t}} \qquad (6)$$

$$\overrightarrow{I_1} = I_i \cdot e^{j\beta_i \cdot t} \qquad (7)$$

Where:

$\overrightarrow{V_o}$ And $\overrightarrow{I_\iota}$ are amplitude of $V_o$ and $I_1$),

$\alpha_0'$: Angle between the middle of the section current.

$\beta_i'$: Angle between the middle of the section voltage.

### *A. Representation of converter states in SVM*

The 27 possible states of the converter can be broken down into three groups:

**Group I:** made up of 18 combinations; this group creates vectors with a fixed direction but with an amplitude that varies with input voltages and/or output currents. These combinations result from the use of a single phase-to-phase input voltage.

**Group II:** made up of 3 states; this group creates a free wheel on the load. These combinations are generated by the connection of the three output phases on the same input phase resulting in zero output voltages and zero input currents.

**Group III:** the last six combinations are produced by connecting each of the output phases to a separate input phase. These states generate the creation of rotating vectors of constant amplitude. The control of these vectors is more complex than those of the first two groups. They are not used in the modulation [14-17].

***B. Representation of stationary vectors***

Figure 2 shows the output voltage and input current hexagons. Six sections are obtained, each having an angle of 60°. They are identified by six switch configurations.

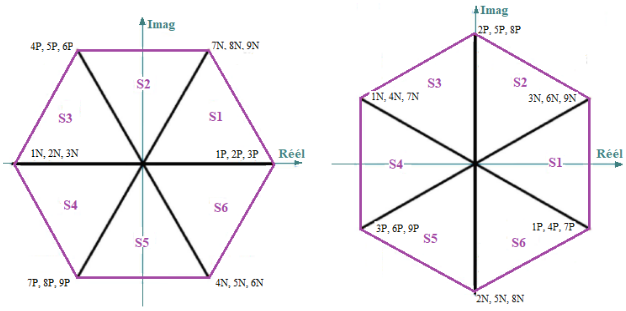



Figure 2 Output Voltage and Input Current Hexagons

*C.* ***Duty cycles***

The duty cycles $\delta_i$ are defined by::

$$\begin{cases} \delta_A = (-1)^{n_v+n_i}\left(\frac{2}{\sqrt{3}}\right)\cdot q\,\frac{\cos\left(\alpha'_0-\frac{\pi}{3}\right)\cdot\cos\left(\beta'_i-\frac{\pi}{3}\right)}{\cos\varphi_i} \\ \delta_A = (-1)^{n_v+n_i+1}\left(\frac{2}{\sqrt{3}}\right)\cdot q\,\frac{\cos\left(\alpha'_0-\frac{\pi}{3}\right)\cdot\cos\left(\beta'_i-\frac{\pi}{3}\right)}{\cos\varphi_i} \\ \delta_A = (-1)^{n_v+n_i+1}\left(\frac{2}{\sqrt{3}}\right)\cdot q\,\frac{\cos\left(\alpha'_0-\frac{\pi}{3}\right)\cdot\cos\left(\beta'_i-\frac{\pi}{3}\right)}{\cos\varphi_i} \\ \delta_A = (-1)^{n_v+n_i}\left(\frac{2}{\sqrt{3}}\right)\cdot q\,\frac{\cos\left(\alpha'_0-\frac{\pi}{3}\right)\cdot\cos\left(\beta'_i-\frac{\pi}{3}\right)}{\cos\varphi_i} \end{cases} \quad (8)$$

With:

$n_v$: Number of section where the phase of the reference output voltage is located.

$n_i$: Number of the section where the phase of the reference input current is located.

$q$: Voltage transfer ratio .

$\varphi_i$: Input current phase shift.

It is then necessary to define the duty cycle $\delta_o$ as given as:

$$\delta_o = 1-(\delta_A+\delta_B+\delta_C+\delta_D) \quad (9)$$

***D. Determination of the cyclic ratios mij of the switches***

From the duty cycles $\delta_i$ it is necessary to calculate the duty cycles $m_{ij}$ of the switches. The simplest method to carry out consists in summing the four duty cycles $\delta_i$ four configurations selected during a sampling step, and to introduce, if necessary, the configuration of the zero vectors chosen.

$$\begin{cases} t_{11}+t_{12}+t_{13} = T \\ t_{21}+t_{22}+t_{23} = T \\ t_{31}+t_{32}+t_{33} = T \end{cases} \quad (10)$$

**3. Fuzzy logic controlled magnitude output current**

The output current is given by:

$$\left|i_{abc}\right| = \sqrt{\frac{2}{3}\left(i_a{}^2+i_b{}^2+i_c{}^2\right)} \quad (11)$$

The error and its variation are given by :

$$e(k) = i_{abc-ref} - i_{abc} \quad (12)$$

$$\Delta e(k) = (e(k) - e(k-1)) \quad (13)$$

The voltage transfer ratio q(k) is limited between $0 \le q(K) \le 0.86$. It's expressed by the following equation [19-20]:

$$q(k) = q(k-1) + \Delta q(k) \quad (14)$$

The fuzzy logic controller based matrix converter is designed to obtain a fixe transfer ratio voltage *q(k)* as shown in figure 3.

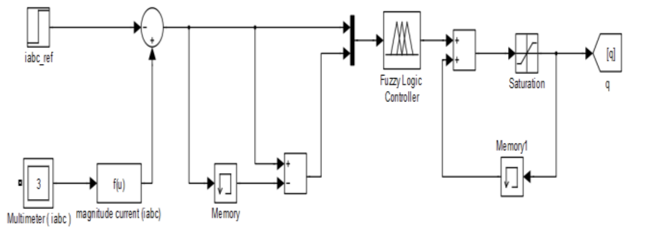


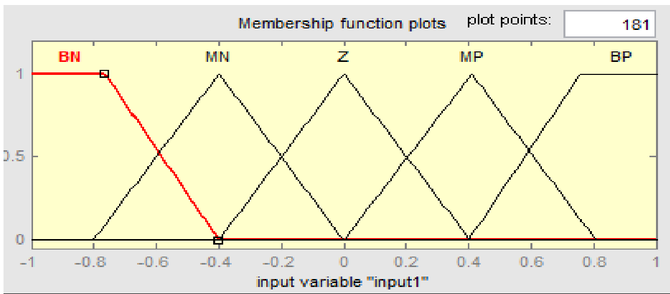

Figure 3 Fuzzy logic controller diagrams

Five linguistic variables of the input and output variables are given in table 1.

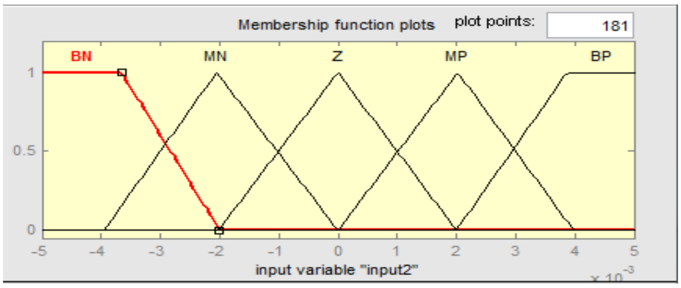
Table 4 Inference rules

| e(k) / Δe(k) | BN | MN | Z | MP | BP |
|---|---|---|---|---|---|
| BN | BP | MP | MP | SM | MN |
| BN | PB | MP | SP | SM | MN |
| BN | MP | MP | Z | MN | BN |
| BN | MP | SP | SM | MN | BN |
| BN | MP | SP | MN | MN | BN |

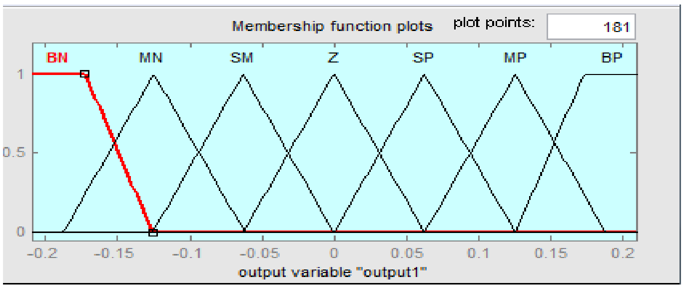
The input and output triangular forms function as shown in figure.4.




a) Error Membership functions




b) Variation error membership functions




c) Membership function of output variables

Figure 4 memberships function of fuzzy logic controller

**4. Simulation results**

In order to evaluate the performance and efficiency of the proposed system, we have realized some simulation tests. In the first case, the matrix converter fed RL Load under normal condition. In the second case, the input voltage was distorted with 5th and 7th harmonics. In the last case, the matrix converter fed unbalanced Load. Figure 5 represents the block diagram of matrix converter under Simulink/Matlab.

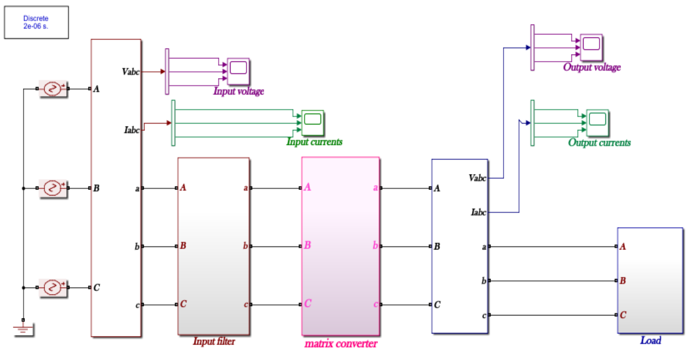



Figure 5 Simulation block

The Simulation parameters are shown in table 2.

Table 2 System parameters

| Parameters | Values |
|---|---|
| Load | R=10Ω, L=30mH; |
| Input voltage | 600V, 50Hz |
| Input filter | 0.1 Ω, 0.5mH; 35µF |
| Frequency cycle | 10Khz |

***4.1 In the normal condition***

Figure 6, 7 and 8 shows respectively the input, simple output voltage and line to line output voltage.

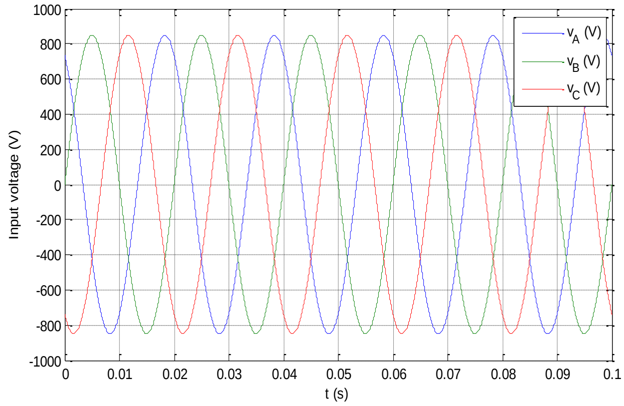



Figure 6 Input voltages

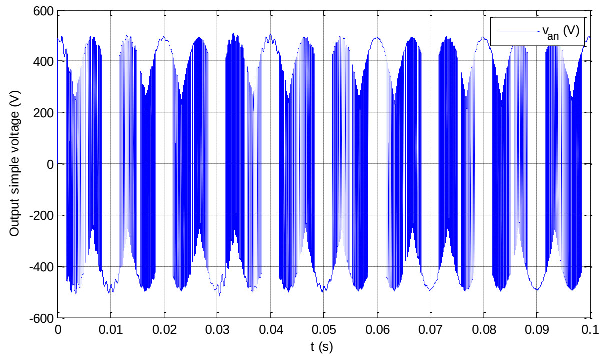



Figure 7 Simple Output voltages

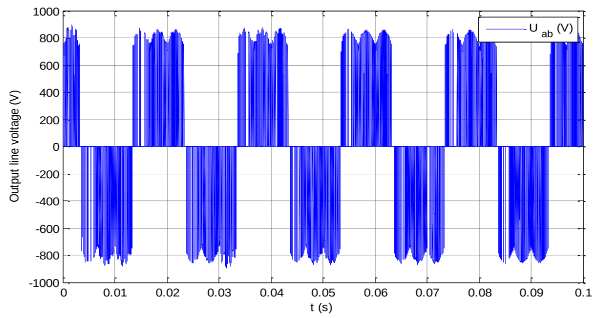



Figure 8 Line to line Output voltage

Figure 9 and 10 shows respectively the output currents and its amplitude. We can see that the amplitude output current value follows up its reference. In the first time t= 0.03s and in the second time t=0.07s, we have changed the reference value from 10A to 8A, we can see that the magnitude output current follow up perfectly its reference.

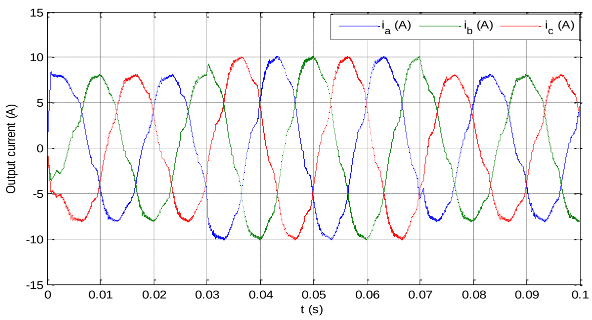



Figure 9 Output currents

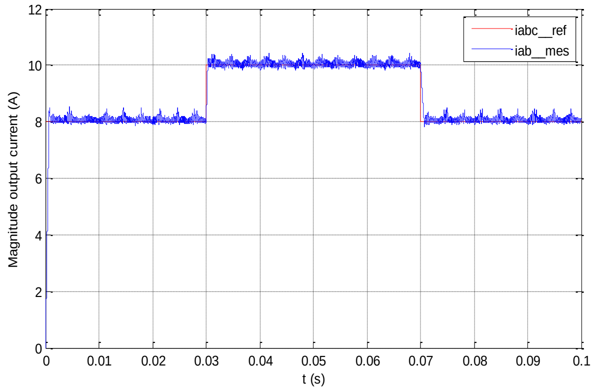



Figure 10 Amplitude output current and its reference

### *4.2 Under unbalanced Load*

For the last case, the matrix converter fed unbalanced load, the figures 11, 12, 13 and 14 shows successfully the waveforms of simple output voltage, line to line Output voltage, Output currents and the amplitude output currents and its reference. We can see in this case that the same simulation results are obtained. The waveforms output currents are nearly sinusoidal and the output amplitude currents follow-up perfectly its reference.

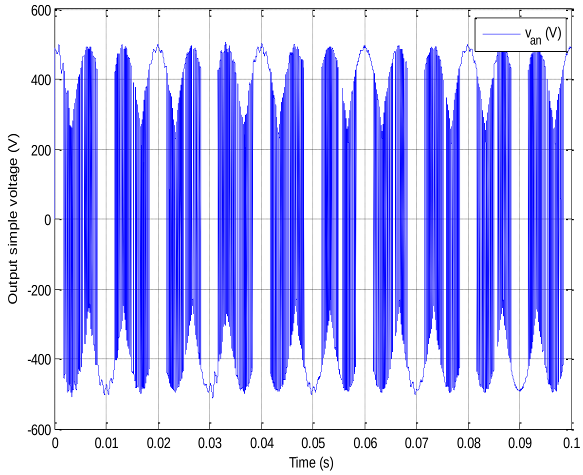



Figure 11 Simple Output voltages

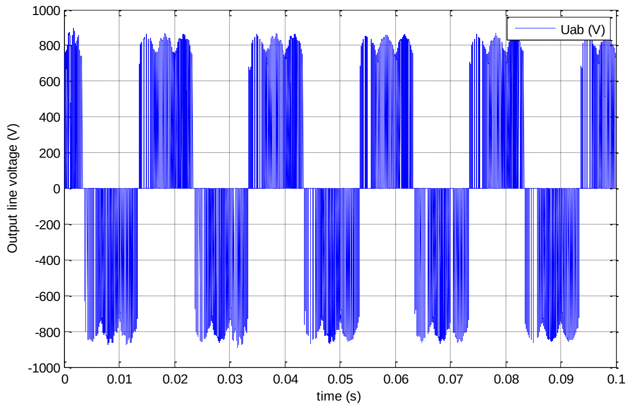



Figure 12 Line to line Output voltage

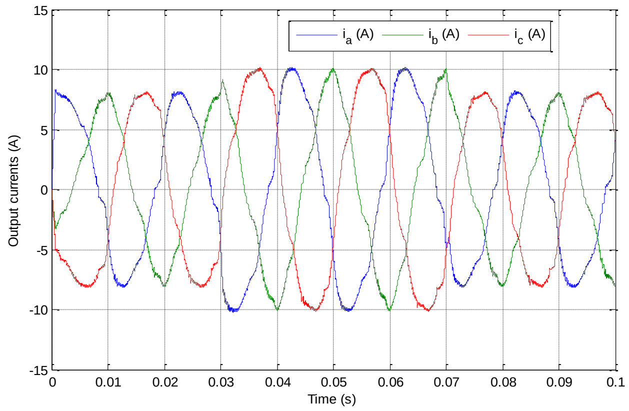



Figure 13 Output currents

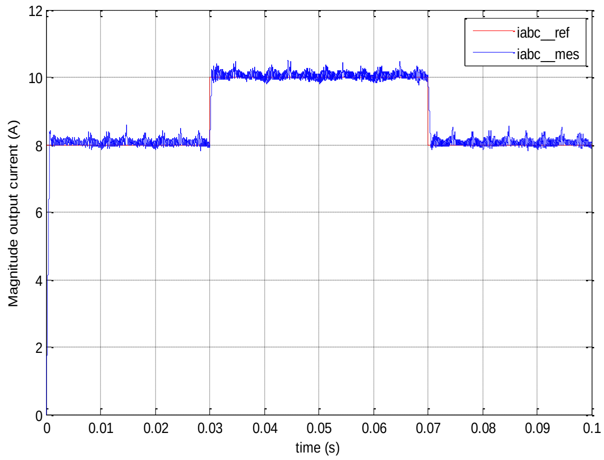



Figure 14 Amplitude output currents and its reference

## 5. Conclusion

In this work, the matrix converter powered by different types of load using a fuzzy logic controller is studied; the mathematical model is given. The overall objective of the proposed system is to design a fuzzy logic controller capable of generating a sinusoidal output current regardless of the degree of disturbance of the input voltages and unbalanced load. It appears from the simulation results that proposed fuzzy logic controller based on SVM technique can achieve all the desired output performances.

## References


1. P. W. Wheeler, J. C. Clare, L. Empringham, M. Bland and K. G. Kerris, "Matrix converters," in IEEE Industry Applications Magazine, vol. 10, no. 1, pp. 59-65, Jan.-Feb. 2004, doi: 10.1109/MIA.2004.1256253.
2. L. Huber and D. Borojevic, "Space vector modulated three-phase to three-phase matrix converter with input power factor correction," in IEEE Transactions on Industry Applications, vol. 31, no. 6, pp. 1234-1246, Nov.-Dec. 1995, doi: 10.1109/28.475693.
3. G. Mirzaeva and Y. Liu, "Matrix Converters: Challenges and Solutions," 2022 IEEE IAS Petroleum and Chemical Industry Technical Conference (PCIC), Denver, CO, USA, 2022, pp. 157-166, doi: 10.1109/PCIC42668.2022.10181267.
4. R. W. Erickson and O. A. Al-Naseem, "A new family of matrix converters," IECON'01. 27th Annual Conference of the IEEE Industrial Electronics Society (Cat. No.37243), Denver, CO, USA, 2001, pp. 1515-1520 vol.2, doi: 10.1109/IECON.2001.976015.
5. S. Ichiki, "New Modulation Method for Three-Phase Matrix Converter: Mathematical Theory and Demonstration Test Results," in IEEE Transactions on Industrial Electronics, vol. 69, no. 4, pp. 3959-3966, April 2022, doi: 10.1109/TIE.2021.3075878.

6. J. Xie, D. Henneberg, M. Suberski, M. Kusebauch, U. Rädel and J. Petzoldt, "An Optimized Compensation Strategy of Direct Matrix Converter-Fed PMSM Drives with Field Weakening under Unbalanced Supply Conditions," 2022 24th European Conference on Power Electronics and Applications (EPE'22 ECCE Europe), Hanover, Germany, 2022, pp. P.1-P.10.
7. S. Ichiki, "New Modulation Method for Three-Phase Matrix Converter: Mathematical Theory and Demonstration Test Results," in IEEE Transactions on Industrial Electronics, vol. 69, no. 4, pp. 3959-3966, April 2022, doi: 10.1109/TIE.2021.3075878.
8. J. Zhang, L. Li and D. G. Dorrell, "Control and applications of direct matrix converters: A review," in Chinese Journal of Electrical Engineering, vol. 4, no. 2, pp. 18-27, June 2018, doi: 10.23919/CJEE.2018.8409346.
9. N. Islam, A. Mohammed Arfi, M. A. Uz Zaman, A. Baul and A. Mohammed Abir, "Design and Implementation of a Matrix Converter Using Direct IGBT Switching Method," 2019 IEEE International Conference on Power, Electrical, and Electronics and Industrial Applications (PEEIACON), Dhaka, Bangladesh, 2019, pp. 69-73, doi: 10.1109/PEEIACON48840.2019.9071943.
10. M. A. Waghmare, B. S. Umre, M. V. Aware, A. Iqbal and A. Kumar, "Dual Stage Single-Phase to Multiphase Matrix Converter for Variable Frequency Applications," in *IEEE Transactions on Power Electronics*, vol. 38, no. 2, pp. 1372-1377, Feb. 2023, doi: 10.1109/TPEL.2022.3207515.
11. L. Stanić, L. Ristić, M. Bebić and M. Rivera, "Extended SVM for direct matrix converter based drive operating under unbalanced grid conditions," *2021 21st International Symposium on Power Electronics (Ee)*, Novi Sad, Serbia, 2021, pp. 1-6, doi: 10.1109/Ee53374.2021.9628195.
12. P. Jin, Y. Hu, G. Lei, Y. Guo and J. Zhu, "A Novel SVM Strategy to Reduce Current Stress of High-Frequency Link Matrix Converter," in *IEEE Transactions on Industrial Electronics*, doi: 10.1109/TIE.2023.3279581.
13. M. Sanjeev, M. Israyelu and S. Sashidhar, "Comparative Analysis of Direct SVM and Indirect SVM Techniques for Direct Matrix Converter," *2021 International Symposium of Asian Control Association on Intelligent Robotics and Industrial Automation (IRIA)*, Goa, India, 2021, pp. 95-100, doi: 10.1109/IRIA53009.2021.9588683.
14. A. Boukadoum, A. Bouguerne and T. Bahi, "Fuzzy Logic Controlled Voltage Transfer Ratio of a Matrix Converter under Harmonic Distortion," *2022 IEEE 2nd International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering (MI-STA)*, Sabratha, Libya, 2022, pp. 70-74, doi: 10.1109/MI-STA54861.2022.9837547.
15. K. Omrani, M. A. Dami and M. Jemli, "A SVM control strategy for a direct matrix converter," *2017 International Conference on Green Energy Conversion Systems (GECS)*, Hammamet, Tunisia, 2017, pp. 1-6, doi: 10.1109/GECS.2017.8066130.
16. A. Soyed, A. Aouiti and F. Bacha, "ISVM Control and Virtual DC Bus Voltage Regulation for Direct Matrix Converter for Wind Energy Conversion System," *2023 IEEE International Conference on Advanced Systems and Emergent Technologies (IC_ASET)*, Hammamet, Tunisia, 2023, pp. 1-6, doi: 10.1109/IC_ASET58101.2023.10151291.
17. R. B. Roy, J. Cros, E. Basher and S. M. B. Taslim, "Fuzzy logic based matrix converter controlled indution motor drive," *2017 IEEE Region 10 Humanitarian Technology Conference (R10-HTC)*, Dhaka, Bangladesh, 2017, pp. 489-493, doi: 10.1109/R10-HTC.2017.8289005.