International Journal of Engineering Technology and Management Sciences
Website: ijetms.in Issue: 3 Volume No.7 May - June – 2023
DOI:10.46647/ijetms.2023.v07i03.004 ISSN: 2581-4621

Implementation of Three-Phase AC-to-DC Matrix Rectifiers Using Space Vector Modulation: A Review

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***Abstract*:** Matrix converter is a versatile scheme consisting of controlled semiconductor devices that has a command in delivering input of constant amplitude and frequency to the output of three phase with adjustable amplitude and frequency and it is able to produce multiple output frequencies with single input frequency. In the recent trends of power electronics, the use of these converters is increased vastly due to its versatile behaviour. During the past years the utilization of these converters are increased rapidly as they have several applications in industries. This paper presents the literature assessments of matrix converter and configurations discussed in the early stages of research. Also, the performance indices like power factor improvement, harmonic content in the output voltage, absence of energy storage elements and DC link between input and output stages of the system has been clearly discussed.
***Index Terms*:** Matrix converter, AC/AC converter, PWM techniques

INTRODUCTION:

With the implementation of various electrical technologies like integration diverse sources of energy sources and their combination provided the need of power electronic technology. A variety of topologies of power circuits using power electronic components have been implemented. Basically, matrix converted defined as a group of fully controlled semiconductor switches connected directly to three phase load and source respectively in the absence of energy storage elements, DC link. The most important advantage of these converters is that they operate at a power factor of unity and both the input and output voltages are sinusoidal waveforms. During the past years the utilization of these converters are increased rapidly as they have several applications in industries. The attention towards the vast majority of utilization of different converters has been increased with recent years. Compared with other converters like various circuits of inverter, cycloconverters, AC voltage converters these matrix converters have several benefits, and their utilization has increased in industries. Some of the important advantages of matrix converters are power factor can be changeable and can be made nearer to unity, both voltage and current waveforms are sinusoidal, stability increment and bidirectional flow of power. With the absence of capacitor between both output and input stages in direct converter matrix which provides an additional feature. Basically, a matrix converter is designed with bidirectional semiconductors switches constructed with an array of m x n. These switches are arranging in such a way that, irrespective of time it enable three input lines and output lines are connected. With input lines as three (m=3) the pulse width modulation technique used with 27 combinations of switches obtained from 3^n as here n equals to 3 with avoiding non conducting state.

The most Acceptable and desirable features of these matrix converters is:

- Circuit is simple and compatible.
- With random amplitude and frequency generation of load voltage
- Input and output currents are sinusoidal in nature.
- Unity power factor operation for any load.
- Capability of regeneration.

DOI:10.46647/ijetms.2023.v07i03.004 ISSN: 2581-4621

As these characteristics are nearer to ideal which are supposed to fulfilled by these topologies of these converters hence there is a vast interest towards for implementation.
As these converter uses Forced commutation for controlling bidirectional semiconductor switches to obtain a variable output voltage with vast range of no frequency restrictions. As there is no need of any dc-link circuit and absence of capacitor for energy storage which make the system more reliable. A high frequency operation with the available four-quadrant fully controlled bidirectional switch is defined as a most important element of the matrix converter.
In the earlier studies thyristors are used and are controlled externally with force commutation to obtain the bidirectional control and these power circuits make the system bulkier in nature and reduces the system performance.

FUNDAMENTALS:

The name “matrix converter” obtained as the power circuit consists of bidirectional switches with an array of rows and columns. It is a single stage converter consisting of array of m x n bidirectional switches with ‘m’ switched connected to the source and ‘n’ switches directly to load. A basic 3 x 3 converter is shown in figure:1 consisting of ‘m’ as 3-phase voltage source connected to three phase loads generally a motor load whose speed is supposed to be controlled.

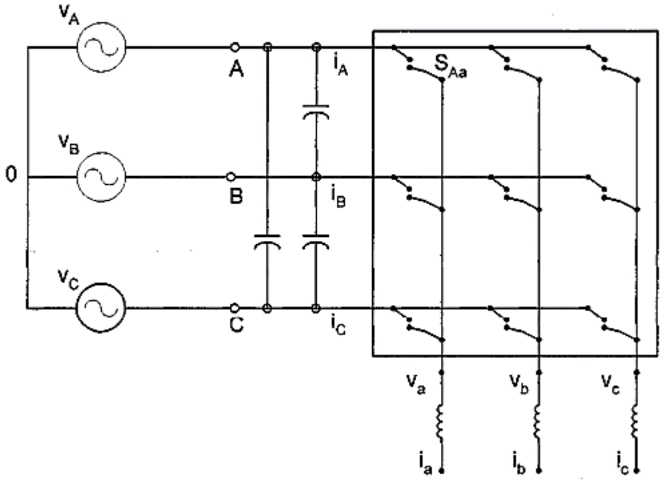

Figure : Basic 3 x 3 converter

The input terminals of this basic converter are fed from the voltage source hence it is supposed to be short-circuited and the output load is generally an inductive load and it is should not be open circuited.
A single switch switching function can be defined as:

$$SW_{kj} = \begin{cases} 1, \text{SWkj is closed} \\ 0, \text{SWkj is opened} \end{cases} \quad \text{as } K=\{A,B,C\} \text{ and } j=\{a,b,c\}$$

Hence the Constraints can be defined as $SW_{Aj}+SW_{Bj}+SW_{Cj}=1$, with $j=\{a,b,c\}$
With these a basic 3 x 3 converter will have 3^n possible states of switching. As ‘n’ determined as 3 here hence a 27 possible combination of switching states is made available. With reference to neutral the input source and output load is defined as

$$V_{in}=\begin{bmatrix} VA(t) \\ VB(t) \\ VC(t) \end{bmatrix} \quad \text{and} \quad V_{out}=\begin{bmatrix} Va(t) \\ Vb(t) \\ Vc(t) \end{bmatrix}$$

Input and output voltages can be related as

$$\begin{bmatrix} Va(t) \\ Vb(t) \\ Vc(t) \end{bmatrix} = \begin{bmatrix} SW_{Aa}(t) & SW_{Aa}(t) & SW_{Aa}(t) \\ SW_{Aa}(t) & SW_{Aa}(t) & SW_{Aa}(t) \\ SW_{Aa}(t) & SW_{Aa}(t) & SW_{Aa}(t) \end{bmatrix} \begin{bmatrix} VA(t) \\ VB(t) \\ VC(t) \end{bmatrix}$$

$V_{out}=\mathbf{T}.\ V_{in}$

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Where **T** is the transfer matrix at any time instant.

Matrix converter is a most versatile with direct frequency conversion and high-power quality input with capability of regeneration. With the absence of any frequency storage element, it became more versatile compared to inverter PWM drives. Moreover, it has the same disadvantage as conventional drives like disturbance on ac line side which degrades its performance and reliability. As the matrix converter is a direct frequency conversion device if any disturbance on grid side due to the absence of any storage element, which directly reflects the load side of the system. Due to this an impedance balance on the line side causes the inclusion of undesirable harmonics in the system. There is a need of versatile techniques which reduce the harmonics both on the source and load side of the system. Various authors designed a converter technique that improves the total system power quality by reducing the harmonic contents in the input and output currents. AC grid failure is another important problem, due to the absence of any storage element and dc link associated with it. Due to these the total power losses of the system increased and reduces the system capacity. To avoid this a power line failure which is momentary is done rapidly to avoid large in rush of current. An investigation carried out on the transient nature of power loss and their recovery conditions, and the results show that the safety turnoff times of semiconductor devices provide the restoration of the grid rapidly and restores. Due to symmetry and inherent bidirectional behaviour of matrix converter a dual connection will be quite feasible with current, and voltage fed system at input and output of the matrix converter respectively.

ADANTAGES AND DISADVANTAGES OF MATRIX CONVERTERS:

Compared to traditional schemes like rectifier-based inverter type frequency power converter matrix converters. It provides a pure sinusoidal output and input waveforms with the absence of sub-harmonics and only a minimum higher order harmonics with a capability of bidirectional current flow with a control over input power factor. Along with above benefits it has a minimum requirements of energy storage requirements with makes the system without any bulky with grid. Coming to disadvantages with maximum transfer of input and output transfer ratio of voltage is limited to @ 88 % for sinusoidal waveforms. Compared with conventional indirect AC/AC convertors the number of semiconductor devices required is more with matrix converters because of monolithic bi-directional switches exist and consequently discrete unidirectional devices, variously arranged, have to be used for each bi-directional switch. Moreover, it is quite sensitive to any change or disturbance in input voltage.

VARIOUS ARCHITECTURES OF MATRIX CONVERTERS:

commutation failure issues and limited to applications of various drive control. A configuration called A matrix converter [MC] of single-phase type has various configurations based on number of power semiconductor switches exclusively used for that configuration. For example, a basic type one [1] will resemble a H-bridge type consisting of four bidirectional switches with no energy storage elements. This type is previously used in UPS applications and faces performance issues like commutation failure and low voltage conversion efficiency. A Z-source matrix converter [2] having a configuration of five bidirectional switches with energy storage elements, i.e., 2-L & 2-C have both buck and boost capabilities with overcome of commutation failures. When the number of switches is increased to six, a configuration of matrix converter [3] with current flowing in unidirectional and voltage blocking with bidirectional capabilities has applications in motor drives, induction heating. This type has overcome the commutation failure issue and have bucking and boosting the voltages with fast MOSFETS in its configuration. When the same matrix converter is integrated with combination of high frequency transformer at supply side, single DC blocking capacitor, and single level shifting capacitor can be used for applications involving isolation and dynamic voltage restoring. When such configurations [4] are employed, only buck operation is possible for its complexity and commutation problems.

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Coming to three phase matrix converters, a configuration called direct MC type [5] has nine bidirectional switches with no energy storage elements, i.e., unity power factor operation. This configuration also faces sparse MC type [6] with fifteen power semiconductor switches, i.e., IGBTS and three diodes has shown features like zero DC-link current commutation with variable frequency. This type has employed for applications with elevator drives and aircraft appliances. Another three phase MC type configuration called very sparse type MC [7] consists of twelve power semiconductor switches, i.e., IGBTS and eighteen diodes with no energy storage elements, i.e., unity power factor operation. This type also faces commutation problems and high conduction loss because of high number of power semiconductor switches. Another three phase MC type configuration called ultra-sparse type MC [8] consists of nine power semiconductor switches, i.e., IGBTS and nine diodes with no energy storage elements, i.e., unity power factor operation. This type offers features like low conduction loss and provides a 30 degrees displacement in both directions between the applied input side current and output side current. The maximum displacement obtained with currents on both sides can also be observed with voltages on both sides. When twenty-one power semiconductor switches, i.e., IGBTS and a combination of 3-L & 3-C is used for a configuration called Z-source MC type [9] has exclusive applications for PMSM drives. This configuration offers both bucking and boosting the voltage with added variable frequency feature. This type is costly and bulky in nature with high conduction losses. The direct matrix converter is readily available from manufacturer like YASKAWA, EUPEC and FUJI. A model called FRENIC from FUJI has maximum voltage of 400 V and maximum power rating of 45 kW for applications like cranes and elevators. Another model called ECONOMAC from EUPEC has maximum voltage of 1200 V and maximum power rating of 42 kVA. The models from YASKAWA ranges from 480 V to 6600 V for maximum voltage and 350 HP to 800 HP for maximum power in their specifications. They are mainly used for motor drive applications with features like energy savings, low harmonics. A legacy product called Z1000U is exclusively used for HVAC applications with negligible input distortion.

CONTROL TECHNIQUES EMPLOYED FOR MATRIX CONVERTERS:

Every type of matrix converter discussed needed control technique for switching on-off the power semiconductor switches appropriately for maximum performance. Some of the widely used control techniques are discussed below with some insights. A basic direct control technique named venturini [10] have low complexity in implementation and provides a good dynamic response. It also exhibits low resonance effect on the system with very low sampling frequency. A similar low complexity control technique called scalar [11] also have similar provisions discussed along with low switching frequency. Coming to carrier based PWM control technique [12] for MC, the complexity is very low in implementation and has similar performance, only difference observed is with the effect of resonance needs a medium sized filter compared to previous techniques. The complexity of implementation is very high for space vector modulation techniques [13], still it has numerous applications involving power factor correction because of absence of L-C filter requirement. In direct torque control technique [14], both sampling and switching frequency is high and the complexity of implementation is slightly reduced compared to space vector modulation method. The dynamic response obtained from this control technique is superior compared to previous techniques, but at the same time it needs a very large resonance filter compared with all other techniques for electric drive applications. Another control technique named predictive torque technique [15] proposed for induction motor drive applications is very similar to direct torque control, added feature is that its dynamic response is very fast, and the requirement of resonance filter is dynamic in nature, i.e., varying from very large to small values. The recent control technique based on current direction, i.e., predictive current control technique [16] has shown performance on par with the predictive torque control technique in all the aspects. For the matrix converter to operate at unity power factor, there is a necessity of reduction of reactive power consumed or absorbed by the various configurations. A basic predictive current control [17] is formulated with reactive power decrement by considering the prediction of input side Q-power for near UPF operation. For this, there is no need for generation of reference current vector or reference Q-power vector. When the same predictive current control is injected with active damping [18], it defiantly requires reference current generation through PLL, Clark's and Park's transformations. If we consider the predictive current control with injected sinusoidal input current [19], then it requires reference Q-power vector generation through the PLL, Clark's and Park's transformations. For generating the reference current vector through the field orient control is another way for operating the matrix converter for reduced Q-power, i.e., near UPF operation. Following the reference current vector generation, a control technique based on negative sequence current regulation [20] is proposed for various matrix converters to be operated in two modes, i.e., Different frequencies mode and Equal frequencies mode. Another approach is circulating current regulation [21], where the control of the matrix converter is based on the capacitor voltage in cluster mode. When the comparison done between different modes, i.e., circulating current and common voltage, if applied alone, both are treated as open loop control techniques with low complexity of implementation. Considering only common voltage mode alone, it requires the Q-power injection for near UPF operation from the input side. The load cell balancing is another important control approach for matrix converters [22], where the criteria is based on pulse width modulation or model predictive control. If the space vector PWM [23] is considered, there is clear usage of redundancy in balancing approach, and it also faces issues like the number of cells required is more. When the phase shifted [24] is incorporated with the space vector PWM, the realization of such circuits in real world scenario is made easy, but it requires closed loop approach with high proportional controllers in its design. A similar criterion known as level shifted [25] is also applicable for space vector modulation, where the performance is on par with the phase shifted approach and it requires the high computational power for its real world or digital implementation design. Coming to the model predictive control approach [26], it is best suited for issues like optimal control with constraints and also it lacks approximated solutions as final solution for its prediction. A very low complexity control approach based on hysteresis control [27] is widely used for matrix converters, where both switching and sampling operating frequency range is high and dynamic in nature. For motor drive applications, the supply side frequency compared to the frequency of the load should be different with control approaches like model predictive and field orient controls. For Power factor correction, i.e., UPFC the supply side frequency compared to the frequency of the load should be exactly same with control approaches like space vector modulation and sliding mode approaches. For wind turbine applications, the supply side frequency compared to the frequency of the load should be entirely different with control approaches like space vector modulation and sliding mode approaches. For utility supply applications, the supply side frequency compared to the frequency of the load should be different with control approaches like space vector modulation and metaheuristic algorithms. For Grid interfacing applications, the supply side frequency compared to the frequency of the load should be nearly same with control approaches like model predictive control. To obtain a desirable high input side power factor in case of grid integration requires weighing factor criteria [28]. When the predictive torque control is integrated with weighing factors, there is clear improvement in dynamic response and power factor. Another way is to totally ignore weighing factors because they require heavy computation burden. Instead of tuning the weighing factors [29], multi-objective framework is suitable for applying metaheuristic techniques. For fault tolerance criteria [30], matrix converters need to overcome two conditions. The primary one is that converter needs to contain redundancy switches in its configuration, if not leads to severe power burden on their switches. The secondary one for improvement of power factor, i.e., constant circulating current injections are mandatory to maintain Q-power on both sides of the converter.

CONCLUSION:

The fundamental matrix converters are studied thoroughly from basic introduction, merits, and demerits. Followed by a brief discussion on single phase MC type and various configuration based on number of power semiconductor switches, number of inductances, number of capacitors, and number of diodes. Both single-phase M-converters and three phase M-converters configurations are elevated with specifications, ratings and problems associated with them. At the later stage, various control techniques are discussed from Q-power injection for power factor improvement, necessity of PWM control, Current Injection, Common mode voltage for grid integration. This literature review is helpful for all the researchers to work on applying grid integration, fault tolerance for the matrix converters.

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DOI:10.46647/ijetms.2023.v07i03.004 ISSN: 2581-4621

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