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Review of Matrix Converter Modulation Topology (Venturini Method) and its Application

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ABSTRACT

This paper presents an overview of the matrix converter and its modulation techniques with application. Matrix converter is one of the most interesting members of power converter family; provide direct AC-AC conversion. A matrix converter is an ac-ac power frequency converter that received extension research attention due to its single stage power conversion technique, which is an alternate to ac-dc-ac converter. MC (matrix converter) is capable to convert energy from an ac source to ac load without the need of bulky and life-time limited energy storage elements. Here the purpose of most of these modulation methods is to generate sinusoidal current on the input and output sides. These methods are compared on the basis of theoretical complexities and performance.

Keywords AC-AC Converter; Matrix Converter Modulation Schemes; Venturini Method; Indirect Matrix Converter.

1.0 Introduction

Converter systems with either a voltage or a current dc-link are mainly used for power conversion from a three-phase mains system to a three-phase load with an arbitrary voltage amplitude and frequency, as required, for example, for variable-speed drives. Over Recent years, the matrix converter (MC) has attracted the interest of the scientific community due to the advantages it offers [3]–[4].

A matrix converter (MC) delivers the following advantages

1. Sinusoidal input and output current waveforms;
2. Controllable input power factor (IPF);
3. Operations in all four quadrants of the torque–speed plane due to the regenerative capability;
4. High reliability and long life due to the absence of bulky electrolytic capacitors;
5. Smaller and lighter design than other regeneration inverters with equivalent power ratings.

Matrix-converter topologies can be divided into two types direct matrix converters (MCs) and indirect matrix converters (2MCs). which has nine bidirectional switches. The 2MC comprises a four-

quadrant current-source rectifier connected to a two-level voltage-source inverter. By applying appropriate modulation scheme [1]–[2] the direct converter and 2MC are able to generate input and output waveforms with the same with the work of Venturini and Alesina in 1980 [5]. Commutation of the bidirectional switches is the biggest difficulties in the operation of this converter and this can be solved by introducing intelligent and soft commutation techniques. In effect, one big manufacturer of power converters (Yaskawa) is now offering a complete line of standard units for upto several megawatts and medium voltage using cascade connection. These units have rated power (voltages) of 9–114 kVA (200 and 400 V) for low-voltage MC and 200–6.000 kVA (3.3 and 6.6 kV) for medium voltage.

2.0 Working Principle Of Mc

MC consists of an array of bidirectional switches, which are used to directly connect the power supply to the load without any intermediate stage. MC is a single stage converter with $l \times n$ bidirectional switches that connects an l -phase voltage source to an n -phase load. The MC of 3×3 switches, shown in Fig. 1, is important from a

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practical point of view because it connects a three-phase source to a three-phase load, typically a motor.

$$k_{ij}(t) = \begin{cases} 1, & \text{switch on} \\ 0, & \text{switch off.} \end{cases} \quad (1)$$

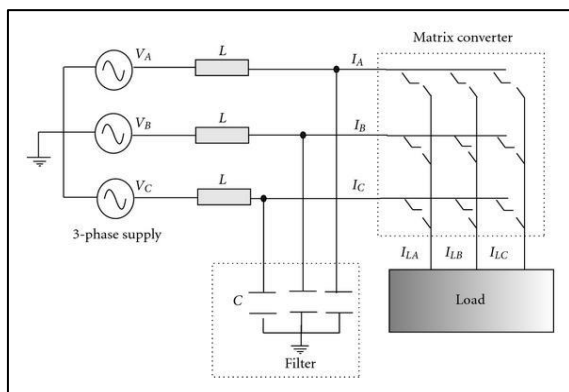
The power filter at input side of converter (R,L,C) reject the high- frequency components of the MC input currents and generate almost sinusoidal source current and avoid generation of overvoltage's.

In order to develop a modulation strategy for the MC, it is necessary to develop a mathematical model, which can be derived from fig.1, i.e

$$V_o = T(k_{ij})V_i \quad (2)$$

$$I_i = T(k_{ij})^T i_o \quad (3)$$

Fig 1: Block Diag. of MC



Where $V_o = [v_a \ v_b \ v_c]^T$ output voltage

$V_i = [v_A \ v_B \ v_C]$ input voltage

$I_i = [i_A \ i_B \ i_C]$ input current

$I_o = [i_a \ i_b \ i_c]^T$ output current

$T(k_{ij}) =$ transfer matrix

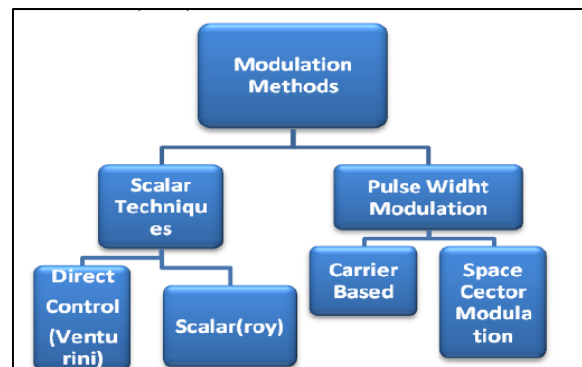
$$K(s_{ij}) = \begin{pmatrix} s_{Aa} & s_{Ba} & s_{Ca} \\ s_{Ab} & s_{Bb} & s_{Cb} \\ s_{Ac} & s_{Bc} & s_{Cc} \end{pmatrix}$$

Equations (2) and (3) are the basis of all modulation methods.

3.0 Modulation Methods

The modulation methods developed up to now, for MC are shown in Fig. 2. The first method is called the direct transfer function approach also known as the Venturini method. Here, the output voltage is obtained by the product of the input voltage and the transfer matrix representing the converter. Another strategy is the scalar method developed by Roy, which consists of using the instantaneous voltage ratio of specific input phase voltages to generate the active and zero states of the converter's switches. An important solution for the control of MCs comes from the use of pulse width modulation (PWM) techniques. The simplest approach is to use carrier-based PWM techniques. A powerful solution currently in use is to apply space-vector modulation (SVM) in MCs.

Fig 2: Block Diagram of Modulation Techniques



4.0 Scalar Techniques

4.1 Direct method venturini

Modulation is the procedure used to generate the appropriate firing pulses to each of the nine bidirectional switches (Kij). This method was proposed by Venturini in [2]. In this method the objective of the modulation is to generate variable frequency and variable amplitude sinusoidal output voltages (vjN) from the fixed-frequency and fixed-amplitude input voltages (Vi). Here, the instantaneous input voltages are used to synthesize a signal whose low-frequency component is the desired output voltage.

If T_{ij} is defined as the time during which switch k_{ij} is on and t_s as the sampling interval, we can express the aforementioned principle as

$$v_jN = TA_j v_A + TB_j v_B + TC_j v_C \quad (5)$$

Where v_jN is the low-frequency component (mean value calculated over one sampling interval) of the j th output phase and changes in each sampling interval. With this strategy, a high-frequency switched output voltage is generated, but a fundamental component has the desired waveform. Obviously,

$t_s = TA_j + TB_j + TC_j$, with $j = a,b,c$, and therefore, the following duty cycles can be defined

$$\begin{aligned} m_{Aj}(t) &= TA_j / t_s \\ m_{Bj}(t) &= TB_j / t_s \\ m_{Cj}(t) &= TC_j / t_s \end{aligned} \quad (6)$$

Extending equation (5) to output phase and using (6), the following equation can be derived

$$v_o(t) = M(t)v_i(t) \quad (7)$$

Where

$$M(t) = \begin{bmatrix} m_{Aa}(t) & m_{Ba}(t) & m_{Ca}(t) \\ m_{Ab}(t) & m_{Bb}(t) & m_{Cb}(t) \\ m_{Ac}(t) & m_{Bc}(t) & m_{Cc}(t) \end{bmatrix}$$

Analogous procedure can be applied for the input current, it can be shown as -

$$i_i(t) = M^T(t)i_o(t) \quad (8)$$

Where $M^T(t)$ is the transpose of $M(t)$

Equations (7) and (8) are the basis of the Venturini modulation method, leading to the conclusion that the low-frequency components of the output voltages are synthesized with the instantaneous input voltages and the low-frequency components of the input currents are synthesized with the instantaneous values of the output currents. Input voltages v_i are given by

$$[V_i(t)] = V_i \begin{bmatrix} \cos(\omega_i t) \\ \cos(\omega_i t - 2\pi/3) \\ \cos(\omega_i t + 2\pi/3) \end{bmatrix} \quad (9)$$

Output currents i_o are sinusoidal and can be expressed as

$$[I_o(t)] = I_o \begin{bmatrix} \cos(\omega_o t + \phi_o) \\ \cos(\omega_o t + \phi_o - 2\pi/3) \\ \cos(\omega_o t + \phi_o + 2\pi/3) \end{bmatrix} \quad (10)$$

with $\omega_i = 2\pi f_i$ and $\omega_o = 2\pi f_o$, where f_i and f_o correspond to the source and load frequencies, respectively. V_i is the input voltage amplitude, and I_o output current amplitude.

Also, suppose that the desired output voltage v_o can be expressed as:-

$$[V_o(t)] = v_o \begin{bmatrix} \cos(\omega_o t) \\ \cos(\omega_o t + 2\pi/3) \\ \cos(\omega_o t + 4\pi/3) \end{bmatrix} \quad (11)$$

With the previous definitions, the modulation problem is reduced to finding a low-frequency transfer matrix $M(t)$

such that (7) and (8) are satisfied. The explicit form of the matrix $M(t)$ can be obtained from [2], and it can be reduced to the following expression

$$m_j(t) = \frac{(1 + 2v_{iN}(t) v_{jN} / v_i^2)}{3} \quad (12)$$

Where $i = A, B, C$ and $j = a,b,c$.

5.0 Application

Application of MC in industrial area is shown by the simulink model, which is used to provide the three phase input to the motor. Here in spite of conventional converters (ac-dc-ac converter) we are using single stage converter i.e. Matrix converter. And by varying the elements of matrix (switching on and off of the bidirectional switches) we can vary the output of the converter.

Fig 3: Simulink Model of MC

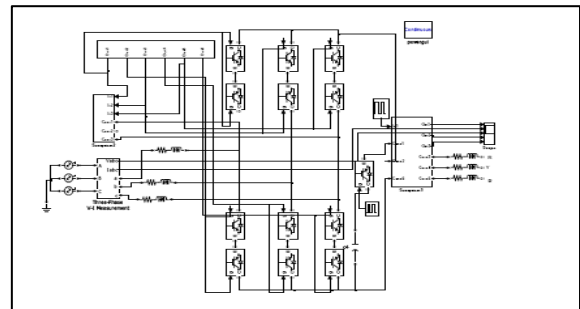
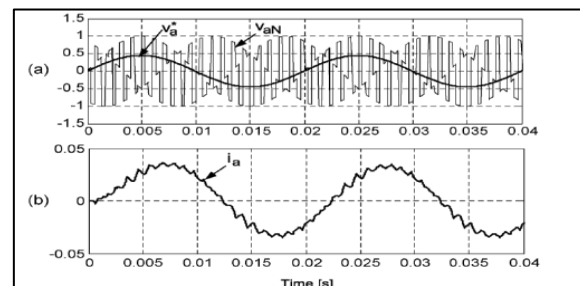


Figure 3 shows the simulink model for induction motor drive; here the input to the motor is given through the indirect matrix converter (2MC). Output terminals RYB are connected to the motor input.

Fig 4. Direct Method Venturini, Typical Waveforms. (a) Output Voltage v_aN (b) Output Current i_a



6.0 Conclusion

The area of MCs has shown continuous development in recent years in terms of new topologies, control methods, and applications. This paper has presented a number of control & modulation methods that are highly investigated today, which, in principle, exhibit good performance. These methods have different theoretical principles and different degrees of complexity. This paper also represents the simulink model of MC with motor application and fig 4 shows the typical waveforms of the output voltage and output current.

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