



# VENTURINI METHOD CONTROL FOR THREE PHASE MATRIX CONVERTER USING FPGA

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**Abstract:-** Matrix converter is a single stage converter which directly connects a three phase voltage source to a three phase load without DC-link components. A matrix converter is an unlimited frequency changer, which can generate both smaller and bigger output frequency than input frequency of the converter. The output voltage waveforms are constructed by piecing together selected segments of the input voltage waveforms. In this paper, the gate signals of the matrix converter power switches mentioned in venturini Modulation method are produced using Model Sim. This method provides the amplitude of output voltage upto 86.6% of input voltage and unity displacement factor at the input regardless of the load displacement factor. The simulation results of the proposed schemes are presented using MATLAB SIMULINK at various operating parameters (voltage & frequency).

**Keywords:-** Matrix Converter (MC), Direct Matrix Converter (DMC), Pulse Width Modulation (PWM).

## I. INTRODUCTION

The matrix converter consists of 9 bi-directional switches that allow any output phase to be connected to any input phase. The circuit scheme of a three phase to three phase matrix converter is shown in Fig.1. The input terminals of the converter are connected to a three phase voltage-fed system, usually the grid, while the output terminal are connected to a three phase current-fed system, like an induction motor might be. The capacitive filter on the voltage-fed side and the inductive filter on the current-fed side represented in the scheme of Fig.1

are intrinsically necessary. Their size is inversely proportional to the matrix converter switching frequency [1]. It is worth noting that due to its inherent bi-directionality and symmetry a dual connection might be also feasible for the matrix converter: a current-fed system at the input and a voltage-fed system at the output. Fig.1 shows Circuit scheme of a three phase to three phase matrix converter a,b,c are at the input terminals & A,B,C are at the output terminal.

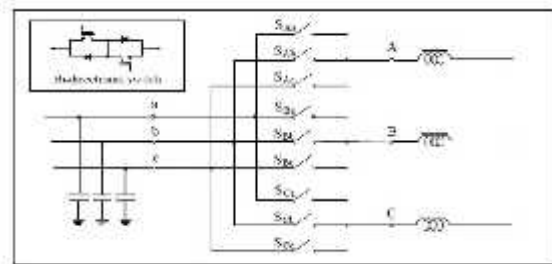


Fig.1 Circuit scheme of a three phase to three phase matrix converter

With nine bi-directional switches the matrix converter can theoretically assume 512 (2<sup>9</sup>) different switching states combinations. But not all of them can be usefully employed. Regardless to the control method used, the choice of the matrix converter switching states combinations (from now on simply matrix converter configurations) to be used must comply with two basic rules. Taking into account that the converter is supplied by a voltage source and usually 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 only one



bi-directional switch per output phase must be switched on at any instant. By this constraint, in a three phase to three phase matrix converter 27 are the permitted switching combinations.

## II. MODULATION TECHNIQUES FOR MATRIX CONVERTER

The purpose of these modulation techniques is to change the voltage transfer ratio. The different types of Modulation techniques are Basic Modulation technique, Voltage ratio limitation and optimization, Alesina –Venturini modulation technique, Scalar modulation technique, Space vector modulation technique, indirect modulation technique. The main modulation techniques which have wide applications are as follows:

- Venturini method
- Space Vector Modulation (SVM)

The modulation methods based on the Venturini approach is known as “direct methods, while those based on the “fictitious dc link” are known as “indirect methods”.

## III. INTRODUCTION TO VENTURINI METHOD

In 1980, Venturini and Alesina presented a converter, which consists of bidirectional power switches constructed as matrix and they introduced to as “matrix converter”. In addition to, they proposed a PWM modulation method for the control of matrix converter. The proposed method by these authors is known to as the Venturini method or the direct transfer function approach. In Venturini method, the appropriate firing pulses to each of the nine bidirectional switches must be calculated to generate variable-frequency and/or variable-amplitude sinusoidal output voltages from the fixed-frequency and the fixed-amplitude input voltages. The matrix converter is a single-stage converter, which has an array of  $m \times n$  bidirectional power switches. Each bidirectional switch is composed of two IGBTs and two fast diodes connected anti-parallel. Theoretically, the number of input phases,  $m$  must be at least three, and the number of output phases,  $n$  can be chosen from one to infinity. A matrix converter is an unlimited frequency changer, which can generate both smaller and bigger output frequency than input frequency of the converter. The output voltage waveforms are constructed by piecing together selected segments of the input voltage waveforms. In this method, the voltage transfer ratio was limited to 0.5.

Under ideal input voltage conditions, the three-phase sinusoidal input voltages of the MC will be as follows

$$v_i(t) = \begin{bmatrix} v_A(t) \\ v_B(t) \\ v_C(t) \end{bmatrix} = \begin{bmatrix} V_i \cos(\omega_0 t) \\ V_i \cos(\omega_0 t + 2\pi/3) \\ V_i \cos(\omega_0 t + 4\pi/3) \end{bmatrix}$$

------(1)

The desired output voltage  $V_o$  can be expressed as

$$\bar{v}_o(t) = \begin{bmatrix} \bar{v}_{oN}(t) \\ \bar{v}_{oN}(t) \\ \bar{v}_{oN}(t) \end{bmatrix} = \begin{bmatrix} q V_i \cos(\omega_0 t) \\ q V_i \cos(\omega_0 t + 2\pi/3) \\ q V_i \cos(\omega_0 t + 4\pi/3) \end{bmatrix}$$

------(2)

$$\bar{v}_o(t) = M(t) \cdot v_i(t)$$

------(3)

Where  $V_o(t)$  is the low frequency output voltage vector,  $v_i(t)$  is the instantaneous input voltage vector and  $M(t)$  is the low-frequency transfer matrix of the MC. In order to develop a modulation strategy for the MC, it is necessary to develop a mathematical model, which can be derived directly from the above equations.

Applying Kirchhoff's voltage law to the switch array, it can be easily found that

$$\begin{bmatrix} v_{oA}(t) \\ v_{oB}(t) \\ v_{oC}(t) \end{bmatrix} = \begin{bmatrix} S_{Aa}(t) & S_{Ab}(t) & S_{Ac}(t) \\ S_{Ba}(t) & S_{Bb}(t) & S_{Bc}(t) \\ S_{Ca}(t) & S_{Cb}(t) & S_{Cc}(t) \end{bmatrix} \begin{bmatrix} v_A(t) \\ v_B(t) \\ v_C(t) \end{bmatrix}$$

------(4)

Each switch  $s_{ij}$ ,  $i = \{A, B, C\}$ ,  $j = \{a, b, c\}$ , can connect or disconnect phase  $i$  of the input stage to phase  $j$  of the load and, with a proper combination of the conduction states of these switches, arbitrary output voltages  $v_{jN}$  can be synthesized. Each switch is characterized by a switching function, defined as follows:



$$S_{ij}(t) = \begin{cases} 0 & \text{if switch } S_{ij} \text{ is open} \\ 1 & \text{if switch } S_{ij} \text{ is closed} \end{cases}$$

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

-----(5)

Due to the presence of capacitors at the input of the MC, only one switch of each column can be closed. Furthermore, the inductive nature of the load makes it impossible to interrupt the load current suddenly and therefore, at least one switch of each column must be closed. Consequently, it is necessary that one and only one switch per column are closed at each instant. This condition can be stated in a more compact form as follows:

$$\sum_{i=A,B,C} S_{ij}(t) = 1; \quad j = (a,b,c), \quad \forall t$$

-----(6)

The output currents  $i_o$  are sinusoidal and can be expressed as

$$\vec{i}_o(t) = \begin{bmatrix} i_a(t) \\ i_b(t) \\ i_c(t) \end{bmatrix} = \begin{bmatrix} I_o \cos(\omega_o t + \phi) \\ I_o \cos(\omega_o t + 2\pi/3 + \phi) \\ I_o \cos(\omega_o t + 4\pi/3 + \phi) \end{bmatrix}$$

-----(7)

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.  $V_i$  corresponds to the input voltage amplitude, and  $I_o$  corresponds to the output current amplitude. Furthermore, suppose that the desired input current vector is given by

$$\vec{i}_i(t) = \begin{bmatrix} I_a(t) \\ I_b(t) \\ I_c(t) \end{bmatrix} = \begin{bmatrix} I_i \cos(\omega_i t) \\ I_i \cos(\omega_i t + 2\pi/3) \\ I_i \cos(\omega_i t + 4\pi/3) \end{bmatrix}$$

-----(8)

Following an analogous procedure for the input current, it can be easily shown that:

$$\vec{i}_i(t) = [M(t)]^T \vec{i}_o(t)$$

-----(9)

Where,  $[M(t)]^T$  is the transpose matrix of  $[M(t)]$ -----  
-----(10)

Applying Kirchoff's current law to the switch array, it can be found that

$$\begin{bmatrix} i_a(t) \\ i_b(t) \\ i_c(t) \end{bmatrix} = \begin{bmatrix} S_{Aa}(t) & S_{Ab}(t) & S_{Ac}(t) \\ S_{Ba}(t) & S_{Bb}(t) & S_{Bc}(t) \\ S_{Ca}(t) & S_{Cb}(t) & S_{Cc}(t) \end{bmatrix} \begin{bmatrix} i_a(t) \\ i_b(t) \\ i_c(t) \end{bmatrix}$$

-----(11)

If it is defined as  $T_{kj}$ , the time during which switch  $S_{kj}$  is on at time  $T_s$  sampling interval, the duty cycle of switch  $S_{kj}$  can be given as

$$m_{Kj}(t) = \frac{T_{Kj}}{T_s}$$

-----(12)

Control of the matrix converter must comply with the constraints

$$\sum_{K=A,B,C} m_{Kj}(t) = \sum_{K=A,B,C} m_{Kj}(t) = \sum_{K=A,B,C} m_{Kj}(t) = 1$$

-----(13)

In Venturini method, the appropriate firing pulses to each of the nine bidirectional switches must be calculated to generate variable-frequency and/or variable-amplitude sinusoidal output voltages from the fixed-frequency and the fixed-amplitude input voltages.

#### IV. ACHIEVING 50% VOLTAGERATIO

The first method attributable to Venturini is defined by and calculating the switch timings directly from these equations is cumbersome for a practical implementation. They are more conveniently expressed directly in terms of the input voltages and the target output voltages (assuming unity displacement factor) in the form of



$$m_{Kj} = \frac{t_{Kj}}{T_{seq}} = \frac{1}{3} \left[ 1 + \frac{2V_K V_j}{V_{in}^2} \right] \quad \text{-----(14)}$$

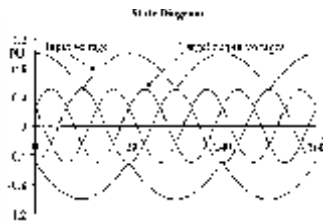


Fig.2 Illustrating voltage ratio of 50%

Where  $k=\{A,B,C\}$  and  $j=\{a,b,c\}$ . This method is of little practical significance because of the 50% voltage ratio limitation. Illustrating voltage ratio 50% is shown in Fig.2.

### V. SWITCHING PATTERN

This modulation procedure is used to generate the appropriate firing pulses to each of the nine bi- directional switches ( $S_{ij}$ ) in order to generate the desired output voltage and output frequency. The easiest way of doing this is to consider time windows in which the instantaneous values of the desired output voltages are sampled and the instantaneous input voltages are used to synthesize a signal whose low-frequency component is the desired output voltage. The switches on each output phases are closed sequentially and repetitively. The sequence time

$$T_s = m_A T_s + m_B T_s + m_C T_s \quad \text{-----(15)}$$

Where  $f_s = 1/T_s$  is the switching frequency which should be 20 times higher than the output frequency, so as to have low harmonic content in the output voltage. Switches are operated such that the average value of the output voltage is equal to the desired voltage during each sampling period  $T_s$ . The maximum peak-peak output voltage should be contained within the continuous envelope of the input voltage in order to have complete control of output voltage. General switching pattern is shown in Fig.3.

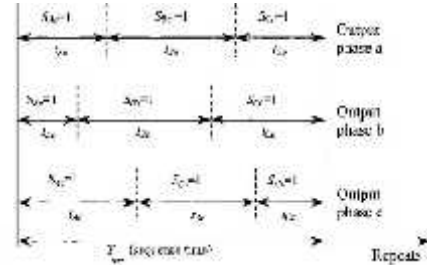


Fig.3 General form of switching pattern

$$S_{A_j} + S_{B_j} + S_{C_j} = 1, j = \{a, b, c\} \quad \text{-----(16)}$$

Signals,  $X$  and  $Y$  are obtained by comparing saw tooth signal with switching frequency and these calculated duty cycles. Final gate drive signals ( $S_{Kj}(t)$ ) determining turn-on-time of the power switches can be obtained according to the logic statements in by using duty cycles. Gate signals of the power switches are shown in Fig.4. Consequently, only duty cycles of six switches are sufficient to calculate the gate signals for all of the power switches

$$\left. \begin{aligned} X &= t_{A_j} \\ Y &= t_{A_j} + t_{B_j} \end{aligned} \right\} \rightarrow \begin{aligned} S_{A_j} &= (X) \\ S_{B_j} &= \text{not}(X) \text{ and } (Y) \\ S_{C_j} &= \text{not}(X) \text{ and } \text{not}(Y) \end{aligned} \quad \text{-----(17)}$$

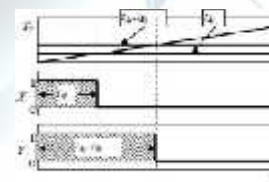


Fig.4 Gate signals of the power

switch VI.INTRODUCTION

TOFPGA

Programmable digital logic chips that can be programmed to perform any digital functions. The computer is used to describe a “logic functions “that is needed. The software provided by the vendor is used to compile and implement the program to the FPGA kit .The



JTAG cable is used to interface with FPGA kit.

### [1].BASIC ARCHITECTURE

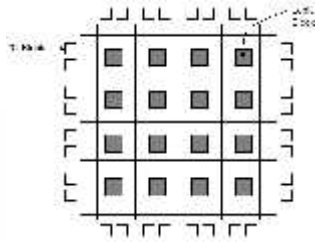


Fig.5 Basic Architecture of FPGA

Basic architecture of FPGA is shown in Fig.5. Fully fabricated chips containing thousands of logic gates or even more, with programmable interconnects, are available to users for their custom hardware to realize desired functionality.

A typical FPGA chip consists of I/O buffers, an array of configurable logic blocks (CLB), and programmable interconnects. It consists of four signal input terminals (A, B, C, D), a clock signal terminal, user programmable multiplexers, an D flip flop and a look up table (LUT). FPGA are arrays of logic blocks, which can be linked together to form complex logic implementations. The user can design, program and make changes to his circuits whenever he wants.

### [2].FEATURES OF FPGA

- Hundreds of thousands of LUTs
- Processors, Dedicated multiplexers, Dual port RAMs, MGTs, Xcites.
- Built on the most advanced semi condenser processor, which improves device size, capability, performance and cost.
- Advanced HDLs/high level languages, cores, functional and timing.
- Verifications, compilers, debuggers, co-design, circuit testing, board layout and board /signal analysis tools
- FPGAs are making their way into more end products.

### [3].ADVANTAGES IN USING FPGA THAN PLD AND ASIC DEVICES

- More number of gates (upto 10 millions)
- 500 MHZ core speed
- FPGAs can contain very large digital

designs, while CPLDs contain small designs only

- More number of package pin counts etc

### VI. SIMULATION MODELLING

The Simulink model for the three phase matrix converter can be used for producing voltage and current waveform. The Simulink model of the matrix converter consists of main blocks such as switching pattern, subsystem 3, output voltage, input current and load circuit. Simulink model for the matrix converter is shown in Fig.6. Each main block consists of subsystems such as pulse generation scheme, generation of output voltage, generation of voltage and current from the load, generation of input current.

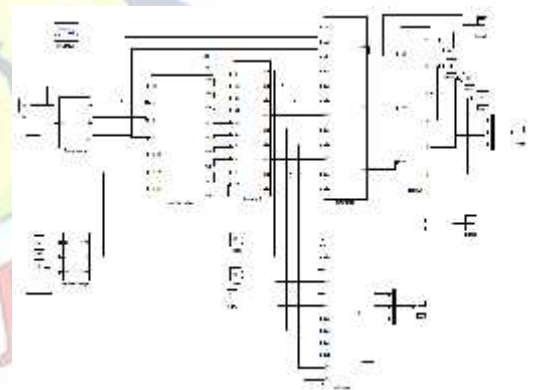


Fig.6 Simulink model for matrix converter

### VII. RESULT & DISCUSSION

Simulations at a switching

frequency of

1000Hz,  $q=0.5$ ,  $f_i=50$ Hz with RL load,  $R=1$  and  $L=30$ Mh. The switching pulse is taken from the subsystem 3 block. Switching pulse s11, s21, s31 is shown in Fig.7. Switching pulse s12, s22, s32 is shown in Fig.8. Switching pulse s13, s23, s33 is shown in Fig. 9.

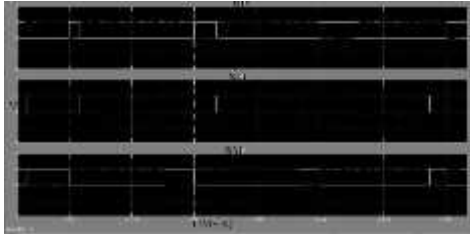


Fig.7 Switching pulse s11, s21, s31

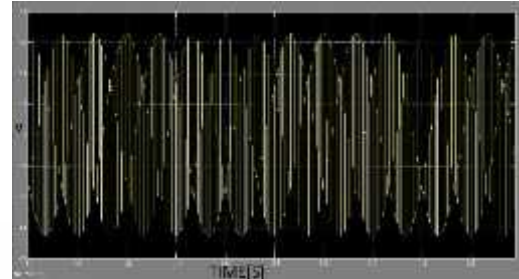


Fig.10 Output phase voltage

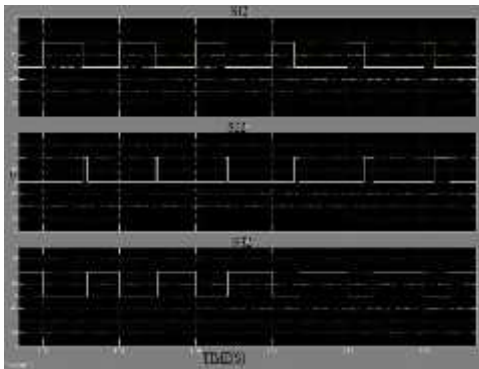


Fig.8 Switching pulse s12, s22, s32

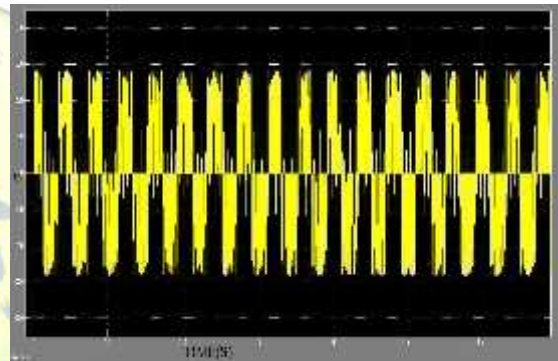


Fig.11 Output line voltage

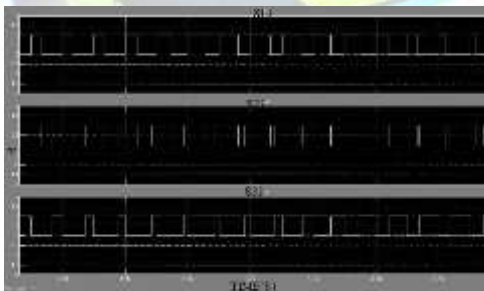


Fig.9 switching pulse s13, s23, s33

The output current waveform for  $q=0.5$ ,  $f_s=1000\text{Hz}$ ,  $R=1$ ,  $L=30\text{mH}$  can be obtained from the load circuit block. Output phase current  $f_0=25\text{Hz}$  is shown in Fig.12 &  $f_0=100\text{Hz}$  is shown in Fig.13. Three phase output current  $f_0=25\text{Hz}$  is shown in Fig. 14. Input current waveform is shown in Fig.15.

Output phase voltage is shown in Fig. 10.  
Output line voltage is shown in Fig 11.

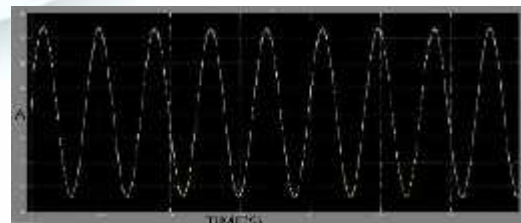


Fig.12 Output phase current  $f_0=25\text{Hz}$

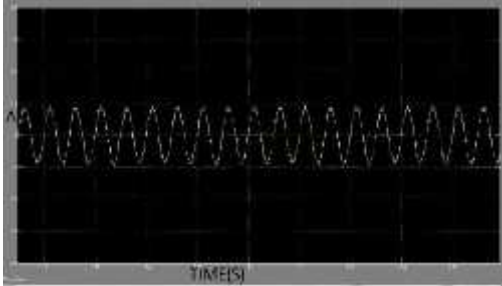


Fig.13 Output phase current  $f_o=100\text{Hz}$ .

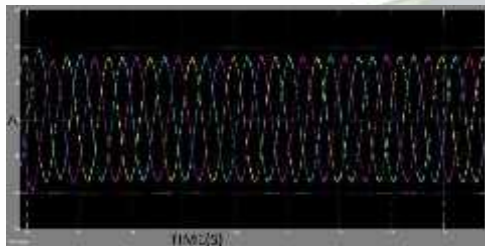


Fig.14 Three phase output current,  $f_o=25\text{Hz}$ .

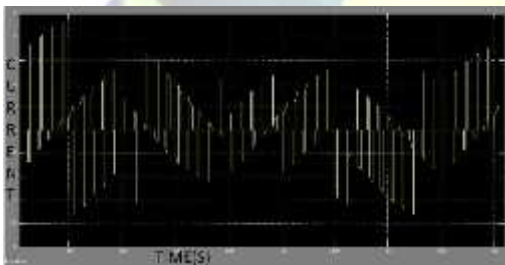


Fig.15 Input current waveform

#### VIII.CONCLUSION

The working principle and analysis of the MC that connects direct three- phase source to three-phase load and controlled with venturini has been

presented. Modulation strategies and fundamental mathematical equations of the MC have been presented clearly .Also, modelling and simulation of the venturini algorithm for 50%, which can given an output voltage with maximum amplitude, has been implemented. The designed model has satisfactorily given the behaviour of the MC. The simulation results show that the

modulation algorithm provides an unity input displacement factor even if the load has an inductive characteristic. As a result, the MATLAB & Simulink model presented can be confidently used in the construction stage of the matrix converter.

#### IX.FUTURE WORK

The future work is generating the nine independent gate pulse using FPGA, which can be applied in areas like Induction motor drive, Wind turbine systems.

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