Voltage Controller for Variable Speed Induction Generator Using Matrix Converter

H. V. Govinda Raju[1]
Dept. of EEE,
Dr. AIT
Bengaluru-560056
govind.raju37@yahoo.com

G. V. Jayaramaiah[2]
Dept. of ECE,
Dr. AIT
Bengaluru-560056
jramgv@yahoo.com

R. H. Vijaykumar[3]
Dept. of ECE,
Dr. AIT
Bengaluru-560056

Abstract-The requirement of variable frequency and variable output voltage for standalone induction generator (IG) is necessary for many applications and is efficiently fulfilled by the development of Matrix Converter connected with voltage source inverter (VSI). The VSI is used to supply the reactive power to the induction generator. The Matrix Converter and VSI are controlled by efficient Space Vector Pulse Width Modulation control algorithm and are tested for R-L load. The simulation results of MC, IG and VSI are presented and the hardware results of VSI are also presented in this paper.

Keywords– *Matrix Converter (MC); Voltage Source Inverter (VSI): Space Vector Pulse Width Modulation (SVPWM); Induction Generator (IG): R-L Load*

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I. INTRODUCTION

The Matrix Converter converts AC input supply of fixed voltage and frequency into variable voltage and frequency AC output. The output filter components required are small values since the conversion does not involve DC. Matrix Converters are having devices conducts in either direction and hence regeneration is possible and energy is supplied back into the mains from the load side where the mains current is sinusoidal

and the displacement factor seen by the mains can be adjusted by proper switching without depending on the type of load.

The most desirable features in power frequency converters are the following:

- Converter size is small.
- Load voltage production with different amplitude and frequency.
- Harmonics are less at supply and load side.
- Power factor is maintained at unity irrespective of load.
- Four quadrant operations are possible.

The above conditions are met by the Matrix Converters and hence this becomes the present interest field [1]. Hence MC carries higher power density and the absence of capacitors makes it more reliable.

Hence, there is considerable interest in the application of MC for the realization of very compact in size of higher power AC drives for industrial, military marine and avionics systems.

II. Objective of Study

Power converters are used to operate AC motors at different frequencies. The controller is used to set the required frequencies and voltage value. Direct Matrix Converter (DMC) is used to produce the necessary output voltage by triggering the devices in the controlled sequence.

It is presented simulation modeling of the matrix converter connected to IG, controlled by Space Vector Pulse Width Modulation technique using MATLAB SIMULINK software. The reactive power required by the IG when operating in standalone mode is supplied by the VSI excited by the small capacitor.

III. DIRECT MATRIX CONVERTERS

A direct MC converts AC energy into AC energy. The important characteristic of this converter is it converts magnitude and frequency of supply into required values of output voltage and frequency. It is also used by the name frequency changers. The circuit Matrix Converter consists of nine dual direction switches arranged in a (3*3) Matrix form [2].

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The MC diagram is shown in figure 1. The dual direction devices are formed by using two controlled switches connected in antiparallel to form one dual direction switch. The on and off time of the switches are controlled to obtain the required output voltage depending on the input supply voltage and required output voltage. The conversion of AC to AC can be done effectively using Matrix Converter. The problem associated with the two stage conversion using rectifier and inverter is easily eliminated. The Matrix Converter does not require any energy storage device. Because of the disposal of the DC link the size of the converter can be reduced and the power flow in either direction is possible with a Matrix Converter. The harmonics of the output voltage and input current can be reduced by selecting the on and off time of the switches at higher rate which pushes the harmonics to the higher frequency value. The nature of load for this case is resistive-inductive and the capacitive load has not been considered.

The MC is used for many areas of power conversion like sinusoidal to sinusoidal of variable values of voltage and frequency, and even for DC voltage to variable DC voltage and hence is termed as universal power converter[7].

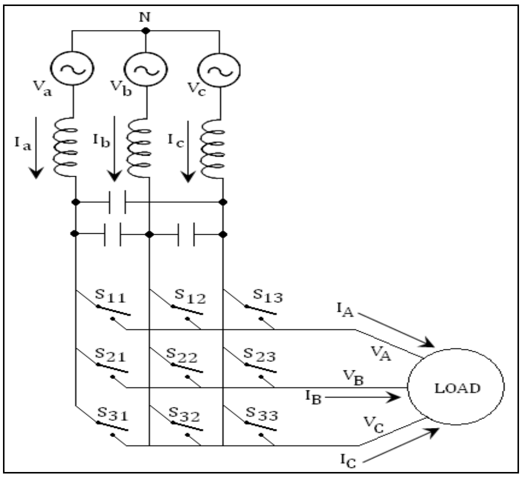

Figure1.Direct Matrix converter schematic diagram

IV. OPERATION OF MATRIX CONVERTERS

Switching function for a MC is defined as, $S_{Kj} = 1$, switch is close

= 0, switch is open,

Where K, j = {1, 2, 3} (1)

Constraints expressed as,

$S_{K1} + S_{K2} + S_{K3} = 1$, K= {1, 2, 3}

The MC shown in figure 1 operates with the condition given in (1). It makes the path for any output line (A, B, C) and the input line (a, b, c) as shown by the relation (2). The current through the Y-connected load are given by the equation (3). The matrix of equation (2) is the transpose of the matrix in equation (3).

$$\begin{cases} \begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} & (2) \\ \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} S_{11} & S_{21} & S_{31} \\ S_{12} & S_{22} & S_{23} \\ S_{13} & S_{23} & S_{33} \end{bmatrix} \begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix} & (3) \end{cases}$$

A. Space Vector Pulse Width Modulation

Matrix Converter operation is conveniently explained using a space vector approach. For the safe operation of Matrix Converter equation (1) should satisfy. This condition results in twenty seven realizable switching combinations. By using equation (5) and (6) to decide the vectors for output voltage and input current respectively. The variation of input voltage due to load connected to the converter don't have any impact on control using SVPWM method [6].

$$\overrightarrow{v_0}(t) = \left(qV_{im}\sqrt{3}\right)Cos(w_0 t) \quad (4)$$

$$\overrightarrow{v_0}(t) = \frac{2}{3}\left(v_{10} + av_{20} + a^2 v_{30}\right) \quad (5)$$

$$\overrightarrow{i_0}(t) = \frac{2}{3}\left(i_{1i} + ai_{2i} + a^2 i_{3i}\right) \quad (6)$$

Where,

v_{10}, v_{20} and v_{30} are output phase voltages.

i_{1i}, i_{2i} and i_{3i} are input line currents.

$$a = e^{j\frac{2\pi}{3}}$$

The vector $\overrightarrow{v_0}(t)$ has a constant magnitude of $qV_{im}\sqrt{3}$ which is spinning at frequency ω_0. The fundamental principle of the space vector modulation techniques is that the possible output voltages for the converter can be conveyed as in the equation (5). At every point of sampling, the location of $\overrightarrow{v_0}(t)$ is estimated with the possible vectors and the required output voltages is synthesized by time mean between adjoining vectors to give the proper average voltage. The circumstance with a Matrix Converter is more

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perplexing as there are twenty seven achievable switching states and the supply voltages are time fluctuating.

B. Selection of switching vectors

As mentioned previously, in a three-phase Matrix Converter the possible switching states are twenty seven. The ouput voltage is divided into three groups:

Group I: Under this group 18 switching combinations with set directions of supply current and output voltage vectors with magnitudes that vary with the supply current phase angle and the output voltage phase angle respectively. These amalgamations outcome when any pair of output phases are connected to the similar pair of input[3].

Group II: Under this group 3 switching combinations giving zero vectors of output voltage and supply current. All output lines are coupled to the common input line.

Group III: Under this group 6 switching combinations in which every output line is connected to a different supply lines. Both amplitude and directions of the output vectors are available in these instance.

Projecting these stationary voltage and current vectors to the α-β plane, the voltage and current hexagons as shown in Fig. 2 and Fig. 4 are obtained.

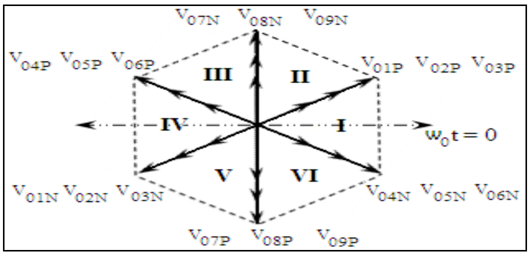

Figure 2. Output voltage vectors

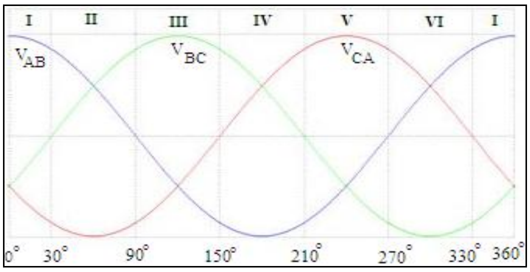

Figure 3.Output Voltage

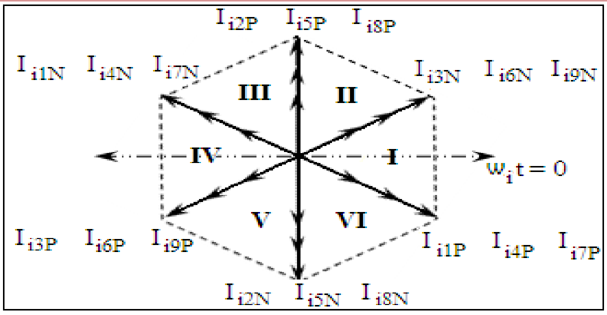

Figure 4.Input Current Vectors

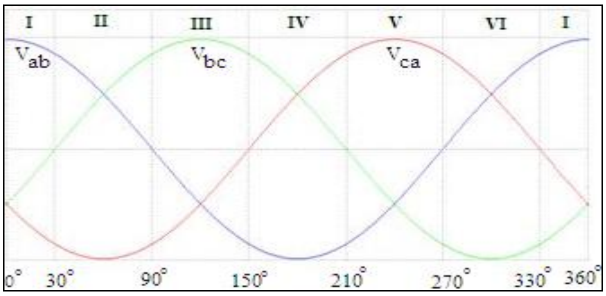

Figure 5.Input Voltage

From the figure 2, the reference output voltage vector can be in any of the six sectors. From the figure 3 three-phase voltage waveform of that sector one of the line-line voltages is bound to be most positive or most negative which is denoted as peak line. Amongst the 18 active vectors, choose the suitable ones which give nonzero voltage values for the peak line.

Now the selection is amongst these 12 active vectors which keep the input power factor unity and achieving maximum output voltage. The unity power factor is achieved by bringing the phase voltage and current in phase. To get the maximum voltage, the peak line has to be switched to the maximum input line-line voltage at that instant.

At any particular instant, the reference input current vector can be in any of the six vectors of Fig. 4. When the reference current vector is in the lower 30° range of a particular sector, the corresponding input voltage vector will be in the same sector as that of the current reference. But when the reference current vector crosses the lower 30° range, the voltage vector moves to the next sector and the line-line, which is giving maximum input voltage value is also switched from one another (Fig. 4 & 5).

C. Computaton of vector time intervals

In SVPWM, the reference output voltage vector in each sampling period is expressed as a weighted average combination of the four active state vectors and one null state vector. If V_1, V_2, V_3 and V_4 are the active voltage vector and V_0, the zero voltage vector then

$$V_{REF}T_s = V_1T_1 + V_2T_2 + V_3T_3 + V_4T_4 + V_0T_0 \quad (9)$$

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where T_1,T_2, T_3, $T_4$and T_0 are the time durations of the application of V_1,V_2, V_3, $V_4$and V_0 respectively. Similarly if I_1,I_2, I_3 and I_4 are the active current vectors and I_0 is the zero current vector, then

$$I_{REF}T_s = I_1T_1 + I_2T_2 + I_3T_3 + I_4T_4 + I_0T_0 \qquad (10)$$

$$T_0 = T_s - (T1 + T_2 + T_3 + T_4) \qquad (11)$$

where, T_1,T_2, T_3, $T_4$and T_0 are the time durations of the application of I_1, I_2, I_3, $I_4$and I_0 respectively. Resolving equations (9) and (10) along mutually perpendicular α–β axis, we will get four equations with four unknowns. Solution of these equations yields T_1, T_2, T_3, and T4. Substituting (11) yields T_0.

V Results and Discussion

The figure 6 shows the block diagram of the system. The induction generator generates the electrical power of variable frequency and voltage. The reactive power required for the operation of induction generator in stand alone operation is supplied from the voltage source inverter. The Matrix Converter supplied from the induction generator of variable voltage and frequency is converted to fixed voltage and frequency demanded by the load.

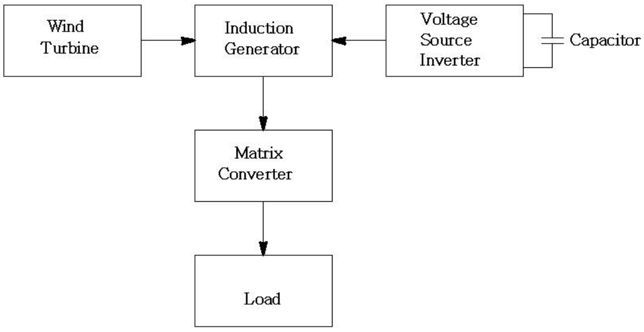
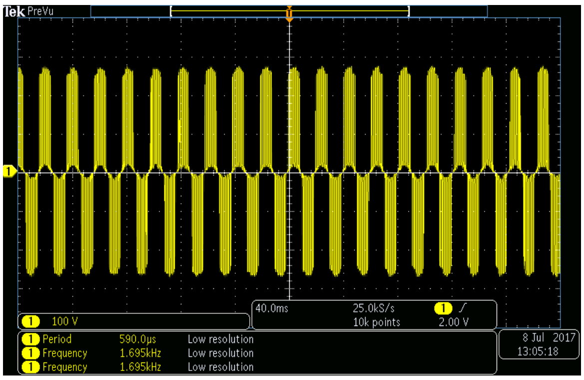


Figure 6. Block diagram of the system

Figure 7 & 8 shows output line voltage and phase current of the inverter before and after the filter to supply the reactive power of the induction generator.



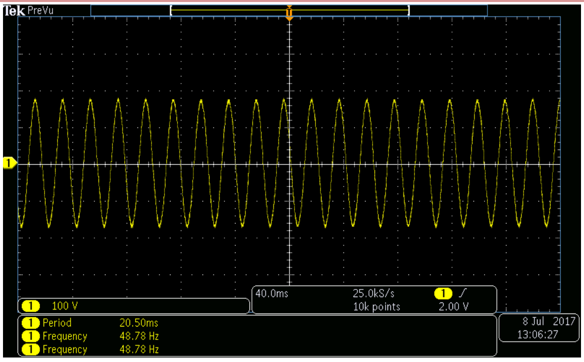


Figure 7: RY- Line Voltage of VSI before and after the Filter.

Figure 8: R- Phase current of VSI before and after Filter.

The Matrix Converter is connected to the R-L load of values 3 Ω and 5 mH the simulated value of the three phase load is shown in figure 9.

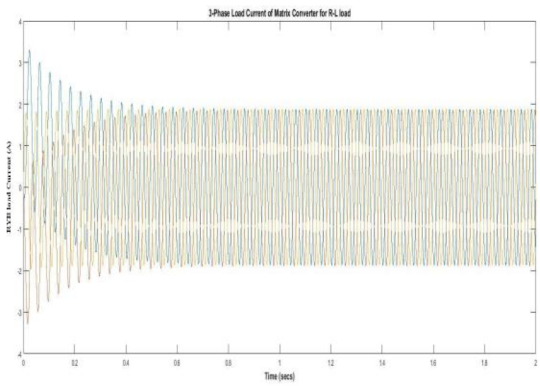


Figure 9: 3-Phase load current of Matrix Converter

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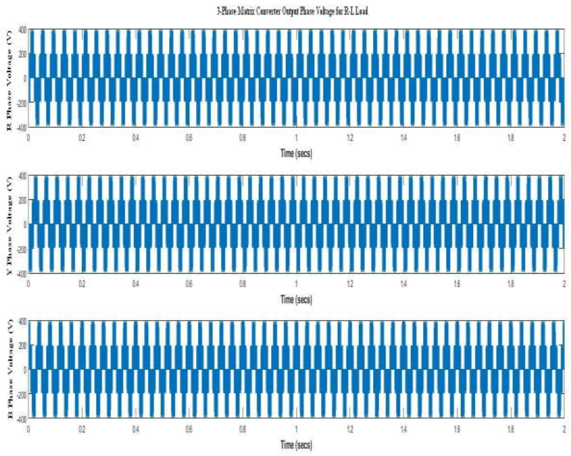

Figure 10: Matrix Converter Output Phase Voltage.

The simulation result of induction generator and Matrix Converter output phase voltages are shown in figure 11 and 10 respectively.

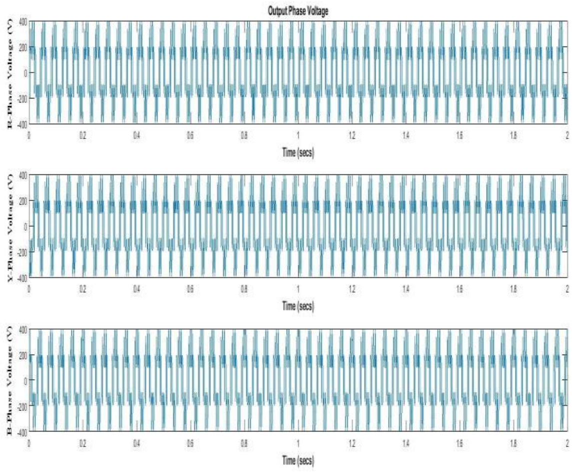

Figure 11: Induction generator output phase voltage

VI. CONCLUSIONS

The MC is simulated using Simulink and the switching state generated method using space vector technique is presented the switching timing generated can be directly used for the actual Matrix Converter using DSP processor. In this paper the Simulation of the direct Matrix Converter controlled with the SVPWM approach connected to the R-L load has been presented.

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