

MODELLING OF MATRIX CONVERTER BASED ON VENTURINI MODULATION SCHEME

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Abstract - In this paper, a matrix converter that connects directly a three phase ac load to a three ac source is modelled using MATLAB & Simulink and its working principles are analysed. The gate signals of the power switches of matrix converter are produced using Venturini Modulation and Optimum Amplitude-Venturini Modulation (OAVM) method. This method provides the amplitude of output voltage up to 86.66% of input voltage, and output currents are sinusoidal. The simulation results obtained from the model at various operating conditions are presented. These results prove effectiveness of the proposed matrix converter model with a unity input power factor. Consequently, the designed MATLAB & Simulink model can be confidently used for an application which requires a variable ac power of variable voltage and frequency.

Keywords— Matrix Converter, Venturini Modulation, MATLAB/Simulink

I. INTRODUCTION

Now-a-days use of ac-ac converters has increased rapidly. One of the most important process in power electronics is to convert electrical power to different forms. In controlling of electrical energy, great advances are provided together with fast improvements in semiconductor power elements and power electronic converters. It is now widely used in industrial applications, replaces the use of dc-link converters.

The matrix converter has several advantages over the traditional rectifier-inverter type two-stage power frequency converters. They are:

- Simple and compact power circuit.
- Arbitrary amplitude and frequency i.e., we can generate output ac power of variable amplitude and/or variable frequency.
- Nearly sinusoidal input and output currents.
- Harmonics are nearer to switching frequency. So, size of filter can be reduced.
- Unity input displacement factor.
- Bi-directional power i.e., power can be transmitted either from source to load or load to source.

But the matrix converter has also some disadvantages. First of all it has a maximum input-output voltage transfer ratio limited to approximately 86.66%. It requires more semiconductor

devices than a conventional AC-AC indirect power frequency converter, since no monolithic bi-directional switches exist and consequently discrete unidirectional devices, variously arranged, have to be used for each bi-directional switch. Finally, it is particularly sensitive to the disturbances of the input voltage system.

Instead of disadvantages it has a wide range of applications in the modern world like inter connection of lines of different frequencies, Speed control of induction motors by v/f ratio method, Recovering energy in elevator, crane and escalator installations.

II. BASIC CIRCUIT

Fig.1 shows a simple representation of a matrix converter. It consists of nine bi-directional power switches which are used to transfer power in both directions. These are controlled to connect the input three-phase voltage source to a three-phase load. Controlling of these switches is achieved according to a certain modulation strategy. The modulation strategy is based on a desired output voltage magnitude and frequency and an input displacement factor. The matrix converter will be modelled by its output voltages and input currents in terms of switching functions of the switches.

$$\begin{pmatrix} v_a(t) \\ v_b(t) \\ v_c(t) \end{pmatrix} = \begin{pmatrix} S_{Aa}(t) & S_{Ba}(t) & S_{Ca}(t) \\ S_{Ab}(t) & S_{Bb}(t) & S_{Cb}(t) \\ S_{Ac}(t) & S_{Bc}(t) & S_{Cc}(t) \end{pmatrix} \begin{pmatrix} v_A(t) \\ v_B(t) \\ v_C(t) \end{pmatrix} \quad \text{--- (1)}$$

The switching functions in equation (1) are defined as follows:

$$S_{Kj} = \begin{cases} 1, & \text{switch } SKj \text{ is ON} \\ 0, & \text{switch } SKj \text{ is OFF} \end{cases} \quad \text{--- (2)}$$

for K={A, B, C},
j={a, b, c}

In order to avoid short circuit of input phases and open circuit of output phases at a particular instant, the switching functions should satisfy the following constraint equation.

$$M_{Aa}(t) + M_{Ba}(t) + M_{Ca}(t) = 1 \quad \text{--- (3)}$$

$$M_{Ab}(t) + M_{Bb}(t) + M_{Cb}(t) = 1 \quad \text{--- (4)}$$

$$M_{Ac}(t) + M_{Bc}(t) + M_{Aa}(t) = 1 \quad \text{--- (5)}$$

The shape of the switching functions depends on the switching pattern used. A typical switching pattern is shown in Fig. 2.

When these rules are provided, the 3 x 3 matrix converter can allow only 27 different switching states.

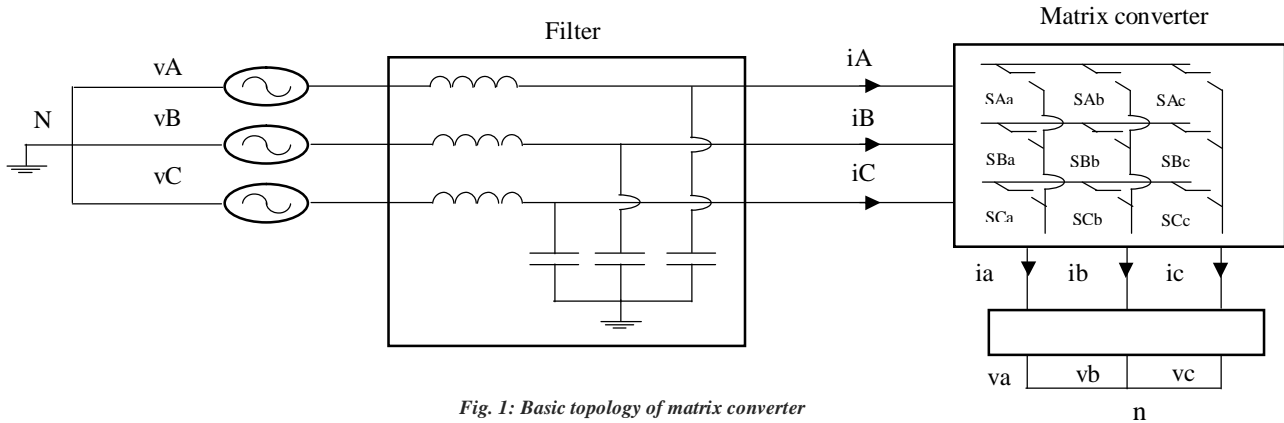


Fig. 1: Basic topology of matrix converter

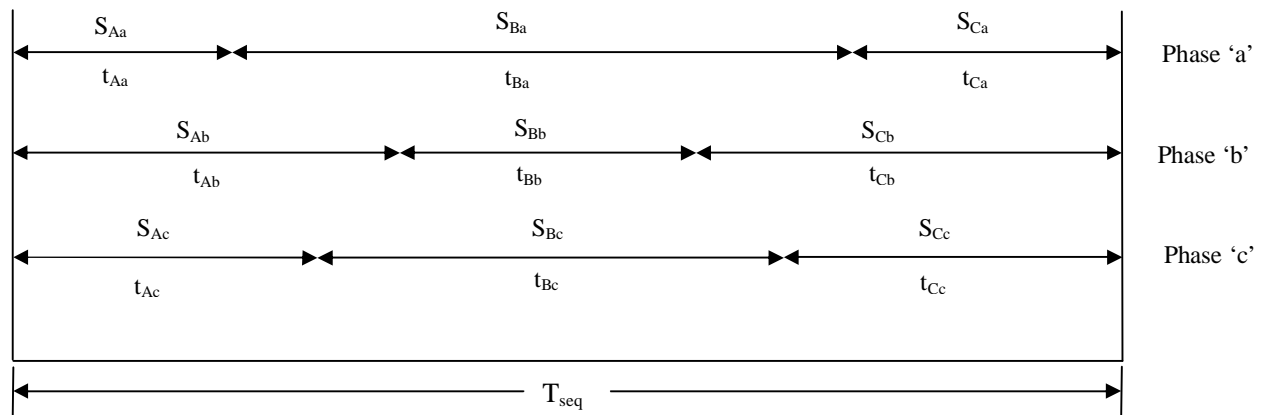


Fig. 2: Switching pattern of all nine switches.

III. MATRIX CONVERTER BASED ON VENTURINI MODULATION SCHEME

Here in matrix converter, v_K are the source voltages, i_K are the source currents, v_{jn} are the load voltages with respect to the neutral point n of the star connected load, and i_j are the load currents. If t_{Kj} is defined as the time during switch S_{Kj} is on and T_s the switching period, duty cycle of switch S_{Kj} can be given as follows:

$$M_{Kj}(t) = \frac{S_{Kj}}{T_s} \quad \text{--- (6)}$$

The following equation (7) describe modulation matrix $M(t)$.

By considering that the bidirectional power switches work with high switching frequency, a low-frequency output voltage of variable amplitude and frequency can be generated by modulating the duty cycle of the switches using their respective switching functions.

$$M(t) = \begin{pmatrix} m_{Aa}(t) & m_{Ba}(t) & m_{Ca}(t) \\ m_{Ab}(t) & m_{Bb}(t) & m_{Cb}(t) \\ m_{Ac}(t) & m_{Bc}(t) & m_{Cc}(t) \end{pmatrix} \quad \text{--- (7)}$$

There are several modulation techniques used to obtain the modulation matrix $M(t)$, such as Venturini method, Venturini optimum method, scalar method and space vector modulation method. In this paper Venturini and Venturini optimum methods were used.

When the voltage gain ratio, 'q' is less than or equal to 0.5 for unity input displacement factor, the modulation duty cycles can be obtained using the Venturini method. These equations are valid only when 'q' is less than or equals to 0.5. Here 'q' denotes the ratio of output voltage to input voltage. The simulation model of matrix converter using the venturini modulation is as shown in fig. 4.

The following equations describe venturini scheme in compact form.

$$m_{kj} = \frac{t_{kj}}{T_{seq}} = \frac{1}{3} \left(1 + \frac{2v_K v_j}{v_{im}^2} \right) \quad \text{--- (8)}$$

v_K denotes input voltages which are given by,

$$v_i = v_{im} \begin{pmatrix} \cos(\omega_i t) \\ \cos(\omega_i t + 2\pi/3) \\ \cos(\omega_i t + 4\pi/3) \end{pmatrix} \quad \text{--- (9)}$$

' v_j ' denotes reference output voltages which are given by,

$$v_o = qv_{im} \begin{pmatrix} \cos(\omega_o t) \\ \cos(\omega_o t + 2\pi/3) \\ \cos(\omega_o t + 4\pi/3) \end{pmatrix} \quad \text{--- (10)}$$

Where, ' v_{im} ' is the peak value of input voltage.

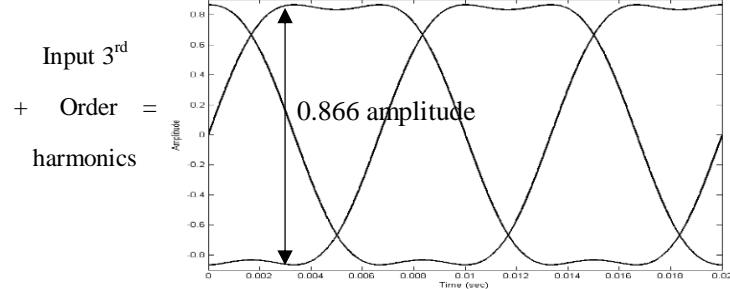
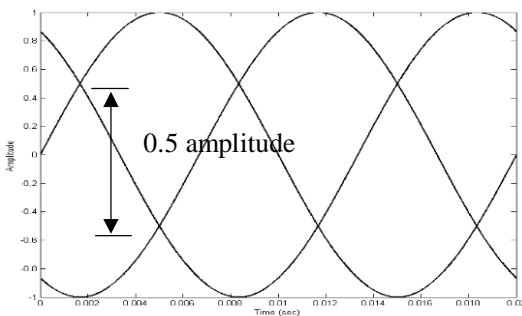


Fig. 3. Waveform showing when 3rd order harmonics are introduced to wave of 0.5 amplitude.

The reference output voltages to be obtained is given by,

$$v_o = qv_{im} \begin{pmatrix} \cos(\omega_o t) - \frac{1}{6} \cos(3\omega_o t) + \frac{1}{2\sqrt{3}} \cos(3\omega_i t) \\ \cos(\omega_o t + 2\pi/3) - \frac{1}{6} \cos(3\omega_o t) + \frac{1}{2\sqrt{3}} \cos(3\omega_i t) \\ \cos(\omega_o t + 4\pi/3) - \frac{1}{6} \cos(3\omega_o t) + \frac{1}{2\sqrt{3}} \cos(3\omega_i t) \end{pmatrix} \quad \text{--- (12)}$$

The main drawback of this scheme is the output currents are non-sinusoidal due to injection of 3rd order harmonics and output voltage may not exceed 86.66% of input voltage.

IV. MATRIX CONVERTER BASED ON OPTIMUM AMPLITUDE VENTURINI MODULATION (OAVM) SCHEME

To overcome the above mentioned drawback of venturini modulation based matrix converter i.e., ' q ' is restricted below 0.5 or equal to 0.5, third order harmonics of input wave are introduced into output waves which increases the amplitude of the output waveform from 0.5 to 0.8666 of input voltage as shown in fig. 3.

The following equations describe the optimum amplitude venturini scheme in compact form.

$$m_{kj} = \frac{1}{3} \left(1 + \frac{2v_K v_j}{v_{im}^2} + \frac{4q}{3\sqrt{3}} \sin(\omega_i t + \beta_k) \sin(3\omega_i t) \right) \quad \text{--- (11)}$$

Here, ' v_K ' denotes input voltages similar to that in venturini modulation scheme.

' β_k ' denotes phase shift, for $K=\{A, B, C\}$, ' β_k '= $\{0, 2\pi/3, 4\pi/3\}$

V. SIMULATION OF MATRIX CONVERTER

The basic matrix converter was simulated in MATLAB & Simulink which consists of three sub-systems namely matrix converter block, load block and a block to generate input currents. As shown in fig. 4, the matrix converter is fed by a three phase ac source. Matrix converter block consists of again two sub-systems one is for adopting venturini method when required voltage is less than or equal to half of the input voltage and other is for adopting optimum amplitude venturini modulation scheme when output voltage required is more than half and less than 0.866 of the input voltage. To enable these two blocks separately an enabling signal is generated depending on the required output voltage.

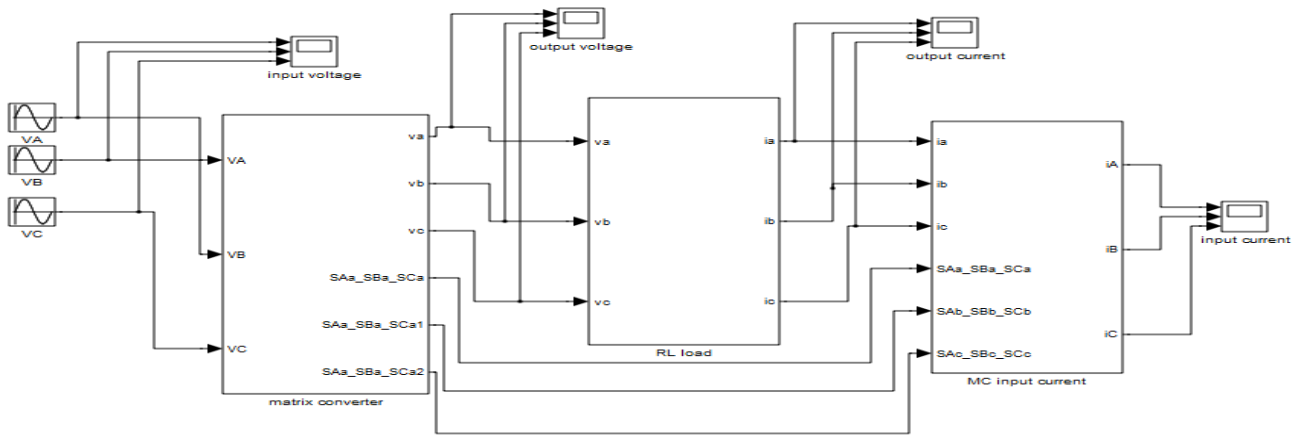


Fig. 4. Matrix converter Simulink block.

In sub-block the modulating signals are generated using 'Fcn' block and these modulating signals generated are compared for pulse width modulation scheme with a carrier wave of some switching frequency. Then the generated modulating pulses are multiplied with the input voltages to get output voltage of variable frequency and amplitude as shown in fig. The entire matrix converter block is masked with two input parameters 'q' and 'fo', where fo is the output frequency.

In the load block the load (R-L) is converted into transfer function. The output voltage is passed through transfer functions to get output currents.

To get input currents the output currents are multiplied with the corresponding modulating pulses.

VI. SIMULATION PARAMETERS

The configuration parameters used for simulation of below matrix converter are:

S.no	Configuration parameter	Value
1.	Type of solver	Variable type
2.	Solver used	Ode(ordinary differential equation)23tb
3.	Min step size	1e-6
4.	Max step size	1e-4
5.	Relative tolerance	1e-3

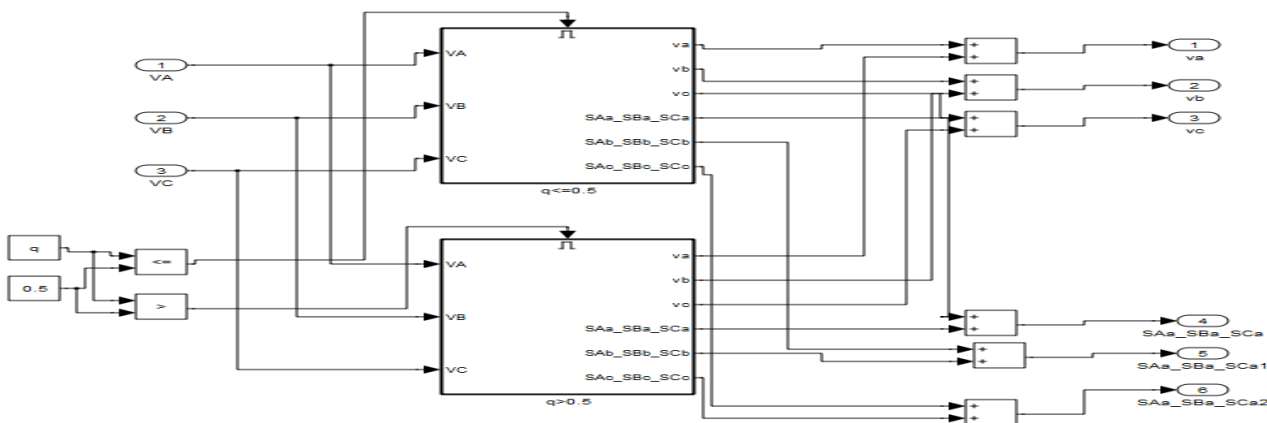


Fig. 5. Sub-system inside the matrix converter block

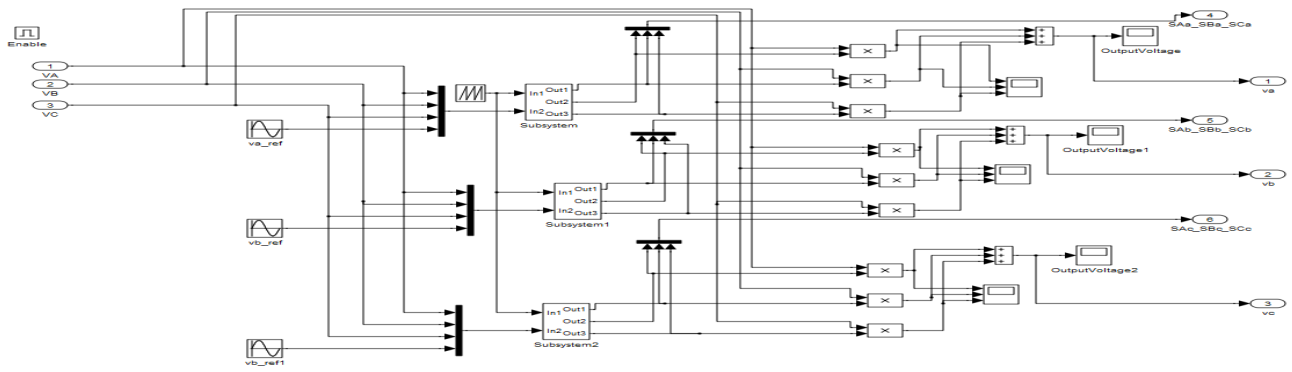


Fig. 6. Sub-system of ' $q \leq 0.5$ ' block.

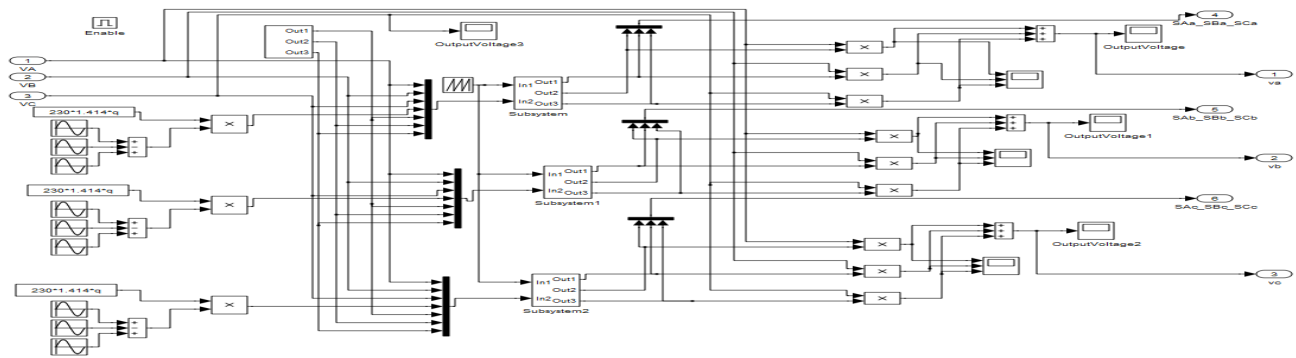


Fig. 7. Sub-system of ' $0.5 < q \leq 0.866$ ' block.

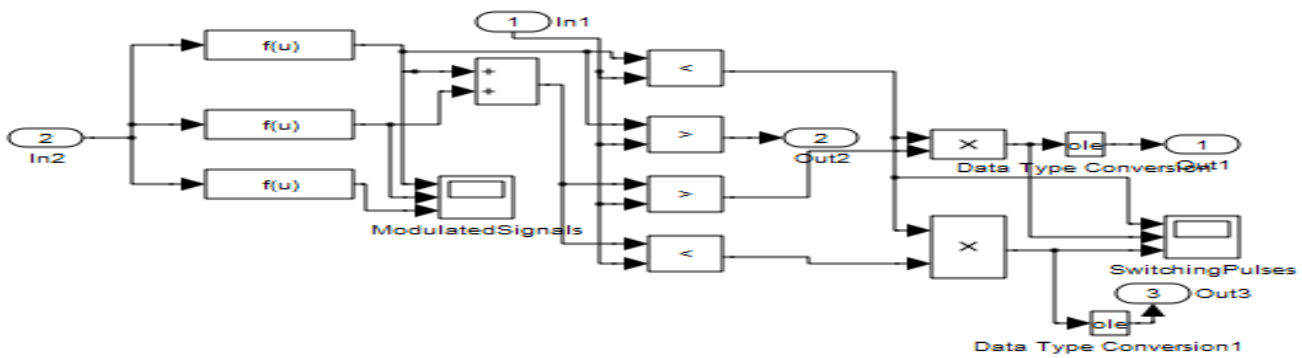


Fig. 8. Subsystem in figures 6 & 7.

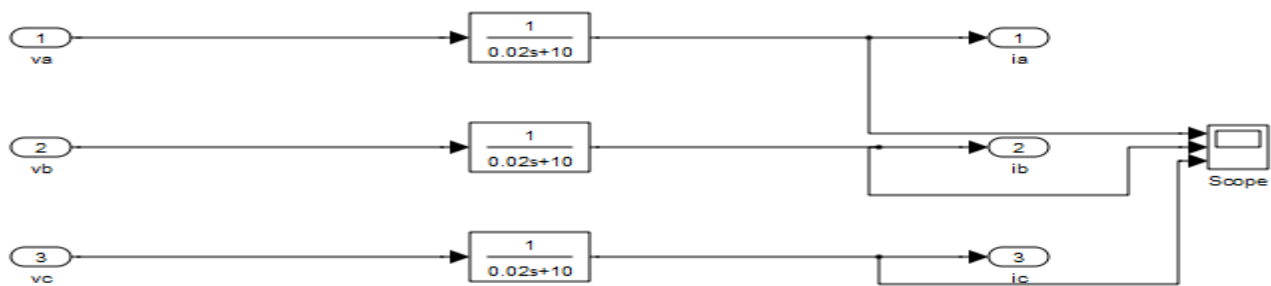


Fig. 9. R-L load block.

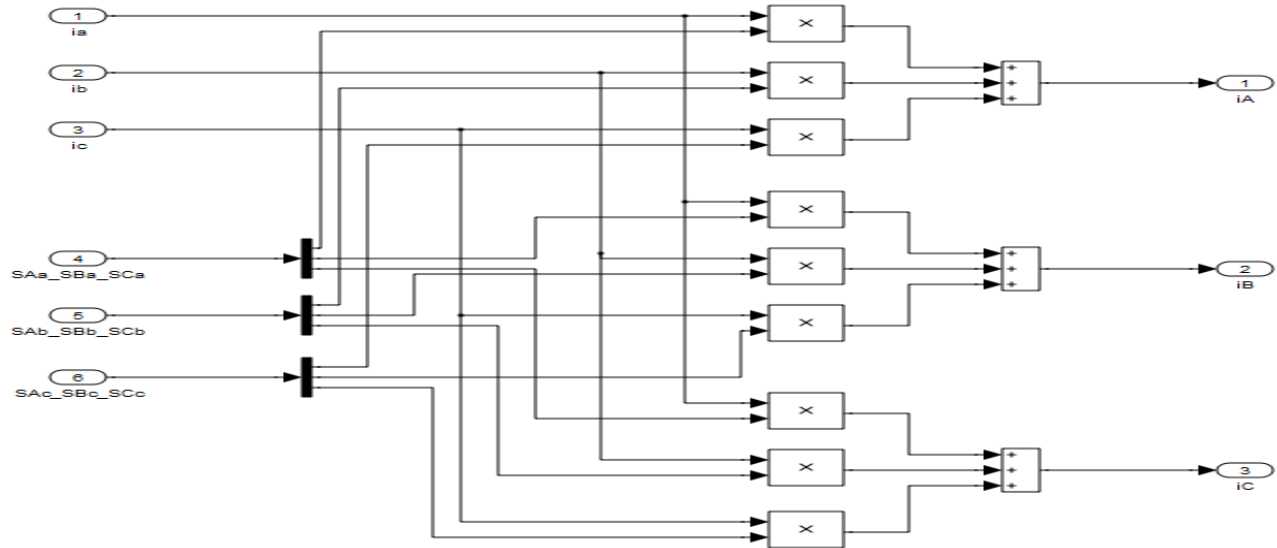


Fig. 10. Matrix converter input current block.

VII. SIMULATION RESULTS

The above shown matrix converter was simulated successfully. The model was simulated for an R-L load of having a resistance of 10 Ω and an inductance of 20 mH and

simulated for a switching frequency of 5 KHz. The fig. 11 & 12 shows the output voltage and current waveforms when matrix converter was simulated for fo=60 Hz and q=0.5. The fig. 13 & 14 shows the output voltage and current waveforms when matrix converter was simulated for fo=10 Hz and q=0.8.

Fig. 11. Output voltage waveform for fo=60 Hz and q=0.5.

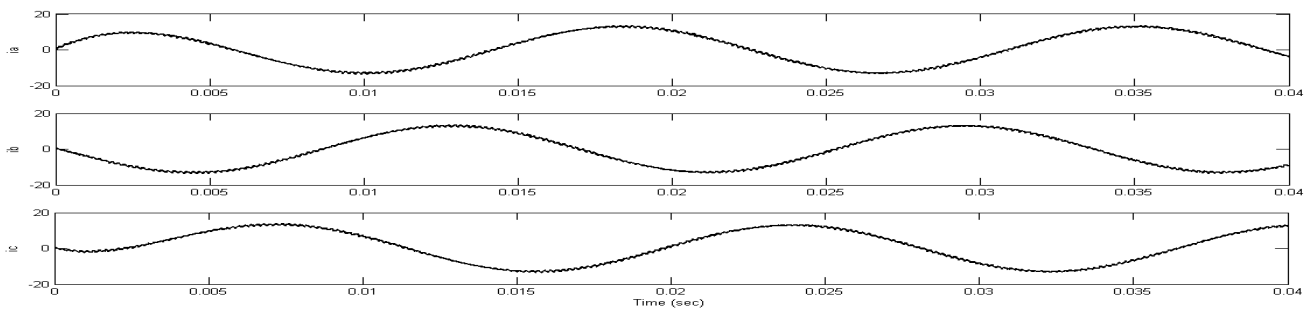
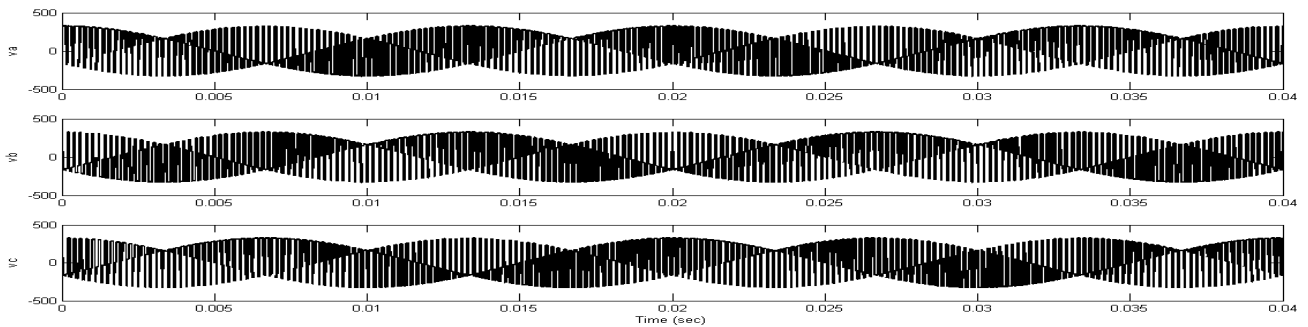


Fig. 12. Output current waveform for fo=60 Hz and q=0.5

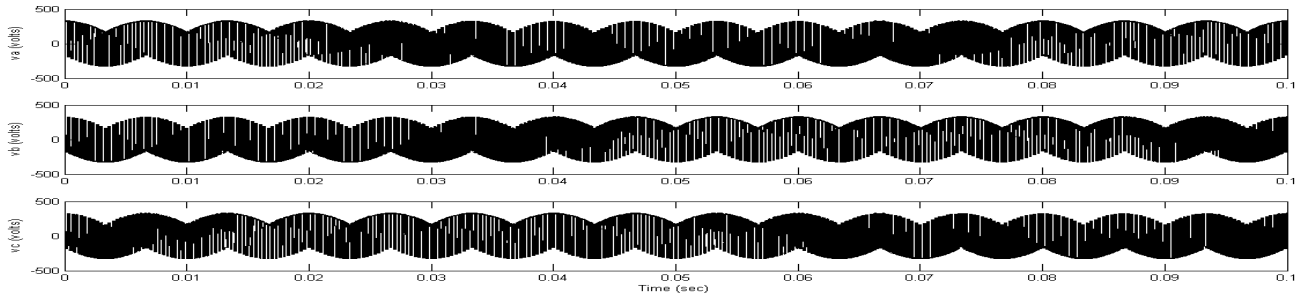


Fig. 13. Output voltage waveform for fo=10 Hz and q=0.8.

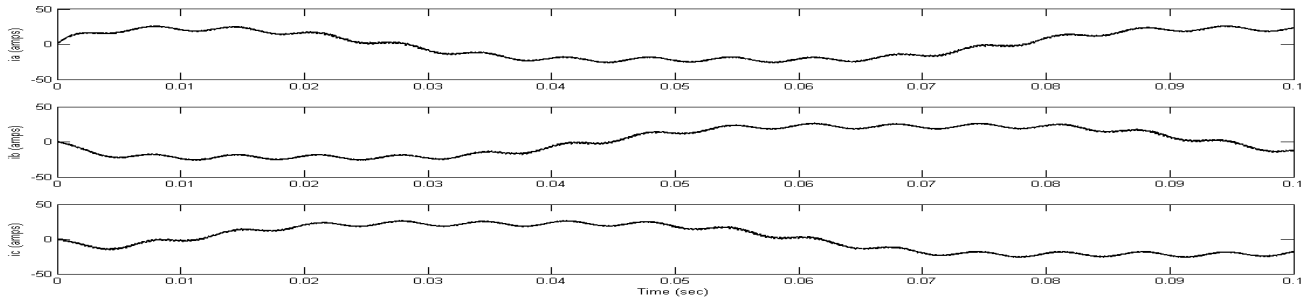


Fig. 14. Output current waveform for fo=10 Hz and q=0.8.

VIII. SPEED CONTROL OF INDUCTION MOTOR USING MATRIX CONVERTER

One of the major applications of matrix converter is speed control of induction motor by keeping v/f ratio as constant.

Speed of induction motor is given by the equation,

$$N_s = \frac{120 * f}{p} \quad \text{--- (12)}$$

E.m.f induced in motor is given by the equation,

$$E = 4.44 * K * \phi * T * f \quad \text{--- (13)}$$

$$\text{From (13), } \phi = \frac{E}{4.44 * K * T * f}$$

-- (14)

Where, ‘K’ denotes winding factor and ‘T’ denotes turns ratio. As mentioned in equation (12), by varying the frequency at stator side the speed of the machine can be controlled. But from equation (14) as frequency changes flux will change and deep increase or deep decrease in flux will saturate the core of machine which is not advisable. The only option is to vary the

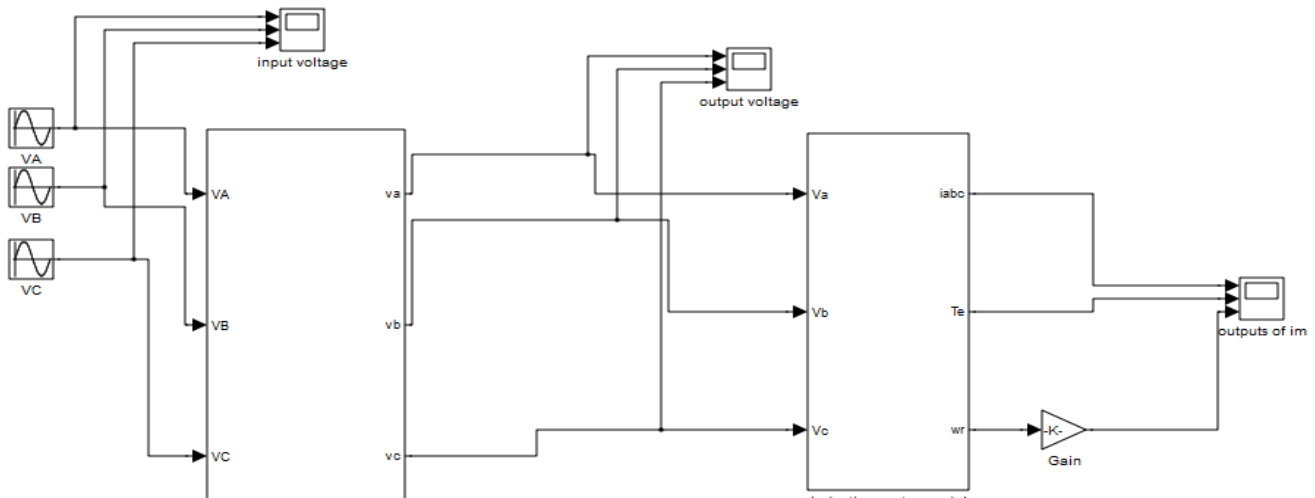


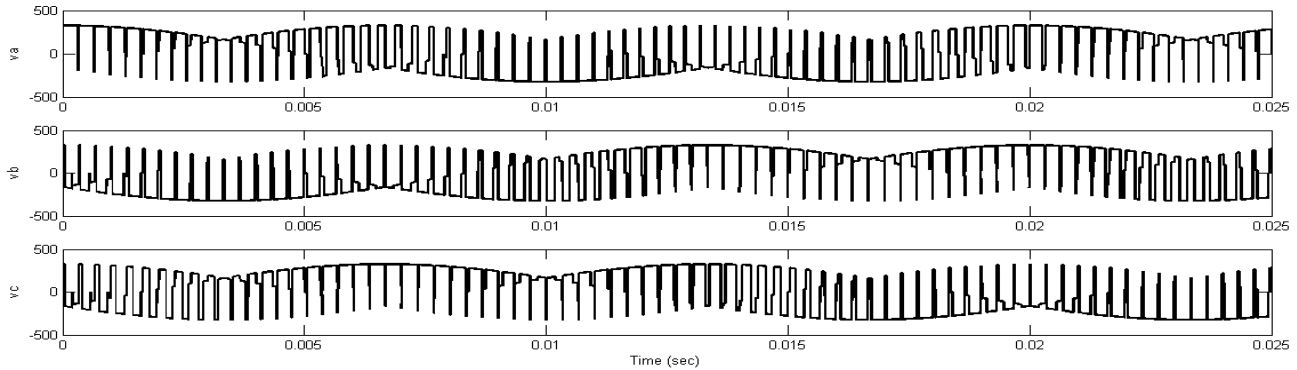
Fig. 15. Induction motor controlled using matrix converter simulation block.

voltage in proportional

to frequency such that the v/f ratio of the machine remains constant. A converter which changes both frequency and voltage simultaneously is required. So, matrix converter can be used with no objection for this purpose.

Fig. 15. Shows the Simulink block of induction motor whose speed is controlled using matrix converter. To obtain a speed of 1200 r.p.m from equation (12), frequency required is 40 Hz

times of input voltage magnitude. A waveform of 0.8 times the input magnitude and frequency of 40 Hz is obtained using matrix converter and shown in fig. 16 and fig. 17 shows output current waveform and fed to induction motor. Fig. 18 shows the torque vs time and speed vs time waveform for fig. 16 voltage waveform.



and to keep v/f ratio as constant voltage required will be 0.8

Fig. 16. Voltage at stator side of induction motor with 40 Hz frequency and 0.8 of input magnitude.

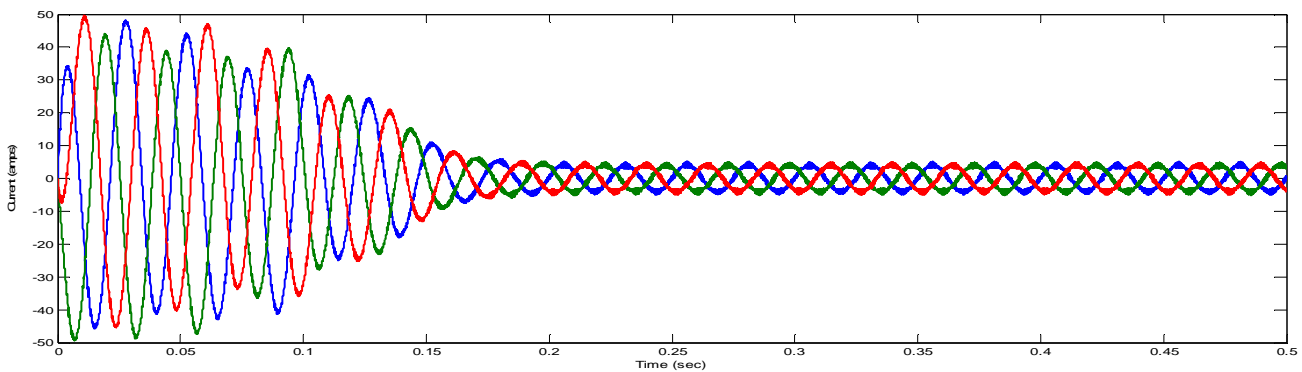


Fig. 17. Current at stator side of induction motor with 40 Hz frequency and 0.8 of input magnitude.

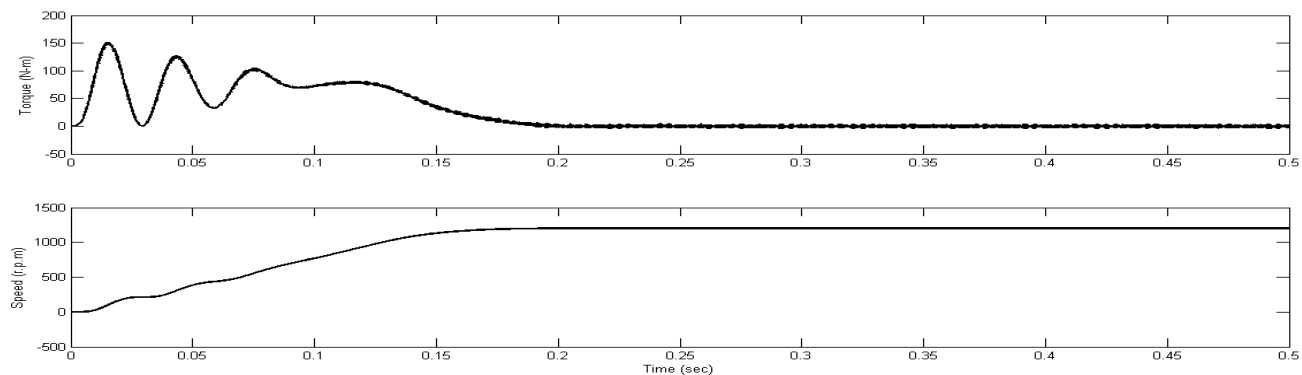


Fig. 18. Waveform showing torque & speed with respect to time.

IX. CONCLUSION

The working principle and analysis of the matrix converter that connects direct three phase load and three phase source controlled by venturini modulation scheme and optimum-amplitude venturini scheme has been presented. Mathematical equations for modulation strategies are presented clearly. Also modelling of venturini method is implemented in MATLAB/Simulink. The designed matrix converter has given satisfactory results.

A matrix converter designed using venturini modulation has been successfully used for speed control of induction motor.

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