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A Simplified Switch Modulation Strategy for Matrix Converter

G.N. Surya, Subroto Dutt

Abstract— The domain of soft conversion has always been an area of continuous research and development. The technology and topologies related with conversion of electrical energy from one form to another have taken great strides since the then era of 'Mercury Arc Rectifiers' to present 'AC-DC-AC' two stage converters & 'Cyclo-Converters'. However, the recent developments are dominated by a host of studies related with single stage converters. But, there is dearth of studies which meticulously present the modulation techniques useful for emerging researchers. The present study is only a small attempt basically intended to bridge this observed gap and to envisage the stirring concept of single stage soft conversion topology. An attempt has been made in the present study to outline salient design features of Matrix Converter (MC). The study deals with the straight forward technique for converting fixed frequency at the input to variable frequency at the output by proposing a new simplified switch modulation strategy. The modeling of the presentation has been done in MATLAB. It is not intended in this study just to list out various works done so far but to bring forth the straight forward control and simulation results of the designed model which is much needed and constitutes the interest area for researchers in this direction. The study also paves in scope for future research in controlling and witnessing the exciting contribution of single stage converter technology. The present simple yet formidable study establishes the brevity of fundamental concept representing the simplified design along with its application areas mainly the VFDs and Wind Energy Conversion System. The study first exhibits the design of frequency changing converter and subsequently, the models designed for 100 Hz and 25 Hz output frequencies are used to control the speed of induction motor. Results for change in frequency and variation in speed according to change in frequency have been obtained by simulating the model through MATLAB/simulink software. The waveforms of changed frequencies and varied speed generated by simulink confirm the results anticipated at design stage.

Keywords **– conversion topologies; ideal switches; matrix converter (MC); single stage AC-AC conversion; switch modulation strategy.**

I. INTRODUCTION

"Matrix Converters" were first mentioned in the early 1980's by Alesina and Venturini [1]. They proposed a general model and a relative mathematical theory for high-frequency synthesis converters. They stated that the maximum input-output transformation ratio possible for the new AC-AC converter is $\sqrt{3}/2$ and also, they suggested a specific modulation and a feed-back-based control implementation of the proposed converter.

The conventional SVM algorithm [2]-[3] usually generates both even and odd order harmonic voltages. The AC-AC Matrix Converter is optimal in terms of minimum switch number and minimum filtering requirements. A three-phase AC-AC conversion requirement can also be met through a back to back cyclo converter, but it uses 36 thyristers thus making the system bulky as shown in fig. 1. A three-phase AC-AC Matrix Converter consists basically of nine bidirectional voltage-blocking current-conducting switches. These switches are arranged in a matrix and by using this arrangement any input phase can be connected to any output phase at any time. Figure 2 shows such arrangement.

Almost for two and half decades no substantial work was witnessed carrying forward the work of Venturini and Alesina. University of Nottingham saw the research work related to matrix converter picking up again in the year 2004.

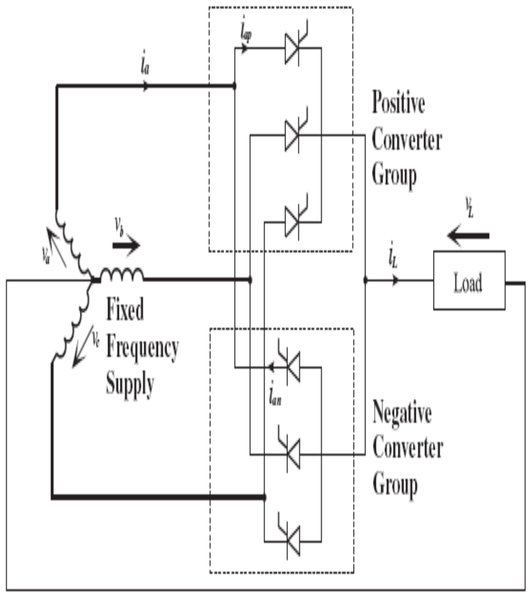

Fig. 1: Schematic of AC-AC converter

(Source- MC for frequency changing power supply applications, S. Lopez, Ph.D. Dissertation)

Since then useful studies have been brought out through IEEE. A few amongst them are mentioned below.

In recent years, the hard switching three-phase to three phase matrix converter has received great attention as an alternative to the dc-voltage link converter with active front end dealing with modulation schemes [4]. Some studies have dealt with operation at unbalanced input voltages [5], gate-drive concepts [6], and the commutation procedure for bidirectional switches [7]. Another possibility of implementing Direct Power Conversion (DPC) providing similar input and output performance as a standard single stage MC is the two-stage DPC [8], referred as "Dual Bridge MC" [9].

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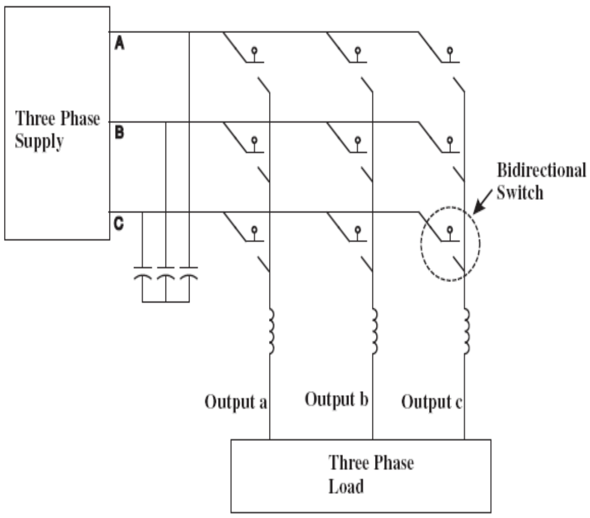

Fig. 2: Simplified representation of MC (Source- MC for frequency changing power supply applications, S. Lopez, Ph.D. Dissertation, Univ. of Nottingham, 2008)

Design and implementation of single leg matrix converter was proposed by Malcom Tabone, Cyril Spiteri Stains and Joseph Cilia [10]. A low cost micro controller supported operation of matrix converter was proposed by them. A new indirect matrix converter topology with a three level phase-neutral output voltage compatibility and reduced number of devices was proposed by Christian Klumpner et al [11]. A new and simple current control for matrix converter based on the fact that if the magnitude of output current space vector is constant, the output currents are sinusoidal and balanced, was proposed by Milton E. De oliveira Filho et al [12]. Problems in commutation of matrix converter were dealt by L. Empringham [13]. A new modulation strategy was proposed for matrix converter by G. Clos [14]. A class of new AC-DC-AC MC referred as AC Chopper MC (ACCMC), was proposed in 2009, which generates high voltage transfer ratio which is not found in conventional AC-AC MC [15]. Effects of various abnormal voltage conditions on MC were studied and tests were carried out to evaluate and improve the stability of the system under these conditions [16].

The characteristics desired in AC-AC single stage converter are: Eliminating the use of passive components such as large AC boost inductors and bulky and limited life time DC-link electrolytic capacitors. A three-phase AC-AC MC is shown in Figure 2:

II. Methodology

Testing of the model has been done for change in frequencies by connecting a resistive load and for variability of speed by connecting a squirrel cage induction motor as load; and simulation through MATLAB/simulink. But prior to that, proposed MC structure has been modeled and implemented using MATLAB, as shown in figure 3, and then simplified switch modulation scheme is proposed for the implemented model.

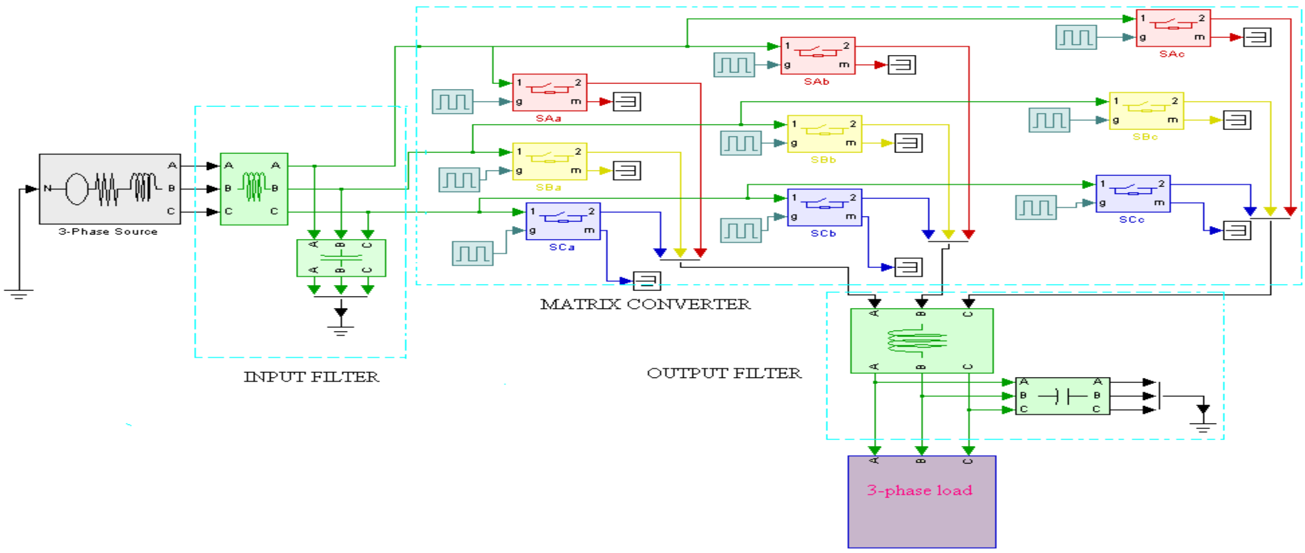

Fig. 3: MATLAB based model of proposed MC

III. Switch Modulation Strategy

The concept of switching functions is used to derive a mathematical model of the matrix converter. Performance of MC with three different modulation techniques such as PWM, SVPWM and SVM was studied in April, 2010 [17] and it was observed that THD is better for SVM technique and that the performance of MC varies with the control technique used. H. Mohd. Hanafi, N.R. Hamzah, A. Saparon and M.K. Hamzah proposed an improved switching sequence of single phase Matrix Converter (SPMC) modulated by Sinusoidal Pulse Width Modulation (SPWM) [18]. H. Mohd. Hanafi, Z. Idris and M.K. Hamzah presented their work on modeling and simulation of SPMC as a frequency changer modulated by SPWM subjected to passive load conditions. IGBTs were used for switching device. [19].

To understand the modulation problem and its solution, consider the arrangement shown in Figure 2. The modulation scheme proposed here in this study is straight forward and improvised over schemes proposed earlier. A sequential and logical pattern is set which generates much smoother wave forms without a serious attempt for designing of input and output filter circuits. This study is of basic nature and the filter circuit design is ignored in this study. Hence, this study provides the opportunities to take up the further work related with designing of filter circuits at the input and output in this model.

Analysis of this arrangement shows that there are no freewheeling diodes. This restriction means that the short circuit in the capacitive input as well as the open circuit in the inductive output must be avoided. Because ideal switches are used, the commutation between switches is instantaneous. A typical switching pattern for matrix converter is shown in fig. 4.

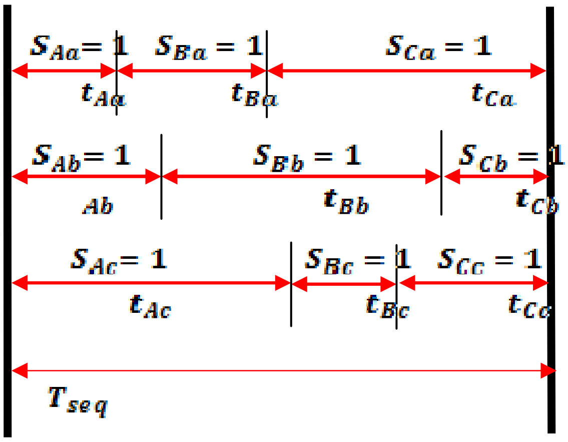

Fig. 4: Switch modulation scheme for proposed MC

If conventional PWM is employed the switching sequence *Tseq* has a fixed period as shown in equation 1.

$$m_{Aa}(t) = \frac{t_{Aa}}{T_{seq}} \quad (1)$$

A modulation duty cycle should be defined for each switch in order to determine the average behavior of the matrix converter output voltage waveform. The modulation duty cycle is defined by equation 1, where *tAa* represents the time when switch *SAa* is ON and *Tseq* represents the time of the complete sequence in PWM pattern. For calculating the *tAa* and *mAa*, Venturni's simplified algorithm [20] is used in this study. The simplified algorithm is reproduced below: -

Vim and ω_{it} are calculated as

$$V_{im}^2 = 4/9(v_{AB}^2 + v_{BC}^2 + v_{AB}v_{BC} \quad (2)$$

$$\omega_i t = arc\tan\left(\frac{v_{BC}}{\sqrt{3}\left(\frac{2}{3}v_{AB} + \frac{1}{3}v_{BC}\right)}\right) \quad (3)$$

Where, V_{AB} and V_{BC} are the instantaneous input line voltages. The target output peak voltage and the output position are calculated as

$$V_{om}^2 = \frac{2}{3(v_a^2 + v_b^2 + v_c^2)} \quad (4)$$

$$\omega_i t = arc\tan\left(\frac{v_b - v_c}{\sqrt{3}v_a}\right) \quad (5)$$

Where, V_a, V_b, V_c are the target phase output voltages. Alternatively, in a closed loop system (for example a field-oriented controlled drive), the voltage magnitude and angle may be direct outputs of the control loop. Then, the voltage ratio is calculated

$$q = \sqrt{\frac{V_{om}^2}{V_{im}^2}} \quad (6)$$

Where, q is the desired voltage ratio, and Vim is the peak input voltage. Triple harmonic terms are found:

$$K_{31} = \frac{2}{9}\frac{q}{q_m}\sin(\omega_i t)\sin(3\omega_i t) \quad (7)$$

$$K_{32} = \frac{2}{9}\frac{q}{q_m}\sin\left(\omega_i t - \frac{2\pi}{3}\right)\sin(3\omega_i t) \quad (8)$$

$$K_{33} = \sqrt{V_{om}^2}\left[\frac{1}{6}\cos(3\omega_0 t) - \frac{1}{4}\frac{1}{q}\cos(3\omega_i t)\right]$$

. (9)

Where, q_m is the maximum voltage ratio (0.866). Then, the three modulation functions for output phase a are given as

$$M_{Aa} = \frac{1}{3} + k_{31} + \frac{2}{(3V_{im}^2)(v_a + k_{32})\left(\frac{2}{3}v_{AB} + \frac{1}{3}v_{BC}\right)} \quad (10)$$

$$M_{Ba} = \frac{1}{3} + k_{32} + \frac{2}{(3V_{im}^2)(v_a + k_{32})\left(\frac{2}{3}v_{BC} + \frac{1}{3}v_{AB}\right)}$$

(11)

$$M_{Ca} = 1 - (M_{Aa} + M_{Ba}) \quad (12)$$

IV. Final Design Of The Proposed Model

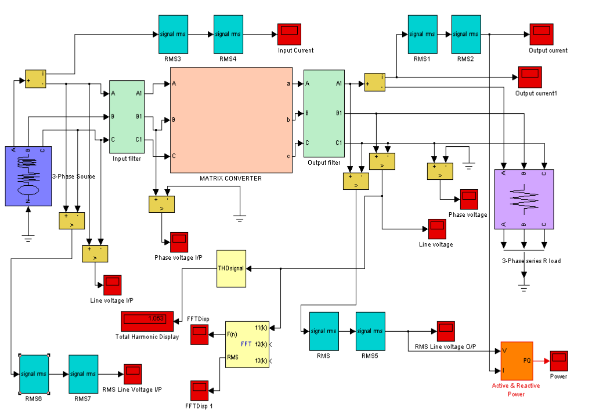

Fig.5. Compact structure of Matrix Converter

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V. RESULTS

The results of change in frequencies at the output as well as controlling the speed of motor with change in frequency have been obtained successfully and is evident through the waveforms generated by simulink thus the envisaged model may be used for the purpose of enhancing the efficiency of the overall system.

Specifically, the input 50 Hz frequency converted to 400 Hz output frequency shows suppression of significant odd harmonics effectively at the output.

A. Conversion of Input Frequency from 50 - 400 Hz

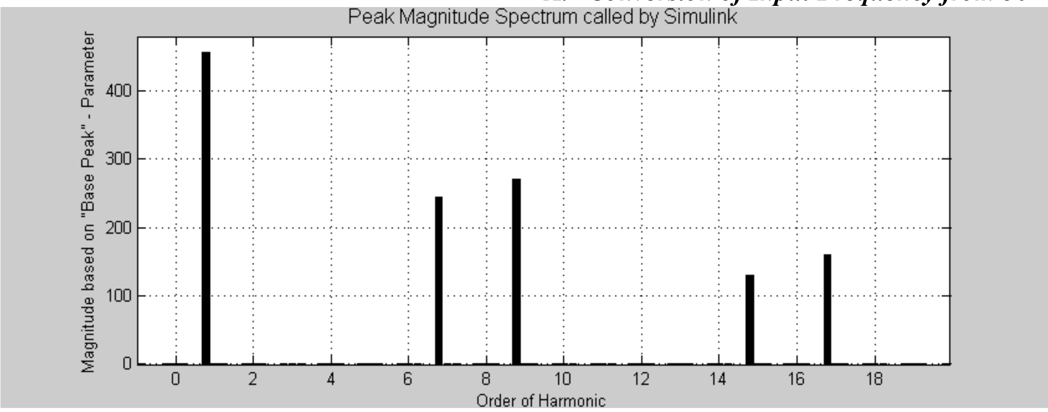

Fig. 6: Total harmonic distortion (400 Hz)

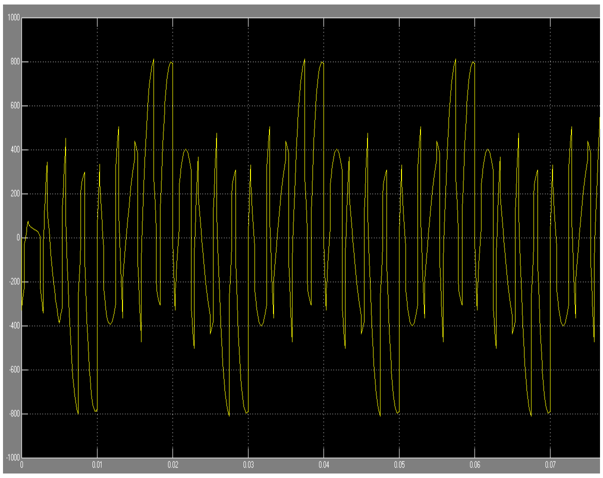

Fig. 7: Line Voltage with filter (400 Hz)

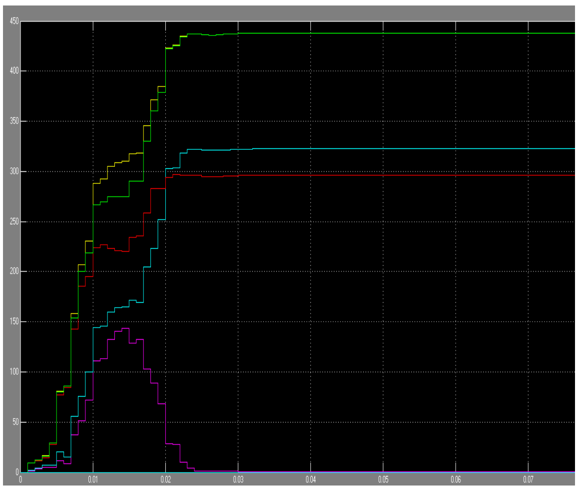

Fig.8: FFT display showing reduced triple harmonic distortions

B. Conversion of Input Frequency from 50 - 100 Hz

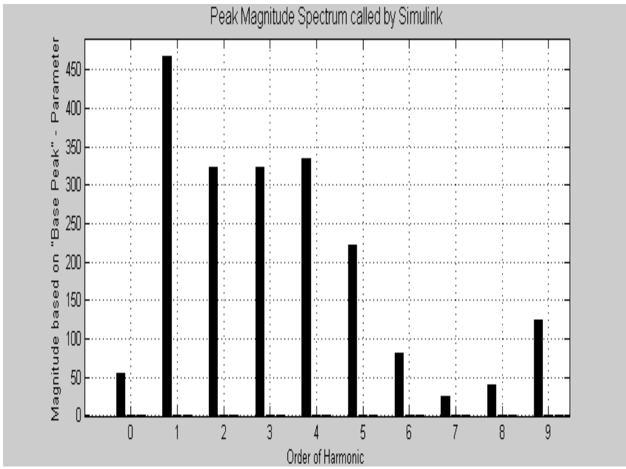

Fig. 9: Total harmonic distortion (100 Hz)

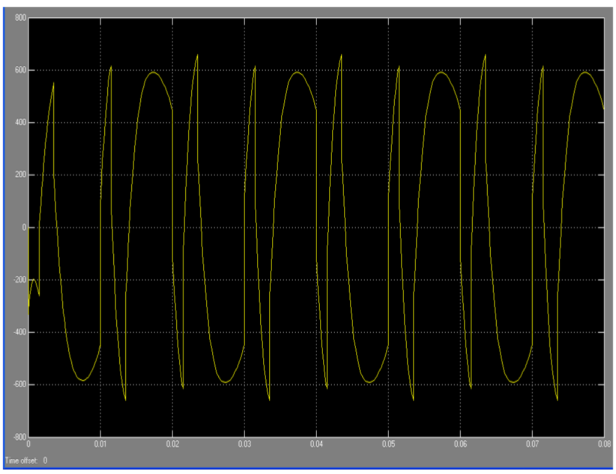

Fig. 10: Line Voltage with filter (100 Hz)

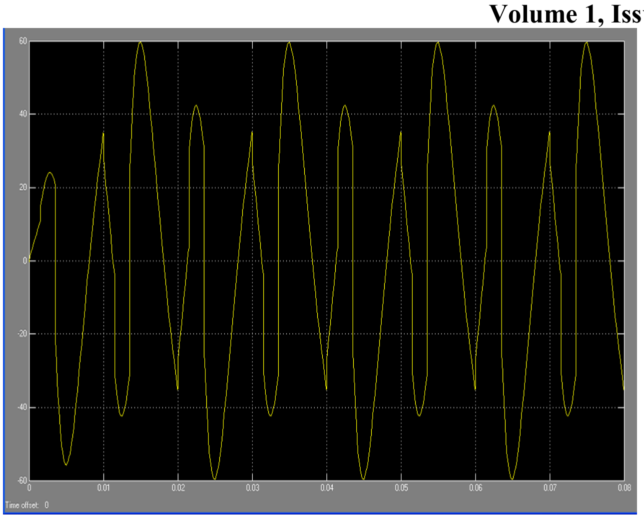

Fig. 11: Output Current with filter (100 Hz)

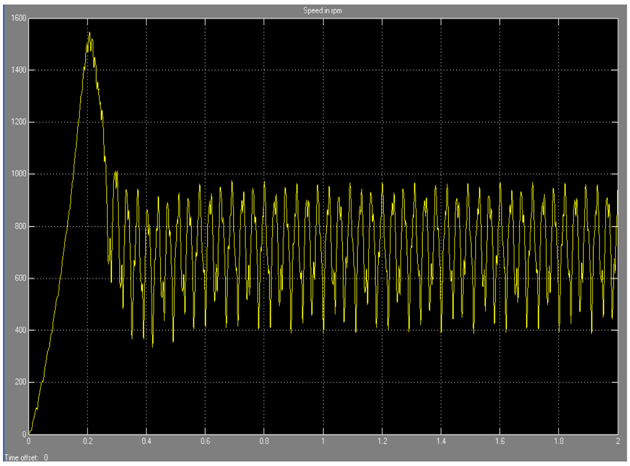

Fig. 12: Speed of motor obtained at 100 Hz with simulation (800 RPM

C. Conversion of Input Frequency from 50 to 25 Hz

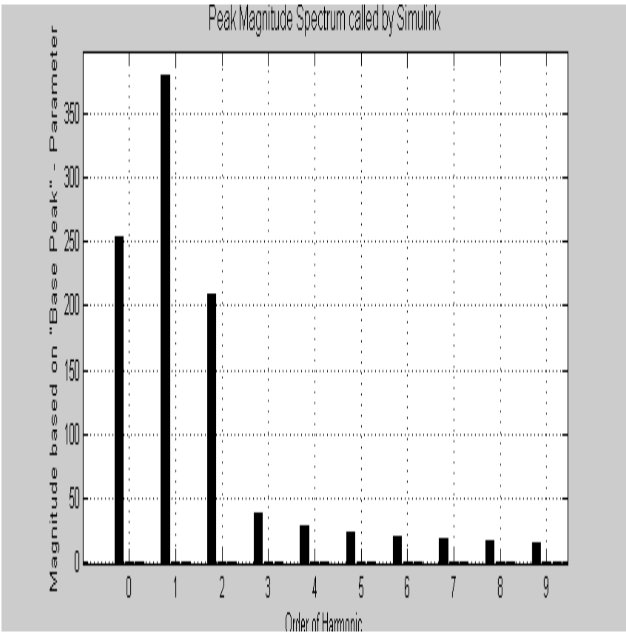

Fig. 13: Total harmonic distortion (25 Hz)

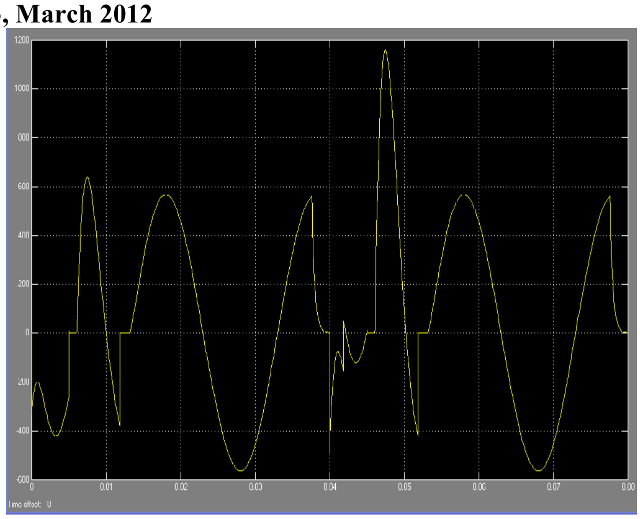

Fig. 14: Line Voltage with filter (25 Hz)

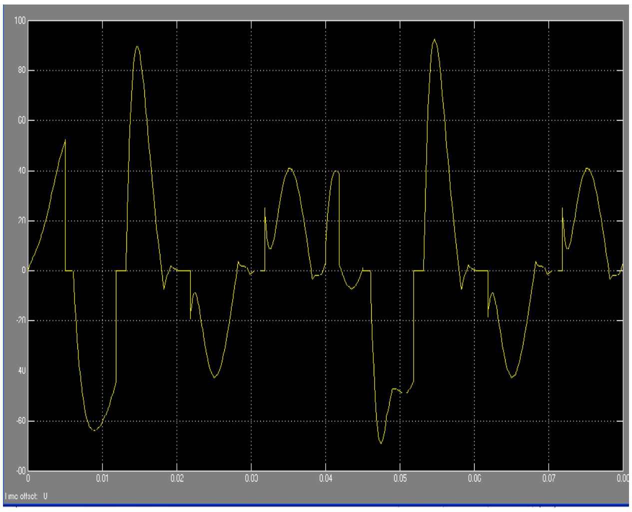

Fig.15: Output Current with filter (25 Hz)

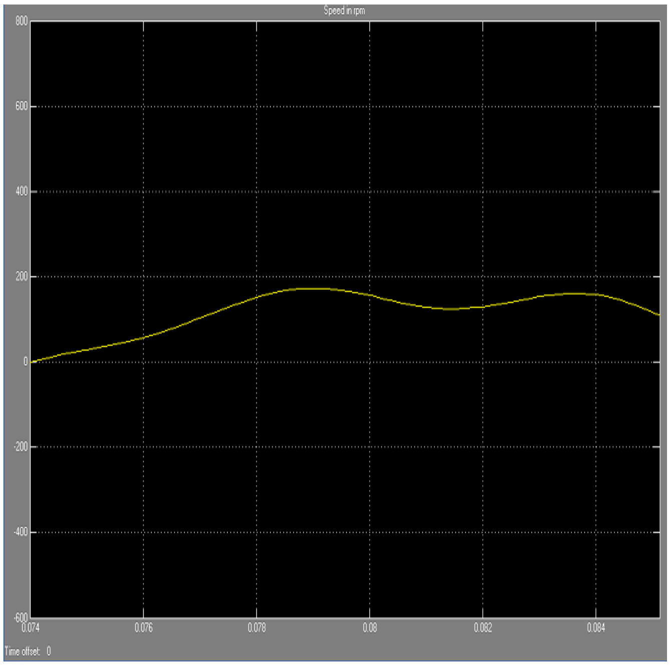

Fig. 16: Speed of motor obtained at 25 Hz (200 RPM)

VI. Conclusions And Discussions

As the title of the study suggests, the aim of the present study was set to carry out the modeling of the single stage AC-AC conversion. In the present study the matrix converter modeling is implemented in MATLAB and then a simplified switch modulation scheme is proposed for the envisaged model. Firstly, the variable frequency output was generated from the designed models for 400 Hz, 100 Hz and 25 Hz. Subsequently, the 100 Hz and 25 HZ models were used for demonstrating the speed control of squirrel cage induction motor according to change in frequency. The testing of the model for change in frequencies and speed control of induction motor was done through MATLAB/Simulink. The waveforms of the motor speed generated by simulation confirmed the variation of the speed with variation of frequency. The study is thus able to pinpoint the specific contribution of the envisaged converter in reducing the harmonic distortions at the output, overall size of the converter by at least half (1/2) thus minimizing the space requirements and at the same time reduction in losses due to single stages of conversion.

VII. Future Scope

The wave forms generated for various frequencies exhibit distortions which can be smoothened by way of appropriate design of input and output filter circuits thus providing the scope for future course of work. Generating fixed frequency output from variable frequency input using the same algorithm and thus integrating such a converter with wind power generation can also be explored.

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