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Simulation Analysis of Matrix Converter for Frequency Changing Power Supply Application

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Abstract

The indirect matrix converter is a converter with no energy storage dc-link. The lack of energy storage components in the dc-link is one of the advantages of the matrix converter. Furthermore, the matrix converter features full four-quadrant operation and sinusoidal input current. The output voltages ratio is limited to 0.866 of the input voltage. The indirect matrix converter needs six bidirectional switches in the rectification stage to connect with six unidirectional switches in the inversion stage. Bidirectional switches are not available on the market today and need to be constructed from semiconductor devices. Most research work about matrix converters has so far regarded the modulation and control of the matrix converter. The practical experience is still very limited. In this thesis presents an indirect matrix converter using simple commutation method base on AC/DC/AC converter. It combines the control method between the rectification stage and the inversion stage which can largely simplified modulation in rectification stage and all bidirectional switches at line side turn on and turn off at zero current. MATLAB/Simulink modeling and simulation of the matrix converter feeding an R load was carried out. The experimental results at variable frequency are presented

Introduction

This system was called cycloconverter at its early stage and this proved to be so appropriate that nowadays it is still used in some high power applications because of high power requirements and the Matrix Converter technology is still not available widely.

Moreover, most of the industrial applications require frequencies in the range of 50Hz-60Hz, which is easily obtained by the cycloconverter. For a three-phase to three-phase cycloconverter, 36 thyristors are required. This makes that cycloconverter systems very large and complicated and tend to be used in applications where high power is required (1MW and up) . Today, high power, multi-megawatts, thyristor based Cycloconverters are very popular for driving induction and wound field synchronous motors. Some general applications of cycloconverter are :

- Cement and ball mill drives
- Rolling mill drives
- Slip-power recovery Scherbius drive Variable-speed, constant-frequency (VSCF) power generation for aircraft 400Hz power supplies

Frequency conversion or modulation techniques can be used to take a fixed frequency or DC source and provide any load with a different or variable frequency supply. Cycloconversion is mostly concerned with converting directly a low-frequency waveform into a desired different frequency waveform.

Matrix Converters were first mentioned in the early 1980's by Alesina and Venturini. 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 $p3=2$ and also, they suggested a specific modulation and a feed-back-based control implementation of the proposed converter . The AC-AC Matrix Converter is optimal in terms of minimum switch number and minimum filtering requirements.

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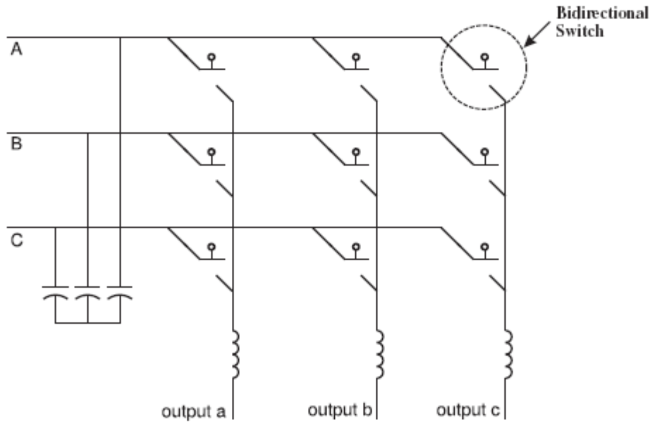

Figure 1: Structure of matrix conveter.

Design Input Filter For Matrix Conveter

Power electronics circuits switch on and o® large amounts of current at high voltages and thus can generate unwanted electrical signals that affect other electronic systems. In practice, the magnitudes of the higher-order harmonics can also be significantly affected by the current spikes caused by the finite slopes of the switching transitions. In consequence, it is always required that a filter be added at the power input of a power converter.

It has been established both by analysis and practical tests that in Matrix Converter application it is advisable to incorporate damping in the filter, in the form of resistors in parallel with the inductors, since there is a high probability that at some operating point the matrix converter input currents will contain a component close to the resonant frequency of the filter. Figure 2 shows the LC input filter with the damping resistor added. The internal resistance of the inductor is represented by *r*. Using this schematic diagram, the transfer function of the input filter can be calculated. This transfer function is used to determine the resonance and cut-off frequency of the input filter. Bode plots are employed to find graphically the resonance and cut-off frequencies.

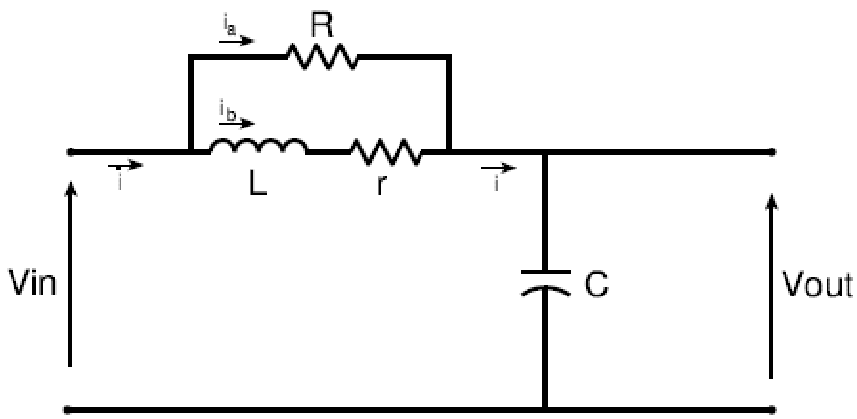

Figure 2: Diagram to calculate transfer function of input FILTER.

The transfer function is defined as the relation between the output to the input, i.e.

$$TF = \frac{V_{out}}{V_{in}} \qquad \text{(1)}$$

Substituting the input and output voltage expression for each of the circuit components,

$$V_{out} = V_C = \frac{1}{C}\int idt = \frac{1}{C}\int (i_a + i_b)dt \qquad \text{(2)}$$

$$V_{in} = L\frac{di_b}{dt} + ri_b + \frac{1}{C}\int idt = L\frac{di_b}{dt} + ri_b + \frac{1}{C}\int (i_a + i_b)dt$$

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(3)

The relationship between i_a and i_b can be found as

$$V_R = V_L + V_r; \quad Ri_a = L\frac{di_b}{dt} + ri_b \qquad \text{(4)}$$

(5)

$$\Rightarrow \quad i_a = \frac{L}{R}\frac{di_b}{dt} + \frac{r}{R}i_b$$

Substituting Equation.5 into Equations.2 and Equation.3 and applying Laplace transform,

$$V_{out} = \frac{Ls + r + R}{RCs} \qquad \text{(7)}$$

(8)

$$V_{in} = \frac{RLCs^2 + (rRC + L)s + (r + R)}{RCs}$$

Finally, the expression of the input filter transfer function is found as,

$$TF = \frac{\frac{Ls+r+R}{RLC}}{s^2 + (\frac{r}{L} + \frac{1}{RC})s + (\frac{r}{LRC} + \frac{1}{LC})} \qquad \text{(9)}$$

Eqn. 9 expresses the general form of the input filter transfer function and is used to obtain the resonance and cut-off frequencies

Design Output Filter For Matrix Converter

The power converter requires a LC filter at the output side to reduce the harmonics generated by the pulsating modulation of voltage waveform. A power converter with higher switching frequency will result in smaller LC filter size. However, switching frequency is generally limited in high power applications.

The trial and error method is used to modified the filter design values to reduce the distortion of the output voltage waveform. Figure 6.2 shows the schematic of the output filter. In this figure *r* represents the internal resistance of the inductor. The transfer function of the output filter can be calculated from this figure. The resonance and cut-off frequencies are determined according to the values of the capacitor and the inductor. Bode plots are employed to find such frequencies.

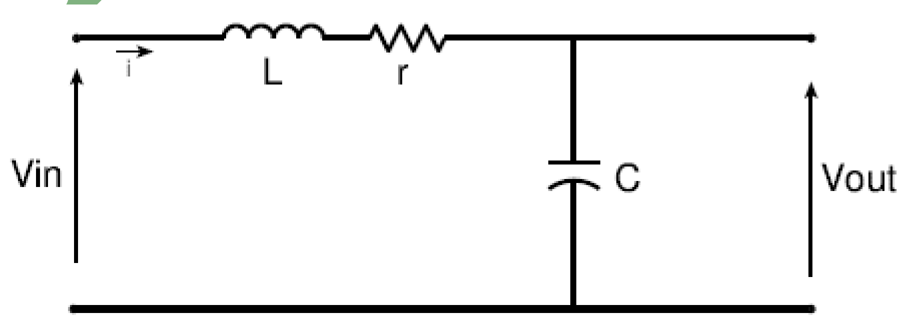

Figure 3: Diagram to calculate transfer function of output FILTER

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Simulation Results

4.1 Single phase to single phase matrix converter

The Single-Phase Matrix Converter consists of a matrix of input and output lines with four bidirectional switches connecting the single-phase input to the single-phase output at the intersections. It comprises of four ideal switches Sl, S2, S3 and S4 capable of conducting current in both directions, blocking forward and reverse voltages (symmetrical devices) and switching between states without any delays.

I. Basic simulation circuit of single phase to SPMC

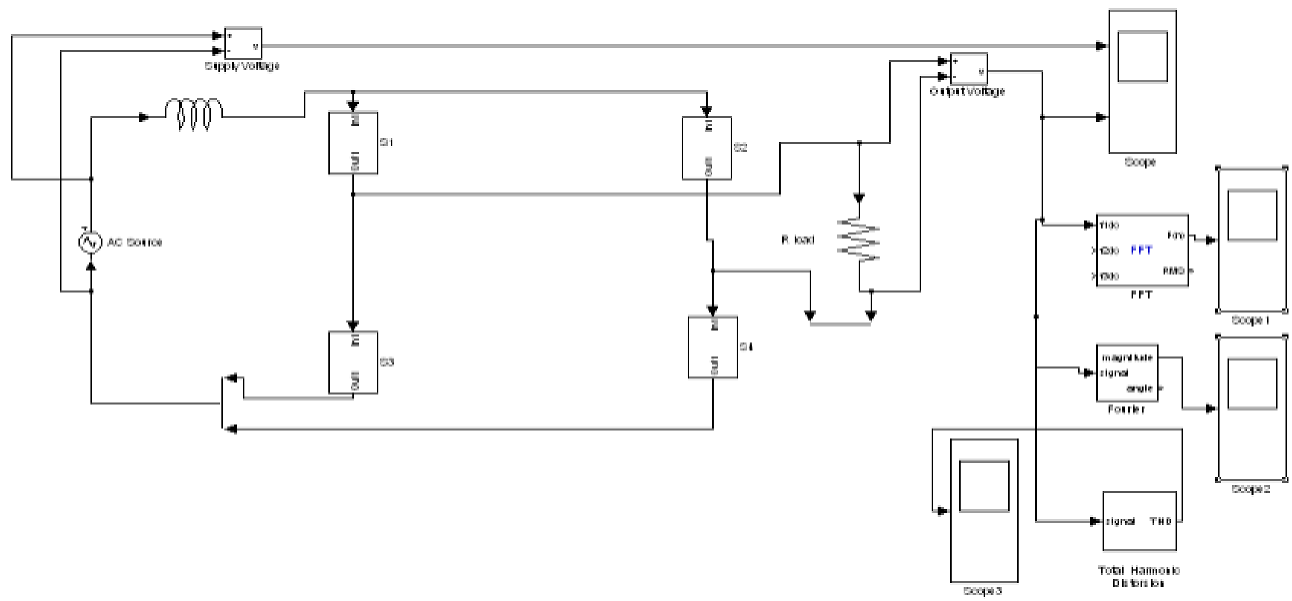


Figure 4: Basic simulation circuit for SPMC

II. Simulation Result

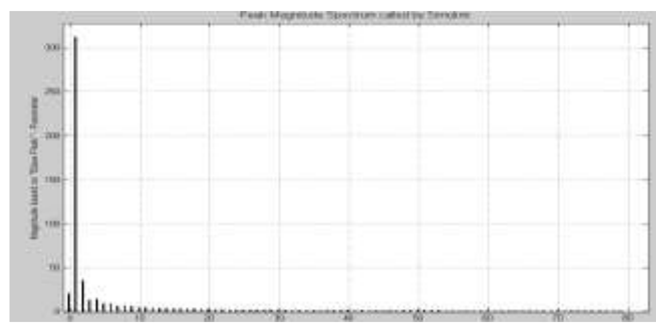
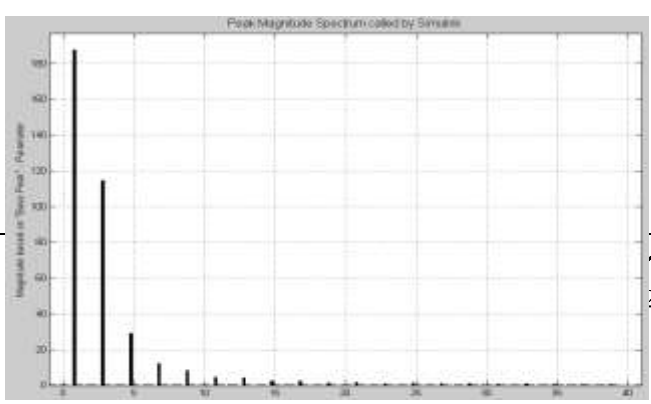
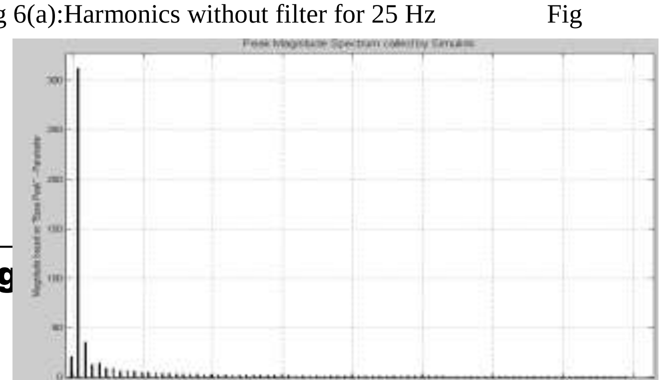


Fig 5(a):Harmonics without filter for 12.5 Hz Fig 5(b):Harmonics after filtration for 12.5Hz

Fig 6(a):Harmonics without filter for 25 Hz Fig





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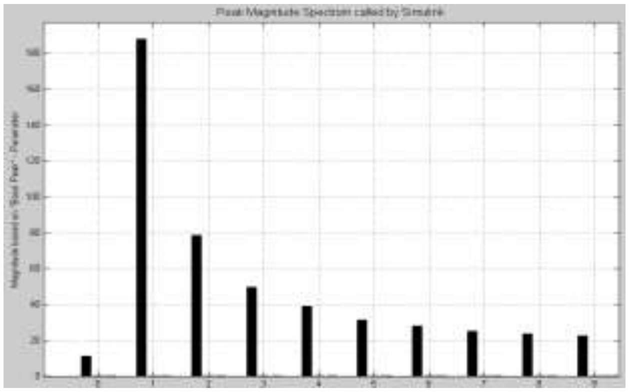
6(b): Harmonics after filtration for 25Hz



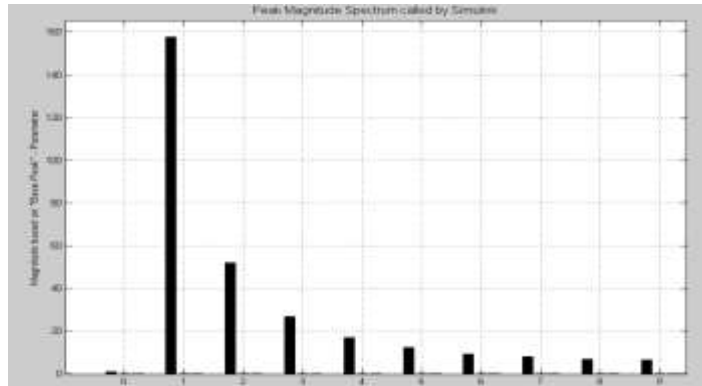
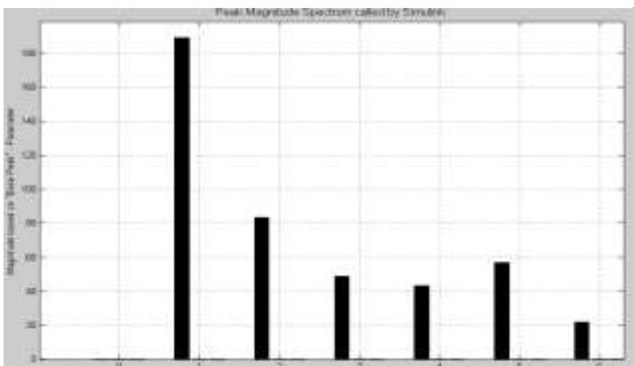


Fig 7(a): Harmonics without filter of 100Hz

Fig 7(b): Harmonics after filtration of 100 Hz



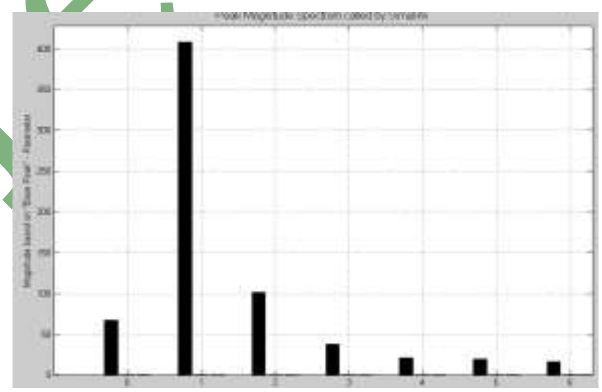
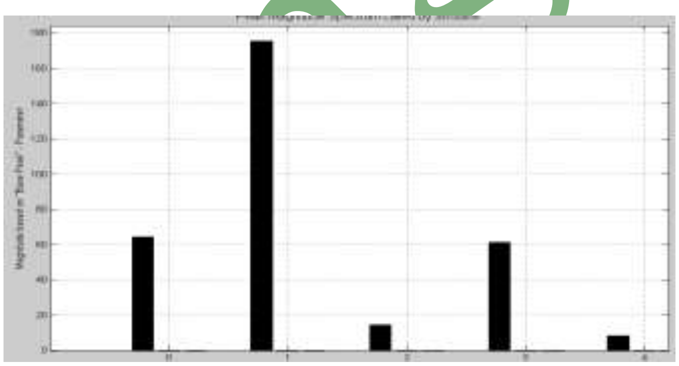


Fig 8(a): Harmonics without filter of 150Hz

Fig 8(b):Harmonics after filtration of 150Hz



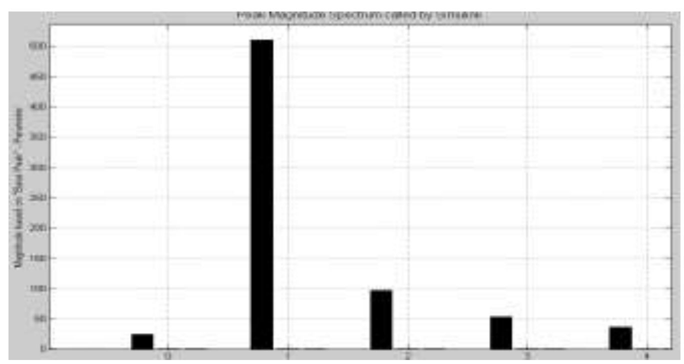


Fig 9(a):Harmonics without filter of 200 Hz

Fig 9(b): Harmonics after filtration of 200Hz

Input and Output waveform

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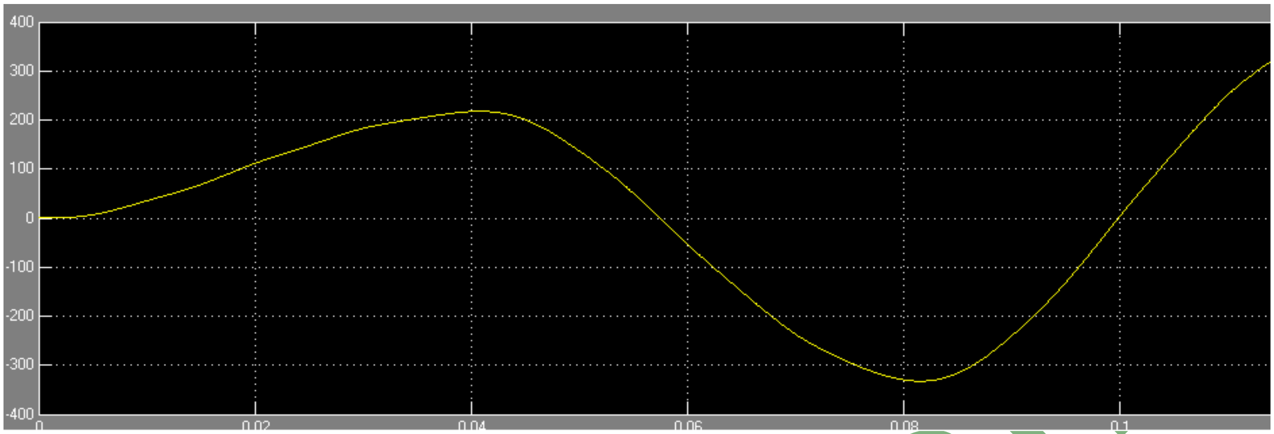

Fig 10: Output voltage of 12.5 after filtration

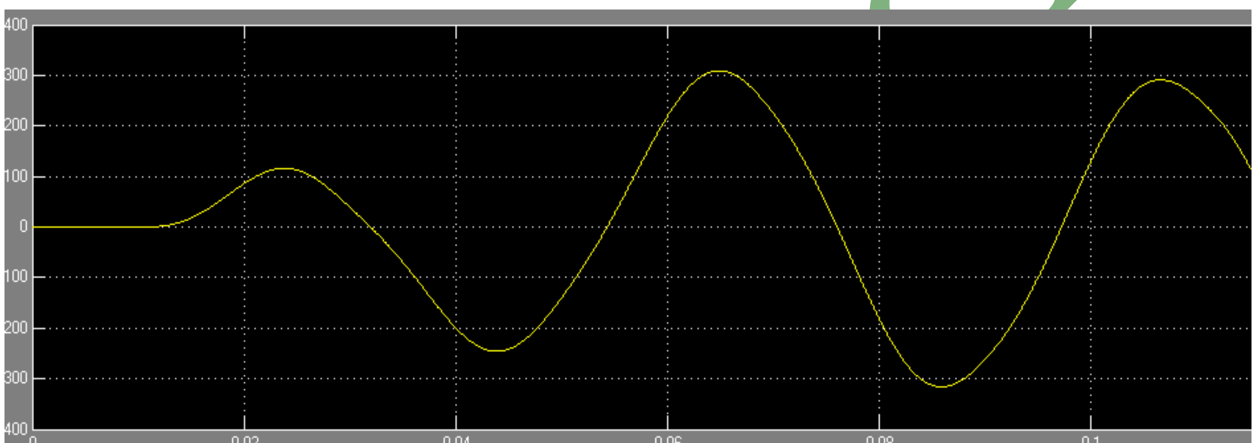

Fig 11:Output voltage of 25Hz after filtration

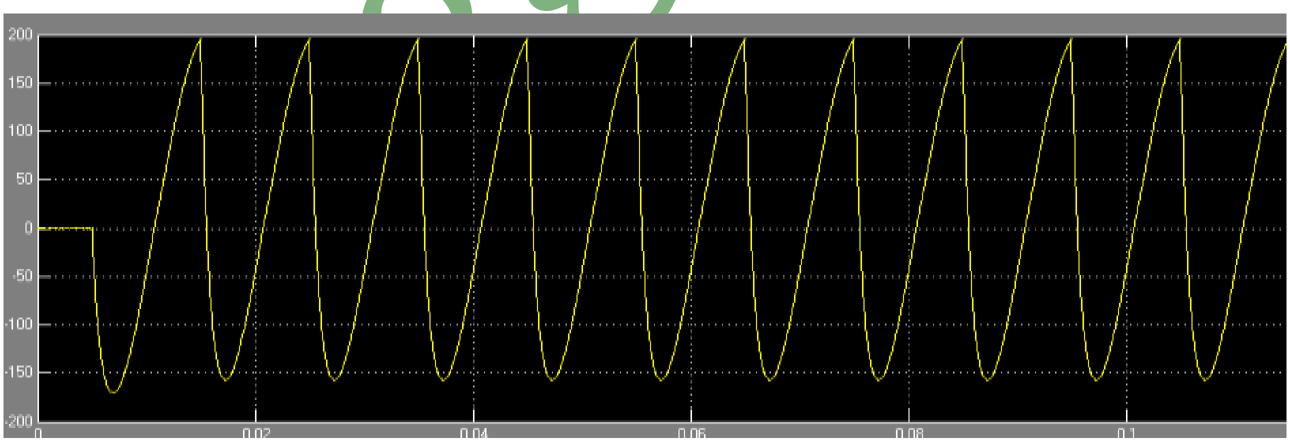

Fig 12: Output frequency of 100Hz after filtration

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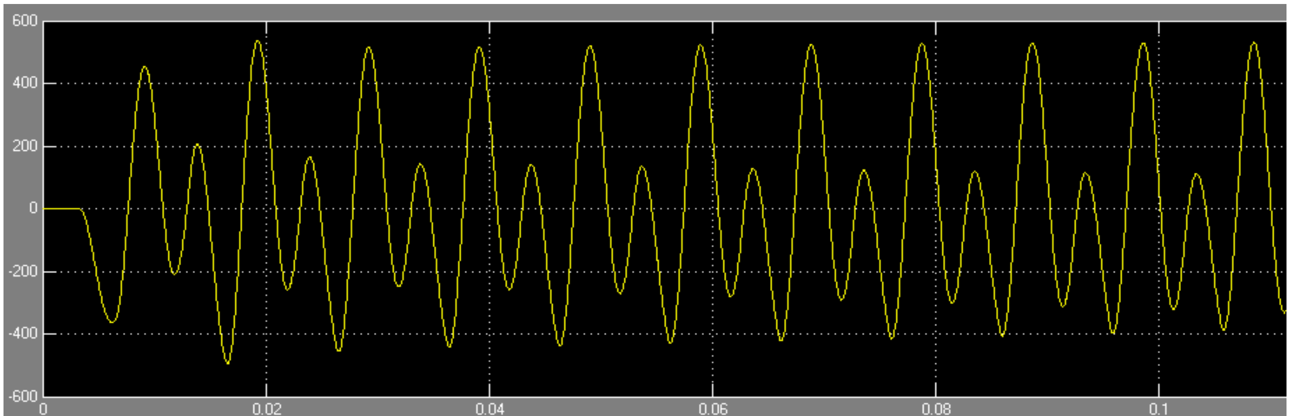

Fig 13:output frequency of 150Hz after filtration

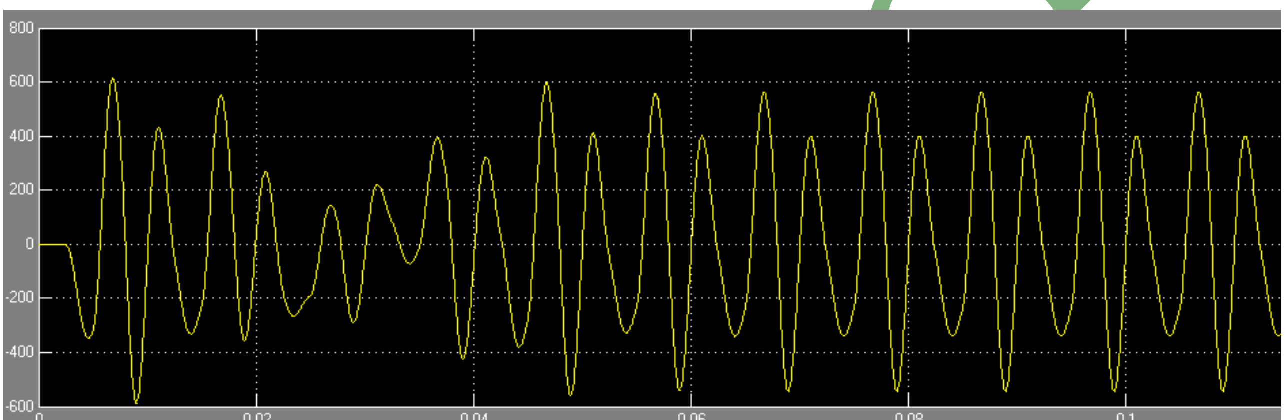

Fig 14: Output waveform of 200Hz after filtration

7.2 Three phase to three phase matrix converter

Basic simulation circuit of three phase to three phase

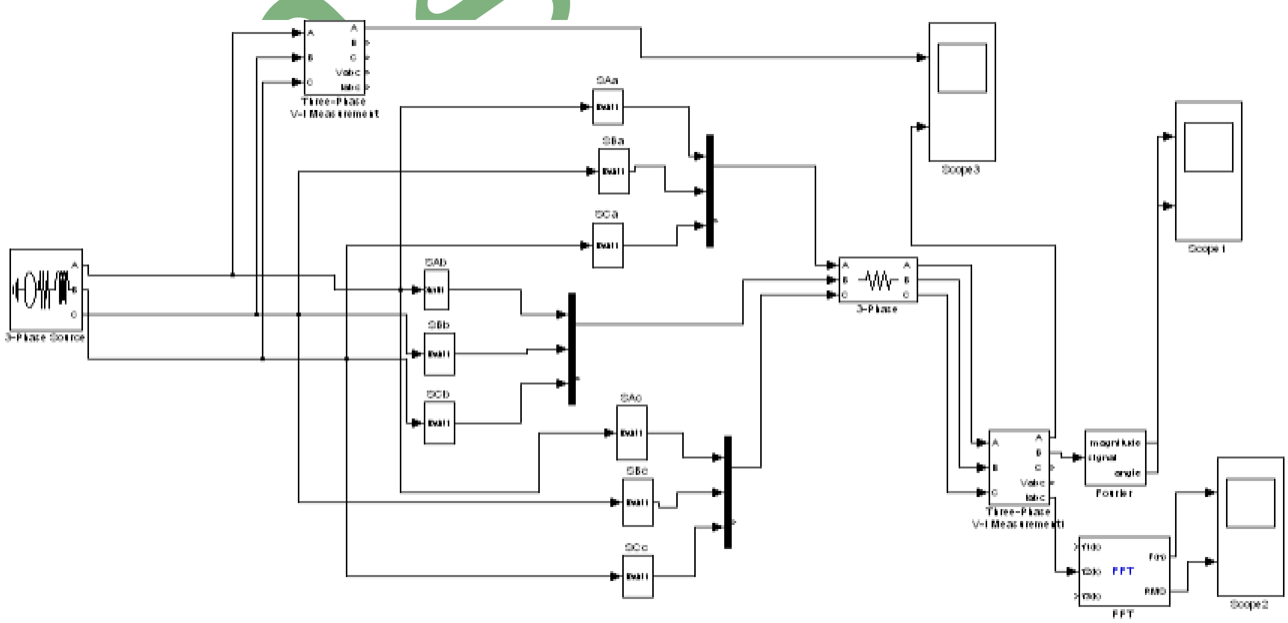

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Fig 15: Basic simulation circuit for 3 phase to 3 phase

SIMULATION RESULT OF 100HZ

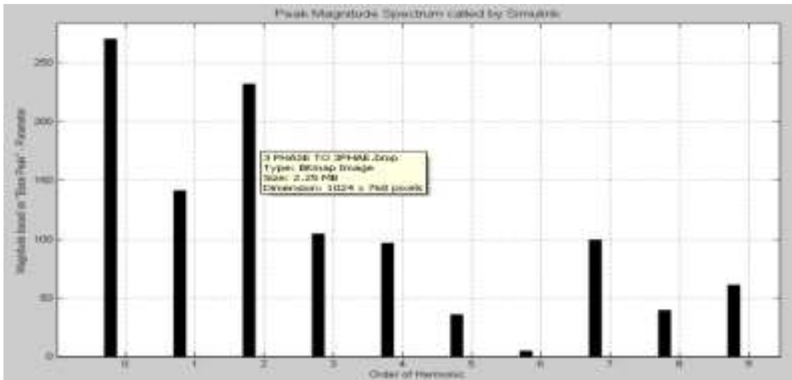

Fig 16: Harmonics graph of 100Hz

Output waveform of 100Hz

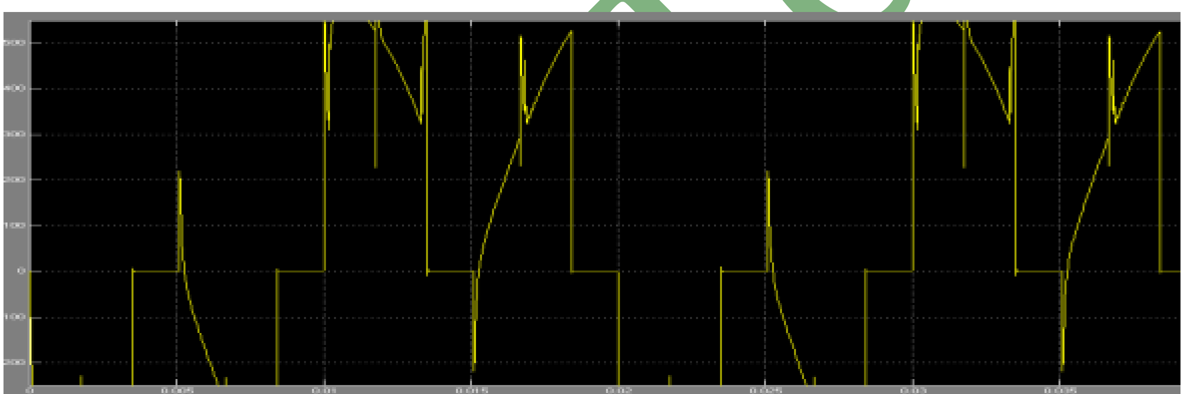

Fig 17: Output waveform of 100Hz

Conclusion

The work presented in this thesis has made an exciting contribution to the research applications of Matrix Converters. In order to optimize the design of the Matrix Converter system, which is going to operate as a power supply for aircraft applications, a detailed analysis using both Saber and Matlab/Simulink software packages were used to select the best topology of Matrix Converter system that could satisfy the specifications. When Saber was used, the Matrix Converter modulation and control were implemented by using the MAST language, which discretised the modulation strategies applied. As a result, the source code obtained from the simulation resembles the final program implemented on a DSP, thus facilitating the implementation of the digital control platform for the converter. To experimentally verify the proposed control strategy for the Matrix Converter based power supply, a laboratory prototype was designed and constructed. The rig consists of a 3-phase to 3-phase direct AC-AC converter (Matrix Converter) which is used as the power conditioning core of the power supply, working in conjunction with input and output LC filters. The control of the experimental rig is performed by a co-operation between a Digital Signal Processor (DSP, TMS320C6713) and a Field

Programmable Gate Array(FPGA) board. Data acquisition and pulse generation are coordinated by the FPGA board. The program implemented in the DSP is written in C using Code Composer Studio. Practical results show good performance of the proposed control strategy when implemented in the Matrix Converter based power supply operating at different loading conditions, besides the capability of bi directional power flow of the converter

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