COMPARISON OF MATRIX CONVERTER AND COMMON CONVERTER FOR INDUCTION MOTOR APPLICATION USING MATLAB

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COMPARISON OF MATRIX CONVERTER AND COMMON CONVERTER FOR INDUCTION MOTOR APPLICATION USING MATLAB

NOR AFIDATUL ASNI BT SEMSUDIN

This thesis is submitted as partial fulfillment of the requirements for the award of the Bachelor of Electrical Engineering (Power System)

Faculty of Electrical & Electronics Engineering

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"I hereby acknowledge that the scope and quality of this thesis is qualified for the award of the Bachelor Degree of Electrical Engineering (Power System)"

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I declare that "*Design and Simulation of Matrix Converter for Induction Motor Application*" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not currently submitted in candidature of any other degree.

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Special dedicated to my beloved parents, brothers, and sisters.

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ABSTRACT

Among the most desirable features in power frequency changers are simple and compact power circuit, generation of load voltage with arbitrary amplitude frequency, regeneration capability, and operation with unity power factor for any load. These ideal characteristics can be fulfilled by matrix converter (MC) which is become increasingly attractive for the AC drive applications. It has the potential to replace the conventionally converter. Matrix converter is a new type of direct AC to AC converter which converts input line voltage into variable voltage with unrestricted frequency without using an intermediate DC link circuit. MC uses the space vector modulation technique to control the input power factor which is the simpler method than the other control modulation. The objectives of the project are to implement the MC to control speed and torque of induction motor by using MATLAB Simulink and to design the common converter for induction motor application besides to compare the performance of the induction motor by using matrix converter and common converter. The simulation results of voltage and current waveform will be achieved if the project is implemented successfully.

ABSTRAK

Antara ciri-ciri yang paling dikehendaki dalam penukaran kuasa frekuensi elektrik ialah kuasa litar elektrik padat dan mudah, penghasilan voltan beban dengan sebarang frekuensi amplitud, kemampuan dalam pengahasilan semula, dan beroperasi dengan faktor kesatuan daya untuk sebarang beban. Ciri-ciri ideal ini dapat dipenuhi oleh penukar matrik (PM) yang menjadi semakin popular untuk aplikasi dalam pemacu arus ulang alik. PM ini juga mempunyai potensi untuk menggantikan penukar konvensional (PK). PM merupakan kaedah baru bagi menukarkan secara langsung arus ulang alik kepada penukar arus ulang alik dan juga menukarkan voltan garis input kepada pelbagai voltan dengan frekuensi yang tidak terbatas tanpa menggunakan rangkaian tengah litar arus terus. PM menggunakan teknik modulasi vektor ruang untuk mengawal faktor input daya dan ini merupakan kaedah mudah berbanding dengan modulasi kawalan lain. Tujuan projek ini adalah untuk melaksanakan PM pada motor aruhan bagi mengawal kuasa putaran serta kelajuan motor aruhan dengan menggunakan simulasi MATLAB dan untuk mereka penukar konvensional (PK) untuk aplikasi motor aruhan selain untuk membandingkan pencapaian motor aruhan yang menggunakan PM dan juga PK. Keputusan simulasi untuk voltan dan arus gelombang akan dicapai jika projek ini dilaksanakan dengan jayanya.

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LIST OF SYMBOLS

C_s	-	Snubber Capacitance
R_s	-	Snubber Resistance
Ω	-	Ohm
VA	-	Volt Ampere
Hz	-	Hertz
HP	-	Horse Power
F	-	Farad
H	-	Hendry
deg	-	Degree
V_{rms}	-	Root Mean Square Voltage
T	-	Time
V	-	Volt
A	-	Ampere
rpm	-	Revolution per Minute
Nm	-	Newton Meter

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LIST OF ABBREVIATION

MC	-	Matrix Converter
CC	-	Common Converter
DTC	-	Direct Torque Control
SVM	-	Space Vector Modulation
DC	-	Direct Current
AC	-	Alternating Current
PWM	-	Pulse Width Modulation
IGBT	-	Insulated Gate Bipolar Transistor
SVPWM	-	Space Vector Pulse Width Modulation
THD	-	Total Harmonics Distortion
V_{env}	-	Voltage envelope
VSI	-	Voltage Source Inverter
LC	-	Inductance Capacitance
RLC	-	Resistance Inductance Capacitance

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In many AC drive applications, it is desirable to use a compact voltage source converter to provide sinusoidal output voltages with varying amplitude and frequency, while drawing sinusoidal input currents with unity power factor from the AC source. The development of matrix converter started when *Alesina* and *Venturini* proposed the basic principles of operation in the early 1980's. Matrix Converter is increasingly becoming popular because it does not have any intermediate energy storage devices except small AC filters for the elimination of switching ripples. This converter fulfills all the requirements of the conventionally used rectifier/ DC link/ inverter structures and provides an efficient way to convert electric power [1].

This paper describes matrix converter by using space vector modulation technique implemented to the induction motor. The performance of the induction motor by using matrix converter will be compared with the performance of the induction motor by using common converter. The common converter consists of rectifier part which converts AC to DC and inverter part that converts DC to AC. The project is performed by using MATLAB Simulink and all the results will be analyzed.

1.1.1 General Introduction of Matrix Converter

Matrix converter (MC) is a new type of direct AC to AC converter which consists of 9 bi-directional switches, arranged as three sets of three so that any of the three input phases can be connected to any of the three output lines. 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 and the permanent magnet synchronous motor might be that requires variable voltage with variables frequencies. It is very simple in structure and has powerful controllability [2].

Since there is no DC link as in common converters, the matrix converter can be built as a full-silicon structure. However, a mains filter is necessary to smooth the pulsed currents on the input side of the matrix converter. Using a sufficiently high pulse frequency, the output voltage and input current both are shaped sinusoidal. The matrix converter is an alternative to an inverter drive for three-phase frequency control [3].

The matrix converter has several advantages over traditional rectifier-inverter type power frequency converters. It provides sinusoidal input and output waveforms, with minimal higher order harmonics and no sub harmonics; it has inherent bi-directional energy flow capability; the input power factor can be fully controlled. Last but not least, it has minimal energy storage requirements, which allows to get rid of bulky and lifetime- limited energy-storing capacitors [4].

But the matrix converter has also some disadvantages. First of all it has a maximum input output voltage transfer ratio limited to ≅ 87 % for sinusoidal input and output waveforms. 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 [5].

1.2 Problem Statement

The matrix converter is superior to the traditional VSI because of regeneration ability and sinusoidal input current. Therefore, it meets the stringent energy efficiency and power quality requirements of the new century. MC can be considered to be a direct converter, in this respect similar to a cycloconverter, because it does not employ a DC link and the output waveforms are composed switched segments of the input waveforms.

According to the advantages of matrix converter, this project comes out with the problem statements of common converter cannot fully control the input power factor. The implementation of the matrix converter to the induction motor needs a better speed and torque controller. To overcome these issues, the implementation of induction motor load in MC with the space vector modulation (SVM) applies as the control strategy of the input power factor as it is the most popularly switching. It allows the control of input current and output voltage independently.

1.3 Objectives

The objectives of this project are:

1. To implement the matrix converter to control torque and speed of the induction motor.
2. To design common converter for induction motor application.
3. To compare the performance of the induction motor by using matrix converter and common converter.

1.4 Scopes of Project

The several scopes that need to be proposed for the project is focusing on the performance of the induction motor through matrix converter using MATLAB Simulink with space vector modulation as control strategy. The project also will cover on designing the common converter circuit (AC/DC/AC) with the same induction motor as a load.

After that, the performance of the induction motor from matrix converter and common converter will be compared. In order to compare the both converters, the comparison of the matrix converter by using different load which are resistance and induction motor and the comparison of the performance of the induction motor from source through matrix converter and direct source will be done first.

1.5 Thesis Outline

Generally the thesis contains five main chapters and the details of each chapter are summarized as below:

Chapter 1 consists of introduction and overview of the project. The problem statement is mentioned together with the relevant objectives to overcome the problem. The scopes of the project are also explained.

Chapter 2 reviews the main idea of matrix converter for induction motor application from the previous researches. Literature review is crucial for every thesis not only to support the proposed title but also to for guidelines and references.

Chapter 3 covers on the methodology that been used to design the project. It also covers about the scope of the project where every step on how to approach the solutions to solve the stated problems. This chapter also focuses on the basic design of matrix converter and common converter besides the space vector modulation technique in order to complete the project. The methodology of the project is summarized in the flow chart.

Chapter 4 explains details about the overview of the project by using MATLAB Simulink. The output waveform of the experimental results of the matrix converter will be discussed. The performance of the induction motor from matrix converter and common converter is compared. Besides, the performance of the induction motor by using different source and the comparison of matrix converter by using different load also will be analyzed before doing the comparison of the matrix converter and common converter. In this section, all the results will be explained and discuss briefly.

Chapter 5 contains the conclusion from the overall project. Future recommendations also stated in order to improve this project in the future undertakings.

CHAPTER 2

LITERATURE REVIEW

2.1 Previous Research

The research of the project is important for guidelines and references to obtain the results. The research is covered detail on the matrix converter and the implementation of matrix converter for induction motor application.

2.1.1 Matrix Converter-Theory and Simulation [6]

The theory of three-phase AC/AC converters, known also through their modem name, the matrix converter is presented. Analysis of the three-phase converter loaded by a passive R, L load and by an induction motor follows. The analysis was performed by means of the software package "Simulink", a dynamic system simulation tool. This simulation environment was found suited for straight forward modeling and simulation of the electronic converter and the electric drive. The switching angles needed to control the electronic converter are calculated within the same environment by means of "MATLAB".

2.1.2 MATLAB/Simulink Implementation for Reducing the Motor Derating and Torque Pulsation of Induction Motor using Matrix Converter [7]

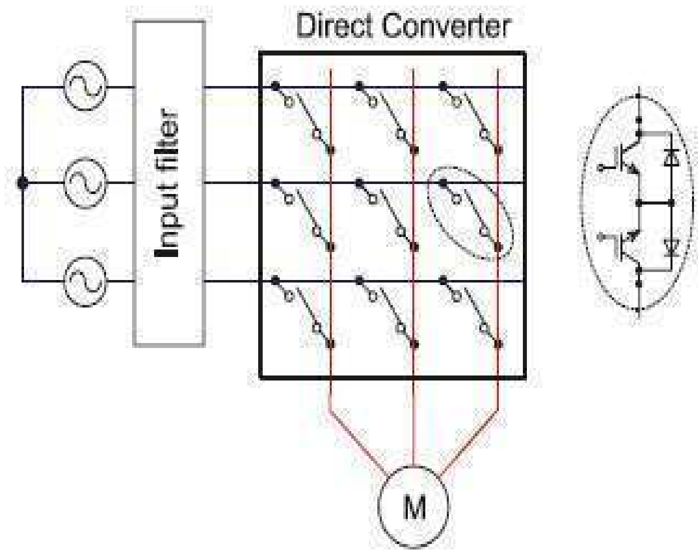
The output voltages of the variable voltage and variable frequency voltage sources employing voltage source inverter is non sinusoidal. The output current of a variable frequency current source using current source inverter is also non sinusoidal. When the induction motor is fed by using these inverters odd harmonics will be present in the input supply, because of these inverters output voltage is non sinusoidal. This harmonics do not contribute the output power of the motor, they produce additional losses in the machine. This harmonic loss reduces the efficiency and cause derating of the motor. These limitations can be overcome by using matrix converter because of its unique feature is pure sinusoidal as output. The matrix converter is superior to inverter drives because of its regeneration ability and four-quadrant operation. Therefore it meets the stringent energy efficiency and power quality**.**

2.1.3 Simulation on Matrix Converter Fed Induction Motor DTC Drive System [8]

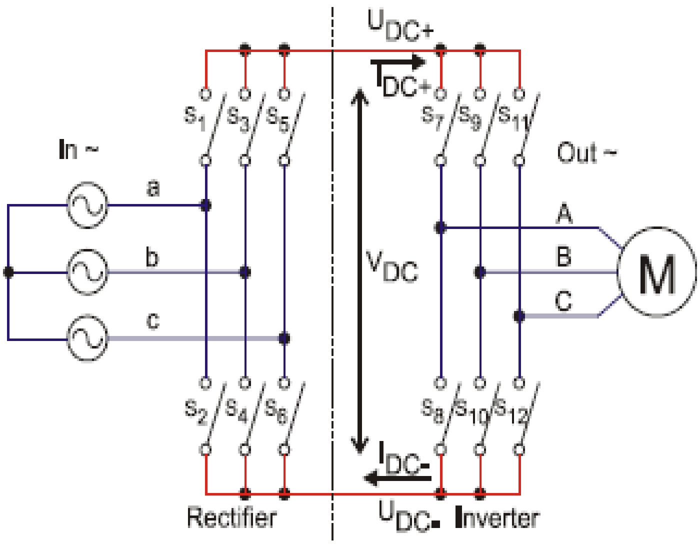
The Matrix Converter (MC) has received considerable attention in recent years because of its appealing operational characters. Namely, sinusoidal input and output waveforms, bidirectional power flow, controllable input power factor, absence of energy storage reactive elements, and compact size. Though MC has the lower voltage transfer ratio, the disadvantage can be eliminated by design the Matrix Converter Motor (MCM) to reach the nominal flux at the maximum voltage ration of MC to integrate the frequency converter, the induction motor into a single unit. The direct torque control (DTC) for induction motors has been presented to voltage source inverter (VSI). In this paper, Matrix Converter fed motor system is studied, which integrates MC and motor into a single unit, solves the problem of low voltage transfer ratio of MC, reduces the cost and increases the overall efficiency and the equipment ability. The mathematics model of Matrix Converter fed motor drive system in the static plane based on the fictitious link concept is given. A novel control method for Matrix Converter fed motor drive system is proposed which allows, under the unity input power factor and the required voltage vectors to implement the direct torque control (DTC). The simulations show that this way combines the advantages of Matrix Converter with the advantage of DTC.

2.1.4 Indirect Matrix Converter Based on Investigations of Field-oriented Control for Induction Motor [9]

The rectifier and inverter are used in vector control of induction motor. The most shortcomings are that exist a big capacitor and energy pass only from power sources to load. This paper details a novel matrix converter—indirect matrix converter. It is used in vector controlling research of induction motor and displaced for conventional inverter to supply power for induction motor. Because switches are bidirectional in the rectifier, it can realize bidirectional pass of the energy and decrease pollution of harmonic wave. Meanwhile bidirectional switches can act in zero current. Four step commutations do not be needed so that it decreases complexity of control process. In addition, indirect matrix converter which compared with direct matrix converter has the same advantages but it is simpler in controlling strategy. Matrix converter has a good prospect in frequency control system because it does not need filter capacitor and it has bidirectional energy pass, small harmonic pollution and a good controllability. Matrix converter can be divided direct matrix converter (DMC) and indirect matrix converter (IMC) in the structure. The main topology of DMC and IMC and the structure of bidirectional switches are shown in Figure 2.1.



(a) Direct Matrix Converter



(b) Indirect virtual DC-link matrix converter

Figure 2.1 Direct matrix converter (DMC) and indirect matrix converter (IMC) [9]

2.1.5 Modeling and Simulation of Matrix Converter Using Space Vector Control Algorithm [10]

MATLAB/Simulink modeling and simulation of the three - phase matrix converter feeding a passive RL load have been performed using the space vector control algorithm. The model has been designed to support real time implementation with a simulation supported digital signal processor control board. The algorithm uses a simpler method than the other control algorithms to control the input power factor. In addition, it has lower switching loses and easy implementation. Simulation has been implemented for various output frequencies at unity input power factor. The simulation results of input current, output voltage and current waveforms are presented with their spectra.

2.1.6 Space Vector Modulated Three-Phase to Three-Phase Matrix Converter with Input Power Factor Correction [11]

Analysis, design, and implementation of the space vector modulated three-phase to three-phase matrix converter with input power factor correction are presented. The majority of published research results on the matrix converter control are given an overview, and the one, which employs simultaneous output-voltage and input-current space vector modulation, is systematically reviewed. The modulation algorithm is theoretically derived from the desired average transfer functions, using the indirect transfer function approach. The algorithm is verified through implementation of a 2-kVA experimental matrix converter driving a standard induction motor as a load. The switching frequency is 20 kHz. The modulator is implemented with a digital signal processor. The resultant output voltages and input currents are sinusoidal, practically without low-frequency harmonics. The input power factor is above 0.99 in the whole operating range.

2.1.7 Simulation and Modeling of Vector Controlled 3-Phase Matrix Converter Induction Motor Drive [12]

A vector controlled matrix converter-fed induction motor drive has been simulated using the MATLAB/Simulink package program. The feed forward indirect field orientation technique has been implemented in the drive system. A modulation algorithm giving a unity power factor at the input is used to generate switching signals of the devices in the matrix converter power circuit. Simulation results obtained for various load conditions at 2 kHz switching frequency are presented. The results illustrate the feasibility of the high performance matrix converter drive system.

2.1.8 Comparison of Modulation Techniques for Matrix Converter [13]

Matrix Converters can directly convert an ac power supply of fixed voltage into an ac voltage of variable amplitude and frequency. Matrix Converter is a single stage converter. The matrix converters can contribute to the realization of low volume, sinusoidal input current, bidirectional power flow and lack of bulky reactive elements. All the reasons lead to the development of matrix converter. Based on the control techniques used in the matrix converter, the performance varies. So this paper analyses the performance of matrix converter with three different modulation techniques such as PWM, SVPWM and SVM. The basic principle and switching sequence of these modulation techniques are presented in this paper. The output voltage, output current waveforms, voltage transfer ratio and THD spectrum of switching waveforms connected to RL load are analyzed by using MATLAB/Simulink software. The simulated result is analyzed and shows that the THD is better for SVM technique.

2.1.9 Matrix Converter Output Voltage Control with Overmodulation [14]

The matrix converter is a very popular topic today. Many papers about matrix converter deal with modulation strategies and control algorithms. In this paper, special attention is paid to the indirect space vector modulation, which is based on the virtual dc link concept. The entire converter is interpreted as a series connection of two matrix converters (rectifying and inverting virtual matrix converter). Thanks to this insight, it is possible to compose the modulation strategy for the entire matrix converter from the inverter and rectifier part modulations. The main goal is to achieve the maximal possible output voltage by overmodulation employment. The overmodulation method based on the indirect vector modulation is presented. By means of the square wave modulation the voltage transfer ratio can be increased from 0.866 up to 0.955. Moreover, together with control of the current modulation index, a linear and continuous adjustment of the output voltage can be achieved.

2.1.10 New Modulation Method for Matrix Converter [15]

This paper presents a new modulation method for matrix converters based on the indirect modulation model. During the switching period, the proposed modulation method uses a combination of only one active vector and a zero vector in the inversion stage to achieve minimum flux error, whereas in the rectification stage, a single current vector is selected according to the angle error of the input current vector. This reduces the number of switching states in the switching period, which improves the accuracy of generating the reference output voltage vector, especially in the low-modulation-index range. In addition, closed-loop control of the input current vector is achieved. The input currents are not measured but are estimated by applying inverse transformation to the measured output currents using the matrix associated with the chosen active switching state.

2.1.11 Implementation of Space Vector Modulated 3 Phase to 3 Phase Matrix Converter Fed Induction Motor [16]

Matrix Converters (MC) are compact voltage source converters capable of providing variable voltage and variable frequency at the output. Compared with traditional topologies the MC does not require an intermediate dc link and provides sinusoidal output waveform with minimum higher order harmonics. To yield higher rms O/P voltage, it is proposed to use Space Vector Modulation (SVM) algorithm for the voltage control of converter. The proposed modulation technique is derived from Indirect Transfer Approach (ITF).The time arc information of the supply voltages and the desired output frequency are used to identify the sectors of the SVM technique, to generate the pulses of desired duration. The digital implementation of Space Vector Modulated (SVM) switching scheme for a three phase to three phase MC is done through Digital Signal Processor (DSP) TMS 320C 2407A. To verify the validity of the algorithm a 15 KVA MC is built. SVM pulses are generated and given to the appropriate MC switches through a decoder circuit and the experimental results are presented. The proposed modulation algorithm can be used for v/f control of Induction Motor.

2.1.12 Application of the Matrix Converter to Induction Motor Drives [17]

This paper presents the technical issues of applying the matrix converter to field oriented induction motor drives. A newly developed matrix converter switching sequence combination is described in detail, the purpose of which is to minimize harmonic components of the matrix converter input currents. It is demonstrated that small size capacitors work efficiently as input filters. Matrix converter losses are calculated with a developed power converter loss calculation model. The calculation results indicate that the matrix converter realizes good converter efficiency.

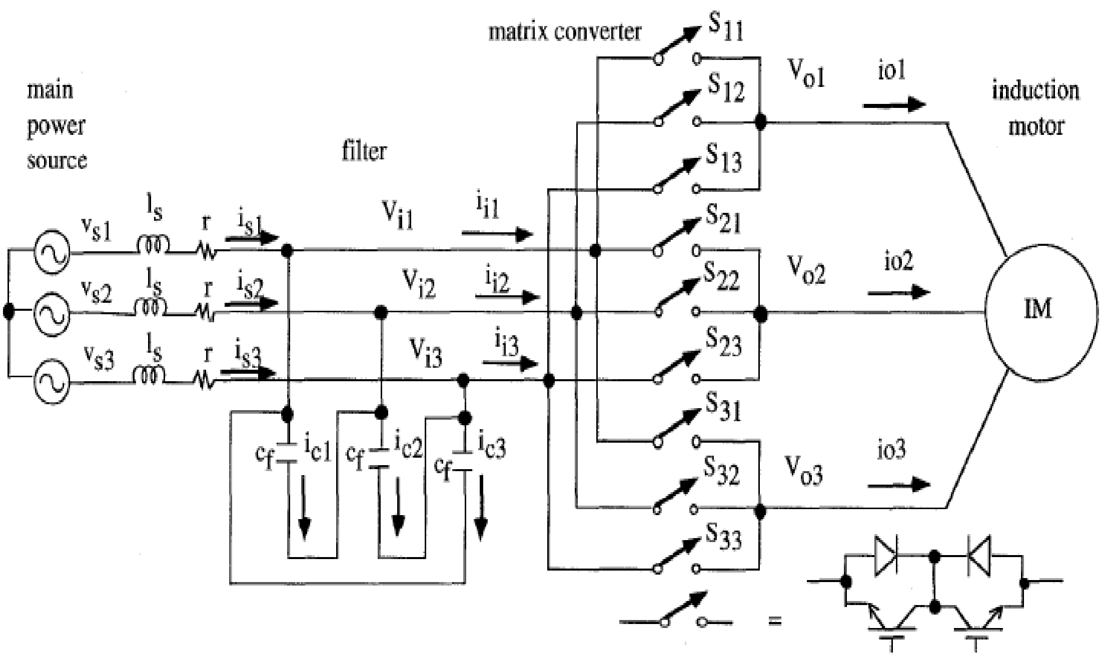


Figure 2.2 Three Phase AC to AC Matrix Converter [17]

2.1.13 Basic Characteristics of Matrix Converter Controlled by Space Vector Modulation Considering Input Voltage Conditions [18]

Matrix-converter is three phase AC to AC direct converter which is absence of dc-link capacitors for energy storage by using hi-directional switches. Like a conventional inverter, matrix-converter can control input waveform and power factor and can revive the electric power of load. Therefore, matrix-converter is superior to conventional Pulse Width Modulation (PWM) inverter. The theoretical indirect modulation simulation result considering input voltage conditions will be obtained. The simulation result in the state of input voltage unbalanced will be performed as this simulation performed only three phase balanced state.

2.1.14 Matrix Converters: A Technology Review [19]

The matrix converter is an array of controlled semiconductor switches that connects directly the three-phase source to the three-phase load. This converter has several attractive features that have been investigated in the last two decades. In the last few years, an increase in research work has been observed, bringing this topology closer to the industrial application. This paper presents the state-of-the-art view in the development of this converter, starting with a brief historical review. An important part of the paper is dedicated to a discussion of the most important modulation and control strategies developed recently. Special attention is given to present modern methods developed to solve the commutation problem. Some new arrays of power bidirectional switches integrated in a single module are also presented. Finally, this paper includes some practical issues related to the practical application of this technology, like overvoltage protection, use of filters, and ride-through capability.

2.2 This Project

By referring to the previous researches, the project comes out with the implementation of the induction motor as a load connected to the matrix converter which control speed and torque of the motor. The performance of the induction motor will be compared with the performance of the induction motor by using common converter. The induction motor is installed as the load and the input filters are installed in order to reduce harmonics. The space vector modulation will be used as the strategy method of the matrix converter.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In order to get the result of implementing matrix converter for induction motor application and the performance of the induction motor from matrix converter and common converter, there are some methodologies that need to be followed. This chapter discussed the methodology approach in simulating the matrix converter for induction motor application using MATLAB software.

3.2 Analysis Approach

There are several steps that have to follow in order to complete the project. First of all, the project starts by finding the suitable literature review relates with the MC as references. Then the matrix converter (MC) by using space vector modulation as the control strategy will be applied to the DTC induction motor load. Power circuit of the MC has been modeled using Power Electronics Toolbox in MATLAB Simulink. In the model, the switches that will be turned on should be determined in one switching period to obtain the output phases.

By using the same load which is DTC induction motor, the performance of the motor will be analyzed according to the source through MC and from the direct source. The MC also will be connected to the resistance load and the performance of the MC according to the different load will be compared. After implementing the MC, the common converter (AC/DC/AC) will be designed in the MATLAB simulation software. This converter uses rectifier to convert AC to DC and inverter to convert DC to AC. It is the basic design for the project before go detail on the performance comparison of the induction motor. The same induction motor like MC will be used as the load and the performance of the induction motor will be analyzed compare to the performance of the induction motor in MC.

3.3 Common Converter

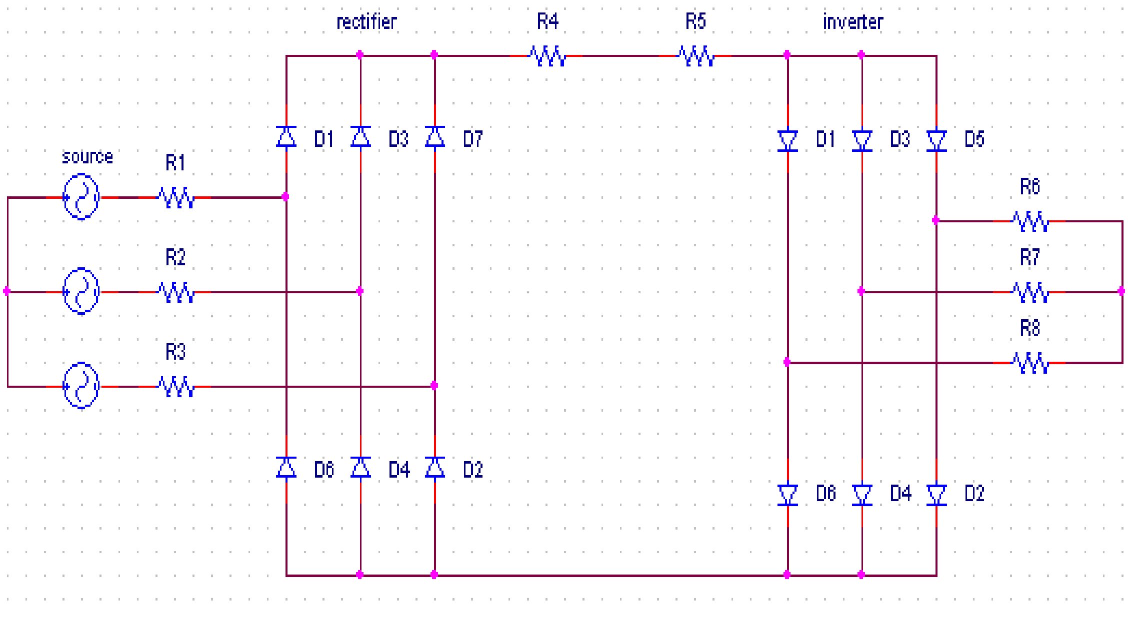


Figure 3.1 Basic design of common converter

The common converter (CC) circuit is designed using two power switches from the SimPowerSyetem library. It is called universal bridge and it consist two parts of circuit. The first part is rectifier circuit which is an electrical device that converts alternating current (AC) to direct current (DC), a process known as rectification. This almost always involves the use of some device that only allows one-way flow of electrons, a diode.

The three phase rectifier is commonly used in high industrial applications up to 120kW level, where a two-quadrant operation is required and it is shown in Figure 3.1. It can operate with or without a transformer. The diodes are numbered in order of conduction sequences and each one conducts for 120^o. The conduction sequence for diodes is D_1-D_2, D_3-D_2, D_3-D_4, D_5-D_6, and D_1-D_6. The pair of diodes which are connected between that pair of supply lines having the highest amount of instantaneous line-to line voltage will conduct.

The three phase voltage source is balanced and has phase sequence a-b-c. The source and the diodes are assumed to be ideal in the initial analysis of the circuit. Only one diode in the top half of the bridge conducts at one time (D_1, D_3 or D_5). For bottom group, diode with the its cathode at the lowest potential will conduct. The other two will be reversed. Diode with its anode at the highest potential will conduct at one time. The other two will be reversed. The diode that is conducting will have its anode connected to the phase voltage which is the highest at that instant. D_1 and D_4 cannot conduct at the same time. Similarly, D_3 and D_6 cannot conduct simultaneously, nor can D_5 and D_2.

The second part of the CM is inverter circuit, converts DC input voltage to a symmetric AC output voltage by which both magnitude and frequency can be controlled. As shown in Figure 3.1, the three phase inverter can be connected in parallel. The gating signal of single phase inverter should be advanced or delayed by 120^o with respect to each other to obtain three phase balanced voltages.

3.4 Matrix Converter

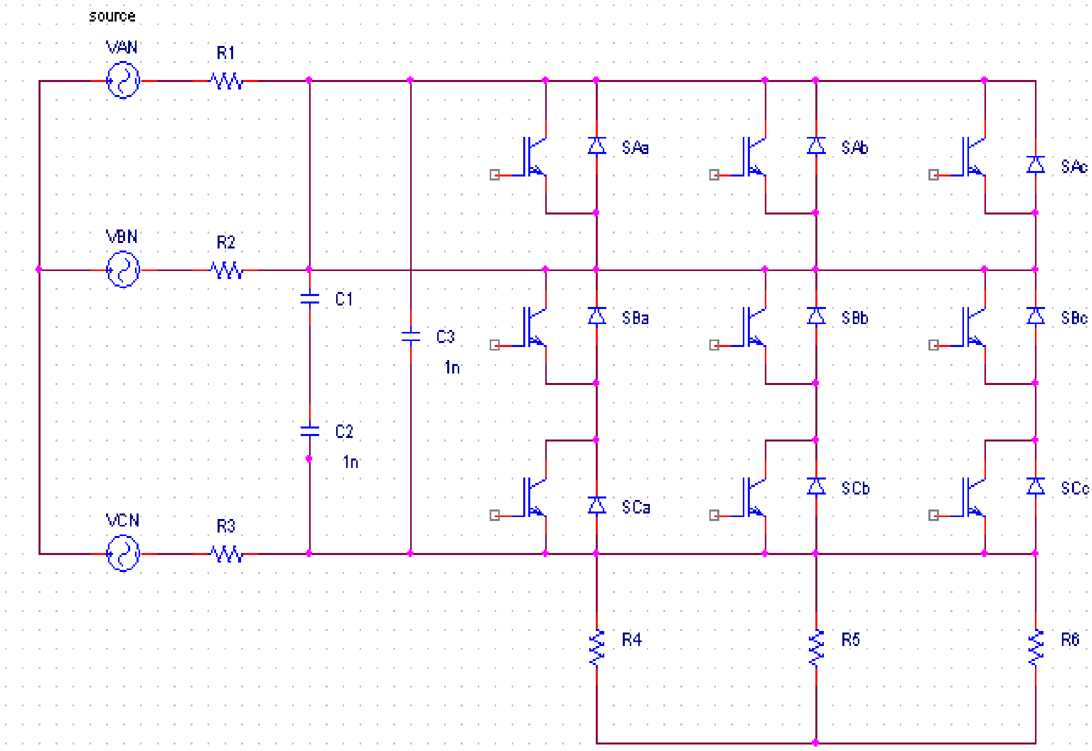


Figure 3.2 Basic design of matrix converter

By using MATLAB Simulink, matrix converter is designed by using space vector modulation technique. Figure 3.2 is designed as the basic of the matrix converter. The system consists of a three-phase matrix converter constructed from 9 back-to-back IGBT switches. Figure 3.3 shows a block connection of matrix converter in switching 1 (S_{Aa}).

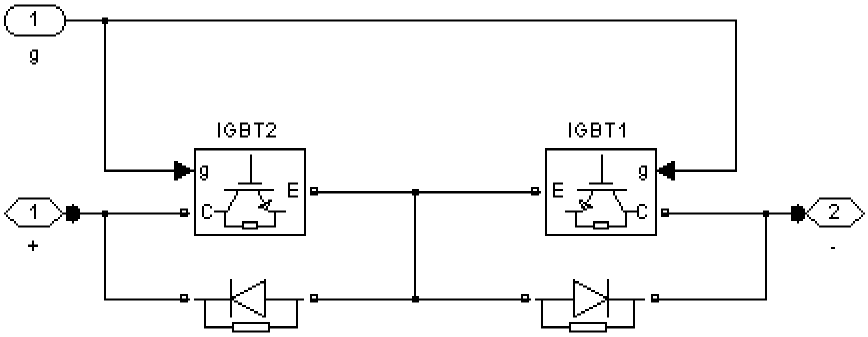


Figure 3.3 Matrix converter connections

It is an alternative to the double-sided PWM voltage source rectifier inverter. The 9 bidirectional switches are so arranged that any of three input phases could be connected to any output phase through the switching matrix symbol. Thus, the voltage at any input terminal may be made to appear at any output terminal or terminals whereas the current in any phase of the load may be drawn from any phase or phases of the input supply.

The term matrix is due to the fact that it uses exactly one switch for each for the possible connections between the input and the output. The switches should be controlled in such way that any time, one and only one of the three switches connected to an output phase be closed to prevent short circuiting of the supply lines or interrupting the load current flow in an inductive load.

The MC is connected any input phase (A, B, C) to any output phase (a, b, c) at any instant. When connected, the voltages V_{an}, $V_{bn,}$ V_{cn} at the output terminals are related to the input voltages $V_{AN,}$ V_{BN}, V_{CN} as:

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \begin{bmatrix} S_{Aa} & S_{Ba} & S_{Ca} \\ S_{Ab} & S_{Bb} & S_{Cb} \\ S_{Ac} & S_{Bc} & S_{Cc} \end{bmatrix} \begin{bmatrix} V_{AN} \\ V_{BN} \\ V_{CN} \end{bmatrix} \quad (1)$$

S_{Aa} through S_{Cc} are the switching variables of the corresponding switches. For a balanced linear Y-connected load at the output terminals, the input phase currents are related to the output phase currents by

$$\begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} = \begin{bmatrix} S_{Aa} & S_{Ab} & S_{Ac} \\ S_{Ba} & S_{Bb} & S_{Bc} \\ S_{Ca} & S_{Cb} & S_{Cc} \end{bmatrix}^{T} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (2)$$

The matrix of the switching variables in equation 1 is a transpose of the respective matrix in equation 2. The MC should be controlled using a specific and appropriately timed sequence of the values of the switching variables, which result in balanced output voltages having the desired frequency and amplitude, whereas the input currents are balanced and in phase with respect to the input voltages.

However, the maximum peak to peak output voltage cannot be greater than the minimum voltage difference between two phases of the input. Regardless of the switching strategy, there is a physical limit on the achievable output voltage and the maximum voltage transfer ratio is 0.866.

3.5 Space Vector Modulation

The space vector modulation will base on the representation of the three phase input current and three phase output line voltages on the space vector plane. In MC, each output phase is connected to each input phase depending on the state of the switches. For safe switching in the MC, the input phases should never be short-circuited, and the owing to the presence of inductive load, the load currents should not be interrupted at any switching time.

The space vector modulation (SVM) is well known and established in conventional PWM inverters. Its application to matrix converters is conceptually the same, but is more complex. With a MC, the SVM can be applied to output voltage and input current control.

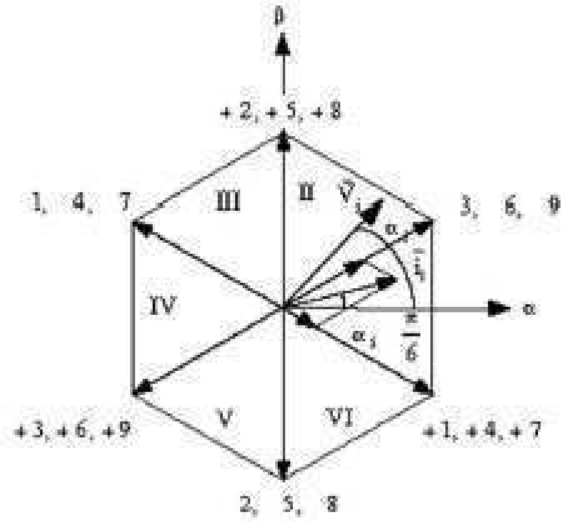
There are 27 different switching combinations for connecting output phases to input phases (refer Table 1 in Appendix). The table also shows which input and output phases are mutually connected for each allowed switching combination, as well as the resulting output line (phase-to-phase) voltages and input phase currents. These switching combinations can be analyzed in three groups with the following characteristics:

a) Group I: each output line will connect to a different input line. Output space vectors are constant in amplitude, rotating (in either direction) at the supply angular frequency [20].

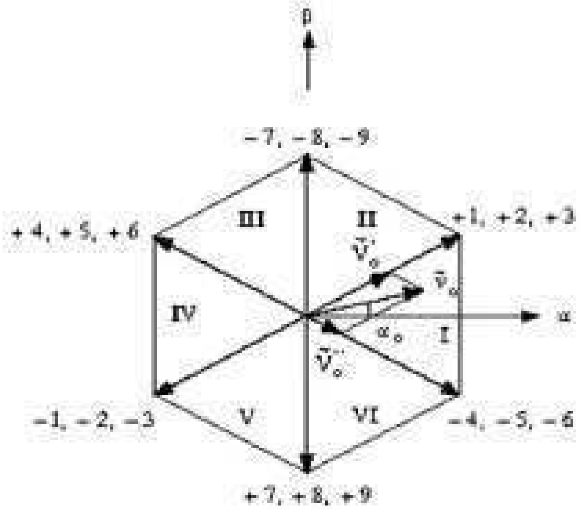
b) Group II: two output lines will connect to a common input line, the remaining output line will connect to one of the other input lines. Output space vectors have varying amplitude and fixed direction occupying one of six positions regularly spaced 60^{o} apart. The maximum length of these vectors is 2/ 3Venv where Venv is the instantaneous value of the rectified input voltage envelope [20].

c) Group III: all output lines will connect to a common input line. Output space vectors have zero amplitude (locate at the origin) [20].

Figure 3.4 shows the representation of the input current and output line voltage space vectors



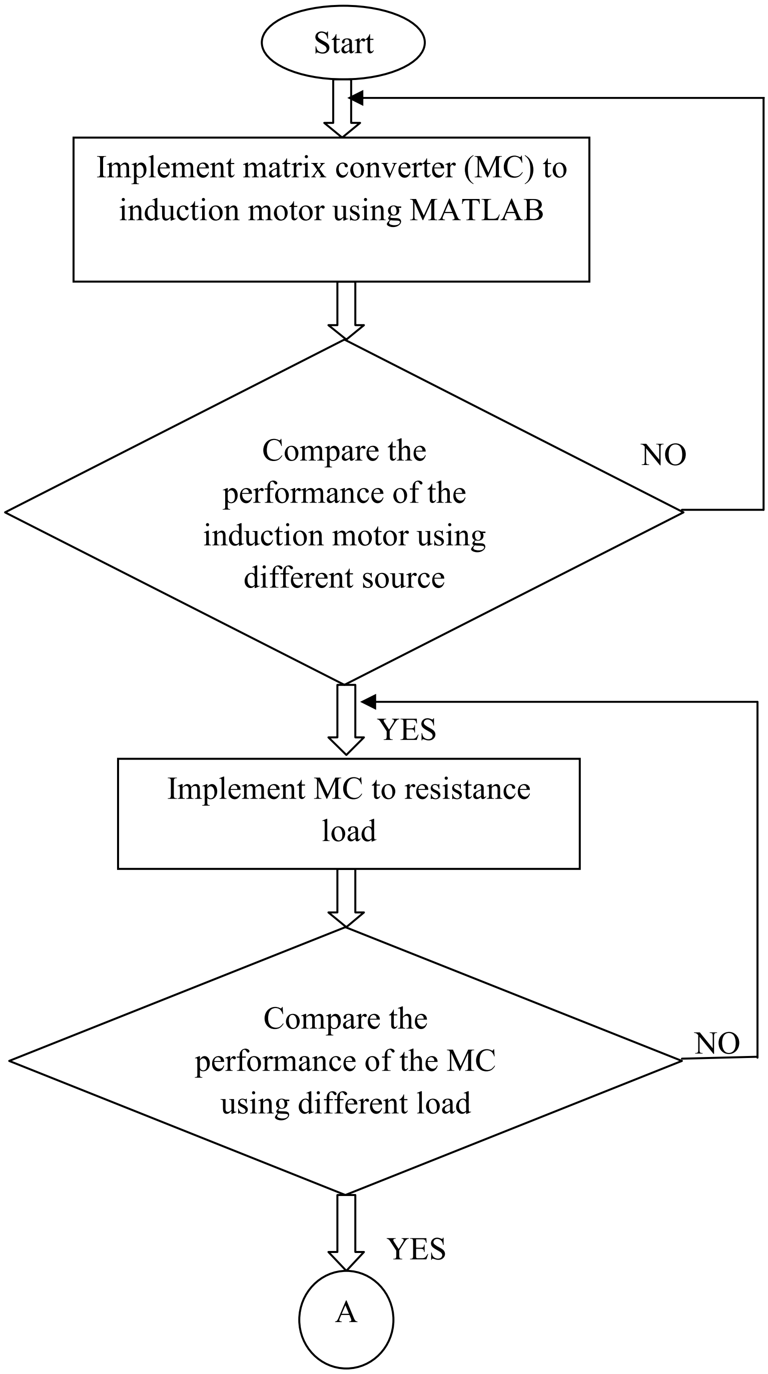
a) Input currents

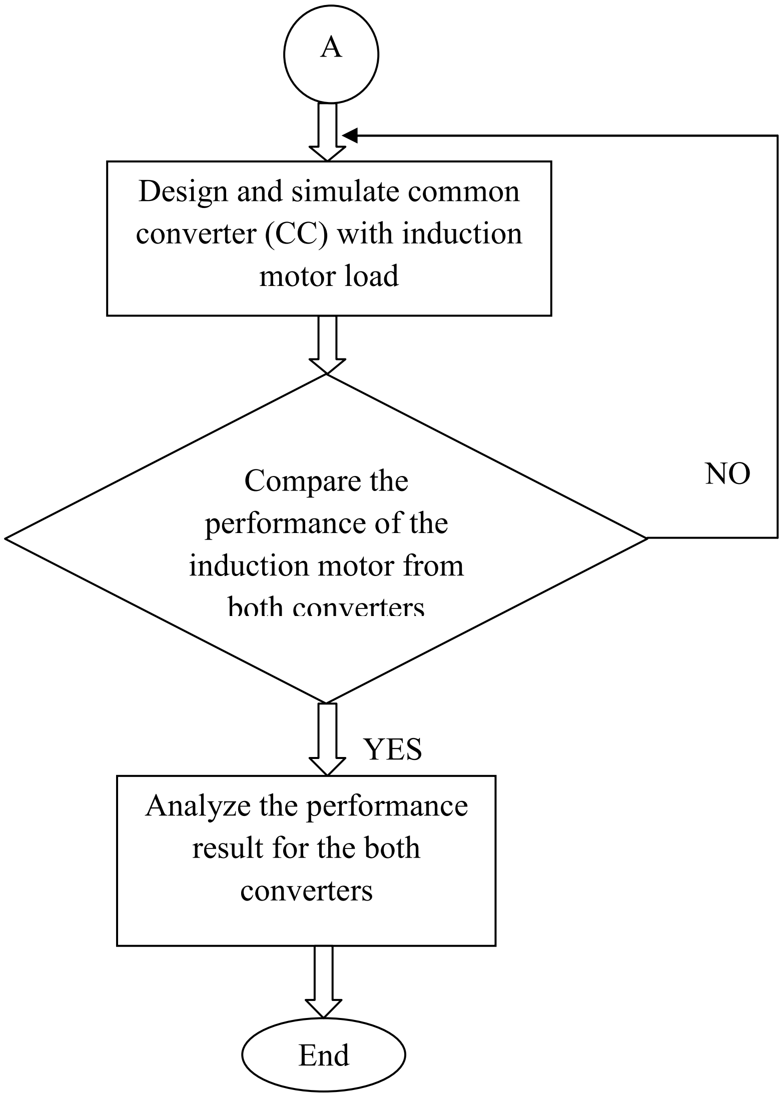


b) Output line voltage

Figure 3.4 Space vector representations [20]

3.6 Flow Chart




A
Design and simulate common converter (CC) with induction motor load
Compare the performance of the induction motor from both converters
NO
YES
Analyze the performance result for the both converters
End

CHAPTER 4

SIMULATION, RESULT AND DISSCUSSION

4.1 Introduction

This chapter explains the results obtained from the simulation done in MATLAB software. This is followed by analysis and discussion which is included the performance of the induction motor comparison between common converter (CC) and matrix converter (MC).

4.2 Simulation Result

The simulation result is divided in three sections. The first section is the comparison of MC by using different load which are resistance load and DTC induction motor load. This section will cover on the comparison of input source and output signal at the load. The next section is by using the same load which is DTC induction motor load, the comparison is analyzed according to the direct AC source and source through MC. As the result for all the comparisons are correct, the last section is done by comparing the performance result of DTC induction motor load by using CC and MC.

4.3 Figure of the Models

4.3.1 Matrix Converter with Resistance Load

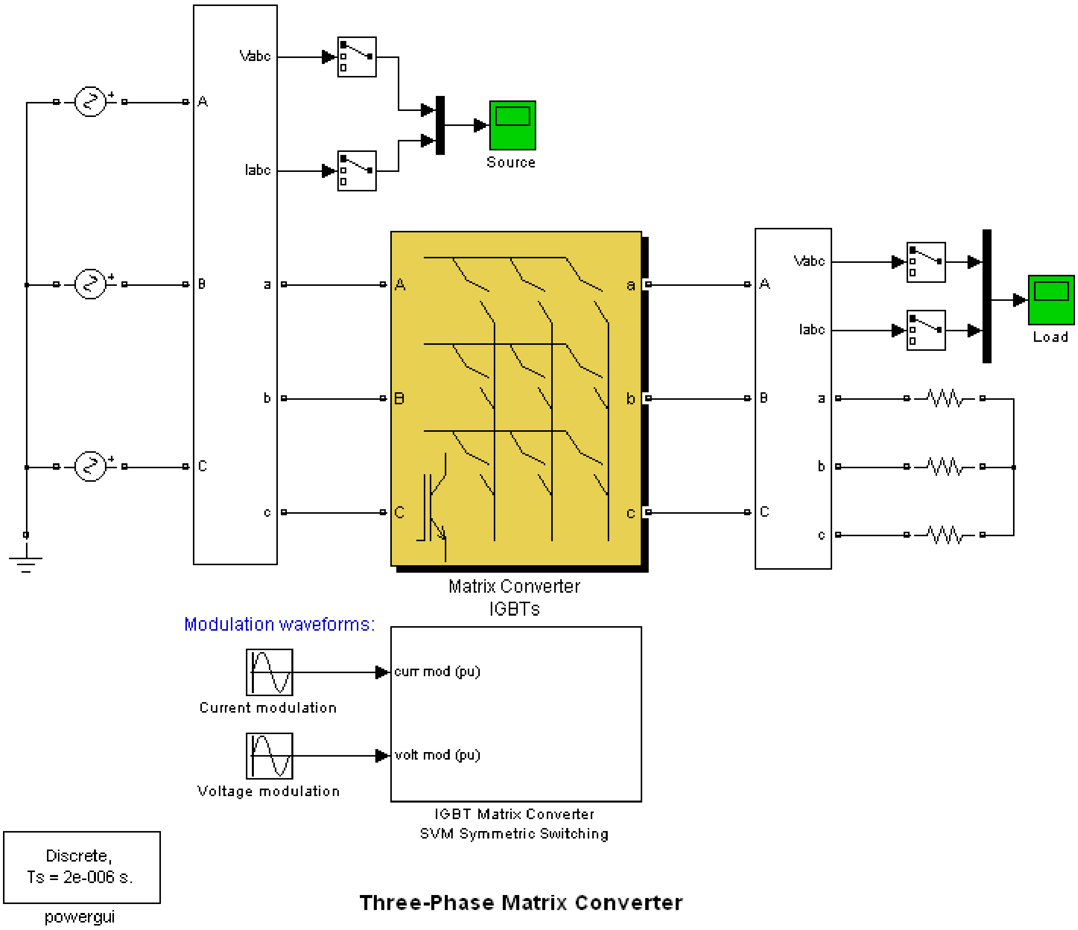


Figure 4.1 Matrix converters with resistance load

Figure 4.1 shows the three phase matrix converter with the supplied by an ideal 60 Hz three phase source and drives static resistive load. In the MC subsystem's, there has 9 back-to-back IGBT switches with the resistances load of 2 Ω are connected to the MC.

4.3.2 Matrix Converter with DTC Induction Motor

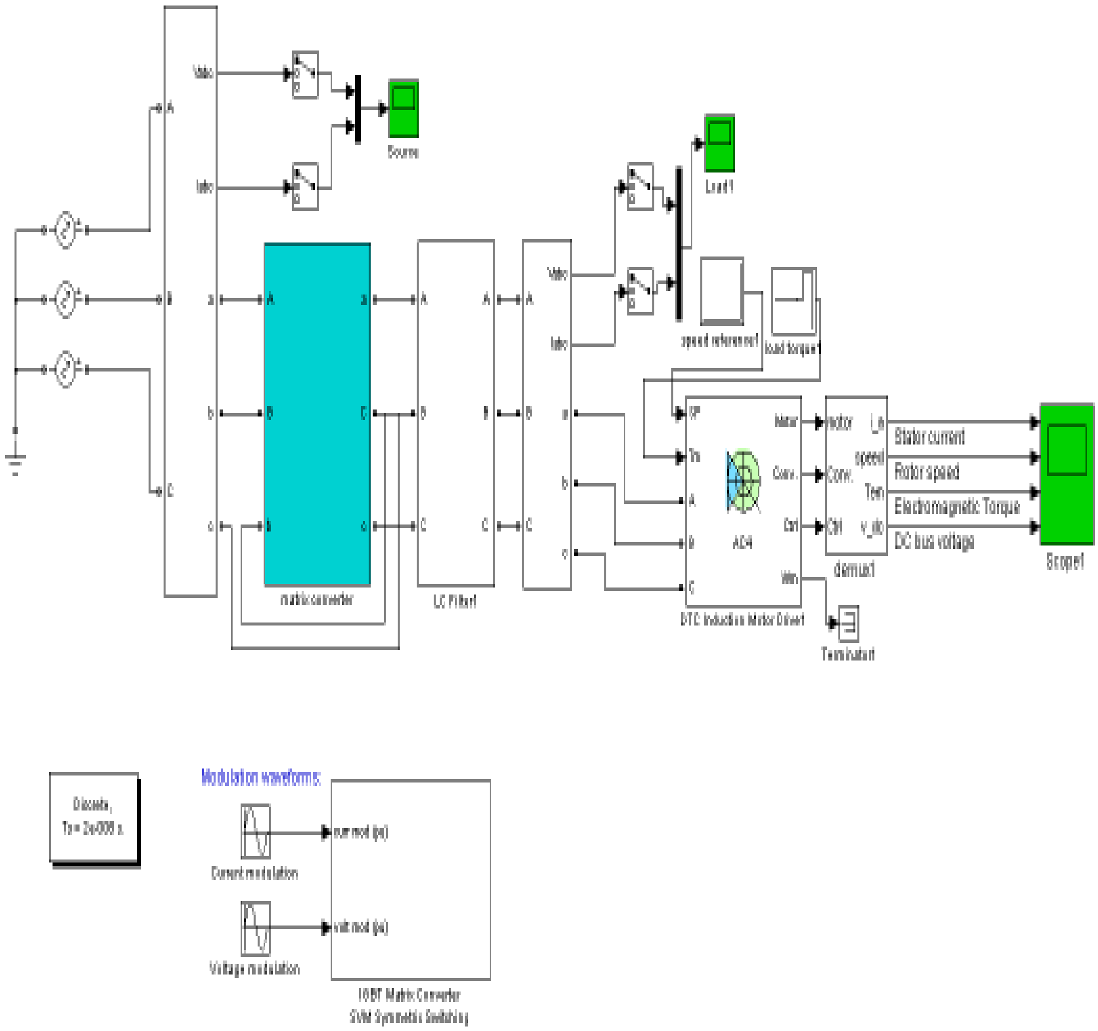


Figure 4.2 Matrix Converter with DTC Induction Motor

Figure 4.2 shows the implementation of the entire matrix converter to DTC induction motor drive system into a simulation program. It is described which includes a three phase AC to AC matrix converter, an induction motor, a filter and a power source. To illustrate how the MC for induction motor drive system works, a simulation is carried out with the input source line to line voltage of 415 V. The filter capacitance of 5 kF, filter inductance of 5 mH and the induction motor rating of 2238 VA is used for this simulation run.

Ideal sinusoidal AC voltage source with the peak amplitude 415 V and frequency of 60 Hz is used as the supply source. The project consists of three sources with the different phase which are 0 deg, 120 deg and -120 deg.

The switching modulation is based on an indirect space-vector modulation which considers the MC as a rectifier and inverter connected via a DC link with no energy storage. Indirect space-vector modulation allows direct control of input current and output voltage and hence allows the power factor of the source to be controlled. The switching algorithm utilizes a symmetric switching sequence.

In MC, the two diodes are used to provide the reverse voltage blocking capability. The diodes are also effectively placed in parallel with the IGBT by use of the short at the midpoint of the two branches. The total number of sets of an IGBT and a diode that are required to implement the matrix converter in the project is 18. The parameters of the IGBT's and diodes block are shown in the Table 2 and Table 3.

The MC is implemented to DTC induction motor as the load to control speed and torque. The load is same with the load of common converter which is the load voltage regulated at 460 $V_{rms.}$ The direct torque control (DTC) induction motor is driven with a braking chopper for a 200HP AC motor.

From the DTC induction motor drive, the output display of stator current, rotor speed, electromagnetic torque and DC bus voltage are recorded and the performance of the matrix converter is compared with the performance of the common converter.

Table 2: Parameter of IGBT's

Resistance, Ron (Ω)	0.001
Inductance, Lon (H)	0
Forward voltage (V)	1
Current 10% fall time (s)	1e-6
Current all time (s)	2e-6
Initial Current, Ic (A)	0
Snubber resistance, Rs	1e5
Snubber capacitance, Cs	inf

Table 3: Parameter of diodes

Resistance, Ron (Ω)	0.001
Inductance, Lon (H)	0
Current all time (s)	2e-6
Initial Current, Ic (A)	0
Snubber resistance, Rs	1e4
Snubber capacitance, Cs	250e-9

4.3.3 DTC Induction Motor from Direct Source

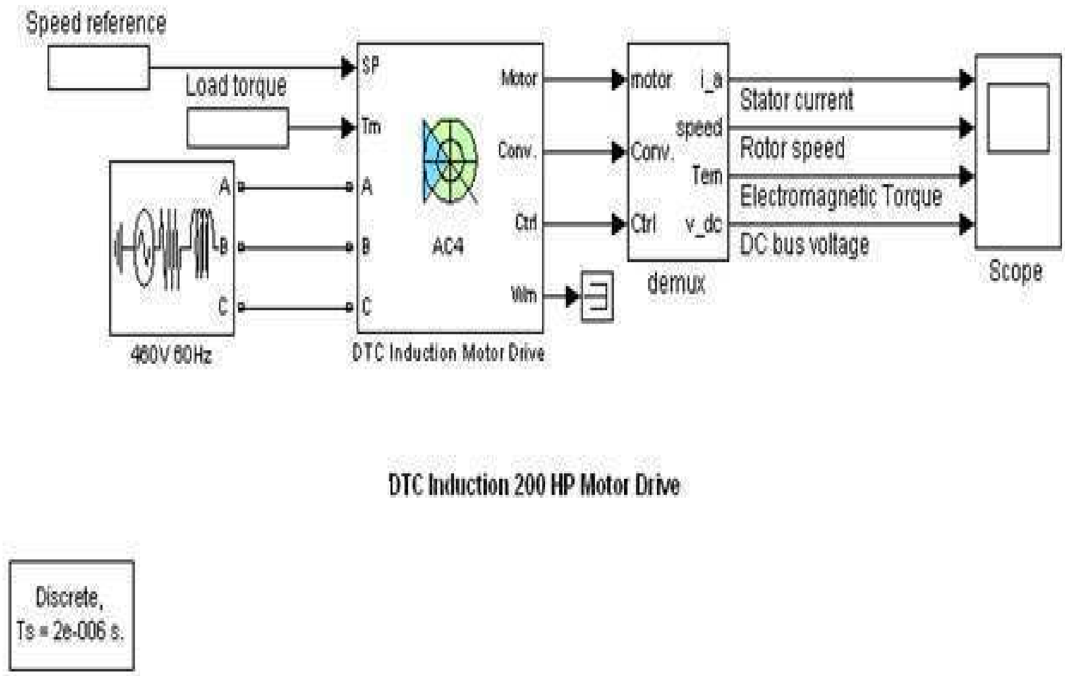


Figure 4.3 DTC Induction Motor from Direct Source

Figure 4.3 shows the designing of the DTC induction 200 HP motor drive is connected direct to the three phase source with the supplied voltage of 460 V and frequency of 60 Hz. The stator current, rotor speed, electromagnetic torque of the DTC induction motor is analyzed.

4.3.4 Common Converter Circuit with DTC Induction Motor

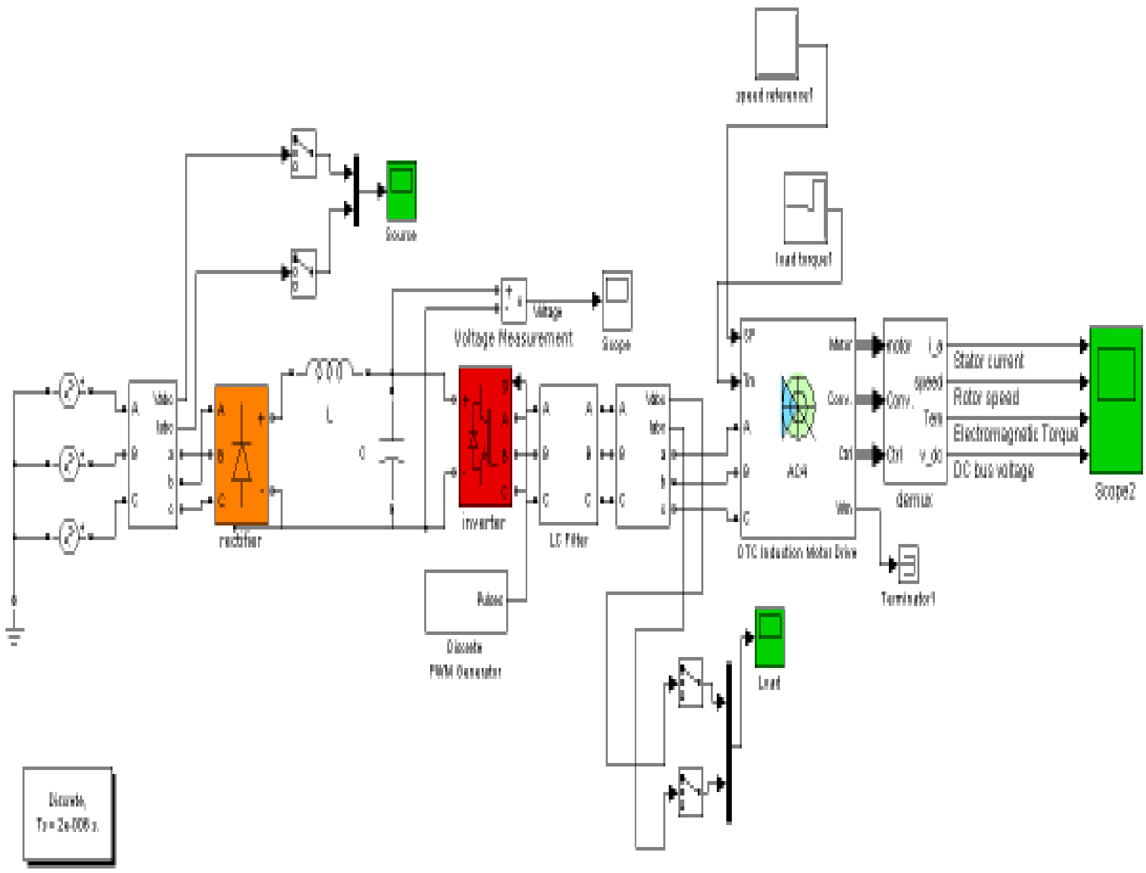


Figure 4.4 Common Converter Circuit with DTC Induction Motor

Figure 4.4 shows the common converter circuit with the connected of the DTC induction motor drive load. In common converter, it clearly shows the rectifier part (orange block) which convert AC to DC and inverter part (red block) which convert DC to AC.

In the rectifier block, snubber resistance, R_s is set as 100Ω and snubber capacitance, C_s is 0.1e-6F. To convert DC to AC, the inverter circuit is designed by using the selected power electronics device which is IGBT/diodes. In the inverter circuit, the snubber resistance, R_s and the snubber capacitance, C_s are set 5000Ω and infinity. The controller circuit system is designed to control speed and torque of induction motor.

A 60 Hz, voltage source feeds a 50 Hz, 2238 VA DTC induction motor load through an AC-DC-AC converter. The filtered DC voltage is applied to an IGBT two-level inverter generating 50 Hz. The IGBT inverter uses Pulse Width Modulation (PWM) at a 5 kHz carrier frequency. The circuit is discretized at a sample time of 2 us.

The high-level of DTC induction motor is built from six main blocks. The induction motor, the three-phase inverter, and the three-phase diode rectifier models are provided with the SimPowerSystems library. It models a direct torque control (DTC) induction motor drive with a braking chopper for a 200HP AC motor. The load voltage is regulated at 460 V_{rms}.

The induction motor is fed by a PWM voltage source inverter which is built using a Universal Bridge Block. The speed control loop uses a proportional-integral controller to produce the flux and torque references for the DTC block. The DTC block computes the motor torque and flux estimates and compares them to their respective reference. The comparators outputs are then used by an optimal switching table which generates the inverter switching pulses.

The simulation is started. After a transient period of approximately 50 ms, the system reaches a steady state. The harmonics generated by the inverter around multiples of 2 kHz are filtered by the LC filter. At the same time, from DTC induction motor, the motor stator current, the rotor speed, the electromagnetic torque and the DC bus voltage are displayed on the Scope. The speed set point and the torque set point are also shown.

The Discrete 3-Phase PWM Pulse Generator is available in the Extras/Discrete Control Blocks library. The voltage regulator has been built from blocks of the Extras/Measurements and Extras/ Discrete Control libraries.

4.4 Performance Comparison

4.4.1 Comparison of Different Load by using Matrix Converter

4.4.1.1 Input source

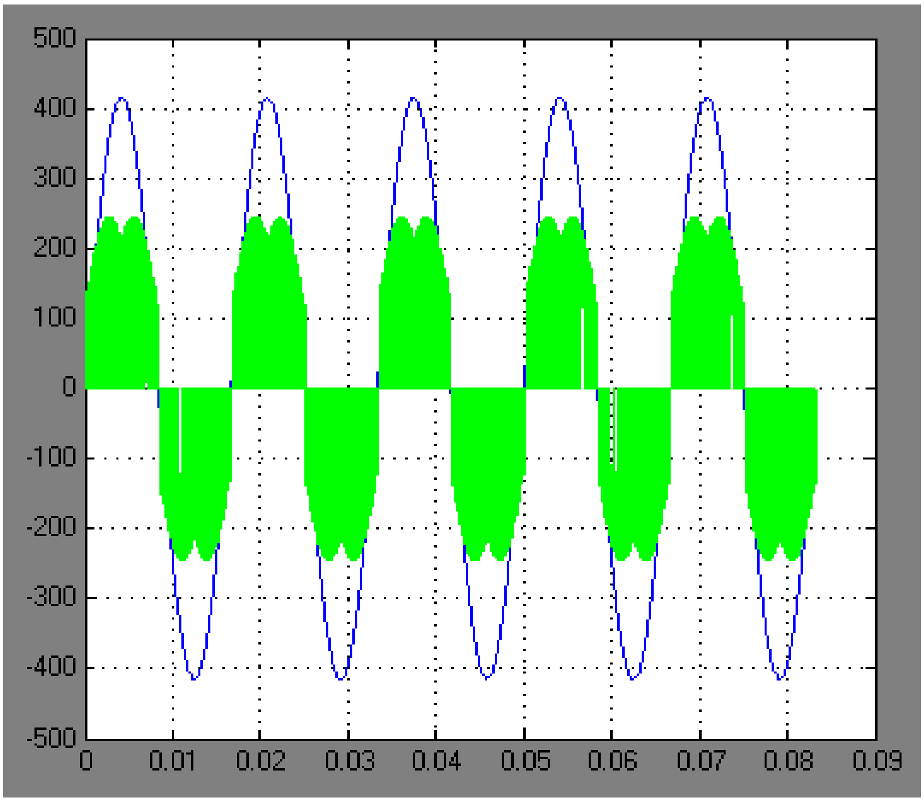


Figure 4.5 Input of Matrix Converter by using Resistance Load

Figure 4.5 shows the input and Figure 4.6 shows the output of the Matrix Converter by using resistance load. The result will be compared with the input of Matrix Converter for induction motor load.

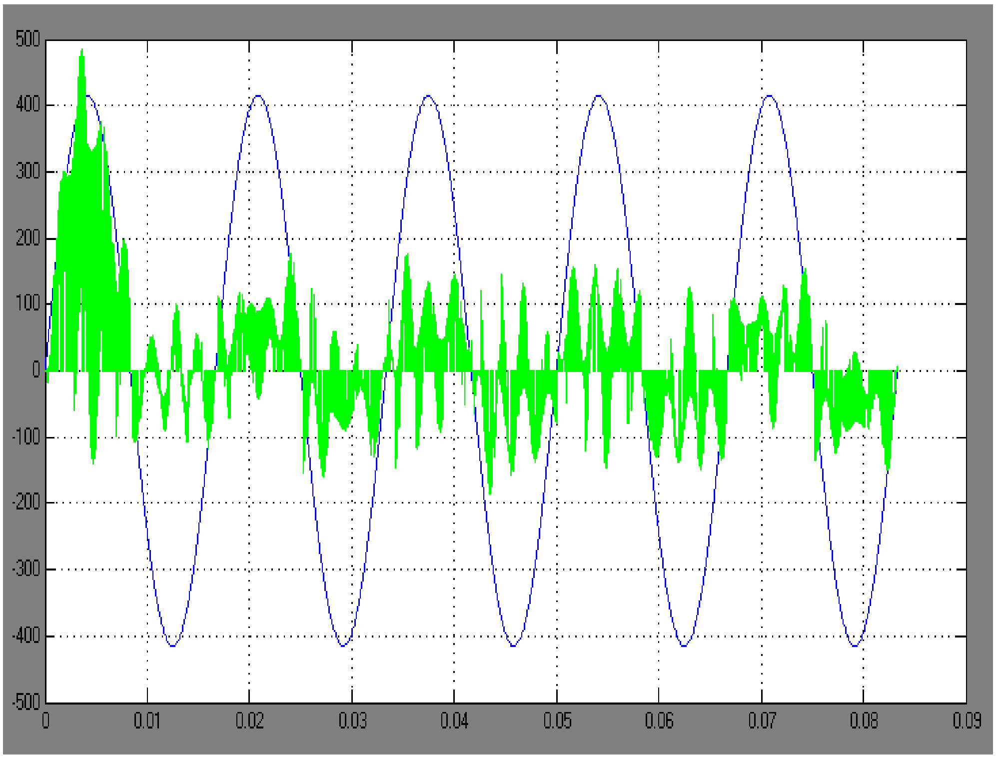


Figure 4.6 Input of Matrix converter by using Induction Motor Load

Simulation of the Matrix Converter has been performed using a passive resistance load with the input source as in Figure 4.1 and DTC induction motor load as in Figure 4.2. The input current and voltage waveform performance of the Matrix Converter is illustrated in Figure 4.5 and Figure 4.6 with the frequency of 60 Hz.

For Figure 4.5, the input voltage is smooth sinusoidal waveform with the amplitude of 415 V while the input current is sinusoidal waveform with the amplitude is about 220 A. Compare to the input source of Matrix Converter by using induction motor load as in Figure 4.6, the input voltage and input current is also AC signal. The average input voltage is approach 400 V and the input current waveform is about 120 A.

The input current during each half period of the input voltage is 120^o conduction. A single current vector per sector is used in the rectification stage so that the maximum line to line voltage is always used as a source to produce the active vectors in the inversion stage.

4.4.1.2 Output Signal at Load

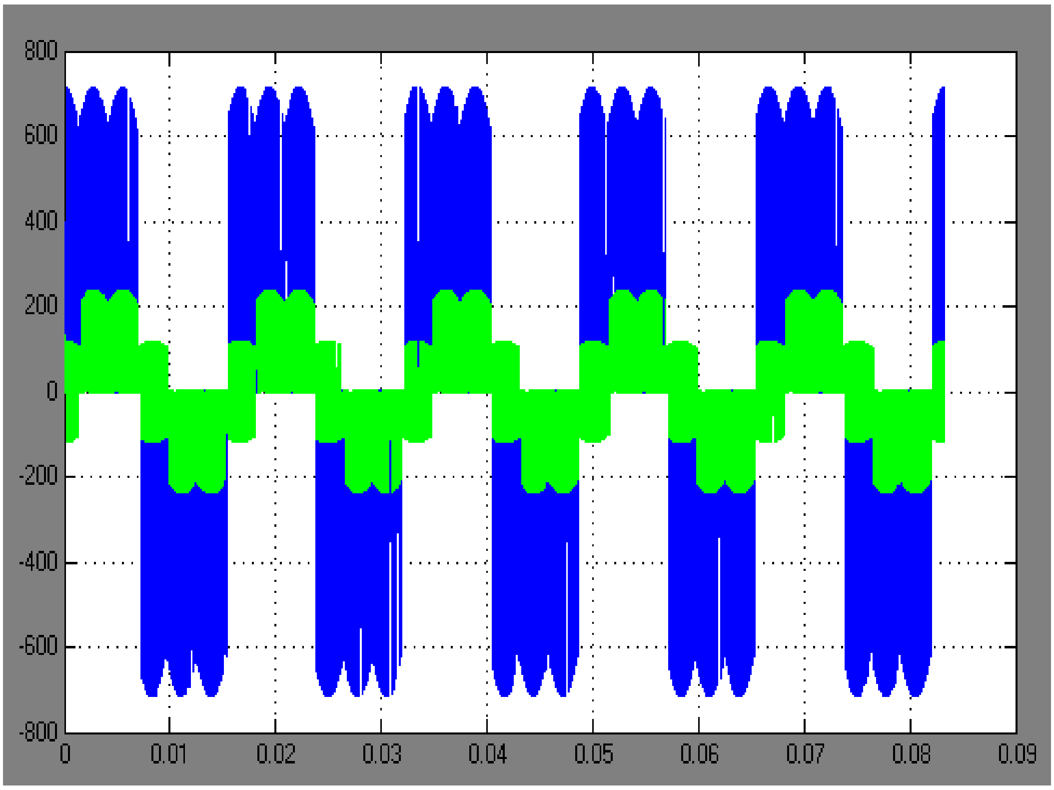


Figure 4.7 Output of Matrix Converter by using Resistance Load

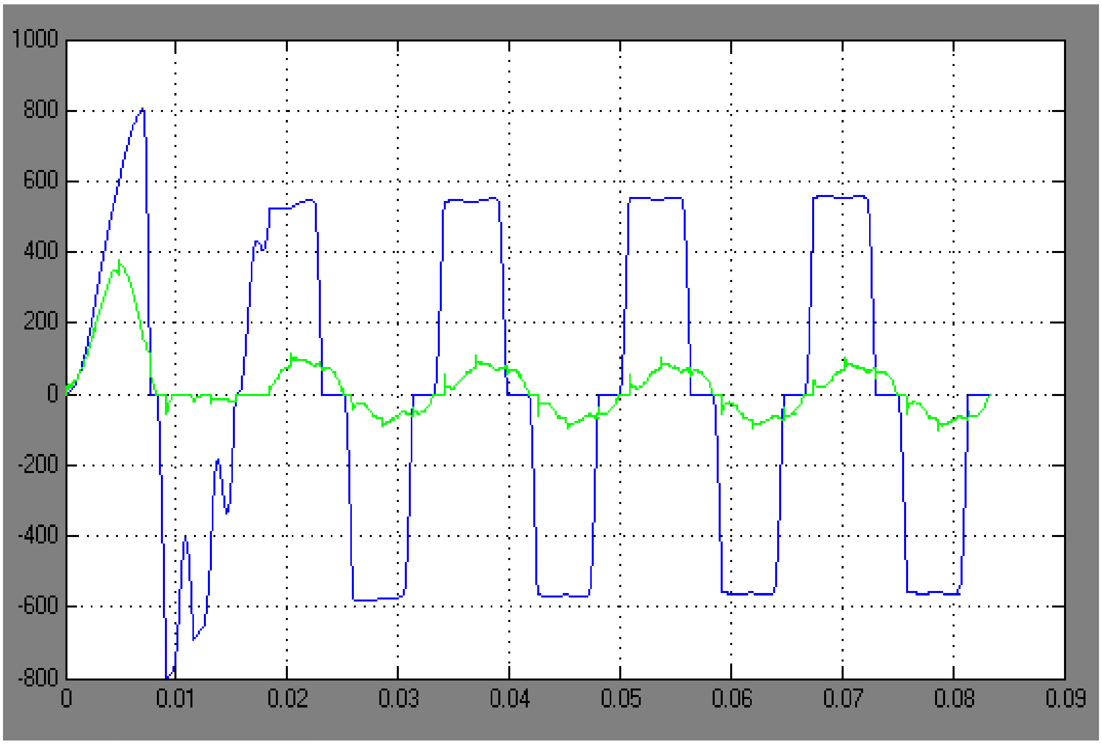


Figure 4.8 Output of Matrix Converter by using Induction Motor Load

From the output waveform voltage, the peak value of the load voltage of Matrix Converter by using resistance load as shown in Figure 4.7 is about 160 V and the current load is about 50 A. The result shows AC output voltage is not smooth and there has harmonics occurs for the output waveform of Matrix Converter by using induction motor load as in Figure 4.8 with the average amplitude of the voltage is approximately 600 V and the average current is 50 A.

The value is approximately same for both load but there is some harmonics occur in the DTC induction motor load implementation due to the non-linear load which cause the characteristic of the load is dynamic with the changing current and resulting complex waveform. The filtered waveform of the phase a matrix converter output voltage, where it is clearly shown that the matrix converter output voltage includes harmonic components at the output frequency in addition to the fundamental component even the capacitor at the matrix converter input function as a filter circuit has been used.

4.4.2 Comparison of Output Performance of DTC Induction Motor

4.4.2.1 Direct Source

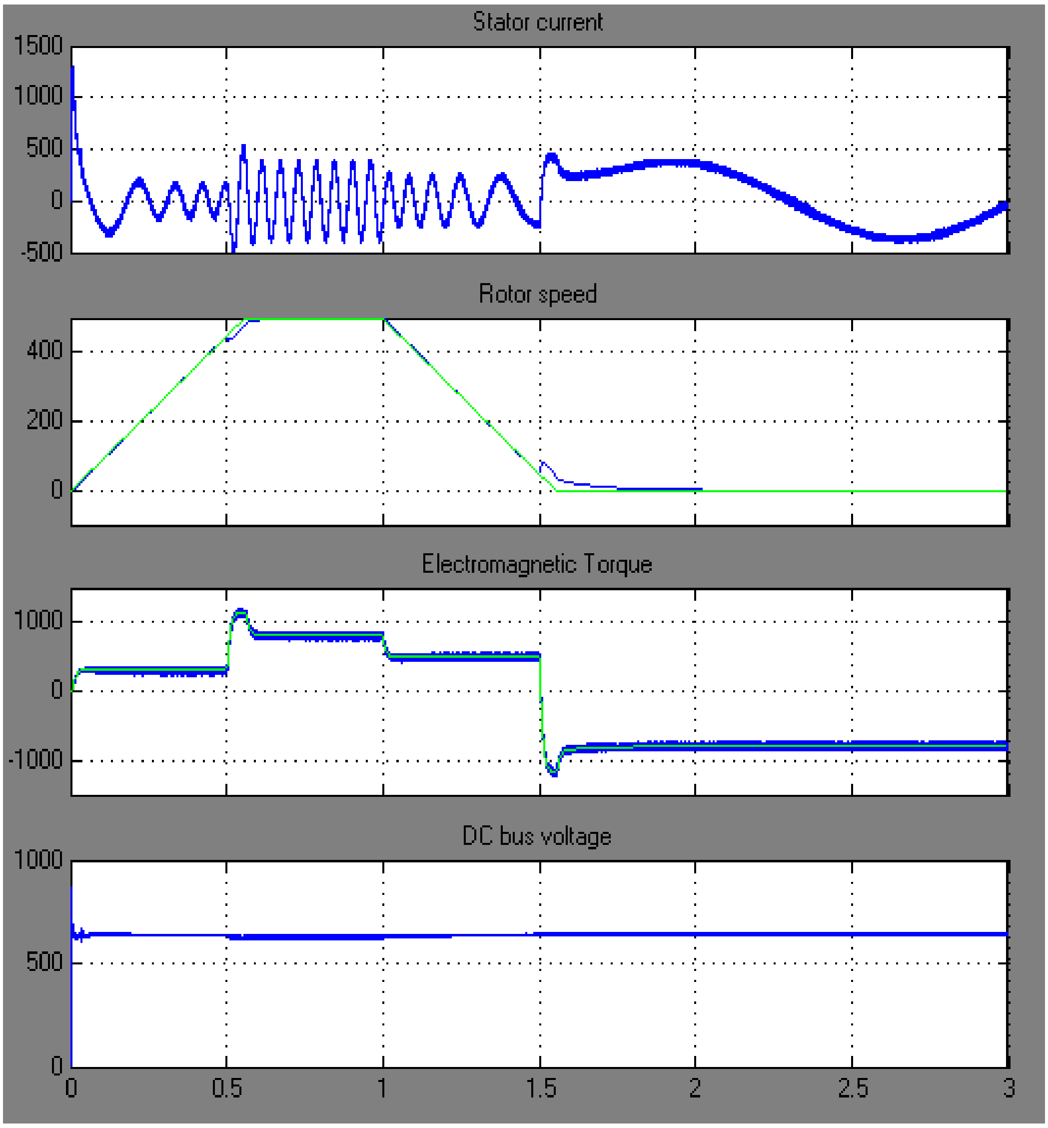


Figure 4.9 Performance of DTC Induction Motor from Direct Source

The simulation result of the stator current, rotor speed, electromagnetic torque and DC bus voltage are presented through Figure 4.9 with the performance from direct source as in Figure 4.3. When start the simulation the motor stator current, the rotor speed, the electromagnetic torque and the DC bus voltage on the scope will be observed. The speed set point and the torque set point are also shown.

At time t = 0 s, the speed set point is 500 rpm. Observe that the speed follows precisely the acceleration ramp. At t = 0.5 s, the full load torque is applied to the motor shaft while the motor speed is still ramping to its final value. This forces the electromagnetic torque to increase to the user-defined maximum value (1200 Nm) and then to stabilize at 820 Nm once the speed ramping is completed and the motor has reached 500 rpm.

At t = 1 s, the speed set point is changed to 0 rpm. The speed decreases down to 0 rpm by following precisely the deceleration ramp even though the mechanical load is inverted abruptly, passing from 792 Nm to - 792 Nm, at t = 1.5 s. Shortly after, the motor speed stabilizes at 0 rpm.

Finally, note how well the DC bus voltage is regulated during the whole simulation period with the amplitude of 600 V.

4.4.2.2 Matrix Converter

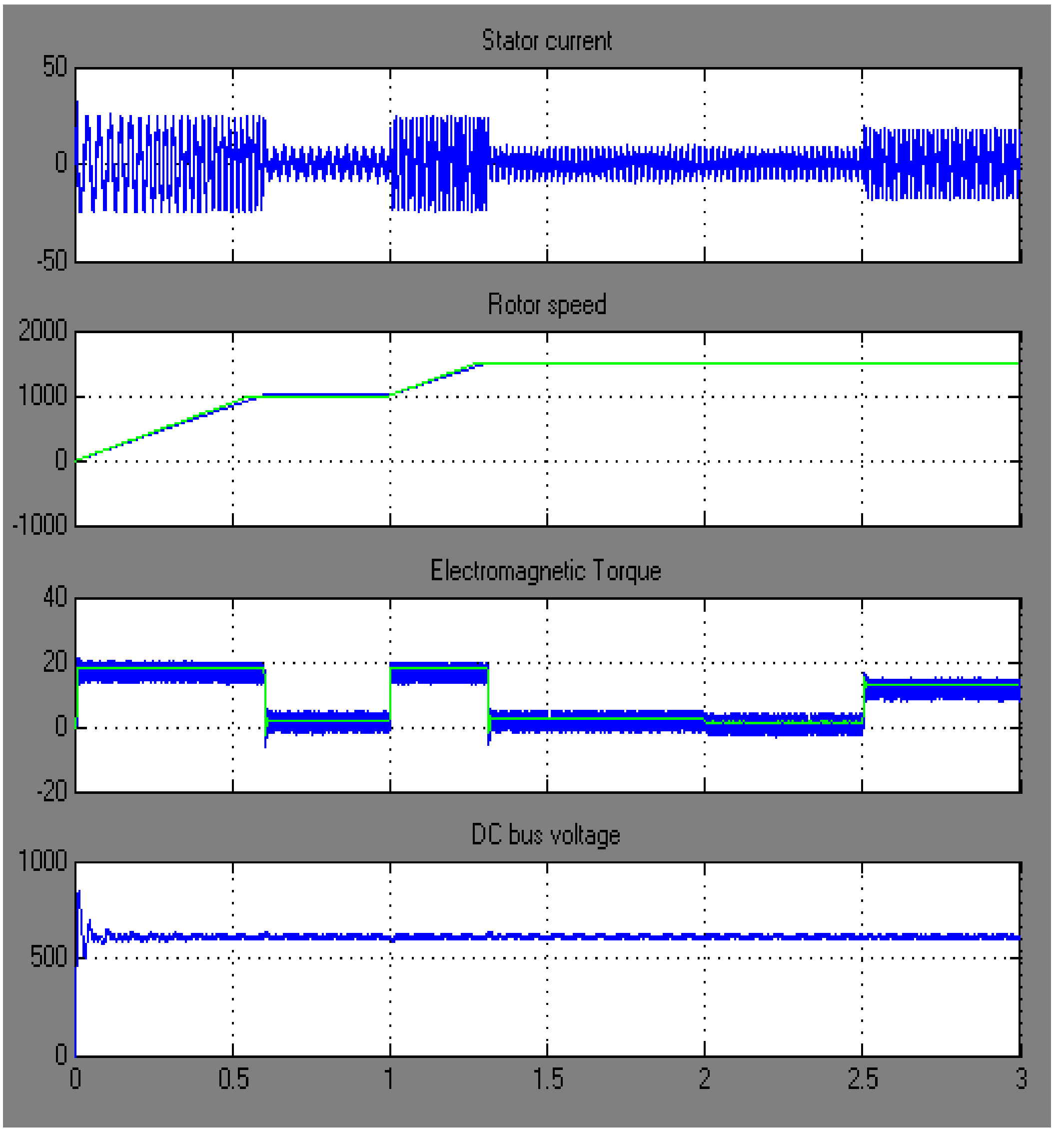


Figure 4.10 Performance of DTC Induction Motor by using Matrix Converter

The entire design for this part is in Figure 4.2. For the stator current, the value is about 25 rpm starting from 0.05 s until 0.6 s and at time 1 s until 1.3 s. The speed follows precisely the acceleration ramp. For the 0.6 s to 1 s and for 1.3 s above until 2.5 s, the value of stator current is decrease to 10 rpm. Above 2.5 s until stop time of 3 s, the stator current is increase but below than 25 rpm which is about 18 rpm.

The rotor speed is increase proportional to the time starting from 0 s to 0.6 s with the rotor speed of 1000 rpm. The value is constant after 0.6 s. Starting on 1 s until 1.25 s, the rotor speed increase to the maximum value which is 1500 rpm and it is constant after 1.25 s above until 3 s.

The motor is supplied from a fixed voltage at a constant frequency, the developed torque is a function of the slip and the electromagnetic torque can be determined. The electromagnetic torque for matrix converter circuit shows the maximum value of 20 Nm for time from 0 s until 0.6 s and 1 s until 1.35 s. In range between 0.6 s until 1 s and after 1.35 s until 2.5 s, the electromagnetic torque is decrease to 2 Nm. For the time of 2.5 s until 3 s, the electromagnetic torque is increase to 12 Nm.

For the Matrix Converter implementation for induction motor application, the DC bus voltage is 600 V as the DC bus voltage is regulated during the whole of the simulation.

According to the simulation result of the DTC induction motor from direct source and source through Matrix Converter, the source through Matrix Converter has more advanced potential as compared with direct source which includes compact design and long life due to absence of a bulky electrolytic capacitor, bidirectional energy flow capability and controllable power factor. So that, the DTC induction motor performance by using matrix converter is more effective.

4.4.3 Comparison of Matrix Converter and Common Converter

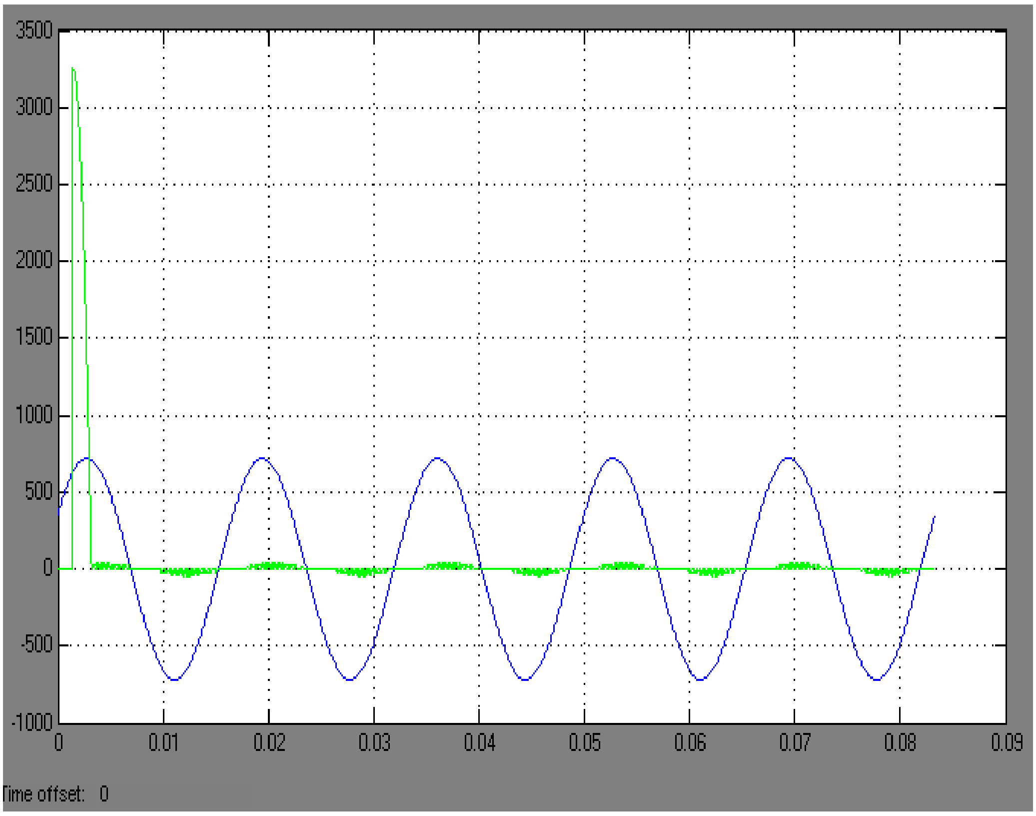


Figure 4.11 Input of Common Converter by using Induction Motor Load

The three phase source in series with RLC branch is used and the phase to phase rms voltage is setup as 25 kV. Figure 4.11 shows the input voltage waveform of the converter of 60 Hz is sinusoidal waveform with amplitude is about 700 V and the maximum input current is about 20A. It is referred to the circuit design as in Figure 4.4. Compare to the result of Matrix Converter implementation for DTC induction motor as in Figure 4.6, the waveform current is 0A and constant until the end of the time. The waveform voltage for both converters are smoothing sinusoidal as there is not connected to the load and no losses occur.

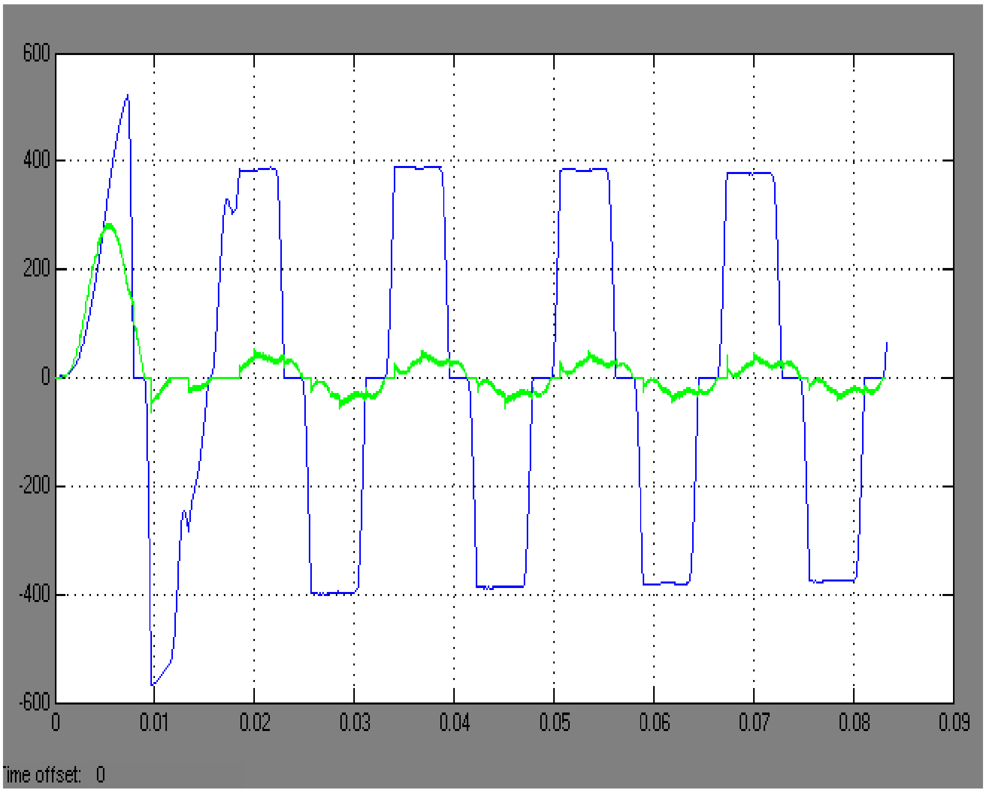


Figure 4.12 Output of Common Converter by using Induction Motor Load

From the output waveform voltage in Figure 4.12, the peak value of the load voltage is about 380V and output current is about 30A. The result shows AC output voltage is not smooth and there has some harmonics occurs.

Harmonics are sinusoidal component of a periodic waveform having a frequency that is an integer multiple of a fundamental frequency (50 Hz or 60 Hz). The result has gotten due to the induction motor load which is non linear load and it produces losses during the operation.

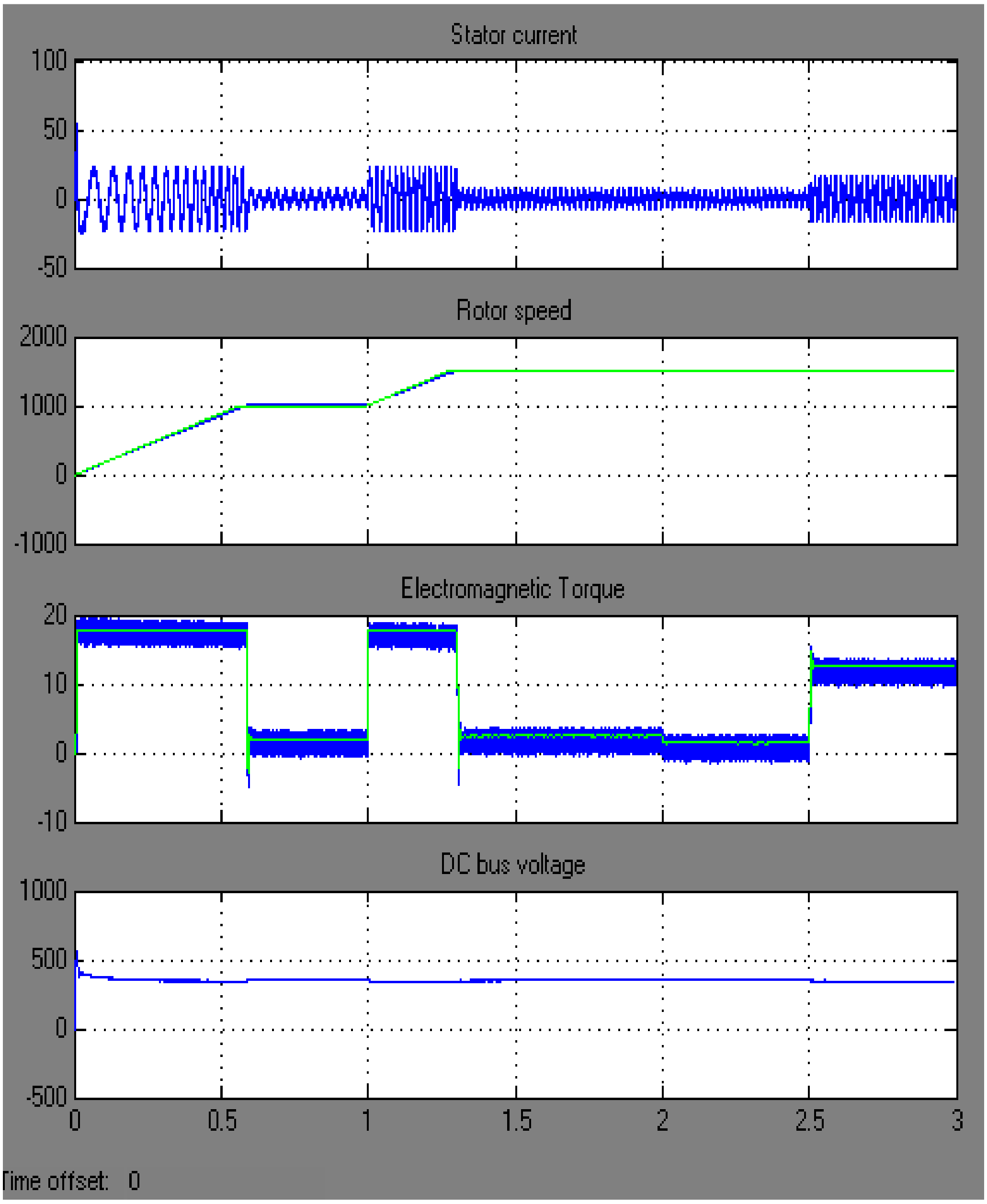


Figure 4.13 Performance of DTC Induction Motor by using Common Converter

The simulation result of the stator current, rotor speed, electromagnetic torque and DC bus voltage are presented through Figure 4.13 with starting from 0 s to 3 s. For the first part which is stator current, the value is about 30 rpm starting from 0.05 s until 0.6 s. The speed follows precisely the acceleration ramp. For the 0.6 s to 1 s, the value of stator current is decrease to 10 rpm. At 1.1 s until 1.35 s, the stator current increase to 30 rpm as previous and decrease again to 10 rpm at 1.36 s to 2.5 s. After that, the stator is increase back to 30 rpm until the time is 3 s.

For the second part, the rotor speed is increase proportional to the time starting from 0 s to 0.6 s with the maximum rotor speed of 1000 rpm. The value is constant after 0.6 s until 1 s. After 1 s until 1.25 s, the rotor speed is increase to 1500 rpm and it is constant until 3 s.

The full load torque is applied to the motor shaft while the motor speed is still ramping to its final value. For time from 0 s to 0.6 s, the electromagnetic torque is about 18 Nm and there has the same electromagnetic torque for 1.1 s until 1.4 s. For time from 0.7 s until 1 s and after 1 s until 1.35 s, the electromagnetic speed is decrease to 2 Nm. After 2.5 s until stop time of 3 s, the electromagnetic torque increase to 13 Nm.

At t = 0.6 s, the speed set point is changed to 0 rpm. The speed decreases down to 0 rpm by following precisely the deceleration ramp even though the mechanical load is inverted abruptly. Shortly after, the motor speed stabilizes at 0 rpm.

Finally, note how well the DC bus voltage is regulated during the whole simulation period. The DC bus voltage is 480 V.

CHAPTER 5

CONCLUSION AND FUTURE COMMENDATIONS

5.1 Conclusion

The project is successfully done in order to use the new type of direct AC to AC converter which is matrix converter by using the space vector modulation. There are a few problems encountered during completing this project and there have been solved in order to finish the project successfully. The first problem is in understood the switching of the matrix converter as it is the new type of converter. Besides that, the problem also encountered to get the smooth AC signal for the input and output as it used the non linear load which causes the resulting of complex waveform.

The goal of this project is to implement the matrix converter for induction motor application to control speed and torque. In this project, the modeling and simulation of the matrix converter with DTC induction motor load employing space vector modulation technique has been realized in Simulink or MATLAB package program.

Mainly, a matrix converter consists of nine bi-directional switches, which are required to be commutated in the right way and sequence in order to minimize losses and produce the desired output with a high quality input and output waveforms. The input and output waveforms of the common converter and matrix converter have been investigated. The performance of the induction motor is analyzed through the common converter and matrix converter.

5.2 Future Recommendation

After completing this project, there might be some enhancement for future's study. It may be on:

- Modeling and simulation the matrix converter by using another modulation technique like Venturini method and PWM method.
- Modeling the matrix converter by using another bidirectional switches.
- Implementation the matrix converter to the large technology as example in doubly-fed induction generators for wind generators
- Using another integration method by entering command in MATLAB's command window for simulation.
- Study on the future impact on economy value from the implementation of the matrix converter in the technologies. A cost analysis benefit must be conduct to make sure its impact on operation and maintenance cost.

5.3 Commercialization

Making analysis for the project is the first step before making the real project. The analysis is doing based on the simulation of the project. The successfully of the project is depend on the analysis of the simulation that be done before.

In industry, the engineers always make analysis on the machine either single phase or three phase motor to see their problems. By making the simulation on that machine, the analysis can be done to look what the problems and how to overcome it.

This project presented the simulation by using MATLAB/Simulink as a tool in making analysis. So, this project can be used as reference for the engineering student or any engineer that work with simulation and doing analysis.

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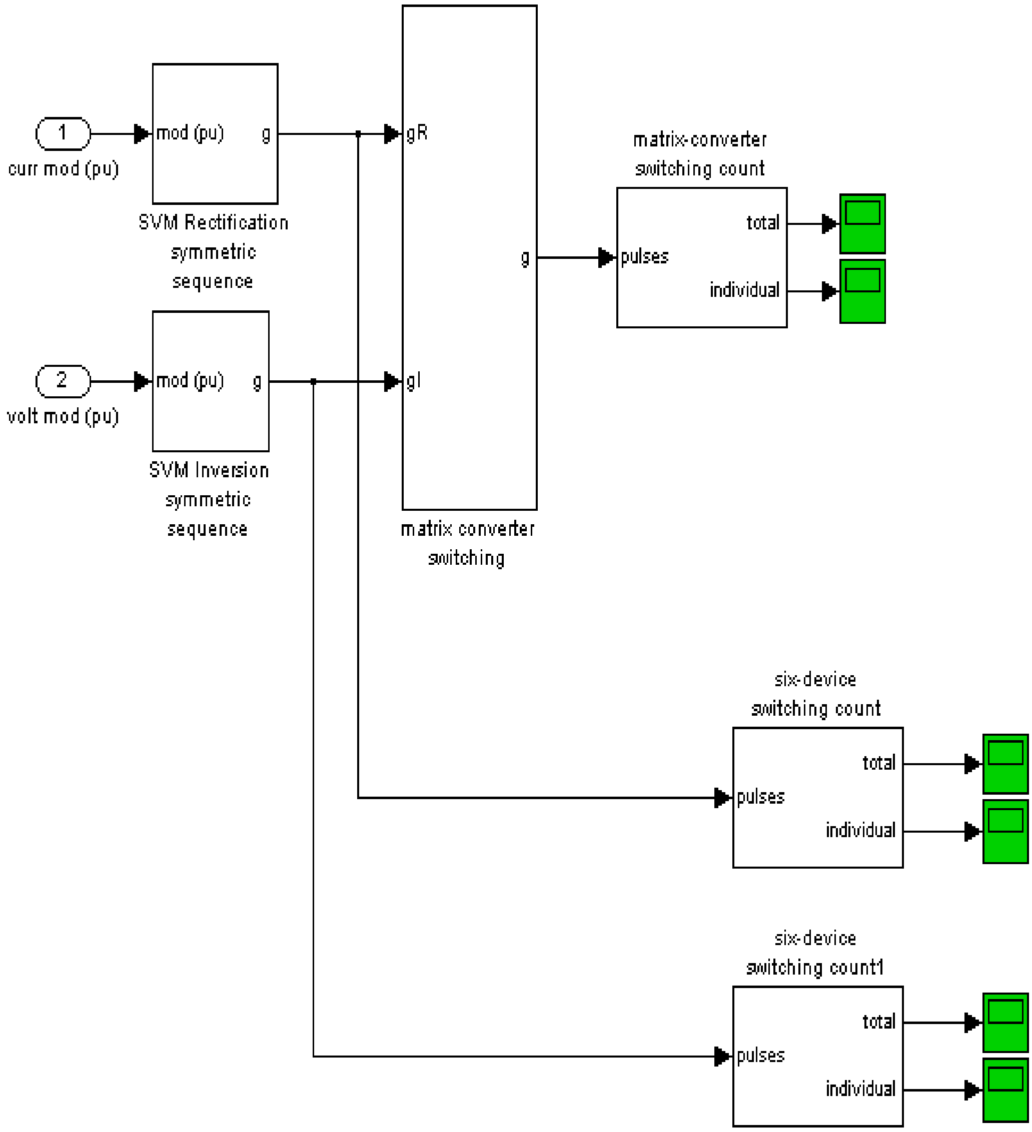
APPENDICES

APPENDIX A- Table of Three Phase Matrix Converter Switching Combination

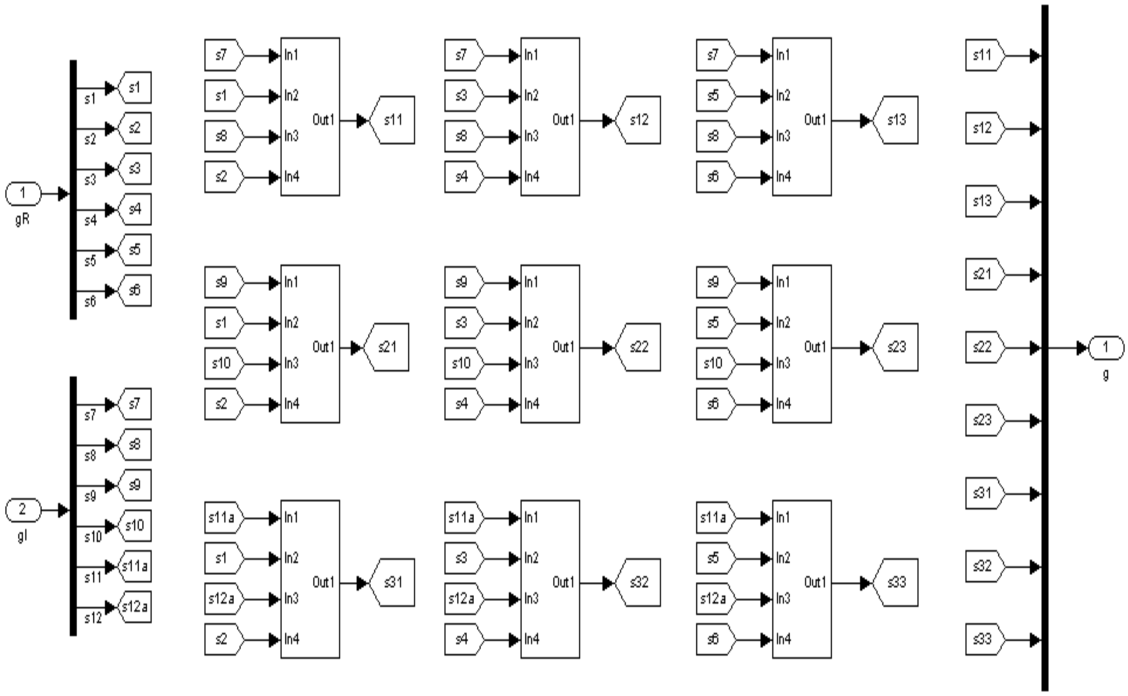
Table 1: Three Phase Matrix Converter Switching Combination

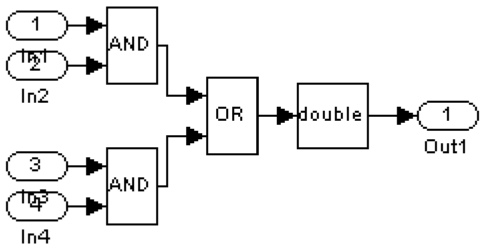
Group	A	B	C	v_{AB}	v_{BC}	v_{CA}	i_a	i_b	i_c	S_{Aa}	S_{Ab}	S_{Ac}	S_{Ba}	S_{Bb}	S_{Bc}	S_{Ca}	S_{Cb}	S_{Cc}
I	a	b	c	v_{ab}	v_{bc}	v_{ca}	i_A	i_B	i_C	1	0	0	0	1	0	0	0	1
	a	c	b	$-v_{ca}$	$-v_{bc}$	$-v_{ab}$	i_A	i_C	i_B	1	0	0	0	0	1	0	1	0
	b	a	c	$-v_{ab}$	$-v_{ca}$	$-v_{bc}$	i_B	i_A	i_C	0	1	0	1	0	0	0	0	1
	b	c	a	v_{bc}	v_{ca}	v_{ab}	i_C	i_A	i_B	0	1	0	0	0	1	1	0	0
	c	a	b	v_{ca}	v_{ab}	v_{bc}	i_B	i_C	i_A	0	0	1	1	0	0	0	1	0
	c	b	a	$-v_{bc}$	$-v_{ab}$	$-v_{ca}$	i_C	i_B	i_A	0	0	1	0	1	0	1	0	0
II-A	a	c	c	$-v_{ca}$	0	v_{ca}	i_A	0	$-i_A$	1	0	0	0	0	1	0	0	1
	b	c	c	v_{bc}	0	$-v_{bc}$	0	i_A	$-i_A$	0	1	0	0	0	1	0	0	1
	b	a	a	$-v_{ab}$	0	v_{ab}	$-i_A$	i_A	0	0	1	0	1	0	0	1	0	0
	c	a	a	v_{ca}	0	$-v_{ca}$	$-i_A$	0	i_A	0	0	1	1	0	0	1	0	0
	c	b	b	$-v_{bc}$	0	v_{bc}	0	$-i_A$	i_A	0	0	1	0	1	0	0	1	0
	a	b	b	v_{ab}	0	$-v_{ab}$	i_A	$-i_A$	0	1	0	0	0	1	0	0	1	0
II-B	c	a	c	v_{ca}	$-v_{ca}$	0	i_B	0	$-i_B$	0	0	1	1	0	0	0	0	1
	c	b	c	$-v_{bc}$	v_{bc}	0	0	i_B	$-i_B$	0	0	1	0	1	0	0	0	1
	a	b	a	v_{ab}	$-v_{ab}$	0	$-i_B$	i_B	0	1	0	0	0	1	0	1	0	0
	a	c	a	$-v_{ca}$	v_{ca}	0	$-i_B$	0	i_B	1	0	0	0	0	1	1	0	0
	b	c	b	v_{bc}	$-v_{bc}$	0	0	$-i_B$	i_B	0	1	0	0	0	1	0	1	0
	b	a	b	$-v_{ab}$	v_{ab}	0	i_B	$-i_B$	0	0	1	0	1	0	0	0	1	0
II-C	c	c	a	0	v_{ca}	$-v_{ca}$	i_C	0	$-i_C$	0	0	1	0	0	1	1	0	0
	c	c	b	0	$-v_{bc}$	v_{bc}	0	i_C	$-i_C$	0	0	1	0	0	1	0	1	0
	a	a	b	0	v_{ab}	$-v_{ab}$	$-i_C$	i_C	0	1	0	0	1	0	0	0	1	0
	a	a	c	0	$-v_{ca}$	v_{ca}	$-i_C$	0	i_C	1	0	0	1	0	0	0	0	1
	b	b	c	0	v_{bc}	$-v_{bc}$	0	$-i_C$	i_C	0	1	0	0	1	0	0	0	1
	b	b	a	0	$-v_{ab}$	v_{ab}	i_C	$-i_C$	0	0	1	0	0	1	0	1	0	0
III	a	a	a	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0
	b	b	b	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0
	c	c	c	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1

APPENDIX B- IGBT Matrix Converter SVM Symmetric Switching (Behind Subsystem)

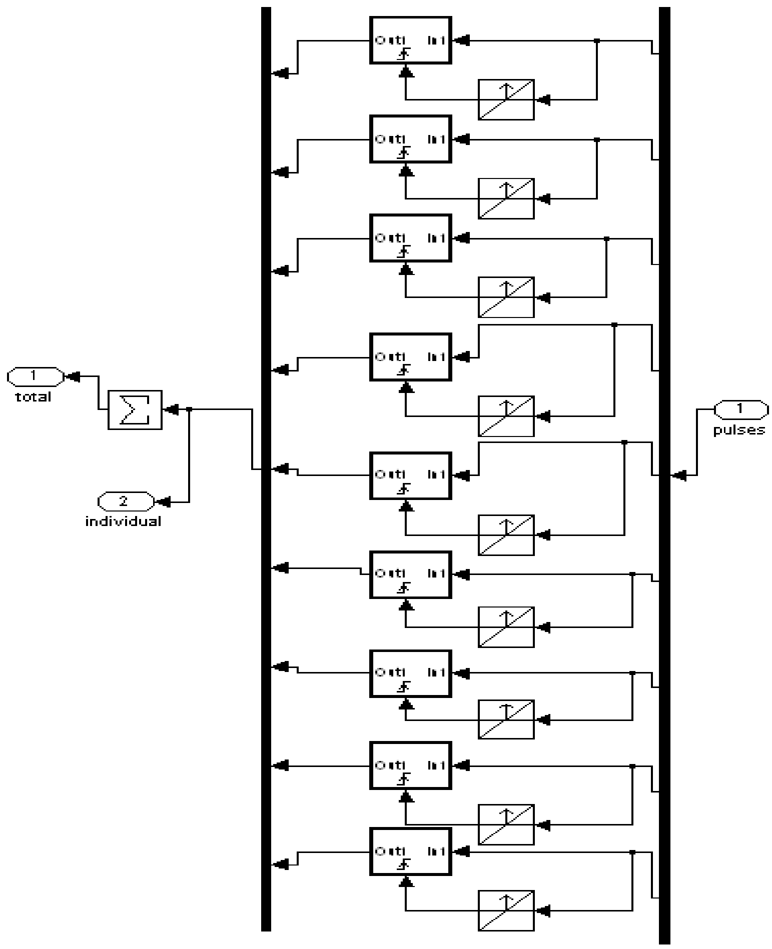


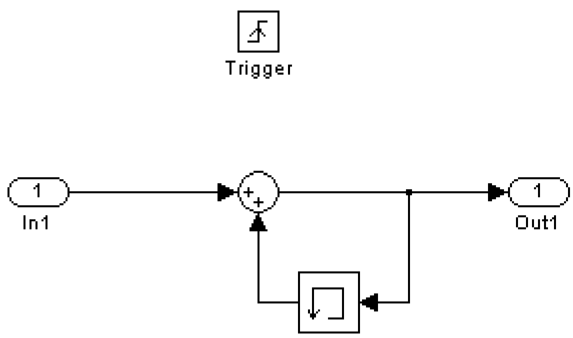
APPENDIX C- Matrix Converter Switching (Behind Subsystem)



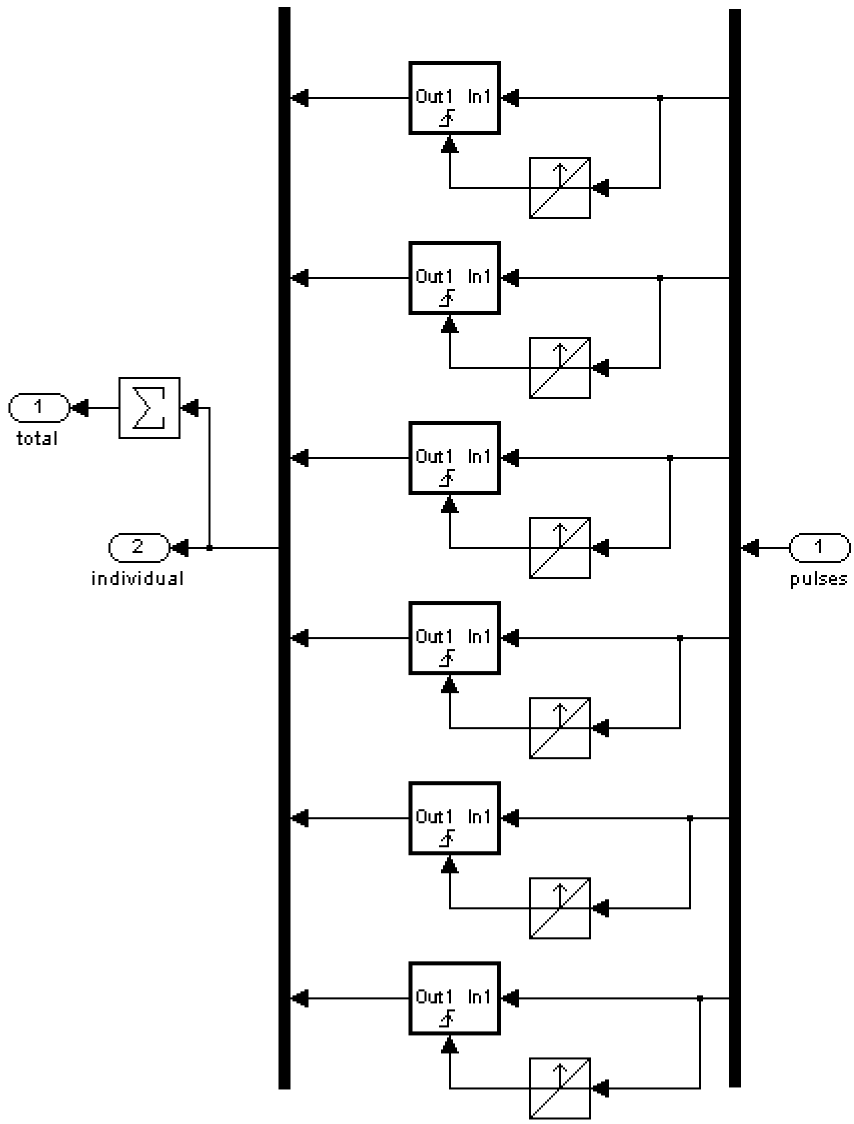


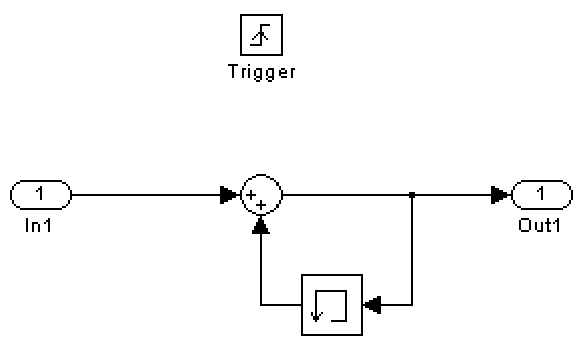
APPENDIX D- Matrix Converter Switching Count (Behind Subsystem)



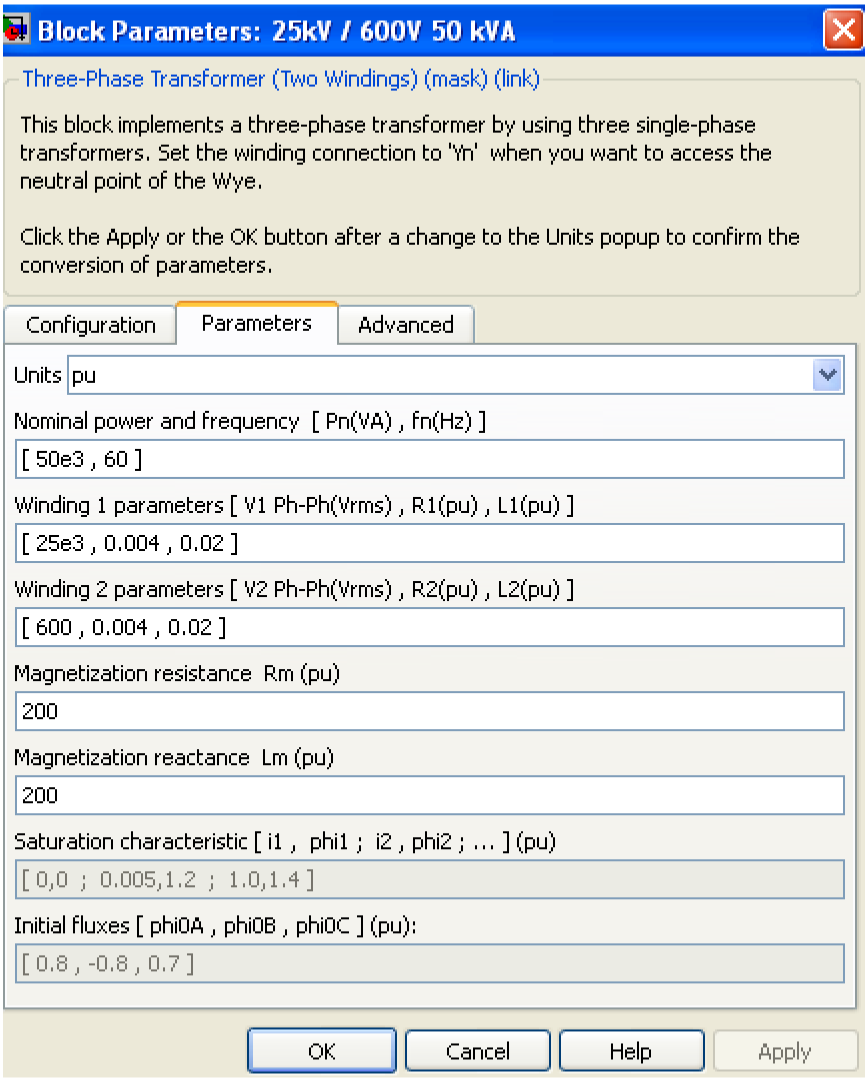


APPENDIX E- Six Device Switching Count (Behind Subsystem)



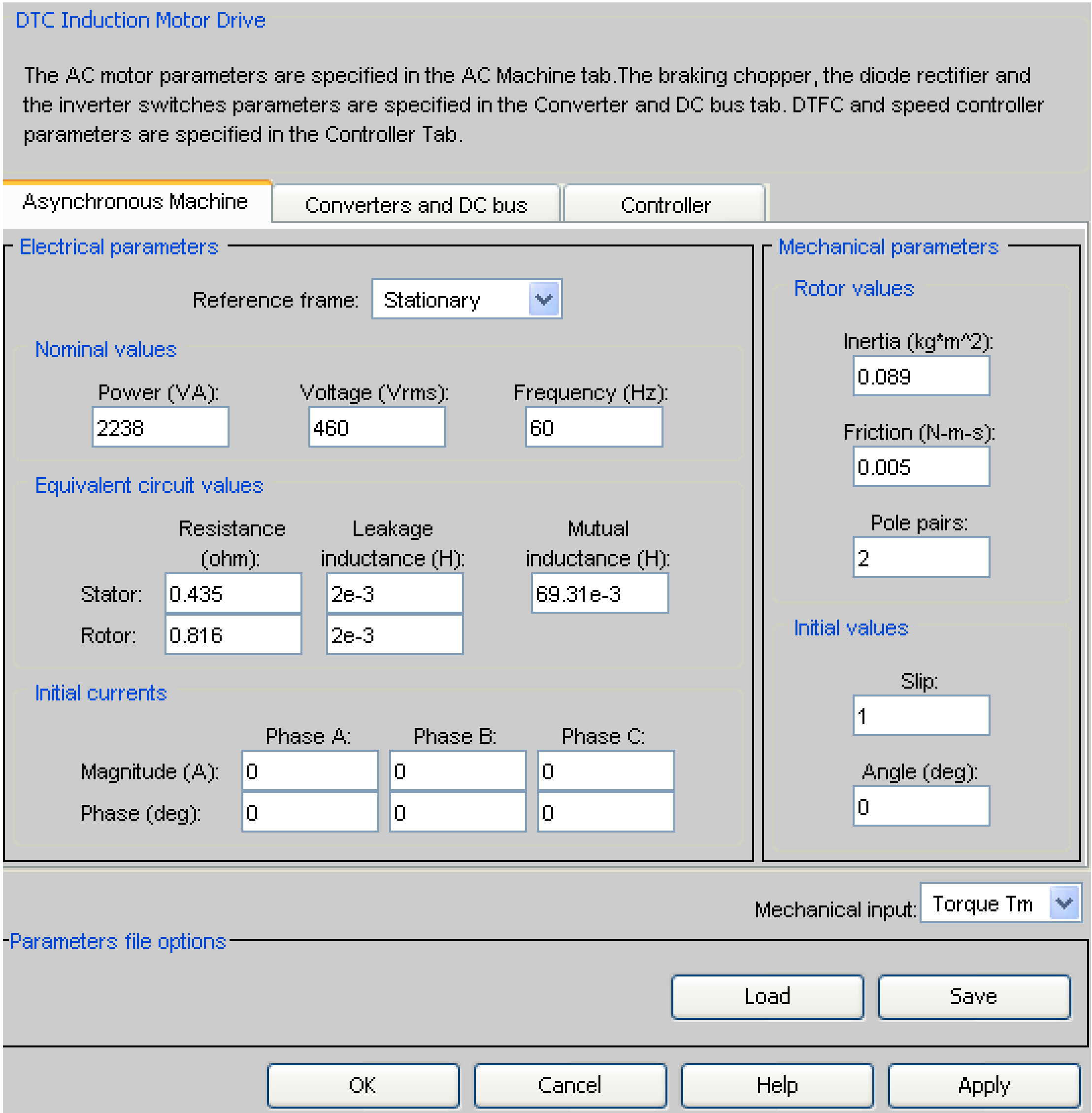


APPENDIX F- Block Parameter of Three Phase Transformer

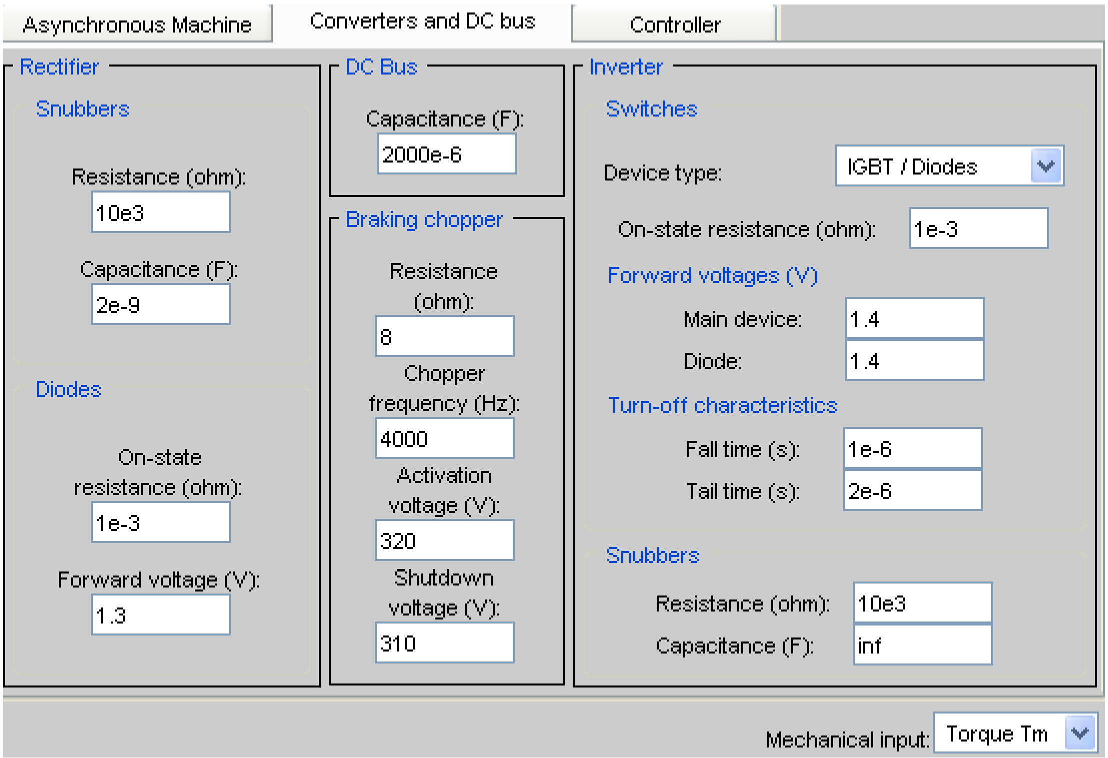


APPENDIX G- DTC Induction Motor Drive Parameter

a) Asynchronous Machine Part



b) Converter and DC bus Part



c) Controller Part