Ministry of Higher Education
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University of Diyala
College of Engineering
Computer and Software
Engineering Department

SIMULATION OF THREE PHASE INDUCTION MACHINE USING MATLAB/SIMULINK

A project
Submitted to the Department of (Computer and Software Engineering Dep.)-University of Diyala-College of Engineering, in Partial Fulfillment of the Requirements for the Degree of Bachelor (Computer and Software) Engineering

By

AYA MOHAMMED and AHMED KHADEIR

Supervised by

MSc. SERAJ M. HAMEED

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بسم الله الرحمن الرحيم

(قَالَ رَبِّ اشْرَحْ لِي صَدْرِي (25) وَيَسِّرْ لِي أَمْرِي (26) وَاحْلُلْ عُقْدَةً مِنْ
لِسَانِي (27) يَفْقَهُوا قَوْلِي (28))

صدق الله العظيم

(سورة طه)

DEDICATIONS

For our Beloved Families ……

…………… Friends

………… Classmates

…………………… Lecturers

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In the name of Allah, the Most Beneficent, the Most Merciful

We would like to express our heartiest thanks to our supervisor **“MSc. SERAJ M. HAMEED”** for his guidance, patience, advice and devotion of time, throughout our research. He taught us how to be a researcher with his wonderful personality. We have the honor to work under his supervision and we will ask Allah to keep him safe, and support him with good health and the power to help the students with knowledge and his scientific abilities. We are forever indebted to them for excellent guidance.

Finally, family for their unconditional care until we reach to this point, without their continuous support and precious prayers we could not have been able to finish our research. We know their blessings will always be with us in all our endeavors and we dedicate this success to them. Thanks our beloved family.

SUPERVISOR CERTIFICATION

I certify that this project entitled **"SIMULATION OF THREE PHASE INDUCTION MACHINE USING MATLAB/SIMULINK"**, was prepared under my supervision at the Computer and Software Engineering Department/College of Engineering by (**AYA MOHAMMED and AHMED KHADEIR**) as a partial fulfillment of the requirements for the degree of B. Sc. in Computer and Software Engineering.

Signature:

Name: MSc; SERAJ M. HAMEED

Title: Asst. Lecturer

Date: / /

Proof reader's signature:

Name:

Title: Lecturer

Date: / /

Signature:

Name: DR. ALI J. ABBOUD

(Head of Department)

Title: Lecturer

Date: / /

CERTIFICATION OF THE EXAMINATION COMMITTEE

We certify that we have read this project entitled **"SIMULATION OF THREE PHASE INDUCTION MACHINE USING MATLAB/SIMULINK"** and as examining committee examined the students (**AYA MOHAMMED and AHMED KHADEIR**) in its contents and that in our opinion it meets the standards of a project for the degree of B. Sc. in Computer and Software Engineering.

Signature:	Signature:
Name :	Name :
Title :	Title :
(Member)	(Member)
Date : / / 2016	Date : / / 2016

Signature:

Name :

Title :

(Chairman)

Date : / / 2016

Approved for Computer and Software Engineering Department.

Signature:

Name: DR. ALI J. ABBOUD

(Head OF Department)

Title: Lecturer

Date: / / 2016

ABSTRACT

This project illustrate implementing three phase induction machine modeled designed in MATLAB/SIMULINK . depending on clarck transformation from three phase component (abc) to only two component (dq).

Is operated and simulated in MATLAB/SIMULINK in tow mode generating mode and motoring mode

List of Contents

Chapter Three: Modeling of three phase induction machine In matlab/simulink.

Chapter Four: Simulation Results and Discussion

Chapter Five: Conclusions and Suggestions for Future Work

List of Symbols

Symbol	Meaning
a, b, c	Switching states
d, q	Rotating reference frame system
ψ_m	Mutual flux
R	Rotor variable
M	Modulation index
$V_{ds}, V_{qs}, V_{dr}, V_{qr}$	q and d-axis stator and rotor voltages respectively
$I_{ds}, I_{qs}, I_{dr}, I_{qr}$	q and d-axis stator and rotor currents respectively
$\psi_{ds}, \psi_{qs}, \psi_{dr}, \psi_{qr}$	q and d-axis stator and rotor fluxes respectively
ω_s	angular velocity of the synchronously rotating
ω_r	rotor angular velocity
R_s and R_r	stator and rotor resistances, respectively
L_s, L_r	Stator and rotor inductances respectively
L_m	Mutual inductance
T_m	mechanical torque
T_{e_M}	electromagnetic torque
x_s, x_r	Stator and rotor reactance
x_m	Magnetizing reactance
P_g	generated power
P_s	stator power
P_r	rotor power
V_s	Stator voltage
V_r	Rotor voltage
m_1	modulation index of the stator-side

$\mathbf{m_2}$	modulation index of the rotor-side
$\mathbf{V_{dc}}$	DC-bus voltage
$\boldsymbol{S}$	Slip
$\mathbf{P_m}$	Mechanical power

CHAPTER ONE

Introduction

1.1 introduction

The three phase induction motor is the most widely used electrical motor. Almost 80% of the mechanical power used by industries is provided by three phase induction motors because of its simple and rugged construction, low cost, good operating characteristics, absence of commutator and good speed regulation. In three phase induction motor the power is transferred from stator to rotor winding through induction. The Induction motor is also called asynchronous motor as it runs at a speed other than the synchronous speed. Like any other electrical motor induction motor also have two main parts namely rotor and stator[1].

1. Stator: As its name indicates stator is a stationary part of induction motor. A stator winding is placed in the stator of induction motor and the three phase supply is given to it.
2. Rotor: The rotor is a rotating part of induction motor. The rotor is connected to the mechanical load through the shaft.

The rotor of the three phase induction motor are further classified as

1. Squirrel cage rotor,
2. Slip ring rotor or wound rotor or phase wound rotor.

Depending upon the type of rotor construction used the three phase induction motor are classified as:

1. Squirrel cage induction motor,
2. Slip ring induction motor or wound induction motor or phase wound induction motor.

The construction of stator for both the kinds of three phase induction motor remains the same and is discussed in brief in next paragraph. The other parts, which are required to complete the induction motor, are:

1. Shaft for transmitting the torque to the load. This shaft is made up of steel.
2. Bearings for supporting the rotating shaft.
3. One of the problems with electrical motor is the production of heat during its rotation. In order to overcome this problem we need fan for cooling.
4. For receiving external electrical connection Terminal box is needed.
5. There is a small distance between rotor and stator which usually varies from 0.4 mm to 4 mm. Such a distance is called air gap [1]

1.2 History

IN 1824, the French physicist François Arago formulated the existence of rotating magnetic fields, termed Arago's rotations, which, by manually turning switches on and off, Walter Baily demonstrated in 1879 as in effect the first primitive induction motor.[2]

The first alternating-current commutatorless induction motors have been independently invented by Galileo Ferraris and Nikola Tesla, a working motor model having been demonstrated by the former in 1885 and by the latter in 1887[2].

Tesla applied for U.S. patents in October and November 1887 and was granted some of these patents in May 1888. In April 1888, the *Royal Academy of Science of Turin* published Ferraris's research on his AC polyphase motor detailing the foundations of motor operation.

In May 1888 Tesla presented the technical paper *A New System for Alternating Current Motors and Transformers* to the *American Institute of Electrical Engineers* describing three four-stator-pole motor types: one with a four-pole rotor forming a non-self-starting reluctance motor, another with a wound rotor forming a self-starting induction motor, and the third a true synchronous motor with separately excited DC supply to rotor winding.[1]

George Westinghouse, who was developing an alternating current power system at that time, licensed Tesla's patents in 1888 and purchased a US patent option on Ferraris' induction motor concept[2].

Tesla was also employed for one year as a consultant. Westinghouse employee C. F. Scott was assigned to assist Tesla and later took over development of the induction motor at Westinghouse. Steadfast in his promotion of three-phase development, Mikhail Dolivo-Dobrovolsky invented the cage-rotor induction motor in 1889 and the three-limb transformer in 1890 [1,2].

1.3 The standard Induction Machine types

1.3.1 Type A: squirrel cage rotor

Most of the induction motors (up to 90%) are of squirrel cage type. **Squirrel cage type rotor** has very simple and almost indestructible construction. This type of rotor consist of a cylindrical laminated core, having parallel slots on it. These parallel slots carry rotor conductors. In this type of rotor, heavy bars of copper, aluminum or alloys are used as rotor conductors instead of wires[3].

Rotor slots are slightly skewed to achieve following advantages -

1. it reduces locking tendency of the rotor, i.e. the tendency of rotor teeth to remain under stator teeth due to magnetic attraction.

2. Increases the effective transformation ratio between stator and rotor

3. Increases rotor resistance due to increased length of the rotor conductor

The rotor bars are brazed or electrically welded to short circuiting end rings at both ends. Thus this rotor construction looks like a squirrel cage and hence we call it. The rotor bars are permanently short circuited, hence it is not possible to add any external resistance to armature circuit.[3,4]

1.3.2 Type B: wound rotor

A wound-rotor motor is a type of induction motor where the rotor windings are connected through slip rings to external resistances. Adjusting the resistance allows control of the speed/torque characteristic of the motor.

Wound-rotor motors can be started with low inrush current, by inserting high resistance into the rotor circuit; as the motor accelerates, the resistance can be decreased[5].

Compared to a squirrel-cage rotor, the rotor of the slip ring motor has more winding turns; the induced voltage is then higher, and the current lower, than for a squirrel-cage rotor. During the start-up a typical rotor has 3 poles connected to the slip ring.

Each pole is wired in series with a variable power resistor. When the motor reaches full speed the rotor poles are switched to short circuit. During start-up the resistors reduce the field strength at the stator. As a result the inrush current is reduced. Another important advantage over squirrel-cage motors is higher starting torque[6].A wound-rotor motor can be used in several forms of adjustable-speed drive.

Certain types of variable-speed drives recover slip-frequency power from the rotor circuit and feed it back to the supply, allowing wide speed range with high energy efficiency.

Doubly fed electric machines use the slip rings to supply external power to the rotor circuit, allowing wide-range speed control. Today speed control by use of slip ring motor is mostly superseded by induction motors with variable-frequency drives.[6]

1.4 aim of the work

The main aim of the work is to studying the behavior of THREE PHASE INDUCTION MACHINE and watching results by changing the input mechanical torque to get two operation modes :
1-generating mode
2-motoring mode
Based on MATLAB/SIMULINK

1.5 project organization

The content of chapters are briefly introduced here:

Chapter Two: including mathematical model of induction motors.Concentrates on the equations and equivalent circuit of induction machine And simulated for three phase transformation of induction machine model.

Chapter three :A SIMULINK model is developed for the induction Machine model and simulated for three phase transformation of induction machine model.

Chapter four: covers the results and discussion of all results and Torque in motoring and Generating mode .

Chapter five: has the conclusions, the limitation of the study and suggestion for future works.

CHAPTER TWO

Theoretical Model and Operation of 3 Phase IM

2.1 introduction

The popularity of 3 phase induction motors on board ships is because of their simple, robust construction, and high reliability factor in the sea environment.

A 3 phase induction motor can be used for different applications with various speed and load requirements. Electric motors can be found in almost every production process today. Getting the most out of your application is becoming more and more important in order to ensure cost-effective operations[7].

The three-phase induction motors are the most widely used electric motors in industry. They run at essentially constant speed from no-load to full-load. However, the speed is frequency dependent and consequently these motors are not easily adapted to speed control. We usually prefer d.c. motors when large speed variations are required. Nevertheless, the 3-phase induction motors are simple, rugged, low-priced, easy to maintain and can be manufactured with characteristics to suit most industrial requirements. Like any electric motor, a 3-phase induction motor has a stator and a rotor[7].

The stator carries a 3-phase winding (called stator winding) while the rotor carries a short-circuited winding (called rotor winding). Only the stator winding is fed from 3-phase supply.

The rotor winding derives its voltage and power from the externally energized stator winding through electromagnetic induction and hence the name. The induction motor may be considered to be a transformer with a rotating secondary and it can, therefore, be described as a "transformer type" a.c. machine in which electrical energy is converted into mechanical energy[7].

2.2 Operation of Three Phase Induction Motor

An electrical motor is such an electromechanical device which converts electrical energy into a mechanical energy. In case of three phase AC operation, most widely used motor is Three phase induction motor as this type of motor does not require any starting device or we can say they are self starting induction motor[8].

For better understanding the principle of three phase induction motor, the basic constructional feature of this motor must be known to us. This Motor consists of two major parts:

Stator: Stator of three phase induction motor is made up of numbers of slots to construct a 3 phase winding circuit which is connected to 3 phase AC source. The three phase winding are arranged in such a manner in the slots that they produce a rotating magnetic field after 3Ph. AC supply is given to them[9].

Rotor: Rotor of three phase induction motor consists of cylindrical laminated core with parallel slots that can carry conductors. Conductors are heavy copper or aluminum bars which fits in each slots & they are short circuited by the end rings. The slots are not exactly made parallel to the axis of the shaft but are slotted a little skewed because this arrangement reduces magnetic humming noise & can avoid stalling of motor[8].

2.2.1 production of rotating magnetic field

A rotating magnetic field in the stator is the first part of operation. To produce a torque and thus rotate, the rotors must be carrying some current. In induction motors, this current comes from the rotor conductors. The revolving magnetic field produced in the stator cuts across the conductive bars of the rotor and induces an e.m.f[9].

The rotor windings in an induction motor are either closed through an external resistance or directly shorted. Therefore, the e.m.f induced in the rotor causes current to flow in a direction opposite to that of the revolving magnetic field in the stator, and leads to a twisting motion or torque in the rotor[10].

As a consequence, the rotor speed will not reach the synchronous speed of the r.m.f in the stator. If the speeds match, there would be no e.m.f. induced in the rotor, no current would be flowing, and therefore no torque would be generated. The difference between the stator (synchronous speed) and rotor speeds is called the slip[9].

Production of rotating magnetic field

Now that we have a picture of the field, we turn to how it is produced. If we inspect the stator winding of an induction motor we find that it consists of a uniform array of identical coils, located in slots. The coils are in fact connected to form three identical groups or phase windings, distributed around the stator, and symmetrically displaced with respect to one another. The three-phase windings are connected either in star (wye) or delta (mesh) [10]. The three-phase windings are connected directly to a three-phase a.c. supply, and so the currents (which produce the MMF that sets up the flux) are of equal amplitude but differ in time phase by one-third of a cycle (120°), forming a balanced three-phase set[10].

Field produced by each phase winding

The aim of the winding designer is to arrange the layout of the coils so that each phase winding, acting alone, produces an MMF wave (and hence an air-gap flux wave) of the desired pole number, and with a sinusoidal variation of amplitude with angle. Getting the desired pole number is not difficult: we simply have to choose the right number and pitch of coils, as shown by the diagrams of an elementary 4-pole winding in Figure(2-1) [11].

In Figure (2-3(a)) we see that by positioning two coils (each of which spans one pole-pitch) 180° apart we obtain the correct number of poles (i.e. 4). However, the air-gap field – shown by only two flux lines per pole for the sake of clarity – is uniform between each go and return coil side, not sinusoidal[11].

Figure (2-1) Star (wye) and Delta connection of the three phase windings of a 3-phase induction motor

Plate Stator of three-phase induction motor. The semi-closed slots of the stator core obscure the active sides of the stator coils, but the ends of the coils are just visible beneath the binding tape. (Photograph by courtesy of Brook Crompton)

Plate(2.2) Cage rotor for induction motor. The rotor conductor bars and end rings are cast in aluminium, and the blades attached to the end rings serve as a fan for circulating

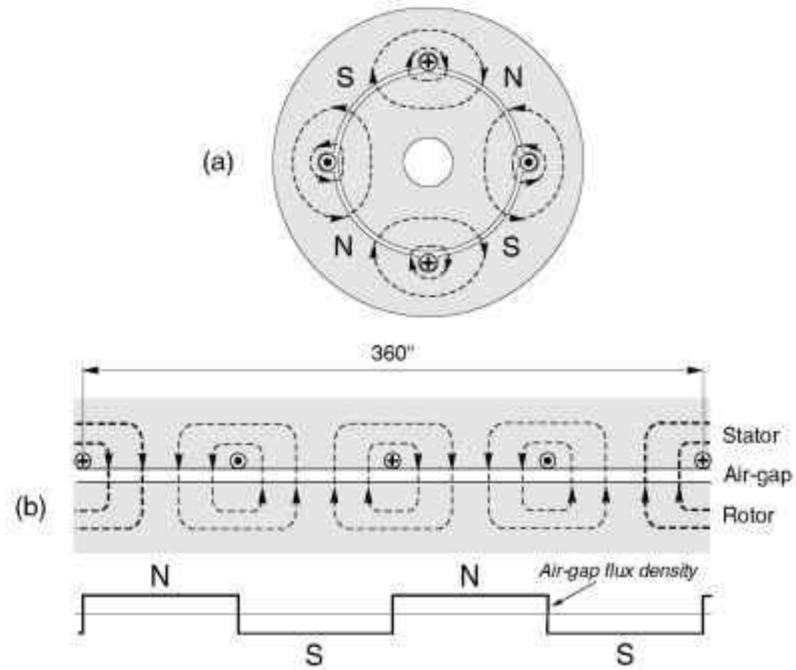


Figure 2.3 Arrangement (a) and developed diagram (b) showing elementary 4-pole, single-layer stator winding consisting of 4 conductors spaced by 90°. The 'go' side of each coil (shown by the plus symbol) carries current into the paper at the instant shown, while the 'return' side (shown by the dot) carries current out of the paper

A clearer picture of the air-gap flux wave is presented in the developed view in Figure (2.3(b)), where more equally spaced flux lines have been added to emphasise the uniformity of the lux density between the go and return sides of the coils. Finally, the plot of the air-gap flux density underlines the fact that this very basic arrangement of coils produces a rectangular flux density wave, whereas what we are seeking is a sinusoidal wave[11].

We can improve matters by adding more coils in the adjacent slots, as shown in Figure 5.4. All the coils have the same number of turns, and carry the same current. The addition of the extra slightly displaced coils gives rise to the stepped waveform of MMF and air-gap flux density shown in Figure 2.4. It is still not sinusoidal, but is much better than the original rectangular shape[11].

It turns out that if we were to insist on having a perfect sinusoidal flux density waveform, we would have to distribute the coils of one phase in a smoothly varying sinusoidal pattern over the whole periphery of the stator. This is not a practicable proposition, firstly because we would[12].

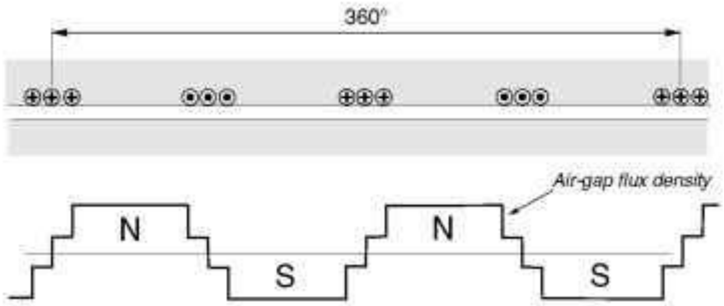


Figure 2.4 Developed diagram showing flux density produced by one phase of a single-layer winding having three slots per pole per phase

also have to vary the number of turns per coil from point to point, and secondly because we want the coils to be in slots, so it is impossible to avoid some measure of discretisation in the layout. For economy of manufacture we are also obliged to settle for all the coils being identical, and we must make sure that the three identical phase windings it together in such a way that all the slots are fully utilised[13].
Despite these constraints we can get remarkably close to the ideal sinusoidal pattern, especially when we use a 'two-layer' winding. A typical arrangement of one phase is shown in Figure 2.5. The upper expanded sketch shows how each coil sits with its go side in the top of a slot while the return side occupies the bottom of a slot rather less than one pole-pitch away. Coils which span less than a full pole-pitch are known as short-pitch or short-chorded: in this particular case the coil pitch is six slots, the pole-pitch is nine slots, so the coils are short-pitched by three slots[13]. This type of winding is almost universal in all but small induction motors, the coils in each phase being grouped together to form 'phase-bands' or 'phase-belts'. Since we are concentrating on the field produced by only one of the phase windings (or 'phases'), only one-third of the coils in Figure 2.5 are shown carrying current. The remaining two-thirds of the coils form the other two phase windings[13].

Returning to the flux density plot in Figure 2.5 we see that the effect of short-pitching is to increase the number of steps in the waveform, and that as a result the field produced by one phase is a fair approximation to a sinusoid.

The current in each phase pulsates at the supply frequency, so the field produced by, say, phase A, pulsates in sympathy with the current in phase A, the axis of each 'pole' remaining fixed in space, but its polarity[13].

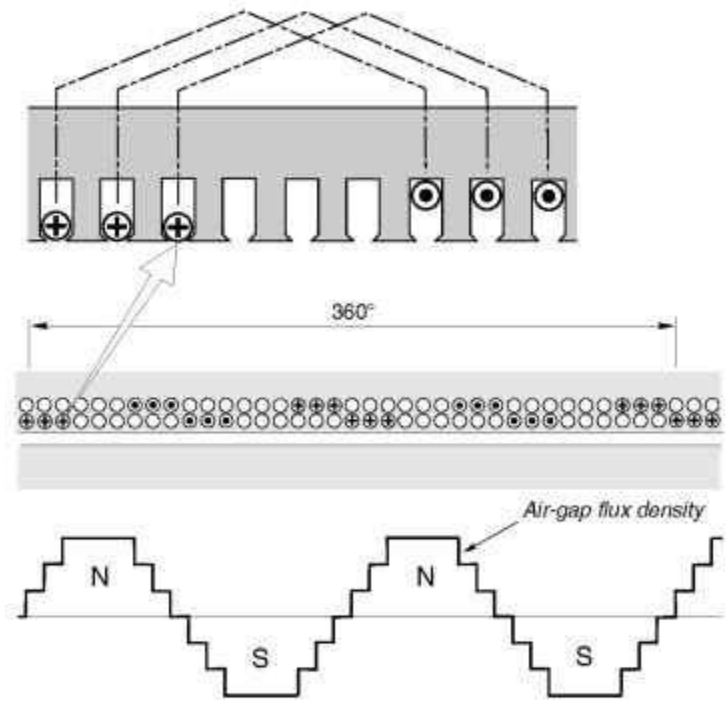


Figure 2.5 Developed diagram showing layout of windings in a 3-phase, 4-pole, two-layer induction motor winding, together with the flux density wave produced by one phase acting alone. The upper detail shows how the coil sides form upper and lower layers in the slots

changing from N to S and back once per cycle. There is no hint of any rotation in the field of one phase, but when the fields produced by each of the three-phases are combined, matters change dramatically[13].

2.2.2 **Equivalent Circuit**

The equivalent circuits as in Fig.(2.6) can be represented the steady state behavior of a three-phase induction motor.

Where

X_1 : stator leakage reactance

Rc : core loss resistance,

Xm : magnetizing reactance,

R_2 : rotor resistance referred to stator,

X_2 : rotor leakage reactance referred to stator,

Xeq : equivalent leakage reactance (X1 + X2),

S : slip

From the six-impedance and approximate equivalent circuits, the equations of stator current (I1) and power factor (PF) can be expressed as in (1) and (2) respectively[14].

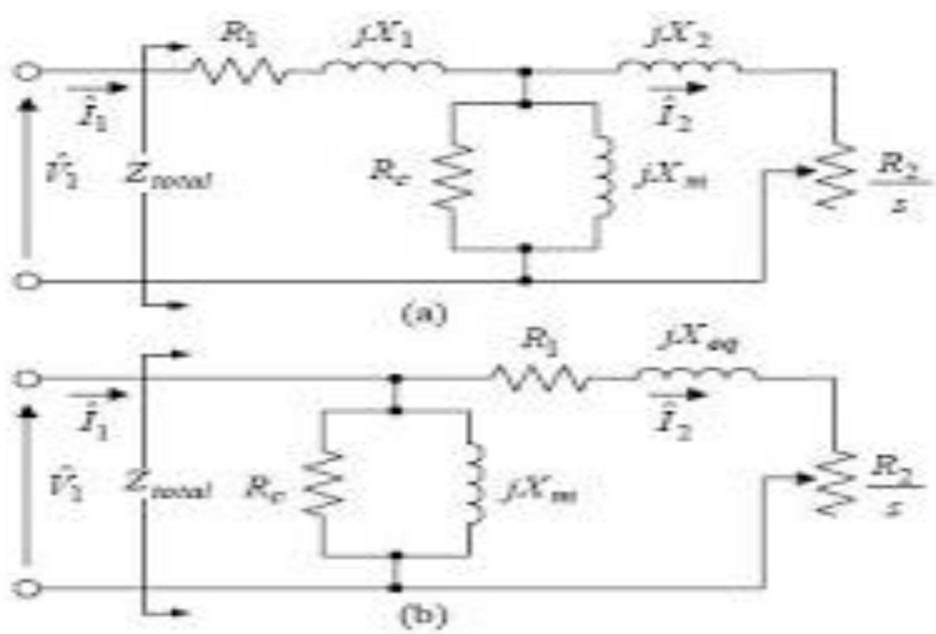


Fig. 2.6 Equivalent circuits of three-phase induction motor
a) six-impedance b) approximate

2.3 Modeling Of Three Phase Induction Machine.

2.3.1. Mathematical modeling of Three Phase Induction Machine.

The steady-state model of a three phase induction machine. It uses the stationary (dq0) reference frame in which the (d-axis) leads the (q-axis) by ninety degrees. known as (Clarke's transformation) . as shown in Figure(2-8), [15].

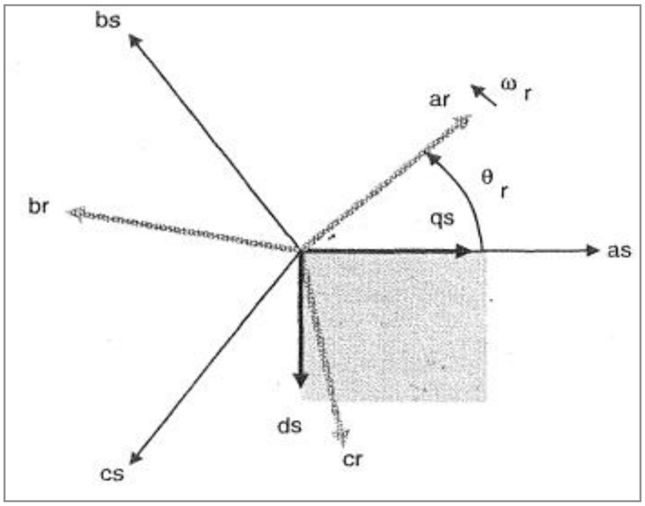


Figure:(2-8) Axes of abc winding to dq stationary

The model equations of the induction machine in the stationary dq0 reference frame can be written into the following:

Consider next the transformation of phase stator voltages to dq stationary voltages[16].

$$
\begin{aligned}
v_{qs}^{s} &= \tfrac{2}{3}v_{as} - \tfrac{1}{3}v_{bs} - \tfrac{1}{3}v_{cs} \\
v_{ds}^{s} &= \tfrac{1}{\sqrt{3}}\left(v_{cs} - v_{bs}\right) \\
v_{0s} &= \tfrac{1}{3}\left(v_{as} + v_{bs} + v_{cs}\right)
\end{aligned}
\qquad (2\text{-}1)
$$

The resulting equations of the rotor voltages after the first transformation are

similar to those of the stator voltages ,that is:

$$v_{qr}^{r} = \tfrac{2}{3} v_{ar} - \tfrac{1}{3} v_{br} - \tfrac{1}{3} v_{cr}$$

$$v_{dr}^{r} = \tfrac{1}{\sqrt{3}} (v_{cr} - v_{br}) \qquad (2\text{-}2)$$

$$v_{0r} = \tfrac{1}{3} (v_{ar} + v_{br} + v_{cr})$$

The stator abc phase currents can be determined from the stator qd0 currents using the inverse transformation:

$$[T_{(dq0)}^{s}]^{-1} = \begin{bmatrix} 1 & 0 & 1 \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} & 1 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} & 1 \end{bmatrix} \qquad (2\text{-}3)$$

The stator abc phase currents will be:

$$i_{as} = i_{qs}^{s} + i_{0s}$$

$$i_{cs} = -\tfrac{1}{2} i_{qs}^{s} + \tfrac{\sqrt{3}}{2} i_{ds}^{s} + i_{0s} \qquad (2\text{-}4)$$

$$i_{bs} = \tfrac{-1}{2} i_{qs}^{s} - \tfrac{\sqrt{3}}{2} i_{ds}^{s} + i_{0s}$$

The equations of fluxes may be rearranged into the following form :

$$\Psi_{qs}^{s} = \omega b \int \{ v_{qs} + \frac{rs}{xls} (\Psi_{mq}^{s} - \Psi_{qs}^{s}) \} dt$$

(2-5)

(2-5) $$\Psi_{ds}^{s} = \omega b \int \{ v_{ds} + \frac{rs}{xls} (\Psi_{md}^{s} - \Psi_{ds}^{s}) \} dt$$

$$\Psi_{qr}^{rs} = \omega b \int \{ v_{qr}^{rs} + \frac{\omega r}{\omega b} \Psi_{dr}^{rs} + \frac{r_r}{x_{lr}} (\Psi_{mq}^{s} - \Psi_{qr}^{rs}) \} dt$$

$$\Psi_{dr}^{rs} = \omega b \int \{ v_{dr}^{rs} - \frac{\omega r}{\omega b} \Psi_{qr}^{rs} + \frac{r_r}{x_{lr}} (\Psi_{md}^{s} - \Psi_{dr}^{rs}) \} dt$$

$$i_{0s} = \tfrac{\omega b}{xls} \int (v_{0s} - i_{0s} r_s) dt$$
$$i_{0r} = \tfrac{\omega b}{xlr} \int (v_{0r} - i_{0r} r_r) dt \qquad (2\text{-}6)$$

$\Psi_{qs}^{s} and \Psi_{ds}^{s}$: Stator fluxes in q and d axis.

$\Psi_{qr}^{rs} and \Psi_{dr}^{rs}$: Rotor flux in q and d axis.

$\Psi_{mq}^{s} and \Psi_{md}^{s}$: magnetizing flux in q and d axis.

Where,(w_b) is the based speed(synchronous speed), (r_s,r_r) stator and rotor resistances,(x_{ls},x_{lr}) stator and rotor leakage reactances,(i_{0s},i_{0r}) zero sequence stator and rotor currents[17].

The torque equation is :

$$\mathrm{T}_{em} = \tfrac{3}{2} \tfrac{\mathrm{P}}{2\omega_b} (\Psi_{ds}^{s} i_{qs}^{s} - \Psi_{qs}^{s} i_{ds}^{s}) \qquad (2\text{-}7)$$

The equation of motion of the rotor is obtained by equating the inertia torque to accelerating torque , that is:

$$J\,\frac{d\omega_{rm}}{dt} = T_{em} + T_{mech} - T_{damp} \tag{2-8}$$

T_m is mechanical torque, T_{damp} is the damping torque, J is inertia constant

2.3.2 abc to dq transformation

This VI assumes that $I_a+I_b+I_c=0$, where I_a is the value of the a current, I_b is the value of the b current, and I_c is the value of the c current of the three-phase current[18].

The following equations convert three-phase current to direct and quad current:

$$I_d = \frac{2}{3}\left(I_a \cos\theta + I_b \cos\left(\theta - \frac{2}{3}\pi\right) + I_c \cos\left(\theta + \frac{2}{3}\pi\right)\right)$$

$$I_q = -\frac{2}{3}\left(I_a \sin\theta + I_b \sin\left(\theta - \frac{2}{3}\pi\right) + I_c \sin\left(\theta + \frac{2}{3}\pi\right)\right) \tag{2-9}$$

Where
I_d is the d or direct current;
I_q is the q or quad current;
θ is the rotor position in radians.

The values of I_d and I_q are also derived from the following equations:

$$I_d = \alpha\cos\theta + \beta\sin\theta \tag{2-10}$$

$$I_q = -\alpha\sin\theta + \beta\cos\theta$$

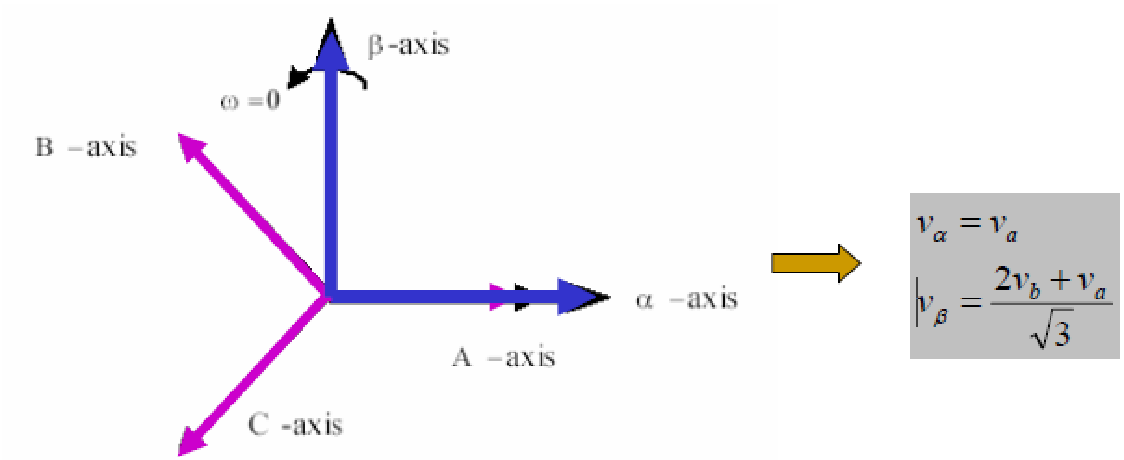
Where

$$\alpha = I_a \qquad (2\text{-}11)$$

$$\beta = \frac{1}{\sqrt{3}} I_a + \frac{2}{\sqrt{3}} I_b \qquad (2\text{-}12)$$

2.3.2.1 Clark Transformation

The transformation of stationary circuits to a stationary reference frame was developed by E. Clarke.The stationary two-phase variables of Clarke's transformation are denoted as α and β, α-axis and β-axis are orthogonal[15].



In order for the transformation to be invertible, a third variable,known as the zero-sequence component, is added. The resulting transformation is where *f* represents voltage, current, flux linkages, or electric charge.[19]

The transformation matrix T:

$$\lfloor f_{dqs} \rfloor = \lfloor T_{dqs} \rfloor * \left[f_{abc} \right] \tag{2-13}$$

$$\left[T_{dqs} \right] = \frac{2}{3} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \tag{2-14}$$

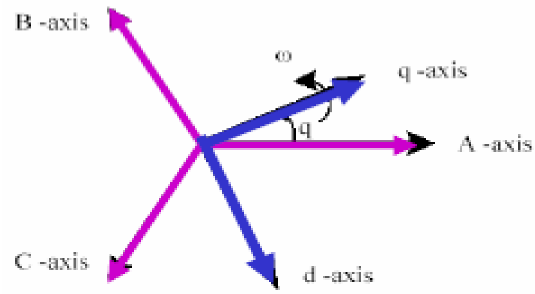
The inverse transformation is given by:

$$\left[T_{dqs} \right]^{-1} = \frac{2}{3} \begin{bmatrix} 1 & 0 & 1 \\ \frac{-1}{2} & \sqrt{\frac{3}{2}} & 1 \\ -\frac{1}{2} & -\sqrt{\frac{3}{2}} & 1 \end{bmatrix} \tag{2-14}$$

2.3.2.2 Parck’s Transformation

In the late 1920s, R.H. Park introduced a new approach to electric machine analysis. He formulated a change of variables associated with fictitious windings rotating with the rotor.He referred the stator and rotor variables to a reference frame fixedon the rotor.From the rotor point of view, all the variables can be observed as constant values. Park’s transformation, a revolution in machine analysis, has the unique property of eliminating all time varying inductances from the voltage equations of three-phase ac machines due to the rotor spinning[19].

- Park's transformation is a well-known three-phase to two-phase transformation in synchronous machine analysis.



$$\begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} = \begin{bmatrix} \cos\theta_S & -\sin\theta_S & 1 \\ \cos(\theta_S - \frac{2\pi}{3}) & -\sin(\theta_S - \frac{2\pi}{3}) & 1 \\ \cos(\theta_S - \frac{4\pi}{3}) & -\sin(\theta_S - \frac{4\pi}{3}) & 1 \end{bmatrix} \begin{bmatrix} v_{sd} \\ v_{Sq} \\ v_{So} \end{bmatrix}$$

$$\begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} = [P(\theta_S)] \begin{bmatrix} v_{sd} \\ v_{sq} \\ v_{so} \end{bmatrix} \text{ and } \begin{bmatrix} v_{sd} \\ v_{Sq} \\ v_{So} \end{bmatrix} = [P(\theta_S)]^{-1} \begin{bmatrix} v_{s1} \\ v_{S2} \\ v_{S3} \end{bmatrix}$$

The Park's transformation equation is of the form

$$\lfloor f_{dq0} \rfloor = \lfloor T_{dq0}(\theta_d) \rfloor \lfloor f_{abc} \rfloor \qquad (2\text{-}16)$$

$$\lfloor T_{dq0}(\theta_d) \rfloor = \begin{bmatrix} \cos\theta_d & \cos(\theta_d - \frac{2\pi}{3}) & \cos(\theta_d + \frac{2\pi}{3}) \\ -\sin\theta_d & -\sin(\theta_d - \frac{2\pi}{3}) & -\sin(\theta_d + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \qquad (2\text{-}17)$$

θ is the angular displacement of Park's reference frame. The angular displacement θ must be continuous, but the angular velocity associated with the change of variables is unspecified.The frame of reference may rotate at any constant, varying angular velocity, or it may remain stationary[19].

The angular velocity of the transformation can be chosen arbitrarily to best fit the system equation solution or to satisfy the system constraints.The change of variables may be applied to variables of any waveform and time sequence; however, we will find that the transformation given above is particularly appropriate for an a-b-c sequence.

2.4 Slip

It is a fact that slip in the motor is dependent to a great extent on the parameters associated with motor performance. Slip of an induction motor varies in the same proportion as the load torque, rotor resistance, and the voltage frequency of stator. The induction speed of the wounded motor can be controlled by increasing the slip. The traditional way of increasing slip is by subjecting the rotor circuit to increased resistance. Lower horsepower motors have higher slip as compared to high horsepower motors since small motors have the tendency to generate greater resistance in the rotor winding[20].

In the condition of induction motor slip, the voltage remains the maximum and slip is 100% as the motor starts rotating but both slip as well as voltage reduce as soon as the rotor starts to turn. Frequency is directly proportional to the slip, i.e. *frequency decreases with decrease in slip*. Inductive reactance of an induction motor depends on both frequency as well as slip. When the rotor is stationary, the frequency, slip, and inductive reactance are at the maximum level. When the rotor turns, the inductive reactance remains low and power factor reaches to 1. The inductive reactance changes with slip because the rotor is the summation of constant resistance and changeable inductive reactance[20].

As the motor starts rotating, the inductive reactance remains high and the impedance is inductive, however, as soon as the speed of the motor increases, the inductive reactance decreases and becomes equal to the resistance. As discussed earlier, the slip generates torque. Since the slip never becomes 0, it drives the rotor in induction motors. If the slip becomes zero, then the rotor field catches the stator field and the force between the rotor and stator becomes 0 and finally the rotor stops rotating. This creates attraction between rotor and stator and the slip becomes effective[20].

Concept of SLIP

The interaction of currents that is flowing in rotor and stator bars generate a torque. In an actual operation, the rotor speed always lags the magnetic field’s speed, thereby allowing the rotor bars to cut the magnetic lines of force and produce torque. This speed difference is called slip.[20]

Therefore, the difference between the synchronous speed Ns of the rotating stator field and the actual rotor speed N is called slip.

The slip increase with load and is necessary for torque production. Slip speed is equal to the difference between rotor speed and synchronous speed. Percent slip is slip multiplied by 100[20].

Slip is expressed as a percentage of synchronous speed i.e.,

% of slip,s=(Ns-N/Ns) *100 (2-18) (2-18)

The quantity Ns-N is sometimes called as slip speed.

When the rotor is stationary,slip s=1 or 100%

In an induction motor ,change in slip from no load to full load is hardly 0.1%to 3% so that it is essentially a constant speed motor.

Three phase induction motor is a particular form of transformer which has secondary winding rotating. In transformer, the frequency of primary and secondary winding is same but in induction motor the frequency of emf induced in rotor depends on slip.

Rotor emf frequency=s*sf ,

Where, sf is frequency of applied voltage to stator[21].

2.5 Operating modes

2.5.1 generating mode

The construction of induction generator is same as of induction motor. In case of induction generator the rotor speed is advanced with respect to stator magnetic field rotation.
The rotor is being driven at a speed more than synchronously rotating magnetic field for prime mover speed above synchronous speed. Rotating flux cut the rotor conductors in a direction opposite to that during motoring mode. So rotor generated emf, rotor current and hence its stator components change their signs. When the speed during induction generator operation is not synchronous then it is called an asynchronous generator[20,21].

Classification of Induction Generators:
For hydro and wind power plants, the induction machine has great advantages because of its easy operation as either a motor or generator. It has different application in different areas[22].

Induction generators can be classified on the basis of excitement process as :
Grid connected induction generator
Self-excited induction generator

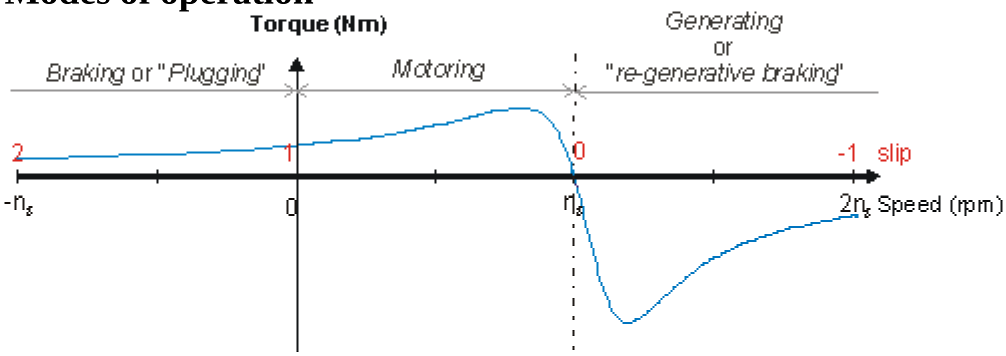
Further induction generators are classified on the basis of rotor construction as :
Wound rotor induction generator
Squirrel cage induction generator

Depending upon the prime movers used and their locations, generating schemes can be broadly classified as under
Constant speed constant frequency [CSCF]
Variable speed constant frequency [VSCF]

Variable speed variable frequency [VSVF]

2.5.2 motoring mode

Modes of operation



Torque-Speed Curve

As mentioned when considering the induction machine torque-speed curve, the three main modes of operation are braking, motoring and generating. We have concentrated on analysis of a machine being used as a motor, but the analysis is general for other modes of operation[21].

Motoring: Small Slips

In usual operation of an induction machine, as a motor attached to a fixed frequency supply, there is little control over the operating point: the motor will operate at the speed where the load torque is equal and opposite to the motor torque[22].

Considering again the torque speed equation:

$$\tau = \frac{3V_{TH}^2}{\left(R_{TH} + \frac{R_2}{s}\right)^2 + \left(X_{TH} + X_2\right)^2} \frac{R_2}{s} \frac{1}{\omega_s}$$

If the slip is small then

$$\frac{R_2}{s} \gg \left| R_{TH} + j\left(X_{TH} + X_2\right) \right|$$

and the torque equation can be re-written as

$$\tau \approx \frac{3V_{TH}^2}{R_2 \omega_s} s$$

It can be seen that at small slips, torque is proportional to slip, doubling the load will approximately double the slip.

It is clear from the above analysis that there is very little speed variation in an induction machine if the synchronous speed is constant. The rotor will rotate at a small slip, slightly below synchronous speed. If operation at more than one fixed speed is required, it is necessary to change the synchronous speed. [22]

Considering the equation for synchronous speed

$$n_s = \frac{120 f_e}{p}$$

CHAPTER THREE

Modeling of 3 Phase IM using MatLab/Simulink

3.1 Modeling of three phase induction machine In matlab/simulink.

The model of three phase induction machine (1hp test machine) is shown in Figure (3-1), This machine designed in matlab/simulink and tested in generating mode and motoring mode [20]:

a- For generating mode by applying positive mechanical torque to the rotor and the result is negative electromotive torque.

b- For motoring mode by applying negative mechanical torque constant load to the rotor and the result is positive electromotive torque.

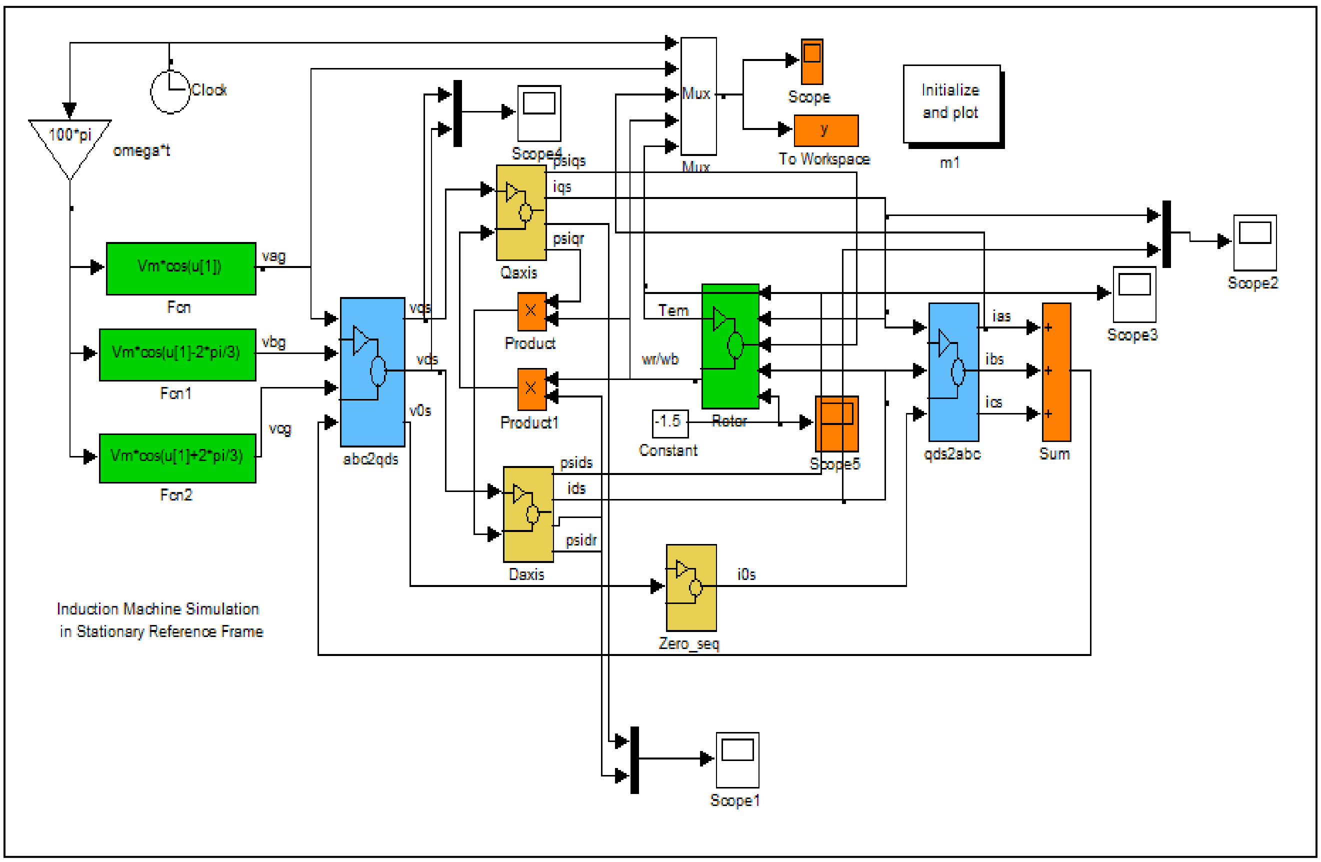


Figure (3-1): Model of three phase induction machine in matlab

3.2. Implementation of the model of IM in MatLab/SIMULINK

3.2.1 Implementation of the rotor circuit in Matlab/SIMULINK

The detail of rotor block are shown in Figure (3-2) .

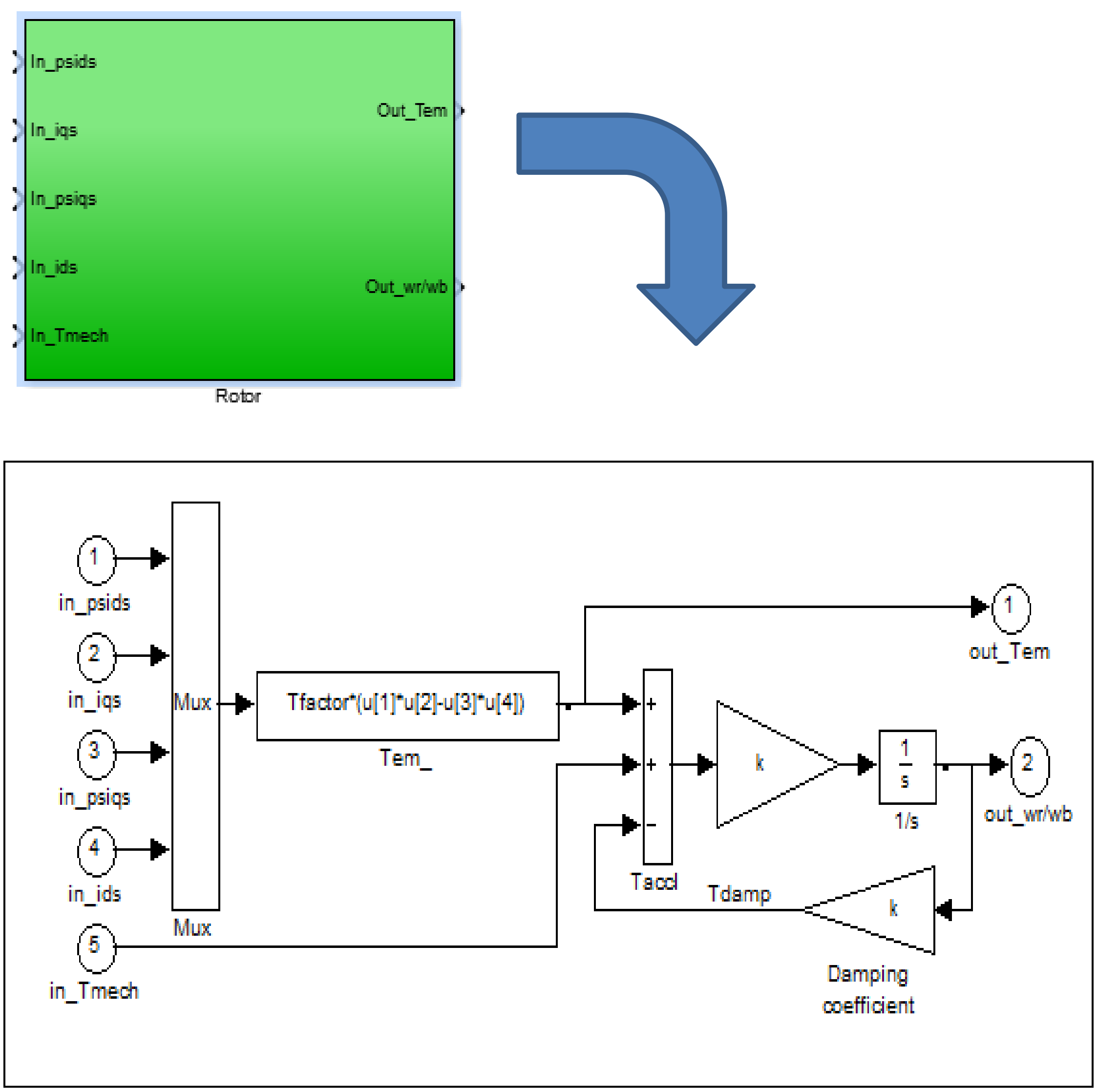


Figure (3-2): Inside rotor block

3.2.2 Modeling of the the transformation block

3.2.2.1 The transformation block (abc to dq)

The transformation block (abc to dq) illustrated in Figure(3-3).

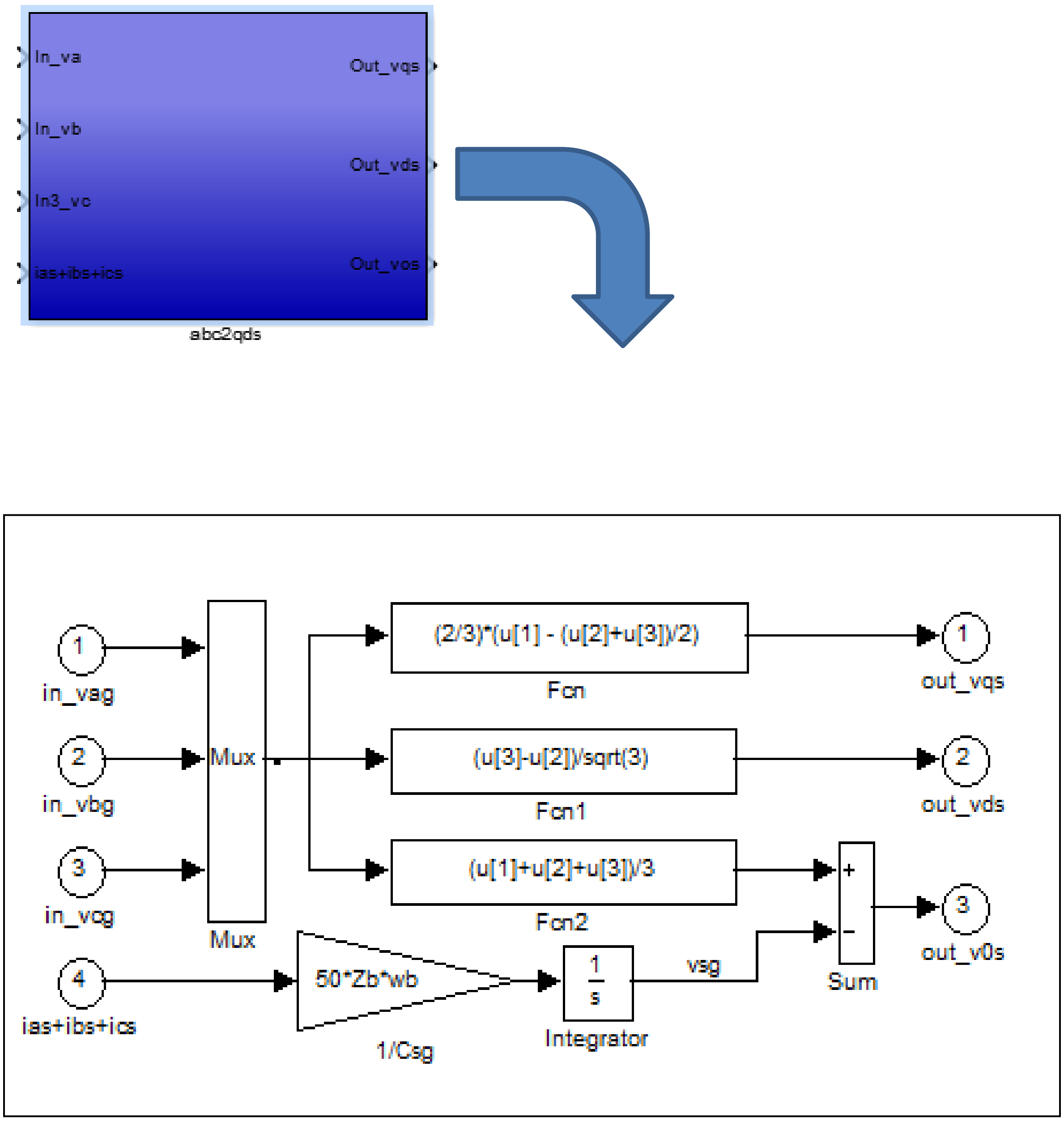


Figure (3-3): The transformation block (abc to dq)

3.2.2.2 The transformation block (dq to abc)

The transformation block (dq to abc) illustrated in Figure(3-4).

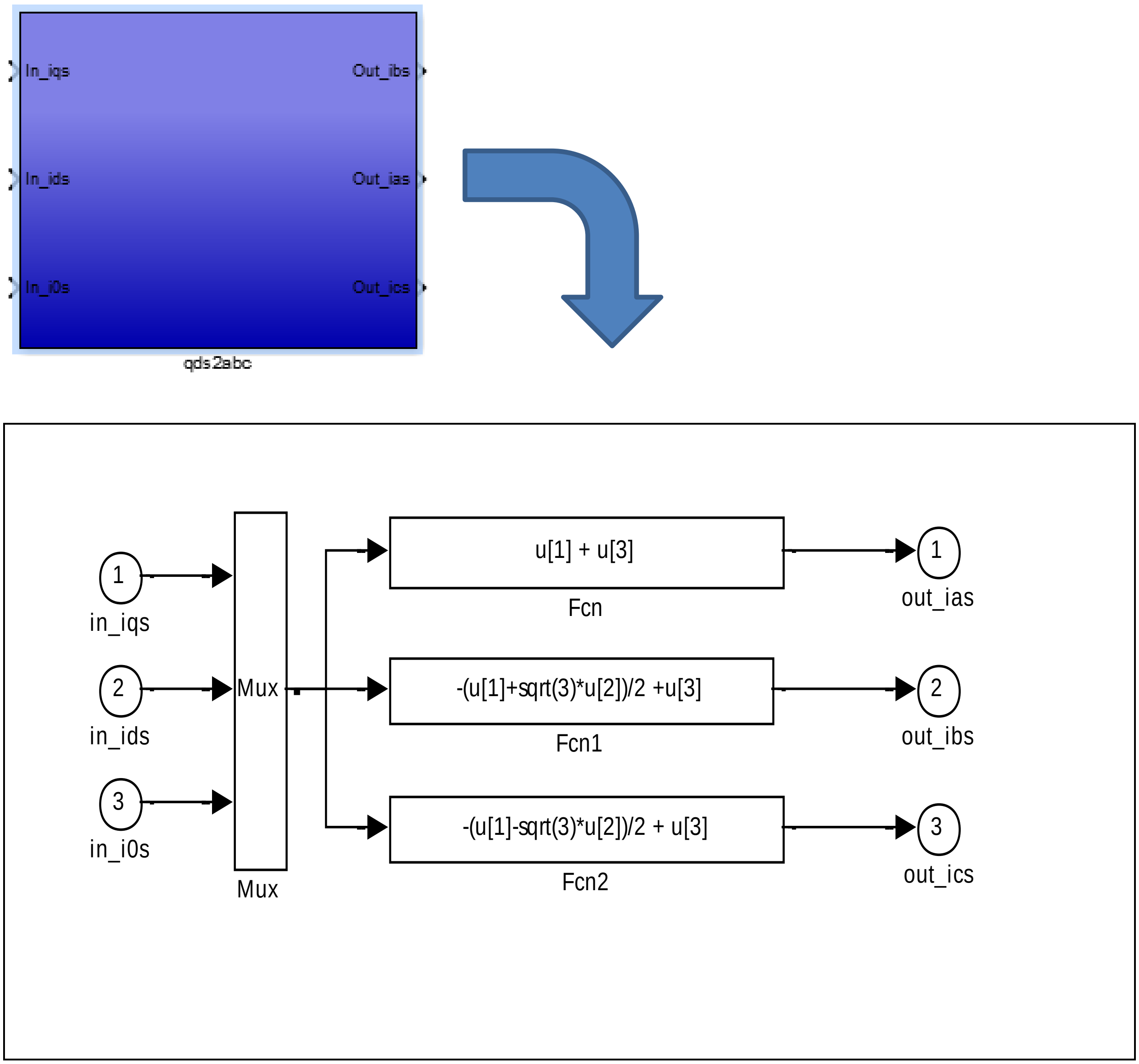


Figure (3-4): The transformation block (dqs2abc)

3.3 Modeling of the the DQ0 blocks in matlab/Simulink

3.3.1 D _axis block

The (d_axis) are showing in detailed in Figure(3-5).

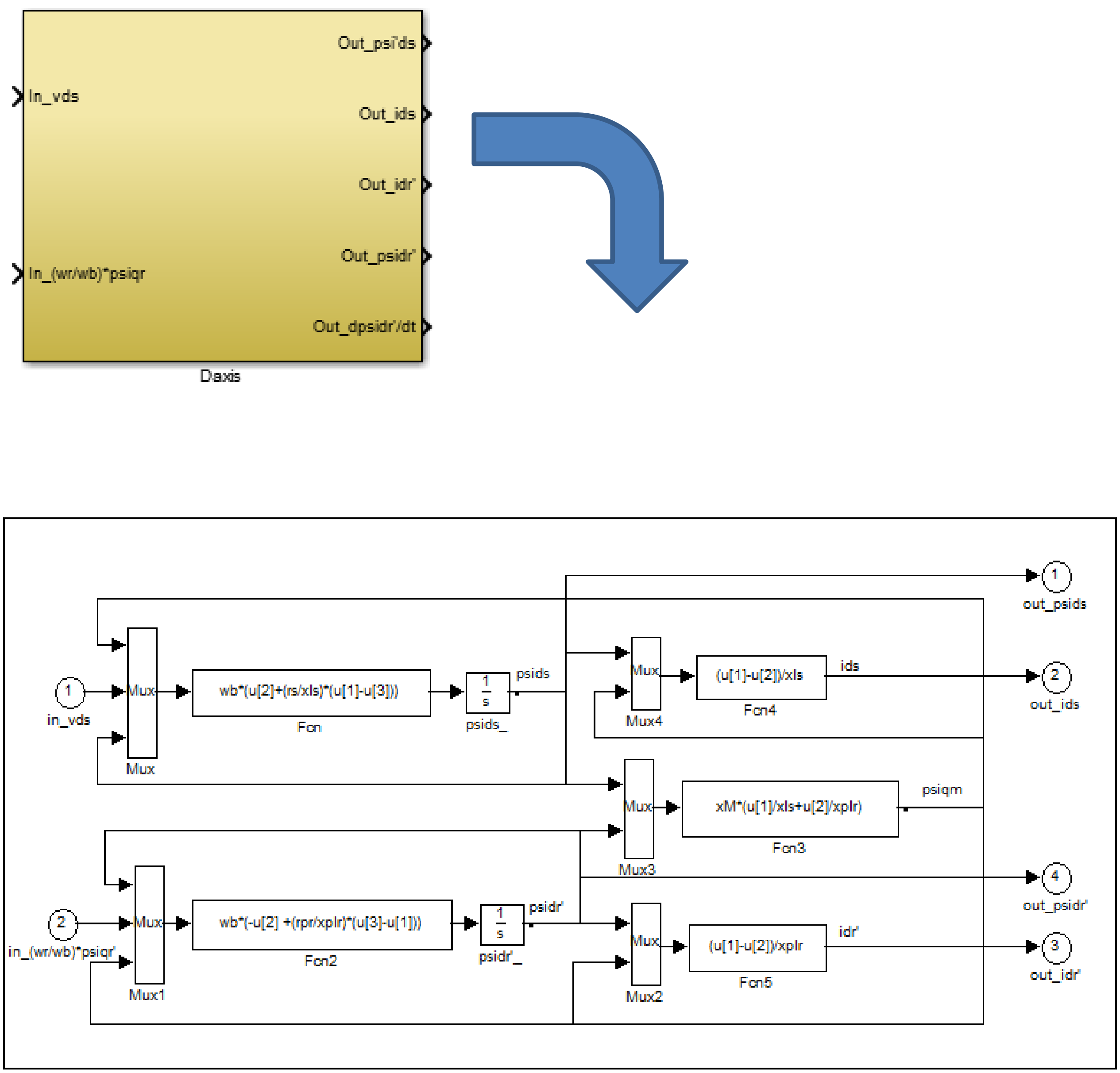


Figure (3-5): Inside d_axis block

3.3.2 Q _axis block

The (q_axis) are showing in detailed in Figure(3-6).

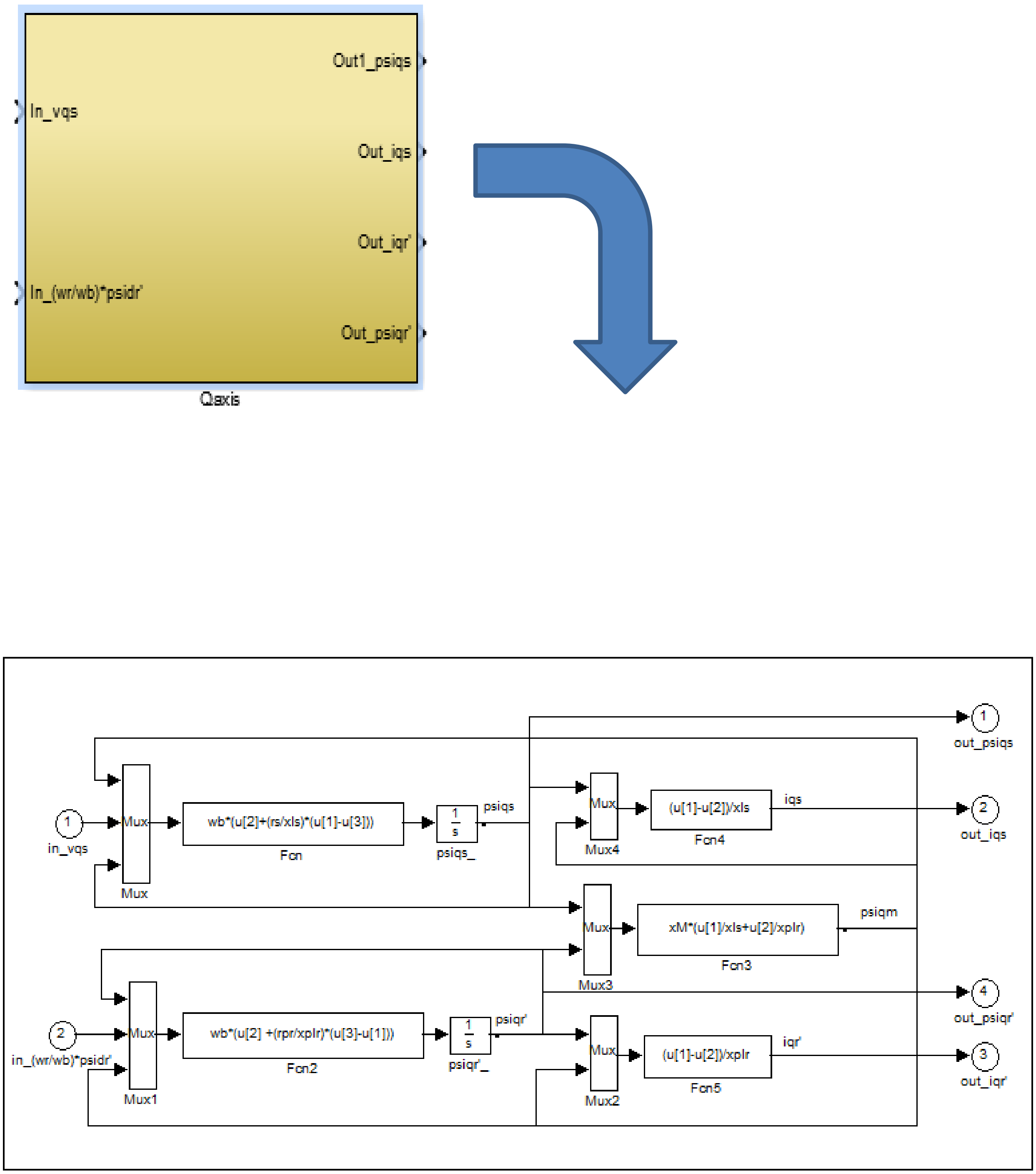


Figure (3-6): Inside q_axis block

3.3.3 0 _axis block

The (0_axis) are showing in detailed in Figure(3-7).

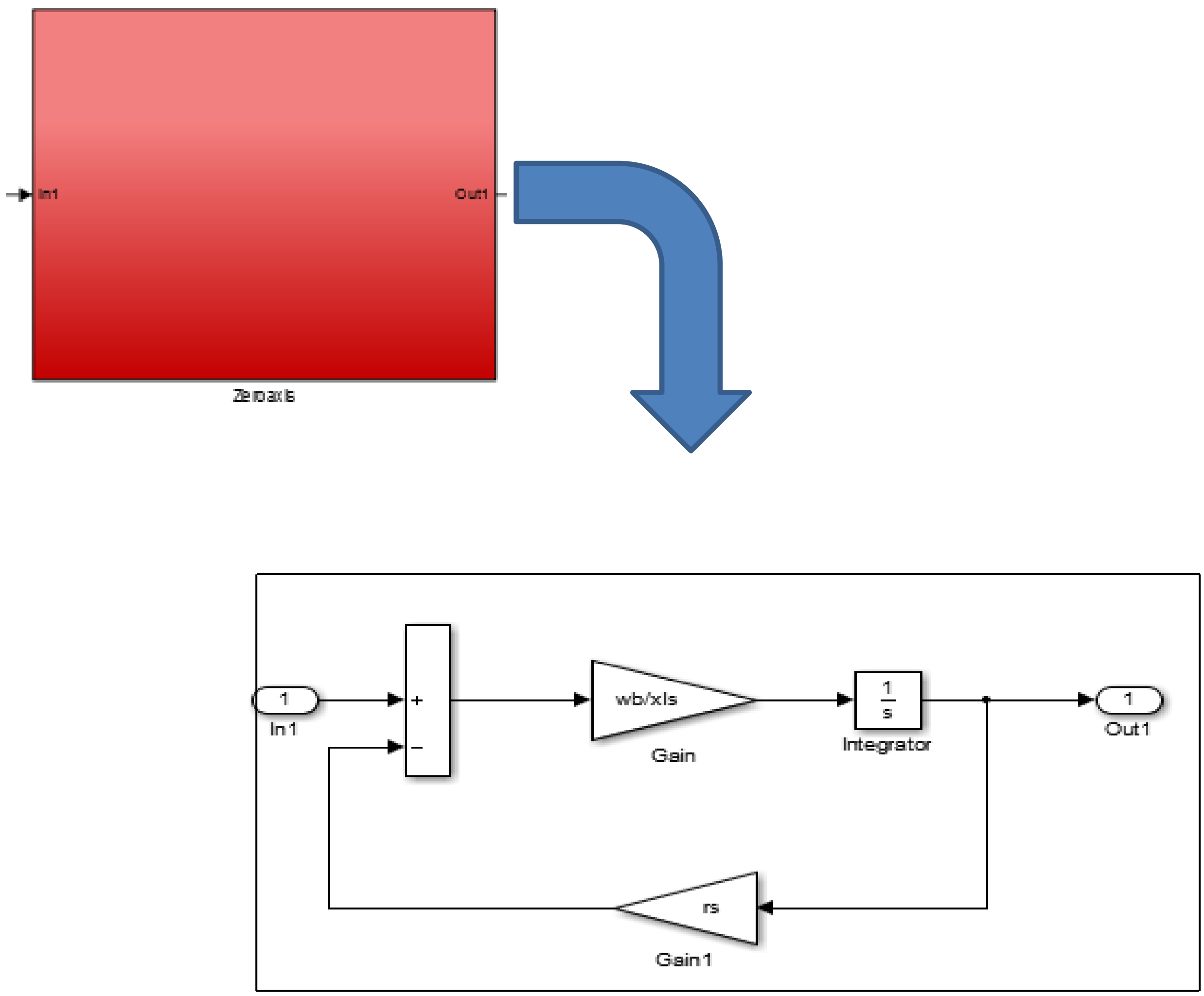


Figure (3-7): Inside 0_axis block

CHAPTER FOUR

Simulation Results and Discussion

4.1 Introduction

In this chapter we show and discuss the results of the three phase IM Modeled and implemented using Matlab/Simulink

4.2 IM drive model simulation result

The simulation results of (1HP, three phase, 50hz, four pole , 220v, R_s=3.35 ohm , R_r =1.99 ohm, L_{ls} = L_{lr} = 6.94 mH , L_m=163.73 mH, Jrotor =0.1 kgm^2,Tm= constant value (1.5), damping torque=0), are shown as next:

1-The stator voltages and currents in stationary reference frame are shown in Figure (4-1-a) & Figure (4-1-b), and the angle between d and q is (90 degree).

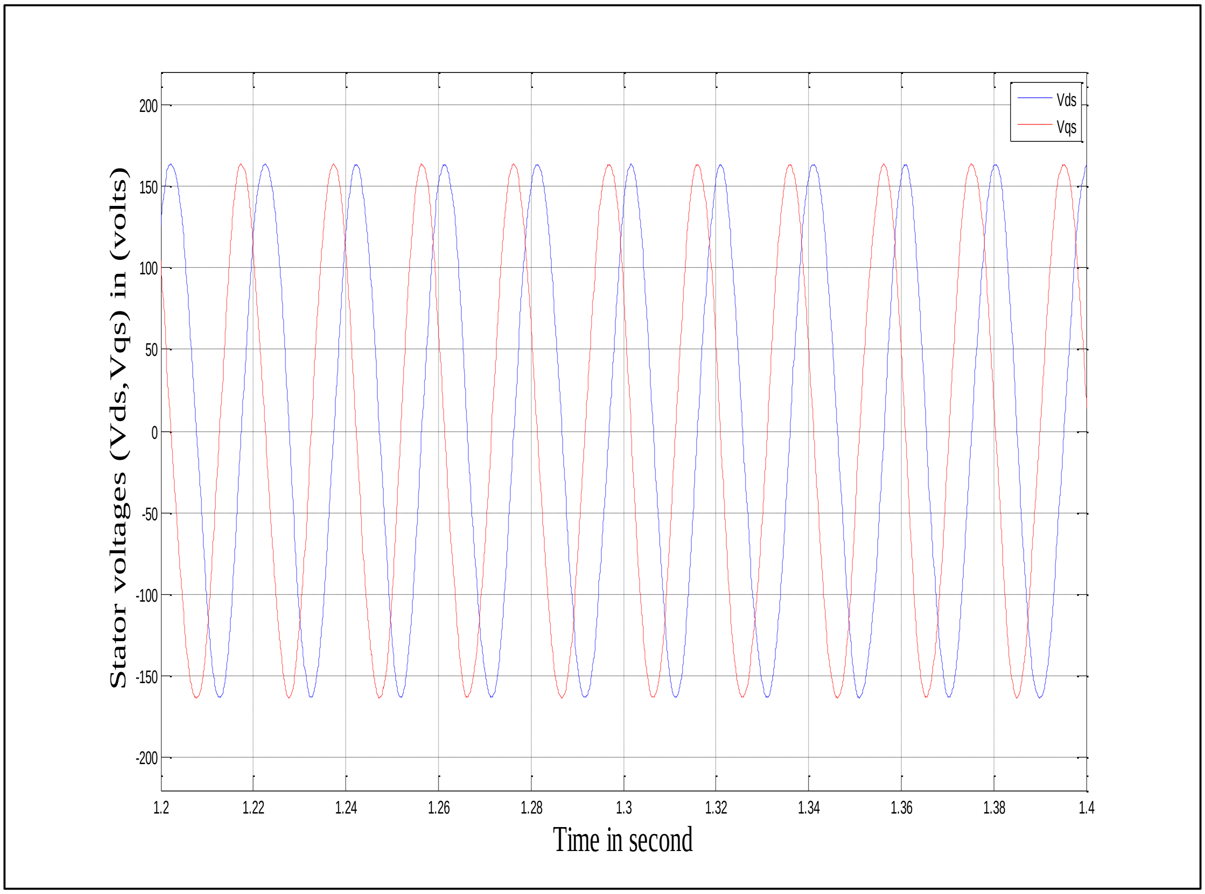


Figure (4-1-a): Stator dq voltages

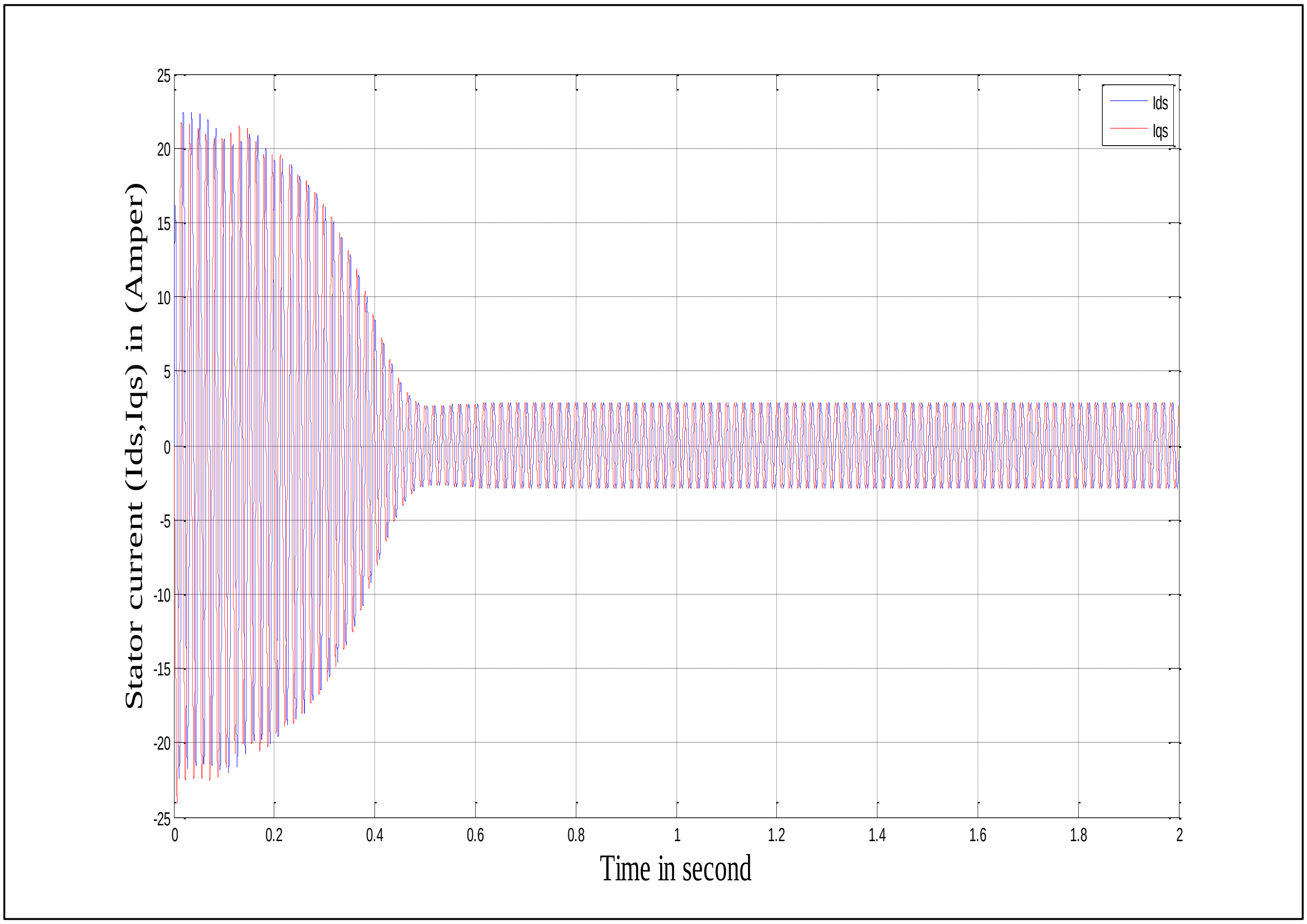


Figure (4-1-b): Stator dq currents

2- The rotor currents in stationary reference frame are shown in Figure (4-2).

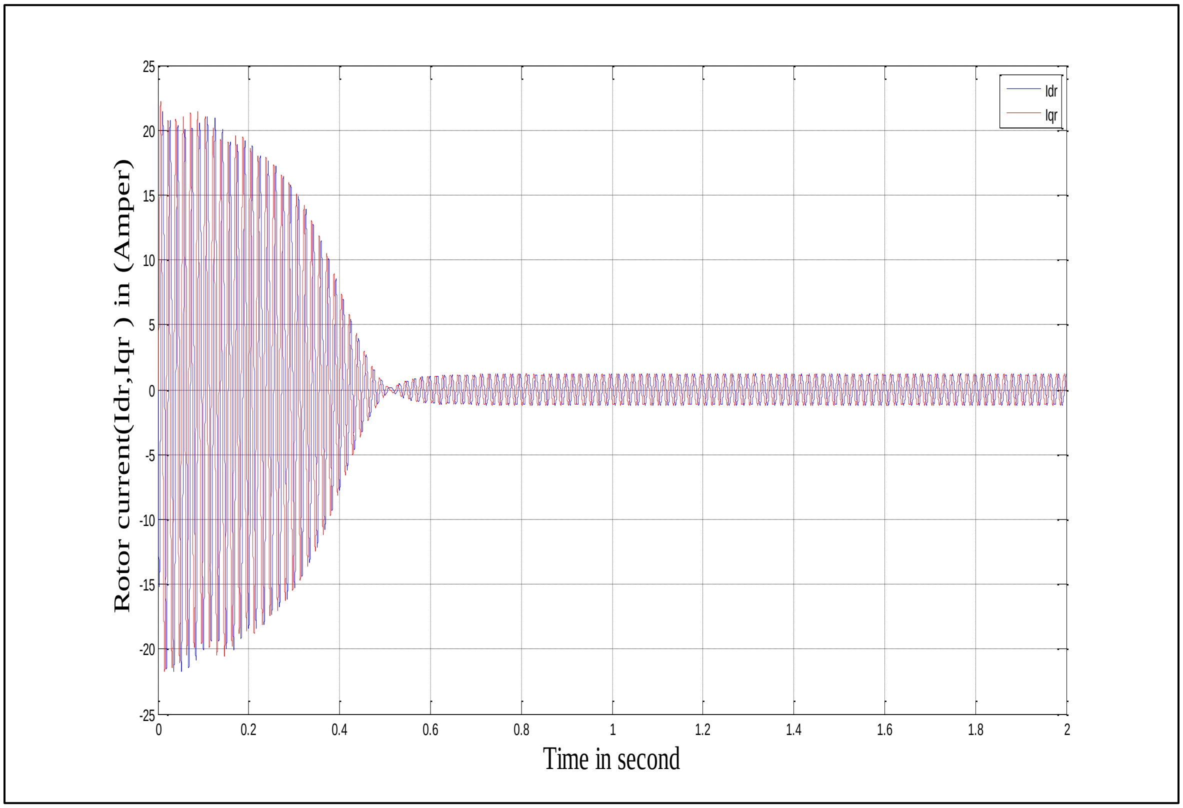


Figure (4-2): Rotor dq currents

3-Figure (4-3) show the electromotive torque (T_{em}) is negative which means the machine in generating mode the input torque is positive, (T_m =1.5).

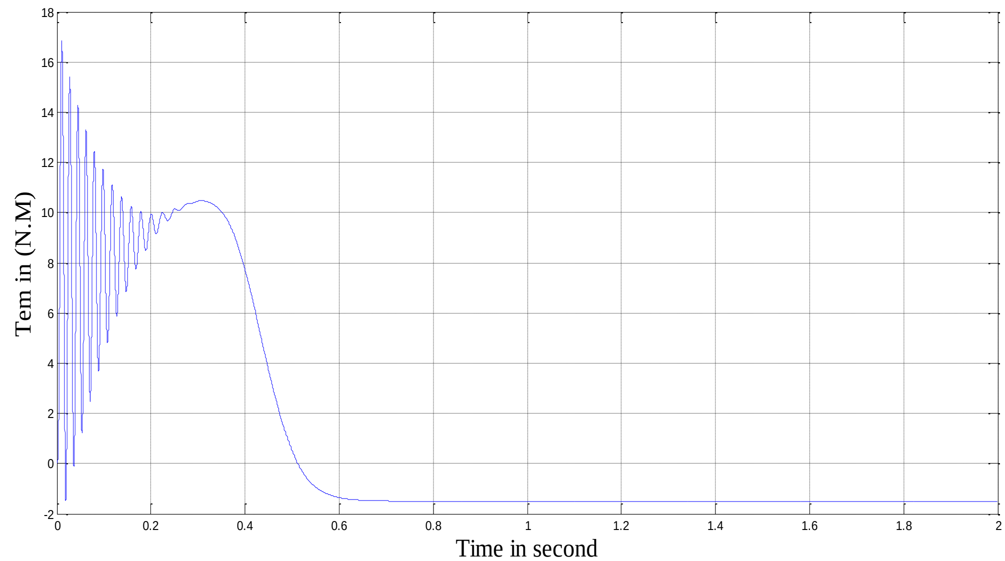


Figure (4-3): The electromotive torque (Tem) in generating mode

4-Figure (4-4) show the electromotive torque (T_{em}) is positive which means the machine in generating mode the input torque is negative, (T_m = -1.5).

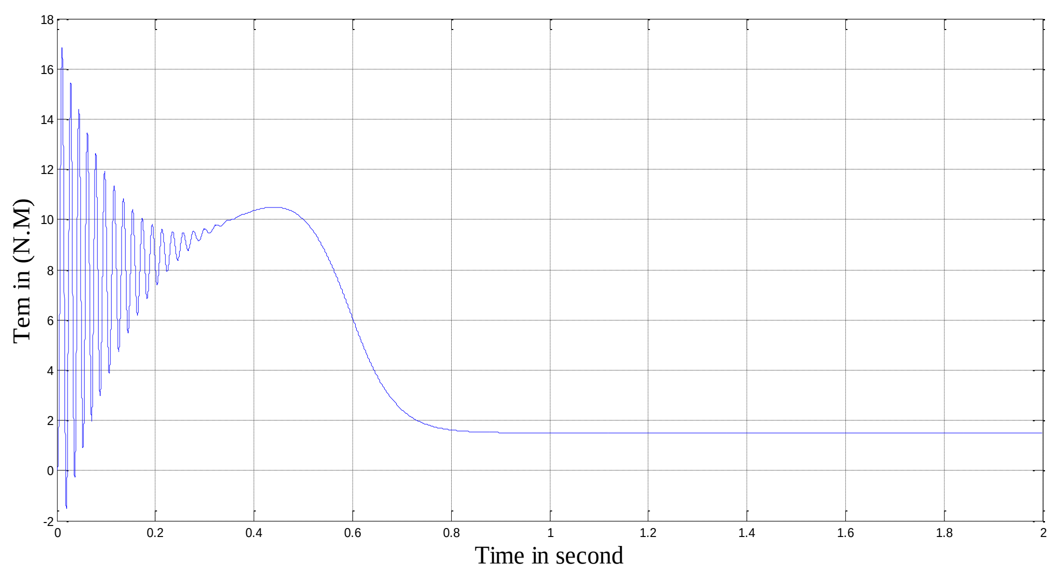


Figure (4-4): The electromotive torque (Tem) in motoring mode

5- The ids & iqs currents of stator are showing in figure (4-5) & (4-6)

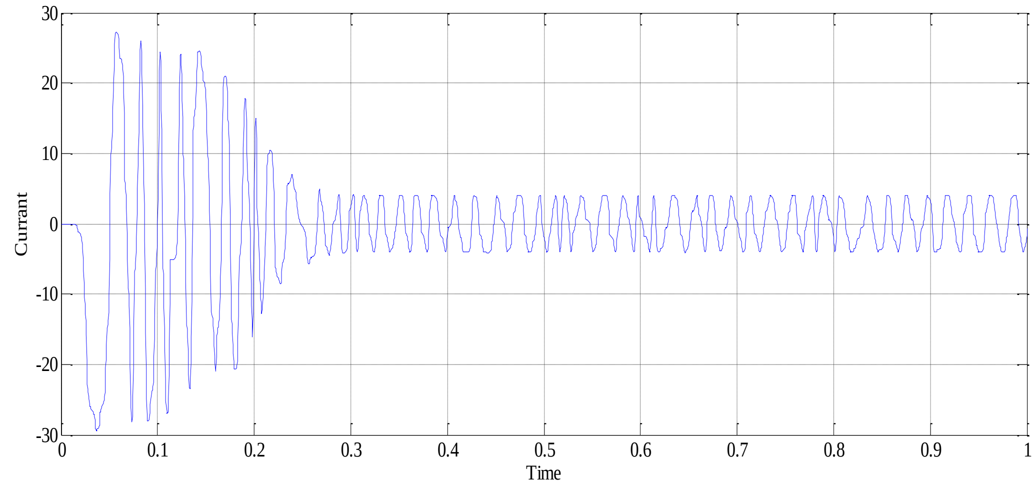


Figure (4-5): ids currents

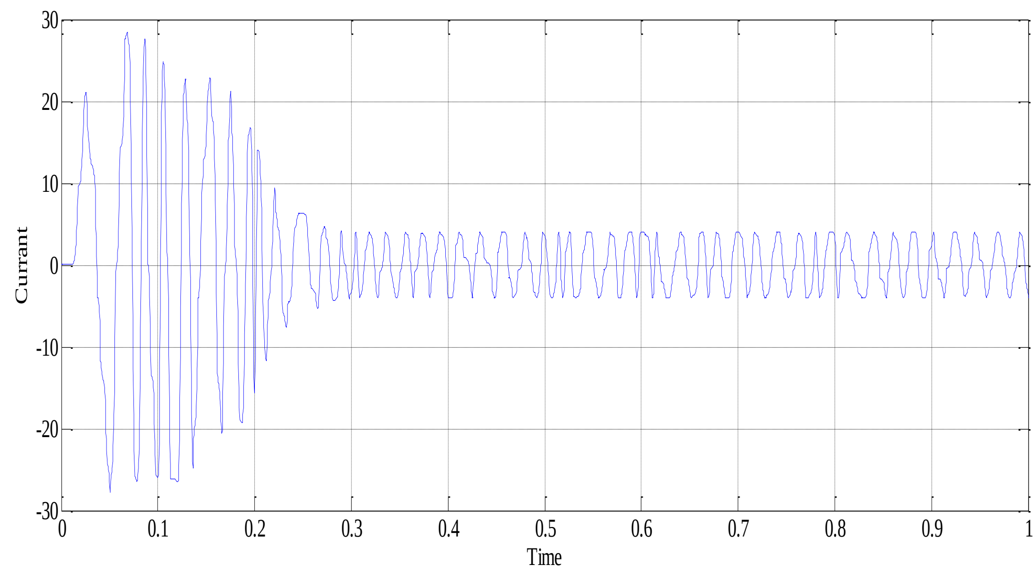


Figure (4-6): iqs currents

6- The psids & psiqs currents of stator are showing in figure (4-7) &(4-8).

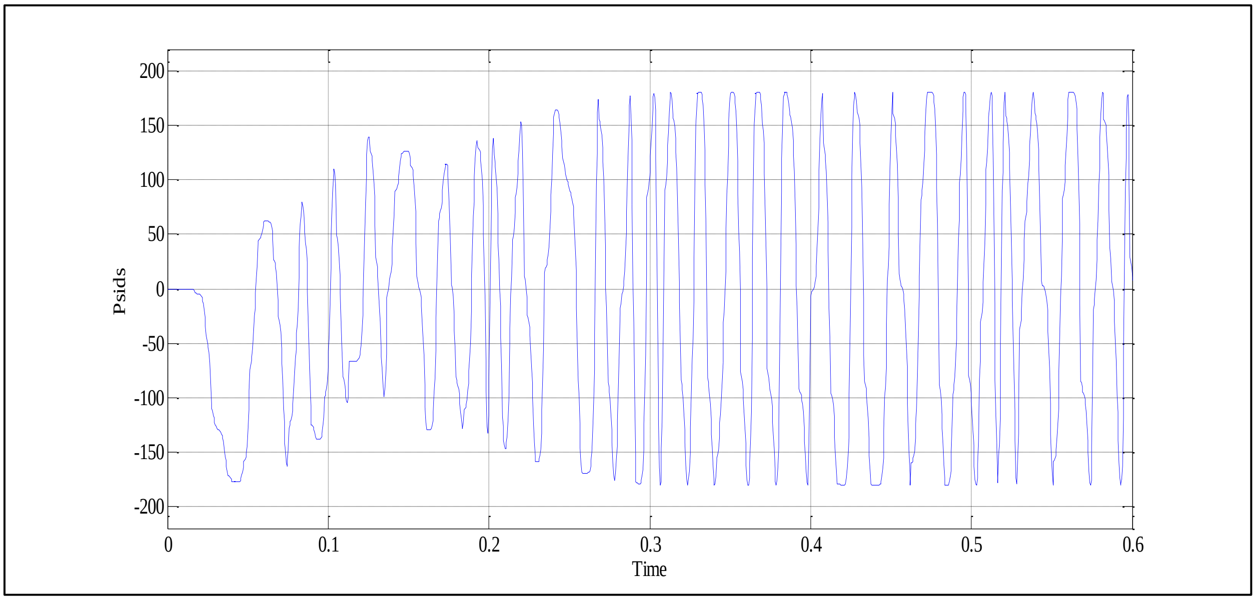


Figure (4-7): psids currents

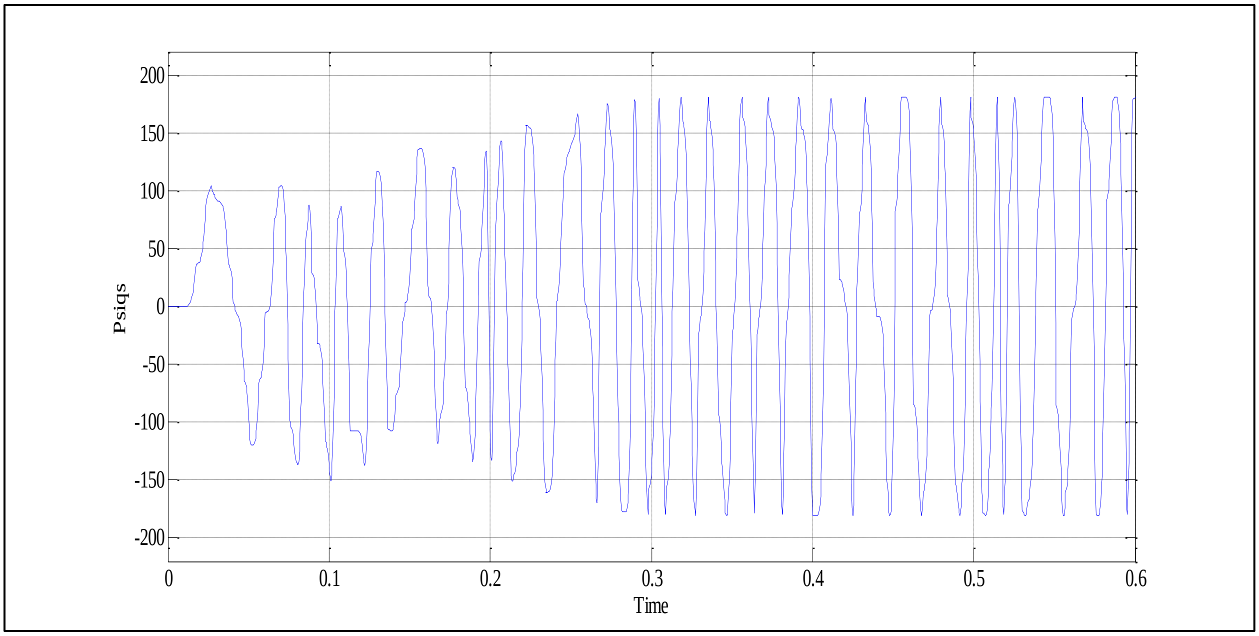


Figure (4-8): psiqs currents

DISCUSSION

In figure (4-1) show the stator voltage in clarck's form that illustrate the behavior of($v_{d\,:}$ direct component) and ($v_{q:}$ quadratic component) and the phase difference between them is 90^0 .

figure (4-1-b)&(4-2) shows the current of stator and rotor in (dq clarck transform) and show the current in operation in both transient and steady state.

In figure (4-3) show the electromotive torque (T_{em}) in negative value at steady state because in generating mode the slip is negative.

In figure (4-4) show the electromotive torque (T_{em}) in positive value at steady state because in motoring mode the slip is positive.

in figure (4-5) &(4-6) show ids & iqs currents of stator.

In figure (4-7) &(4-8) show the flux of d-axis and q-axis and the phase difference of 90^0

CHAPTER FIVE

Conclusions and Suggestions for Future Work

5.1 conclusions

The model that implemented and design in matlab can operate in generating mode and motoring mode depending on the input torque negative and positive or (source or load)and that behavior Of induction machine and confirm the flexibility of the operation of induction machine and give the important of induction machine around the world.

5.2 Suggestions for future work

1-controlling speed of three phase induction machine .
2-simulation of three synchronous machine in MATLAB/SIMULINK

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Appendix A: Parameters of IM

% Parameters of 20 hp, three-phase induction machine

Sb = 20*746;	% rating in VA
Vrated = 220;	% rated line-to-line voltage in V
pf = 0.853;	% rated power factor
Irated = Sb/(sqrt(3)*Vrated*pf);	% rated rms current
P= 4;	% number of poles
frated = 60;	% rated frequency in Hz
wb = 2*pi*frated;	% base electrical frequency
we=wb;	
wbm = 2*wb/P;	% base mechanical frequency
Tb = Sb/wbm;	% base torque
Zb=Vrated*Vrated/Sb;	%base impedance in ohms
Vm = Vrated*sqrt(2/3);	% magnitude of phase voltage
Vb=Vm;	
Tfactor = (3*P)/(4*wb);	% factor for torque expression
srated=0.0287;	% rated slip
Nrated = 1748.3;	% rated speed in rev/min
wmrated=2*pi*Nrated/60;	% rated speed in rad/sec
Trated = Sb/wmrated;	% rated torque
iasb= 49.68;	% rated rms phase current
rs = 0.1062;	% stator wdg resistance in ohms
xls = 0.2145;	% stator leakage reactance in ohms
xplr = xls;	% rotor leakage reactance in ohms
xm = 5.8339;	% stator magnetizing reactance in ohms
rpr = 0.0764;	% referred rotor wdg resistance in ohms
XM= 1/(1/xm + 1/xls + 1/xplr);	
J = 2.8;	% rotor inertia in kg m2
H = J*wbm*wbm/(2*Sb);	% inertia constant in sec
Domega = 0;	% rotor damping coefficient

الخلاصة

هذا المشروع يوضح نموذج محرك كهربائي حثي ثلاثي الطور تم تصميمه وكتابة معادلاته بواسطة برنامج التحليل الرياضي اعتمادا على تحويل كلارك للتحويل من ثلاثي الطور الى ثنائي الطور .

وتم تشغيل النموذج ومحاكاته بواسطة برنامج التحليل الرياضي لكلا الحالتين:
في حالة الموطور وحالة المولدة

وزارة التعليم العالي والبحث العلمي

جامعة ديالى

كلية الهندسة

قسم هندسة الحاسوب و البرمجيات

محاكاة محرك كهربائي ثلاثي الطور بأستخدام برنامج التحليل الرياضي

مشروع مقدم الى قسم هندسة الحاسبات والبرمجيات
في جامعة ديالى – كلية الهندسة كجزء من متطلبات نيل درجة
البكالوريوس في هندسة الحاسبات والبرمجيات

من قبل

اية محمد و احمد خضير

بإشراف

م.م. سراج منهل حميد

2016