

CHAPTER ONE

INTRODUCTION

1.1 General Concepts:

As general rule of the Induction motor conversion of electrical power in to mechanical power and classified induction motor to type squirrel cage motors and wound motors, and The constructional of the induction motor consists essentially of two major parts Stator and rotor.

The general principle of the Induction motor the stator winding connected to a balanced three phase source, and to the rotor winding by Induction from the stator balanced poly-phase stator and rotor currents create stator and rotor component m.m,fs waves of constant amplitude rotating in the air gap at synchronous speed and therefore stationary with respect to each other regardless of the mechanical speed of the rotor. The resultant of these mmfs creates the Resultant air gap flux density wave. Interaction of the flux wave and the rotor m.m.fs wave gives rise to torque. All the conditions are fulfilled for the production of steady value of torque at all speeds other than synchronous speed.

When the stator winding poly-phase Induction machine is excited by balanced poly-phase voltages a rotating magnetic field is produced in the air gap. The rotating field is traveling at synchronous speed. To examine the air gap flux and mmfs waves, the space fundamental component of the resultant air gap flux wave than travels past the rotor at slip speed and induces slip-frequency emfs in the rotor circuits.

With a cage rotor or with a coil wound rotor wound for the same number of poles as the Stator the slip frequency rotor circuits create an mmf whose space fundamental also travels at slip speed with respect to the rotor. the mmf and flux-density waves are thus stationary relative to each other and steady torque is produced by their interaction.

On no load with the rotor windings short circuited the machines runs at a speed vary close to the Synchronous speed at which the stator travelling –wave field revolves the rotor current is very small because only the loss torque (for winding and friction) the stator takes a corresponding active current which, with the core-loss current is the active no load current component the magnetizing current is match larger than the active current.

And power factor is low, rotor frequency is very small, inductive reactance has little effect. Starting of poly-phase Induction machine may be apply full voltage or with reduced voltage across the stator terminals reduced in voltage starting reducing the starting current. Yet it produces an objectionable reduction in the starting torque.

1.2 Problem statement:

When a voltage is applied to a3-phase induction motor the starting current is too large; in small or large motor it may reach 8 times of the rated current value.

This current causes disturbances in surrounding network. This disturbances can be avoided by applying a reduced voltage therefor in practice star delta starter is used to start until the machine has reached (60-80) percent of synchronous speed where upon full voltage is applied . When a voltage is reduced by 40 percent of it is rated value, the current also reduced by the same value .but the reduction in the voltage decreases the transient starting torque about one third.

1.3 Objective:

The objective of this project is to study the transient of three-phase induction machine during starting condition , by developing the mathematical model of the machine , and make a computer program to simulate the startup of a balanced three phase induction motor when directly connected to a balanced three phase supply by using MATLAB.

1.4 Methodology:

The method applied is converted the three phase induction motor to two phases without loss or any affection in dynamic performance by using phase transformation C_1 and convert two phase rotating axes to stationary axes by using commutator transformation C_2 .

Then the new voltages, current and impedance equations have been deduced and they have been used to find current and speed differential equations and then a MATLAB program has been used to solve these equation and to simulate the startup in order to Study and understand the dynamic performance of three phase induction motor.

1.5 Research Outline:

This research is presented in five chapters. The scope of each chapter is explained as follows: Chapter one:

Gives an introduction including general concepts, problem statement, objectives and methodology.

Chapter two:

The induction motor including construction, equivalent circuit, torque speed curve and power flow.

Chapter three:

Presents two points; First point the transient of three phase induction machine including switching , re-switching and electromechanical transient including change of load and fluctuating load , Second point transformation from three-phase to d-q axis and the Mathematical model of induction machine.

Chapter four:

Gives an Introduction to program and result.

Chapter five:

Present the result discussion, recommendation and appendix

CHAPTER TWO

THREE PHASE INDUCTION MACHINE

2.1 Three Phase Induction Machine:

The popularity of a 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. 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 DC 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. 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) AC machine in which electrical energy is converted into mechanical energy.

2.1.1 Advantages:

- * It has simple and rugged construction.
- * It is relatively cheap.

- * It requires little maintenance.
- * It has high efficiency and reasonably good power factor.
- * It has self-starting torque.

2.1.2 Disadvantages:

- * It is essentially a constant speed motor and its speed cannot be changed easily.
- * Its starting torque is inferior to DC shunt motor.

2.2 Construction of 3-phase Induction Motor:

The 3-phase induction motor as we said consist of two main parts:

2.2.1 Stator:

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. Stator is made up of number of stampings in which different slots are cut to receive 3-phase winding circuit which is connected to 3-phase AC supply. The three phase windings are arranged in such a manner in the slots that they produce a rotating magnetic field after AC supply is given to them. The windings are wound for a definite number of poles depending upon the speed requirement, as speed is inversely proportional to the number of poles, given by the formula:

$$N_s = \frac{120 \times f}{p} \quad (2.1)$$

The stator of the three phase induction motor consists of three main parts:

- * Stator Frame
- * Stator Core
- * Stator Winding or Field Winding

2.2.2 Rotor:

The rotor is a rotating part of induction motor. The rotor is connected to the mechanical load through the shaft. Rotor consists of cylindrical laminated core with parallel slots that carry conductor bars. Conductors are heavy copper or aluminum bars which fits in each slots. These conductors are brazed to the short circuiting end rings. The slots are not exactly made parallel to the axis of the shaft but are slotted a little skewed for the following reason, they reduce magnetic hum or noise and They avoid stalling of motor. The rotor, mounted on a shaft, is a hollow laminated core having slots on its outer periphery. The winding placed in these slots (called rotor winding) may be one of the following two types:

* Squirrel cage rotor:

Applications:

Squirrel cage induction motor is used in lathes, drilling machine, fan, blower printing machines etc.

* Wound rotor:

Application:

Slip ring induction motor are used where high starting torque is required i.e in hoists, cranes, elevator etc.

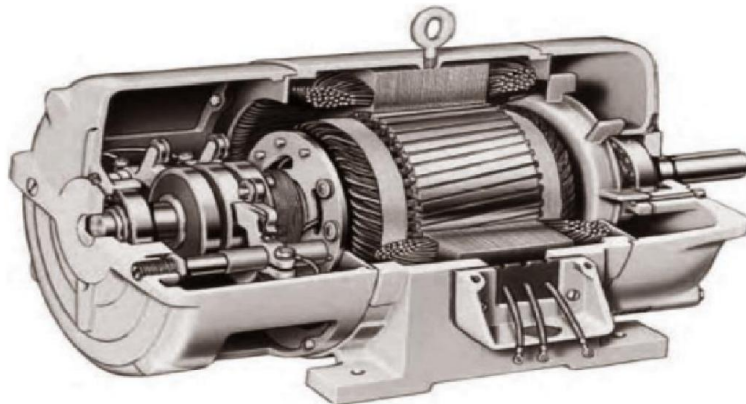


Figure 2.1: Cutaway diagram of a wound-rotor induction motor

2.2.3 Another Components of 3-phase Induction Motor:

- * Shaft for transmitting the torque to the load. This shaft is made up of steel
- * Bearings for supporting the rotating shaft.
- * One of the problems with electrical motor is the production of heat during its rotation. In order for this problem we need fan for cooling.
- * For receiving external electrical connection Terminal box is needed.
- * 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.

2.3 Equivalent Circuit of an Induction Motor:

The energy is transferred from primary winding to secondary winding entirely by induction, therefore induction motor is essentially a transformer, at stand still. The induction motor is actually a static transformer having its secondary winding short-circuited.

When the rotor operates at slip S , the frequency of rotor currents is, S times the frequency of the stator currents therefore the revolving field produced by the rotor currents revolves with respect to rotor itself at speed:

$$\frac{120 \times sf}{P} = \frac{120 \times f}{P} = N_s \times s \quad (2.2)$$

Mechanical speed of the rotor:

$$N = N_s(1 - s) \quad (2.3)$$

The speed of the revolving field of the rotor with respect to stator or space is obtained by combining the rotational speed of rotor field with respect to rotor with mechanical speed of the rotor, hence speed of the rotor revolving field with respect to stationary stator or space

$$N_s = sN_s + N_s(1 - s) \quad (2.4)$$

Hence from the point of view of stator, the induction motor still can be considered as static transformer, even when its rotor is rotating, and it's possible to represent

the performance of an induction motor by a transformer phasor diagram. Actually the rotor field does not exist alone but combine with the revolving field of stator to produce a resultant field, just as in the transformer, the resultant field is produced by the combination of primary & secondary ampere-turns. In the transformer the load on secondary is electrical and in an induction motor the load is mechanical. The equivalent circuit for a 3-phase induction motor is shown in the figure (2.2)

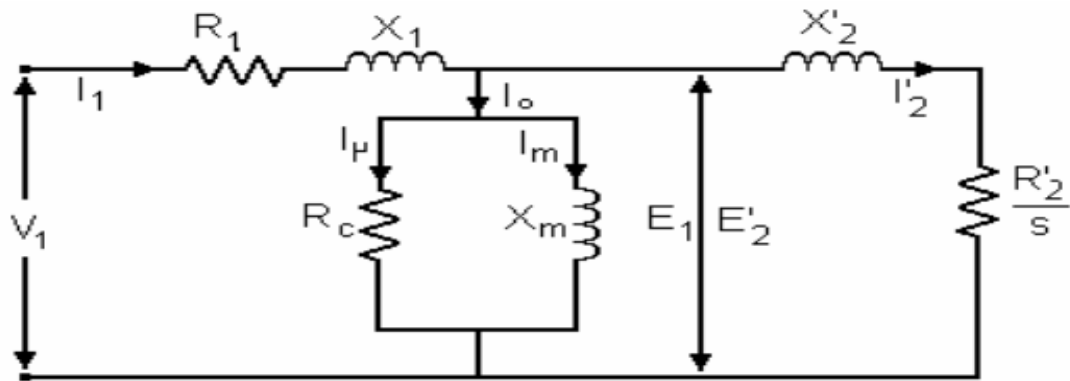


Figure 2.2: The exact equivalent circuit

Where V is applied voltage per phase, R_1 and X_1 are stator resistance and leakage reactance per phase respectively, R_r and X_r are rotor resistance and stand still leakage reactance per phase respectively, K is the turn ratio of secondary to primary, R_m and X_m no load resistance.

The equivalent circuit can be simplified by transferring no load current component to the supply terminals, as shown in figure (2.3)

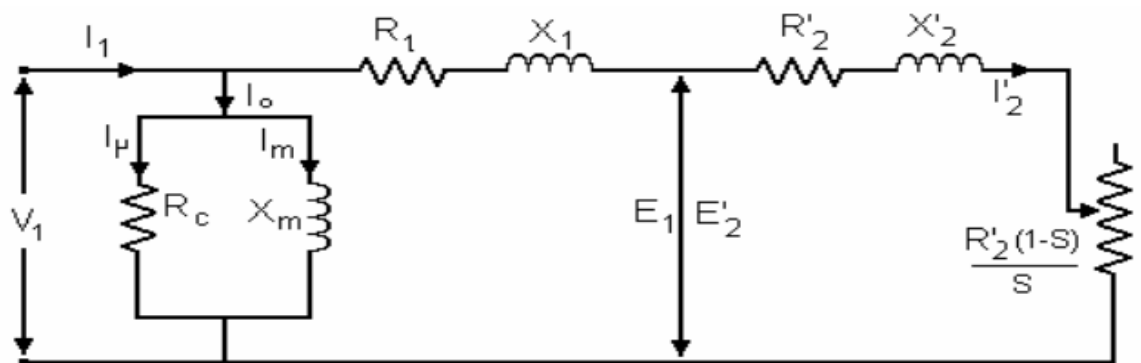


Figure 2.3: Approximate equivalent circuit

2.4 Torque and Speed Curves:

The torque and speed curves shown in figure (2.4) for a range of $s=0$, to $s=1$, with R_2 as the parameter.

Where:

$$T = \frac{K \cdot \Phi \cdot s E_2 \cdot R_2}{R_2 + s X_2^2} \quad (2.5)$$

It is clear that when $s=0$, $T=0$, hence the curve starts from point o. At normal speed, close to synchronism, the term (sX_2) is small and hence negligible R_r .

$$T \propto \frac{s}{R_2} \quad (2.6)$$

Or: $T \propto s$ (if R_2 is constant)

Hence for low values of slip, the slip/ torque curve is approximately straight line. As slip increases (increasing load in the motor) the torque also increases, and become maximum when:

$$s = \frac{R_2}{X_{i2}} \quad (2.7)$$

this torque is known as (pull-out) or (breakdown) torque (T_b) or stalling torque. As the slip further increases (i.e. motor speed faults) with further increase in motor load, then R_r becomes negligible as compared to (sX_r) . Therefore, for large values of slip

$$T_b \propto \frac{s}{(sX_r^2)} \propto \frac{1}{s} \quad (2.8)$$

hence, the torque/slip curve is a rectangular hyperbola. So, we see that beyond the point of maximum torque, any further increase in motor load results in decrease of torque developed by the motor. The result is that the motor slows down and eventually stops. The circuit-breakers will be tripped open if the circuit has been so protected. In fact, the stable operation of the motor lies between the values of $(s=0)$ and that corresponding to maximum torque. It is seen that although

maximum torque does not depend on R_2 . Yet the exact location of T_{max} is dependent on it. Greater the R_r , greater is the value of slip at which the maximum torque occurs.

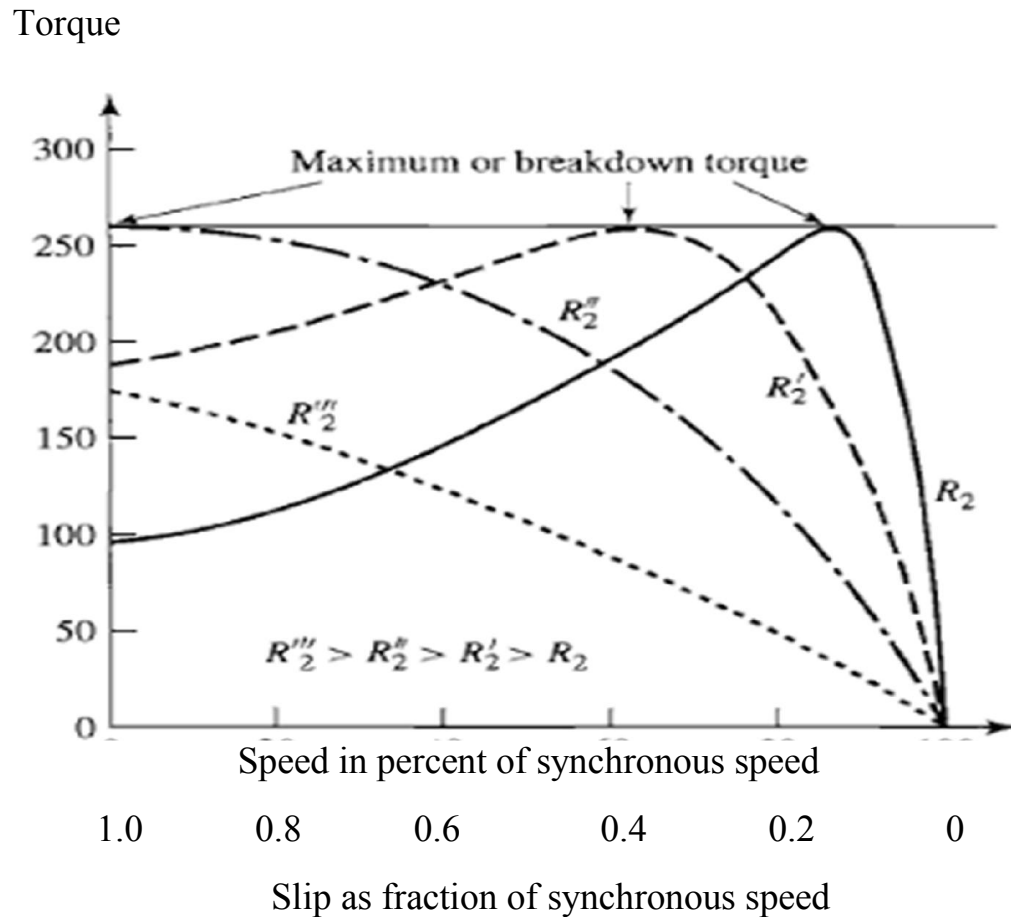


Figure 2.4: torque/slip and speed curve

2.5 Power Flow in a 3-phase Induction Motor:

From the equivalent circuit for induction motor we see that the total power input to the rotor (P_g) is the power flow diagram like bellow:

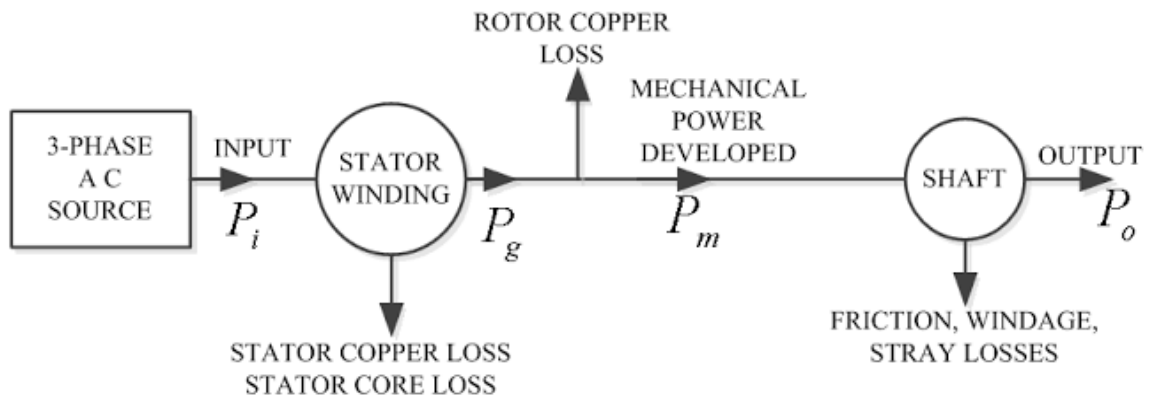


Figure 2.5: Power Flow diagram

CHAPTER THREE

TRANSIENT & PASSIVE TRANSFORMATION

3.1 Transients:

The steady-state stator and rotor currents and the travelling wave gap flux that exist induction machine running at fixed speed with constant unidirectional torque have to be established from the instant when the stator of the inert machine is switched on to the supply. Magnetic energy has to be supplied, as has the kinetic energy of the rotating systems and the various losses, as well as the energy absorbed by the load in raising it to the final steady-state condition. The energizing process is complicated by the reaction of cores to the rapid rise of flux density. The skin effect in conductors, and the mechanical deformations of motor shaft and structure as quickly varying torques are developed. The difference between the actual and the steady-state conditions for given speed and load are bridged by transient currents and fluxes which appear instantaneously and there after decay exponentially at rates determined by the parameters and time constants of the several electric circuits and the instantaneous speed of the machine. The term switching is applied to transients arising as a result of the energizing of an inert machine.

Transients are also generated when one steady-state is changed to another, as when re-switching, if it is disconnected from the supply for a brief and then reconnected, transient currents and torques appear. These transients are some times of great severity, as when a motor is plugged or dynamically beaked, or subjected to supply-voltage interruptions especially where there are capacitor banks across the stator terminals, considerable torque and current transients may occur even when motor terminal connections are changed during run-up a star-delta switch. Very large induction machines when switched, re-switched or subject

to the voltage fluctuation resulting from a power system fault, may react strongly on the system by drawing or supplying transient power.

3.2 Constant-linkage theorem:

Physical appreciation of the transient condition is afforded by the theorem of the constant linkage. Which states that in a closed circuit of zero resistance, the algebraic sum of its magnetic linkages remains constant. No circuit (super conduction part) is devoid of resistance but the linkage nevertheless remains instantaneously constant immediately after a sudden change because it takes time for stored magnetic energy to be altered a process approximating to a time exponential rise or decay. When for example a 3-phase voltage is suddenly applied to the stator terminals of an inert induction machine, phase fluxes begin to build up at rates proportional to the instantaneous voltages (which are inevitably, unequal). The stationary rotor develops corresponding opposition currents that initially maintain the inert condition of zero linkage. If the rotor moves, these currents may be carried round, but rapidly decay. On disconnecting a running motor, the stator currents are quenched; but as the short-circuited motor maintains its linkage by unidirectional current a trapped or 'frozen' flux is carried round with the rotor. The trapped flux decays, but induces rotational emf, in the stator winding, the transient currents and torques that occur on re-switching depend on the stator emf so induced, and if these have phase-opposition to the supply voltages at the instant of reconnection. The transient currents may be severe and transient torque may have negative(-ve) peak.

3.3 Switching:

Starting torque transients are affected by the instant of the first phases to close, and the delay (if any) in closure of the other two phases. The initial peak torque may also be affected by residual flux left after a previous duty cycle.

Assuming the machine to remain at rest. On all phases, the main component being a damped alternating torque.

3.4 Re-switching:

When a running motor is disconnected from the supply and the reconnected a transient torque is developed primarily as a result of the e.m.fs induced into the stator phase winding by the gap flux of the unidirectional decaying rotor currents, the phase angle of these e.m.fs with respect to the re-applied supply voltage is significant, and the amplitude and sign of the first peak of the transient torque are closely dependent on the rotor speed and the duration of the interruption. In the worst case the first peak may reach 15p.u of the full-load torque. The corresponding transient peaks of stator current are typically (5-7) p.u of full-load current.

Plugging, dynamic braking and bus bar transfer are examples of fast re-switching in which re-connection may be made with appreciable e.m.fs existing in the stator winding in plugging the re-connected supply has the reversed phase-sequence; even at reduced voltage the transient torques and currents are severe, e.g with 15p.u peak torque and 20p.u current in term of rated values, plugging is a drastic operation, complicated by the effects of eddy currents and saturation.

Marked transient effects occur when terminal capacitors are used for power factor correction, self- excitation of an induction generator or capacitance braking when a motor supply is interrupted with the capacitors left across the stator terminals, the capacitors tend to maintain the gap flux and the stator may build up and over voltage in spite of drop in rotor speed on re-connection with un favorable conditions of e.m.fs and supply voltage phasing, the resulting current and of torque transients can be server. In the case of an induction generator, the effects of re-connection are intensified by the rise in speed due to the prime- mover.

3.5 Electromechanical transient:

When the induction motor transfer from an operating condition to another there are many changes happened in the motor behavior. To study this changes there are some cases shown below:

3.5.1 Change of load:

Reduced low-slip damping and transient synchronizing torques are also exhibited when a running motor is subjected to sudden change of load. During the rapid retardation following a large load application, the trapped rotor flux combines with the main synchronously rotating field to produce synchronizing torque which reverses cyclically as the speed drops and develops wide resultant fluctuations of motor torque, the peaks decaying as the rotor currents settle to the new condition.

3.5.2 Fluctuating load:

If a load, such as a reciprocating compressor, imposes a slip and torque oscillation, cyclically generated rotor fluxes are trapped, of magnitude dependent on the load-oscillation frequency and the short-circuit time constant. They produce synchronizing torques, the elastic nature of which in combination with the load (or to one of its harmonics) the slip-swing may be augmented by resonance, causing a strong pulsation of the stator current wave form envelope.

3.6 Transformations from 3-phase to d-q axes:

In general, for any induction machine, the direct and quadrature axis coils do not correspond directly to those of the actual machine though they represent by their resultant m.m.f, the resultant m.m.f, of the windings they replace. It is not essential that the transformed winding axes are fixed with respect to the stator; they may alternatively be aligned with moving references frame. If they so are chosen that they move at the same speed as the air-gap field itself.

3.6.1 Mathematical model:

Figure (3.1) shows the three phases of an induction machine R, B, Y phases of stator and r, b, y phases of rotor

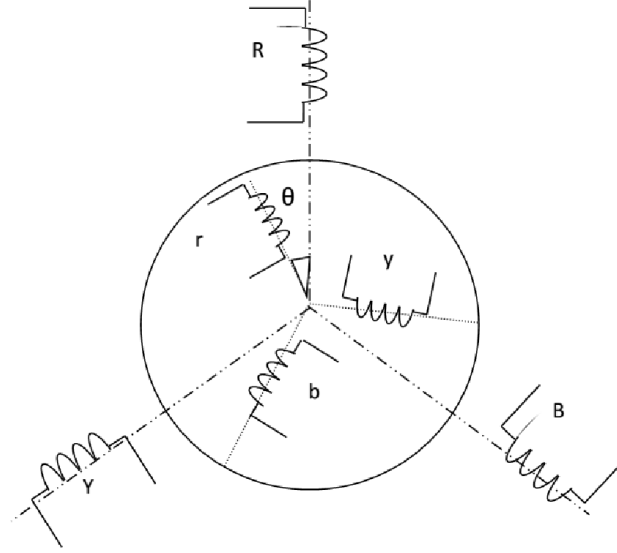


Figure 3.1 : rotor and stator for 3-phase induction motor

The equation can be:

$$\begin{bmatrix} vR \\ vY \\ vB \\ vr \\ vy \\ vb \end{bmatrix} = \begin{bmatrix} Rs + \rho Ls & \rho Ms & \rho Ms & M \cos \theta & M \cos \theta 2 & M \cos \theta 3 \\ \rho Ms & Rs + \rho Ls & \rho Ms & M \cos \theta 2 & M \cos \theta 3 & M \cos \theta \\ \rho Ms & \rho Ms & Rs + \rho Ls & M \cos \theta 3 & M \cos \theta & M \cos \theta 2 \\ M \cos \theta & M \cos \theta 2 & M \cos \theta 3 & Rr + \rho Lr & \rho Mr & \rho Mr \\ M \cos \theta 2 & M \cos \theta 3 & M \cos \theta & \rho Mr & Rr + \rho Lr & \rho Mr \\ M \cos \theta 3 & M \cos \theta & M \cos \theta 2 & \rho Mr & \rho Mr & Rr + \rho Lr \end{bmatrix} * \begin{bmatrix} iR \\ iY \\ iB \\ ir \\ iy \\ ib \end{bmatrix} \quad (3.1)$$

Where:

$$\theta 2 = \theta - 2\pi/3, \quad \theta 3 = \theta + 2\pi/3$$

The system impedance matrix is:

$$[Z] = \begin{bmatrix} Z_{ss} & Z_{sr} \\ Z_{rs} & Z_{rr} \end{bmatrix} \quad (3.2)$$

Where:

$$Z_{ss} = \begin{bmatrix} R_s + \rho L_s & \rho M_s & \rho M_s \\ \rho M_s & R_s + \rho L_s & \rho M_s \\ \rho M_s & \rho M_s & R_s + \rho M_s \end{bmatrix} \quad (3.3)$$

$$Z_{sr} = \begin{bmatrix} M \cos \theta & M \cos \theta_2 & M \cos \theta_3 \\ M \cos \theta_2 & M \cos \theta_3 & M \cos \theta \\ M \cos \theta_3 & M \cos \theta & M \cos \theta_2 \end{bmatrix} \quad (3.4)$$

$$Z_{rs} = \begin{bmatrix} M \cos \theta & M \cos \theta_2 & M \cos \theta \\ M \cos \theta_2 & M \cos \theta_3 & M \cos \theta_3 \\ M \cos \theta_3 & M \cos \theta & M \cos \theta_2 \end{bmatrix} \quad (3.5)$$

$$Z_{rr} = \begin{bmatrix} R_r + \rho L_r & \rho M_r & \rho M_r \\ \rho M_r & R_r + \rho L_r & \rho M_r \\ \rho M_r & \rho M_r & R_r + \rho L_r \end{bmatrix} \quad (3.6)$$

The transformation of the three-phase induction machine to tow-phase machine is done by using the phase transformation matrix C1 as follows:

$$[V] = \begin{bmatrix} C1t & 0 \\ 0 & C1t \end{bmatrix} [V'] = \begin{bmatrix} V_m \cos \omega r t \\ V_m \sin \omega r t \\ 0 \\ 0 \end{bmatrix} \quad (3.7)$$

$$[I] = \begin{bmatrix} C1t & 0 \\ 0 & C1t \end{bmatrix} \quad (3.8)$$

$$[Z] = \begin{bmatrix} C1t & 0 \\ 0 & C1t \end{bmatrix} [Z'] \begin{bmatrix} C1 & 0 \\ 0 & C1 \end{bmatrix} \quad (3.9)$$

Then the new voltage equation is written as follws:

$$\begin{bmatrix} v_0 \\ v_A \\ v_B \\ v_0 \\ v_a \\ v_b \end{bmatrix} = \begin{bmatrix} R_s + \rho L_s & 0 & 0 & \rho M \cos \theta & 0 & 0 \\ 0 & R_s + \rho L_s & 0 & 0 & \rho M \cos \theta & \rho M \sin \theta \\ 0 & 0 & R_s + \rho L_s & 0 & \rho M \sin \theta & -\rho M \cos \theta \\ \rho M \cos \theta & 0 & 0 & R_r + \rho L_r & 0 & 0 \\ 0 & \rho M \cos \theta & \rho M \sin \theta & 0 & R_r + \rho L_r & 0 \\ 0 & \rho M \sin \theta & -\rho M \cos \theta & 0 & 0 & R_r + \rho L_r \end{bmatrix} * \begin{bmatrix} i_0 \\ i_A \\ i_B \\ i_0 \\ i_a \\ i_b \end{bmatrix} \quad (3.10)$$

Under normal conditions, the zero component can be ignored and then the impedance will be:

$$\begin{bmatrix} v_A \\ v_B \\ v_a \\ v_b \end{bmatrix} = \begin{bmatrix} R_s + \rho L_s & 0 & \rho M \cos \theta & \rho M \sin \theta \\ 0 & R_s + \rho L_s & \rho M \sin \theta & -\rho M \cos \theta \\ \rho M \cos \theta & \rho M \sin \theta & R_r + \rho L_r & 0 \\ \rho M \sin \theta & -\rho M \cos \theta & 0 & R_r + \rho L_r \end{bmatrix} * \begin{bmatrix} i_A \\ i_B \\ i_a \\ i_b \end{bmatrix} \quad (3.11)$$

Applying the commutator transformation C2 on voltage current and impedance matrixes:

$$[V''] = \begin{bmatrix} U & 0 \\ 0 & C_{2t} \end{bmatrix} [V'] = \begin{bmatrix} V_m \cos \omega t \\ V_m \sin \omega t \\ 0 \\ 0 \end{bmatrix} \quad (3.12)$$

$$[I''] = \begin{bmatrix} U & 0 \\ 0 & C_{2t} \end{bmatrix} [I'] \quad (3.13)$$

$$[Z''] = \begin{bmatrix} U & 0 \\ 0 & C2t \end{bmatrix} [Z'] \begin{bmatrix} C1 & 0 \\ 0 & C1 \end{bmatrix} = \begin{bmatrix} Z'ss & Z'srC2 \\ C2tZ'rs & C2tZ'rrC2 \end{bmatrix} \quad (3.14)$$

$$[V''] = [Z''] [I''] \quad (3.15)$$

$$\begin{bmatrix} vD \\ vQ \\ vd \\ vq \end{bmatrix} = \begin{bmatrix} Rs + \rho Ls & 0 & \rho M & 0 \\ 0 & Rs + \rho Ls & 0 & \rho M \\ \rho M & \omega r M & Rr + \rho Lr & \omega r Lr \\ -\omega r M & \rho M & -\omega r Lr & Rr + \rho Lr \end{bmatrix} \begin{bmatrix} iD \\ iQ \\ id \\ iq \end{bmatrix} \quad (3.16)$$

From equation (3.16) we found:

$$vD = iD(Rs + \rho Ls) + \rho M id \quad (3.17)$$

$$vQ = iQ(Rs + \rho Ls) + \rho M iq \quad (3.18)$$

$$vd = \rho M iD + \omega r M iQ + id(Rr + Lr) + \omega r Lr iq \quad (3.19)$$

$$vq = -\omega r M iD + \rho M iQ - \omega r Lr id + iq(Rr + \rho Lr) \quad (3.20)$$

CHAPTER FOUR

SIMULATION AND RESULTS

4.1 Introduction of Simulation:

The six first order differential equations were solved by using the Matlab program. The impedance matrix of the general slip- ring machine after subsection to the phase transformation C1 and the commutator transformation C2, this matrix will apply to the particular case of the three wound rotor induction motor. The transformed voltage equations for this machine becomes:

$$\rho[I] = [L]^{-1} ([V] - [R][I] - \omega r[G][I]) \quad (4.1)$$

Where :

$$[L] = \begin{bmatrix} L_s & 0 & 0 & M \\ 0 & L_s & M & 0 \\ 0 & M & L_r & 0 \\ M & 0 & 0 & L_r \end{bmatrix} \quad (4.2)$$

$$[L]^{-1} = \frac{1}{L_r * L_s - M * M} \begin{bmatrix} L_r & 0 & M & 0 \\ 0 & L_r & 0 & M \\ M & 0 & L_s & 0 \\ 0 & M & 0 & L_s \end{bmatrix} \quad (4.3)$$

$$[R] = \begin{bmatrix} R_s & 0 & 0 & 0 \\ 0 & R_s & 0 & 0 \\ 0 & 0 & R_r & 0 \\ 0 & 0 & 0 & R_r \end{bmatrix} \quad (4.4)$$

$$[G] = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & M & 0 & L_r \\ -M & 0 & -L_r & 0 \end{bmatrix} \quad (4.5)$$

$$[R][I] = \begin{bmatrix} R_s & 0 & 0 & 0 \\ 0 & R_s & 0 & 0 \\ 0 & 0 & R_r & 0 \\ 0 & 0 & 0 & R_r \end{bmatrix} * \begin{bmatrix} iD \\ iQ \\ iq \\ id \end{bmatrix} = \begin{bmatrix} RsiD \\ RsiQ \\ Rriq \\ Rrid \end{bmatrix} \quad (4.6)$$

$$\omega r [G][I] = \omega r \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ -M & 0 & 0 & -Lr \\ 0 & M & Lr & 0 \end{bmatrix} * \begin{bmatrix} iD \\ iQ \\ iq \\ id \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ -\omega r(MiD - Lrid) \\ \omega r(MiQ - Lriq) \end{bmatrix} \quad (4.7)$$

$$V - [R][I] - \omega r [G][I] = \begin{bmatrix} vD - Rsid \\ vQ - RsiD \\ vq - Rriq + \omega r(MiD + Lrid) \\ vD - Rrid - \omega r(MiQ + Lriq) \end{bmatrix} \quad (4.8)$$

When:

$$\omega r = \frac{d\theta}{dt} \quad (4.9)$$

$$\rho = \frac{d}{dt} \quad (4.10)$$

$$\frac{d}{dt} \begin{bmatrix} iD \\ iQ \\ iq \\ id \end{bmatrix} = \begin{bmatrix} L_s & 0 & 0 & M \\ 0 & L_s & M & \\ 0 & M & L_r & \\ M & 0 & 0 & L_r \end{bmatrix}^{-1} \begin{bmatrix} vD - Rsid \\ vQ - RsiD \\ vq - Rriq + \omega r(MiD + Lrid) \\ vD - Rrid - \omega r(MiQ + Lriq) \end{bmatrix} \quad (4.11)$$

$$[Te] = [It][G][I] \quad (4.12)$$

$$[Te] = [iD \ iQ \ id \ iq] * \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & M & 0 & Lr \\ -M & 0 & -Lr & 0 \end{bmatrix} * \begin{bmatrix} iD \\ iQ \\ id \\ iq \end{bmatrix} = MidiQ - MiquD \quad (4.13)$$

$$T_e - T_m = J \frac{d\omega_r}{dt} \quad (4.14)$$

$$\frac{d\omega_r}{dt} = \frac{T_e - T_m}{J} \quad (4.15)$$

The equations (4.15),(4.9) and equation (4.11) were solved and then the dynamic performance of both motors were analyzed.

The following data for a 3hp,220 volts, 60Hz induction motor parameters.

Table 4.1:

Machine rating			TB	IB(abc)	r1	x1	xm	r1'	x1'	J
Hp	volts	rpm	Nm	amps	ohm	ohm	ohm	ohm	ohm	Kg.m ²
3	220	1710	11.9	5.8	0.435	0.754	26.13	0.816	0.435	0.089

The following data for a 2250hp, 2300 volts, 60Hz induction motor parameters.

Table 4.2:

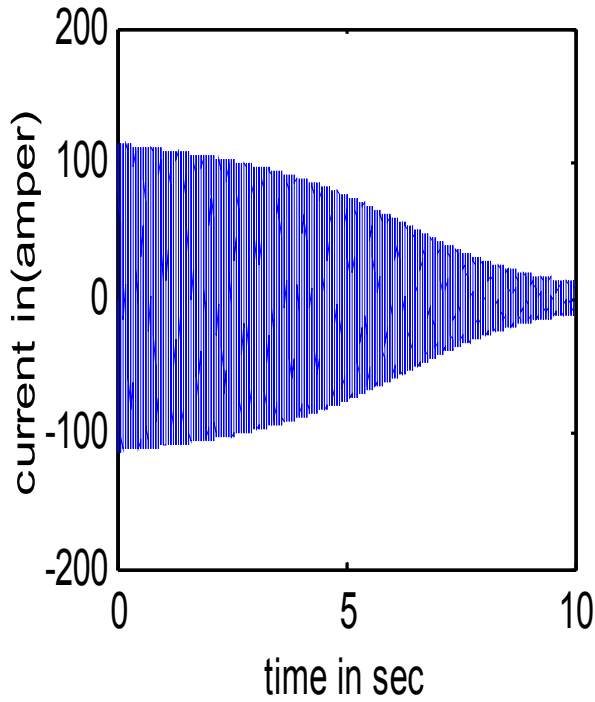
Machine rating			TB	IB(abc)	r1	x1	xm	r1'	x1'	J
Hp	volts	rpm	kNm	amps	Ohm	ohm	ohm	ohm	ohm	Kg.m ²
2250	2300	1786	8.9	421	0.029	0.226	13.04	0.226	0.022	63.87

4.2 Result of program:

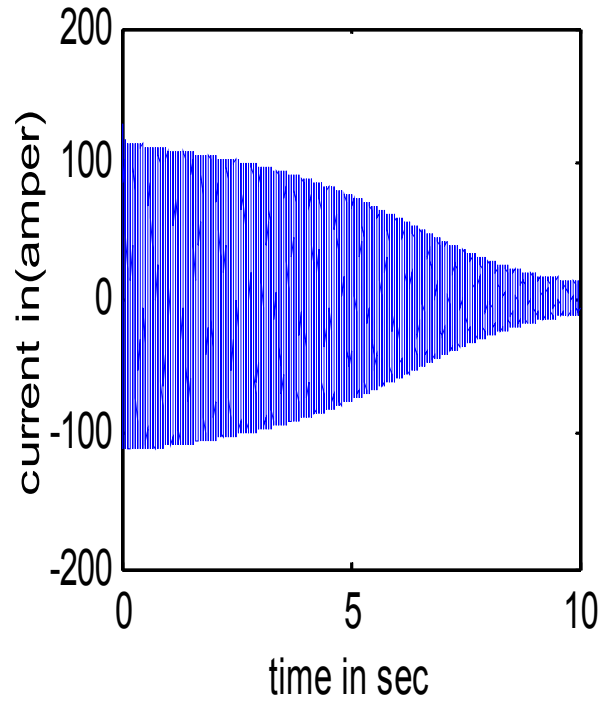
4.2.1 Result of a 3hp induction motor when applied full voltage:

- * When a full voltage is applied to a 3hp motor at free acceleration, currents R, Y, B have different values due to a phase shift at instant of switching.
- * The duration of transient performance is (7) second.
- * The speed is increased exponentially up to the rated speed within (15) second.
- * Duration the dynamic performance the torque reached ten times rated torque.

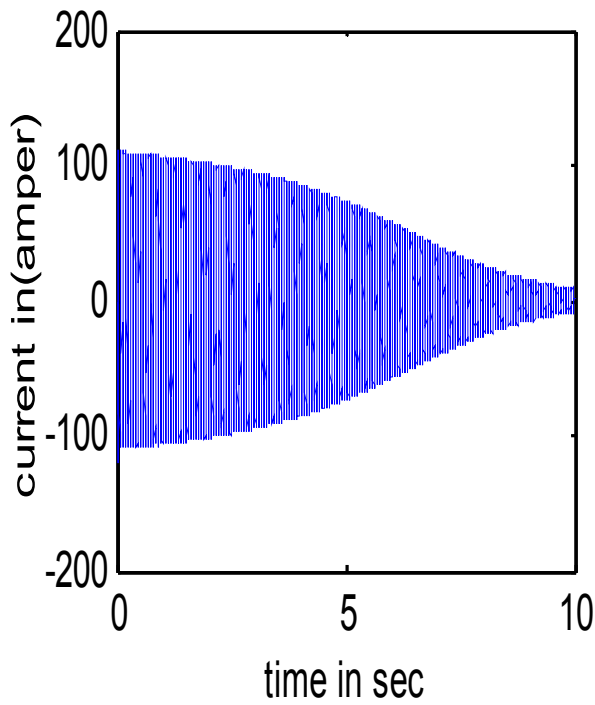
current ia against time figure 3-1



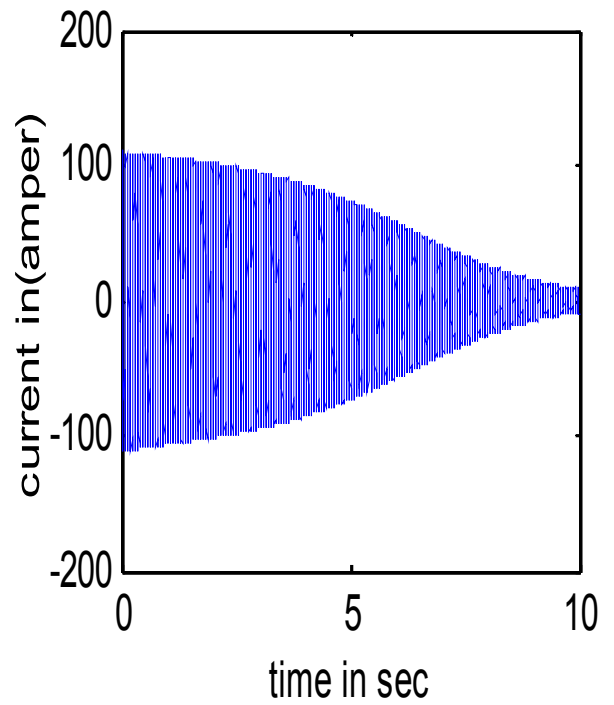
current(ib)against time figure 3-2

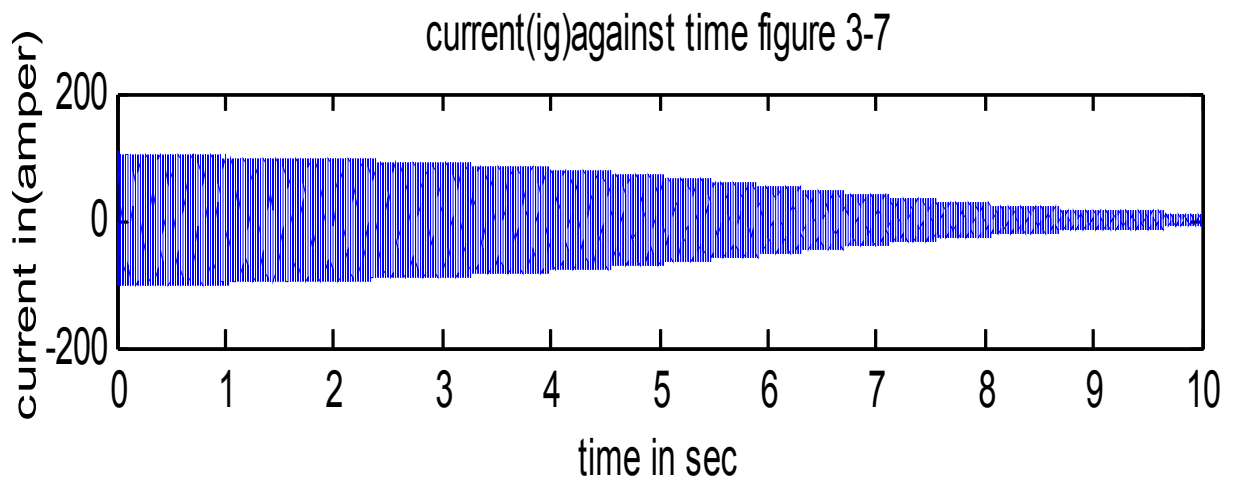
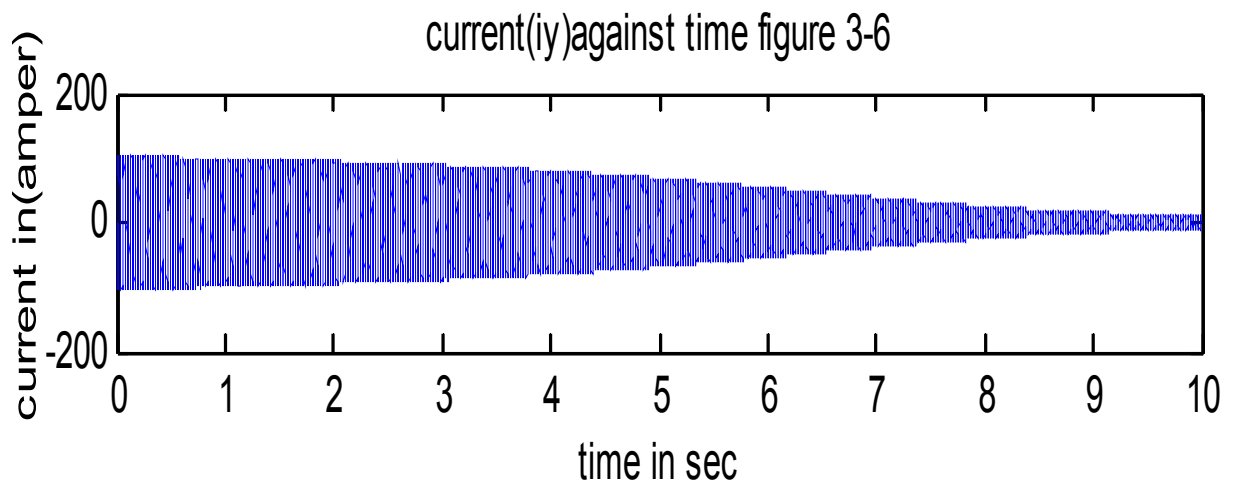
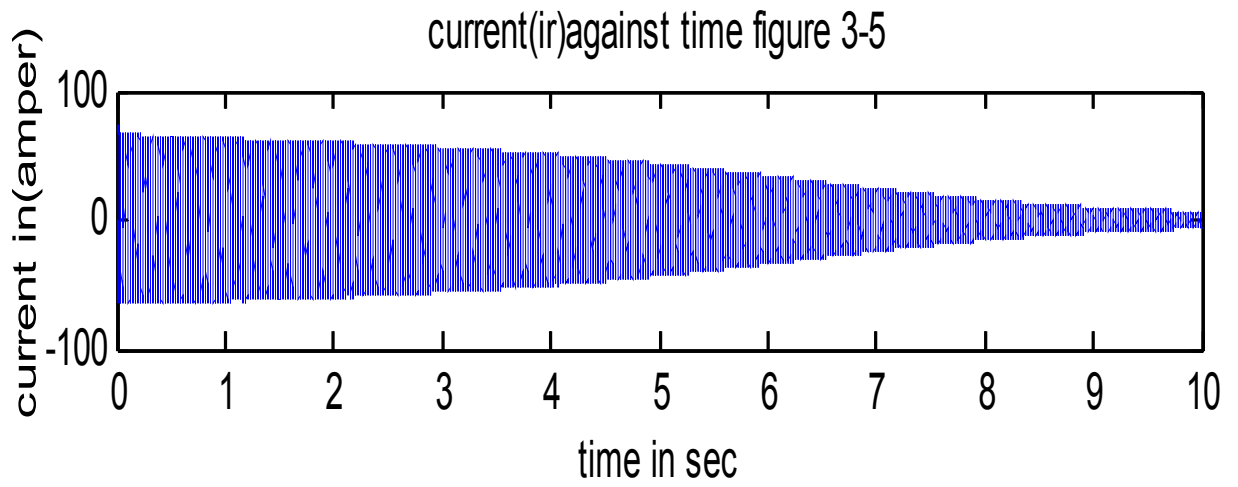


current(iq)against time figure 3-3

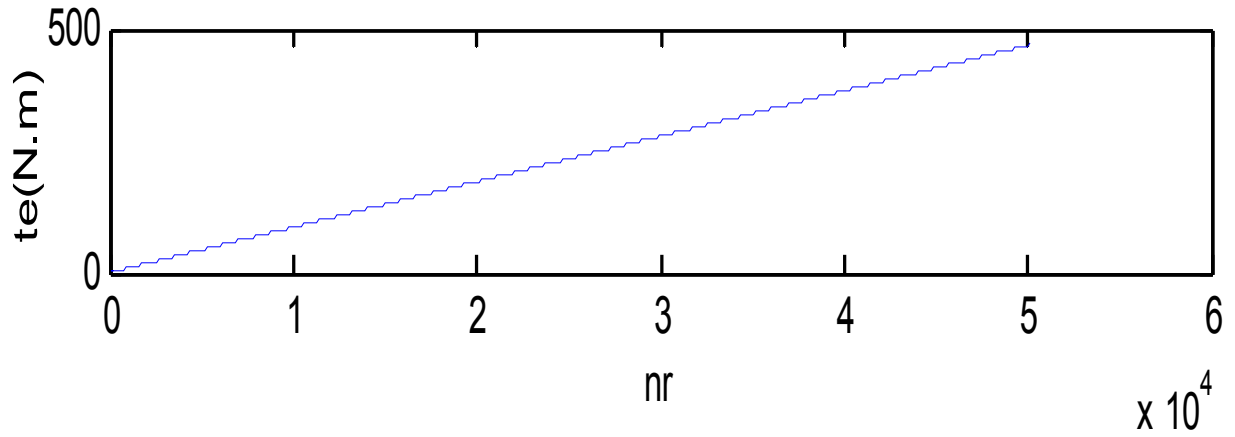


current(id)against time figure 3-4

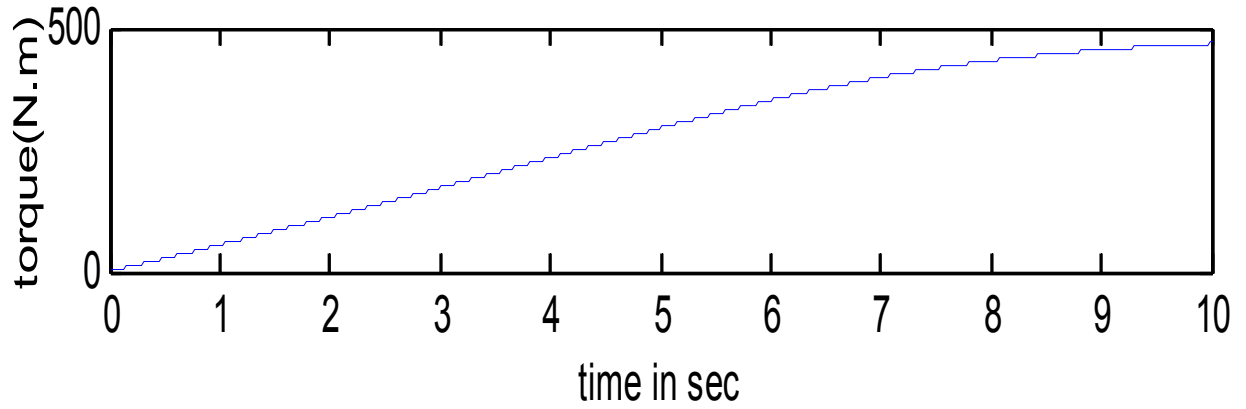




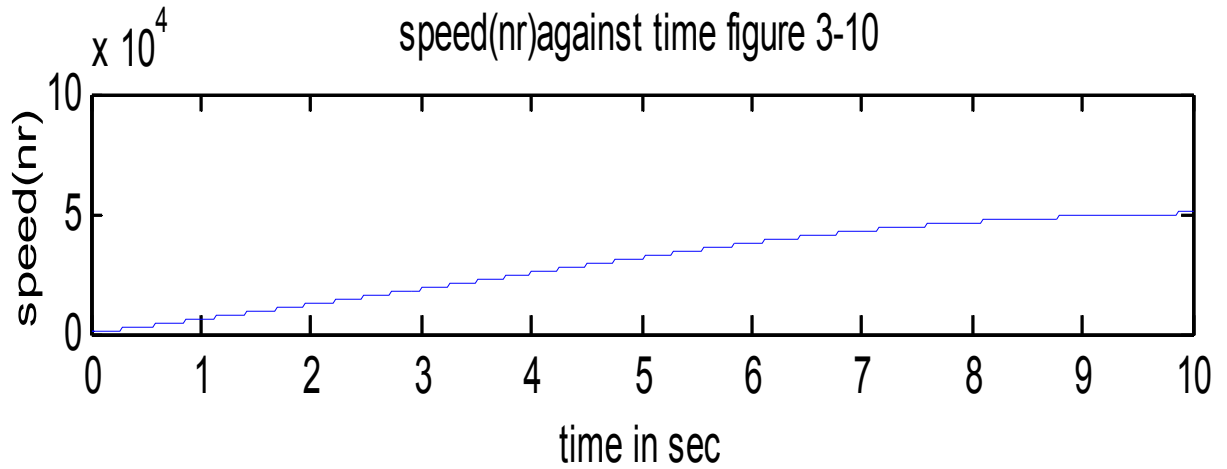
torque against speed figure 3-8



torque against time figure 3-9



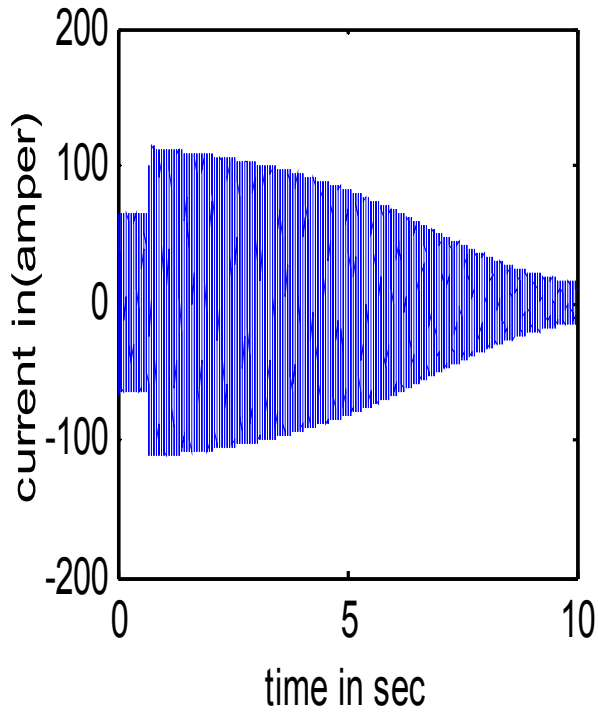
speed(nr) against time figure 3-10



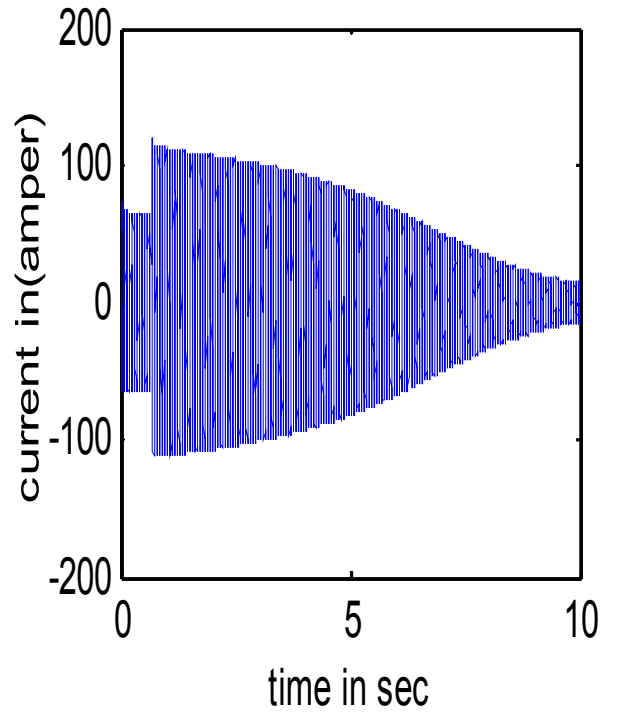
4.2.2 Result of 3hp when a reduced voltage is applied:

- * When a reduced voltage is applied the maximum transient current reduced to about 60 percent compared with Applying a full voltage whereupon the maximum transient torque is reduced to one third.
- * The duration for the speed to reach a rated value is doubled compared with the duration when a full voltage is applied.

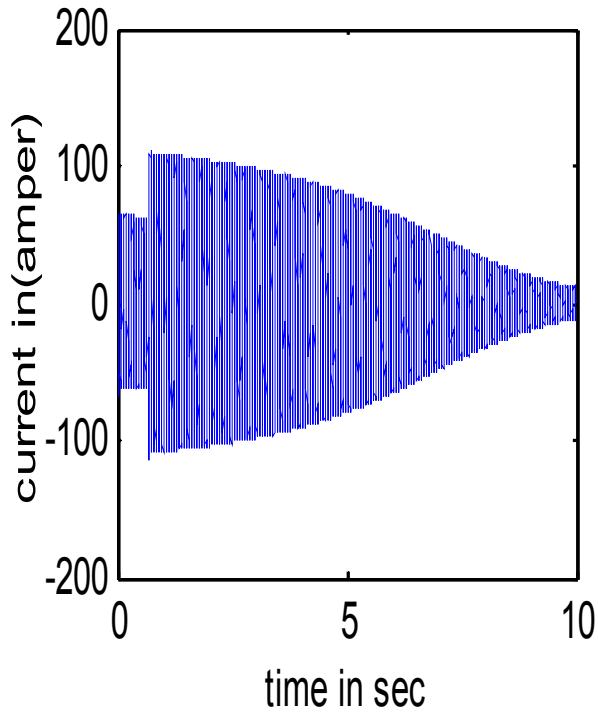
current ia against time figure 3-11



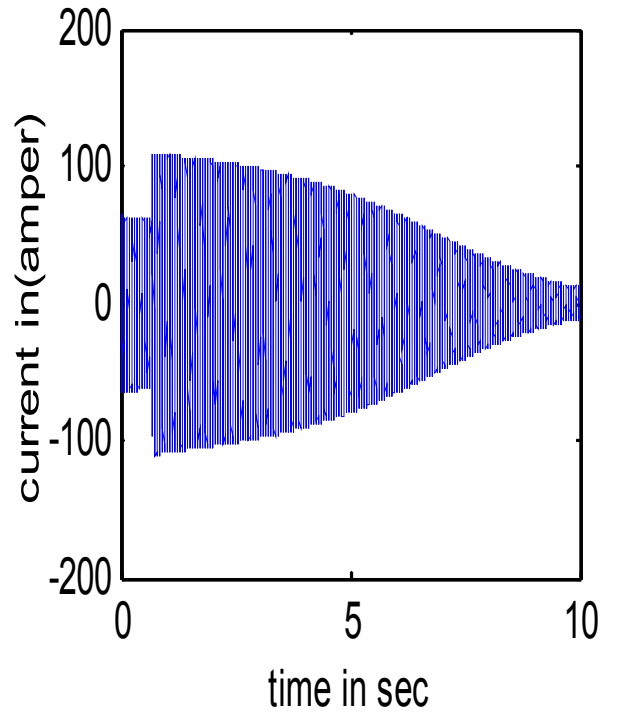
current(ib)against time figure 3-12

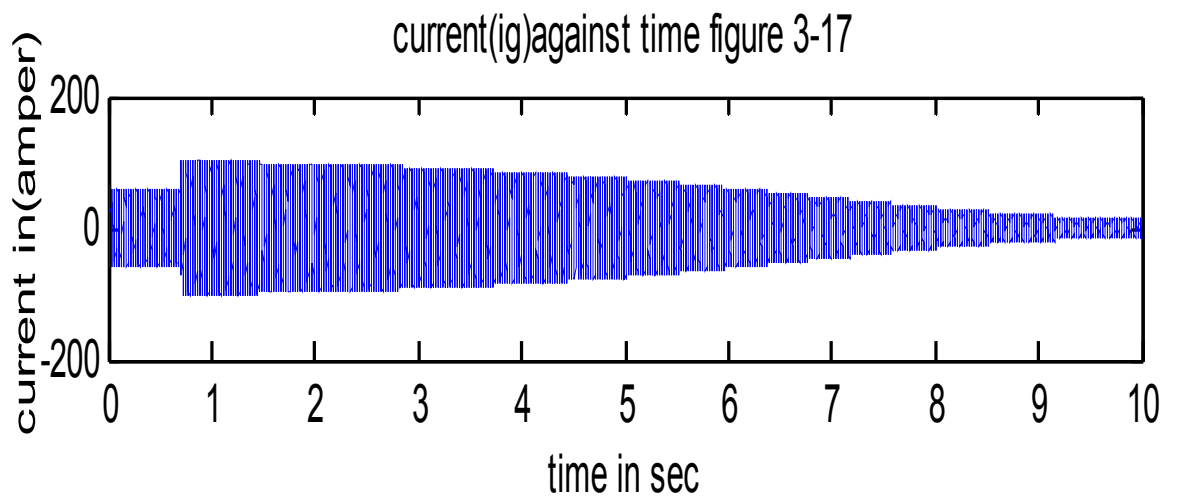
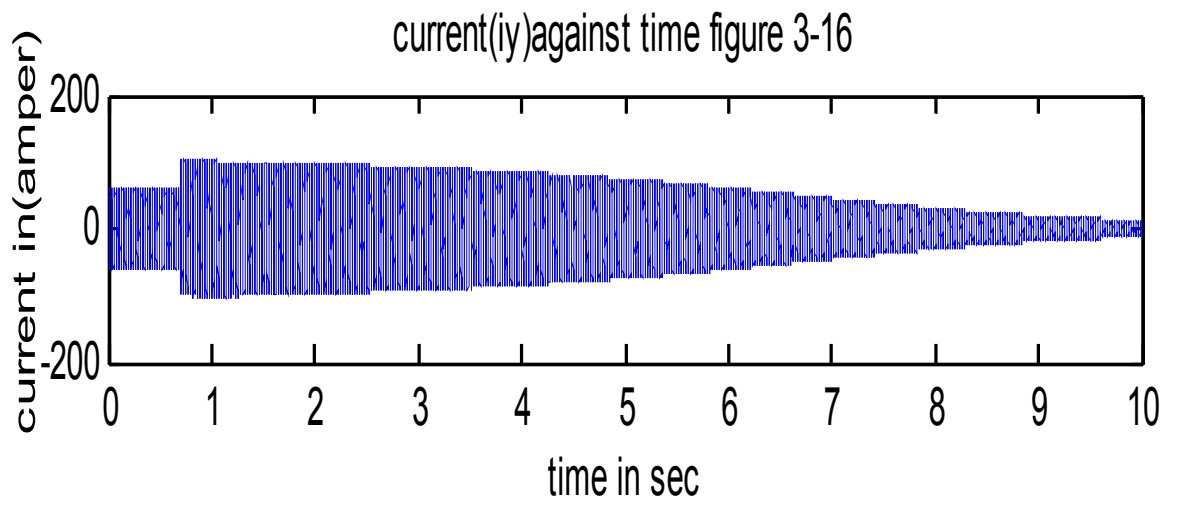
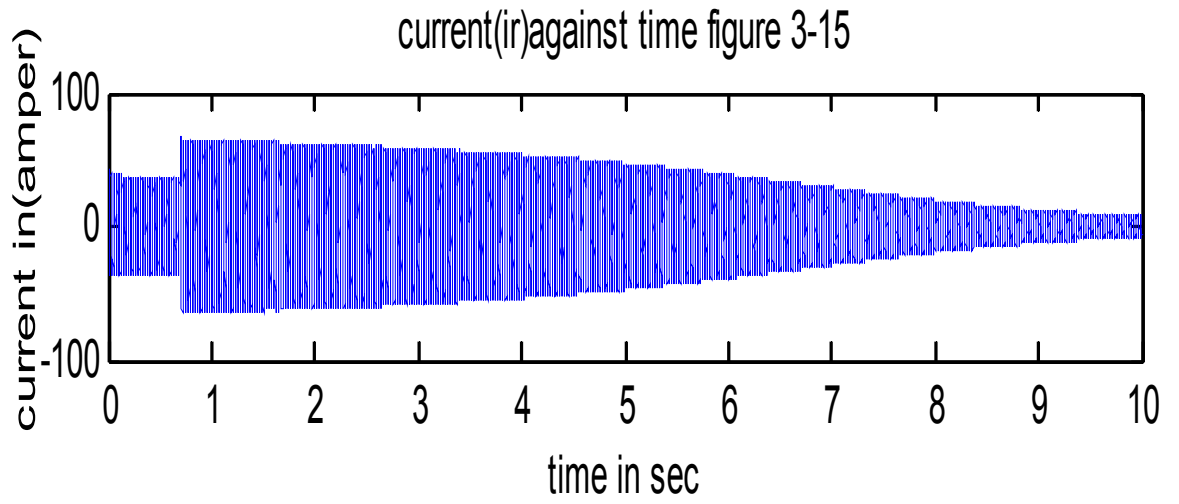


current(iq)against time figure 3-13

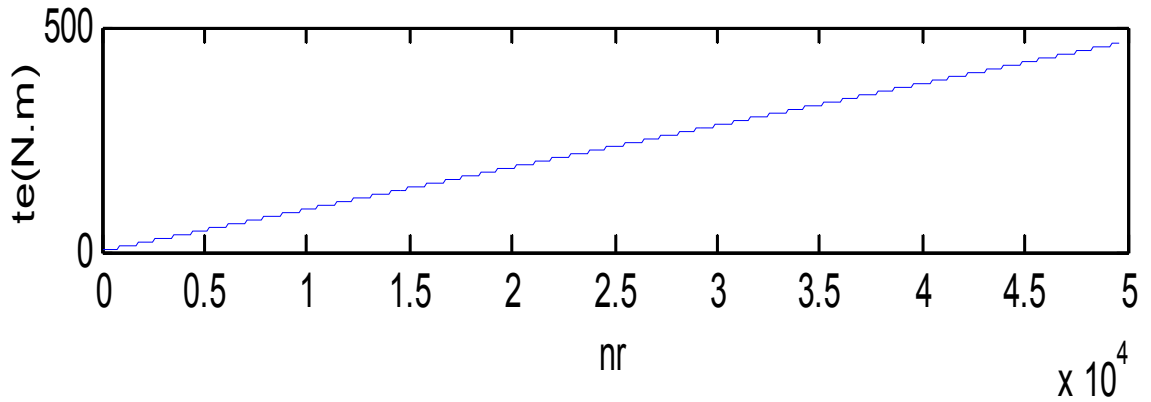


current(id)against time figure 3-14

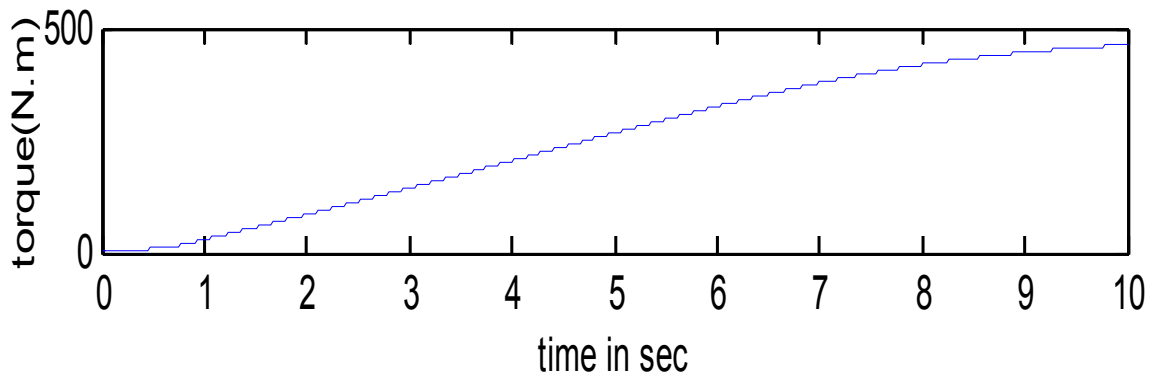




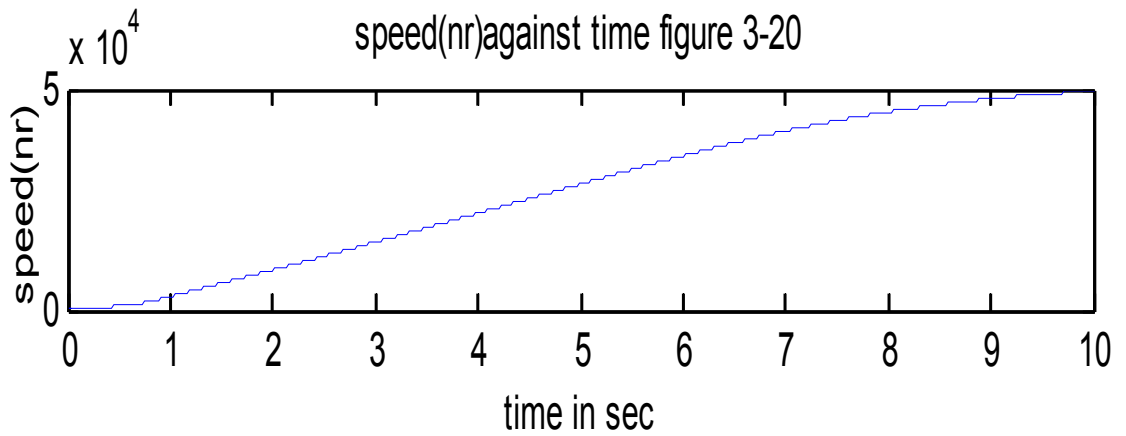
torque against speed figure 3-18



torque against time figure 3-19



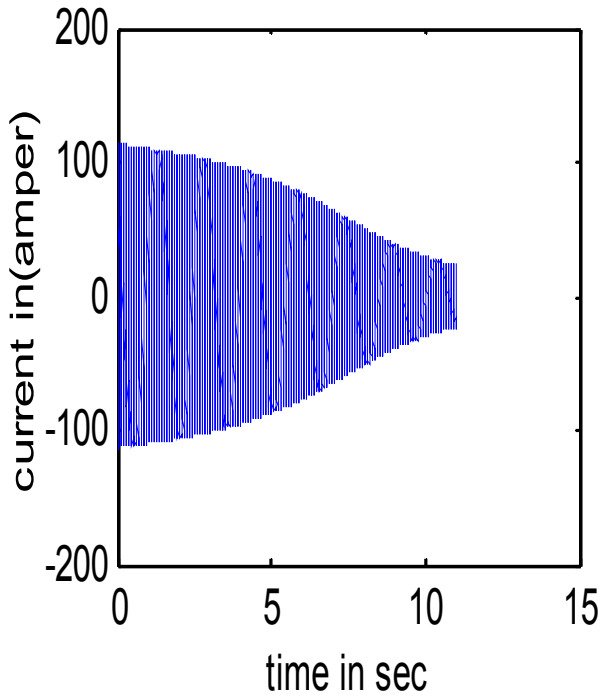
speed(nr) against time figure 3-20



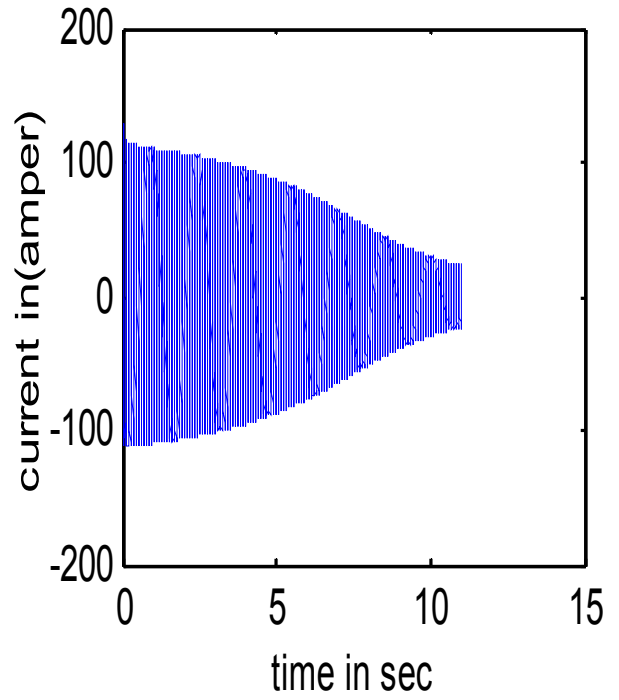
4.2.3 A result of 3hp induction motor when change in load torque is applied:

* When a rated load torque is applied to the motor after the dynamic performance currents and speed are increased slightly

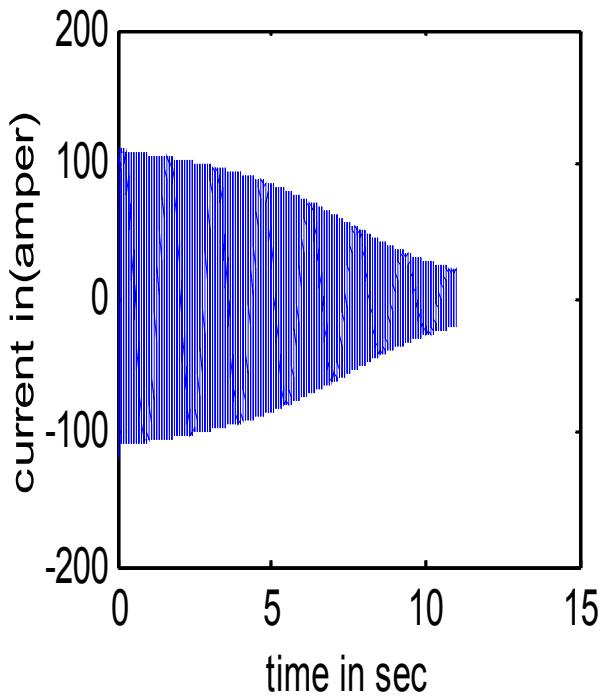
current ia against time figure 3-21



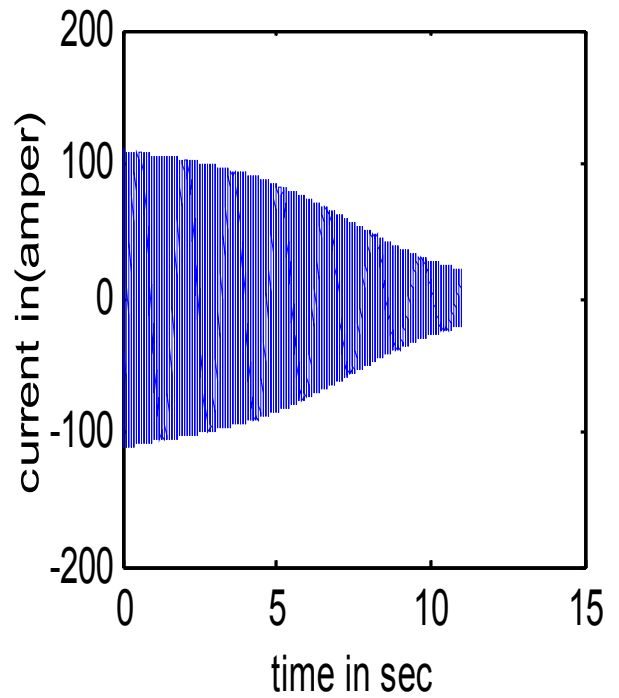
current(ib)against time figure 3-22

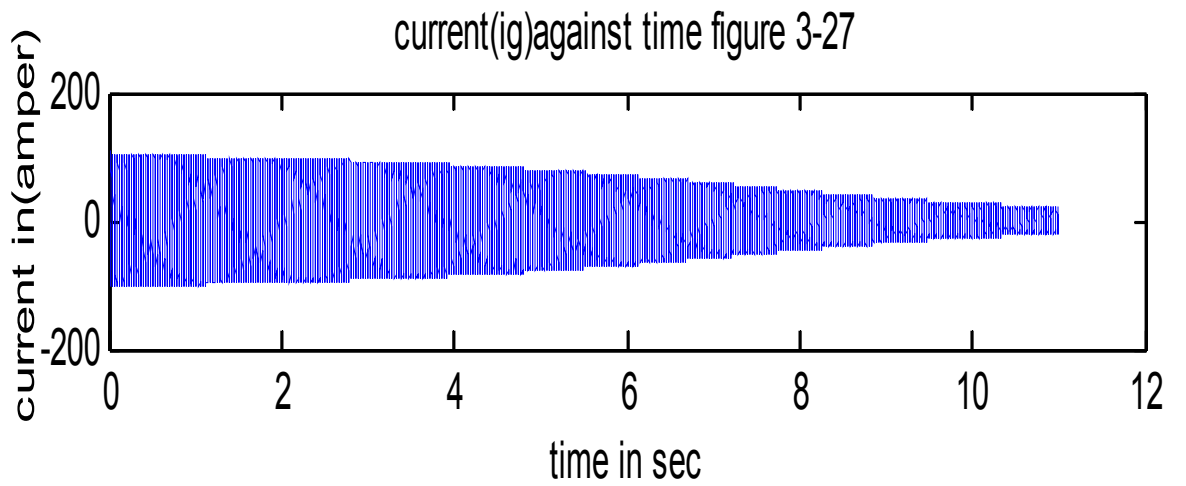
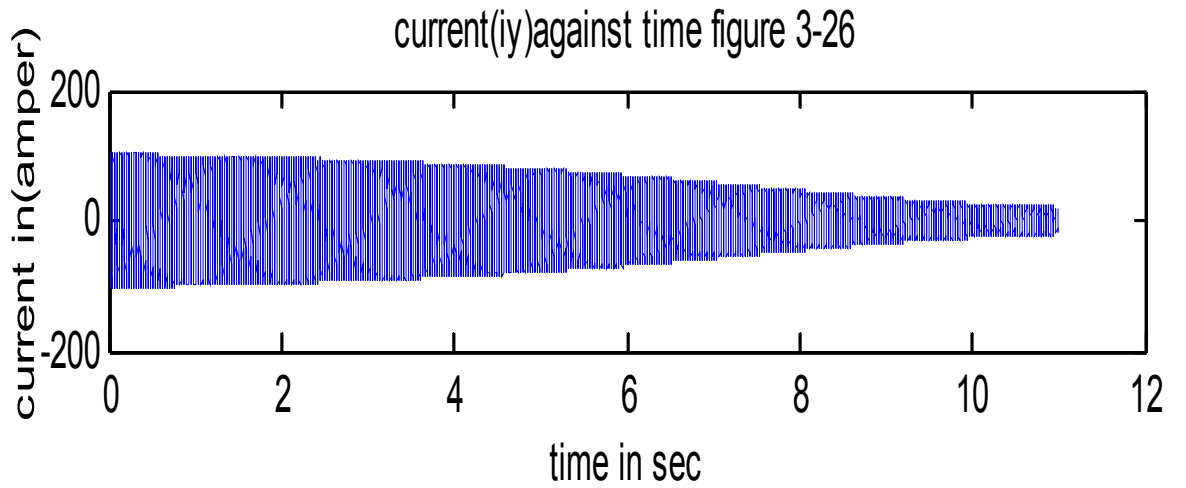
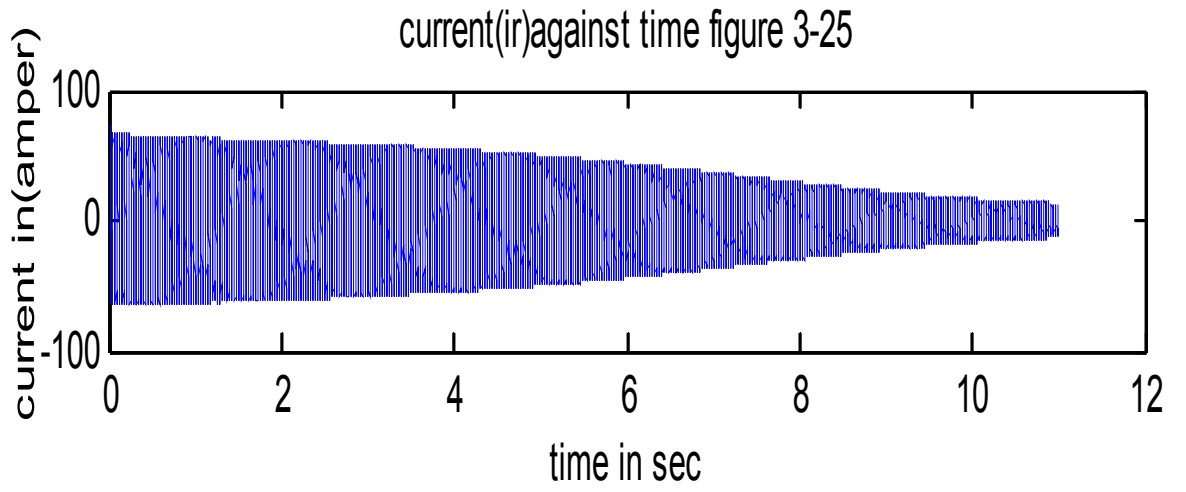


current(iq)against time figure 3-23

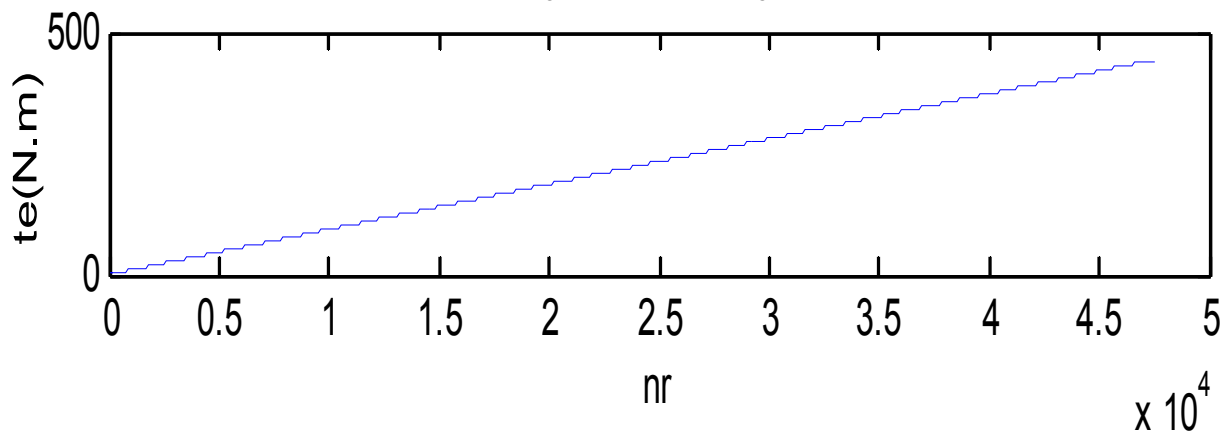


current(id)against time figure 3-24

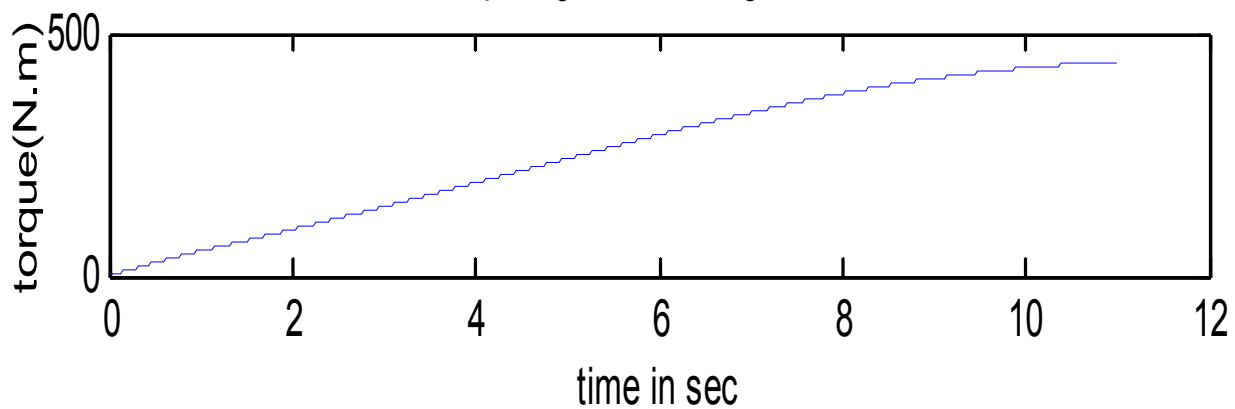




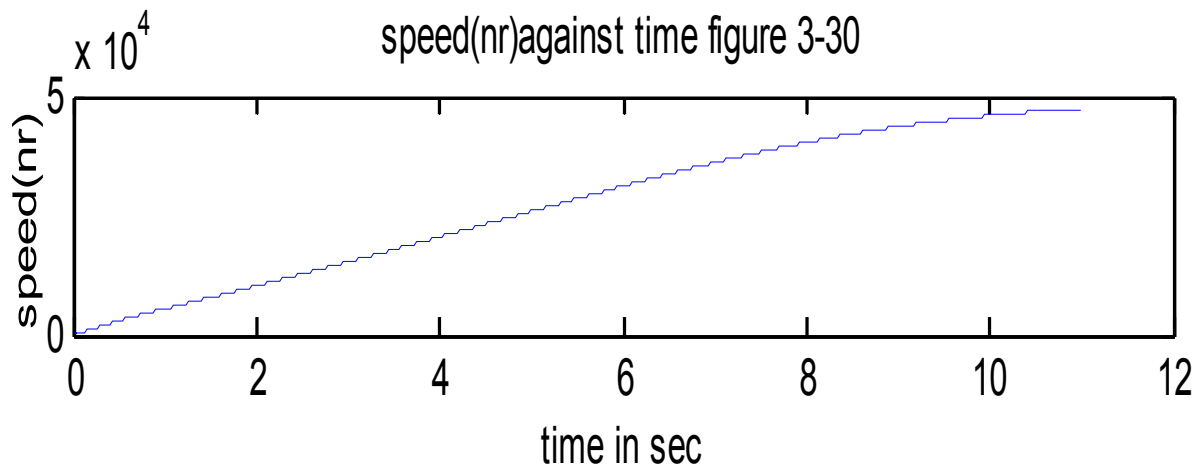
torque against speed figure 3-28



torque against time figure 3-29



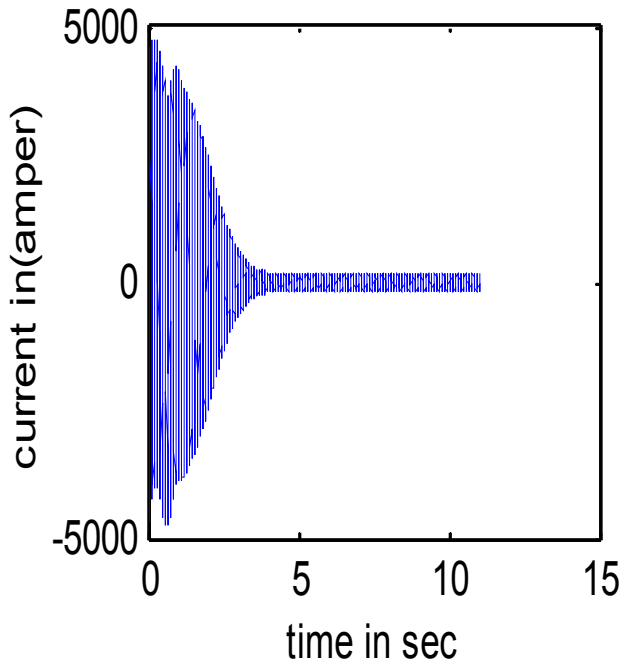
speed(nr) against time figure 3-30



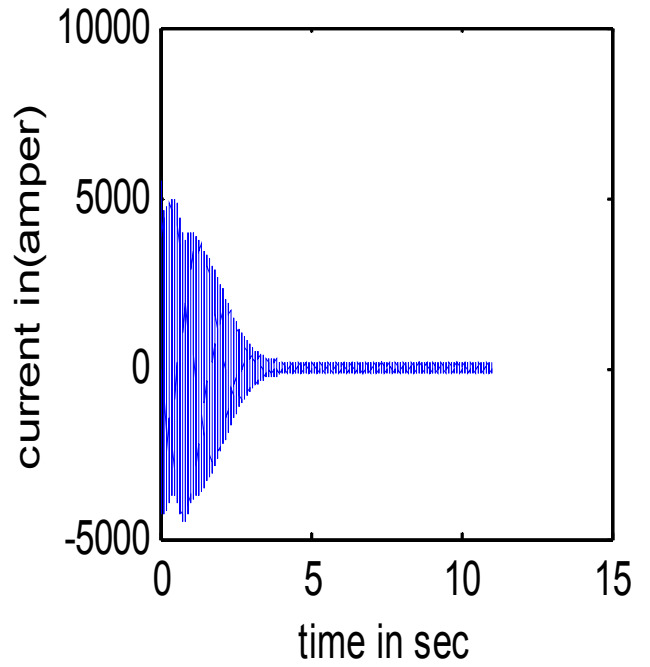
4.2.4 Result of 2250hp when full voltage is applied:

- * The duration of transient performance is (0.3) second.
- * The speed is increased exponentially up to the rated speed within (0.3) second.
- * During the dynamic performance the torque reached three times a rated torque.

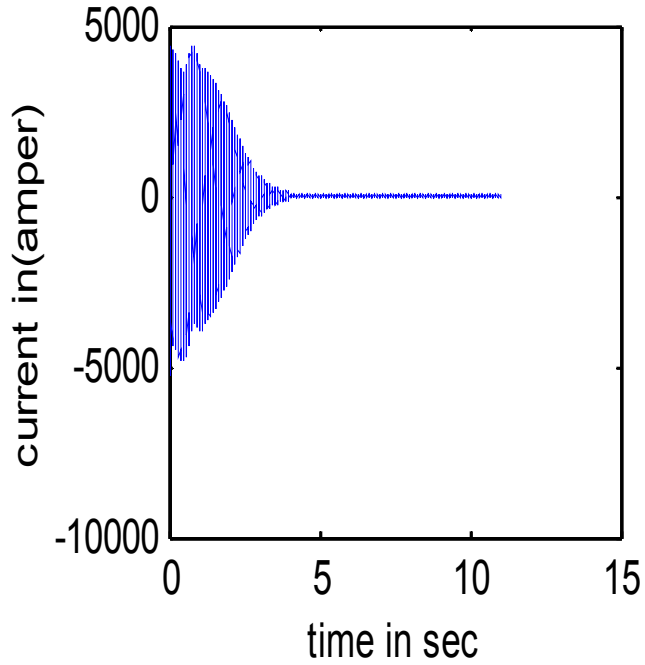
current ia against time figure 3-31



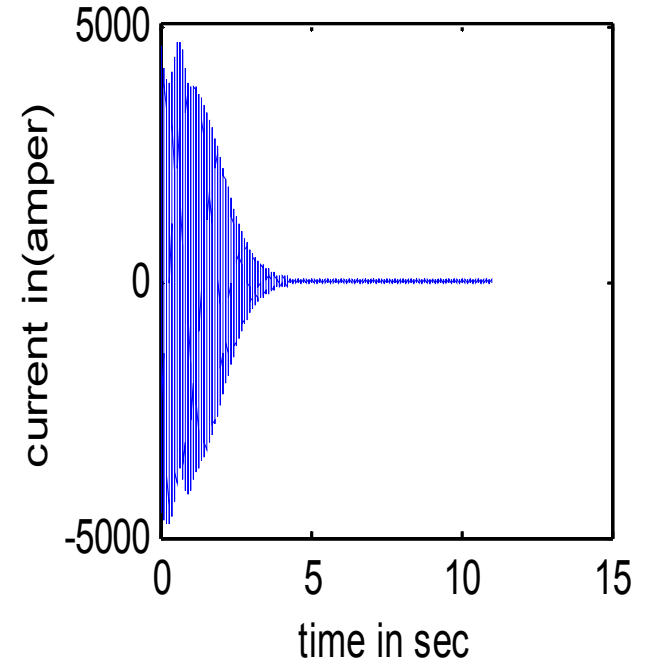
current(ib)against time figure 3-32



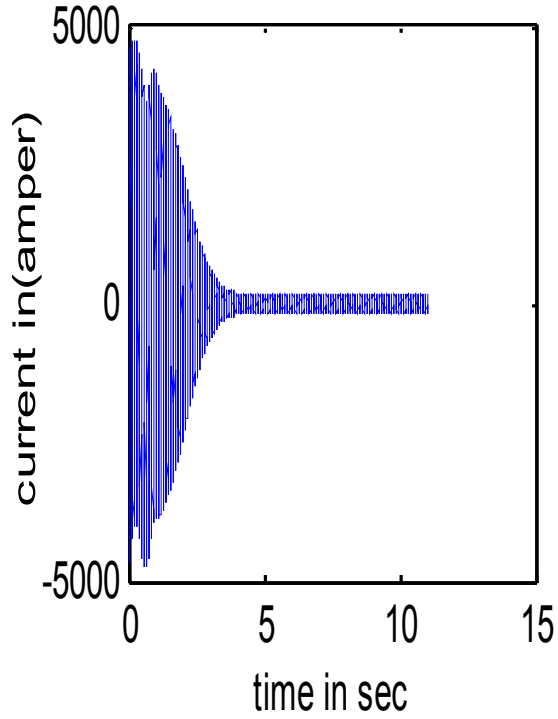
current(iq)against time figure 3-33



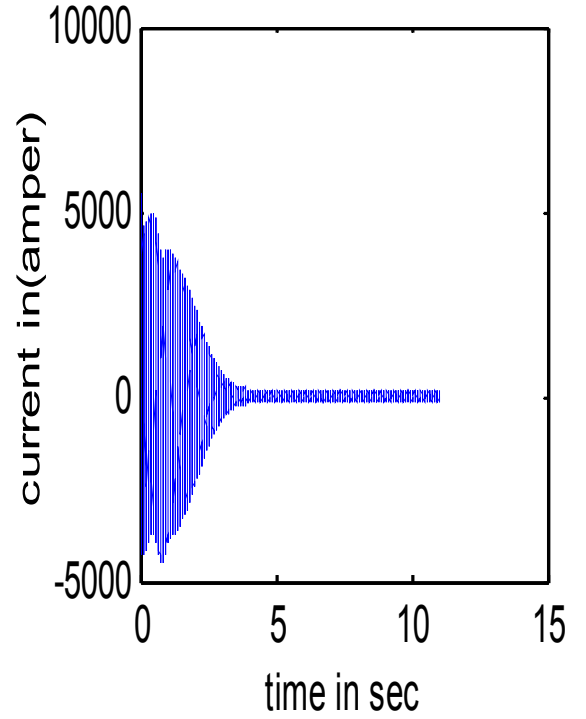
current(id)against time figure 3-34



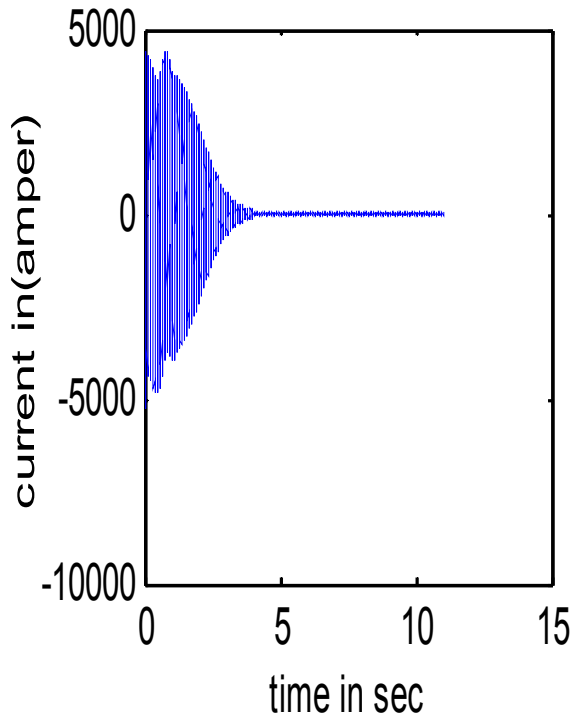
current ia against time figure 3-31



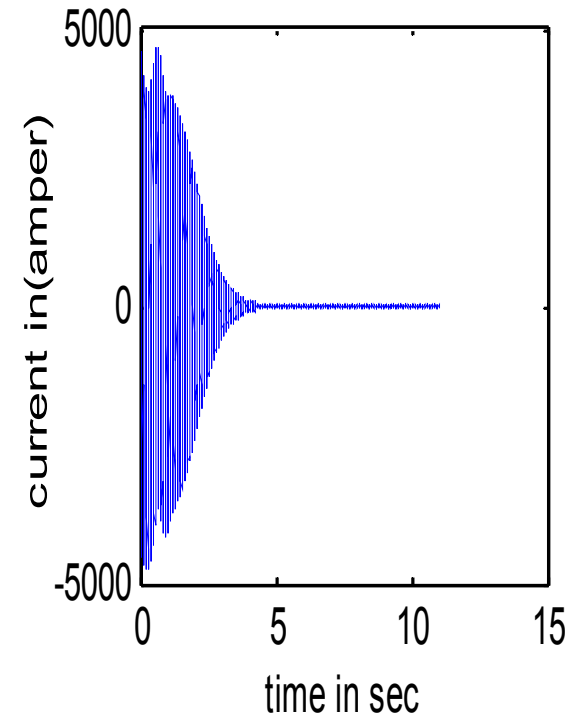
current(ib)against time figure 3-32



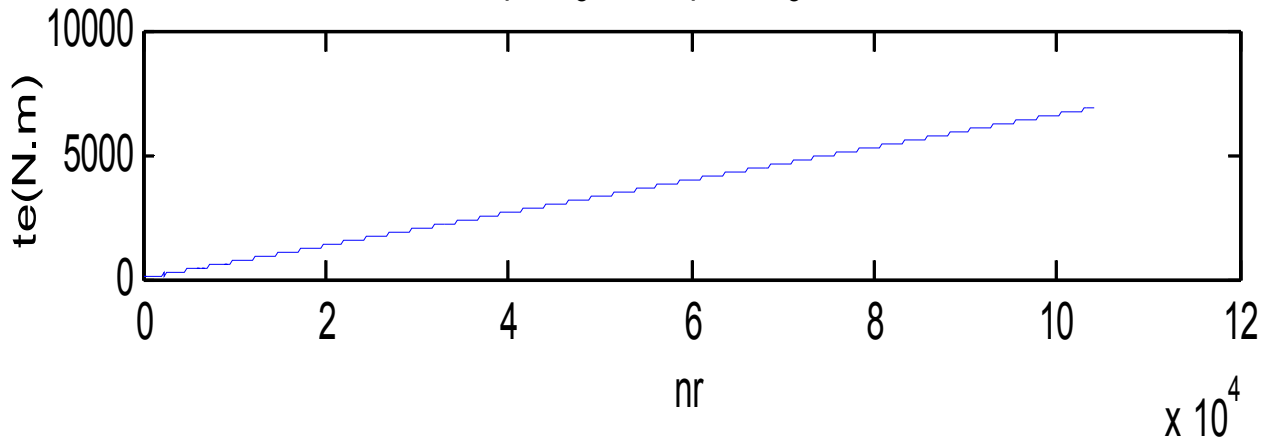
current(iq)against time figure 3-33



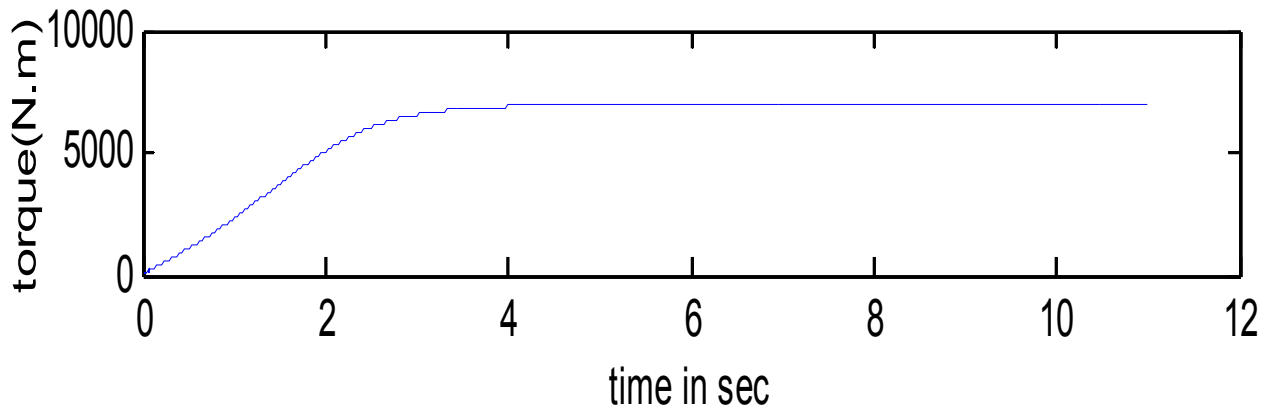
current(id)against time figure 3-34



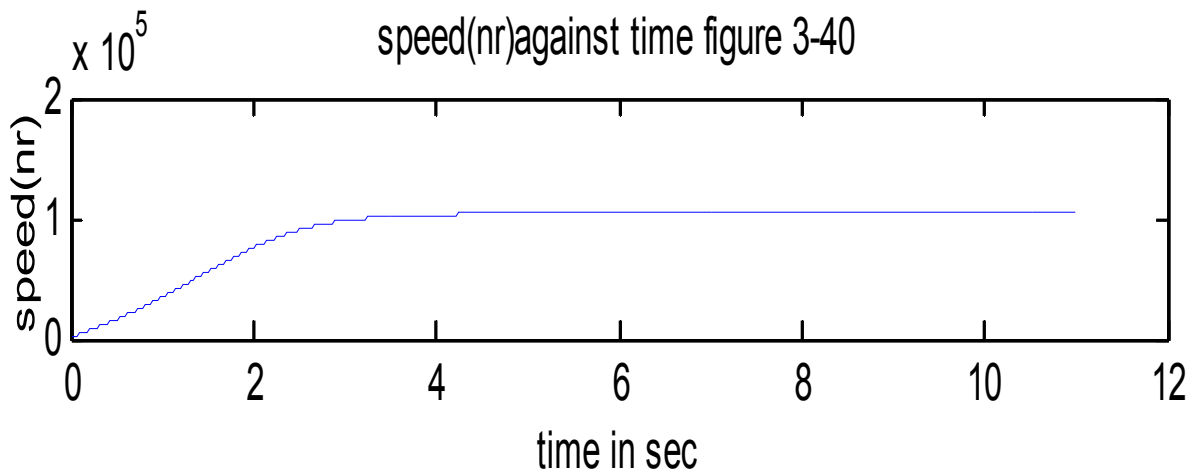
torque against speed figure 3-38



torque against time figure 3-39



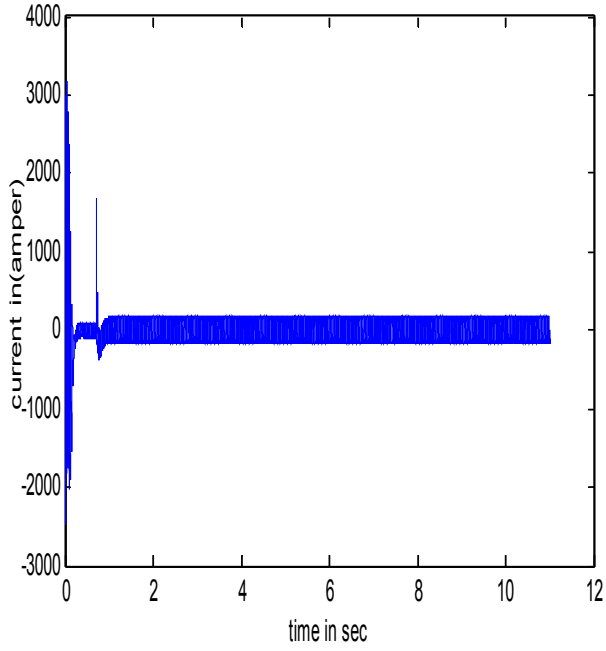
speed(nr) against time figure 3-40



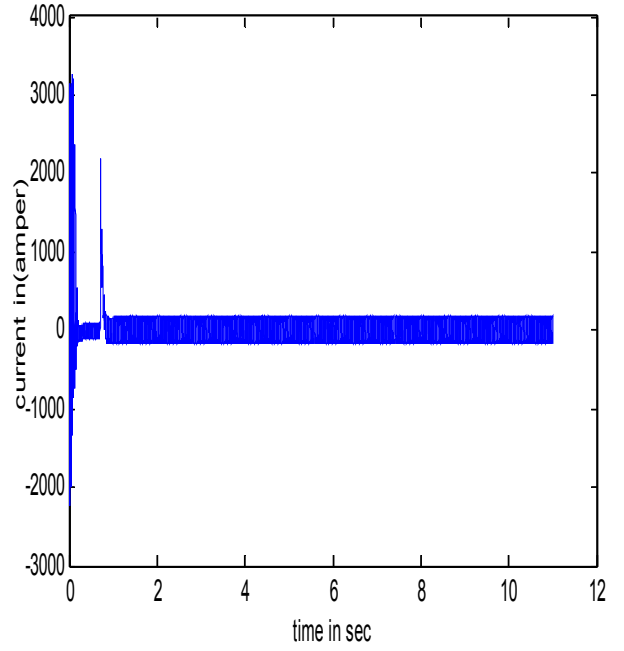
4.2.5 A result of 2250hp when a reduced voltage is applied:

- * When a reduced voltage is applied the maximum transient current to the same value when a full voltage is applied. While the duration is decreased to 40%.
- * The duration for the speed to reach a rated value is doubled compared with the duration when a full voltage is applied.

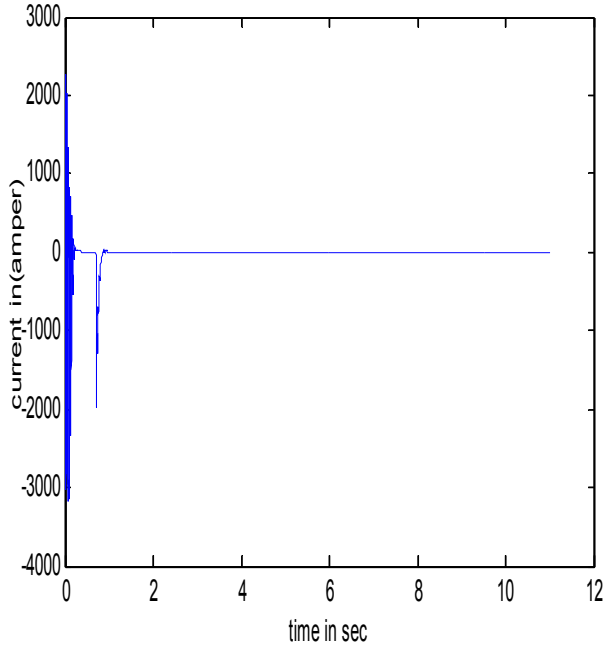
current ia against time figure 3-41



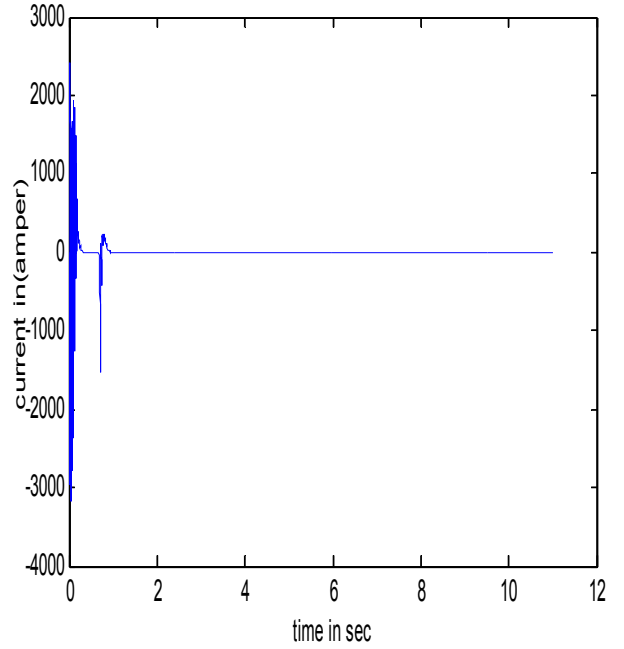
current(ib)against time figure 3-42



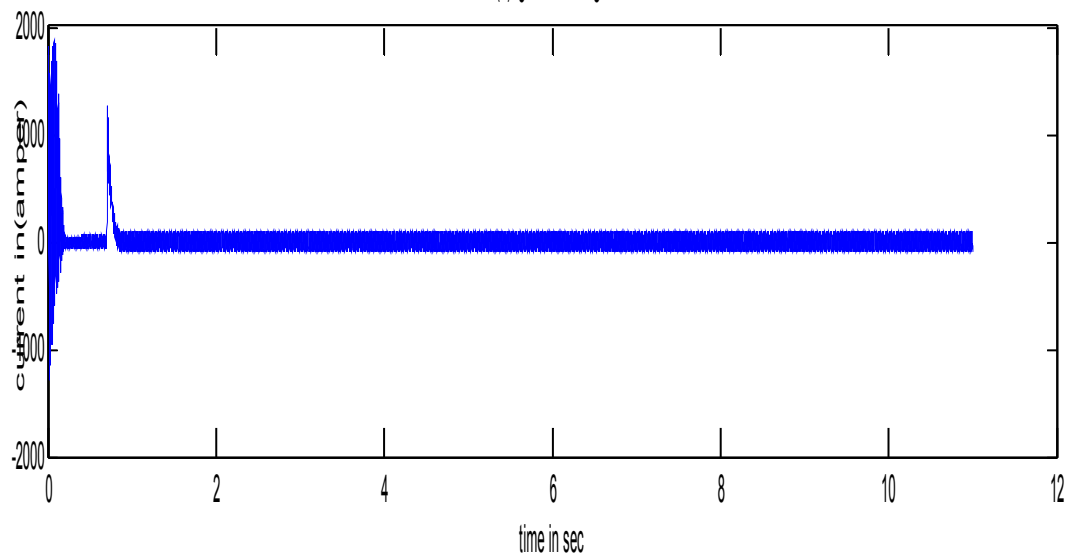
current iq against time figure 3-43



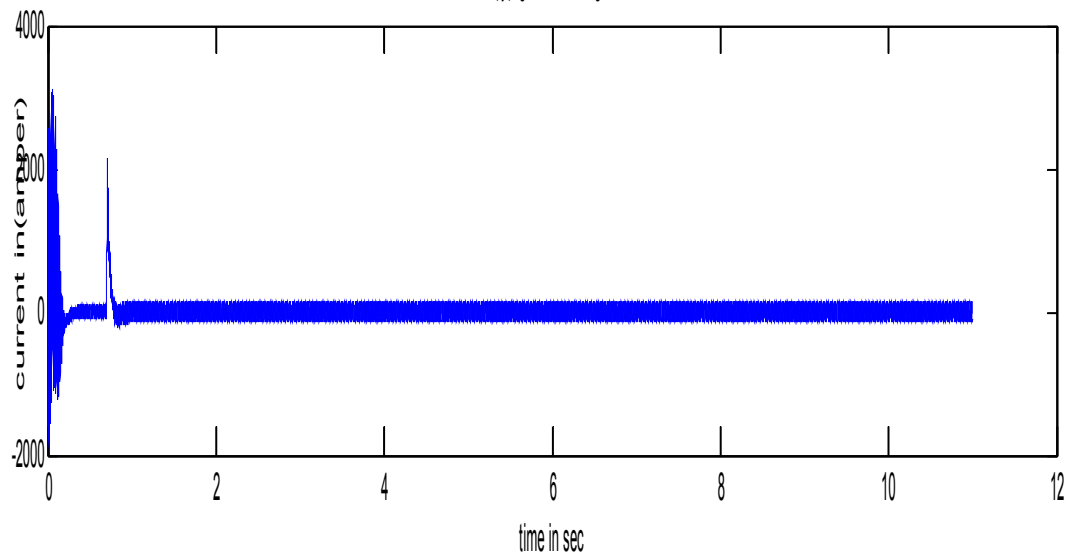
current id against time figure 3-44



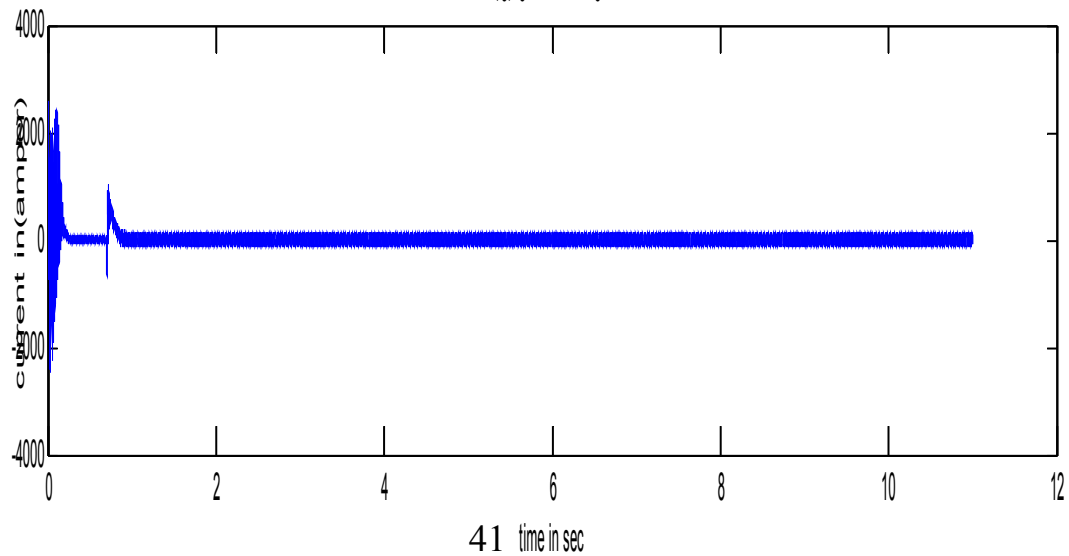
current(i) against time figure 3-45



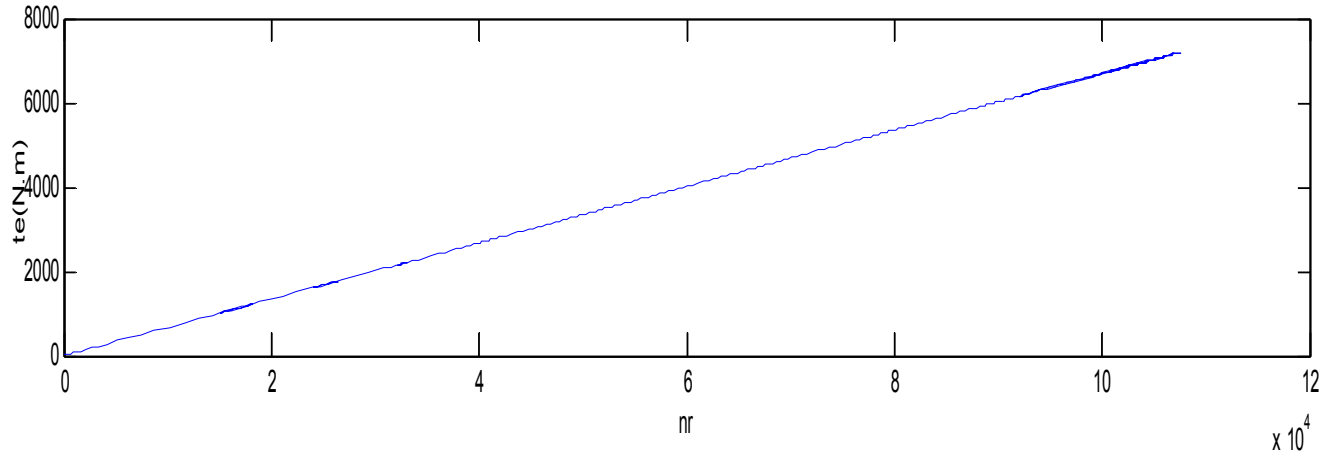
current(y) against time figure 3-46



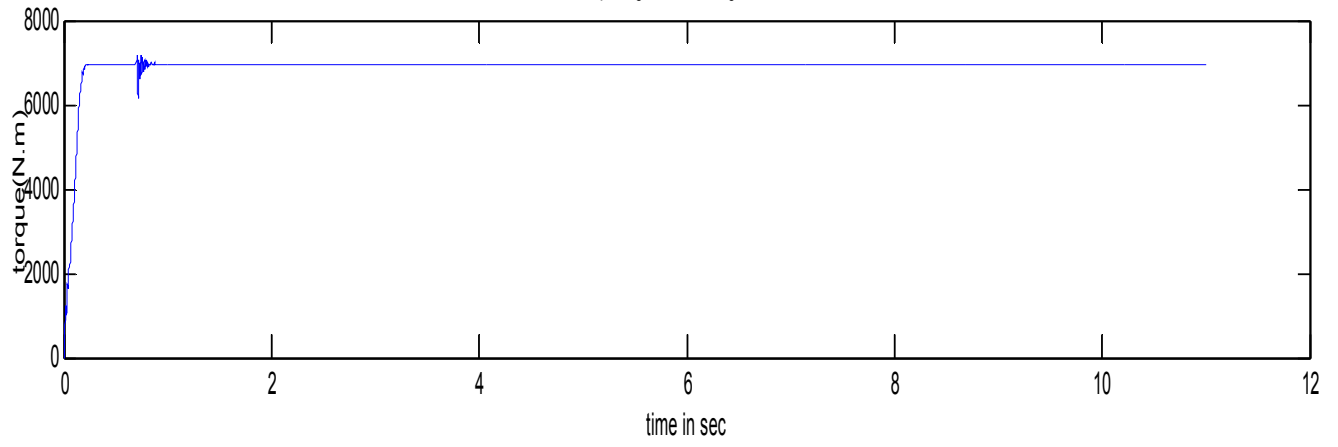
current(g) against time figure 3-47



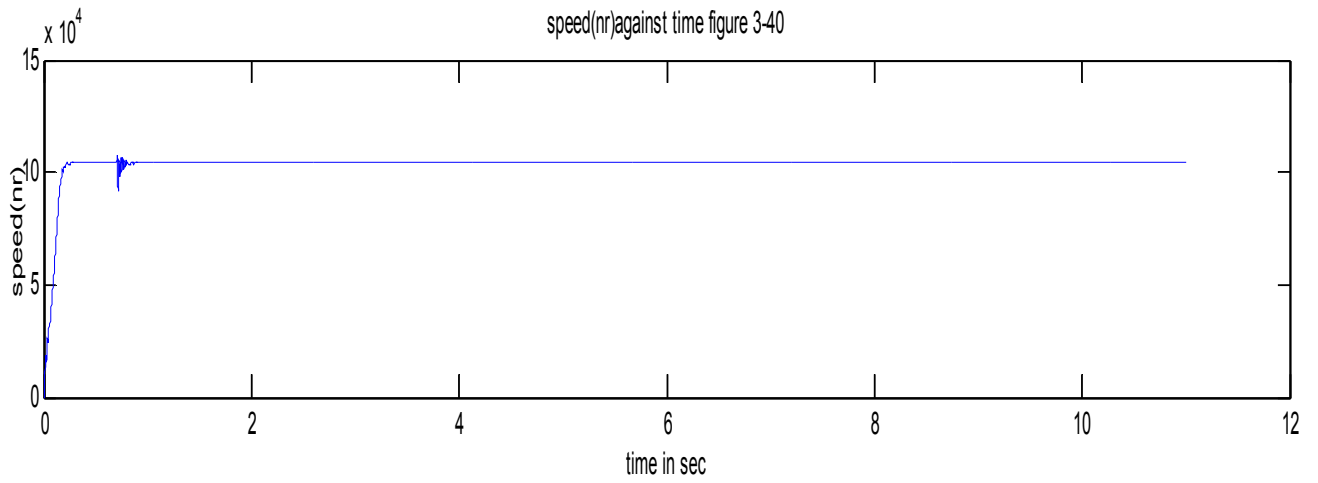
torque against speed figure 3-48



torque against time figure 3-49



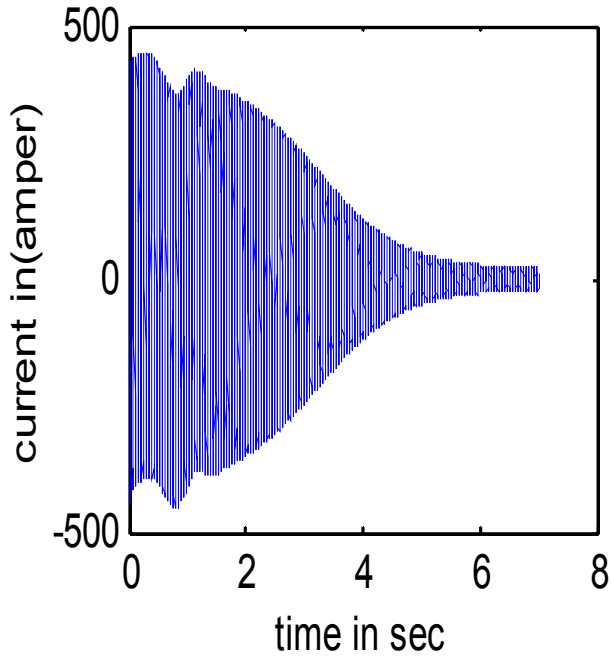
speed(nr) against time figure 3-40



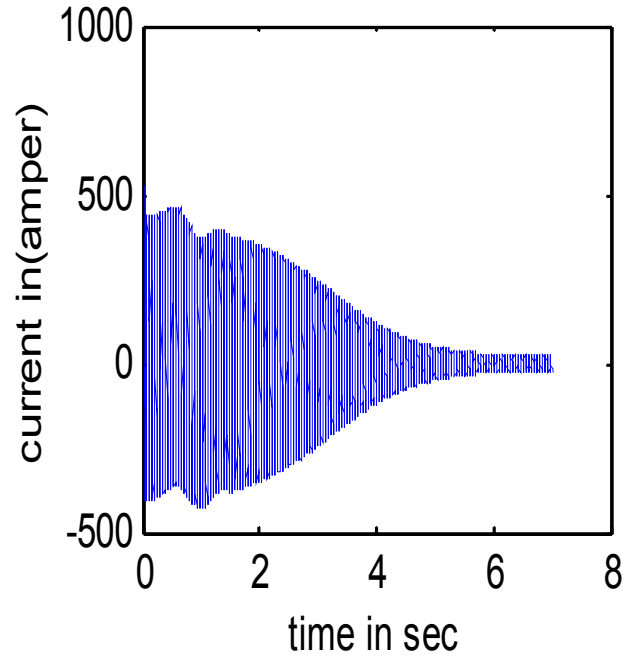
4.2.6 A result of 2250hp when a change load is applied:

* When a rated load torque is applied to the motor after the dynamic performance current and speed were increase slightly.

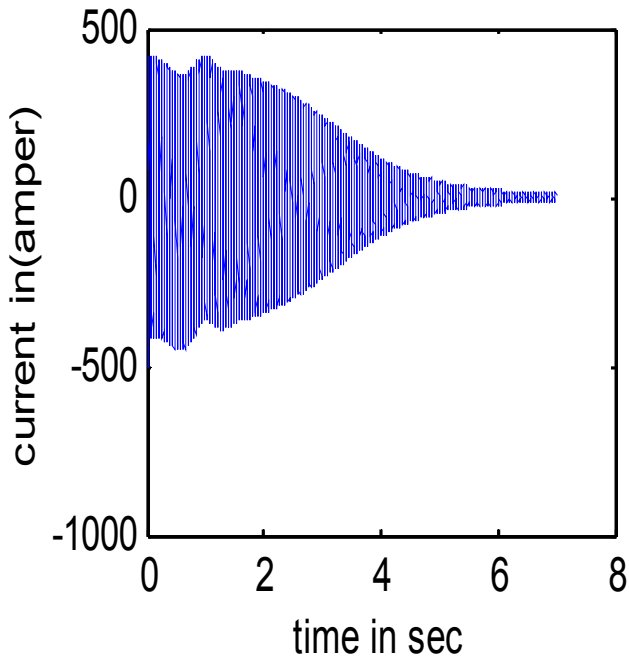
current ia against time figure 3-51



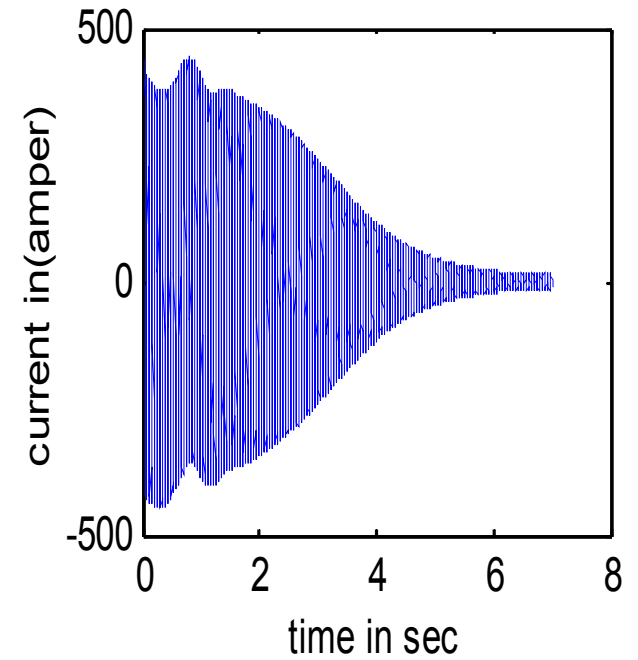
current(ib)against time figure 3-52

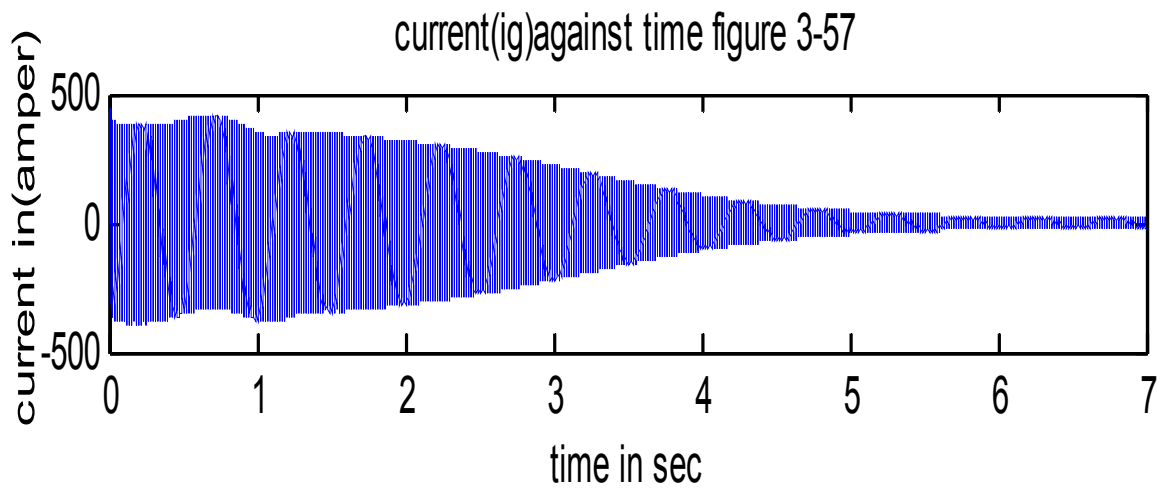
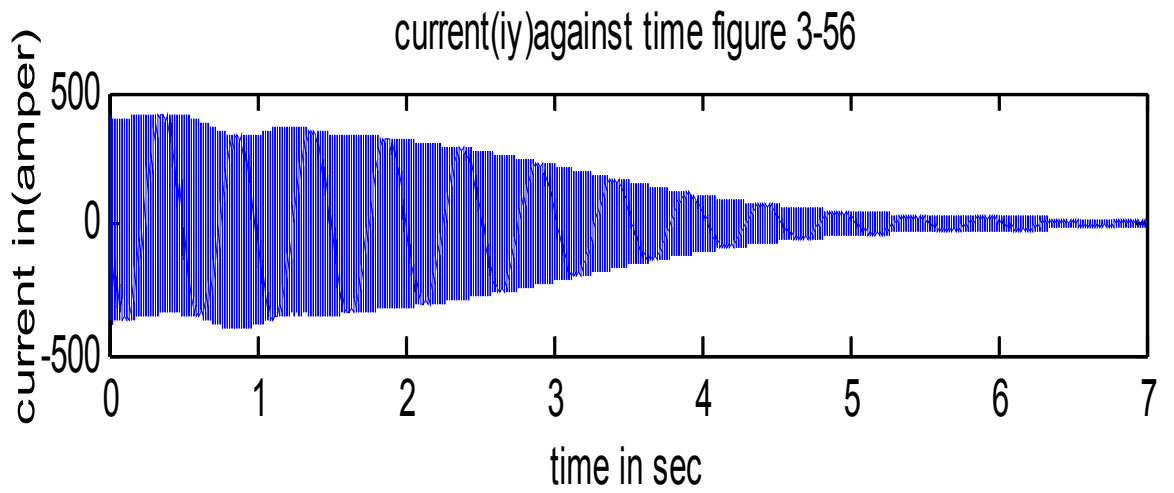
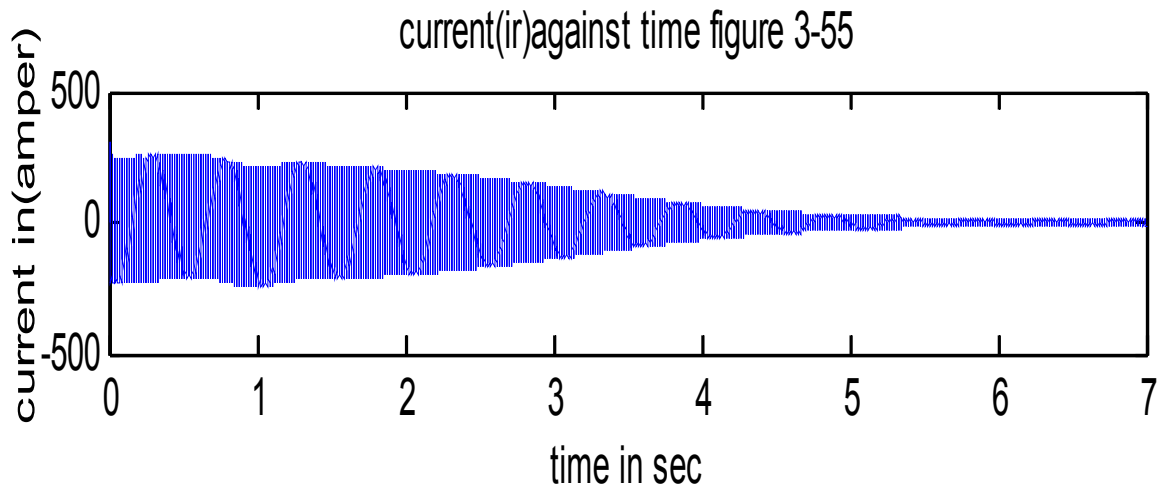


current(iq)against time figure 3-53

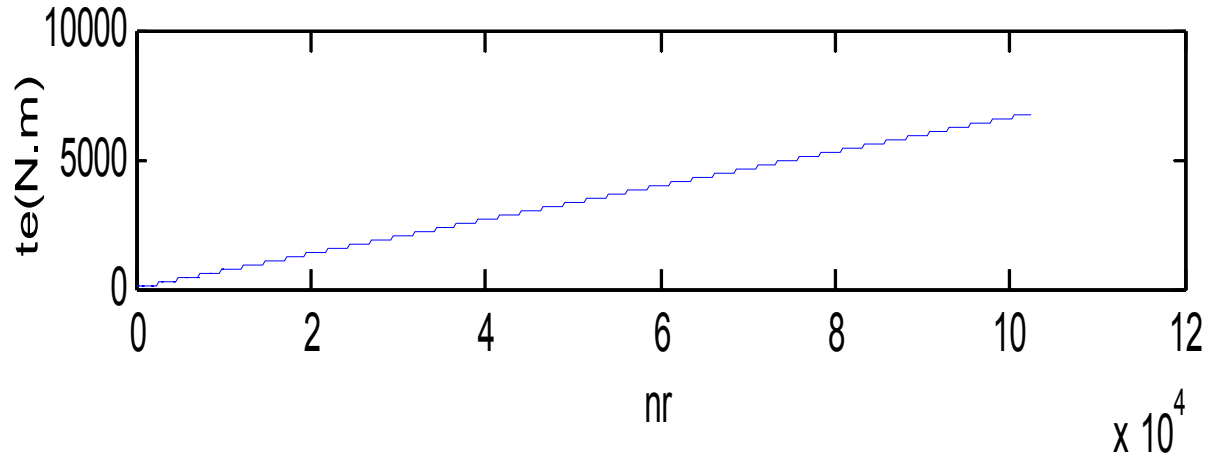


current(id)against time figure 3-54

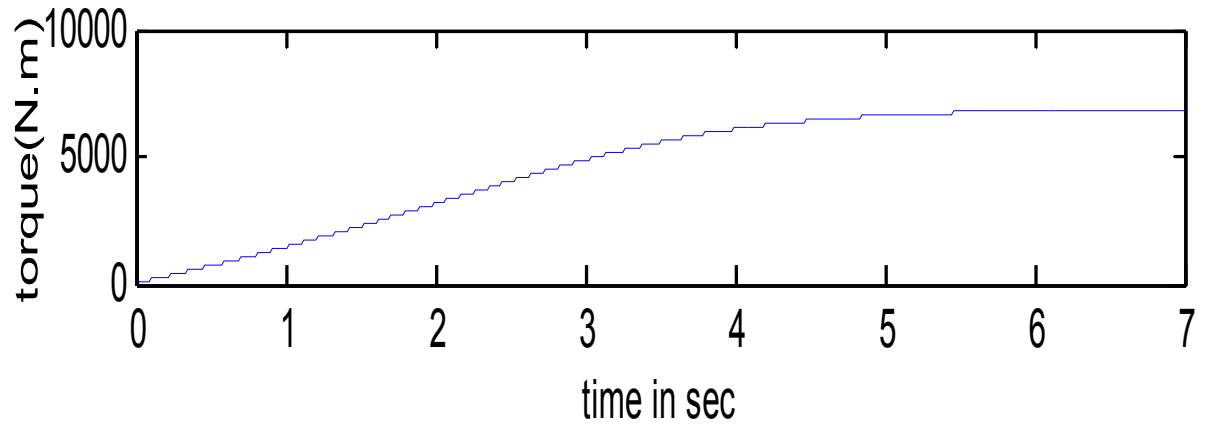




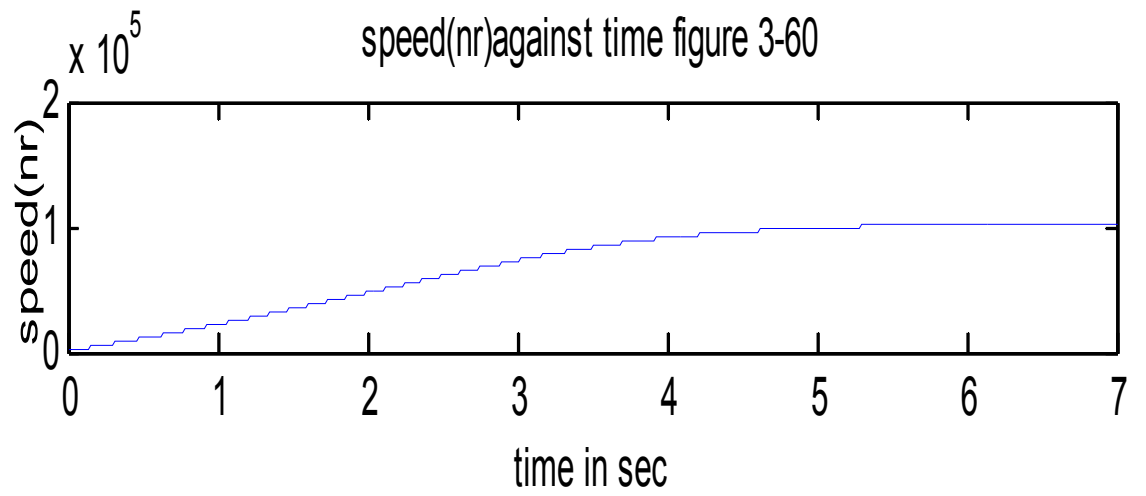
torque against speed figure 3-58



torque against time figure 3-59



speed(nr) against time figure 3-60



CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion and Discussion:

When a voltage is applied to a 3-phase induction motor the starting current is too large, in small or large motor it may reach 8 times of the rated current value, as shown from figure (3-1) to figure (3-7) for small motor and figure (3-31) to figure (3-37) for the large motor. In the big motor this current causes a disturbance in surrounding network. This disturbance can be avoided by applying a reduced voltage therefore in practice star delta starter is used to start until the machine has reached (60-80) percent of synchronous speed whereupon full voltage is applied. When a voltage is reduced by 40 percent of its rated value, the current also reduces by the same value but the reduction in the voltage decreases the transient starting torque about one third.

The dynamic of the 3 and 2250 hp induction motor during step change in the load torque is shown from figure (3-28) to figure (3-30) and figure (3-58) to figure (3-60) respectively. Initially each machine is operating at synchronous speed. The load torque is first stepped from zero to rated torque (slightly less than rated torque) and the machine allows to establish this new operation condition point. Next, the no-load torque is stepped from base torque back to zero whereupon the machine reestablishes its original operating condition. This change in the load torque causes a slight increase in current value for both motors.

5.2 Recommendation:

- *This study is applicable to be carried out by using Simulink.
- *We advise to study the power factor Vs speed or time curve.
- *We recommend to study the dynamic performance of 3-phase induction motor in case of one phase failure.

5.3 REFERENCES

- [1] Paul C .Krause ,McGraw-Hill Book Company, Analysis of Electric Machinery And Drive System, 1986
- [2] Charles V. Jones, Butterworth and Co Publisher Ltd, The Unified Theory of Electrical Machines, 1967
- [3] Dr.P.S. Bimbhra, Khanna Publishers, Generalized Theory of Electrical Machine,2011
- [4] N.N.HANCOK Matrix Analysis of Electrical Machinery, Pergamon Ltd ,1974

APPENDIX

Program1-1:

```
function iprime =dpim(t,i)
f=60;
p=4;
j=0.089;
tm=0.0;
w=2*pi*f;
vs=220;
m=26.13/(w);
l1=0.754/(2*pi*f)+m;
l2=11;
l2=11;
r1=0.435;
r2=0.816;
m=26.13/(w);
va=vs*cos(w*t);
vb=vs*sin(w*t);
g=[0 0 0 0 ;0 0 0 0 ;-m 0 0 -l2;0 m l2 0];
te=(p/2)*m*(i(2)*i(4)-i(1)*i(3));
l=[l1 0 0 m;0 l1 m 0;0 m l2 0;m 0 0 l2];
dw=(te-tm)/j;
li=inv(l);
a1=va-r1*i(1);
a2=vb-r1*i(2);
a3=-r2*i(3)+m*i(5)*(m*i(1)+l2*i(4));
a4=-r2*i(4)-m*i(5)*(m*i(2)+l2*i(3));
a=[a1;a2;a3;a4];
x=li*a;
x1=x(1);
x2=x(2);
x3=x(3);
x4=x(4);
x5=dw;
x6=w;
iprime=[x1;x2;x3;x4;x5;x6];
```

Program1-2:

```
t0 =0; tfinal = 10.0;
i0 = [0; 0; 0; 0; 0; 0];
tspan = [t0,tfinal];
[t, i] = ode45('dpim',tspan,i0); % use for MATLAB 5
ia=i(:,1);
ib=i(:,2);
iq=i(:,3);
id=i(:,4);
w=i(:,5);
p=4;
m=26.13/(2*pi*60);
j=0.089;
tm=0.0;
te=w*j+tm;
nr=i(:,5)*60/(2*pi);
figure(1)
subplot(2,2,1),plot(t,ia)
xlabel('time in sec'),ylabel('current in(amper)')
title('current ia against time figure 3-1');
subplot(2,2,2),plot(t,ib)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(ib)against time figure 3-2');
subplot(2,2,3),plot(t,iq)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(iq)against time figure 3-3');
subplot(2,2,4),plot(t,id)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(id)against time figure 3-4');
it=zeros(length(ia),1);
ie=sqrt(2/3).*[1 0 1/sqrt(2);-0.5 sqrt(3)/2 1/sqrt(2);-0.5 -sqrt(3)/2 1/sqrt(2)];
ik=[it ia ib];
ih=ie*ik';
z=ih';
ir=z(:,1);
iy=z(:,2);
ig=z(:,3);
figure(2)
subplot(3,1,1),plot(t,ir)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(ir)against time figure 3-5');
```

```

subplot(3,1,2),plot(t,iy)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(iy)against time figure 3-6');
subplot(3,1,3),plot(t,ig)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(ig)against time figure 3-7');
theta=i(:,6);
figure(3)
subplot(3,1,1),plot(nr,te)
xlabel('nr'),ylabel('te(N.m)')
title('torque against speed figure 3-8');
subplot(3,1,2),plot(t,te)
xlabel('time in sec'),ylabel('torque(N.m)')
title('torque against time figure 3-9');
subplot(3,1,3),plot(t,nr)
xlabel('time in sec'),ylabel('speed(nr)')
title('speed(nr)against time figure 3-10')

```

Program 2-1:

```
function iprime =dpim(t,i)
f=60;
p=4;
j=0.089;
tm=0.0;
if t<=0.7
    vs=220/sqrt(3);
else vs=220;
end
w=2*pi*f;
m=26.13/(w);
l1=0.754/(2*pi*f)+m;
l2=l1;
l2=l1;
r1=0.435;
r2=0.816;
m=26.13/(w);
va=vs*cos(w*t);
vb=vs*sin(w*t);
g=[0 0 0 0 ;0 0 0 0 ;-m 0 0 -l2;0 m l2 0];
te=(p/2)*m*(i(2)*i(4)-i(1)*i(3));
l=[l1 0 0 m;0 l1 m 0;0 m l2 0;m 0 0 l2];
dw=(te-tm)/j;
li=inv(l);
a1=va-r1*i(1);
a2=vb-r1*i(2);
a3=-r2*i(3)+m*i(5)*(m*i(1)+l2*i(4));
a4=-r2*i(4)-m*i(5)*(m*i(2)+l2*i(3));
a=[a1;a2;a3;a4];
x=li*a;
x1=x(1);
x2=x(2);
x3=x(3);
x4=x(4);
x5=dw;
x6=w;
iprime=[x1;x2;x3;x4;x5;x6];
```

Program 2-2:

```
t0 =0; tfinal = 10.0;
i0 = [0; 0; 0; 0; 0; 0];
tspan = [t0,tfinal];
[t, i] = ode45('dpim',tspan,i0); % use for MATLAB 5
ia=i(:,1);
ib=i(:,2);
iq=i(:,3);
id=i(:,4);
w=i(:,5);
p=4;
m=26.13/(2*pi*60);
j=0.089;
tm=0.0;
te=w*j+tm;
nr=i(:,5)*60/(2*pi);
figure(1)
subplot(2,2,1),plot(t,ia)
xlabel('time in sec'),ylabel('current in(amp)')
title('current ia against time figure 3-11');
subplot(2,2,2),plot(t,ib)
xlabel('time in sec'),ylabel('current in(amp)')
title('current(ib)against time figure 3-12');
subplot(2,2,3),plot(t,iq)
xlabel('time in sec'),ylabel('current in(amp)')
title('current(iq)against time figure 3-13');
subplot(2,2,4),plot(t,id)
xlabel('time in sec'),ylabel('current in(amp)')
title('current(id)against time figure 3-14');
it=zeros(length(ia),1);
ie=sqrt(2/3).*[1 0 1/sqrt(2);-0.5 sqrt(3)/2 1/sqrt(2);-0.5 -sqrt(3)/2 1/sqrt(2)];
ik=[it ia ib];
ih=ie*ik';
z=ih';
ir=z(:,1);
iy=z(:,2);
ig=z(:,3);
figure(2)
subplot(3,1,1),plot(t,ir)
xlabel('time in sec'),ylabel('current in(amp)')
title('current(ir)against time figure 3-15');
```

```

subplot(3,1,2),plot(t,iy)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(iy)against time figure 3-16');
subplot(3,1,3),plot(t,ig)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(ig)against time figure 3-17');
theta=i(:,6);
figure(3)
subplot(3,1,1),plot(nr,te)
xlabel('nr'),ylabel('te(N.m)')
title('torque against speed figure 3-18');
subplot(3,1,2),plot(t,te)
xlabel('time in sec'),ylabel('torque(N.m)')
title('torque against time figure 3-19');
subplot(3,1,3),plot(t,nr)
xlabel('time in sec'),ylabel('speed(nr)')
title('speed(nr)against time figure 3-20')

```

Program 3-1:

```
function iprime =dpim(t,i)
f=60;
p=4;
j=0.089;
vs=220;
if t<=0.7
    tm=0.0;
else tm=11.9;
end
w=2*pi*f;
m=26.13/(w);
l1=0.754/(2*pi*f)+m;
l2=l1;
l2=l1;
r1=0.435;
r2=0.816;
m=26.13/(w);
va=vs*cos(w*t);
vb=vs*sin(w*t);
g=[0 0 0 0 ;0 0 0 0 ;-m 0 0 -l2;0 m l2 0];
te=(p/2)*m*(i(2)*i(4)-i(1)*i(3));
l=[l1 0 0 m;0 l1 m 0;0 m l2 0;m 0 0 l2];
dw=(te-tm)/j;
li=inv(l);
a1=va-r1*i(1);
a2=vb-r1*i(2);
a3=-r2*i(3)+m*i(5)*(m*i(1)+l2*i(4));
a4=-r2*i(4)-m*i(5)*(m*i(2)+l2*i(3));
a=[a1;a2;a3;a4];
x=li*a;
x1=x(1);
x2=x(2);
x3=x(3);
x4=x(4);
x5=dw;
x6=w;
iprime=[x1;x2;x3;x4;x5;x6];
```

Program 3-2:

```
t0 =0; tfinal = 11.0;
i0 = [0; 0; 0; 0; 0; 0];
tspan = [t0,tfinal];
[t, i] = ode45('dpim',tspan,i0); % use for MATLAB 5
ia=i(:,1);
ib=i(:,2);
iq=i(:,3);
id=i(:,4);
w=i(:,5);
p=4;
m=26.13/(2*pi*60);
j=0.089;
tm=0.0;
te=w*j+tm;
nr=i(:,5)*60/(2*pi);
figure(1)
subplot(2,2,1),plot(t,ia)
xlabel('time in sec'),ylabel('current in(amper)')
title('current ia against time figure 3-21');
subplot(2,2,2),plot(t,ib)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(ib)against time figure 3-22');
subplot(2,2,3),plot(t,iq)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(iq)against time figure 3-23');
subplot(2,2,4),plot(t,id)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(id)against time figure 3-24');
it=zeros(length(ia),1);
ie=sqrt(2/3).*[1 0 1/sqrt(2);-0.5 sqrt(3)/2 1/sqrt(2);-0.5 -sqrt(3)/2 1/sqrt(2)];
ik=[it ia ib];
ih=ie*ik';
z=ih';
ir=z(:,1);
iy=z(:,2);
ig=z(:,3);
figure(2)
subplot(3,1,1),plot(t,ir)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(ir)against time figure 3-25');
```



```

subplot(3,1,2),plot(t,iy)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(iy)against time figure 3-26');
subplot(3,1,3),plot(t,ig)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(ig)against time figure 3-27');
theta=i(:,6);
figure(3)
subplot(3,1,1),plot(nr,te)
xlabel('nr'),ylabel('te(N.m)')
title('torque against speed figure 3-28');
subplot(3,1,2),plot(t,te)
xlabel('time in sec'),ylabel('torque(N.m)')
title('torque against time figure 3-29');
subplot(3,1,3),plot(t,nr)
xlabel('time in sec'),ylabel('speed(nr)')
title('speed(nr)against time figure 3-30')

```

Program 4-1:

```
function iprime = dpim(t,i)
f=60;
p=4;
j=0.089;
tm=0.0;
w=2*pi*f;
vs=2300;
m=13.04/(w);
l1=0.226/(2*pi*f)+m;
l2=11;
l2=11;
r1=0.029;
r2=0.226;
va=vs*cos(w*t);
vb=vs*sin(w*t);
g=[0 0 0 0 ;0 0 0 0 ;-m 0 0 -l2;0 m l2 0];
te=(p/2)*m*(i(2)*i(4)-i(1)*i(3));
l=[l1 0 0 m;0 l1 m 0;0 m l2 0;m 0 0 l2];
dw=(te-tm)/j;
li=inv(l);
a1=va-r1*i(1);
a2=vb-r1*i(2);
a3=-r2*i(3)+m*i(5)*(m*i(1)+l2*i(4));
a4=-r2*i(4)-m*i(5)*(m*i(2)+l2*i(3));
a=[a1;a2;a3;a4];
x=li*a;
x1=x(1);
x2=x(2);
x3=x(3);
x4=x(4);
x5=dw;
x6=w;
iprime=[x1;x2;x3;x4;x5;x6];
```

Program 4-2:

```
t0 =0; tfinal = 11.0;
i0 = [0; 0; 0; 0; 0; 0];
tspan = [t0,tfinal];
[t, i] = ode45('dpim',tspan,i0); % use for MATLAB 5
ia=i(:,1);
ib=i(:,2);
iq=i(:,3);
id=i(:,4);
w=i(:,5);
p=4;
m=26.13/(2*pi*60);
j=0.089;
tm=0.0;
te=w*j+tm;
nr=i(:,5)*60/(2*pi);
figure(1)
subplot(2,2,1),plot(t,ia)
xlabel('time in sec'),ylabel('current in(amper)')
title('current ia against time figure 3-31');
subplot(2,2,2),plot(t,ib)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(ib)against time figure 3-32');
subplot(2,2,3),plot(t,iq)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(iq)against time figure 3-33');
subplot(2,2,4),plot(t,id)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(id)against time figure 3-34');
it=zeros(length(ia),1);
ie=sqrt(2/3).*[1 0 1/sqrt(2);-0.5 sqrt(3)/2 1/sqrt(2);-0.5 -sqrt(3)/2 1/sqrt(2)];
ik=[it ia ib];
ih=ie*ik';
z=ih';
ir=z(:,1);
iy=z(:,2);
ig=z(:,3);
figure(2)
subplot(3,1,1),plot(t,ir)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(ir)against time figure 3-35');
```

```

subplot(3,1,2),plot(t,iy)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(iy)against time figure 3-36');
subplot(3,1,3),plot(t,ig)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(ig)against time figure 3-37');
theta=i(:,6);
figure(3)
subplot(3,1,1),plot(nr,te)
xlabel('nr'),ylabel('te(N.m)')
title('torque against speed figure 3-38');
subplot(3,1,2),plot(t,te)
xlabel('time in sec'),ylabel('torque(N.m)')
title('torque against time figure 3-39');
subplot(3,1,3),plot(t,nr)
xlabel('time in sec'),ylabel('speed(nr)')
title('speed(nr)against time figure 3-40')

```

Program 5-1:

```
function iprime =dpim(t,i)

f=60;
p=4;
j=0.089;
tm=0.0;
w=2*pi*f;
if t<=0.7
    vs=2300/sqrt(3);
else vs=2300;
end
m=13.04/(w);
l1=0.226/(2*pi*f)+m;
l2=l1;
l2=l1;
r1=0.029;
r2=0.226;
va=vs*cos(w*t);
vb=vs*sin(w*t);
g=[0 0 0 0 ;0 0 0 0 ;-m 0 0 -l2;0 m l2 0];
te=(p/2)*m*(i(2)*i(4)-i(1)*i(3));
l=[l1 0 0 m;0 l1 m 0;0 m l2 0;m 0 0 l2];
dw=(te-tm)/j;
li=inv(l);
a1=va-r1*i(1);
a2=vb-r1*i(2);
a3=-r2*i(3)+m*i(5)*(m*i(1)+l2*i(4));
a4=-r2*i(4)-m*i(5)*(m*i(2)+l2*i(3));
a=[a1;a2;a3;a4];
x=li*a;
x1=x(1);
x2=x(2);
x3=x(3);
x4=x(4);
x5=dw;
x6=w;
iprime=[x1;x2;x3;x4;x5;x6];
```

Program 5-2:

```
t0 =0; tfinal = 11.0;
i0 = [0; 0; 0; 0; 0; 0];
tspan = [t0,tfinal];
[t, i] = ode45('dpim',tspan,i0); % use for MATLAB 5
ia=i(:,1);
ib=i(:,2);
iq=i(:,3);
id=i(:,4);
w=i(:,5);
p=4;
m=26.13/(2*pi*60);
j=.6387;
tm=0.0;
te=w*j+tm;
nr=i(:,5)*60/(2*pi);
figure(1)
subplot(2,2,1),plot(t,ia)
xlabel('time in sec'),ylabel('current in(amp)')
title('current ia against time figure 3-41');
subplot(2,2,2),plot(t,ib)
xlabel('time in sec'),ylabel('current in(amp)')
title('current(ib)against time figure 3-42');
subplot(2,2,3),plot(t,iq)
xlabel('time in sec'),ylabel('current in(amp)')
title('current(iq)against time figure 3-43');
subplot(2,2,4),plot(t,id)
xlabel('time in sec'),ylabel('current in(amp)')
title('current(id)against time figure 3-44');
it=zeros(length(ia),1);
ie=sqrt(2/3).*[1 0 1/sqrt(2);-0.5 sqrt(3)/2 1/sqrt(2);-0.5 -sqrt(3)/2 1/sqrt(2)];
ik=[it ia ib];
ih=ie*ik';
z=ih';
ir=z(:,1);
iy=z(:,2);
ig=z(:,3);
figure(2)
subplot(3,1,1),plot(t,ir)
xlabel('time in sec'),ylabel('current in(amp)')
title('current(ir)against time figure 3-45');
```

```

subplot(3,1,2),plot(t,iy)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(iy)against time figure 3-46');
subplot(3,1,3),plot(t,ig)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(ig)against time figure 3-47');
theta=i(:,6);
figure(3)
subplot(3,1,1),plot(nr,te)
xlabel('nr'),ylabel('te(N.m)')
title('torque against speed figure 3-48');
subplot(3,1,2),plot(t,te)
xlabel('time in sec'),ylabel('torque(N.m)')
title('torque against time figure 3-49');
subplot(3,1,3),plot(t,nr)
xlabel('time in sec'),ylabel('speed(nr)')
title('speed(nr)against time figure 3-40')

```

Program 6-1:

```
function iprime = dpim(t,i)
f=60;
p=4;
j=0.089;
vs=220;
if t<=0.7
    tm=0.0;
else tm=11.9;
end
w=2*pi*f;
m=13.04/(w);
l1=0.226/(2*pi*f)+m;
l2=l1;
l2=l1;
r1=0.029;
r2=0.226;
va=vs*cos(w*t);
vb=vs*sin(w*t);
g=[0 0 0 0 ;0 0 0 0 ;-m 0 0 -l2;0 m l2 0];
te=(p/2)*m*(i(2)*i(4)-i(1)*i(3));
l=[l1 0 0 m;0 l1 m 0;0 m l2 0;m 0 0 l2];
dw=(te-tm)/j;
li=inv(l);
a1=va-r1*i(1);
a2=vb-r1*i(2);
a3=-r2*i(3)+m*i(5)*(m*i(1)+l2*i(4));
a4=-r2*i(4)-m*i(5)*(m*i(2)+l2*i(3));
a=[a1;a2;a3;a4];
x=li*a;
x1=x(1);
x2=x(2);
x3=x(3);
x4=x(4);
x5=dw;
x6=w;
iprime=[x1;x2;x3;x4;x5;x6];
```


Program 6-2:

```
t0 =0; tfinal = 7.0;
i0 = [0; 0; 0; 0; 0; 0];
tspan = [t0,tfinal];
[t, i] = ode45('dpim',tspan,i0); % use for MATLAB 5
ia=i(:,1);
ib=i(:,2);
iq=i(:,3);
id=i(:,4);
w=i(:,5);
p=4;
m=26.13/(2*pi*60);
j=.6387;
tm=0.0;
te=w*j+tm;
nr=i(:,5)*60/(2*pi);
figure(1)
subplot(2,2,1),plot(t,ia)
xlabel('time in sec'),ylabel('current in(amp)')
title('current ia against time figure 3-51');
subplot(2,2,2),plot(t,ib)
xlabel('time in sec'),ylabel('current in(amp)')
title('current(ib)against time figure 3-52');
subplot(2,2,3),plot(t,iq)
xlabel('time in sec'),ylabel('current in(amp)')
title('current(iq)against time figure 3-53');
subplot(2,2,4),plot(t,id)
xlabel('time in sec'),ylabel('current in(amp)')
title('current(id)against time figure 3-54');
it=zeros(length(ia),1);
ie=sqrt(2/3).*[1 0 1/sqrt(2);-0.5 sqrt(3)/2 1/sqrt(2);-0.5 -sqrt(3)/2 1/sqrt(2)];
ik=[it ia ib];
ih=ie*ik';
z=ih';
ir=z(:,1);
iy=z(:,2);
ig=z(:,3);
figure(2)
subplot(3,1,1),plot(t,ir)
xlabel('time in sec'),ylabel('current in(amp)')
title('current(ir)against time figure 3-55');
```

```

subplot(3,1,2),plot(t,iy)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(iy)against time figure 3-56');
subplot(3,1,3),plot(t,ig)
xlabel('time in sec'),ylabel('current in(amper)')
title('current(ig)against time figure 3-57');
theta=i(:,6);
figure(3)
subplot(3,1,1),plot(nr,te)
xlabel('nr'),ylabel('te(N.m)')
title('torque against speed figure 3-58');
subplot(3,1,2),plot(t,te)
xlabel('time in sec'),ylabel('torque(N.m)')
title('torque against time figure 3-59');
subplot(3,1,3),plot(t,nr)
xlabel('time in sec'),ylabel('speed(nr)')
title('speed(nr)against time figure 3-60')

```