Global Scientific JOURNALS

GSJ: Volume 8, Issue 6, June 2020, Online: ISSN 2320-9186
www.globalscientificjournal.com

PERFORMANCE ANALYSIS OF STARTING AND CONTROL EFFECT OF THREE PHASE INDUCTION MOTORS

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ABSTRACT

Induction motors are the most widely used electrical motors due to their reliability, low cost and robustness. However, induction motors do not inherently have the capability of variable speed operation and high starting current. Starting large motors, especially across-the-line, can cause severe disturbances to other motors and any locally connected load and connected electrically. Ideally, a motor-starting study should be made before a large motor is purchase. The aim of this research is to perform analysis of a three-phase induction motor on different starting methods. Several staring method of induction motor such as variable resistance method, variable frequency method, variable voltage method and variable frequency voltage method was studied. The study was conducted on a 1HP, 3-phase, 415V, 50Hz, 4 poles induction motor; and simulated using an Engineering tool, MATLAB/Simulink, based on analytical technique. Amongst the induction motor starting methods considered, variable voltage frequency (V/F) produced a better result. In this method, by use of rectifier and Pulse Width Modulation (PWM) inverter, the supply voltage as well as the supply frequency is varied such that the ratio remains constant as well as the flux. in doing this, the maximum torque remains unchanged and different operating zone for various speeds and torques are achieved as well as different synchronous speed with almost same maximum torque. With this method, the starting torque of the motor was improved to 18N-m compared to the variable resistor method which has about 2.4N-m when the motor was started with highest resistance. The speed of the motor with V/F method was also obtained to be close to the motor reference speed, which is 1500RPM, while the speed for variable resistance method is 160RPM. The machine with V/F also has reduced starting current of about 20 Amps compared to the variable resistance method which has high starting current of about 400 Amps. Hence, it is recommended that during starting of the induction motor, the stator resistance and the motor inductance (both rotor and stator) must be kept low to reduce the steady state time and also to reduce the jerks during starting caused by inrush current.

Keywords : Analysis of Starting and control effect of three phase induction Motors

I. INTRODUCTION

Motors have been around for over a hundred years, and it has find its application into so may application that life finds it difficult to leave without, because it has been an integral part of our daily process, like in pulley system, electric traction, pumping system and so in both large and small scale (Sandru, 2013). But as we know every system has its own setbacks.

Engine turning over and its related issues are notable to numerous large industrial processes, in the industrial process plant, several power system analyses is needed to be carried out during planning stage or during operation when remarkable change occurs in plant operating pattern, like fault, outage, load/power flow, short circuit and motor analysis, where motor starting study happens to be integral part of power system analysis.

In process plant, several AC (Substituting current) and DC (Direct current) engines are for the most part used to run mechanical loads. One of the AC motors used in in the industrial process plants is three phase induction motor. Large induction motor has low values of rotor resistance in range of ohms. Therefore, when these motors are started, there is large inrush current of around 5 to multiple times of appraised full burden current. Due to that there is a huge voltage drop which may have an adverse effect on the remaining power systems as well as motor itself. Since the engine introductory quickening torque is corresponding to square of voltage, there is expected heavy voltage drop. Sometimes motors won't be able to attain its rated speed as a result of this. To ensure successful start-up of large motors without violating operating parameters, motor starting analysis is performed.

The problem associated in starting induction motors is not only limited to large motors. It might be important to make an examination for littler drive sizes relying upon the day by day change of ostensible voltage, voltage level, size and length of the engine feeder link, measure of burden, guideline of the stock voltage, the impedance and tap proportion of the inventory transformer(s), load torque versus engine torque, and the reasonable beginning time. Furthermore, a few applications may include beginning huge gatherings of littler engines of adequate aggregate size to affect framework voltage guideline during the beginning interim.
During the starting, it is required that the engine terminal voltage ought to be kept up at around 80% of the evaluated voltage for type B engines having a standard 150% beginning torque at full voltage with a steady torque load applied. On account of plan B engines, the draw out torque is 200% of the appraised torque. In the event that the engine terminal voltage falls underneath 71% of the appraised voltage the engine may slow down. This expect the created torque is corresponding to V. On the off chance that other than structure B engines are utilized on the framework, a comparative rule can be set up to assess re-quickening following an engine turning over. Additionally, for each situation the beginning time must be assessed for the harm furthest reaches of the engine.

II. EXTENT OF PAST WORKS

Engine Starting Studies are performed on a force framework to decide irregular outcomes of turning over a huge engine. There are numerous contemplations to turning over an engine other than adequately interfacing it to the line voltage. Irritation stumbling and over the top running flows, just as darkening of lights, are signs that a force framework isn't performing appropriately. In the past, AC acceptance engine or AC synchronous engine will draw more noteworthy than-ordinary running current, commonly about 600% of evaluated full-load current and will keep going as the engine goes to max throttle. On the off chance that an engine is turned over with a mechanical burden associated with the pole, inrush current will be drawn for a more extended period. Notwithstanding, it won't be more prominent in greatness than if the engine was turned over with no heap.

The power system should be able to supply inrush to any motor on the system while supplying normal service for the rest of the system. If the system does not have sufficient capacity, there will be excessively low voltage drops and insufficient capacity for motor starting (Consult, 2018).

III. METHODOLOGY

Before considering the approaches used to achieve the objectives of this research, it is critical to carryout circuit examination of three-stage enlistment engine. To examine the conduct of the acceptance engine at different working conditions, it is a great idea to infer an equal circuit of the engine under sinusoidal consistent state working condition.The proportionate circuit of the engine can be utilized to decide a wide assortment of consistent state execution qualities of polyphone acceptance machine. These incorporate variety of current, speed, and misfortunes as the heap torque prerequisites change just as the beginning torque and greatest torque. The area of interest in this project is the consistent state torque speed attributes of enlistment engine thinking about different beginning technique. MATLAB/Simulink was used for coding and simulation of the motor based on the developed equations.

3.1 Developed Equations for Motor Maximum Slip and Maximum Torque

As the premise of the engine turning over investigation, over line beginning is presented first. The over line beginning applies the force supply recurrence of 50Hz/60Hz to the engine terminal **(Xiaodong & Obinna , 2010)**. The comparable circuit of acceptance engines is generally used to ascertain electrical parameters of enlistment engines during typical activity and engine turning over.

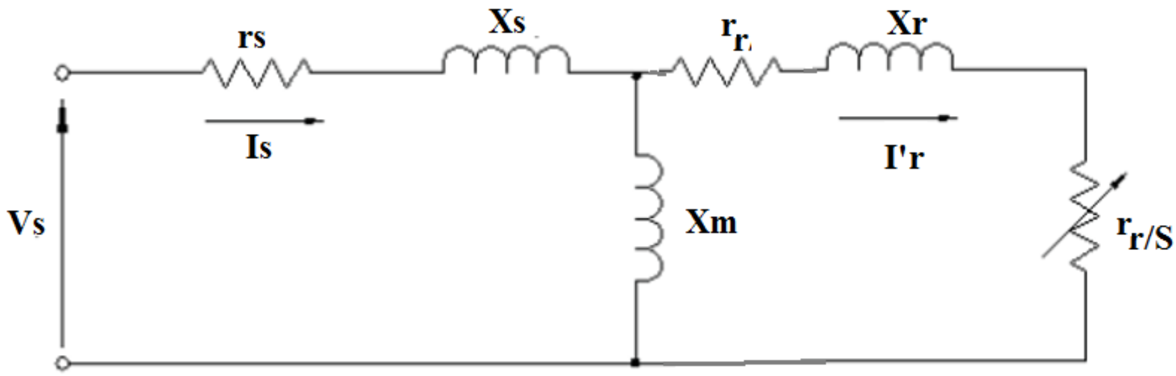

Figure 3.1: Per Phase Equivalent Circuit of an Induction Motor at any Slip (Xiaodong & Obinna , 2010)

The equivalent circuit of Figure 3.1can be utilized to decide a wide assortment of consistent state execution attributes of polyphone enlistment machine. These incorporate variety of current, speed, and misfortunes as the heap torque necessities change just as the beginning torque and greatest torque. Right now, our region of intrigue is the consistent state torque speed attributes, where the derivation of maximum torque will be of benefit.

Splitting Figure 3.1 into two part as represented in Figure 3.2, for the rotor circuit part, the rotor voltage condition in per-stage structure can be composed as:

$$E_r = I_r[\frac{r_r}{s} + jX_r] \quad (3.1)$$

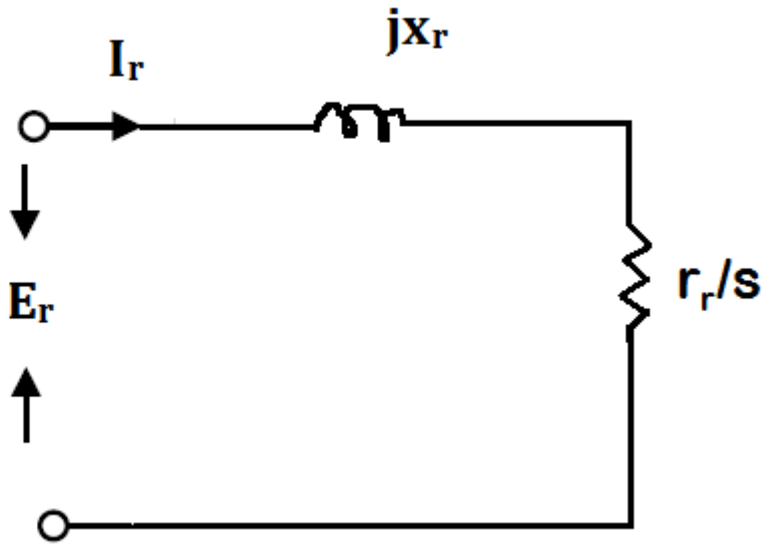

Figure 3.2: Rotor Equivalent Circuit of an Induction Motor

The per-stage rotor current at any slip is given by:

$$I_r = \frac{E_r}{\sqrt{\left(\frac{r_r}{s}\right)2 \ \ +X_r^2}} \qquad (3.2)$$

$\Theta_r$is given as tan^{-1}($\frac{sX_r}{V_r}$)

On the off chance that the rotor current slacks the rotor voltage E_r by Θ_r, at that point the information power is expressed as:

$$P_{ag} = I_r E_r \cos\Theta_r \qquad (3.3)$$

Where cos $\Theta_r$is the power factor, and can be expressed as:

$$\cos\Theta_r = \frac{\text{per phase rotor resistance}}{\text{per phase rotor impedance}} =$$

$$\frac{\frac{r_r}{s}}{\sqrt{\left(\frac{r_r}{s}\right)2+X_r{}^2}} \qquad (3.4)$$

From 3.3, P_{ag}can then expressed as:

$$E_r I_r \frac{\frac{r_r}{s}}{\sqrt{\left(\frac{r_r}{s}\right)2+X_r{}^2}} \qquad (3.5a)$$

$$= I_r{}^2 \frac{r_r}{s} \qquad (3.5b)$$

In essence, $P_{ag}$is really the force moved from the stator to the rotor over the air hole.

And it can be rewritten as $I_r{}^2 \frac{r}{s} + I_r{}^2 \frac{r_r}{s}\left(\frac{1-s}{s}\right)$ (3.5c)

Where $I_r{}^2 \frac{r_r}{s}$is the rotor ohmic loss and $I_r{}^2 \frac{r_r}{s}\left(\frac{1-s}{s}\right)$is the internal mechanical force created in the rotor.

But the mechanical output power can be given as:

$$P_m = (1-s)P_{ag} = I_r^2 \frac{r_r}{S}\left(\frac{1-s}{s}\right) \tag{3.6}$$

Similarly, the mechanical torque can be given as:

$$T_m = \frac{internal\ mechanical\ power\ developed\ in\ rotor}{rotor\ speed\ in\ mechanical\ rad/sec}$$

$$= \frac{P_m}{\omega_r} \tag{3. 7}$$

But $\omega_r = \omega_s(1-s)$

So, $T_m = \frac{[1-s]P_{ag}}{[1-s]\omega_s}$ (3.8)

If $(1-s)$cancel each other,

$$T_m = \frac{P_{ag}}{\omega_s} \tag{3.9}$$

The output or shaft power is

$$P_{out} = P_m - P_{rot} \tag{3.10}$$

Where $P_{rot}$is the rotational power including mechanical losses

Then, similarly, the output torque is

$$T_{out} = \frac{P_{out}}{\omega_r} = \frac{P_{out}}{(1-s)\omega_s} \tag{3.11}$$

In Figure 3.2, resistance $\frac{r_r}{S}$is not the secondary winding resistance but a larger resistance and is varied as the slip, S varies. If we divide this resistance into two components, r_r, the actual resistance and $r_r\left(\frac{1-s}{s}\right)$, the equivalent circuit of Figure 3.1 can be redrawn to represent the 12r misfortune in the rotor circuit as in Figure 3.3 when the magnetizing inductance is transferred to the input terminal without much error in the calculations.

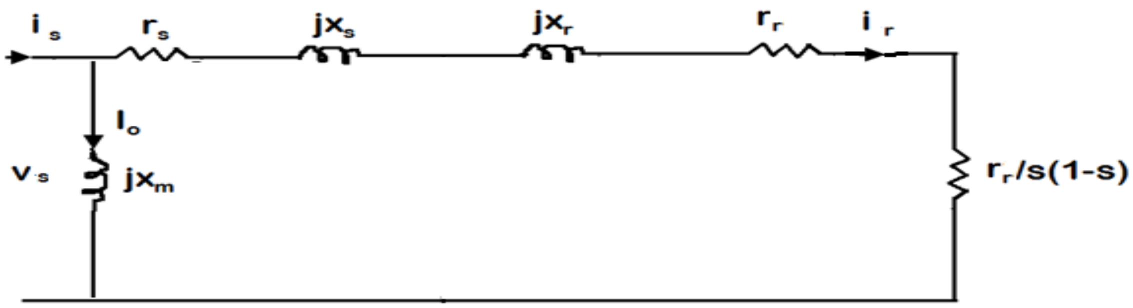

Figure 3.3: The Appropriate Equivalent circuit of an enlistment engine

Using the per-stage proportional circuit of the acceptance engine in Figure 3.3, if the stator power loss is given as $P_s = I^2{}_s\, r_s$, and the rotor loss is expressed as $P_r = [I_r]^2 r_r$; and they are neglected, the motor current can be expressed as:

$$I_r = \frac{V_s}{(r_s + \frac{r_r}{S}) + j(X_{s+}X_r)} \tag{3.12}$$

For a three-phase motor, relating that to the stator input power; the air hole force can be given as:

$$P_{ag} = 3[I_r]^2 \frac{r_r}{S} \tag{3.13}$$

Substituting the value $I_r$into the above equation, we have

$$P_{ag} = \frac{3V^2{}_s}{(r_s + \frac{r_r}{S})2 + j(X_{s+}X_r)2} * \frac{r_r}{S} \tag{3.14}$$

From equation 3.8$T_m = \frac{P_{ag}}{\omega_s}$, now by substituting the value of P_{ag}

$$T_{m=} \frac{3}{\omega_s} * \frac{V^2{}_s}{\left(r_s + \frac{r_r}{S}\right)2 + j\left(X_{s+}X_r\right)2} * \frac{r_r}{S} \tag{3.15}$$

If we differentiate T_m concerning S and likening to zero, the slip for most extreme torque can be given as

$$S_m \pm \frac{r_r}{\sqrt{(r_s)2+j(x_r+X_r)2}} \quad (3.16)$$

Subbing S_(m) in T_m gives the estimation of most extreme torque, in this way

$$T_{max}= \frac{V^2{}_s}{2\omega_s[r_r \pm \sqrt{(r_s)2+j(X_r+X_r)2}]} \quad (3.17)$$

Where

$$\frac{3}{\omega_s} = constant = k$$

The two segments of the torque-slip curve can be obtained analytically from equation 3.16 by considering the slip *s* to be very large and very small respectively. For slip being very large, equation 3.16 reduces to

$$T_{em} = \frac{K}{s} \quad (3.18)$$

And for s being very small

$$T_{em} = Ks \quad (3.19)$$

The Starting torque is obtained by putting s = 1 in equation 3.14 while neglecting the stator parameters

$$T_{st}= \frac{kV^2{}_s * r_r}{(r_r+X_r)2} \quad (3.20)$$

Hence, it is clear from the above equation that the beginning torque is corresponding to the square of the stator applied voltage.

Where,

Z_m = equivalent impedance of the motor,

I_S = stator current,

Ir' = rotor current referred to stator side,

T_{em} = electromagnetic torque,

R_S and Xs = resistance and leakage reactance of the stator,

Rr and Xr = resistance and leakage reactance of the rotor

referred to the stator side,

X_m = magnetizing reactance,

V_m = voltage per phase at the motor terminal

V_{source} = voltage per phase of the power supply at 50Hz/60Hz,

P_{em} = electromagnetic power,

P_{cu2} = copper losses of the rotor,

f = frequency

S = slip

n_1 = synchronous speed in rpm

P = pole number of induction motors

Ω_1 = rotating speed in angles

When a Variable Frequency Device (VFD) or method is utilized to supply capacity to an enlistment engine, various frequencies can be applied to the engine terminal during the engine fire up and under ordinary working conditions **(Xiaodong & Obinna , 2010)** by keeping up a steady volt for each hertz level at the drive as follows:

$$\frac{\text{Voltage}}{\text{Frequency}} = \text{constant} \quad (3.21)$$

The yield voltage of the drive during engine turning over can be determined dependent on the base or reference recurrence beginning recurrence and information voltage of the drive as follows:

$V_{stVFDoutput} = \frac{V_{VFD\ input}}{f_{Base\ VDF}} * f_{st\ VFD}$ (3.22)

Where:

$Vst_{VFDoutput}$ = output voltage of the drive during the motor starting

$V_{VFDinput}$ = input voltage of the drive

$f_{BaseVFD}$ = base frequency of the VFD

f_{stVFD} = starting frequency of the VFD

$V_m = V_{st\ VFD\ output} - V_{voltage\ drop\ in\ circuit}$ (3.23)

The comparable circuit of enlistment engines appeared in Figure 3.1 is additionally utilized for the engine turning over examination with VFDs. The opposition esteems for R1 and R2 are consistent while disregarding the impact of temperature. The reactance esteems for X1, X2 and Xm are capacity of the recurrence, which can be resolved as follows

$X_s = 2\pi f * L_1$ (3.24)

$Xr = 2\pi f * L_2$ (3.25)

$X_m = 2\pi f * L_m$ (3.26)

where

L1, L2 &Lm = Stator spillage inductance, rotor spillage inductance alluded to the stator, and polarizing inductance, separately. Inductances are steady.

f = frequency applied at the motor terminal

The beginning voltage, beginning present and beginning torque of the engine utilizing the VFD beginning can be determined by:

$V_{st} = V_m$ (3.27)

$$I_{st} = \left(\frac{V_m}{(R_1 + j2\pi f_{st} L_1) + \frac{(R_2 + j2\pi f_{st} L_2)(j2\pi f_{st} L_m)}{R_2 + j2\pi f_{st}(L_2 + L_m)}} \right) \quad (3.28)$$

$$T_{st} = \frac{3PR_2}{4\pi f_{st}} * V_m^2 * \left(\frac{j(2\pi f_{st} L_m)}{[R_1R_2 - (2\pi f_{st})^2(L_1L_2 + L_mL_1 + L_mL_2)] + j2\pi f_{st}[R_1L_2 + R_2L_1 + L_m(R_1 + R_2)]} \right)^2 \quad (3.29)$$

$$T_{st} = \frac{3PR_2}{4\pi f_1}\left(\frac{j(2\pi f_1 L_m)}{R_2 + j2\pi f_1(L_2 + L_m)}\right) * I_{st}^2 \qquad (3.30)$$

Equations 3.27 and 3.28show that the turning over torque for engine turning over with VFDs isn't just controlled by the engine terminal voltage and beginning current, yet in addition a component of the beginning recurrence of the drive.

3.2. Motor Parameter for Matlab Code

Basic theory of different techniques for speed control of 3-stage acceptance engine, for example, Variable Supply Frequency, Variable rotor obstruction control, Variable stock voltage control etc. have been already been presented in chapter two. However, in this chapter, programmed in MATLAB code will be developed to verify some of these methods and their comparative performance analysis with constant variable frequency method. For a typical enlistment engine with given parameters appeared in Table 3.1, the torque speed conduct of the engine will be studied.

Table 3.1: Machine Detail Parameter

Parameters	Values
RMS value of supply voltage (line-to-line)	230V
Stator Resistance (Rs)	0.095Ω
Rotor Resistance (Rr)	0.2Ω
Number of poles(P)	4
Frequency(f)	50Hz
Stator leakage reactance at 50Hz frequency	0.672Ω
Rotor leakage reactance at 50Hz frequency	0.68Ω
V/F ratio	8.3
Power Rating	1.8kW
Motor Amps	35

3.3 Dynamical Model of Induction Motor

The conventional per stage comparable circuit investigation of an enlistment engine has the weakness that it is substantial just if the framework is a reasonable one. Any awkwardness in the framework prompts mistaken examination. Likewise, the dynamic reaction of the engine can't be gotten from the per stage proportional circuit. The d-q tomahawks model prompts a less complex examination of an acceptance engine. A d-q tomahawks model with the d-pivot adjusted along the synchronously turning rotor outline, prompts the decoupled examination where the torque and the transition segments can be freely controlled simply like if there should arise an occurrence of a DC engine.

In order to analyses the induction motor, we need to make reference to the acceptance machine model in the discretionary reference edge and subbing 0=ω, build up a unique model of the enlistment engine. This is finished by changing over the 3-stage amounts into 2-tomahawks framework called the d-pivot and the q-hub. Such a change is called tomahawks change. The d-q tomahawks can be picked to be stationary or turning. Further, the pivoting casing can either be the rotor arranged or charging transition situated. Be that as it may, synchronous reference outline in which the d-hub is lined up with the rotor transition is seen as the most advantageous from investigation perspective.

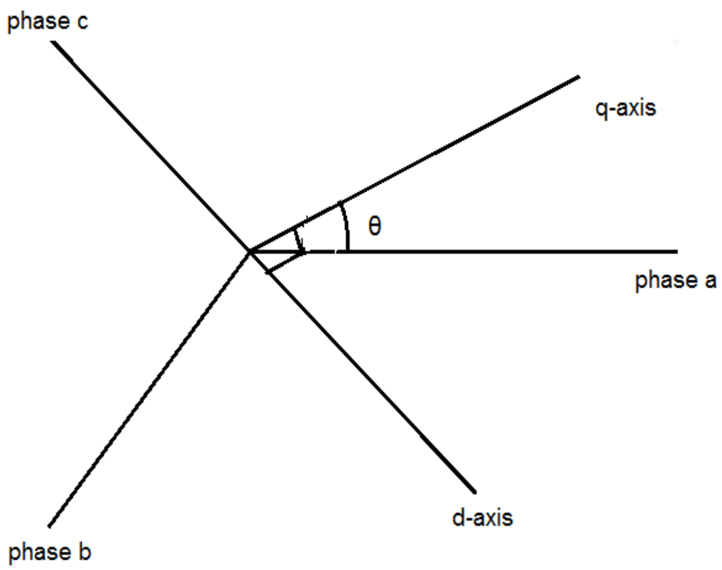

Figure 3.4: Angular Relationship between Axis in the Stationary Reference Frame (Xiaodong & Obinna , 2010)

From Figure 3.4, the machine flux linkage model in stationary reference frame for a squirrel cage induction machine is

$$\begin{bmatrix} \lambda_{qs}{}^{a} \\ \lambda_{ds}{}^{a} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_S + L_{mP} & \omega_a L_S & L_{mp} & \omega_s L_m \\ -\omega_a L_s & R_s + L_{SP} & -\omega_a L_m & L_{mp} \\ L_{mp} & -(\omega_a - \omega_O) L_m & R_r L_{rp} & (\omega - \omega_O) L_r \\ -(\omega_a - \omega_O) L_m & L_{mp} & (\omega_a - \omega_O)\ L_r & R_r + L_{rp} \end{bmatrix} \begin{bmatrix} I_{qs^a} \\ I_{ds^a} \\ I_{qr^a} \\ I_{dr^a} \end{bmatrix} \quad (3.31)$$

If we substitute $\omega_a = 0$, the above equation can be written as below:

$$\begin{bmatrix} \lambda_{qs}{}^{a} \\ \lambda_{ds}{}^{a} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_S + L_{mP} & 0 & L_{mp} & 0 \\ 0 & R_s + L_{SP} & 0 & L_{mp} \\ L_{mp} & -\omega_O L_m & R_r + L_{rp} & -\omega_O L_r \\ \omega_O L_m & L_{mp} & \omega_O L_r & R_r + L_{rp} \end{bmatrix} \begin{bmatrix} I_{qs^a} \\ I_{ds^a} \\ I_{qr^a} \\ I_{dr^a} \end{bmatrix} \tag{3.32}$$

This is called stationary reference frame.

Similarly, the voltage can also be expressed as

$$\begin{bmatrix} V_{qs}{}^{a} \\ V_{ds}{}^{a} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_S + L_{SP} & 0 & L_{mp} & 0 \\ 0 & R_s + L_{SP} & 0 & L_{mp} \\ L_{mp} & -\omega_O L_m & R_r + L_{rp} & -\omega_O L_r \\ -\omega_O L_m & L_{mp} & \omega_O L_r & R_r + L_{rp} \end{bmatrix} \begin{bmatrix} I_{qs^a} \\ I_{ds^a} \\ I_{qr^a} \\ I_{dr^a} \end{bmatrix} \tag{3.33}$$

Where the flux linkage variables are defined by

$$\lambda_{qs} = L_s I_{qs} + L_m I_{qs}$$

$$\lambda_{ds} = L_s I_{ds} + L_m I_{ds}$$

$$\lambda_{qr} = L_m I_{qs} + L_r I_{qr}$$

$$\lambda_{dr} = L_m I_{ds} + L_r I_{dr}$$

Transforming the 3-Φ quantities into d-q quantities will give us equation (3.34)

$$\begin{bmatrix} Y_a \\ Y_b \\ 0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\theta\left(\theta + \frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\vartheta\left(\theta + \frac{2\pi}{3}\right) \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \begin{bmatrix} Y_a \\ Y_b \\ Y_c \end{bmatrix} \tag{3.34}$$

The inverse transform of equation 3.5 is expressed as:

$$\begin{bmatrix} Y_a \\ Y_b \\ Y_c \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) & 1 \\ \cos\left(\theta + \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} Y_a \\ Y_b \\ 0 \end{bmatrix} \tag{3.35}$$

In terms of complex number, 3-ϕ quantities transformed into d-q quantities can be expressed as:

$$S_{qs} = \frac{2}{3}\{(e^{-j\theta})(S_{as} + \alpha S_{bs} + \alpha^2 S_{cs})\} \tag{3.36}$$

$$S_{ds} = -\frac{2}{3}\{(e^{-j\theta})(S_{as} + \alpha S_{bs} + \alpha^2 S_{cs})\} \tag{3.37}$$

$$T_r = \frac{3}{2} P \frac{L_m}{L_r} \lambda_{dr} I_{qr} - \lambda_{qr} I_{dr} \tag{3.38}$$

IV.

RESULTS AND DISCUSSION

4.1 Results

One of the purposes of this research is to study the behaviour of three phase induction motor on various starting approach. In this chapter, performance evaluations of this motor approaches (i.e. variable rotor resistance method, variable stator voltage method, variable frequency method and constant voltage/frequency method) were conducted; as well as the proposed Voltage/Frequency ratio control technique.

4.2. Variable Rotor Resistance Method

Figure 4.1 shows the steady state torque-speed characteristics of induction motor output Torque-Speed characteristics was developed using MATLAB code, using variable rotor speed method. The motor rated resistance is 0.10Ω. From this rated resistance, other values: 0.30Ω, 0.50Ω, 1.70Ω and 1.90Ω were used for variation of the starting current. It is seen that the electromagnetic torque developed in induction motor is related to the induced current.

The graph also shows that maximum torque produced is independent of rotor circuit resistance. Higher torque is produced at bigger values of resistance and degree of speed control is minimal. By making use of appropriate value of resistors, the maximum torque can be made to appear during starting. This can be used in applications requiring high starting torque. Once the motor is started, the external resistance can be cut out to obtain high torque throughout the accelerating range. As external resistances are connected, most of the I^2R loss is dissipated through them thus the rotor temperature can be made to rise during starting is limited.

It can also be said that maximum torque varies inversely as stand still reactance of the rotor. Furthermore, the slip at which the maximum torque occurs depends upon the resistance of the rotor.

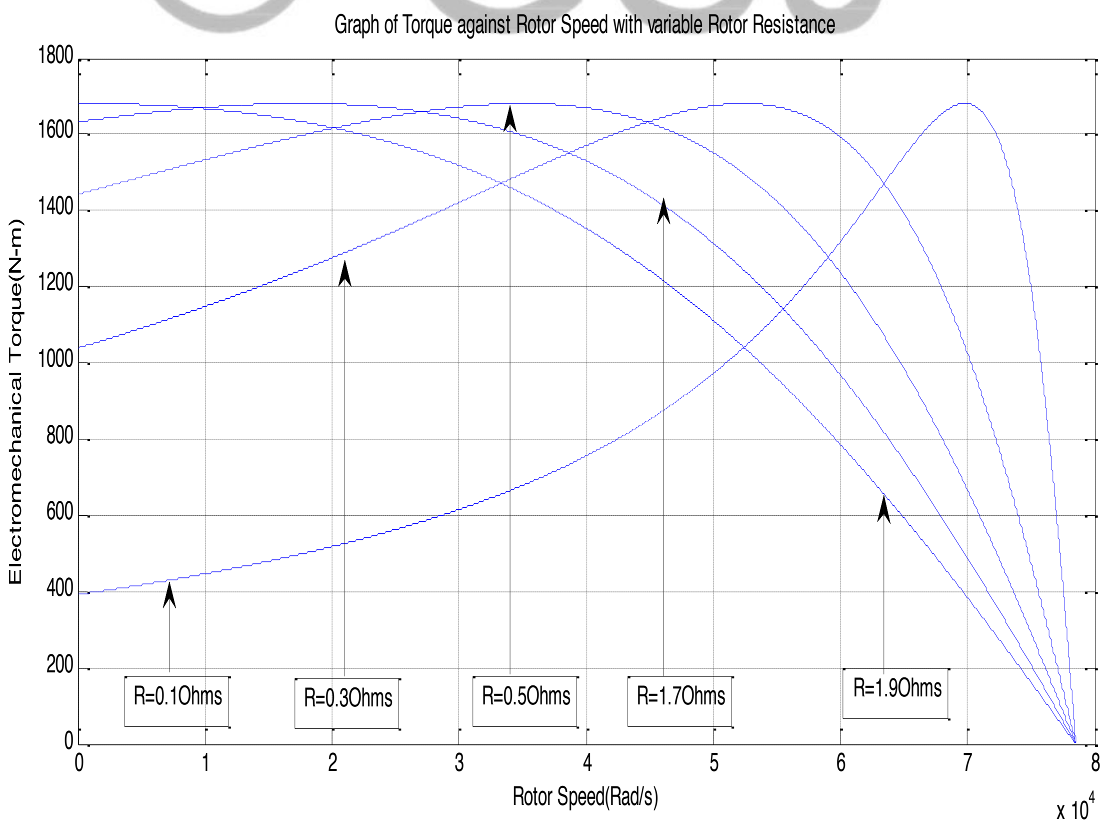

Figure 4.1: Torque–Speed Characteristics of Induction Motor on Different Rotor Resistance

4.3. Variable Stator Voltage Method

The result of variable voltage method of the induction motor start is illustrated in Figure 4.2. From the result obtained, it is indicated that as the supply voltage is decreased, the value of maximum torque also decreases (Equation 3.25). However, this still occurs at the same slip as earlier (Equation 3.24). Even the starting torque and the overall torque reduce. Thus, the machine is highly underutilized. Thus, this method of speed control has very limited applications. This will be well suited for loads that require very little starting torque, but their torque requirement may increase with speed. Further, since the load torque at zero speed is zero, the machine can start even at reduced voltages. This will not be possible with constant torque type of loads.

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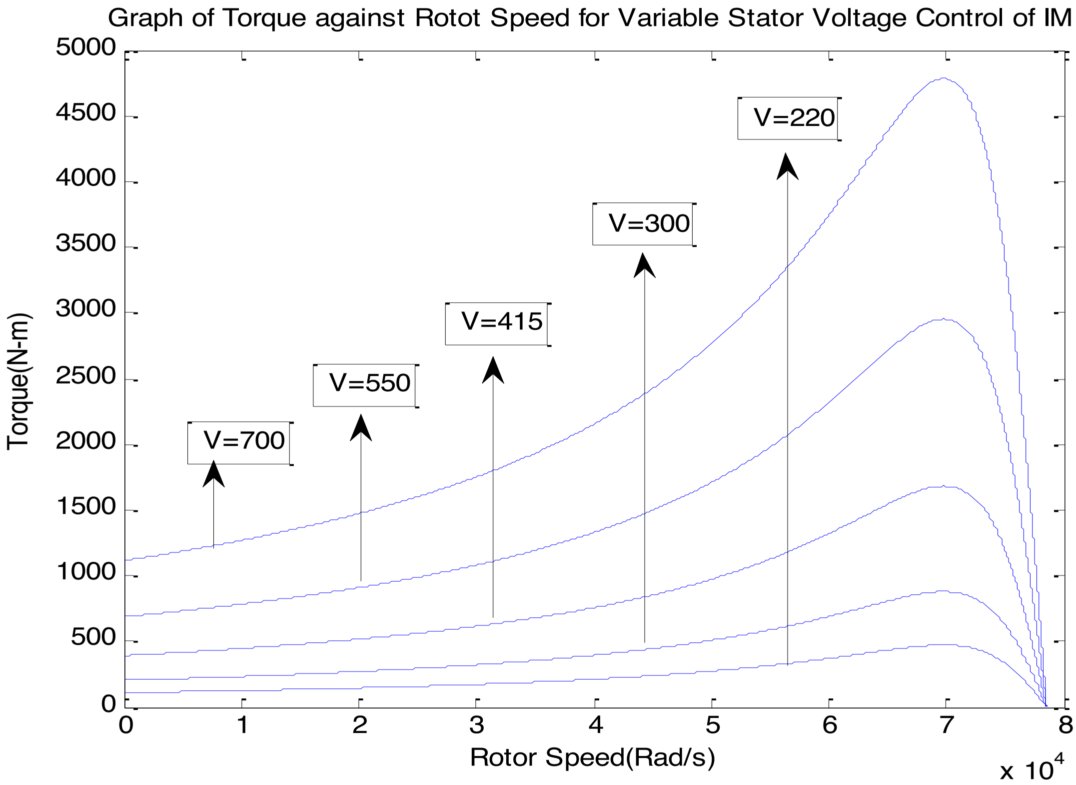

Figure 4.2: Torque–Speed Characteristics of Induction Motor on Different Stator Voltage

4.4. Variable Frequency Method

The result of the output Torque-Speed characteristics of variable frequency is are shown in Figure 4.3. The values of the varying frequencies are 30Hz, 40Hz, 50Hz and 60Hz. The AC supply can be applied to a PWM inverter to obtain a variable frequency, variable magnitude 3-phase AC supply. As can be, the electromagnetic torque developed by the motor is directly proportional to the magnetic field produced by the stator and the flux produced by the stator is proportional to the frequency of supply. It can be seen that by increasing the supply frequency, the starting torque is reduced by the maximum torque is improved. Therefore, by varying the frequency, the torque can be varied through various speed range.

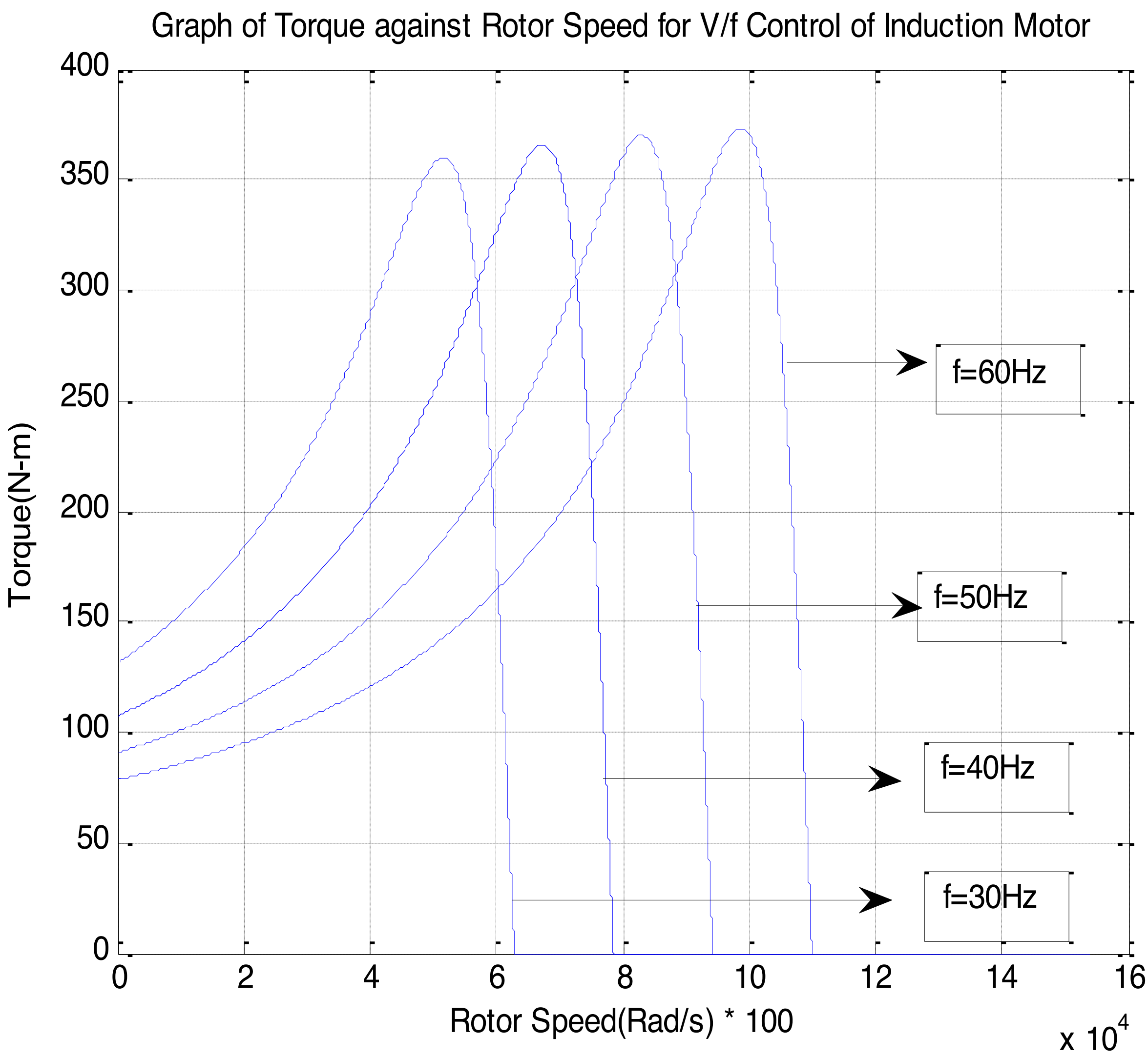

Figure 4.3: Torque –Speed Characteristics of Induction Motor on Constant V/F Ratio

As can be seen again, the Maximum Torque of the Induction Motor remains constant, across the speed range, while the frequency is varied. When applied with AC drives, the AC supply from the mains is supplied to a rectifier which converts into DC and this is fed to the PWM

Inverter. The PWM Inverter varies the frequency of the supply and the voltage is varied accordingly to keep the ratio constant. The electromagnetic torque is directly proportional to the flux produced by the stator which is in turn directly proportional to the ratio of the terminal voltage and the supply frequency. Hence by varying the magnitudes of V and f while keeping the V/F ratio constant, the flux and hence the torque can be kept constant throughout the speed range.

4.5. Open-Loop V/F Control of Induction Motor Using Matlab

The output Torque-Speed characteristics of the VF method are shown in Figure 4.5 below. From this graph, it can be observed that as the frequency is varied, the maximum torque on the rotor remains constant across the speed range. This is the result of keeping the flux constant by maintaining a constant V/F ratio. Thus, the speed of the rotor is measured and compared with the reference speed. This generates an error that is processed by the Proportional Controller which modifies the supply frequency accordingly. As the Proportional Controller feeds the Voltage Source Inverter, the voltage is also varied such that the V/f ratio remains constant. This keeps the flux value constant which in turn ensures a constant maximum torque throughout the speed range. Hence Speed control is achieved in the Induction motor. The speed range is achieved at various loads. Other graphs (Figure 4.5, Figure 4.6 Figure 4.7 and Figure 4.8) for various rotor reference speeds at different loads are shown below.

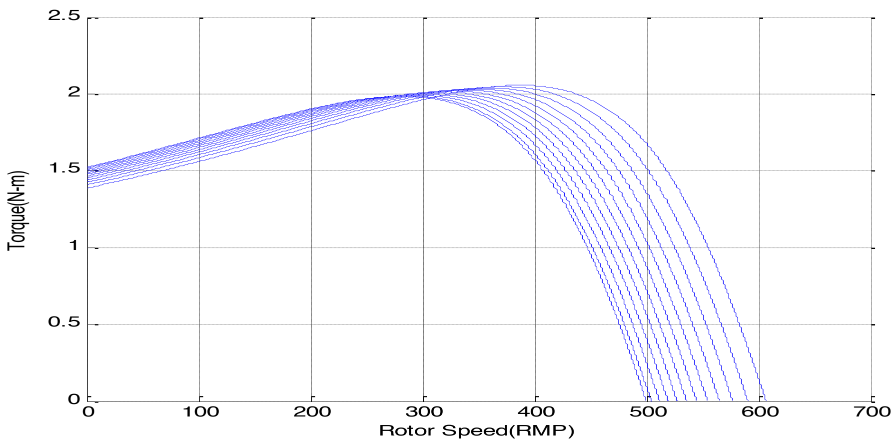

Figure 4.4: Torque–Speed Characteristics of Induction Motor with 0 Starting Load Torque and 500RPM reference Speed

From this graph, it can be observed that as the frequency is varied, the maximum torque on the rotor remains constant across the speed range. This is the result of keeping the flux constant by maintaining a constant V/F ratio. Thus, the speed of the rotor is measured and compared with the reference speed. This generates an error that is processed by the Proportional Controller which modifies the supply frequency accordingly. As the Proportional Controller feeds the Voltage Source Inverter, the voltage is also varied such that the V/F ratio remains constant. This keeps the flux value constant which in turn ensures a constant maximum torque throughout the speed range. Hence Speed control is achieved in the Induction motor. The speed range is achieved at various loads. Other graphs for various rotor reference speeds at different loads are shown below. It was seen that at lower reference speed, higher initial torque is generated before being controlled. And for all the values of reference speed entered, the torque initial stating torque is controlled until it reaches the maximum.

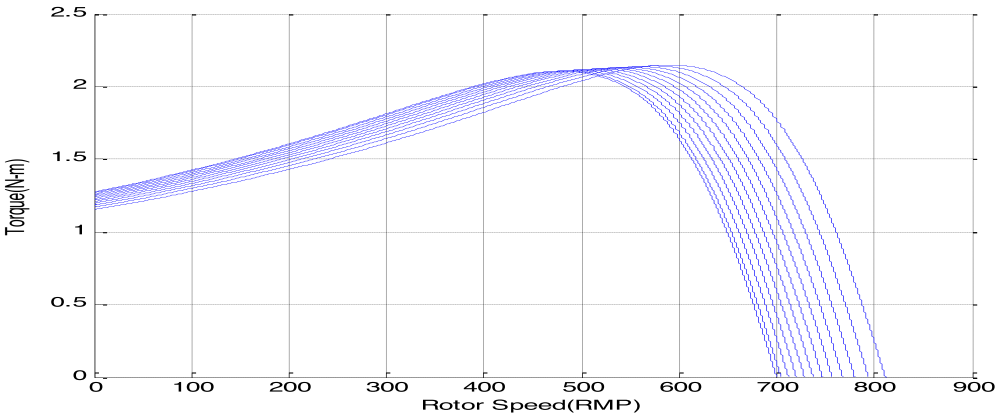

Figure 4.5: Torque–Speed Characteristics of Induction Motor with 0 Starting Load Torque and 700RPM reference Speed

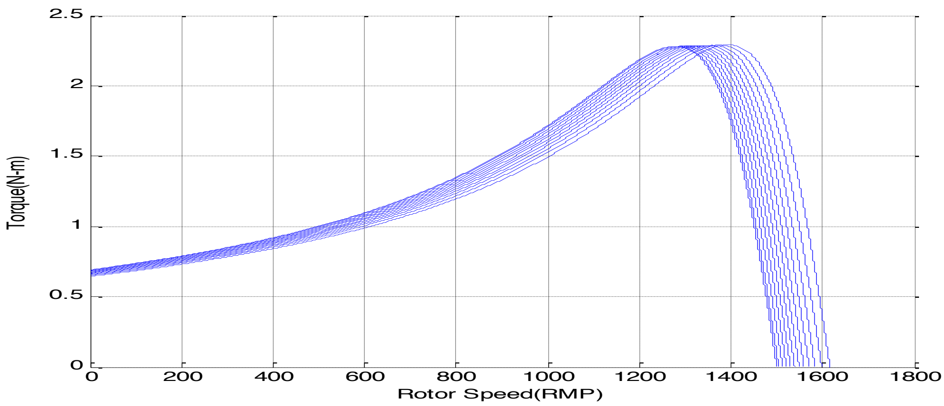

Figure 4.6: Torque–Speed Characteristics of Induction Motor with 0 Starting Load Torque and 1500RPM reference Speed

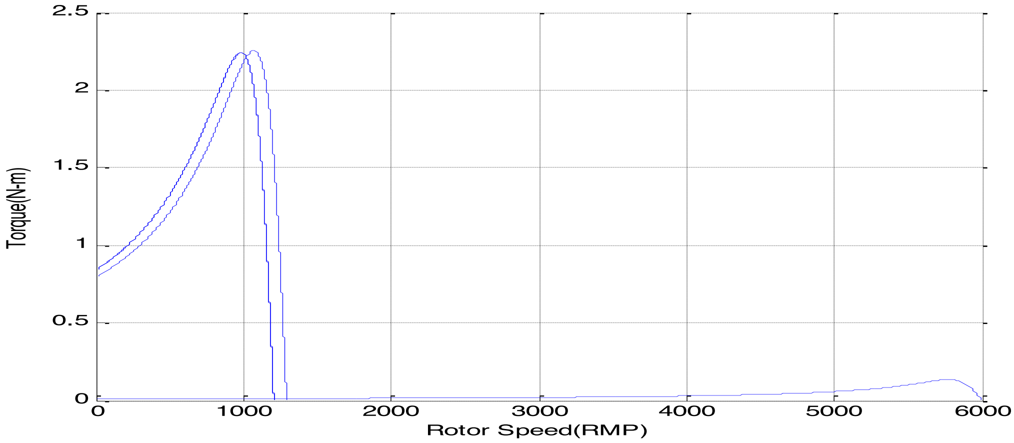

Figure 4.7: Torque–Speed Characteristics of Induction Motor with 0 Starting Load Torque and 3000RPM Reference Speed

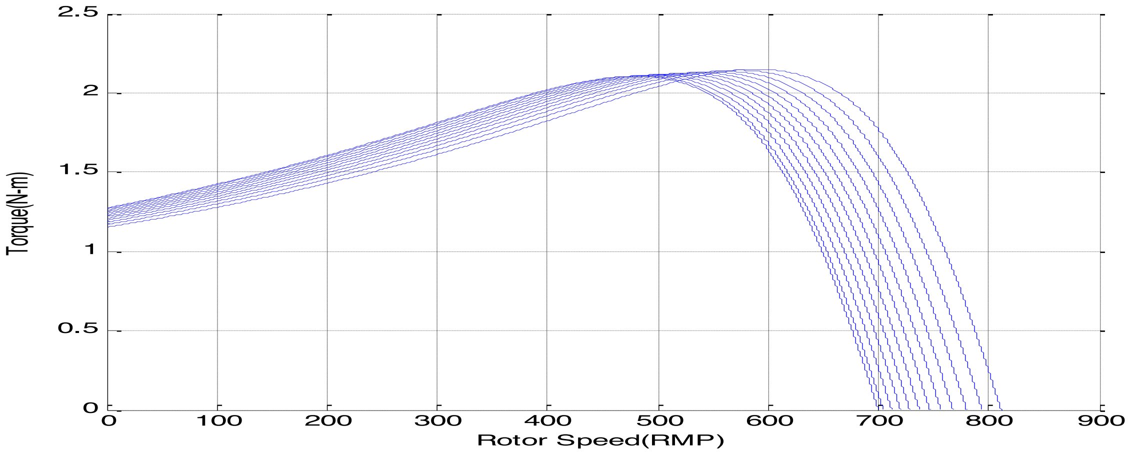

Figure 4.8: Torque–Speed Characteristics of Induction Motor with 1 Starting Load Torque and 1200RPM Reference Speed

Starting the motor using starting load torque value other than zero will produce a graph as in figure 4.8 for reference speed equal or greater than 1000RPM; and this generates a high starting torque. It is then good to start the motor on zero load torque.

4.6. Dynamic Analysis of Induction Motor on Variable Rotor Resistance Start And Control Method

The dynamic study of the three-phase induction motor using variable rotor resistance method is carried out here. The rotor inductance is kept constant while the resistance was varied from 0.1002Ω, 0.5002Ω, 0.1622Ω, 0.1822Ω.

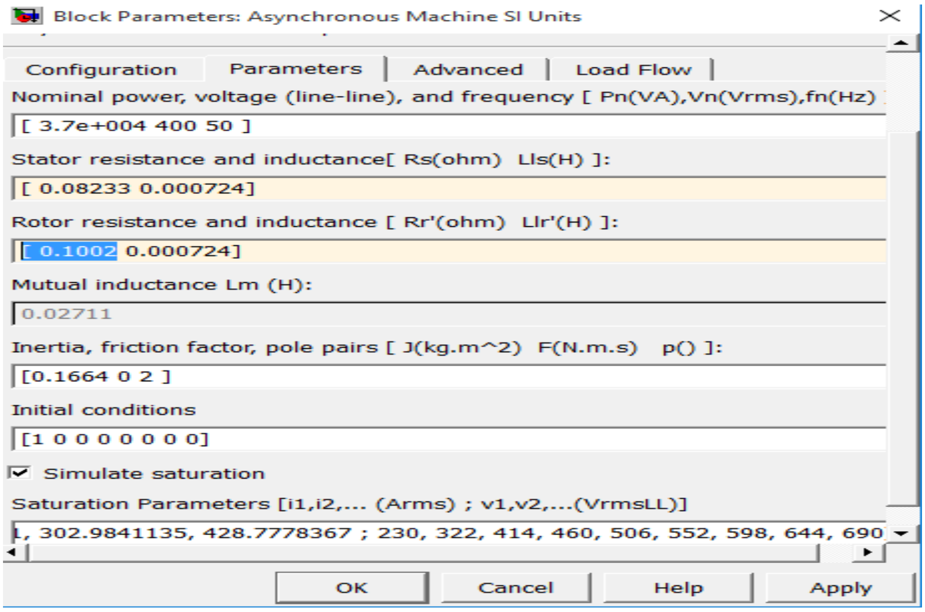

Figure 4.9: Parameters of a Three Phase Induction Motor for low Rotor Resistance (0.1Ω)

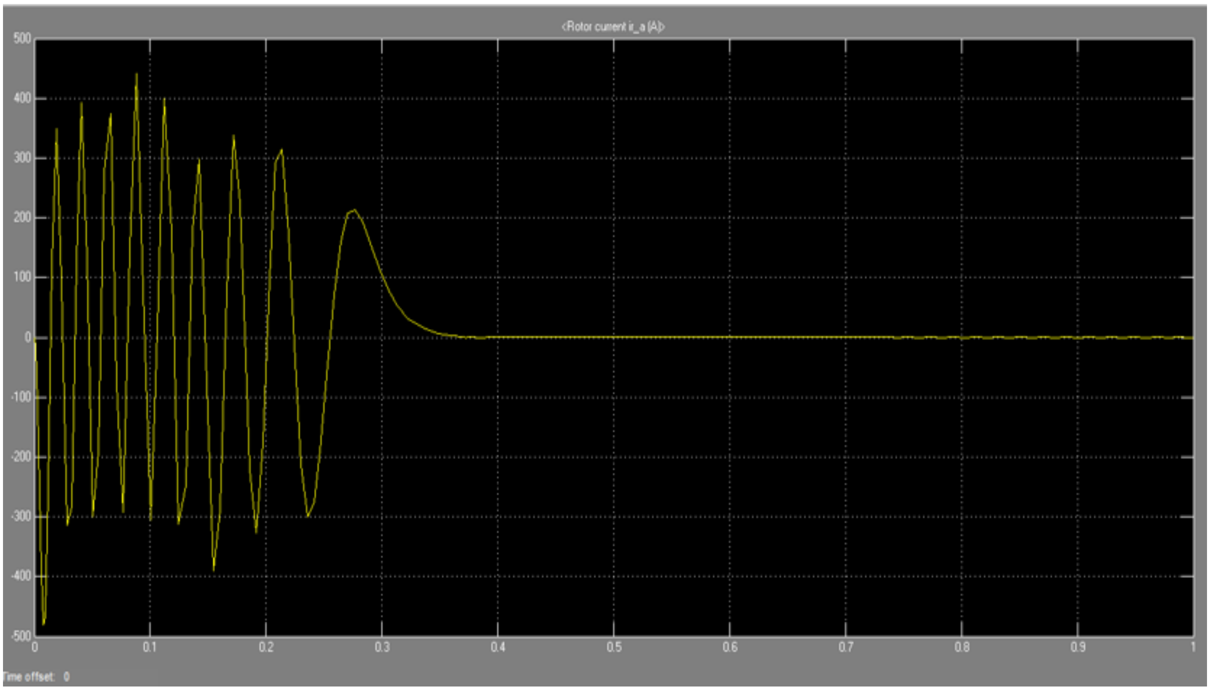

Figure 4.10: Rotor Current verses Time Graph for Machine in figure 4.9

Keeping all other parameters constant, and keeping the rotor resistance at 0.1 Ω, the rotor current becomes unstable beyond 0.2 seconds.

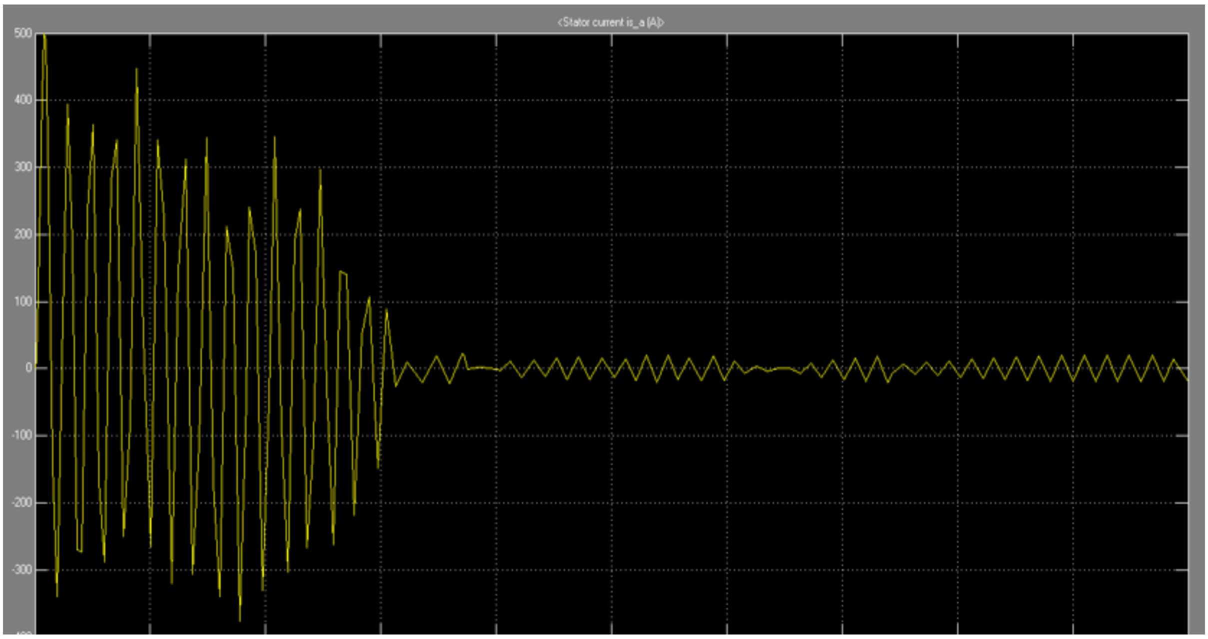

Figure 4.11: Stator Current verses Time Graph for Machine in figure 4.9

Also, by keeping all other parameters constant, and keeping the rotor resistance at 0.1 Ω, the stator current becomes unstable beyond 0.2 seconds.

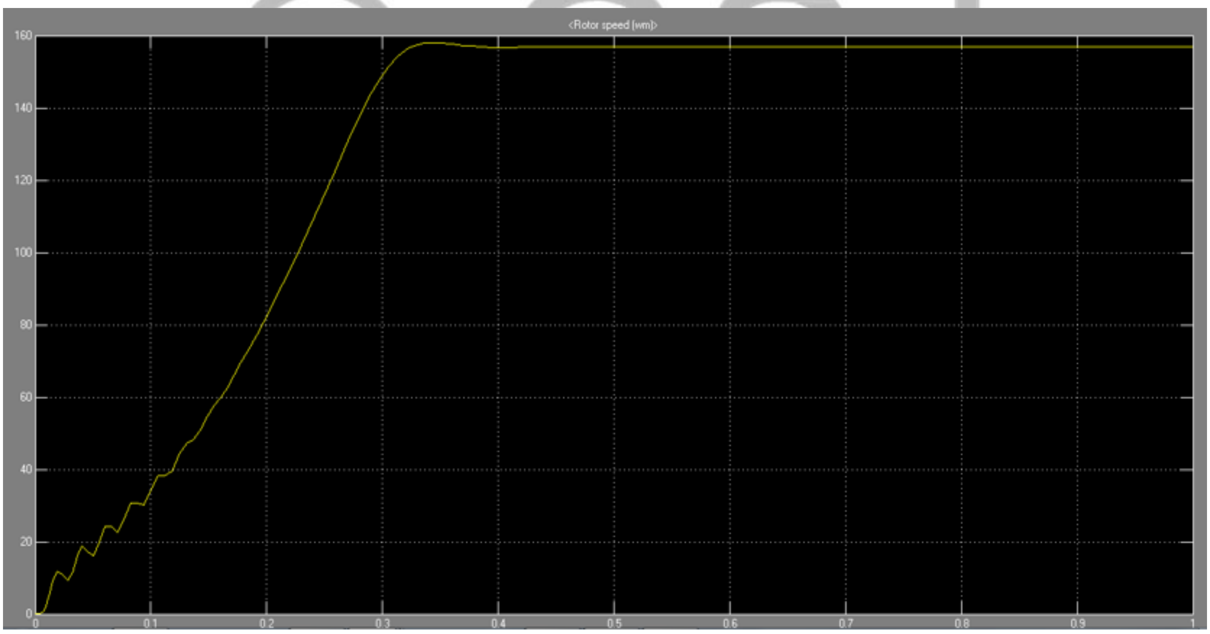

Figure 4.12: Machine Speed verses Time Graph for Machine in figure 4.9

Here the motor speed took little time to be controlled.

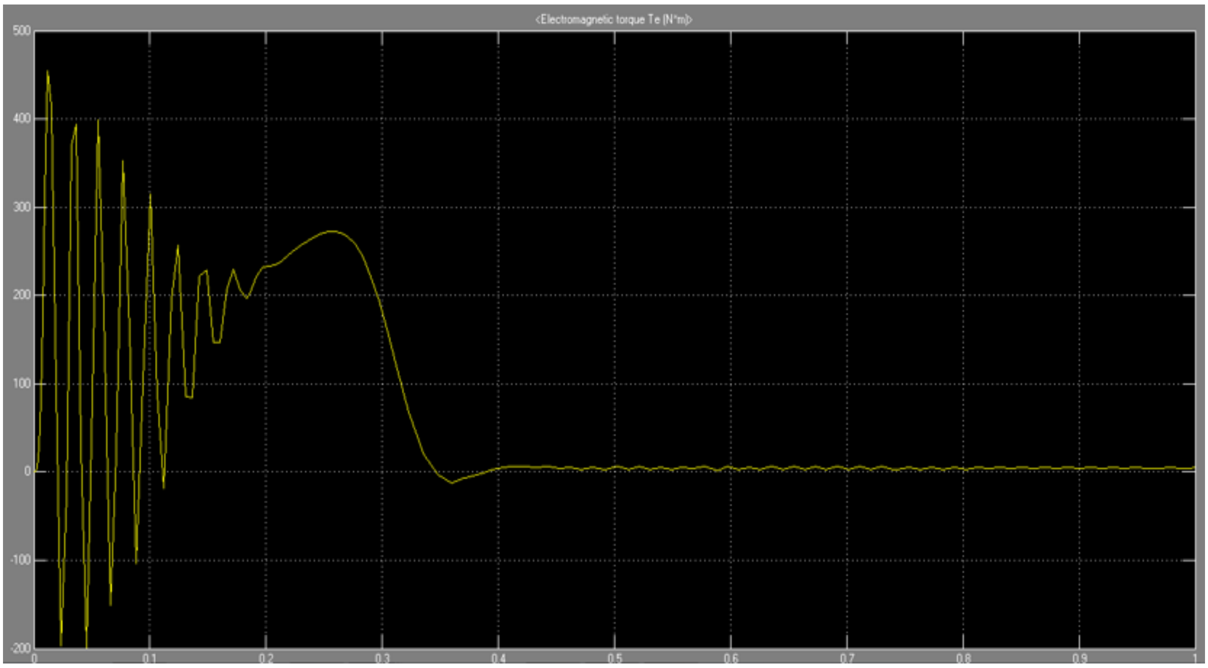

Figure 4.13: Developed Torque verses Time Graph for Machine in figure 4.9

The torque with 0.1 Ohm's rotor resistor also took a longer time to be stabilized due to jerking.

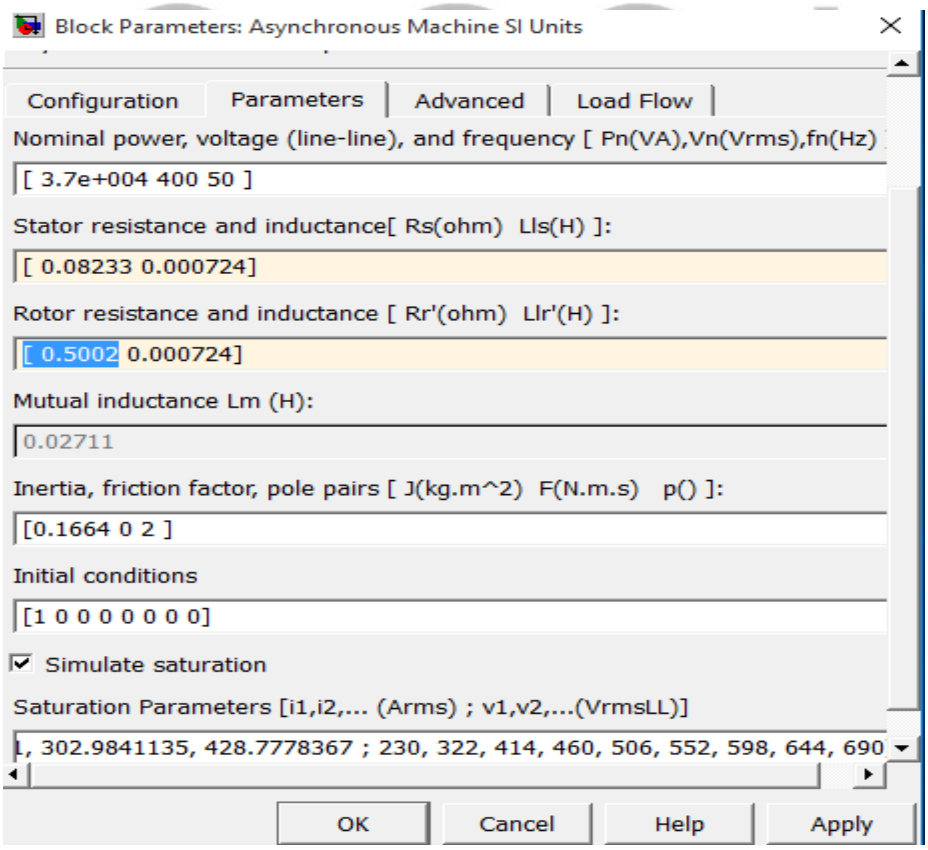

Figure 4.14: Parameters of a Three Phase Induction Motor for High Rotor Resistance (0.5Ω)

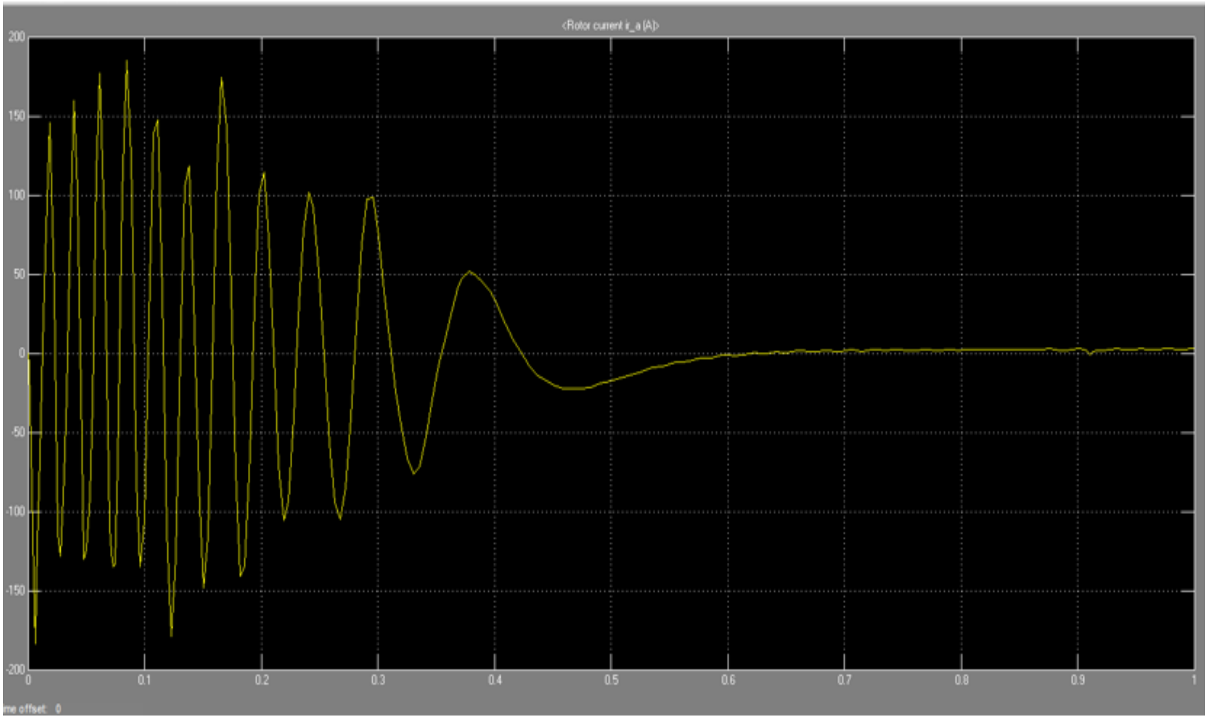

Figure 4.15: Rotor Current verses Time Graph for Machine in figure 4.14

More time is taken here for the rotor current to be steady at 0.5 increased rotor resistance.

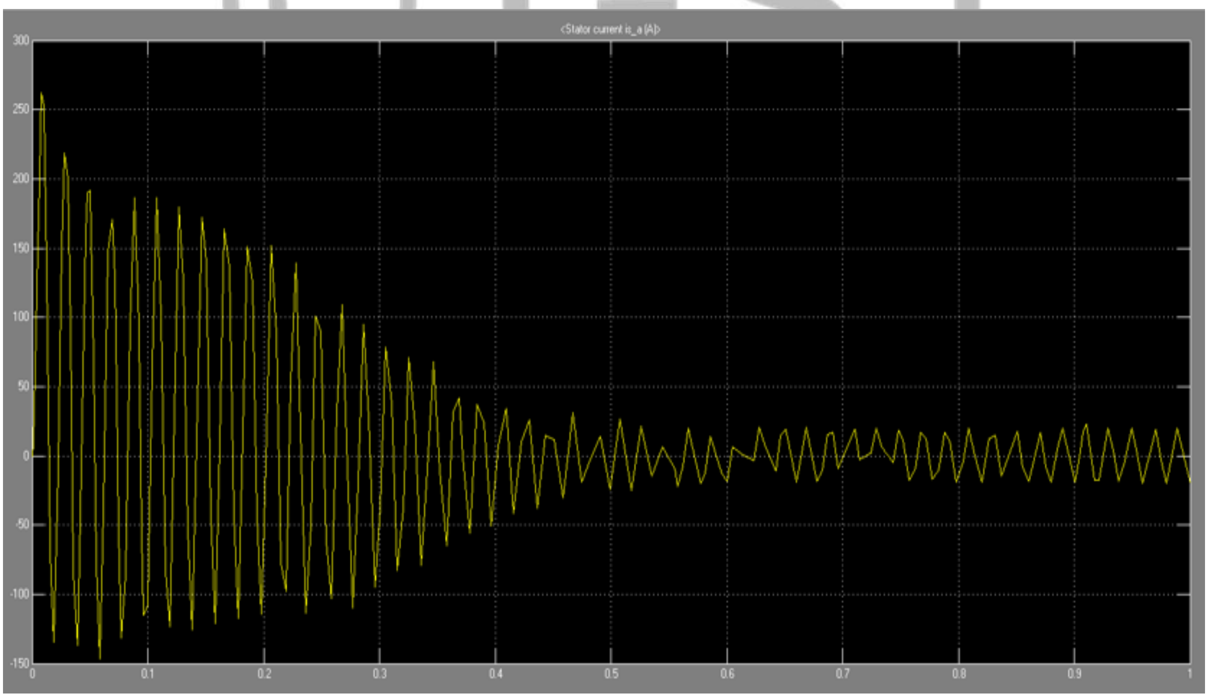

Figure 4.16: Stator Current Verses Time Graph for Machine in Figure 4.14

The steady state of the stator current at 0.5 Ohm's increased rotor current is difficult to achieve here.

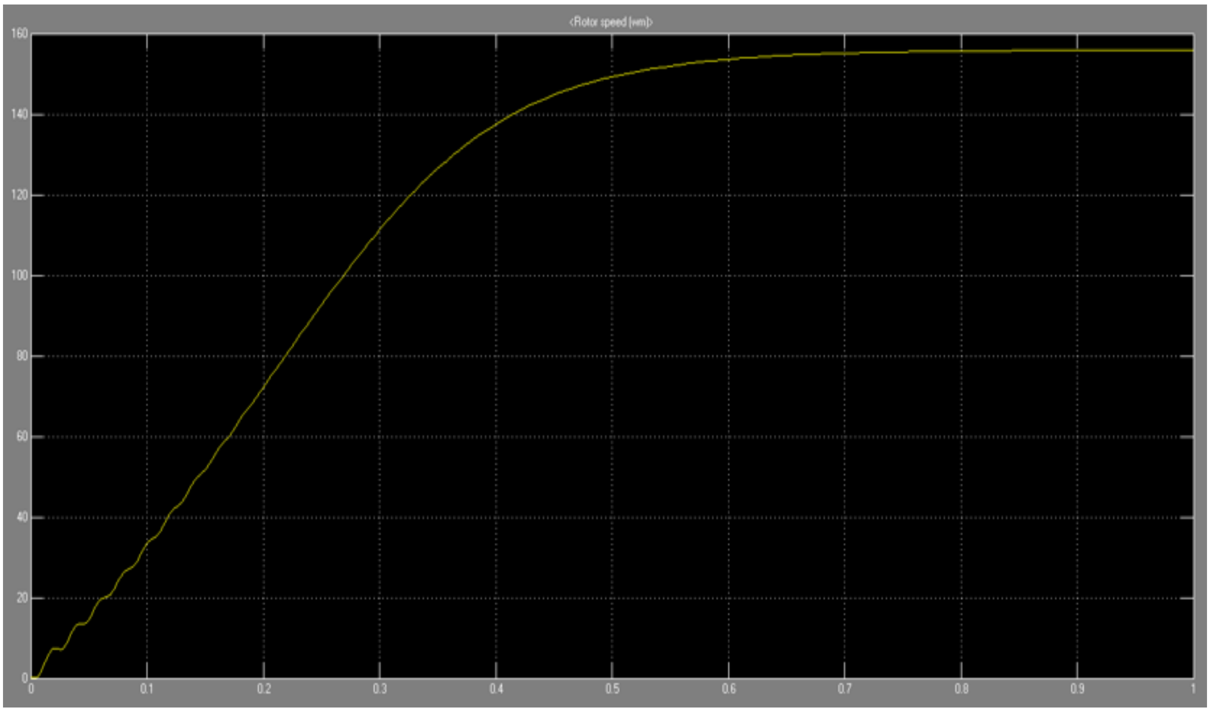

Figure 4.17: Machine Speed Verses Time Graph for Machine in Figure 4.14

Here, the more speed is improved but could not get to the maximum.

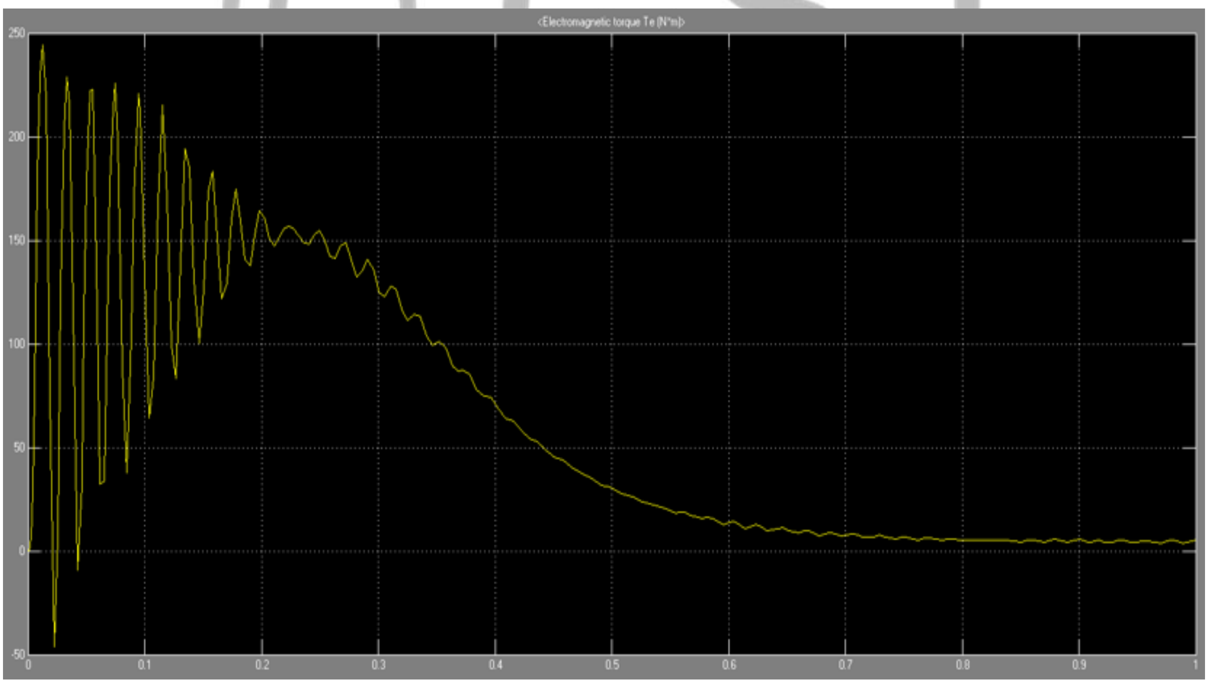

Figure 4.18: Developed Torque Verses Time Graph for Machine in Figure 4.14

Here, the starting torque is the high but little longer time taken reach steady state.

4.7. Summary of Results

For better understanding, the following observations were made from the results of the simulation: There was no much effect on the steady state time when the rotor resistance high and the machine started with lesser jerks. And so, the fluctuations in the transient period were reduced. With this setting also, the maximum torque occurred at a lower speed. When the rotor inductance is high, the transients lasted for longer period i.e., the machine took longer time to achieve its steady state speed, current and torque. Also, the start was a bit jerky.

4.8. Control with Open Loop V/F Speed

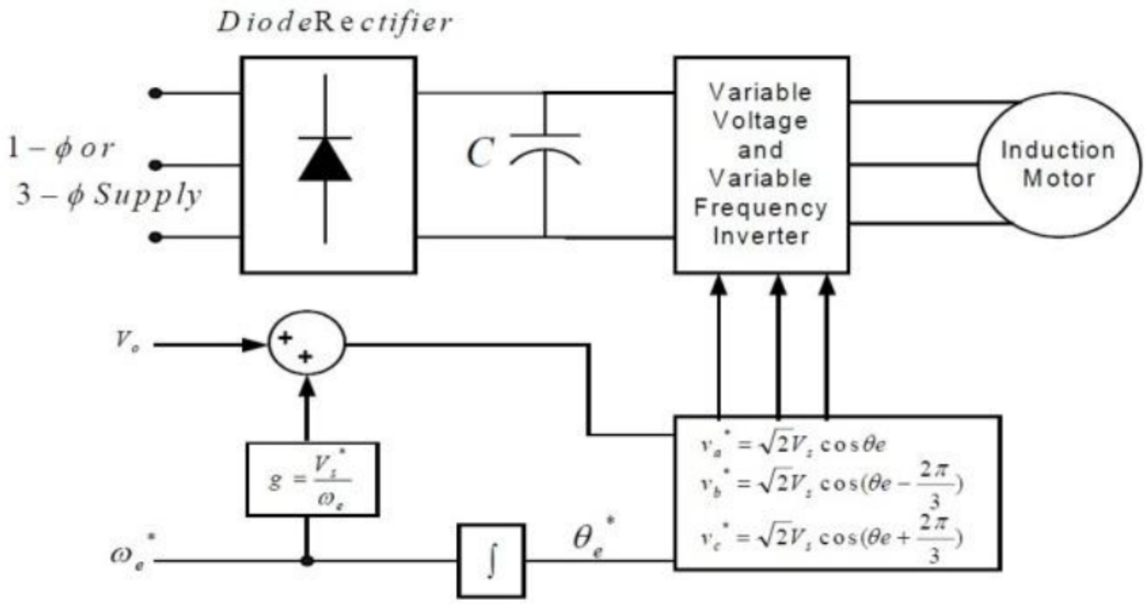

Figure 4.19: Block Diagram of the Open Loop V/F Control for an Induction Motor

The open loop V/F control of an induction motor is the most common method of speed control because of its suitability. For adjustable speed drive applications, frequency control is natural. However, voltage is required to be proportional to frequency so that the stator flux remains constant if the stator resistance is neglected. As shown in figure 4.19, the power circuit consists of a diode rectifier with a single or three-phase ac supply filter and PWM voltage-fed inverter. Ideally no feedback signals are required for this control scheme. The PWM converter is combined with the inverter block.

A Simulink model was developed to observe the motor behavior using the open loop constant V/F control method. The stator current, DC voltage, electromagnetic torque and rotor speed were plotted against time. The results are shown in Figure 4.20 through Figure 4.23. In Figure 4.20, the stator current seems to be unstable, showing a higher degree of control.

In Figure 4.22 and Figure 4.23, the motor starting torque and speed is measure against time. From this result, the starting torque is high at start. The speed range is achieved at various loads. It was seen that at lower reference speed, higher initial torque is generated before being controlled. And for all the values of reference speed entered, the torque initial stating torque is controlled until it reaches the maximum which is 18Nm. Thus, the speed of the rotor, which is 150RPM is measured and compared with the reference speed. This generates an error that is processed by the Proportional Controller which modifies the supply frequency accordingly. As the Proportional Controller feeds the Voltage Source Inverter, the voltage is also varied such that the V/F ratio remains constant. This keeps the flux value constant which in turn ensures a constant maximum torque throughout the speed range. Hence Speed control is achieved in the induction motor.

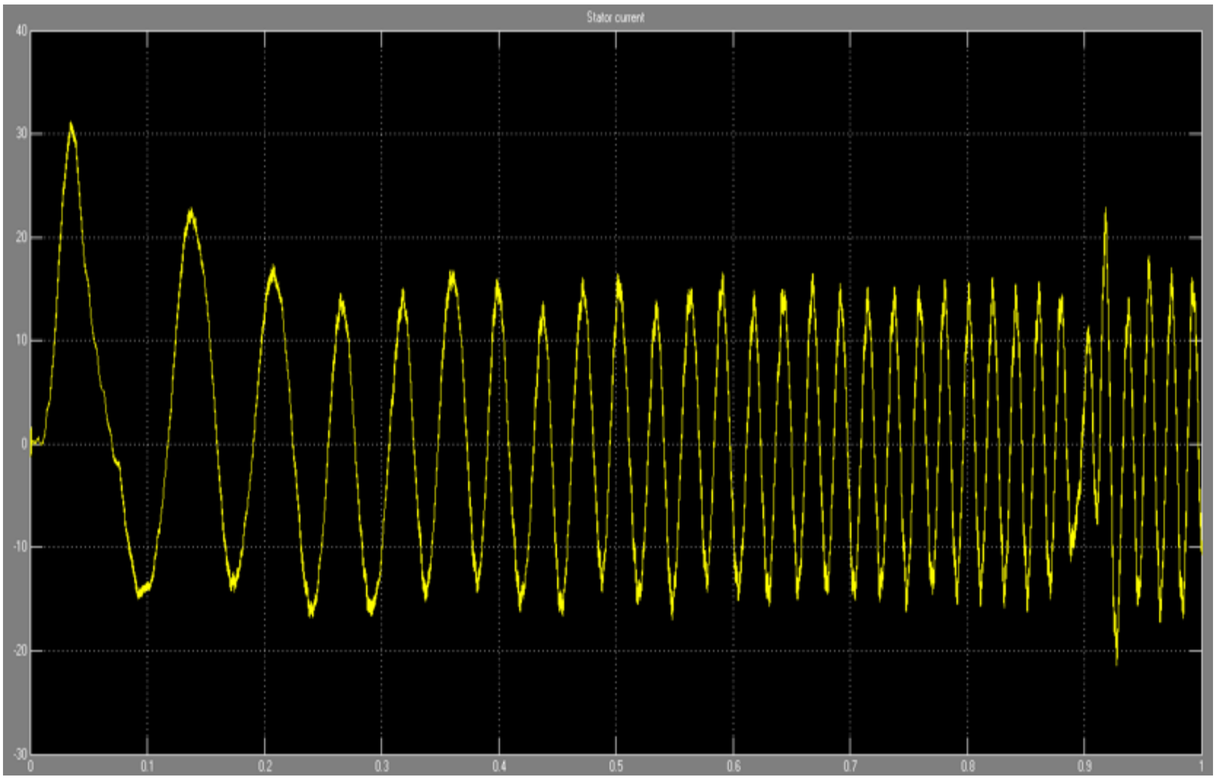

Figure 4.20: Stator Current Verse Time for the 3-Phase Induction Motor

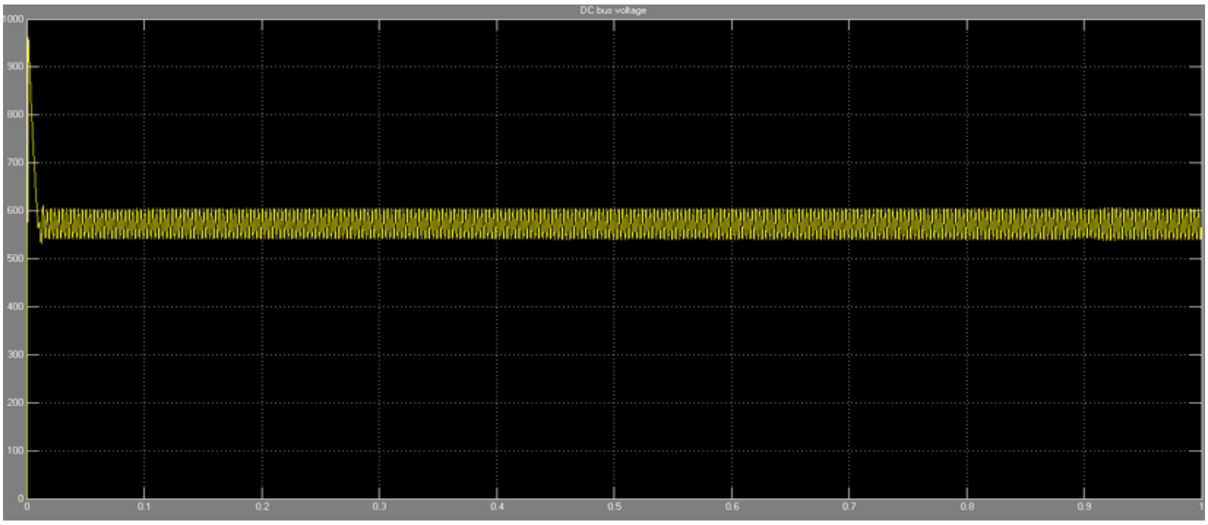

Figure 4.21: DC Bus Voltage Verse Time for the 3-Phase Induction Motor

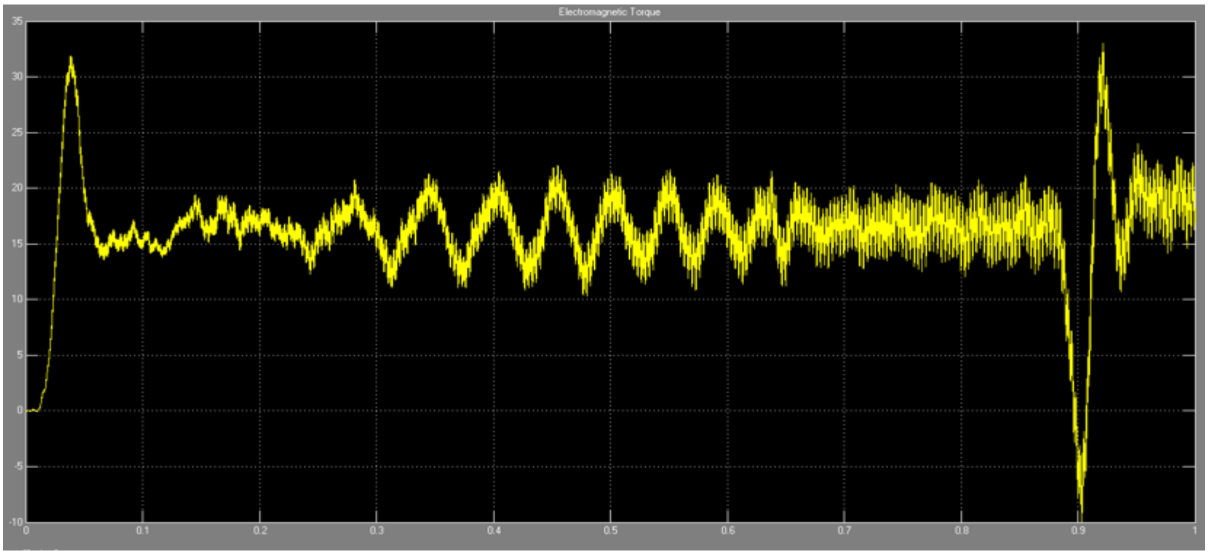

Figure 4.22: Torque Verse Time for the 3-Phase Induction Motor

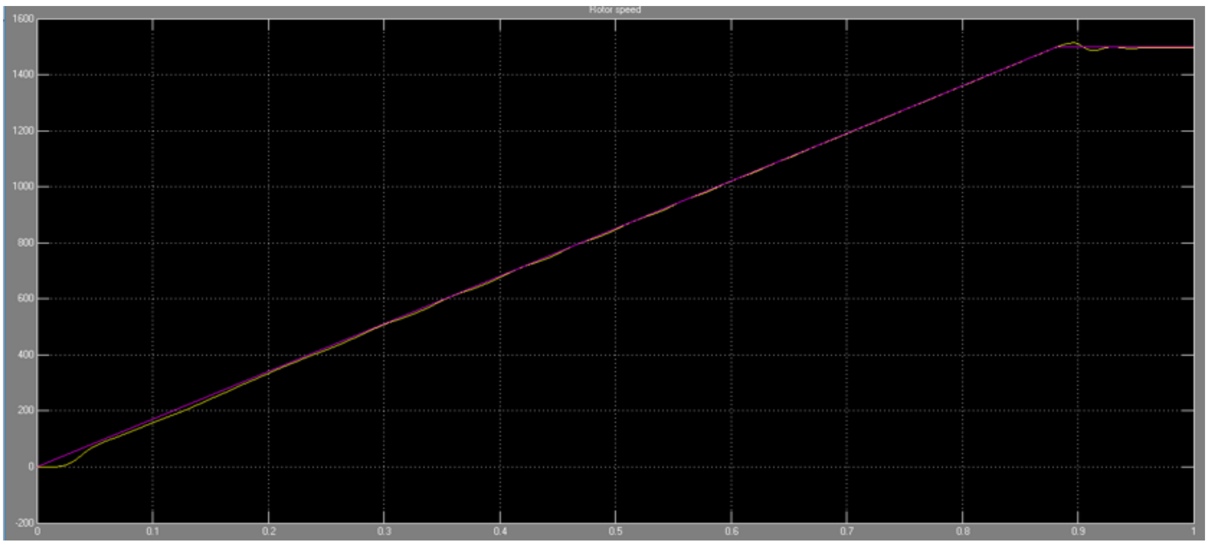

Figure 4.23: Rotor Speed Verse Time for the 3-Phase Induction Motor

V.

CONCLUSION

The steady state torque-speed characteristics for different methods of speed control of an Induction Motor were obtained and analysed. These achievements were made possible by developing MATLAB programming codes. Real motor parameters were used for the creation of the codes. The graph results of the various methods were as well analyses.

In rotor resistance start method the starting torque can be varied with the variation of rotor resistance. The maximum torque, however, remains unaffected. Thus, for operations requiring high starting torque, the rotor resistance can be varied to even obtain the maximum torque during starting. But simultaneously the copper losses will increase due to increase of resistance. So, this method is highly inefficient and cannot be used throughout the operation.

In variable stator voltage control method of speed control, the maximum torque decreases with the decrease of supply voltage and thus the motor remains underutilized. So, then the variable stator voltage control method cannot be used for good performance due to this weakness.

In constant, employing the techniques of constant V/F ratio control, the supply voltage as well as the supply frequency can varied such that the flux remains constant. So, we can get different operating zone for various speeds and torques can be achieved at constant flux. Achieving different synchronous speed with almost same maximum torque makes the motor is completely utilized and, we have a good range of speed control.

VI.

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