Experimental Investigations of Load Characteristics of Induction Motor Drive

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Abstract. The three phase induction motors are most widely used for electric drive applications due to its simple, rugged construction and easy maintenance. Induction motors are considered as workhorse of the industry. This paper presents an experimental investigation of load characteristics along with equivalent circuit parameters of three-phase induction motor drive. The dynamic mathematical model of the machine under different reference frames is analysed with the parameters of the motor obtained through experiments. The equivalent circuit model under steady state is developed; performance of the induction motor is determined form the developed equivalent circuit and the results obtained are verified using the dynamic model under different reference frames. A 5 hp induction motor is used for the experimental verification.

1. Introduction

The induction machine is an important class of machine, widely used in industry. Almost 85% of the industrial motors are the induction motors. Almost 50% of the industrial power requirements are used by induction motors. Torque is developed due to inducement of current in the rotor, which is at asynchronous speed, hence induction motors are known as asynchronous motors. Due to ease in speed control, dc motors were widely used in industry for constant speed applications. Wide range of speed control is also possible in induction motors due to developments in power electronics. The Induction motors have the advantages such as cheap, robust and low maintenance over other classes of motor, they are used for wide applications in industries ranging from fractional kW applications to MW applications [1].

By knowing the parameters of the induction motor, operating performance of the induction motor such as efficiency, torque, current and power factor could be easily determined. The field efficiency of the induction motor may be determined by various ways as from name plate details, slip method, equivalent circuit method, shaft torque method and segregated loss method. The equivalent circuit method is the one of the standard approach of deterring the machine performance parameters as specified by IEEE Standard 112-2004 and IEC Standard 60034-2-1[3]. With the equivalent circuit method, the performance of the machine is easily predicted by knowing the impedance of the machine.
One of the easiest methods of determining the equivalent circuit parameters is by performing Blocked rotor test and No load test [2]. The induction motor may be considered as a rotating transformer having stationary primary winding and a rotating secondary winding. As like transformers, the circuit parameters are easily obtained by performing the non loading tests as Blocked rotor test and No load test. Induction motor is also represented by the equivalent circuit as per the IEEE recommendation [7]. The Thevenin circuit model developed from the equivalent circuit parameters is useful in studying the performance of the machine in steady state where all electrical transients during load changes and variations in stator frequency are neglected.

Iron loss, friction and windage losses are neglected in the dynamic mathematical models. The dynamic mathematical models are used for the transient and steady state behavior of the machines. The three phase machine is transformed into two phase machine by adopting the power invariance concept. In this paper, performance of the machine is evaluated using stator reference frame, rotor reference and synchronously rotating reference frame models and steady state performance evaluated from equivalent circuit model developed for a 5hp motor is validated. In the dynamic model of the machine with all reference frames, the assumptions made are air gap is uniform, stator and rotor windings are balanced, mmf distribution and inductance versus rotor position are sinusoidal. Further saturation and parameter variations are neglected. To achieve fast and precise control of speed and torque, field orientation control can be used. Decoupling the stator current vector into torque producing and flux producing components helps in decoupled control of flux linkage and electromagnetic torque.

2. Tests on Induction Motor for discovering motor parameters

The parameters of the equivalent circuit model is determined by performing non loading tests such as No load test and Blocked rotor test. The stator resistance is determined by using volt-amp method. Name plate details of the squirrel cage induction motor used for conducting tests is given in Table 1.

| Sl No | Voltage (Volts) | Current (Amps) | DC Resistance (Ohm) | Average Resistance (Ohm) | Stator AC Resistance (Ohm) |
|-------|-----------------|----------------|---------------------|--------------------------|---------------------------|
| 1     | 6.82            | 1.5            | 4.55                |                          |                           |
| 2     | 9.34            | 2              | 4.67                | 4.57                     | 5.71                      |
| 3     | 11.21           | 2.5            | 4.484               |                          |                           |

2.1 Stator Resistance Measurement

With rotor at stationary, dc voltage is applied to one of the phase winding of the stator. The dc resistance is calculated from the readings of voltmeter and ammeter. The ac resistance is obtained by multiplying dc resistance by a factor of 1.25. The effect temperature variation is neglected.

![DC resistance measurement of stator winding](image-url)
2.2 No Load Test
With rated voltage and frequency applied, motor is run with no load. The voltage, current and power input are measured. Since motor is with no load, power input accounts for the stator copper loss and stator iron loss. From the measurements, no load power factor, magnetizing current and inductance, core loss resistance is estimated.

![No load test circuit](image)

**Fig 2. No load test circuit**

| Voltage (Vas) | Ia   | Ib   | Ic   | No Load Current (Io) | W1 (watts) | W2 (watts) | Power Input (Poc) | Speed (rpm) |
|---------------|------|------|------|----------------------|------------|------------|------------------|-------------|
| 415           | 4.15 | 4.10 | 4.10 | 4.12                 | -672       | 1080       | 408              | 1498        |

2.3 Blocked Rotor Test
Rotor is locked to keep it in standstill and reduced voltage is applied so that rated current flows through stator. The voltage, current and power inputs are measured. From the measurements equivalent circuit is developed which helps to determine rotor resistance and total leakage reactance.

**Table 4. Blocked Rotor Test observations**

| Voltage (Vsc) | Current (Isc) | W1 (Watts) | W2 (Watts) | Power Input (Psc) (Watts) |
|---------------|---------------|------------|------------|----------------------------|
| 82            | 7.5           | -11        | 510        | 499                        |

3. Equivalent Circuit Model from No Load and Blocked Rotor tests
From the no load and blocked rotor test measurements, the equivalent circuit model (IEEE model) is developed.

3.1 From no load test:
No load current /phase \( = \frac{4.12}{\sqrt{3}} = 2.38 \text{A} \)
No load power factor \( \cos \Phi_0 = \frac{P_{oc}}{\sqrt{3}V_{loc} I_L} = 0.1377 \)
No load impedance/phase \( Z_0 = \frac{V_L}{I_{phase}} = 174.47 \Omega \)
Magnetizing current = Im = I_{\text{phase}} \sin \Phi_o = 2.36 A

Core loss branch current I_c = I_{\text{phase}} \cos \Phi_o = 0.33 A

With neglecting stator impedances, Magnetizing inductance = L_m = \frac{V_{as}}{2\pi f_{slm}} = 0.5597 H

Core loss resistance R_c = \frac{V_{as}}{I_c} = 1267.17 \Omega

3.2 From Blocked Rotor Test

Short circuit current/phase = \frac{I_{sc}}{\sqrt{3}} = 4.42 A

Power factor \cos \Phi_{sc} = \frac{P_{sc}}{\sqrt{3}V_{sc}I_{sc}} = 0.5219

Locked rotor impedance = Z_{sc} = \frac{V_{sc}}{I_{sc}} = 18.795 \Omega

The stator impedances, core loss resistance and magnetizing inductance are recalculated by considering stator impedance as shown in Fig. 3

Magnetizing branch voltage = V_m = V_{as} - (R_s + jX_{ls})I_o

Magnetizing reactance = \frac{V_m}{I_m} = 169 \Omega

Core loss resistance = \frac{V_m}{I_c} = 1227.14 \Omega

3.3 Equivalent circuit model and Thevenin equivalent of induction motor circuit model

From the parameters obtained by the no load test and blocked rotor test, equivalent circuit of the induction motor is shown in Fig 5.
In Fig 5, Re represents the core loss, friction and windage loss. These losses are separated out by no load and blocked rotor tests. By subtracting these losses from gross mechanical power output, exact circuit (IEEE circuit) model is developed as in Fig 6.

The Thévenin’s equivalent circuit model of induction motor is developed by finding the Thévenin’s voltage and Thévenin’s impedance to the left of the rotor impedances as

$$|V_{TH}| = \left| V_{as} \frac{jX_{ls}}{R_s + j(X_{ls} + X_m)} \right| = 396 \text{ V}$$  \hspace{1cm} (1)

$$Z_{TH} = \frac{jX_m (R_s + jX_{ls})}{R_s + j(X_{ls} + X_m)} = R_{TH} + jX_{TH} = 5.19 + j7.819$$  \hspace{1cm} (2)

From the parameters obtained from equations (1) and (2), the Thévenin’s equivalent circuit model of an induction motor is shown in Fig 7.

From the Thévenin’s equivalent circuit, slip for maximum electromagnetic torque is obtained as

$$\frac{R_r}{S_{max,T}} = \sqrt{R_{TH}^2 + (X_{TH} + X_r)^2}$$  \hspace{1cm} (3)

Substituting the obtained values in equation (3), the slip for maximum electromagnetic torque obtained as $S_{max,T} = 0.2466$

$Z_{Total} = 21.85 + j15.834 \Omega$

$$|I_2| = \frac{|V_{TH}|}{{|Z_{Total}|}} = 14.67 \text{ A}$$
Fig 7. Thevenin’s equivalent circuit model

The maximum electromagnetic torque \( T_{\text{max}} = \frac{3I_2^2 R_s P}{S_{\text{max}} \omega_s^2} \) = 68.5 N-m

Where \( \omega_s \) is the synchronous speed in electrical radian/sec = 314.15 rad/sec

4. Analysis of induction motor performance by the generalized dynamic models

The performance of the induction motor is analyzed by the generalized dynamic models in synchronously rotating reference frame, rotor reference frame and stator reference frame. The performance parameter is determined for the slip \( S_{\text{max},T} \) of 0.2466.

In dynamic model, three phase machine is transformed to two phase machine. Stator and rotor voltages and currents are represented in d-q axes.

The machine parameters obtained from no load and blocked rotor test given in Table 5 is used in the analysis of the machine by dynamic model with different reference frames.

Table 5. The Induction Motor parameters

| Rs (ohm) | Rr (ohm) | Ls = Lls+Lm | Lr=Llr+Lm | Lm |
|---------|---------|------------|------------|----|
| 5.7     | 4.11    | 0.5634     | 0.5634     | 0.5379 |

The model of the induction machine in arbitrary reference frame is given as

\[
\begin{bmatrix}
V_{qs} \\
V_{ds} \\
V_{qc} \\
V_{dc} \\
V_{qr} \\
V_{dr}
\end{bmatrix} =
\begin{bmatrix}
Rs + LsP & \omega_c Ls & LmP & \omega_c Lm & 0 \\
-\omega_c Ls & Rs + LsP & -\omega_c Lm & LmP & 0 \\
LmP & (\omega_c - \omega_r)Lm & Rr + LrP & (\omega_c - \omega_r)Lr & 0 \\
-(\omega_c - \omega_r)Lm & LmP & -((\omega_c - \omega_r)Lr) & Rr + LrP & 0
\end{bmatrix}
\begin{bmatrix}
i_{qs} \\
i_{ds} \\
i_{qc} \\
i_{dc} \\
i_{qr} \\
i_{dr}
\end{bmatrix}
\] (4)

Where \( \omega_c \) is the speed of arbitrary reference frame in electrical radian/sec

\( \omega_r \) is the speed of rotor in electrical radian/sec

P is the differential operator \( \frac{d}{dt} \)

The subscripts s and r refers to stator and rotor quantities respectively.

4.1 Synchronously rotating reference frame model

As the reference frame rotates at the synchronous speed, \( \omega_c = \omega_s \)

\( \theta_c = \theta_s = \omega_s t \) (5)

\( V_m = V_m \sin(\omega_s t) = 586.89 \sin(\omega_s t) \)

\( V_{bs} = V_m \sin(\omega_s t - 2\pi/3) = 586.89 \sin(\omega_s t - 2\pi/3) \)

\( V_{cs} = V_m \sin(\omega_s t + 2\pi/3) = 586.89 \sin(\omega_s t + 2\pi/3) \)

\[
\begin{bmatrix}
V_{qs} \\
V_{ds} \\
V_{qc} \\
V_{dc} \\
V_{qr} \\
V_{dr}
\end{bmatrix} = [T_{abc}^e]
\begin{bmatrix}
V_{as} \\
V_{bs} \\
V_{cs}
\end{bmatrix}
\] (7)

[\( T_{abc}^e \)] is the transformation matrix from abc to d-q variables
\[ T_{abc}^e = \frac{2}{3} \begin{bmatrix} \cos \theta_s & \cos \left( \theta_s - \frac{2\pi}{3} \right) & \cos \left( \theta_s + \frac{2\pi}{3} \right) \\ \sin \theta_s & \sin \left( \theta_s - \frac{2\pi}{3} \right) & \sin \left( \theta_s + \frac{2\pi}{3} \right) \end{bmatrix} \]  

(8)

Substituting for \( V_{as}, V_{bs}, V_{cs} \) and equation (8) in equation (7)

\[
\begin{bmatrix} V_{qs}^e \\ V_{ds}^e \\ V_0 \end{bmatrix} = \begin{bmatrix} 0 \\ V_m \\ 0 \end{bmatrix} = \begin{bmatrix} 586.89 \\ 0 \\ 0 \end{bmatrix} 
\]

(9)

Obtained d and q axes stator voltages are dc quantities, hence responses are also dc quantities. Thus system becomes linear.

\[ P_i q_s = P_i d_s = P_i q_r = P_i d_r = 0 \]  

(10)

Substituting equations (5), (6), (9) and (10) in equation (4)

\[
\begin{bmatrix} V_m \\ 0 \end{bmatrix} = \begin{bmatrix} 5.7 & 176.99 & 0 & 168.98 \\ -176.99 & 5.7 & -168.98 & 0 \\ 0 & 41.67 & 4.11 & -43.64 \\ -41.67 & 0 & -43.64 & 4.11 \end{bmatrix} \begin{bmatrix} i_{qs}^e \\ i_{ds}^e \\ i_{qr}^e \\ i_{dr}^e \end{bmatrix}
\]

Which is of the form \( V=ZI \) where \( Z \) is the impedance matrix.

\[ \omega_{sl} = \omega_s - \omega_r = \text{slip speed} = 77.47 \text{ radian/sec} \]

\[
Z = \begin{bmatrix} 5.7 & 176.99 & 0 & 168.98 \\ -176.99 & 5.7 & -168.98 & 0 \\ 0 & 41.67 & 4.11 & -43.64 \\ -41.67 & 0 & -43.64 & 4.11 \end{bmatrix}
\]

Currents are obtained as \( I = Z^{-1} V = \begin{bmatrix} -13.86 \\ 16.88 \\ 11.62 \\ -17.20 \end{bmatrix} \)

Electromagnetic Torque = \( Te = \frac{3P}{2} L_m \left( i_{qs}^e i_{dr}^e - i_{ds}^e i_{qr}^e \right) \) N-m where \( P \) is the number of poles.

\( Te = 68.82 \text{ N-m} \)

Actual phase stator currents \( i_{abc} = [T_{abc}]^{-1} i_{qdo} \)

\[
\begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} = \begin{bmatrix} \cos \omega_s t \\ \cos \left( \omega_s t - \frac{2\pi}{3} \right) \\ \cos \left( \omega_s t + \frac{2\pi}{3} \right) \end{bmatrix} \begin{bmatrix} \cos \omega_s t & \sin \omega_s t \\ \cos \left( \omega_s t - \frac{2\pi}{3} \right) & \sin \left( \omega_s t - \frac{2\pi}{3} \right) \\ \cos \left( \omega_s t + \frac{2\pi}{3} \right) & \sin \left( \omega_s t + \frac{2\pi}{3} \right) \end{bmatrix} \begin{bmatrix} i_{qs}^e \\ i_{ds}^e \\ i_{qr}^e \end{bmatrix}
\]

(11)

4.2 Rotor reference frame model

The speed of the rotor reference frame is the speed of the rotor. \( \omega_c = \omega_r \)

Angular position \( \theta_c = 0 \)
\[
\begin{bmatrix}
V_{qs}^r \\
V_{ds}^r \\
V_o^r
\end{bmatrix} = \begin{bmatrix}
V_{as}^r \\
V_{bs}^r \\
V_{cs}^r
\end{bmatrix} = [T_{abc}^r] \cdot \begin{bmatrix}
V_s^a \\
V_s^b \\
V_s^c
\end{bmatrix}
\] 

(13)

The transformation matrix from abc to dqo variables \([T_{abc}^r] = \frac{2}{3} \begin{bmatrix}
\cos \theta_r & \cos(\theta_r - \frac{2\pi}{3}) & \cos(\theta_r + \frac{2\pi}{3}) \\
\sin \theta_r & \sin(\theta_r - \frac{2\pi}{3}) & \sin(\theta_r + \frac{2\pi}{3}) \\
\frac{1}{2} & \frac{1}{2} & \frac{1}{2}
\end{bmatrix}\]

As the reference frame is stator, \(\omega_s = 4\).

As the stator voltages appear at slip frequency in rotor reference frames, hence currents are also at slip frequency in steady state. Thus \(P = j\omega_s\)

Form equation (xiii),

\[
\begin{bmatrix}
V_{qs}^r \\
V_{ds}^r \\
V_o^r
\end{bmatrix} = \begin{bmatrix}
V_m \sin \omega_s t \\
V_m \cos \omega_s t \\
0
\end{bmatrix} = \begin{bmatrix}
-jV_m \\
V_m \\
0
\end{bmatrix} = \begin{bmatrix}
-586.89 \\
586.89 \\
0
\end{bmatrix}
\] 

As the stator voltages appear at slip frequency in rotor reference frames, hence currents are also at slip frequency in steady state. Thus \(P = j\omega_s\)

Substituting equations (11), (12),(14) and (15) in equation (4)

\[
Z = \begin{bmatrix}
5.7 + j43.65 & 133.34 & j41.67 & 127.31 \\
-133.34 & 5.7 + j43.65 & -127.31 & j41.67 \\
j41.67 & 0 & 4.11 + j43.65 & 0 \\
0 & j41.67 & 4.11 + j43.65
\end{bmatrix}
\]

Currents are obtained as \(I = Z^{-1} V = \begin{bmatrix}
i_{qs}^r \\
i_{ds}^r \\
i_{dr}^r
\end{bmatrix} = \begin{bmatrix}
21.83 \angle -129.47^\circ \\
21.83 \angle -39.47^\circ \\
20.74 \angle 55.90^\circ \\
20.74 \angle 145.90^\circ
\end{bmatrix}\)

Actual phase stator currents \(i_{abc} = [T_{abc}^r]^{-1} i_{qdo}\)

\[
\begin{bmatrix}
i_{as}^r \\
i_{bs}^r \\
i_{cs}^r
\end{bmatrix} = \begin{bmatrix}
\cos(\omega_s t - \frac{2\pi}{3}) & \sin(\omega_s t - \frac{2\pi}{3}) & 1 \\
\cos(\omega_s t + \frac{2\pi}{3}) & \sin(\omega_s t + \frac{2\pi}{3}) & 1 \\
\cos(\omega_s t - \frac{2\pi}{3}) & \sin(\omega_s t - \frac{2\pi}{3}) & 1
\end{bmatrix} \begin{bmatrix}
i_{qs}^r \\
i_{ds}^r \\
i_{dr}^r
\end{bmatrix} = \begin{bmatrix}
21.83 \sin (\omega_s t - 39.46^\circ) \\
21.83 \sin (\omega_s t - 159.27^\circ) \\
21.83 \sin (\omega_s t + 80.47^\circ)
\end{bmatrix}
\]

Electromagnetic Torque \(T_e = \frac{3}{2} P L_m (i_{qs}^r \frac{d}{dr} - i_{ds}^r \frac{d}{dr})\) N-m = 68.82 N-m

4.3 Stator reference frame model
As the reference frame is stator, \(\omega_s = 0\)

\[
\begin{bmatrix}
V_{qs} \\
V_{ds} \\
V_o
\end{bmatrix} = [T_{abc}^s] \begin{bmatrix}
V_{as} \\
V_{bs} \\
V_{cs}
\end{bmatrix} = \begin{bmatrix}
1 & -\frac{1}{2} & -\frac{1}{2} \\
-\frac{1}{2} & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \\
\frac{1}{2} & \frac{1}{2} & \frac{1}{2}
\end{bmatrix} \begin{bmatrix}
V_m \sin \omega_s t \\
V_m \cos \omega_s t \\
0
\end{bmatrix}
\]

Since the stator voltages appear at synchronous frequency in the reference frame, currents are also at synchronous frequency at steady state. Thus \(P = j\omega_s\) in the arbitrary reference frame model. Thus the model of induction motor is
From the developed reference frame model, the equivalent circuit model of the induction motor is the easiest method of determining the machine parameters. In the laboratory, the machine parameters are determined by dc resistance measurement, no load test and blocked rotor tests. From the developed Thevenin’s equivalent circuit model, the maximum electromagnetic torque and the slip at which this occurs is determined. The dynamic model of the machine in all the three reference frames is analyzed. The results obtained from steady state model are validated with dynamic models. The sinusoidal signals are transformed to dc signals in the synchronous reference frame. Decoupling the torque and flux producing components helps in decoupled control of flux linkage and electromagnetic torque, hence control of the induction motor similar to separately excited dc motor is possible. In cases of stator reference frame and rotor reference frame, stator and rotor q-d axes currents are complex and displaced from each other by 90°. Rotor reference frame model is useful when the power and switching elements are to be controlled on rotor side. In case of stator reference frame, input variables are well defined, stator and rotor d-q axes voltages are determined through simple algebraic equations. This model is well suitable for control applications of stator-controlled induction motors as applicable to inverter controlled and phase controlled induction motor drives. Further the performance of the machine can be analysed by considering the effect of variation in stator and rotor winding temperature, iron and core loss.

5. Conclusion
The equivalent circuit model of the induction motor is the easiest method of determining the machine parameters. In the laboratory, the machine parameters are determined by dc resistance measurement, no load test and blocked rotor tests. From the developed Thevenin’s equivalent circuit model, the maximum electromagnetic torque and the slip at which this occurs is determined. The dynamic model of the machine in all the three reference frames is analyzed. The results obtained from steady state model are validated with dynamic models. The sinusoidal signals are transformed to dc signals in the synchronous reference frame. Decoupling the torque and flux producing components helps in decoupled control of flux linkage and electromagnetic torque, hence control of the induction motor similar to separately excited dc motor is possible. In cases of stator reference frame and rotor reference frame, stator and rotor q-d axes currents are complex and displaced from each other by 90°. Rotor reference frame model is useful when the power and switching elements are to be controlled on rotor side. In case of stator reference frame, input variables are well defined, stator and rotor d-q axes voltages are determined through simple algebraic equations. This model is well suitable for control applications of stator-controlled induction motors as applicable to inverter controlled and phase controlled induction motor drives. Further the performance of the machine can be analysed by considering the effect of variation in stator and rotor winding temperature, iron and core loss.

References
[1] Diptarshi Bhowmick and Suparna Kar Chowdhury 2018 Parameter and Loss Estimation of Three Phase Induction Motor from Dynamic Model using H - G Diagram and Particle Swarm Optimization 2018 IEEE 8th Power India International Conference (PIICON) (Kurukshetra, India), DOI: 10.1109/POWERI.2018.8704353
[2] Phumipahk T and Chat-uthai C 2002 Estimation of induction motor parameters based on field test coupled with genetic algorithm International Conference on Power System Technology(Kunming: China) IEEE Xplore Print ISBN:0-7803-7459-2
[3] Ayasun S and Nwankpa C O 2005 Induction motor tests using MATLAB/Simulink and their integration into undergraduate electric machinery courses IEEE Transactions on Education ( Volume: 48, Issue: 1, Feb. 2005) Page(s): 37 - 46
[4] Aminu M, Ainah P K, Abana M and Abu U A 2018 Identification of induction Machine Parameters using Only No Load test Measurement Nigerian Journal of Technology (NIJOTECH) Vol. 37, No. 3, July 2018, pp. 742 – 748

[5] France O. Akpojedje, Ese M. Okah and Yussuf O. Abu 2016 A Comparative Analysis of Three Phase Induction Motor Performance Evaluation International Journal of Engineering and Techniques - Volume 2 Issue 3, May – June 2016 ISSN: 2395-1303 Page 64

[6] Sunil Sehra, Gautam K K and Vijay Bhuria 2012 Performance Evaluation of Three Phase Induction Motor Based on No Load and Blocked Rotor Test Using MATLAB International Journal of Science, Environment and Technology, Vol. 1, No 5, pp. 541 – 547

[7] Pandey K K and Zope P H 2013 Estimating Parameters of a Three-Phase induction motor using Matlab/Simulink International Journal of Scientific & Engineering Research, Volume 4, Issue 12, ISSN 2229-5518

[8] IEEE Standard Test Procedure for Polyphase Induction Motors and Generators Publisher :IEEE Print: ISBN 0-7381-3977-7 SH95211 PDF: ISBN 0-7381-3978-5 SS95211

[9] Tripti Rai and Prashanth Debre 2016 Generalized modeling model of three phase induction motor Proc. International Conference on Energy Efficient Technologies for Sustainability (ICEETS) (Nagercoil: India) Publisher: IEEE Print ISBN:978-1-5090-1534-4

[10] Sonakshi Gupta and Dr. Sulochana Wadhwani 2014 Dynamic Modeling of Induction Motor Using Rotor Rotating Reference Frame International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering Vol. 3, Issue 6, June 2014 ISSN (Print) : 2320 – 3765 ISSN (Online): 2278 – 8875

[11] Krishnan R 2013 Electric Motor Drives Modelling, Analysis and Control (Delhi PHI) Chapter 5 pp 193-217