

MATHEMATICAL MODELING AND SPEED TORQUE ANALYSIS OF THREE PHASE SQUIRREL CAGE INDUCTION MOTOR USING MATLAB SIMULINK FOR ELECTRICAL MACHINES LABORATORY

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Abstract

Different mathematical models have been used over the years to examine different problems associated with induction motors. These range from the simple equivalent circuit models to more complex d,q models and abc models which allow the inclusion of various forms of impedance and/or voltage unbalance. This paper presents speed torque characteristics of induction motor which are calculated on the basis of a mathematical model. This technique is in compliance with the IEEE standard test procedure for polyphase induction motors and generators. Induction machines are the major electromechanical conversion devices in industry. There is a mathematical model of induction motor which is designed from the parameters taken from Machine lab. Through this model we can calculate major features of induction motor very easily. This model solves the issue of torque calculation in three phase squirrel cage induction motor

of Machine lab. These results checked on a simulink Model for induction motor fed by PWM inverter. The dynamic simulation is done which is an important tool in the validation of the design process of the motor drive systems and also removes resulting error in the prototype construction and testing. The results obtained by Simulink designed model were encouraging when compared to the design made by practical experience.

Keywords

Squirrel Cage Induction Motor, Modeling and Simulation, MATLAB Software, Torque, Speed

1.0 INTRODUCTION

Induction machine modeling has continuously attracted the attention of researchers not only because such machines are made and used in largest numbers but

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also due to their varied modes of operation both under steady and dynamic states[7].

The computational tools as a part of laboratory experiments enhance laboratory experience by providing students with the opportunity to verify the results of laboratory experiments and compare them with those obtained by computer simulations. Such a comparison opportunity helps students realize the limitations of hardware experiments and, as a counterpoint, appreciate that computer models cannot substitute for actual hardware experiments that might not exactly represent the operation of induction motors because of some modeling assumptions [9].

With the rapid development in computer hardware and software, new simulation packages which are much faster and more user friendly are now available. This paper discusses the use of one such product, the SIMULINK software of MATLAB, in the dynamic modeling of the induction motor. The dynamic model is based on the two-axis theory of revolving frame transformation. The main advantage of the SIMULINK over other programming sources is that, instead of compilation of program code, the simulation model is built up systematically by basic function blocks. A set of machine differential equations can thus be modeled by interconnection of appropriate function

blocks, each of which perform specific mathematical operation. Programming efforts are drastically reduced and the debugging of errors is easy [11].

2.0 Mathematical Modeling of 3-phase induction motor existing in Machine Lab.

An induction motor can be considered as a rotating transformer whose magnetic circuit is separated by an air gap. The stator is considered as primary and rotor is taken as secondary winding. Air gap between the two is considered as the core of the transformer. When the secondary is short-circuited through external impedance the AC power supplied to primary induces an opposing current in the short circuited secondary. Thus mutual emf is produced due to relative motion between stator and rotor. As rotor of induction motor is in rotating position as compared to secondary of a transformer so it is known as rotating transformer.

Induction machine is different from other type of electric motors in the sense that secondary currents are produced by induction, as in a transformer. And they are not being supplied by a dc exciter or other external power sources, as in other machines. The equivalent circuit for induction motor is shown in fig 3.9.

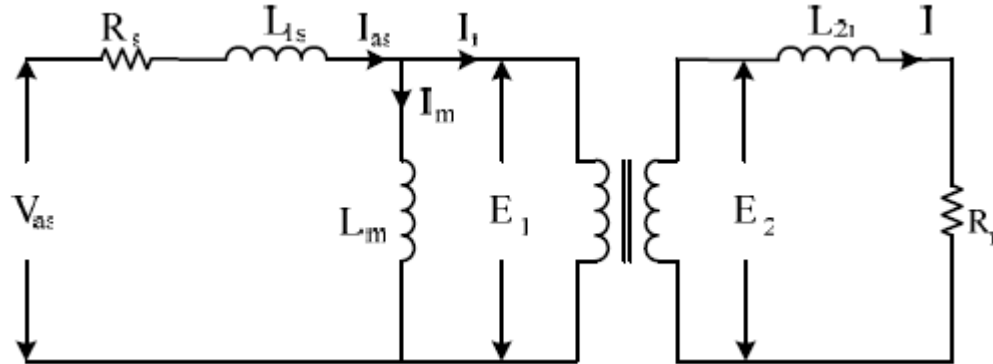


Fig 1: Elementary equivalent circuit for induction motor

Where

R_s = Stator Resistance

R_r = Rotor resistance

L_{1s} = stator inductance

L_{2r} = Rotor inductance

L_m = Magnetizing Inductance

I_m = magnetizing Current

V_{as} = voltage applied to stator

E_1 = self induced e.m.f in stator side

E_2 = mutually induced e.m.f in rotor side

These all parameters of induction motor are measured and given in Table 3.1. Now first of all for calculation of constant losses (core, friction and windage) we run the induction motor without load as described below. The values of different parameters of 3- Φ squirrel cage induction motor existing in Machine lab are tabulated below.

Table 1: Input parameters for 3-phase squirrel cage induction motor

SYMBOL	INPUT QUANTITIES	VALUES
hp	Horse Power	2.94
RPM	speed (revolution per minute)	1500
Φ	Phase	3
F	Frequency	50Hz
p	Poles	4

VL-L	Line to line voltage	110volts
Rs	Stator resistance	0.45Ω
Rr	Rotor resistance	0.86Ω
Xs	Stator magnetizing leakage inductance	3.2e-3 H
Xr	Rotor magnetizing leakage inductance	3.2e-3 H
Xm	Mutual inductance	69.13e-3 H

2.1

NO LOAD TEST

The no load test for an induction motor measures the rotational losses of the motor and provides information about its magnetization current. The circuit diagram for the no load test is given below.

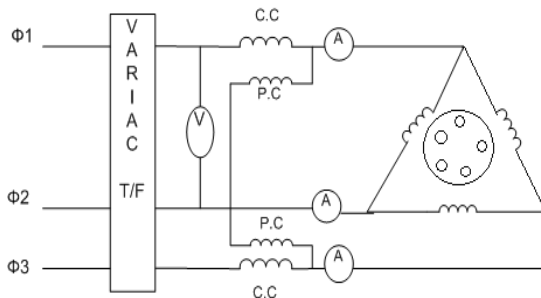


Fig 2: Circuit Diagram for no load test

We connected squirrel cage induction motor with variable transformer because of the reason that input voltages in all three phases have their particular and same value. No fluctuation of voltages will occur. Now first of all calculate the line to line voltage and line current with the help of clamp on meter. We will take average of currents and voltages in 3-phases as follows

$$V_o = \frac{(V_1+V_2+V_3)}{3} \quad (1)$$

$$I_o = \frac{(I_1+I_2+I_3)}{3} \quad (2)$$

Now measure the wattmeter reading connected in the circuit and calculates the input power of induction motor by using the formula

$$P_{in} = \text{Wattmeter reading} \times \text{Multiplying factor} \quad (3)$$

This multiplying factor will be mentioned on the three phase wattmeter apparatus i.e. 1, 10, 100 etc. But in our case it is 10. Now we are able to calculate stator Cu losses as

$$I_L^2 R_S \quad \text{Stator Cu Loss} = \quad (4)$$

Where Rs is 0.45 ohm given in table 3.1. After this calculate constant losses of induction motor as

$$P_{in} - \text{Stator Cu Loss} \quad \text{Const. losses} = \quad (5)$$

Now all the measured values in no load test of 3-Ø squirrel cage induction motor is tabulated in Table 3.3.

Table II: Observation of No load test

I_o (Amp)	V_o (volts)	P_{in} (Watts)	Stator Cu loss (watts)	Constant Loss (Watts)
10.27	113.96	$8 \times 50 = 400$	$10.272 \times 0.45 = 47.46$	$400 - 47.46 = 352.53$

Now in order to proceed further we have to perform load test on induction motor set.

The circuit diagram used for load test is shown in Fig 3.11.

2.2 LOAD TEST

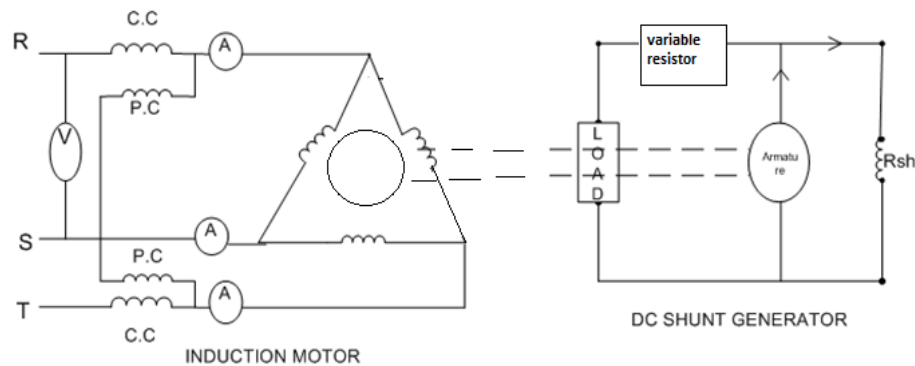


Fig 3: Circuit Diagram for load test

Now the change of load take place by changing the value of resistor bank connected with DC shunt generator. We have to take observations at each change of load. First of all make connections according to circuit diagram shown above then using clamp on meter measure line to line voltage and line current respectively at each load by taking average of three currents and voltages on three phases as under

$$V_{L-L} = \frac{(V_1 + V_2 + V_3)}{3} \quad (6)$$

$$I_L = \frac{(I_1 + I_2 + I_3)}{3} \quad (7)$$

Note down the input power taken by induction motor at each load by using the equation (3). Measure stator copper losses at each load by using equation (4). Now value of stator copper loss changes at each load because value of line current is changing with every load. Calculate the synchronous speed of 3-phase squirrel cage induction motor by using formula

$$(8) \quad N_s = \frac{120f}{P}$$

Where N_s = synchronous speed of motor

f = Supply frequency = 50 Hz

p = no. of poles of motor = 4

After this we measure the speed of rotor at each load by using stroboscope explained earlier in section 3.2.3. Now we start calculations from the observations discussed above. Slip is the difference between synchronous speed and actual speed of rotor. Calculate slip by using the formula

$$(9) \quad s = \frac{N_s - N}{N_s}$$

If we want to find the input power of rotor we should subtract the stator Cu losses from the total input power of motor as follows

$$P_{in} - I_L^2 R \quad \text{Rotor input} = \quad (10)$$

Now let us suppose that

$$\text{phase} = E_1 I_2' \cos \theta \quad \text{Rotor input /} \quad (i)$$

$$(ii) \quad \text{Total rotor input} = 3 E_1 I_2' \cos \theta$$

The electrical input to the rotor which is wasted in the form of heat is

$$(iii) \quad 3 I_2 E_r \cos \theta \quad (\text{or} = 3 I_2^2 R_2)$$

$$\text{Now} \quad I_2' = K I_2$$

$$\text{or} \quad I_2 = (I_2' / K)$$

$$E_r = s E_2 \quad \text{or} \quad E_2 = K E_1$$

$$\text{SO} \quad E_r = s K E_1$$

Rotor cu losses

$$= 3 \times (I_2' / K) \times s K E_1 \times \cos \theta$$

$$= 3 E_1 I_2' \cos \theta \times s$$

$$\text{So} \quad \text{Rotor cu losses} = \text{rotor input} \times \text{slip} \quad (11)$$

Now determine total losses by using equations (4), (5) and (11) as

$$\text{Total losses} = \text{Constant loss} + \text{stator Cu loss} + \text{Rotor Cu loss} \quad (12)$$

Now we know that in any machine

$$\text{Output power} = \text{input power} - \text{total losses} \quad (13)$$

Similarly using general formula find out efficiency of induction motor

$$\% \eta = (\text{output} / \text{input}) \times 100 \quad (14)$$

The output torque of induction motor is due to output power P_{out} which is less than mechanical power developed by the rotor because of rotor's friction and windage losses i.e.

$$(P_{out}/\omega) = (P_{out}/2\pi N) \quad T_{out} =$$

$$(60/2\pi) \times (P_{out}/N) \quad T_{out} =$$

The difference between gross torque developed by rotor and output torque equals the torque lost due to friction and windage loss in the motor. In the above expression rotor speed N is in rps. However if it is taken in rpm then above expression for torque becomes

$$\text{OR} \quad 9.55 \times (P_{out}/N) \quad T_{out} = (15)$$

Now the results taken based on the explained mathematical model are tabulated below

Table III: Observations of Load test

I _L (Amp)	V _L (volts)	P _{in} (watts)	Stator Cu losses (watts)	N _s (rpm)	N (rpm)	Slip	Const losses watts	Rotor input (watts)	Rotor Cu loss (watts)	Total loss watts	P _{out} watts	%η	T _{out} (N-m)
10.37	110	9.1 × 50 = 455	48.39	1500	1450	0.033	352.53	406.61	13.41	414.33	40.67	8.93	0.267
10.5	110	12 × 50 = 600	49.61	1500	1443	0.038	352.53	550.39	20.91	423.05	176.95	29.49	1.17
10.87	110	14.9 × 50 = 745	53.17	1500	1440	0.04	352.53	691.83	27.67	433.37	311.63	41.82	2.06
11.15	110	16.2 × 50 = 810	55.94	1500	1439	0.041	352.53	754.06	30.16	438.63	371.37	45.84	2.46
11.25	110	17.5 × 50 = 875	56.95	1500	1438	0.042	352.53	818.05	32.72	442.2	432.8	49.46	2.87

3.0 Dynamic Modeling of three phase squirrel cage Induction Motor for Speed Torque Analysis

The dynamic modeling of three phase squirrel cage induction motor is done by using a simulink designed model for three phase induction motor fed by PWM inverter.

Table IV: Parameters Description Table of three phase Squirrel Cage Induction Motor

Parameter	Value	Parameter	Value
Nominal Power	2.94 Hp	Stator resistance	0.45Ω
Phase	3	Rotor resistance	0.86Ω
No. of Poles	4	Mutual inductance	0.006913H
Frequency	60	Vl-l	110 V

4.0 SIMULATION RESULTS

The simulation results for induction motor existing in Electrical Machines lab are shown in fig (3).

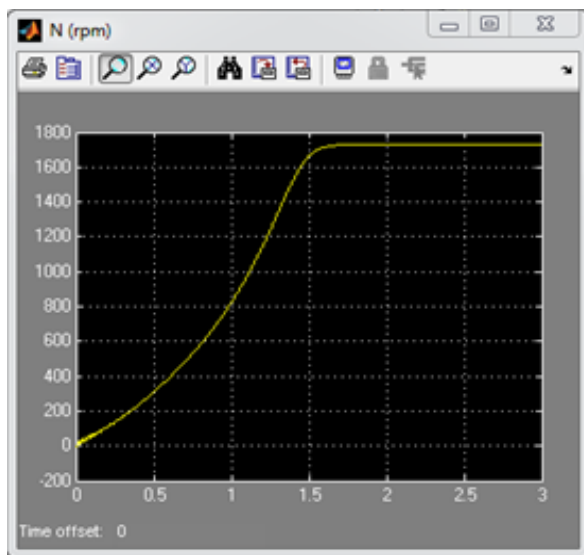


Fig a

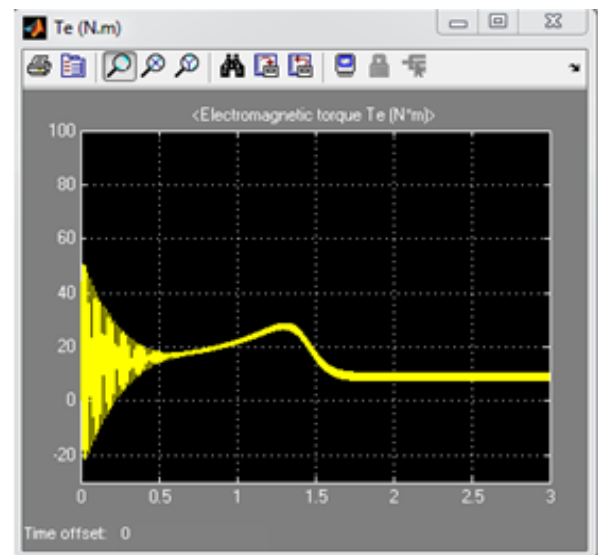


Fig b

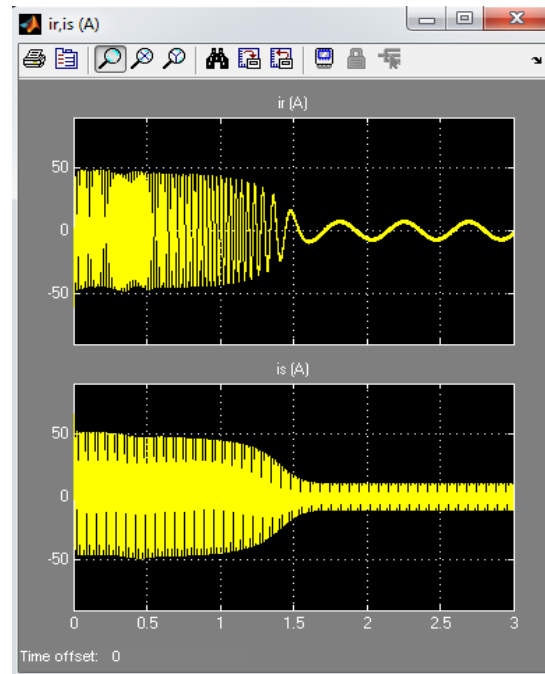


Fig c

Fig 3: Simulation Results of Induction motor (a) Rotor Speed (b) Electromagnetic Torque(c) Rotor & Stator Current

The load torque applied to the machine's shaft is constant and set to its nominal value of 9 N-m. The motor is started from stall. The speed set point is set to 3pu or 1500rpm. But the max speed achieved from this model is approximately 1650rpm as shown in Fig (a). Our required speed is achieved at 1.8 sec. The noise produced in the PWM inverter is also observed in the electromagnetic waveform T_e . However motor inertia prevents this noise from appearing in the motor's speed waveform. In Fig (b) the time response of electromagnetic torque is expressed. The torque is variable from 0 to 0.7 sec. then the rated torque i.e; 9N-m is reached at 2 sec. The stator and rotor current response of squirrel cage induction motor is shown in Fig (c). The rotor current fluctuates between 0 and

1.5 sec. the stator current is drawn about 10A at 2 sec as shown in Fig (c).

5.0 CONCLUSIONS

In this paper, the mathematical modeling of a three-phase induction motor is presented in a step-by-step manner. Then model was tested on a simulink circuit designed for same machine but fed by a static frequency inverter. The simulated machines have given a satisfactory response in terms of the torque and speed characteristics. The same model was checked for small and large machines also. This research provides a sophisticated relationship between hardware and software circuits of induction motor. This concludes that the Matlab/Simulink is a reliable and

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sophisticated way to analyze and predict the behavior of induction motors using the theory of reference frames.

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