Advances in Computer Science and Engineering
© 2016 Pushpa Publishing House, Allahabad, India
Published Online: August 2016
http://dx.doi.org/10.17654/CS016120049
Volume 16, Numbers 1-2, 2016, Pages 49-60 **ISSN: 0973-6999**

VIRTUAL LABORATORY FOR ANALYSIS OF AN INDUCTION MOTOR WITH MATLAB GUI

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Abstract

In this paper, using the GUI environment of Matlab, we simulate the transient behavior of induction motor. For this purpose, the relevant equations are stated in the beginning, and then by the coordinate transformation, the simulation model in two phase $\alpha\beta$ stationary frame is built and put in an appropriate form suitable to be processed with Matlab. The result of simulation curves agrees well with the actual situation of running motors. This virtual laboratory can be used to assist in the understanding and testing of electrical machines in engineering degrees.

Received: June 11, 2016; Accepted: July 9, 2016
Keywords and phrases: Matlab GUI, induction motor, virtual laboratory.

1. Introduction

The establishment and the study of mathematical models for electrical machines open a large field of possibility for research. The possibility to replace a real system by a mathematical model gives many advantages in the research on electrical machines. Model is a valuable contribution in gaining an image of what can be observed experimentally. In addition, it helps to predict the behavior of the machines in situations different from experimental observations.

In the past, we used the three-phase stationary frame for the establishment of induction motors. In this reference frame, the equations contain inductance terms which vary with θ (which is the angle between the same phase axis of stator and rotor) which in turn varies with time. This makes it difficult to establish the mathematical model of induction motor, in three-phase stationary frame. A much simpler form leading to a clearer physical picture is obtained by coordinate transformation, building the induction motor in two-phase $\alpha\beta$ stationary frame.

In this paper, we build the simulation model of induction motor in two phase $\alpha\beta$ stationary frame, and give the simulation results, which demonstrate that the model is more accurately reflecting the actual situation of running motors.

The simulations are conducted using Matlab which is a tool which allows the modelisation of the dynamics of electrical machines. It also offers impressive and easy-to-use tools in applications development using graphical user interfaces (GUIs). This environment is used for the implementation of the model.

2. The Mathematical Model and Coordinate Transformation of the Induction Motor [1]

Firstly, we have the mathematical equations of a squirrel cage induction motor in the three-phase stationary frame. Secondly, transform the model of three-phase static coordinate to the model of two-phase static coordinate through 3S/2S transformation, then put it in an appropriate form suitable to be simulated with Matlab. The concrete procedure is as follows [1].

A. Establishment of the mathematical model of asynchronous motor

The mathematical model of asynchronous motor in the three phase stationary coordinate can be listed as:

1. Voltage equation:

$$\begin{cases} U_{sa} = R_s i_{sa} + \dfrac{d\Psi_{sa}}{dt} \\ U_{sb} = R_s i_{sb} + \dfrac{d\Psi_{sb}}{dt} \\ U_{sc} = R_s i_{sc} + \dfrac{d\Psi_{sc}}{dt} \end{cases} \quad \begin{cases} U_{ra} = R_r i_{ra} + \dfrac{d\Psi_{ra}}{dt} \\ U_{rb} = R_r i_{rb} + \dfrac{d\Psi_{rb}}{dt} \\ U_{rc} = R_r i_{rc} + \dfrac{d\Psi_{rc}}{dt} \end{cases},$$

$U_{sa}, U_{sb}, U_{sc}, U_{ra}, U_{rb}, U_{rc}$ denote the instantaneous values of stator and rotor phase voltage, respectively.

$i_{sa}, i_{sb}, i_{sc}, i_{ra}, i_{rb}, i_{rc}$ denote the instantaneous values of stator and rotor phase current, respectively.

$\Psi_{sa}, \Psi_{sb}, \Psi_{sc}, \Psi_{ra}, \Psi_{rb}, \Psi_{rc}$ denote the whole flux linkage of stator and rotor windings, respectively.

R_s, R_r denote the stator and rotor resistance, respectively.

2. Flux equation

$$\begin{pmatrix} \Psi_{sabc} \\ \Psi_{rabc} \end{pmatrix} = \begin{pmatrix} [L_s] & [M_{sr}] \\ [M_{rs}] & [L_r] \end{pmatrix} \begin{pmatrix} i_{sabc} \\ i_{rabc} \end{pmatrix}.$$

In the equation

$$[L_s] = \begin{bmatrix} l_s & m_s & m_s \\ m_s & l_s & m_s \\ m_s & m_s & l_s \end{bmatrix} = l_s \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ -\frac{1}{2} & 1 & -\frac{1}{2} \\ -\frac{1}{2} & -\frac{1}{2} & 1 \end{bmatrix};$$

$$[L_r] = \begin{bmatrix} l_r & m_r & m_r \\ m_r & l_r & m_r \\ m_r & m_r & l_r \end{bmatrix} = l_r \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ -\frac{1}{2} & 1 & -\frac{1}{2} \\ -\frac{1}{2} & -\frac{1}{2} & 1 \end{bmatrix};$$

$$[M_{sr}] = M_{\max} \begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{4\pi}{3}\right) \\ \cos\left(\theta - \frac{4\pi}{3}\right) & \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) \\ \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{4\pi}{3}\right) & \cos(\theta) \end{bmatrix},$$

where

l_s and l_r are leakage-inductance of stator and rotor;

m_s and m_r are mutual-inductance of stator and rotor;

M_{sr} is the maximum value of mutual-inductance between stator and rotor;

θ denotes the position angle between stator and rotor windings.

B. The mathematical model of two phase coordinate system

A mathematical transformation is used to refer all variables to a common reference frame (related to the stator). The mathematical model of asynchronous motor under two-phase stationary coordinate can be deduced and acquired as follows:

1. Voltage equation

$$\begin{cases} U_{s\alpha} = R_s i_{s\alpha} + \dfrac{d\psi_{s\alpha}}{dt} \\ U_{s\beta} = R_s i_{s\beta} + \dfrac{d\psi_{s\beta}}{dt} \\ U_{r\alpha} = R_r i_{r\alpha} + \dfrac{d\psi_{r\alpha}}{dt} \\ U_{r\beta} = R_R i_{r\beta} + \dfrac{d\psi_{r\beta}}{dt}. \end{cases}$$

The voltages in this system are time variant.

2. Flux equation

$$\begin{cases} \psi_{s\alpha} = L_s i_{s\alpha} + M i_{r\alpha} \\ \psi_{s\beta} = L_s i_{s\beta} + M i_{r\beta} \\ \psi_{r\alpha} = L_r i_{r\alpha} + M i_{s\alpha} \\ \psi_{r\beta} = L_r i_{r\beta} + M i_{s\beta}. \end{cases}$$

Substitute flux equation into voltage equation we get:

$$\begin{cases} U_{s\alpha} = R_s i_{s\alpha} + L_s \dfrac{di_{s\alpha}}{dt} + M \dfrac{di_{r\alpha}}{dt} \\ U_{s\beta} = R_s i_{s\beta} + L_s \dfrac{di_{s\beta}}{dt} + M \dfrac{di_{r\beta}}{dt} \\ U_{r\alpha} = R_r i_{r\alpha} + L_r \dfrac{di_{r\alpha}}{dt} + M \dfrac{di_{s\alpha}}{dt} + \omega_r (L_r i_{r\beta} + M i_{s\beta}) \\ U_{r\beta} = R_r i_{r\beta} + L_r \dfrac{di_{r\beta}}{dt} + M \dfrac{di_{s\beta}}{dt} - \omega_r (L_r i_{r\alpha} + M i_{s\alpha}). \end{cases}$$

For convenience of calculation, we put the equations in the form:

$$[L]\frac{d[I]}{dt} = -[R][I] + [U],$$

where

$$[R] = \begin{bmatrix} R_s & 0 & 0 & 0 \\ 0 & R_s & 0 & 0 \\ 0 & \omega_r M & R_r & \omega_r L_r \\ -\omega_r M & 0 & -\omega_r L_r & R_r \end{bmatrix}, \quad [L] = \begin{bmatrix} L_s & 0 & M & 0 \\ 0 & L_s & 0 & M \\ M & 0 & L_r & 0 \\ 0 & M & 0 & L_r \end{bmatrix}$$

and

$$[I] = \begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \\ i_{r\alpha} \\ i_{r\beta} \end{bmatrix}, \quad [U] = \begin{bmatrix} U_{s\alpha} & U_{s\beta} & 0 & 0 \end{bmatrix}^t.$$

So we can write

$$\frac{d[I]}{dt} = -[L]^{-1}[R][I] + [L]^{-1}[U].$$

This expression represents the equivalent form of the state equation:

$$\frac{dX}{dt} = AX + BU$$

in which $[A] = -[L]^{-1}[R]$; $[B] = [L]^{-1}$, and $[R] = [R_1] + \omega_r[R_2]$,

where

$$[R_1] = \begin{bmatrix} R_s & 0 & 0 & 0 \\ 0 & R_s & 0 & 0 \\ 0 & 0 & R_r & 0 \\ 0 & 0 & 0 & R_r \end{bmatrix} \text{ and } [R_2] = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & M & 0 & L_r \\ -M & 0 & -L_r & 0 \end{bmatrix}.$$

3. Mechanical equation

In order to study the transient phenomena, we need to complete the model with the equation of motion and the torque equation as follows:

$$C_r = J\frac{d\Omega}{dt} + F\Omega, \quad C_s = \frac{3}{2}pM(i_{r\alpha} \cdot i_{s\beta} - i_{r\beta} \cdot i_{s\alpha}).$$

3. Mathematical Resolution

1. Stages for solution

We use Matlab to solve time dependant ordinary differential equations.

a. We create a derivative function. The time-dependant terms (voltage) are computed in this function,

b. We use function handles to pass the derivative function to the solver (for our work, we used ODE45).

The flowchart of the algorithm is showed below:

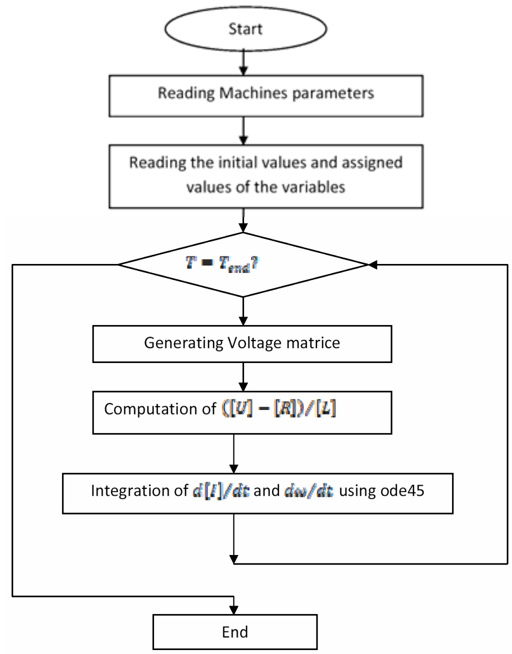

Figure 1. Flowchart of the proposed algorithm

4. Simulation and Analysis

For a user friendly interface, a Matlab GUI is created. Running the created GUI *M*-file from Matlab workspace will display the interactive window with input fields to be entered:

The induction motor chosen for the simulation studies has the following parameters:

The stator resistance $Rs = 1.150\Omega$; the rotor resistance $Rr = 1.144\Omega$; the stator inductance $Ls = 0.156H$; the rotor inductance $Lr = 0.156H$; the mutual inductance between stator and rotor $M = 0.143H$; inertia $J = 0.024\text{kg.m}^2$; the viscous friction coefficient $F = 0N.m.s$; the number of motor pole pairs $P = 2$; the frequency $f = 50\text{Hz}$; the voltage $U = 380\text{V}$.

1. Simulation

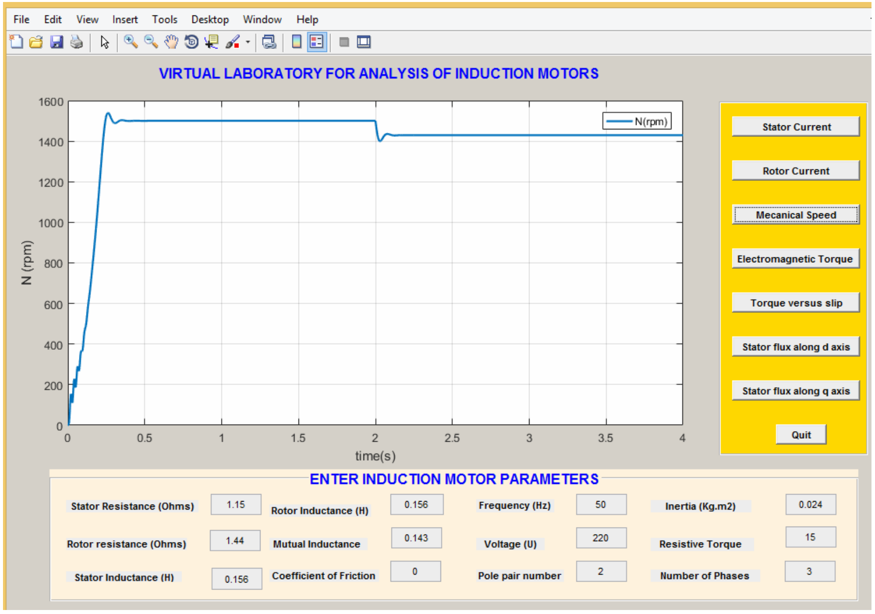

Figure 2. Time response of the speed.

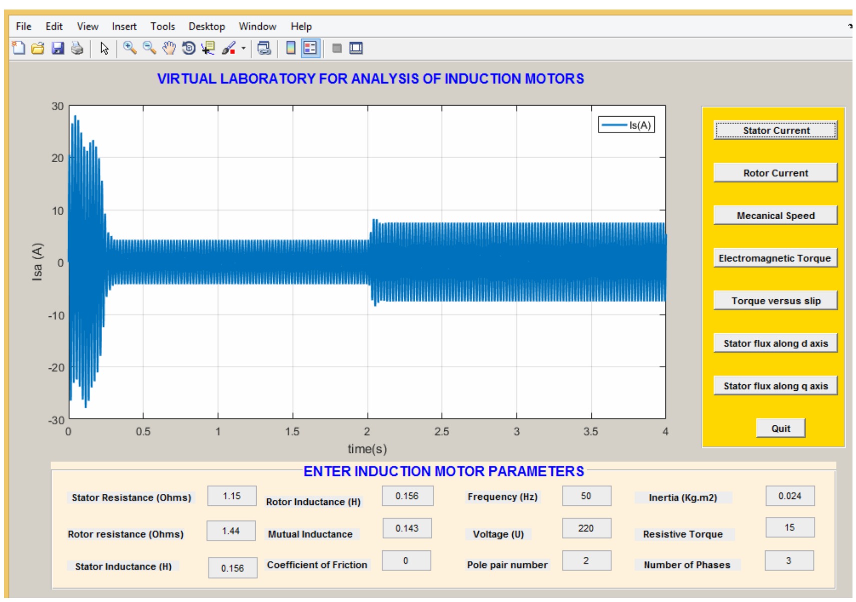

Figure 3. Time response of the stator current.

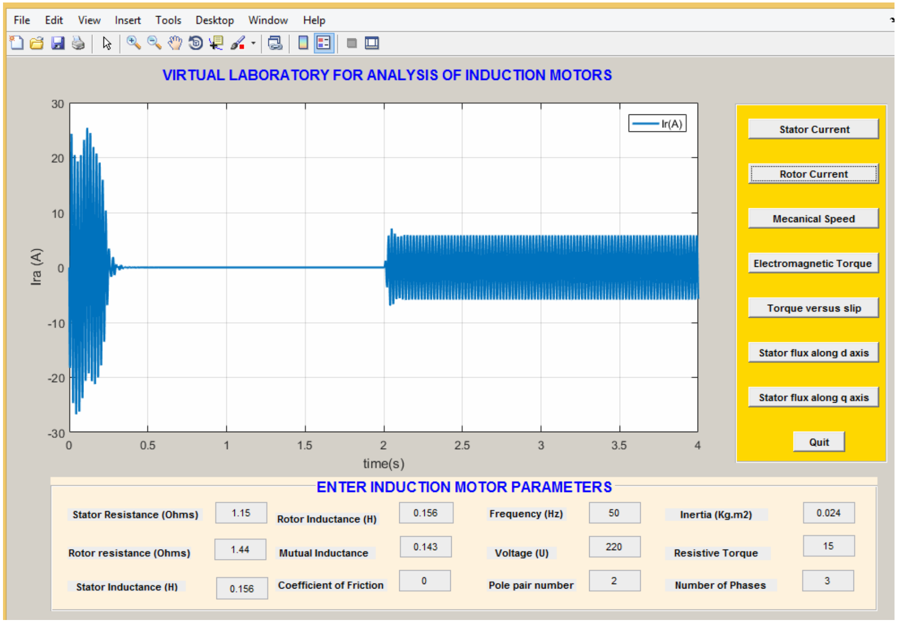

Figure 4. Time response of the rotor current.

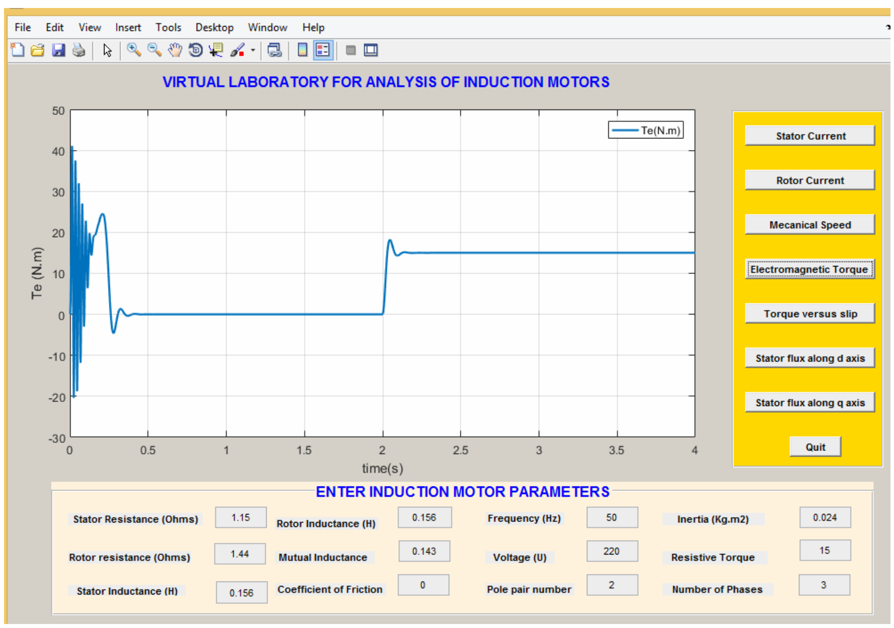

Figure 5. Time response of the magnetic torque.

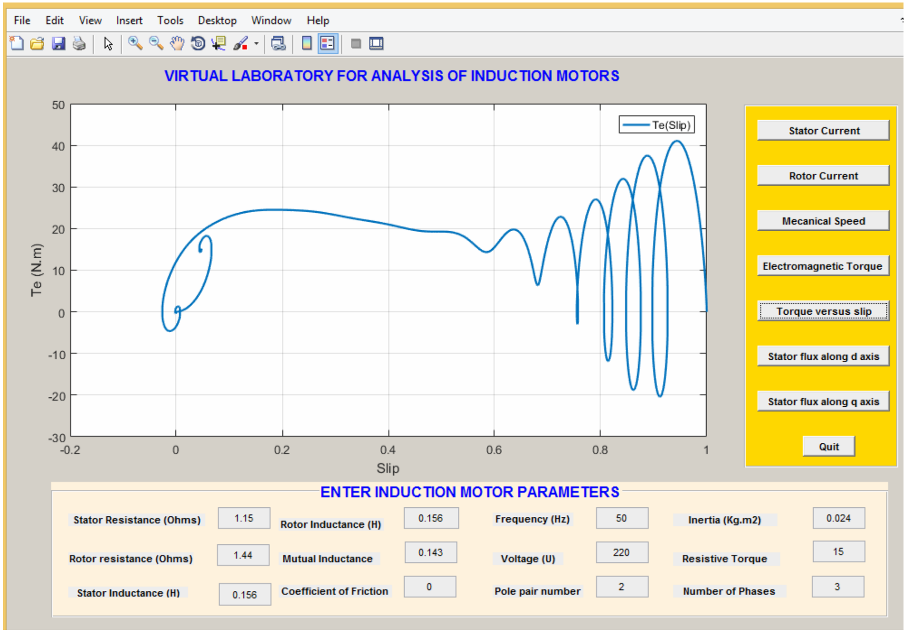

Figure 6. Variation of the magnetic torque as a function of the slip.

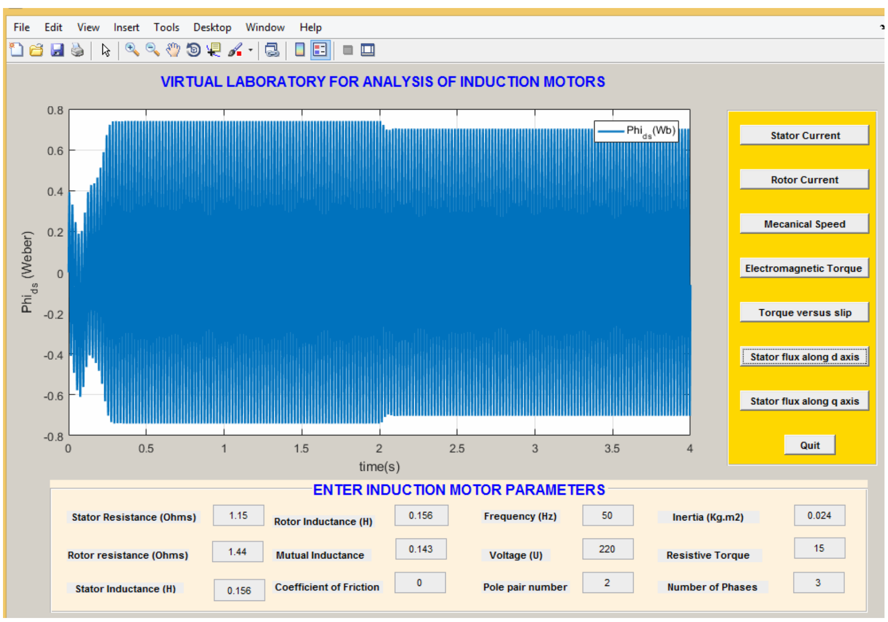

Figure 7. Time response of the stator flux along *d* axis.

2. Simulation analysis

The results obtained from the simulation are shown in Figures 2-7 with the evolution of the speed, the stator current, the rotor current and the electromagnetic torque. At no load, the speed is almost close to the synchronous speed. When the load increases at 2s, the resultant imbalance of the motor and load torques cause deceleration of the drive system to a rating value. This results in an increased motor torque which matches with that of the load ensuring stability of the operation. The evolution of the torque as shown on Figure 5 presents important oscillations in the first moments before stabilizing. These oscillations can be explained by the flux variations of the stator (Figure 7). The evolution of the torque as a function of the slip (Figure 6) is symptomatic of the behavior of induction motors which begins for a slip equal to one to stabilize close to zero. The result of simulation curves agrees well with the actual situation of running motors.

V. Conclusions

Analysis of an induction motor is done under the environment of Matlab GUI. The results of the simulation obtained agree with the results obtained when used a tool as SIMULINK [1]. The use of computer software for modeling and simulation of electrical machines behavior is important in teaching and learning as it helps to understand the machines performances. This virtual laboratory can be used for this purpose to assist in the understanding and testing of electrical machines in engineering degrees.

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