A Generalized Dynamic Model of Induction Motor using Simulink

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Abstract - This paper describes a generalized model of the three-phase induction motor and its computer simulation using MATLAB/SIMULINK having advantage that it does not require the compilation. Constructional details of various sub-models for the induction motor are given and their implementation in SIMULINK is outlined. For this purpose, the relevant equations are stated at the beginning, and then a generalized model of a three-phase induction motor is developed. This approach could be extended to other engineering systems.

Index Terms— mechanical sub model, modeling, speed, torque sub model.

I. INTRODUCTION

In the case of Matlab, the proper state equations should be obtained in order to describe the power conversion circuit. With the state equations, the circuit can be easily modeled by using the functional blocks, which are supported in Matlab Simulink. In particular, in Matlab, the various kinds of control algorithms can be easily implemented without using actual analog components. However, obtaining the state equation according to the circuit configuration is a cumbersome and time-consuming job. Whenever there is a minor change in the circuit configuration, new state equations should be obtained for describing the new circuit. Therefore, a simple method to model the power conversion circuits is highly desirable, which is not based on the state equations.

Thus the SIMULINK software of MATLAB for the dynamic modeling of the induction motor is used here. The main advantage of SIMULINK over other programming software is that, instead of compilation of program code, the simulation model is built up systematically by means of basic function blocks. Through a convenient graphical user interface (GUI), the function blocks can be created, linked and edited easily using menu commands. A set of machine differential equations can thus be modeled by interconnection of appropriate function blocks, each of which performing a specific mathematical operation. Programming efforts are drastically reduced and the debugging of errors is easy. Since SIMULINK is a model operation programmer, the simulation model can be easily developed by addition of new sub-models to cater for various control functions. As a sub-model the induction motor could be incorporated in a complete electric motor drive system.

II. ANALYSIS METHOD

The stator voltages of three phases are phase shifted by 120° each and are given by the equations

\[ V_{as} = |V| \sin(o \theta) \]
\[ V_{bs} = |V| \sin(o \theta - 2\pi / 3) \]
\[ V_{cs} = |V| \sin(o \theta + 2\pi / 3) \]

where \(|V|\) is the amplitude of the terminal voltage, \(v\) is the supply frequency and \(\theta\) is the initial phase angle.

Due to the voltage drop in the supply cable, the terminal voltage is given by Equation:

\[ |V| = E - R_c |I_c| \]

![Fig. 1: Power supply model](image-url)
The three-phase to two-axis voltage transformation means the conversion of coordinates from the three-phase stationary coordinate system to the dq rotating coordinate system. This transformation is made in two steps:

1) a transformation from the three-phase stationary coordinate system to the two-phase, so-called αβ, stationary coordinate system and

2) a transformation from the αβ stationary coordinate system to the dq rotating coordinate system.

The three-phase to two-axis voltage transformation can be achieved using the following Equation

\[
\begin{bmatrix}
V_{ds} \\
V_{qs}
\end{bmatrix} = \frac{2}{3} \begin{bmatrix}
1 & -1/2 & -1/2 \\
0 & \sqrt{3}/2 & -\sqrt{3}/2
\end{bmatrix} \begin{bmatrix}
V_{as} \\
V_{bs} \\
V_{cs}
\end{bmatrix}
\]

[A]

where Vas, Vbs, and Vcs are the three-phase stator voltages, while Vds and Vqs are the two-axis components of the stator voltage vector Vs.

In the two-axis stator reference frame, the current equation of an induction motor can be written as the differentiation operator, \(d/dt\), while \(L_s\), \(L_r\) and \(L_m\) are the stator and rotor leakage inductances and the magnetizing inductance, respectively. The sum of the stator leakage inductance and magnetizing inductance is called the \textit{stator inductance} and denoted by \(L_s\). Analogously, the \textit{rotor inductance}, \(L_r\) is defined as the sum of the rotor leakage inductance and magnetizing inductance. Thus,

\[
L_s = L_{ls} + L_m \\
L_r = L_{lr} + L_m
\]

The dynamic model allows derivation of the voltage-current equation of the induction motor. Using space vectors, the equation can be written as where

\[
\frac{di}{dt} = Av + Bi
\]

where

\[
i = \begin{bmatrix}
i_{ds} \\
i_{qs} \\
i_{dr} \\
i_{qr}
\end{bmatrix}
\]

\[
v = \begin{bmatrix}
v_{ds} \\
v_{qs} \\
v_{dr} \\
v_{qr}
\end{bmatrix}
\]

\[
L^2_{qr} = L_s L_r - L_m^2
\]

In the two-axis stator reference frame, the current equation of an induction motor can be written as

\[
\begin{bmatrix}
\frac{di}{dt} \\
\frac{dq}{dt}
\end{bmatrix} = \begin{bmatrix}
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0
\end{bmatrix} \begin{bmatrix}
R_s & 0 & 0 & 0 \\
0 & R_r & 0 & 0
\end{bmatrix} \begin{bmatrix}
i_{ds} \\
i_{qs} \\
i_{dr} \\
i_{qr}
\end{bmatrix} + \begin{bmatrix}
0 \\
0
\end{bmatrix}
\]

[B]
Matrix [A] in Equation (1) and matrix [B] can be implemented by the 'Matrix Gain' block of SIMULINK, while matrix [C] can be implemented by four 'Fcn' blocks of SIMULINK. In the electrical model, the three-phase voltage [Vas, Vbs, Vcs] is the input and the current vector [ids, iqs, idr, iqr] is the output vector.

The rotor voltage vector is normally zero because of the short-circuited cage rotor winding, i.e. Vdr=0 and Vqr=0.

### Fig.5 Matrix [B] implemented using 4 function blocks

**Torque sub-model of induction motor**

In the two-axis stator reference frame, the electromagnetic \( T \) is given by

\[
T = \frac{3PL_m}{4} (i_{ds}i_{qs} - i_{dr}i_{qr})
\]

### Fig.6 Torque sub-model

**Mechanical sub-model of induction motor**

From the torque balance equations and neglecting viscous friction, the rotor speed \( \omega_0 \) may be obtained as

\[
\omega_0 = \frac{1}{J} \int (T - T_L) dt
\]

where \( J \) is the moment of inertia of the rotor and load and \( T_L \) is the load torque.

### Fig.7 Rotor speed model

**Stator current output sub-model**

The stator current output sub-model is used to calculate the stator current amplitude according to the following equation

\[
|i| = \frac{2}{3} \sqrt{(i_{ds})^2 + (i_{qs})^2}
\]

### Fig.8 Stator current output sub-model

### III. PROPOSED MODEL OF INDUCTION MOTOR

### IV. SIMULATION RESULT AND DISCUSSION

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

- Type: three-phase, 3hp, 380V 4-pole, wye-connected, squirrel-cage induction motor
- \( R_s = 3.5 \) ohm, \( R_r = 3.16 \) ohm
- \( L_{ls} = 6.90732 \) mH, \( L_m = 0.26674 \) H
- \( L_{lr} = 6.81183 \)
- \( J = 0.4 \) kg m\(^2\)
- \( J_L = 0.4 \) kg m\(^2\), \( R_c = 0.2 \)

To illustrate the transient operation of the induction motor, a simulation study is demonstrated. At \( t = 0 \), the motor, previously de-energized and at standstill, is connected to a 380 V, 50 Hz three-phase supply through a cable. The load torque, \( T_L \), is constant at 11.9N.m.
Fig. show the results of computer simulation using the SIMULINK model. The results are similar to those obtained using the traditional simulation method involving differential equations.

Fig 10 a) Three-phase stator voltages

Fig 10.b) Two-axis components of the stator voltage

Fig 10 Simulation voltage waveforms of Induction motor

Fig 11.a) Current id and iqs

Fig 11.b) Current idr and iqr

Fig 11.c) Stator Current is

Fig 11 Simulation current waveforms of Induction motor

Fig 12. Rotor speed (rad/sec)
V. CONCLUSION

Thus simulation of three phase as well as two axis components of stator voltages and currents are obtained. The induction motor model developed may be used alone, as in the direct-on-line starting. It can be incorporated in an advanced motor drive system, e.g. field oriented control. It is also helpful in designing of induction motor according to the requirement.

VI. REFERENCES


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