Volts/Hz Control of Three Phase Induction Machine: Matlab Simulink

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Abstract: Due to the ratios of the power to the speed in the industrial applications, three phase induction motors are Broadly utilized. high reliability and low cost. A Space Vector pulse width modulation (SVPWM) are used for controlling scheme. The modified PI and V/F scalar controller are used to confirm the execution of both the speed and torque. A simple method control the magnitude of constant speed application is scalar control which is state on the controlling the values of voltage and frequency of the machine. The control of V/F implement in matlab/simulink and compared with the PI controller as a mathematical model of the system is described in the next sections. The simulation results provides high performance and smooth speed response under various dynamic operations.

Keywords: three phase, V/H, induction, motor

1. Introduction

Asynchronous machine or the induction motor has many advantages such as simple construction and high strength[1]. The name of induction refers to the principle of its operation Which in turn can be divided into two types depending on the type of input supply: single phase and three phase induction motor[2,3]. Or it can be divided according to the type of rotor: Squirrel cage and Slipring motor (wound motor)[2].

Most induction motors are stationary stator and a rotating rotor so are called rotary type[3]. The construction of stator is a hollow laminated cylinder (core) with pivot holes on its inner surface as shown in Figure(1a) fed by three-phase supply to the winding connected init, The electrical steel laminations are made the stator core and insulated from each other[4]. As shown in the Figure (1b and 1c) The cage rotor, is placed inside the stator with: laminated cylinder (core),outside axial slots,winding and shaft[4,5]. The next sections explain the mathematical and matlab models of three phase induction motor.
2. Mathematical Modelling of Induction Motor:

The dynamic equivalent circuit or d-q analysis and simulation of the induction motor are the most represented method which based on the rotating reference frame shown in Figure (2)[6,7]. All quantities referred to the stator.
The analysis and differential equations of the circuits in Figure 2 are as:

\[ V_{ds} = R_s i_{ds} + \frac{d\lambda_{ds}}{dt} - \omega_e \lambda_{qs} \] \hspace{1cm} (1)

\[ V_{qs} = R_s i_{qs} + \frac{d\lambda_{qs}}{dt} + \omega_e \lambda_{ds} \] \hspace{1cm} (2)

\[ V_{dr} = 0 = R_r i_{dr} + \frac{d\lambda_{dr}}{dt} - (\omega_e - \omega_r)\lambda_q \] \hspace{1cm} (3)

\[ V_{qr} = 0 = R_r i_{qr} + \frac{d\lambda_{qr}}{dt} + (\omega_e - \omega_r)\lambda_{dr} \] \hspace{1cm} (4)

Where:
- \(d\): direct axis.
- \(q\): quadrature axis.
- \(V_{ds}\): d-axis stator voltage.
- \(V_{qs}\): q-axis stator voltage.
- \(V_{dr}\): d-axis rotor voltage.
- \(V_{qr}\): q-axis rotor voltage.
- \(i_{ds}\): d-axis stator current.
- \(i_{qs}\): q-axis stator current.
- \(i_{dr}\): d-axis rotor current.
- \(i_{qr}\): q-axis rotor current.
- \(R_s\): resistance of stator.
- \(R_r\): the resistance of rotor.
- \(\omega_e\): angular velocity of the reference frame.
- \(\omega_r\): angular velocity of the rotor.
- and \(\lambda_{ds}, \lambda_{qs}, \lambda_{dr}, \lambda_{qr}\) are flux linkages.

Assumed that the analyzed of the induction motor is a squirrel cage machine, leading the voltage in equations (3) and (4) being zero. Substituting \(\omega_e = 0\) [8,9,10]. The flux linkages can be written as:

\[ \lambda_{ds} = L_s i_{ds} + L_{m} i_{dr} \] \hspace{1cm} (5)

\[ \lambda_{qs} = L_s i_{qs} + L_{m} i_{qr} \] \hspace{1cm} (6)

\[ \lambda_{dr} = L_s i_{dr} + L_{m} i_{ds} \] \hspace{1cm} (7)

\[ \lambda_{qr} = L_s i_{qr} + L_{m} i_{qs} \] \hspace{1cm} (8)

Where \(L_s\) is the stator selfinductance, \(L_r\) is the rotor selfinductance, \(L_m\) is the magnetizing inductance, \(L_{qr}\) is the stator-leakage inductance, and \(L_{dr}\) is the rotor-leakage inductance. The self-inductances in (5-8) can be expressed as[11,12]:

\[ L_s = L_m + L_{ds} \] \hspace{1cm} (9)

\[ L_r = L_m + L_{dr} \] \hspace{1cm} (10)

The rotational speed is called as synchronous speed as shown in equation (11) [13,14].

\[ N_s = \frac{120f}{P} \] \hspace{1cm} (11)

Where, \(f\) = supply frequency and \(P\) = poles number

The difference between the synchronous speed \(N_s\) and actual speed \(N_r\) of the rotor is called as slip as seen in equation (12)[14,15].

\[ S = \frac{N_s - N_r}{N_s} \] \hspace{1cm} (12)
3. Matlab Model

Matlab Dynamic Model of induction Motor can be divided in to the following submodels:

A. 3-2 Phase Conversion.
B. Fluxes & Currents.
C. Torque & Speed.
D. 2-3 Phase Conversion.

![Proposed overall model of induction motor.](image)

A. 3-2 phase Conversion.

The three-phase stator voltages of an induction machine can be expressed as:

\[ V_a = V_m \sin(\omega t) \]  
(13)

\[ V_b = V_m \sin(\omega t - \frac{2\pi}{3}) \]  
(14)

\[ V_c = V_m \sin(\omega t - \frac{4\pi}{3}) \]  
(15)

Where \( V_m \) is the terminal voltage, and \( \omega \) the supply frequency.

![Model for three phase power supply (stator voltages).](image)

(a) Figure 4. a: Model for three phase power supply (stator voltages).

(b) The shape of the output wave of modal in part (a)
The Clarke Transformation is needed to develop the three phase to two axis transformation of induction motor. The relationship between αβ and abc is as follows [16].

\[
\begin{bmatrix}
V_α \\
V_β \\
\end{bmatrix} = \frac{2}{3} \begin{bmatrix}
1 & -\frac{1}{2} & -\frac{1}{2} \\
\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \\
\end{bmatrix} \begin{bmatrix}
V_a \\
V_b \\
V_c \\
\end{bmatrix}
\]

(16)

**Figure 5.** 3-2 Phase Conversion.

**B. Fluxes & Currents:**

The fluxes & currents submodel shown in the figure below:

**Figure 6.** Submodel of Fluxes & Currents.
The flux linkage expressions of Squirrel cage Induction motor can be written as:

\[
\frac{d\lambda_{ds}}{dt} = V_{ds} - R_s i_{ds} \quad (17)
\]

\[
\frac{d\lambda_{qs}}{dt} = V_{qs} - R_s i_{qs} \quad (18)
\]

\[
\frac{d\lambda_{dr}}{dt} = -R_r i_{dr} - \omega_r \lambda_{qr} \quad (19)
\]

\[
\frac{d\lambda_{ds}}{dt} = -R_r i_{qr} + \omega_r \lambda_{dr} \quad (20)
\]

Equations (17) to (20) are used to develop sub models for obtaining \(\lambda_{ds}, \lambda_{qs}, \lambda_{dr},\) and \(\lambda_{qr}\). Figure (7) show the sub models which have been implemented.

Figure (7a) Submodel to find \(\lambda_{ds}\)

Figure (7b) Submodel to find \(\lambda_{dr}\)

Figure (7c) Submodel to find \(\lambda_{qs}\)
After making substitutions, currents can be expressed in terms of flux linkages as follows:

\[ i_{ds} = \frac{L_r}{L_s L_r - L_m^2} \lambda_{ds} - \frac{L_m L_r}{L_s L_r - L_m^2} \lambda_{dr} \]  
(21)

\[ i_{qs} = \frac{L_r}{L_q L_r - L_m^2} \lambda_{qs} - \frac{L_m L_r}{L_q L_r - L_m^2} \lambda_{qr} \]  
(22)

\[ i_{dr} = \frac{L_q L_r - L_m^2}{L_s L_r} \lambda_{dr} - \frac{L_m L_r}{L_s L_r} \lambda_{ds} \]  
(23)

\[ i_{qr} = \frac{L_q L_r - L_m^2}{L_s L_r} \lambda_{qr} - \frac{L_m L_r}{L_s L_r} \lambda_{qs} \]  
(24)

\[ \sigma = L_s L_r - L_m^2 \]

From equations (21) to (24), we find \( i_{ds}, i_{qs}, i_{dr} \) and \( i_{qr} \) are shown in following figures.

Figure (7d) Submodel to find \( \lambda_{qr} \)

Figure (8a) Submodel to find \( i_{ds} \)

Figure (8b) Submodel to find \( i_{qs} \)
Finally the electromagnetic torque produced by the motor is found by following equation.

\[ T_e = \frac{3}{2} \frac{P}{2} [\lambda_{ds}i_{qs} - \lambda_{qs}i_{ds}] \]  

(25)

And the speed of the motor can be calculated by the equation,

\[ \frac{d\omega_r}{dt} = \frac{P}{2J} [T_e - T_L] \]  

(26)

Where \( T_e \) is load torque, \( J \) is the rotor inertia and \( \omega_r \) is the rotor speed in rad/sec. The sub model finding is shown in figure (9).

C. Torque & Speed

Figure (8c) Submodel to find \( i_{dq} \)

Figure (8d) Submodel to find \( i_{qr} \)

Figure (9) Submodel for \( T_e \).
D.2-3 Phase Conversion:

Three phase current variables can be found by inverse clarke transformation as below:

\[
\begin{bmatrix}
I_a \\
I_b \\
I_c
\end{bmatrix} = \frac{2}{3} \begin{bmatrix}
\frac{2}{\sqrt{3}} & 1 & 0 \\
\frac{1}{\sqrt{3}} & -\frac{1}{2} & -\frac{1}{2} \\
-\frac{1}{\sqrt{3}} & -\frac{1}{2} & -\frac{1}{2}
\end{bmatrix} \begin{bmatrix}
I_x \\
I_y
\end{bmatrix}
\]  

(27)

Figure (11) 2-3 Phase Conversion

4. Simulink Results:

The 3-phase induction motor was tested in this simulated model. The results of the simulation are given with the following input Parameters in table 1:

**Table 1:** simulation with the input Parameters of 3-phase induction motor

| Parameter                  | Value         |
|----------------------------|---------------|
| Voltage                    | 220 V         |
| Frequency (f)              | 50 Hz         |
| StatorResistance (Rs)      | 603*10^2 ohm  |
| RotorResistance (Rr)       | 608*10^2 ohm  |
| StatorInductance (Ls)      | 4893*10^4 Henry |
| RotorInductance (Lr)       | 4893*10^4 Henry |
| MagnetizingInductance (Lm) | 4503*10^4 Henry |
| No. of Poles (P)           | 4             |
| Moment of Inertia (J)      | 6*10^2        |
| Friction (B)               | 0             |
At no-load case the Stator Currents In A, B & C Phases are shown in figure(12), the Electromagnetic Torque Developed figure(13) and the rotor speed in figure(14).

![Figure (12) the Stator Currents.](image1)

![Figure(13) Electromagnetic Torque](image2)

![Figure(14) rotor speed](image3)

The closed-loop (V/Hz) control of the speed of an AC induction motor are implemented based on the constant principle (every change in the voltage give a same change in the frequency resulting controlling the speed of motor at constant value) with good controlling performance of three phase induction motor at 1000 rpm speed and different load.as shown in the figure(15)
5. Conclusion

The overall control system and the modeled motor has been implemented in Matlab as shown in figures above. Where all the parameters have been tested, and show that the speed can be controlled by the proposed system.

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7. References

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