Advanced Engineering Days

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Speed control of three phase induction motor using Field Oriented Control technique

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Cite this study: Dhamo, D., & Panxhi, D. & Spahiu, A. & Bundo, J. (2023). Speed Control of three phase Induction Motor using Field Oriented Control technique. Advanced Engineering Days, 6, 183-186

Keywords
Induction motors
Field Oriented Control
SVPWM
Speed control
Vector control

Abstract

Induction motors are very common in industrial applications like pumps, blowers, compressors, fans, air-conditioning systems and others. The main reason for this popularity in the industry is because they are very simple, require minimum maintenance and manufacturing costs are low. This paper is aimed to give a contribution in speed control of a 250 W three phase induction motor in an application which requires a high performance of electric drive. The Field Oriented Control (FOC) technique is implemented in order to have the required performance. This algorithm has some advantages compared to scalar control such as improved dynamics, full torque control from zero to nominal speed, decoupled control of flux and torque, higher efficiency and others. This study is done in the Simulink/MATLAB environment where the model of speed control of 250 W three phase induction motor is created. Firstly, the fifth order model of the motor is built in a stationary frame. Secondly, the Field Oriented Control technique is implemented when are found also PI regulators coefficients. In the end, Space Vector Pulse Width Modulation (SVPWM) technique was built. This is the final step of FOC to determine the pulse width modulation signal for the inverter switches in order to generate the desired three phase voltage to the motor. Numerical simulations which are presented graphically at the end of this paper shows the advantages of using FOC.

Introduction

Before 1971, induction motors were run at constant speed. This speed was determined by number of pole pairs and frequency. The difficulty of controlling the speed of an induction motor consists in the nonlinearity relationship between the motor current and electromagnetic torque provided by the motor. This nonlinearity does not exist in the DC motor and therefore controlling the speed of the DC motor is a simple task. But, the reason why industrialists were not satisfied with this solution was because there are some disadvantages of DC motors compared to induction motors in terms of maintenance and costs [1-2].

Many studies are made in terms of speed control of induction motors because they can work for a long time without maintenance, they are robust and inexpensive. This type of motor does not need a supply current from outside the motor to create a magnetic field like a DC motor does. After much effort, F. Blasche in 1971 presented the first paper on Field Oriented Control (FOC) technique for speed control of an induction motor. Since that year, the technique was completely developed and nowadays Field Oriented Control technique is implemented for speed control of induction motors in applications which require high performance of electric drives [3-6].

The idea of FOC is to express the machine space vector model in the rotating dq reference frame which has a direct axis aligned with the flux-linkage vector [7]. In this paper the d axis is aligned with the rotor flux-linkage vector because it gives best results and a complete separation of the torque and flux control. This is the same as the DC motor.

Knowing that Simulink/MATLAB is powerful environment for simulating dynamics system, there is built the fifth order model of three phase induction motor and is implemented FOC technique. To determine the state switches of the inverter is used SVPWM technique to offer 15 % increase in the DC link voltage utilization and low output harmonic distortions compared with sinusoidal PWM.

Material and Method

The mathematical model of the induction motor which is built in Simulink is expressed on stator reference frame. The stator voltage is expressed:

$$U_{s\alpha} = R_s i_{s\alpha} + \frac{d\psi_{s\alpha}}{dt} \tag{1}$$

$$U_{s\beta} = R_s i_{s\beta} + \frac{d\psi_{s\beta}}{dt} \tag{2}$$

where:

$$\psi_{s\alpha} = L_s i_{s\alpha} + L_m i_{r\alpha} \tag{3}$$

$$\psi_{s\beta} = L_s i_{s\beta} + L_m i_{r\beta} \tag{4}$$

The rotor voltage is expressed:

$$U_{r\alpha} = 0 = R_r i_{r\alpha} + \frac{d\psi_{r\alpha}}{dt} + \omega_r \psi_{r\beta} \tag{5}$$

$$U_{r\beta} = 0 = R_r i_{r\beta} + \frac{d\psi_{r\beta}}{dt} - \omega_r \psi_{r\alpha} \tag{6}$$

where:

$$\psi_{r\alpha} = L_r i_{r\alpha} + L_m i_{s\alpha} \tag{7}$$

$$\psi_{r\beta} = L_r i_{r\beta} + L_m i_{s\beta} \tag{8}$$

The electromagnetic torque is:

$$T = \frac{3}{2} p \frac{L_m}{L_r} (\psi_{s\alpha} i_{s\beta} - \psi_{s\beta} i_{s\alpha}) \tag{9}$$

The fundamental equation of dynamics is:

$$\frac{d\omega_r}{dt} = \frac{p}{J}(T - T_{load} - \frac{B}{p}\omega_r) \tag{10}$$

Were, $U_{s\alpha}, U_{s\beta}, U_{r\alpha}, U_{r\beta}$ - stator and rotor voltages expressed on stator reference frame, $i_{s\alpha}, i_{s\beta}, i_{r\alpha}, i_{r\beta}$- stator and rotor currents expressed on stator reference frame, $\psi_{s\alpha}, \psi_{s\beta}, \psi_{r\alpha}, \psi_{r\beta}$ - stator and rotor fluxes expressed on stator reference frame, T- electromagnetic toque, T_{load} - load torque, ω_r- angular speed of rotor.

The parameters of induction motor are listed in Table 1.

Table 1. Parameters of induction motor

Parameters	**Symbol**	**Value**	**Unit**
Nominal power	P_n	250	W
Nominal stator voltage	V_n	230	V
Nominal frequency	f_n	50	Hz
Nominal current	I_n	0.9	A
Number of pole pairs	p	2	
Stator resistance	R_s	25.223	Ω
Rotor resistance	R_r	23.004	Ω
Stator inductance	L_s	0.534	H
Rotor inductance	L_r	0.534	H
Magnetizing inductance	L_m	0.487	H
Moment of inertia	J	0.000303	kgm^2
Viscous friction	B	0.000359	Nms

The FOC implemented in Simulink has the stator current of the q axis decoupled into the torque producing and the stator current of the d axis is decoupled into the rotor flux-producing:

$$\psi_{rd} = L_m i_{sd} \tag{11}$$

$$T = \frac{3}{2} p \frac{L_m}{L_r} \psi_{rd} i_{sq} \tag{12}$$

Figure 1 shows the complete model of speed control of induction motor using the FOC technique created in the Simulink/MATLAB environment.

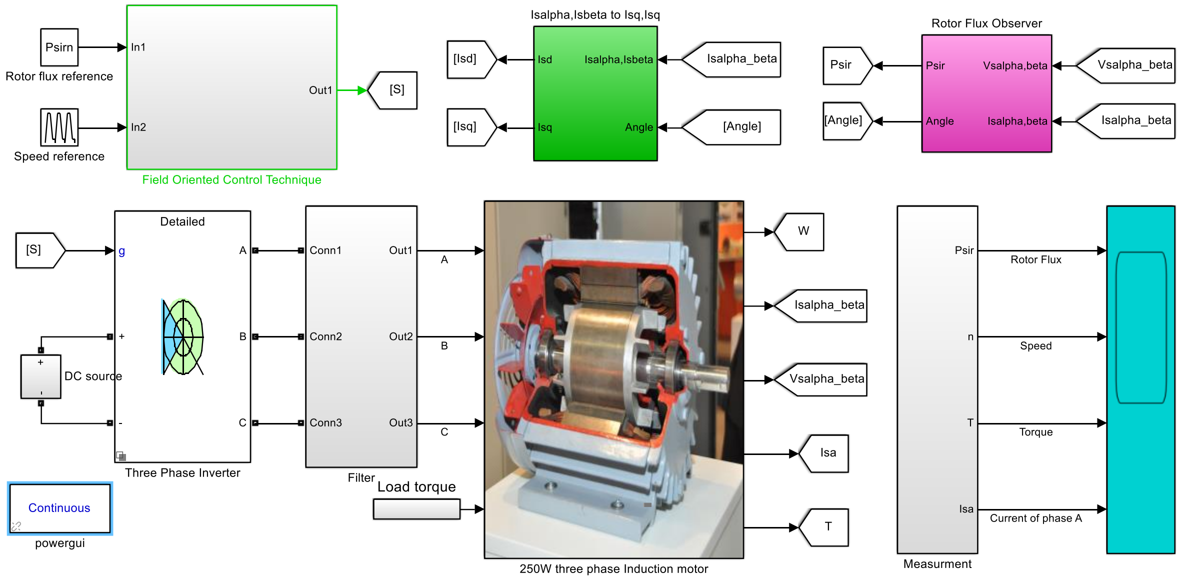

Figure 1. Speed control model of three phase induction motor using FOC technique

Results

The simulation of speed control is carried out using Simulink/MATLAB software.

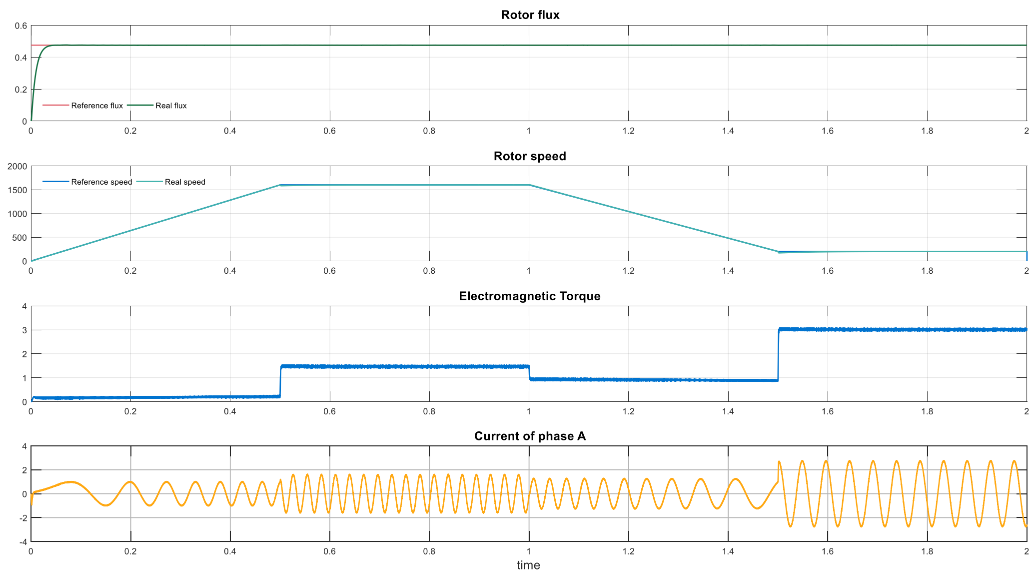

Figure 2. Results of speed control of 250W induction motor using Field Oriented Control technique

The values on Table 2 are the input of the model which is simulated and the result are shown in Figure 2.

Table 2. Reference speed and load torque applied on the motor

Time (s)	Reference speed (rpm)	Load torque (Nm)
0	0	0
0.5	1600	1.4
1	1600	1
1.5	200	3
2	200	3

Discussion

The simulation result shows that the reference value of the rotor flux matches the real value of the flux from time 0.0324 seconds until the end of the simulation. During this time, even though the reference speed and load torque have changed, the flux has remained the same as the reference value. The PI regulator coefficients inserted for rotor flux control are $k_P = 5.23$ and $k_I = 110.87$.

The reference value of the rotor speed is the same as the real speed throughout the simulation, except the cases when the induction motor has been in a transient process because of reference value and load torque have been changed. There is a little difference between the reference speed and the real speed in the transient process thanks to the use of FOC technique. This technique made it possible to change the q-axis current of the stator where the d-axis current has remained the same. With this situation, the flux remains constant and the electromagnetic moment changes quickly to reach the steady state operation. The PI regulator coefficients inserted for speed control are $k_P = 0.56$ and $k_I = 8.7$.

Electromagnetic torque and stator current are characterized by low values of ripples because of voltage signal that feeds the motor, which is not a pure sinusoid but contains high-order harmonics. Placing the filter in the model has smoothed out some of the harmonics but has not completely neutralized them.

Conclusion

In this paper the Field Oriented Control technique for speed control of 250 W three phase induction motor was implemented. The speed control model was created in Simulink/MATLAB when the numerical result was obtained.

Table 3. Quality indicators of speed response

Time (s)	Overshoot (%)	Undershoot (%)	Setting time (s)
0.5	0	1.06	0.07
1	0.18	0	0.04
1.5	0	15	0.15

Based on numerical result and quality indicators in Table 3, it comes to the conclusion that Field Oriented Control technique allows induction motor to operate smoothly over the full speed range. Another benefit of this technique is that it can deliver fast acceleration and deceleration of the induction motor, giving more accurate control.

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