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Vector Approach for PI Controller for Speed Control of 3-Ø Induction Motor Fed by PWM Inverter with Output LC Filter

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Abstract

This paper deals with the speed sensorless vector Control of an induction motor in a special case where the Output voltage of the PWM inverter is filtered by an LC filter. The Vector control strategy is formulated in such a way, that the stator current phasor, in the two-axis synchronously rotating reference frame, has two Components: magnetizing current component and Torque-producing current component. The Generated motor torque is the product of the two; the rotor speed tracks the commanded one smoothly and rapidly, without overshoot and with very negligible steady state error. Computer simulation is carried out to prove the claims.

Keywords: Vector control, Induction motor, LC filters, PWM.

Introduction

Electrical drives based on induction motors are the most widely used electromechanical systems in modern industry. Due to its reliability, ruggedness, simple mechanical structure, easy maintenance and relatively low cost, induction motors are attractive for use in a new generation of electrical transportation systems, such as cars, buses and trains. However, from the control point of view, they represent a complex multivariable nonlinear problem and constitute an important area of application for control theory. In fact, induction motors constitute a class of highly coupled and multivariable systems with two control inputs (stator voltages) and two output variables (rotor speed and rotor flux modulus), required to track desired reference signals [1][2]. Induction motors, which contain a cage, are very popular in variable-speed drives. They are simple, rugged, inexpensive and available at all power ratings. Progress in the field of power electronics and microelectronics enables the application of induction motors for high-performance drives, where traditionally only dc motors were applied. Thanks to Sophisticated control methods, ac induction drives offer the same control capabilities as high performance four-quadrant dc drives [1]. This drive application allows vector control of the ac Induction Motor running in a closed-speed loop with the speed / position sensor coupled to the shaft.

The generalized simulation model of the three-phase induction motor is based on two-axis theory of revolving frame transformation [8]. The model takes power source and load torque as inputs and gives speed and electromagnetic torque as outputs [9],[10].This control strategy exploits the fact that in a suitable rotating frame, aligned with the rotor flux space vector, the torque and flux dynamics are decoupled and the induction motor can be efficiently controlled using linear techniques. By keeping the magnetizing current component at a constant rated value, the motor torque is linearly proportional to the torque-producing component, which is quite similar to the control of a separately excited dc motor. Because the vector control is formulated in the two-axis coordinated frame, the Method requires on-line coordinate transformations that convert three-phase line currents into two-axis Representations and vice-versa [3]. The oscillation at the switching frequency causes additional losses and acoustic noise. This phenomenon can be eliminated by adding an LC filter to the output of the PWM inverter. In addition, the EMI shielding of the motor cable may be avoided if the voltage is nearly sinusoidal [6].Adding an LC filters to a variable speed drive makes the motor control more difficult. Usually, a simple volts-per-hertz control method is chosen. Better control performance is achieved by using vector control i.e., Field oriented control. However, there are only few publications that deal with the vector control of a motor fed through an LC filter [3], [7].

Induction Motor Model

The AC induction motor model is given by the space vector form of the voltage quotations. The system model defined in the stationary α,β-coordinate system attached to the stator is expressed by the following equations. Ideally, the motor model is symmetrical, with a linear magnetic circuit characteristic [8].

The stator voltage differential equations:

$$u_{s\alpha} = R_s i_{s\alpha} + \frac{d}{dt}\Psi_{s\alpha}$$

$$u_{s\beta} = R_s i_{s\beta} + \frac{d}{dt}\Psi_{s\beta} \qquad (1)$$

The rotor voltage differential equations:

$$u_{r\alpha} = 0 = R_r i_{r\alpha} + \frac{d}{dt}\Psi_{r\alpha} + \omega\Psi_{r\beta}$$

$$u_{r\beta} = 0 = R_r i_{r\beta} + \frac{d}{dt}\Psi_{r\beta} - \omega\Psi_{r\alpha} \qquad (2)$$

The stator and rotor flux linkages expressed in terms of the stator and rotor current space vectors:

$$\Psi_{s\alpha} = L_s i_{s\alpha} + L_m i_{r\alpha}$$

$$\Psi_{s\beta} = L_s i_{s\beta} + L_m i_{r\beta}$$

$$\Psi_{r\alpha} = L_r i_{r\alpha} + L_m i_{s\alpha}$$

$$\Psi_{r\beta} = L_r i_{r\beta} + L_m i_{s\beta} \qquad (3)$$

Electromagnetic torque expressed by utilizing space vector quantities

$$t_e = \frac{3}{2} p_p (\Psi_{s\alpha} i_{s\beta} - \Psi_{s\beta} i_{s\alpha}) \qquad (4)$$

Where:

α,β	=	Stator orthogonal coordinate system
$u_{s\alpha,\beta}$	=	Stator voltages [V]
$i_{s\alpha,\beta}$	=	Stator currents [A]
$u_{r\alpha,\beta}$	=	Rotor voltages [V]
$i_{r\alpha,\beta}$	=	Rotor currents [A]
$\Psi_{s\alpha,\beta}$	=	Stator magnetic fluxes [Vs]
$\Psi_{r\alpha,\beta}$	=	Rotor magnetic fluxes [Vs]
R_s	=	Stator phase resistance [Ohm]
R_r	=	Rotor phase resistance [Ohm]
L_s	=	Stator phase inductance [H]
L_r	=	Rotor phase inductance [H]
L_m	=	Mutual (stator to rotor) inductance [H]
ω / ω_s	=	Electrical rotor speed / synchronous speed [rad/s]
p_p	=	Number of pole pairs [-]
t_e	=	electromagnetic torque [Nm]

Simulink model

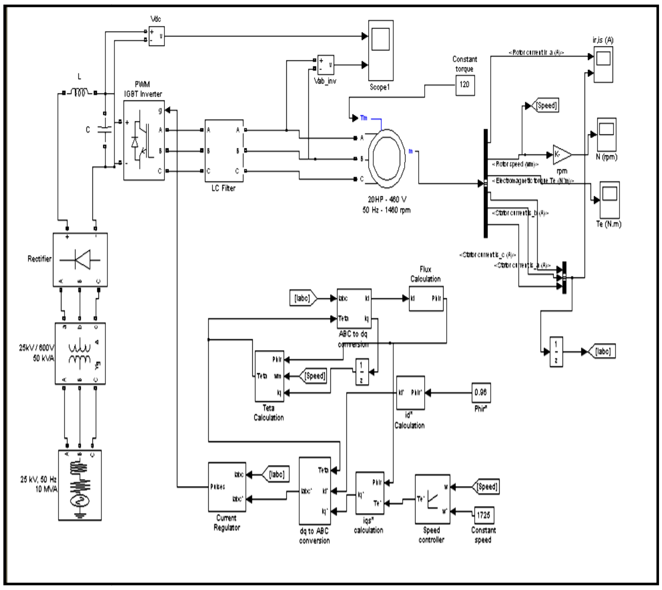


Figure 1: Vector control of 3Ø induction motor fed by a PWM inverter with output LC filter.

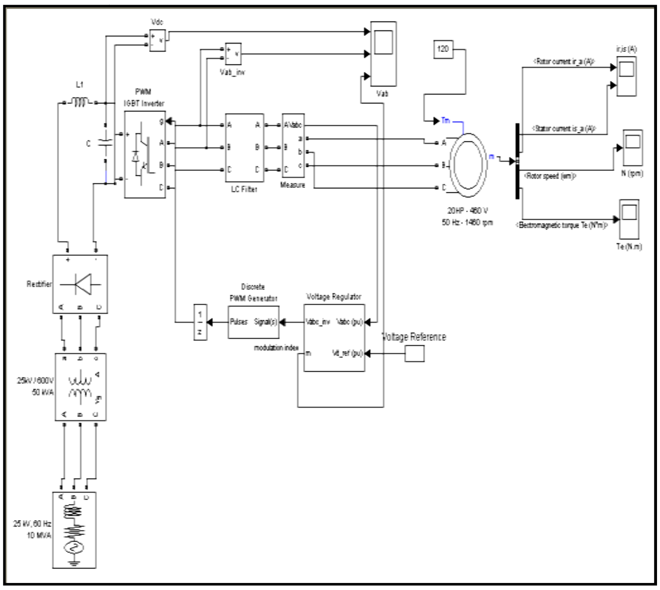


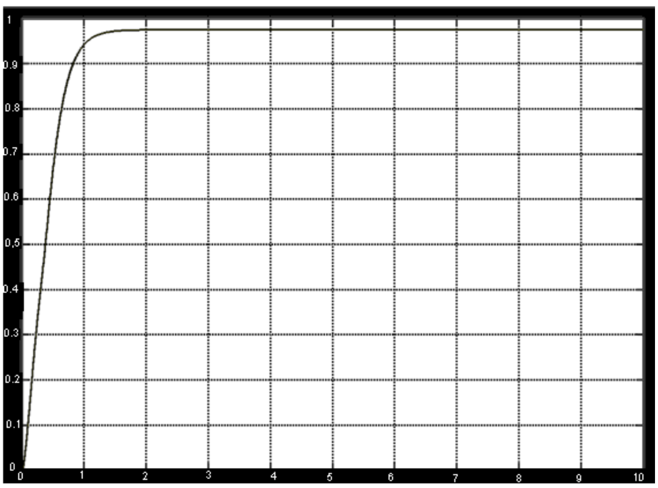
Figure 2: Simulink plant model with output LC filter with PI controller.

Circuit Description

The Induction motor is fed by a current controlled PWM inverter which is built using a universal bridge block. The IGBT block is simplified model of an IGBT pair where the forward voltage of the forced commutated device and diode are ignored. An LC filter is provided in ac line to reduce Harmonics of lower order. The motor drives a mechanical load characterized by inertia J,friction coefficient B and load torque T_L. The speed control loop uses a PI controller to produce the quadrature axis current reference iq* which controls motor Torque. The motor flux is controlled by direct-axis current reference id*.Block dq-ABC is used to convert id* and iq* in to current reference ia*, ib* and ic* for the current regulator. Two cases (PI & Vector control) each with three different loads i.e., constant load, step load& intermittent periodic load

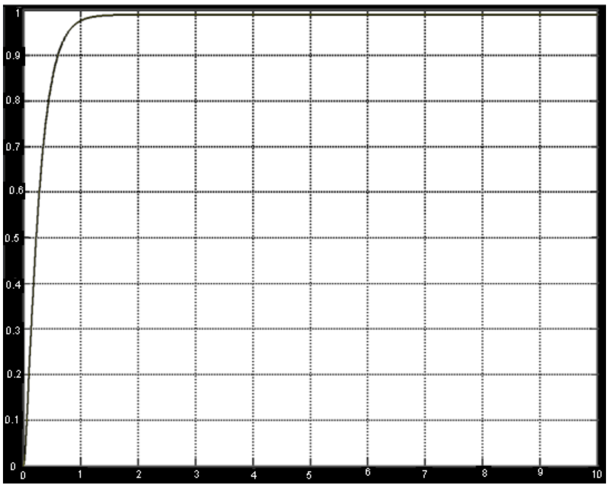
Results and Discussion

Start the simulation. Observe the motor current, voltage, and speed during the starting on the scope. At the end of the simulation time, the system has reached its steady-state. Response to a change in reference speed and load torque for initial conditions state vector `xInitial' to start with wm = 1460 rpm and TL = 120 N.m has been taken as the first case, the resultant waveform is as shown in fig3. Now, switch from the "Constant speed " and "Constant torque" blocks to the variable blocks. (Reference speed changed from 1460 to 1200 rpm at t = 3 s and load torque changed from 120 to 100 N.m at t= 3s). Restart the simulation and observe the drive response to successive changes in speed reference and load torque. In this work, the performance of 3-phase Induction Motor with varying load using conventional Pi and Vector control strategy is evaluated on the basis of settling time, maximum overshoot and steady state error. The simulation of the complete drive system is carried out based on three different loads(constant load, step load and Intermittent periodic loading) the result prove that vector control scheme is robust to variations in mechanical load torque. The speed control of the drive is simulated with conventional pi controller and compared with Vector control drive system and results tabulated in Table 1.



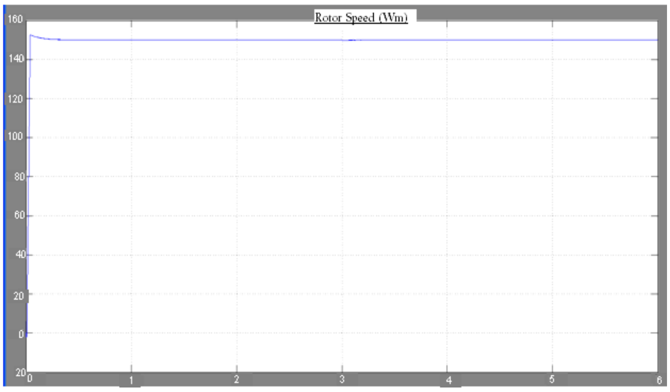
Time Vs Speed(p.u)

Figure 3: Response of Rotor Speed ω_m (p.u.) for Constant Loading (PI control).



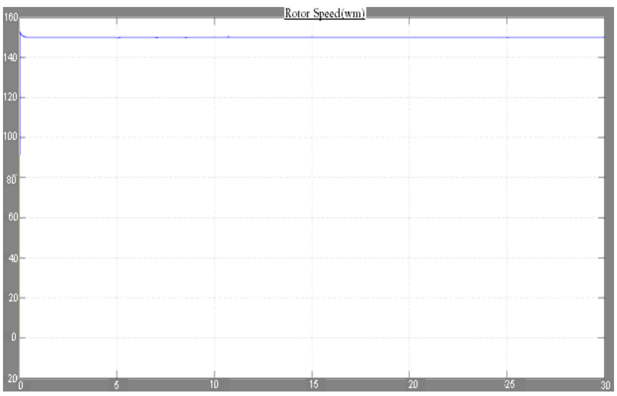
Time Vs Speed(p.u)

Figure 4: Response of Rotor speed ω_m(p.u.) for Step loading (PI control)



Time Vs Speed

Figure 5: Response of Rotor Speed for Step Loading (Vector control).



Time Vs Speed

Figure 6: Response of Rotor Speed for intermittent periodic loading (Vector Control).

Table 1: Comparison Performance Summary.

Cases		Settling time t_s (sec.)		Maximum Overshoot (rad/sec)		Steady state error (rad/sec)	
Case-1 PI Control	Case 1.1	1.9		0.96		0.04	
	Case 1.2	Before Step	After Step	Before Step	After Step	Before Step	After Step
		1.35	1.4	.98	.95	0.02	0.018
	Case 1.3	0.8		0.97		0.03	
Case-2 Vector Control	Case 2.1	0.5		2.346		0.115	
	Case 2.2	Before Step	After Step	Before Step	After Step	Before Step	After Step
		0.5	0.6	2.8	2.695	0.064	0.115
	Case 2.3	0.6		2.955		0.10	

Conclusion

By using Vector control of Induction motor in a closed loop and the inverter output voltage is filtered out by LC filter. Hence the control method makes it possible to add a filter to an existing drive, and no hardware modifications are needed in the frequency converter. The system is stable in wide speed and load ranges, including zero load. Simulation results show that the proposed speed vector control method works properly and the performance is comparable to that of a drive with Pi control. Smoothens out the ripples & Harmonics problems is solved by using LC filter, this has improved the supply current to be sinusoidal and in phase with the supply voltage.

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