IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

Speed Control of Induction Motor Drive Based on Indirect Vector Control Using PI Controller

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Abstract

The induction motors were characterized by complex, highly non-linear and time-varying dynamics, and hence their speed control is a challenging problem in the industry. The advent of vector control techniques has solved induction motor control problems. The vector control analysis of an induction motor allows the decoupled analysis where the torque and the flux components can be independently controlled (just as in dc motor). This makes the analysis easier than the per phase equivalent circuit. In indirect vector control scheme a current controlled voltage source inverter is considered, in which the stator phase currents serve as inputs, hence the stator dynamics can be neglected. In recent years, the field oriented control of induction motor drive is widely used in high performance drive system. It is due to its unique characteristics like high efficiency, good power factor and extremely rugged. This paper presents digital simulation of indirect vector controlled based speed control of induction motor drive by means of PI controller using MATLAB/SIMULINK.

Keywords: Induction motor, indirect vector control, MATLAB, speed control, modeling, field oriented control and PI controller

Introduction

Rotational industrial loads require operation at any one of a wide range of operating speeds. Such loads are generally termed as variable speed drives or adjustable speed drives. The variable speed drive systems are also an integral part of automation. There are three basic types of variable speed drive systems: electrical drives, hydraulic drives and finally mechanical drives [1]. AC motors exhibit highly coupled, nonlinear and multi variable structures as opposed to much simpler decoupled structures of separately excited DC motors [2]. Variable speed drive systems are essential in many industrial applications [3]. The AC motors have a number of advantages: light weight, inexpensive and have low maintenance compared with DC motors. The torque of the DC motors can be controlled by two independent orthogonal variables, stator current and rotor flux, where such a decoupling does not exist in induction motors [4]. Recent years have seen the evolution of a new control strategy for AC motors, called “vector control”, which has made a fundamental change in this picture of AC motor drives in regard to dynamic performance. Vector control makes it possible to control an AC motor in a manner similar to the control of a separately excited DC motor, and achieve the same quality of dynamic performance [5]. As for DC machines, torque control in AC machines is achieved by controlling the motor currents. However, in contrast to a DC machine, in AC machine, both the phase angle and the modulus of the current has to be controlled, or in other words, the current vector has to be controlled. This is the reason for the terminology “vector control” [6]. The indirect vector control uses an induction motor model to predict the voltage required to achieve a desired output torque [7]. The electromagnetic forces or torques developed in the driving motor tend to propagate motion of the drive system. This motion may be uniform if the linear velocity or the angular velocity is constant. Therefore the electrical drives good dynamic performance is mandatory so as to respond the changes in command speed and torques. The most commonly used controller for the speed control of Induction motor is Proportional plus Integral (PI) controller [8]. In this paper application of PI controller for intelligent speed control of Indirect Vector Controlled Induction Motor drive is investigated and implemented in MATLAB/SIMULINK environment. The simulation results obtained from Matlab/Simulink are analyzed and presented.

Mathematical Modeling Of Induction Motor

The electrical part of an induction motor is represented with a fourth-order state-space model and the mechanical part with a second-order system. All electrical parameters and variables are referred to the stator. Before going to analyze the any motor or generator it is very much important to obtain the machine in terms of equivalent mathematical equations. Traditional per phase equivalent circuit has been widely used in steady state analysis and design of induction motor, but it is not appreciated to predict the dynamic performance of the motor. The dynamic model of the induction motor is derived by using a two-phase motor in direct and quadrature axes. In a generalized two-ax reference frame, the electrical equations of an induction machine are,

$$\begin{aligned} v_{ds} &= R_s i_{ds} + \frac{d\lambda_{ds}}{dt} \\ v_{qs} &= R_s i_{qs} + \frac{d\lambda_{qs}}{dt} \\ 0 &= R_r i_{dr} + \omega_r \lambda_{qr} + \frac{d\lambda_{dr}}{dt} \\ 0 &= R_r i_{qr} - \omega_r \lambda_{dr} + \frac{d\lambda_{qr}}{dt} \end{aligned} \qquad (1)$$

The stator and rotor flux linkages in the stator reference frame are defined as,

$$\begin{aligned} \lambda_{qs} &= L_s i_{qs} + L_m i_{qr} \\ \lambda_{ds} &= L_s i_{ds} + L_m i_{dr} \\ \lambda_{qr} &= L_r i_{qr} + L_m i_{qs} \\ \lambda_{dr} &= L_r i_{dr} + L_m i_{ds} \end{aligned} \qquad (2)$$

The electromagnetic torque of the induction motor in stator reference frame is given by

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\left(\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds}\right) \qquad (3)$$

By using the above equations the induction motor model is developed in stator reference frame. The simulation of induction motor has been carried out in the Matlab-Simulink.

Principle of Indirect Vector Control

In this modeling the indirect vector control method is used. In the indirect vector control the unit vector signals are generated in feed forward manner, indirect vector control is very popular in industrial application. Fig.1 explains the fundamental principle of indirect vector control with the help of phasor diagram.

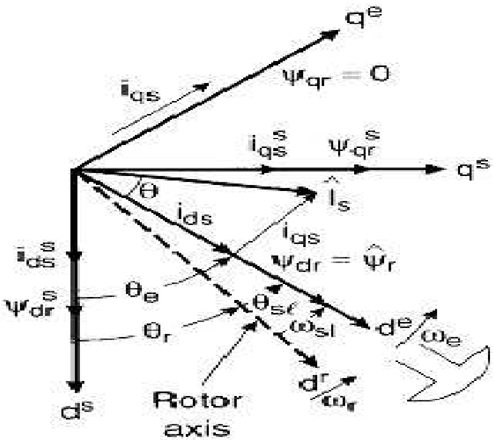


Fig.1 Phasor diagram explaining indirect vector control

The $d^s - q^s$ axes are fixed on the stator, and $d^r - q^r$ axes are fixed on the rotor moves at speed ω_r .Synchronously rotating axes $d^e - q^e$ is rotating ahead of the $d^r - q^r$ axes by the positive slip angle θ_{sl} corresponding to slip frequency ω_{sl}. Since the rotor pole is directed on the d_e axes and $\omega_e = \omega_r + \omega_{sl}$ we can write

$$\theta_e = \int \omega_e dt = \int (\omega_r + \omega_{sl}) dt = \theta_r + \theta_{sl} \qquad (4)$$

For decoupling control, we can now make a derivation of control equations of indirect vector control with the help of $d^e - q^e$ equivalent circuits. The circuit equations can be written as,

$$d\psi_{dr}/dt + R_r I_{dr} - (\omega_e - \omega_r)\psi_{qr} = 0 \qquad (5)$$

$$d\psi_{qr}/dt + R_r I_{qr} + (\omega_e - \omega_r)\psi_{qr} = 0 \qquad (6)$$

From the rotor flux equations the currents I_{dr}, I_{qr} equations as:

$$I_{dr} = 1/L_r \psi_{dr} - L_m/L_r I_{ds} \qquad (7)$$

$$I_{qr} = 1/L_r \psi_{qr} - L_m/L_r I_{qs} \qquad (8)$$

From the above equations we get,

$$d\psi_{dr}/dt + R_r/L_r \psi_{dr} - L_m/L_r R_r I_{ds} - \omega_{sl}\psi_{qr} = 0 \qquad (9)$$

$$d\psi_{qr}/dt + R_r/L_r \psi_{qr} - L_m/L_r R_r I_{qs} + \omega_{sl}\psi_{dr} = 0 \qquad (10)$$

For decoupling control, it is desirable that

$\psi_{qr} = 0$

Therefore, we have slip speed equation as

$$\omega_{sl} = \left(\frac{L_m}{\tau_r}\right)\left(\frac{i_{qs}}{\hat{\psi}_r}\right)$$

Where $\tau_r = \frac{L_r}{R_r}$ = rotor time constant,

The Torque is given by,

$$T_e = (3/2)(P/2)(\psi_{dr} I_{qr})$$

(11)

The field component of the stator current

$$I_{ds}^{*} = \hat{\psi}_r / L_m$$

The torque component of the stator current I_{qs}^{*}

$$I_{qs}^{*} = (2/3)(2/p)\,(L_r/L_m)\,(Te^{*}/\hat{\psi}_{r_{est}})$$

(12)

Where $\hat{\psi}_{r_{est}} = (L_m I_{ds}) / (1+\tau_r s)$

Therefore the slip speed

$$\omega_{sl}^{*} = L_m/\tau_r . (I_{qs}^{*}/\hat{\psi}_{r_{est}}) \quad (13)$$

These equations are used to implement the indirect vector control in SIMULINK.

PI Controller

In this project complete mathematical model of FOC induction motor is described and simulated in MATLAB. The performance of FOC drive with proportional plus integral (PI) controller are presented and analyzed. One common linear control strategy is proportional-integral (PI) control.

$$T = K_p e + K_i \int edt$$

(14)

If the gains of the controller exceed a certain value, the variations in the command torque become too high and will destabilize the system.

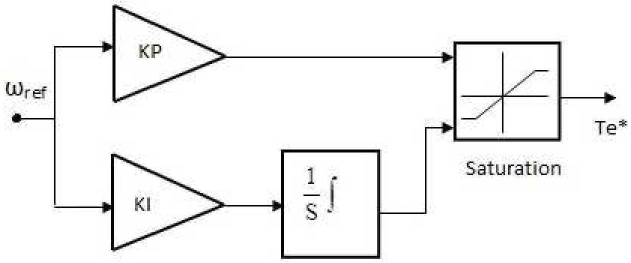
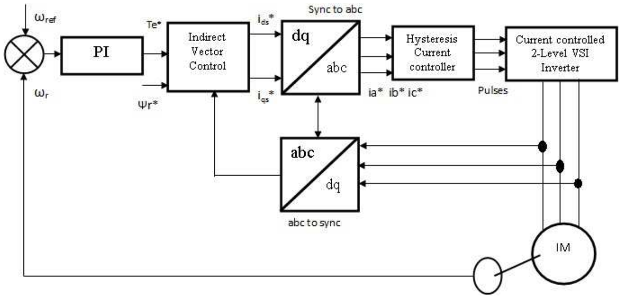


Fig.2 Design of PI controller

To overcome this problem we propose the use of a limiter ahead of the PI controller. This limiter causes the speed error to be maintained within the saturation limits provoking, when appropriately chosen, smooth variations in the command torque even when the PI controller gains are very high. The motor reaches the reference speed rapidly.

Indirect Vector Controlled Based Induction Motor Drive



Simulation Results and Discussion

To validate the proposed indirect vector controlled induction motor drive, a numerical simulation has been carried out by using Matlab/Simulink. The simulation parameters and specifications of induction motor 460V, 5 H.P, 3-Phase, 4-pole, 120 rpm, 50 Hz, R_s=0.087Ω, R_r=0.228Ω, L_m=0.037 H, L_s=0.008H, L_r=0.008H, J=0.0831Kg.m^2. Simulations studies are carried out in MATLAB environment and the results are verified for the speed response on full load condition.

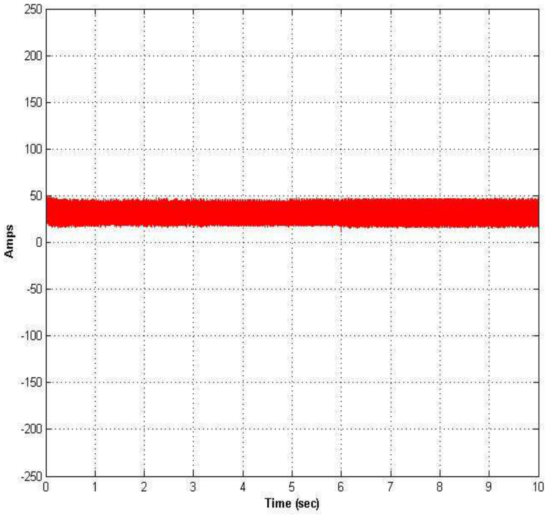


Fig.4 D-axis stator currents of induction motor

ISSN: 2277-9655
Impact Factor: 1.852

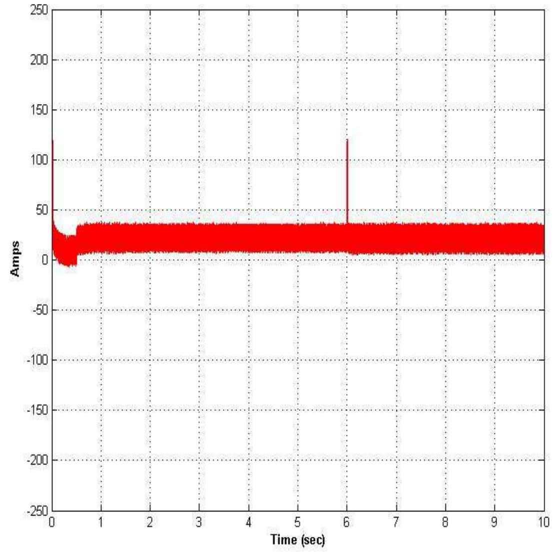


Fig.5 Q-Axis stator currents of induction motor

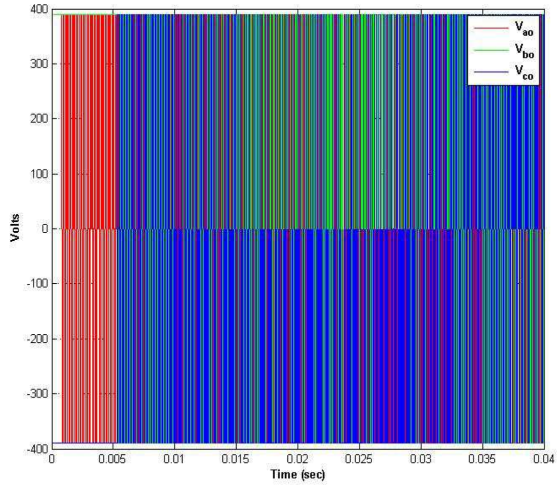


Fig.6 Active phase voltages of induction motor drive

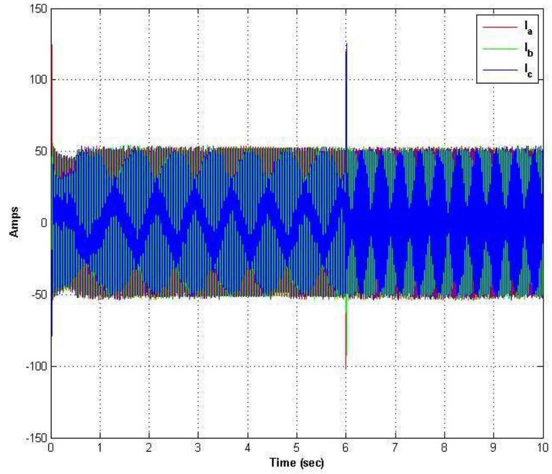


Fig.7 Active phase currents of induction motor drive

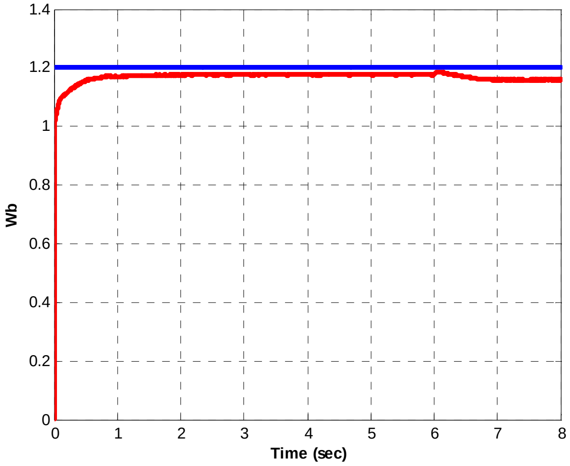


Fig.8 Reference and achieved rotor flux of induction motor drive for no load

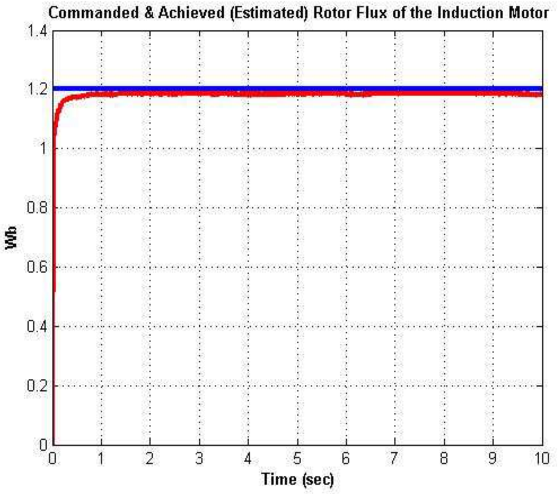


Fig.9 Reference and achieved rotor flux of induction motor drive for full load

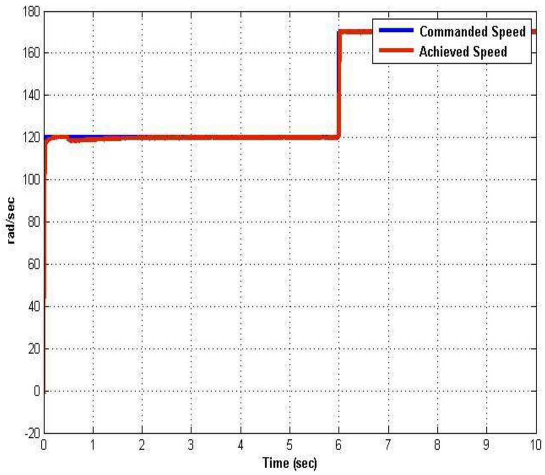


Fig.10 Commanded speed and achieved speed of induction motor drive

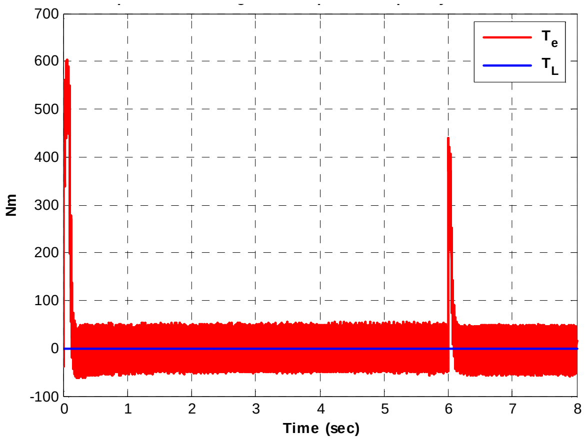


Fig.11 Load torque and electromagnetic torque of induction motor drive for no load

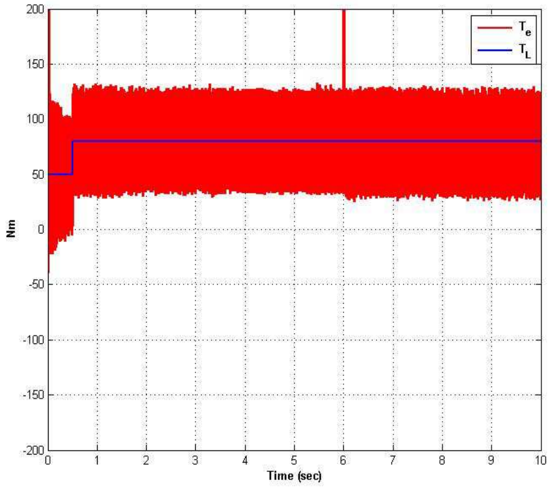


Fig.12 Load torque and electromagnetic torque of induction motor drive for full load

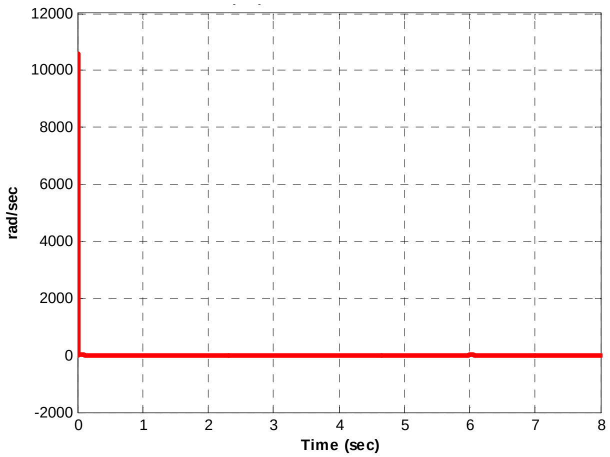


Fig.13 Slip speed of induction motor drive for full load

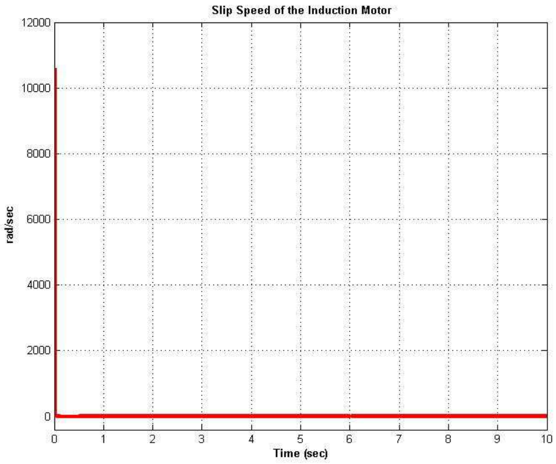


Fig.14 Slip speed of induction motor drive for full load

The d-axis current, q-axis current, active phase voltages and currents of induction motor drive are shown in Fig.4 to Fig.7. The reference and achieved rotor flux of induction motor drive for no-load and full load are shown in Fig. 8 and Fig.9 whereas the commanded and achieved speed are shown in Fig.10 from which the speed response of Induction motor is checked and presented. The load torque and electromagnetic torque of induction motor drive for no load and full load are shown in Fig.11 and Fig.12 from which we can observe that the response of drive using PI controller is superior. When we applied a full load the speed suddenly decreases and is not stable. The slip speed responses for no-load and full load condition are also shown in Fig.13 and Fig.14. So as to improve the speed performance then we use the PID controller. Because of which the steady state error is eliminated and the rise time is improved.

Conclusion

In this paper, the simulation model of indirect vector controlled Induction motor drive using PI controller has been developed. Various essential aspects of an Induction motor and indirect vector control were explored. The validity of the proposed method has been verified by the simulation by using MATLAB. Obtained results using developed simulation model are presented in the form of the waveforms for speed, torque and stator current using PI controller. From the simulation results we can conclude that the PI controller is better to improve the speed performance of induction motor.

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