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Performance Analysis of Indirect Vector Control of Induction Motor Drive Using Fuzzy Logic Controller

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Abstract

The induction motors were characterized by complex, highly non-linear and time-varying dynamics, and hence their promptness control is a stimulating problem in the engineering applications especially in high performance drive system. The fuzzy logic controller is found to be a very useful technique to obtain a high performance speed control. The present approach avoids the use of flux and speed sensor which increase the installation cost and mechanical robustness. The indirect vector controlled induction motor drives involve decoupling of the stator current in to torque and flux producing components. The comparative performance of Fuzzy Logic control technique has been presented and analyzed in this work. This paper based on the speed control of induction motor (IM) using Fuzzy controller with the use of indirect vector control technique using MATLAB.

Keywords: Induction motor, indirect vector control (IVC), MATLAB, speed control, modeling, field oriented control and Fuzzy logic control (FLC).

Introduction

Revolving industrial loads require operation at any one of a wide range of functional speeds. Such loads are generally termed as adjustable speed drives or adaptable speed drives. The adjustable speed drive systems are also an integral part of computerization. There are three basic types of adjustable 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]. Adjustable speed drive systems are essential in many industrial applications [3]. These problems can be solved by vector or field - oriented control. The invention of vector control in the beginning of 1970s , and the demonstration that an induction motor can be controlled like a separately exited dc motor . Because of dc machine -like performance, vector control is also known as decoupling, orthogonal, or Transvector control, Vector control is applicable to both induction and synchronous motor drives [4]-[5]. To implement conventional control, the model of the controlled system must be known. The usual method of computation of mathematical model of a system is difficult. When there are system parameter variations or environmental disturbance, the behavior of the system is not satisfactory. Usually classical control is used in electrical motor drives. The classical controller designed for high performance increases the complexity of the design and hence the cost [6]. fuzzy logic technique are quite different, and yet with unique capabilities useful in information processing by specifying mathematical relationships among numerous variables in a complex system, performing mappings with degree of imprecision, control of nonlinear system to a degree not possible with conventional linear systems [7]. Fuzzy logic is a technique to embody human-like thinking into a control system. A fuzzy controller can be designed to emulate human deductive thinking, that is, the process people use to infer conclusions from what they know. Fuzzy control has been primarily applied to the control of processes through fuzzy linguistic descriptions [8]. Then a conventional PI, fuzzy and neural controller for such drives lead to tracking and regulating performance simultaneously and then compared each other [9]-[10]. Fuzzy control is based on fuzzy logic, which provides an efficient method to handle in exact information as basis reasoning. With fuzzy logic it is possible to convert knowledge, which is expressed in an uncertain form, to an exact algorithm. In fuzzy control, the controller can be represented with linguistic if-then rules [11]. In this paper application of Fuzzy logic 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.

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. 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,

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

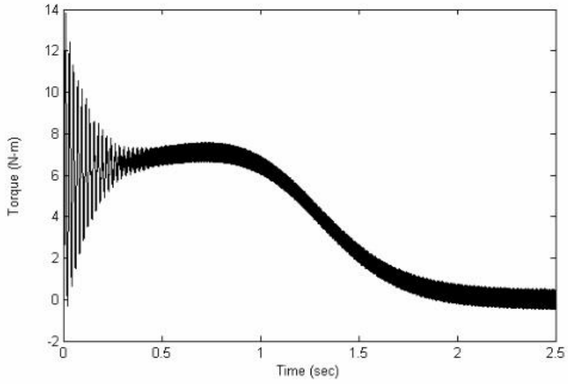
The stator and rotor flux linkages in the stator reference frame are defined as,

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

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.



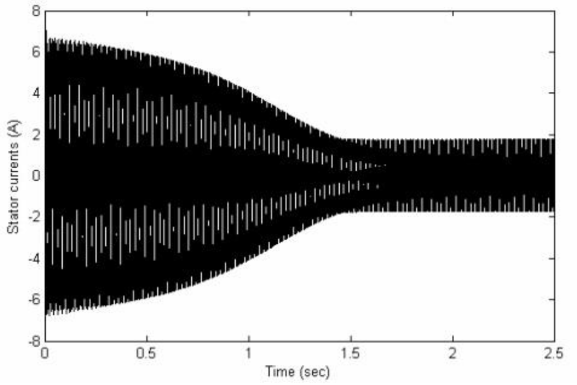


Fig.1. Responses of induction motor using d-q transformation (c) Electromagnetic torque (b) Stator currents.

In adjustable speed drives, the transient behavior of the induction motor has to be taken into consideration. Hence, to study the dynamic behavior of the induction motor under both transient and steady state conditions, accurate mathematical models of the induction motor have been developed in the stationary reference frame by using d-q modeling.

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.

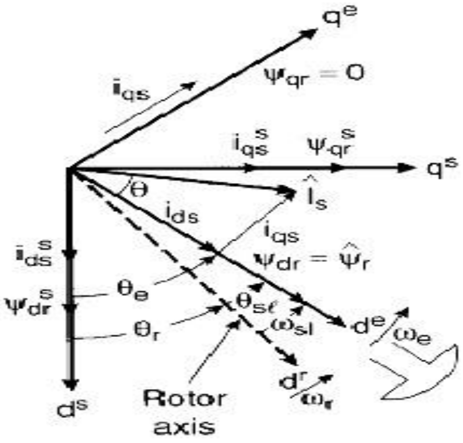


Fig.2. Phasor diagram explaining indirect vector control

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,

$$T_e = (3/2)(P/2)(\psi_{dr} I_{qr}) \qquad (11)$$

The field component of the stator current

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

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

$$I^{*}_{qs} = (2/3)(2/p)\,(L_r/L_m)\,(Te^{*}/\,\hat{\psi}_{r_{est}}) \qquad (12)$$

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

Therefore the slip speed

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

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

Fuzzy Logic Controller

Fuzzy logic is a technique to embody human-like thinking into a control system. A fuzzy controller can be designed to emulate human deductive thinking, that is, the process people use to infer conclusions from what they know. Fuzzy control has been primarily applied to the control of processes through fuzzy linguistic descriptions. The term 'fuzzy' in fuzzy logic was first coined in 1965 by Professor Lofti Zadeh, then Chair of UC Berkeley's Electrical Engineering Department. He used the term to describe multivalued sets in his seminal paper,' Fuzzy Sets'. Before starting the detailed procedure of the FLC design, we have to choose the variables. A fuzzy control system is designed to control a process, and thus it is needed to determine state variables and control variables of the process. The state variables become input variables of the fuzzy control system, and the control variables become output variables. Selection of the variables depends on expert knowledge on the process.

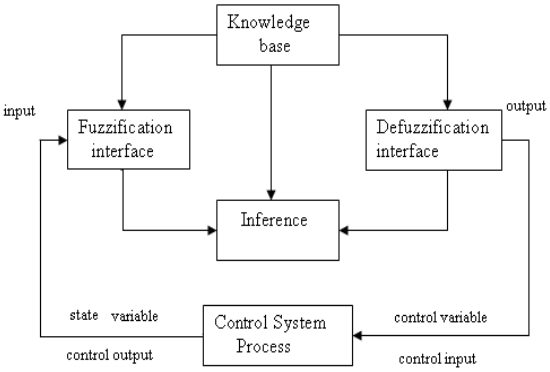
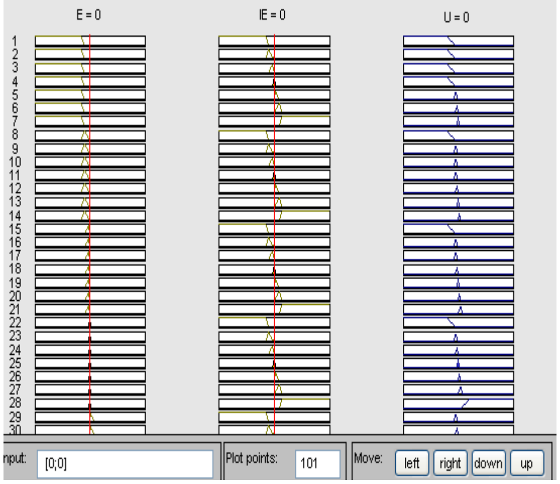


Fig.3. Structure of Fuzzy Logic Controller



Input: [0;0]
Plot points: 101

Fig.4. Fuzzy logic rule viewer

In particular, variables such as state, state error, state error deviation, and state error integral are often used. In the fuzzification component, there are three main issues to be considered: scale mapping of input data, strategy for noise and selection of fuzzification functions. The following is the fuzzy logic rule viewer shown in fig.

Proposed Indirect Vector Controlled Based Induction Motor Drive

Fig.5 shows indirect vector controlled based induction motor drive based on fuzzy logic controller. It consists of a slip frequency calculation, Inverter, Voltage and Current sensing Elements and integrator of error speed signal. The Vector control techniques have made possible the application of induction motors for high-performance applications, where traditionally only DC drives were applied.

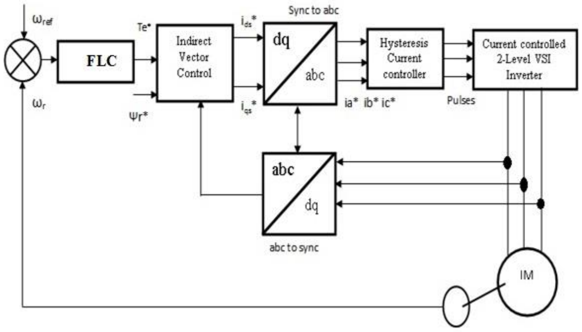


Fig.5. Block diagram of proposed indirect vector controlled based induction motor drive

As in the DC motor, torque control of induction motor is achieved by controlling the torque current component and flux current component independently. In the indirect vector control method, the rotor field angle and thus the unit vectors are indirectly obtained by summation of the rotor speed and slip frequency. The indirect vector control method is essentially same as the direct vector control except that the rotor angle θ_e is generated in an indirect manner using the measured speed ω_r and the slip speed ω_{sl}.

Results

In this the machine is stepped up to speed using the speed reference after that which is subjected to a step change, and also load disturbance. Slightly small disturbance of currents occurred at initial startup of motor from standstill, at step change also the current response changes largely but within short time it responds to a previous position, and at the sudden load disturbance there is a slight change in current. The response of various parameters of proposed indirect vector controlled induction motor drive using fuzzy logic controller is shown in Fig.6 to Fig 14. At the initial startup of the motor from standstill, Drive with Fuzzy controller torque response has a larger peak transient and d- axis, slip speed and rotor flux are constant throughout simulation period.

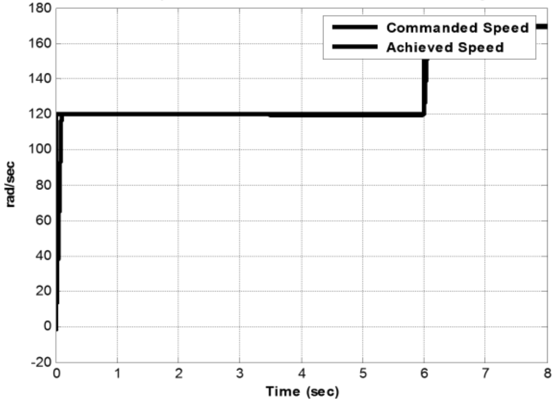


Fig.6. The commanded& achieved speed of the induction motor (wc&we) with load

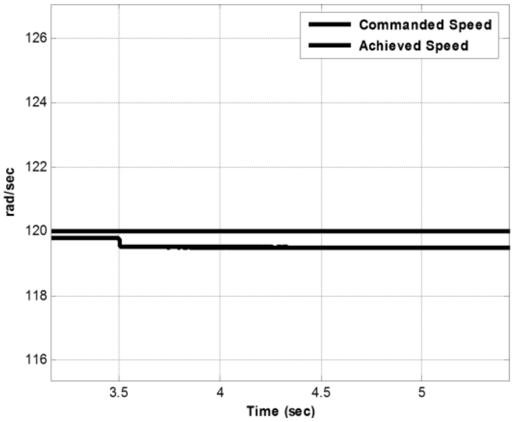


Fig. 7. The commanded& achieved speed of the induction motor (wc&we) with load disturbance at 3.5 sec.

From the above discursion drive performance with fuzzy controller enhanced when compared to the PI controller. Drive with PI controller speed response has peak over shoot, but in case of fuzzy controller speed response quickly and smoothly responds to the programmable speed reference, but at the starting of motor there is a larger transients. Drive with PI controller speed response has peak over shoot, but in case of fuzzy controller speed response quickly and smoothly responds to the programmable speed reference, but at the starting of motor there is a larger transients.

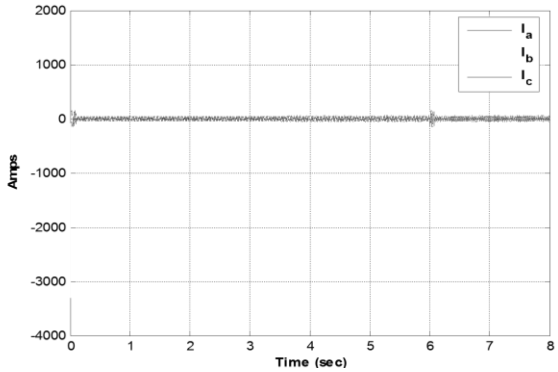


Fig.8. Achieved phase currents (ia,ib,ic) of induction motor with load

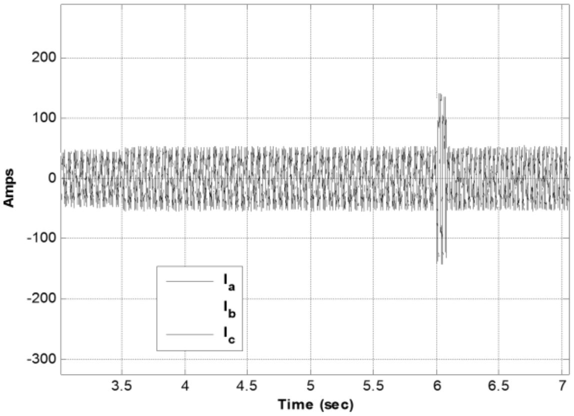


Fig.9. Achieved phase currents (ia,ib,ic) of induction motor with load disturbance at 3.5 sec.

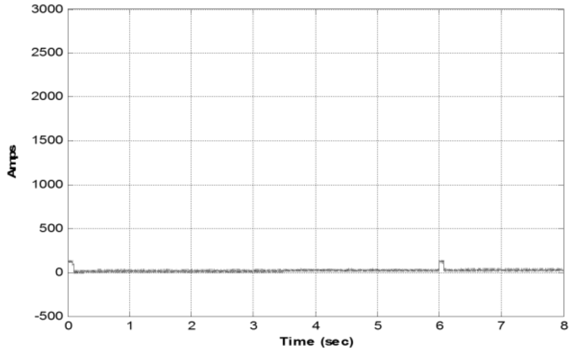


Fig.10. q-axis current (syn. frame) of induction motor[iqs^e] with load

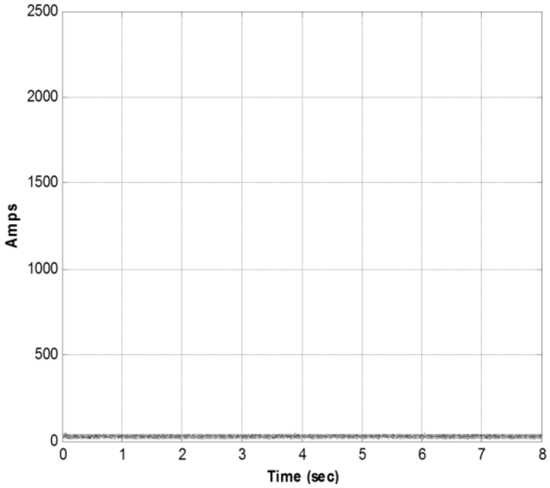


Fig.11. d-axes current (synchronous frame)of induction motor[ids^e] with load

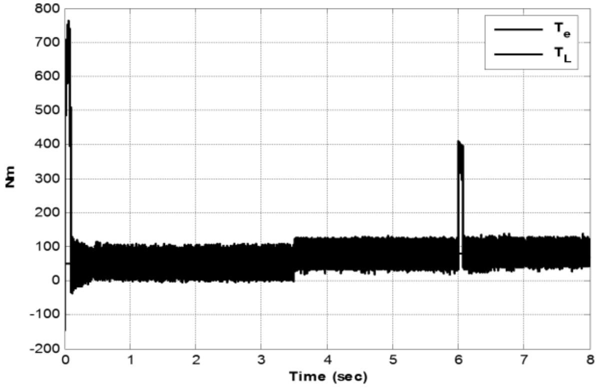


Fig.12. Load torque (T_L) and electromagnetic torque (Te) developed by the motor with load

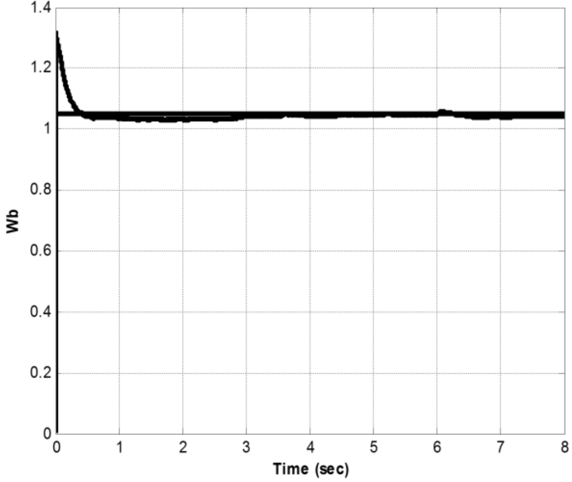


Fig.13. Siyr*&siyr_est(commanded& achieved rotor fluxes) with load

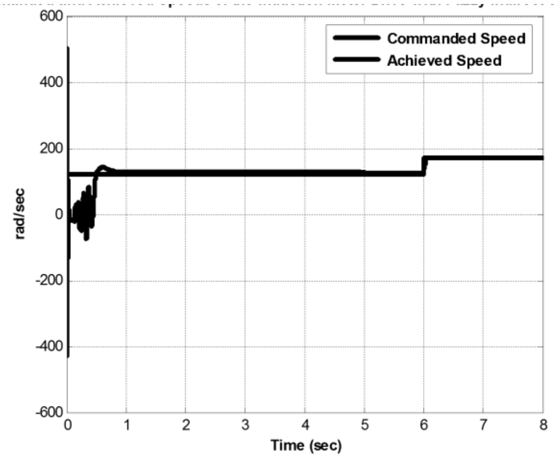


Fig.14. The commanded& achieved speed of the induction motor (wc&we) with no load.

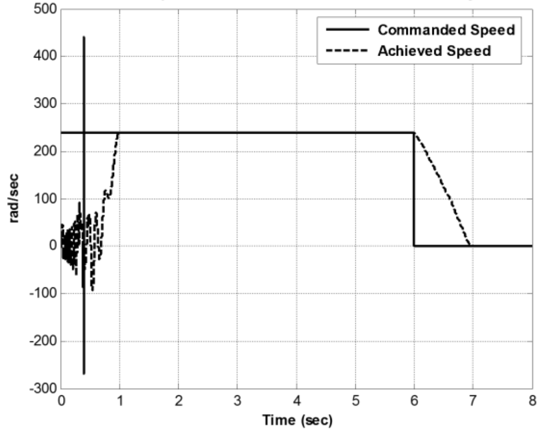


Fig.15. The commanded& achieved speed of the induction motor (wc&we)

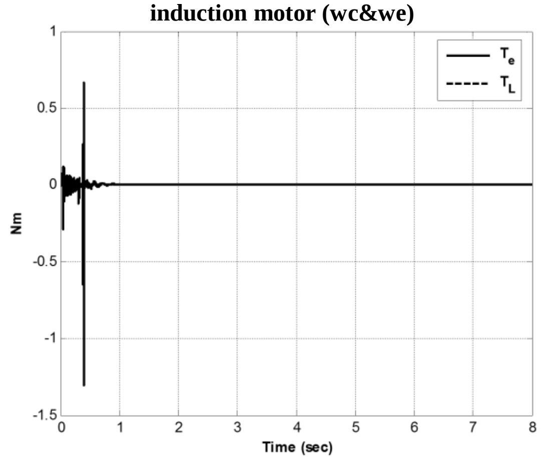


Fig.16. Load torque (T_L) and electromagnetic torque (Te) developed by the motor

For speed reversal condition speed and phase sequence of current reversed but at the time of starting there is a larger disturbance as shown in Fig.15 and Fig.16.

Conclusion

To design the indirect vector control of induction motor drive, we derived indirect vector control model equations from vector control concept by using the dynamic d-q model of induction motor in synchronously rotating reference frame. Finally we have implemented the model by using the Fuzzy speed controller in simulink. Then after taken particular industrial Induction motor parameters and applied to our model. So Fuzzy controller results are better than the PI controller, the efficiency and reliability of proposed speed controller is good, Fast and precise closed-loop control is possible, It also provides better torque response and good performance. Indirect vector control Drive performance enhanced with Fuzzy controller, when compared to PI controller.

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