A Complete Dynamic Model for a PWM VSI-fed rotor flux oriented vector controlled Induction Motor Drive using SIMULINK

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Abstract- *This paper describes the validation of a complete dynamic model of the induction motor, with an indirect rotor flux oriented vector controller using SIMULINK. This model is developed, with a view to studying the effects of parameter variations in a vector controlled drive, and to develop parameter estimators using Artificial Neural Networks and Fuzzy/Fuzzy Neural principles. The SIMULINK model developed, simulates the dynamic model of three phase induction motor together with the inverter and the total control system.*

1. Introduction

Simulation of a three phase induction motor and its associated vector control schemes are well documented in the literature[2,3]. However, these models lack the ability to benefit from the power of development systems which allow interfacing to ANN and Fuzzy controller based modules into these models. Available dynamic models are based on the Pspice or Simnon or some other platform which do not have development capabilities for ANN and fuzzy systems. Available SIMULINK based models do include the dynamic of the inverter or the current controller which are supplied from pulse-width modulated inverters.

In recent years, ANN and fuzzy systems are becoming increasingly important in estimating machine parameters and incorporating these in high-performance controllers for induction motor drive. The incorporation of the rotor time constant estimator in a rotor flux oriented drive is an example. Traditional model based approaches for parameter identification of the induction motor are difficult to adopt since the techniques, which are based on linear systems do not apply well for the highly non linear induction motor. Consequently, great difficulties are faced especially when extensive changes in parameters are to be tracked. These problems are minimized to a great extent, when a complete model is available in SIMULINK. This then allows the considerable power of Matlab based development tools for ANN and fuzzy systems to be used. The work reported in this paper was carried out with a view to meet this goal. The complete model for separate functional blocks are developed and integrated together, easing the debugging process in tracking the changes in the parameter.

2. Modeling of the Drive

To study the effects of parameter variations in an induction motor drive running under rotor flux orientation, with a fuzzy, fuzzy-neural or an artificial neural networks based estimators, and to develop a suitable controller, extensive simulations are necessary in that environment. Matlab Neural Network Toolbox and FuzzyTech softwares[6,7] were found to have adequate capacity to develop these types of models. The models developed with SIMULINK possess very good interface and debugging options with the above toolboxes. There exist, as in [1,5], SIMULINK models which assume ideal supplies. These models ignore the inverter and, and therefore is not suitable for a VSI fed induction motor drive.

The dynamic model of an induction motor in a stationary frame of reference, as shown in fig 1.0 can be written as in (1) – (10)

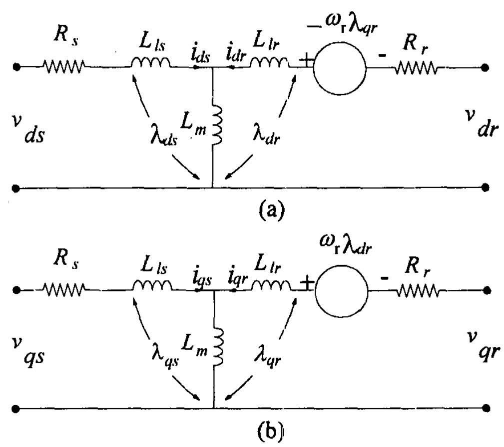

Fig 1. dq equivalent circuit of induction motor in stationary reference frame. (a) d-axis circuit (b) q-axis circuit.

where the stator currents i^s_{ds} , i^s_{qs}, stator voltages v^s_{ds}, v^s_{qs}, rotor currents i^r_{dr} , i^r_{qr} and rotor voltages v^r_{dr}, v^r_{qr}, are in the stator reference frame.

$$v^s_{ds} = r_s i^s_{ds} + \frac{d}{dt}\left(\lambda^s_{ds}\right) \tag{1}$$

$$v^s_{qs} = r_s i^s_{qs} + \frac{d}{dt}\left(\lambda^s_{qs}\right) \tag{2}$$

$$0 = v^r_{dr} = r_r i^r_{dr} + \omega_r \lambda^s_{dr} + \frac{d}{dt}\left(\lambda^s_{dr}\right) \tag{3}$$

$$0 = v^r_{qr} = r_r i^r_{qr} + \omega_r \lambda^s_{qr} + \frac{d}{dt}\left(\lambda^s_{qr}\right) \tag{4}$$

$$\lambda^s_{ds} = L_{ls} i^s_{ds} + L_m (i^s_{ds} + i^s_{dr}) \tag{5}$$

$$\lambda^s_{qs} = L_{ls} i^s_{qs} + L_m (i^s_{qs} + i^s_{qr}) \tag{6}$$

$$\lambda^s_{dr} = L_{ls} i^s_{dr} + L_m (i^s_{ds} + i^s_{dr}) \tag{7}$$

$$\lambda^s_{qr} = L_{ls} i^s_{qr} + L_m (i^s_{qs} + i^s_{qr}) \tag{8}$$

$$t_e = \frac{3}{2} p L_m \left(i_{qs} i_{dr} - i_{ds} i_{qr} \right) \tag{9}$$

$$J_T \frac{d\omega_m}{dt} = \frac{J_T}{p}\frac{d\omega_r}{dt} = t_e - t_L \tag{10}$$

Here t_e is the electromagnetic torque developed and t_L is the load torque.

The SIMULINK model used in this paper, models the induction motor as a continuous system for its dynamic equivalent circuit[2]. The IGBT inverter is also modeled with an SPWM inverter with a switching frequency of 6.26kHz, the on-state voltage drops are neglected in the SIMULINK model. The vector control system was modeled with two separate sampling intervals, 150 µseconds for the current controllers and 750 µseconds for the speed controllers. The ode45(Dormand-Prince) solver was used for running the simulations. Fig 2.0 shows the block diagram of the SIMULINK model which has been developed.

3. The Experimental set up

The SIMULNK model developed was used for predicting the dynamic performance for a 1.1kW, ABB make three phase induction motor. The parameters of the motor was experimentally determined from both no-load and blocked rotor tests.

The vector controller was built with an IGBT inverter , running with a 415V, 50Hz input supply. The inverter had a switching frequency of 6.26 kHz. The control system is in software, using a DS1102 DSP controller card with Texas Instruments 32-bit floating point DSP TMS320C31 at 60 MHz. The induction motor was loaded with a permanent magnet DC motor coupled to the induction motor.

4.Results and Discussion

The modeling and experimental results of figures 2 and 3 compare a few drive transients. The top traces in figures 2 and 3 are for speed when the motor is driven with bi-direction speed references. The speed reference consists of acceleration and deceleration ramps to and from a top speed of ± 1000 rev/min. The drive technique in either case is the indirect rotor flux oriented vector controller.

The middle traces in figures 2 and 3 are the dynamic torque responses from the simulation model and the experiment .The torque response in experiment actually from an on-line computation using measured

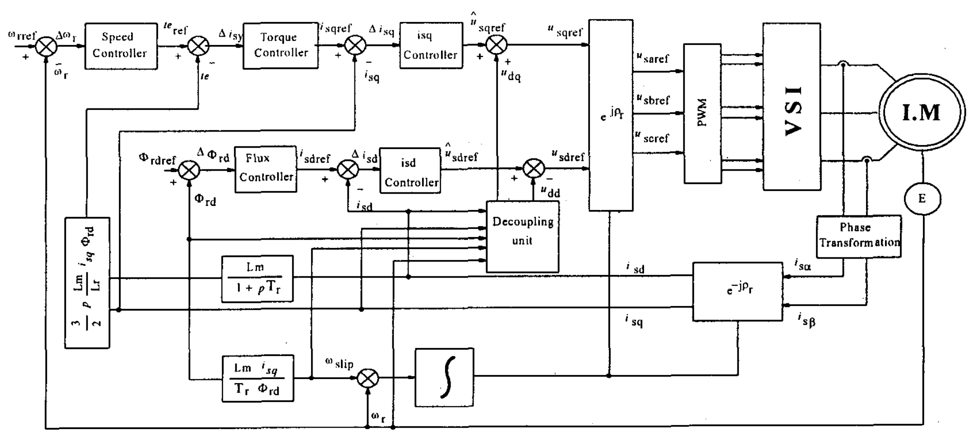

Fig 2.0 Schematic of the rotor-flux oriented control of a voltage source inverter –fed induction motor drive

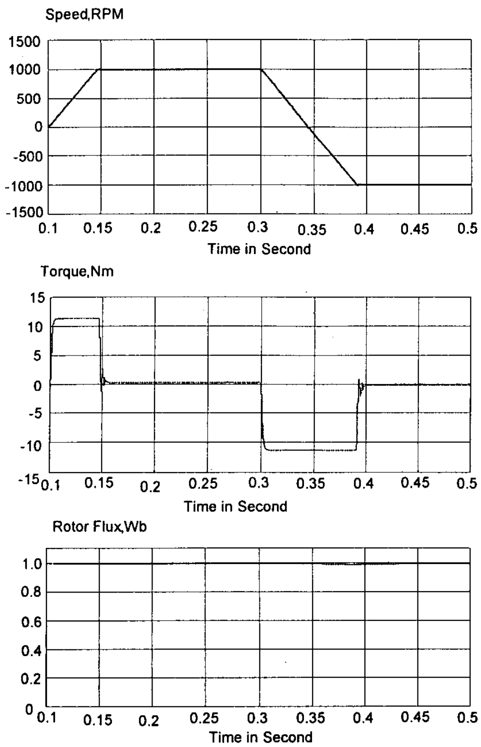

Fig 3. Simulation Results for four quadrant operation – No Load

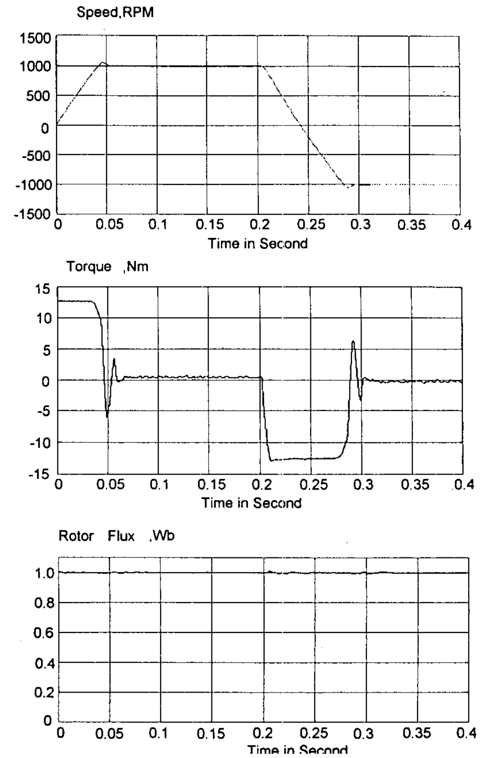

Fig 4. Experimental Results for four quadrant operation – No Load

currents and a dynamic model of the machine in the synchronous reference frame. The bottom traces in figures 3 and 4 are the the rotor fluxes The experimental result on the rotor flux is also computed on-line using stator currents and the machine model in the synchronous reference frame. Clearly very good agreements between experimental and modeling results are achieved.

Figures 5 and 6 show the simulation and experimental results of the drive dynamics when a step load of 5.5 Nm is suddenly applied to the motor shaft. The top trace in fugure 5 shows the step input of load torque in simulation and the middle and the bottom traces indicate its effects on the speed and the rotor flux In the actual experiment, the step load torque of the same amplitude is applied by a dc generator. The generator load is switched on at t = 0.22 sec. This load is however subject to the electrical time constant of the generator. The top trace in figure 6 indicates the electromagnetic torque of the induction motor computed from the measured stator currents and the machine model in the synchronous reference frame. The middle and the bottom traces of figure 6 show the effects of the load lorque on motor speed and the rotor flux. The latter is obtained using the measured stator currents and the machine model in the synchronous reference frame. The modelling and the experimental results are in good agreement.

Figure 7 and 8 indicate the dynamic responses of torque, speed and rotor flux when a load of 5.5 Nm is abruptly removed. Again the responses from the model and from the experiment are in good agreement.

5. Conclusion

The SIMULINK models of the three phase induction motor with a SPWM inverter drive, together with the vector controller have been developed. These models have been tested and validated with experimental measurements. Results from both are in agreement with the experimental results obtained. These models have been developed for further investigations of machine parameter tracking using interfaces with MATLAB Neural Network and FuzzyTech Fuzzy and Fuzzy-neural models.

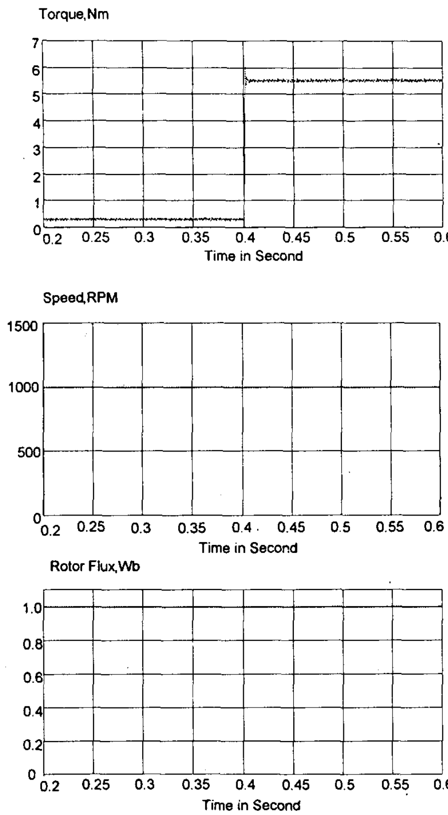

Fig 5. Simulation Results for a step load-on of 5.5 Nm

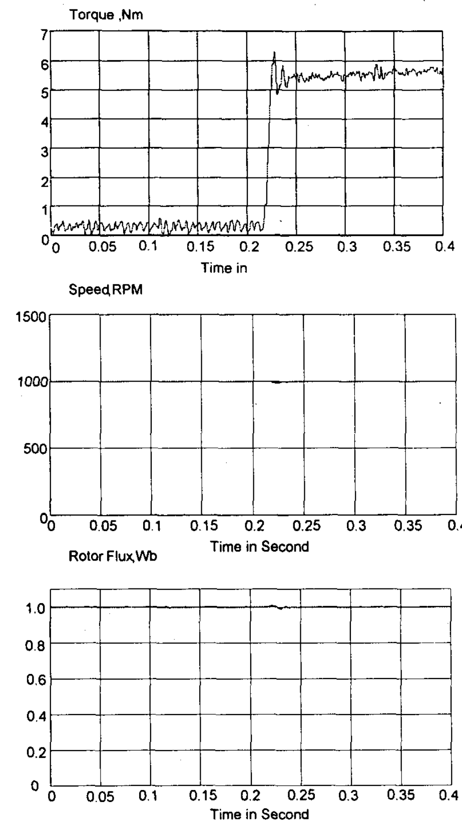

Fig 6. Experimental results for a step load-on of 5.5Nm

Appendix

Induction Motor Data:

Type	3 Phase Y-connected squirrel cage motor
Rated Power	1.1kW
Rated Current	2.77 Amps
Voltage	415V
Frequency	50 Hz
Rated Speed	1415 RPM
Number of pair of poles, p	2
Stator Resistance R_s	6.03 Ω
Stator Leakage Inductance L_{ls}	29.9 mH
Rotor Resistance R_r	6.085 Ω
Rotor Leakage Inductance L_{rs}	29.9 mH
Magnetizing Inductance L_m	489.3 mH
Moment of Inertia J_T	0.00488 Kgm^2

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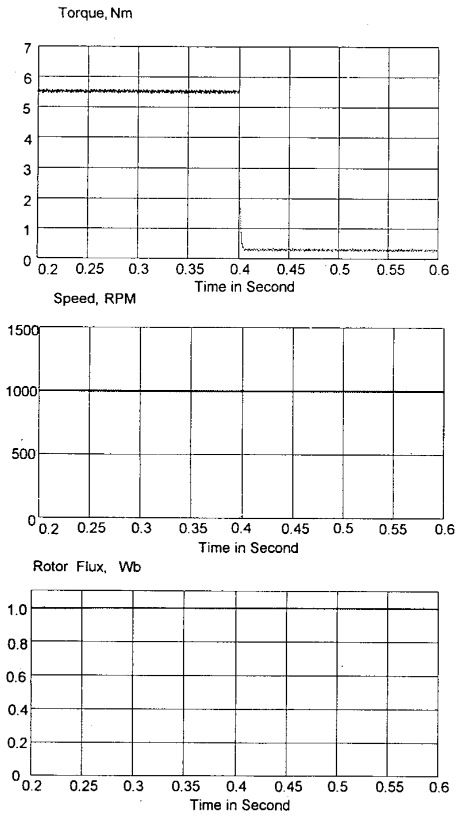

Fig 7. Simulation Results for a step load -off of 5.5 Nm

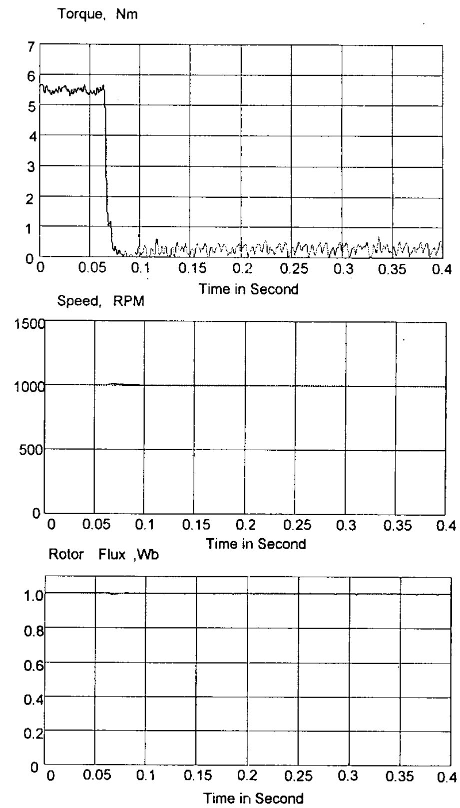

Fig 8. Simulation Results for a step load -off of 5.5 Nm