International Journal of Electrical Engineering.
ISSN 0974-2158 Volume 4, Number 8 (2011), pp.939-946

http://www.irphouse.com

Direct Torque Control of Induction Motor with Improved Switching Scheme

Dr. Sukhdeo Sao[1], Siraj Ahmed T.[2], Amanulla[3] and Ashok Kumar S.[4]

Abstract

This paper focuses on performance improvements of the rotor flux estimation for a direct torque controlled induction motor drive and this is another method to that of to the field oriented control (FOC) or vector control technique. The aim is to control the torque and flux effectively. Torque control of an induction machine based on DTC strategy has been developed and a comprehensive study is presented in this paper. The performance of this control method has been demonstrated by simulations performed using a versatile simulation package, Mat lab/Simulink.

Index terms: Adaptive sliding observer, direct torque control(DTC), Field oriented control (FOC), Adjustable Speed Drives (ADS), Direct Self Control (DSC), Voltage Source Inverter (VSI), Induction motor drive.

Introduction

The Adjustable Speed Drives (ADS) are generally used in industry. In most drives AC motors are applied. Variable speed drives are widely used in application such as pumps, fans, elevators, electrical vehicles, heating, ventilation and air-conditioning (HVAC), robotics, wind generation systems, ship propulsion, etc. [1].

Previously, DC machines were preferred for variable speed drives. However, DC motors have disadvantages of higher cost, higher rotor inertia and maintenance problem with commutators and brushes. Therefore, in last three decades the DC motors are progressively replaced by AC drives. The responsible for those results are development of modern semiconductor devices, especially power Insulated Gate Bipolar Transistor (IGBT) and Digital Signal Processor (DSP) technologies.

The basic scheme of DSC is preferable in the high power range applications, where a lower inverter switching frequency can justify higher current distortion. In this paper, the attention is mainly focused on the basic DTC scheme, which is more suitable in the small and medium power range applications.

The DTC scheme is very simple, in its basic configuration it consists of DTC controller, torque and flux calculator and Voltage Source Inverter (VSI). DTC is a control technique in AC drive systems to obtain high performance torque control. The conventional DTC drive contains a pair of hysteresis comparators. DTC drives utilizing hysteresis comparators suffer from high torque ripple and variable switching frequency. The most common solution to those problems is to use the space vector depends on the reference torque and flux.

In recent years, many studies have been carried out to develop different solution for the induction motor control having the features of precise and quick torque response and reduction of complexity of the field-oriented algorithms. The direct torque control (DTC) technique has been recognized as viable solution to achieve these requirements.

Induction motor (IM) Vector control, allowing operation at low and zero speed, optimizing torque response and efficiency, is presented in this paper. The magnitude and the orientation angle of the rotor flux of the IM are determined by the output of the closed-loop rotor-flux observer based on the calculation of the extended electromotive force of the machine. The proposed rotor-flux-oriented control scheme is robust to parameter variations and external disturbances. Both observer and controller utilize the continuous sliding mode.

A smooth transition into the field-weakening region and the full utilization of the inverter current and voltage capability will be possible. The produced torque is a continuous output variable of control. The performance of the proposed method is investigated and verified with Matlab / Simulink.

Vector controlled drives require estimating the magnitude and spatial orientation of the fundamental magnetic flux waves in the stator or in the rotor. Open loop estimators or closed loop observers are used for this purpose. They differ with respect to accuracy, robustness, and sensitivity against model parameter variations.

Design and Modeling of Observer

Space vector modulation is a sophisticated PWM method that provides advantages to the application when compared to classical sinusoidal weighted modulation PWM:

- Higher bus voltage utilization (86%)
- Lower THD%

One common way to represent the phase voltages A, B, C is the space vector model. The three legs of the three phase inverter can connect the phases of the motor to positive or negative terminal of DC bus voltage. Considering that one and only one switch per leg must be closed, 8 different states are possible. It is possible to associate a reference vector to each of the 8 states. In order to generate a rotating field, the inverter has to be switched in six of the eight states. This mode of operation is called six-step mode. The remaining two states are called zero vectors because in these states the voltage applied in the motor windings is null due to the middle point of each leg is connected to GND or to the DC bus voltage. The zero vectors, located in the middle of the hexagon, see fig.5.6 can be used to regulate the amplitude of the space vector.

The angle between any two vectors is 60°. whenever transistor T1 is on, transistor T2 is off, and vice versa. This makes it easy to adopt a simple notation to describe the state of the inverter. For example, the state when transistors T1, T4 and T6 are "on" (and of course T2, T3, and T5 are "off") can be represented with the notation (+,-,-). The state where transistors T2, T3, T6 are on is denoted by (-, +, -).

Space vector modulation uses six-step mode, but smoothes out the steps through some sophisticated averaging techniques. For example, if a voltage is required between two step voltages, the corresponding inverter states can be activated in such a way that the average of the step voltages produces the desired output. To develop the equations needed to generate this averaging effect, the problem is transformed into an equivalent geometrical problem. The first step in this re-definition is to transform the inverter voltages of six-step mode into a space vector.

Space vectors are similar to phasors and they are denoted by a magnitude and an angle. It's important to note that space vectors are not phasors. Phasors are used to represent a single time varying sinusoid. Space vectors are used to represent three spatially separated time variant quantities. If there are three time varying quantities, which sum to zero and are spatially separated by 120°, then these quantities can be expressed as a single space vector.

The three-phase two level VSI consists of six active switches. It consists of the three legs with IGBT transistors, or (in the case of high power) GTO thyristors and free-wheeling diodes. The inverter is supplied by a voltage source composed of a diode rectifier with a C filter in the dc-link. The capacitor C is typically large enough to obtain adequately low voltage source impedance for the alternating current component in the dc-link.

When creating space vectors, the three time-varying quantities are sinusoids of the same amplitude and frequency that have 120° phase shifts. When this is the case, the space vector at any given time maintains its magnitude. As time increases, the angle of the space vector increases, causing the vector to rotate with a frequency equal to the frequency of the sinusoid.

There are two ways to apply no voltage to the motor. The first way is to simply connect all three phases to the negative rail of the inverter. This is called inverter state 0 and the corresponding switching pattern is (-, -, -). The second way to apply no voltage to the motor is to connect all three phases to the positive rail of the inverter. This is called inverter state 7 and the corresponding switching pattern is (+, +, +).

Each of the vectors U_0, U_{60}, etc., in the Figure.1 represents the six voltage steps developed by the inverter where the zero voltages 0000 and 0111 are located at the origin. At each of these states the inverter transistors are in steady state.

In order to develop a sine wave at the motor then we must devise a switching pattern that produces a voltage at not only the six vectors states but also one which transitions in between these states. This effectively means producing a continuously rotating vector U_{out} that transition smoothly from state to state. SVPWM seeks to average out the adjacent vectors for each sector. Using the appropriate PWM signals a vector is produced that transitions smoothly between sectors and thus provide sinusoidal line to line voltages to the motor.

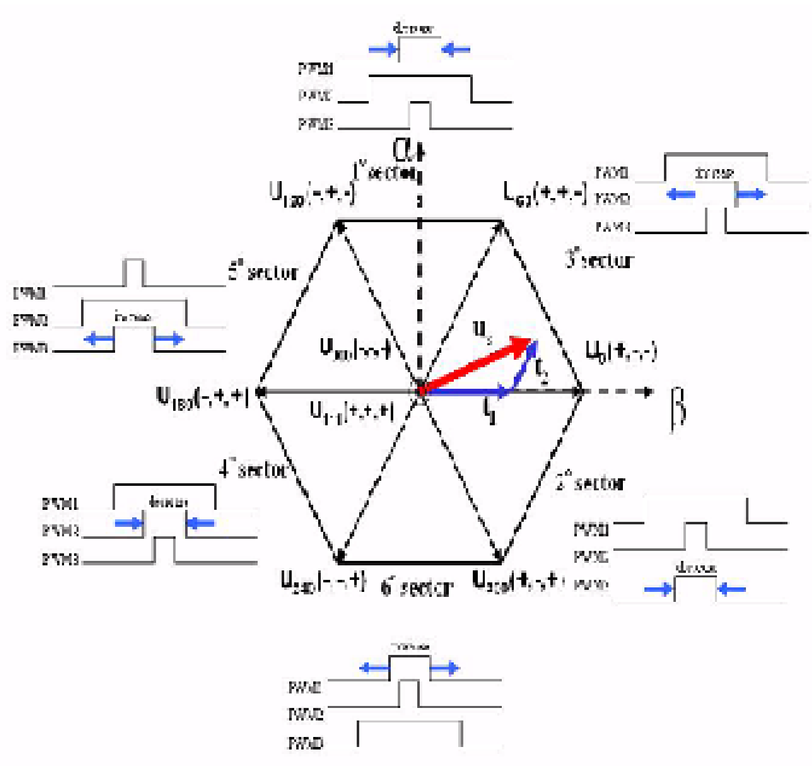

Figure 1: Space Vector Diagram.

Simulink Simulation of SVPWM based IM Drive

The design of the Space Vector Modulation based Induction Motor DTC model is developed using the *Sim Power System* tool bar available. In this paper the line voltage, the three phase currents, the torque and the speed are obtained as the outputs. The developed Simulink model in MATLAB is shown in the Figure 2.

All three of the control schemes have been simulated using Matlab / Simulink. All simulations were performed using a model of the motors that are used in the electric vehicle. For the control schemes that operate at a fixed switching frequency, an inverter switching frequency of 1 KHz was used. For the standard DTC simulations, torque and flux hysteresis bands of 1Nm and 0.96Wb respectively were used to give a switching frequency close to 1 KHz at the chosen motor speed and load. The simulation results are presented based on MATLAB programming.

Various sub – systems are embedded to develop the Simulink model. Simulink model of these sub – system are ABC – DQ Converter, Speed Estimator, i_d*(direct axis current) Calculation, Theta Calculation, DQ – ABC Converter, Speed Controller, Pulse Generator, IGBT Inverter, Induction Motor.

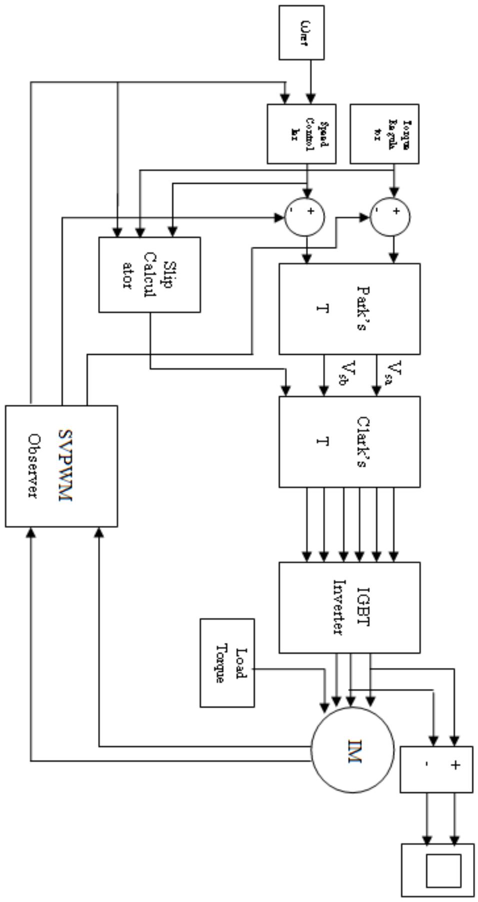

Figure 2: Simulation Model.

The Simulink model of ABC – DQ converter consists of the value of theta and the I_{abc} is fed and using the Parks Transformation the direct axis current i_d and quadrature axis current i_q are obtained. The output values of DQ converter as direct axis current i_d and direct axis flux f_{dq} is converted to the actual instantaneous speed rotor W_r

The Simulink model of i_d* Calculation Unit includes the formulae used for the calculation of direct axis current are also included in the figure. The output is given to the DQ – ABC Converter.

The Simulink model of Theta Calculation Unit receives three inputs quadrature axis current, rotor flux and the rotor mechanical speed.

The Simulink model of DQ – ABC converter converts the values of theta, i_q* and i_d* fed and using the Inverse Parks Transformation the three phase stator current is obtained. The reference speed and the rotor speed are fed as the inputs to the speed controller. The output is the estimated torque which given to the i_{qs}* calculation unit and The output voltage of phase voltage converter as V_{sa} and V_{sb} is converted to series of pulses with the help of NOT gate and bolean algebra. Pulse generated are applied to the gating signals of transistors present in the inverter to trigger.

Simulation Results and Discussions

The simulation of the DTC drive is carried out using Matlab/Simulink package. A 5HP, 460 volts, 60Hz IM is used for analysis. The other parameters of the induction motor extracted are as shown in Table – 1.

The Figure.3 represents the piecewise linear voltage being applied to the stator of the IM using proposed modulation technique The Figure.4 represents the three phase stator currents, it is observed that the magnitude of the current oscillogram reduces within the time of 1.0 sec. the torque of an IM is maximum for the initial period of approximately 0.5 sec. and starts reducing and reaches minimum within a time instant of 1.8 secs. As shown in the Figure.5 The rotor speed steadily increases and reaches its maximum value within 0.65 sec. as shown in Figure.6 The speed curve shows an overshoot at time instant 0.8 sec. and thereby it settles to steady state value within a time instant of 1.8 secs.

Table 1: Induction Motor Parameters.

Parameter	Symbol	Value
Stator Resistance	R_S	0.6 ohms
Stator Inductance	L_S	1.9 mH
Rotor Resistance	R_r	0.41 ohms
Rotor Inductance	L_r	1.9 mH
Mutual Inductance	L_m	41.2 mH
Reference Speed	W_{ref}	1500rpm
Maximum Speed	N	1750rpm
Pairs of poles	P	4

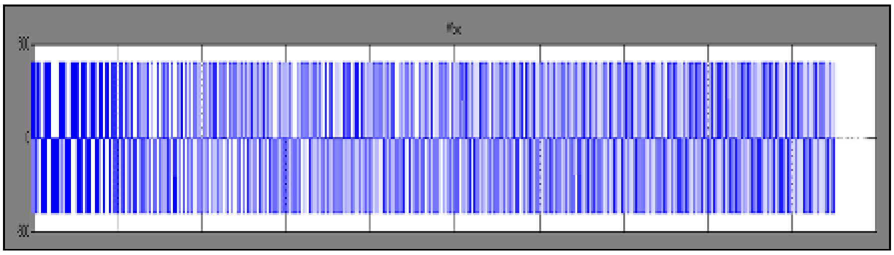

Figure 3: Plot of Control Voltage v/s Time.

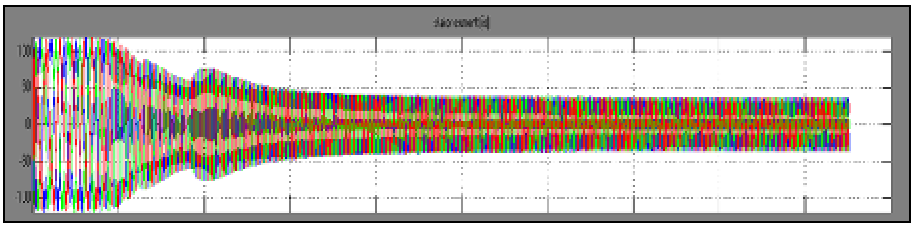

Figure 4: Plot of Stator Current v/s Time.

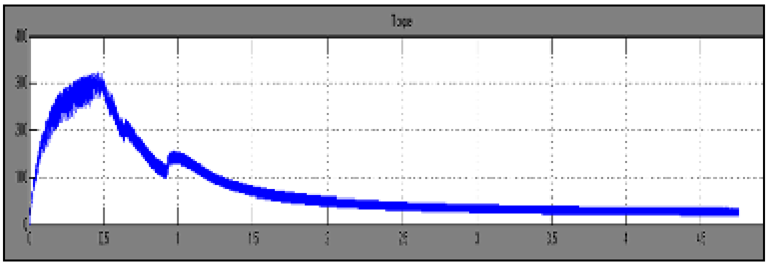

Figure 5: Plot of Torque v/s Time.

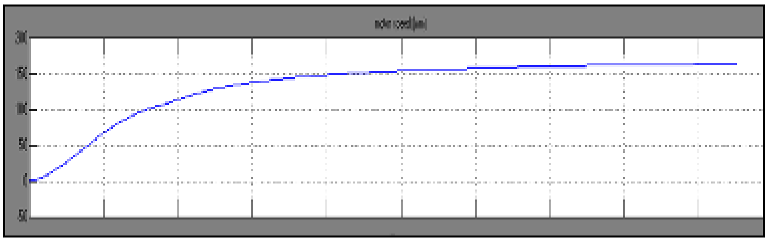

Figure 6: Plot of Speed v/s Time.

Conclusion

The detailed Simulink model of an induction motor drive with direct torque control by means of the Space Vector Pulse Width Modulation concept has been studied in this paper. By this method, efficiency, performance and reliability of induction motor drive increases. The stator current does not exhibit any over shoot or under shoot. The response of the speed curve takes less time to settle and reach the desired value.

Simulation of the direct torque control of the induction motor using SVM technique was carried out using Matlab / Simulink software package. Simulink has been chosen from several simulation tools because its flexibility in working with analog and digital devices. Mathematical models can be easily incorporated in the simulation and the presence of numerous tool boxes and support guides simplifies the simulation of large system compared to Spice. Simulink is capable of showing real time results with reduced simulation time and debugging.

Using the SVM technique the torque of the induction motor can be controlled within a short span of time upto 0.5 – 1.0 sec, thereby bringing the speed of the motor to its rated value much faster. The speed regulation was observed to be between120 to 160 radians per second. The tested load regulation was around 1 to 1.8 Nm.

References

[1] V. Ambrozic, G.S. Buja, R. Menis, "Band-Constrained Technique for Direct Torque control of Induction Motor", IEEE Transactions on Industrial Electronics, Vol. 51, Issue: pp.776 - 784.

[2] F. Blaschke, “The principle of Field Orientation as applied to the transvector closed – loop control system for rotating – field machines”, *Siemens Rev.*, vol. 34, pp. 217 – 220, 1972
[3] I. Takahashi , T. Noguchi, “A new quick response and high-efficiency control strategy of an induction motor”, *IEEE Trans. Ind. Appl.*, vol IA-22, No 5 Sept/Oct 1986
[4] U. Baader, M. Depenbrock, and G. Gierse, “Direct self control (DSC) of inverter-fed-induction machine – A basis for speed control without speed measurement”, *IEEE Trans. on Ind. Applicat.*, vol 28, pp. 581 – 588, May/June 1992.
[5] G. S. Buja and Marian P Kazmierkowski “Direct torque Control of PWM Inverter – Fed AC Motors – A Survey”, *IEEE Transactions on Industrial Electronics*, vol. 51, no. 4 , pp. 744 – 755, Aug. 2004.
[6] R. Zaimeddine, L. Refoufi and E M Berlouk, “ An Improved Direct torque Control Strategy for Induction Motor Drive” Intl. Journal of Electrical and Power Engineering, vol 1, pp. 21 – 27,2007.
[7] P. Tiitinen, “The next generation motor control method, DTC direct torque control”, *Proc. Of Int. Conf. On Power Electronics, Drives and Energy System for Industrial Growth*, N. Delhi, India, pp. 37-43, 1996.

Authors biography

Sukhdeo Sao received his B.Sc (Electrical Engineering) in 1981 from Ranchi University. He received his M.Tech from REC, Kakatiya university, Warangal, Andhra Pradesh and Ph.D from B.R.Ambedkar University, Bihar in the year 2005. He has published several research papers both in National and International Conferences and Journals. Currently he is Professor in the department of Electrical and Electronics engineering , Bharthi College of Engineering, JNTU, Hyderabad, Andhra Pradesh. His research interest includes flexible Power Control, Power Systems and Utility Power Electronics. He is the life member of ISTE and IETE.

Siraj Ahmed T. received his Bachelor of engineering degree and Master degree in the year 1989 and 1996 respectively from Bangalore University, Bangalore, Karnataka. He is pursuing Ph.D from JNTU, Anantapur. Currently he is Assistant Professor in Department of Electrical & Electronics Engineering, Ghousia College of Engineering. His research includes Electrical Machine Drives, Power System and Control. He is a life member of ISTE

Amanulla received his Bachelor of engineering degree and Master degree in the year 1998 and 2002 respectively from Bangalore University, Bangalore, Karnataka. Currently he is Assistant Professor in Department of Electrical & Electronics Engineering, Ghousia College of Engineering. His research includes, Power Electronics, Power System and Control System.

Ashok Kumar S. received his Bachelor of engineering degree from Visvesvaraya Technological university , Belgaum, Karnataka in 2007.Presently he is pursuing his master degree in power system Engineering from Visvesvaraya Technological university. His field of interest are Electrical Machine Drives, Power systems, and High Voltage Engineering.