International Journal of Electronic Engineering and Computer Science
Vol. 1, No. 1, 2016, pp. 1-5
http://www.aiscience.org/journal/ijeecs

SVM and PI Based Simplest Approach to Direct Torque Control of Induction Motor

Hafeezul Haq[1, *], Mehedi Hasan Imran[1], Halil Ibrahim Okumus[1], Zia-ul-Haq[2]

[1]Department of Electrical & Electronics Engineering, Karadeniz Technical University, Trabzon, Turkey
[2]Department of Electrical Engineering, University of Engineering & Technology, Peshawar, Pakistan

Abstract

DTC is a control technique in AC drive systems to obtain high performance torque control. The conventional DTC drive uses a pair of hysteresis comparators. Those DTC drives suffer from high torque ripple and variable switching frequency. The most common and easy solution to those problems is the use of space vector depends on the reference torque and flux. This paper proposes design and simulation of a direct torque controlled induction motor drive system based on Space vector modulation and PI controller to control speed, torque and to reduce torque ripples. For controlling these the principle used here is the simultaneously decoupling of the stator flux and electromagnetic torque. Hysteresis comparators used by DTC drives suffer from high torque ripple and variable switching frequency. The proposed SVM based DTC technique reduces torque ripples and preserve DTC transient merits such as fast torque response. The basis of the SVM-DTC method is the calculation of the required space vector of voltage to compensate the errors in flux and torque and its generation using the SVM for each sample period. The performance of this method in this paper is demonstrated by simulation using Simulink software.

Keywords

Direct Torque Control, Induction Motor, PI Controller, Space Vector Modulation

Received: May 21, 2016 / Accepted: June 3, 2016 / Published online: June 20, 2016

1. Introduction

Almost 70% of the machines used in industries now a days are 3 phase induction motors and the research interest in induction motor (IM) drives has grown significantly over the past few years due to some of their advantages, such as induction motors are simple and rugged in construction, robust and can operate in any environmental condition. Since its introduction in 1985, the direct torque control (DTC) principle is widely using in IM drives with fast dynamics [1]. The direct torque control (DTC) based on switching table is a very simple vector control method for voltage source fed induction motor (IM). However, instead of some attractive qualities such as fast dynamic response, low sensitivity to parameter changes, lack of internal current control loops and inherently motion-sensor-less operation there exist some problems occurring with DTC, as difficulty in starting and low-speed operation, the amount of current and torque ripples, variable switching frequency and high level of noise, violence of polarity rules, as well as high sampling frequency needed for hysteresis controllers [2].

To minimize these problems this paper introduces a new direct torque and flux control based on space vector modulation (DTC-SVM) for IM drives. It uses closed-loop control for both flux and torque and speed in a similar manner as DTC, but the voltage is produced by an SVM unit. In this way, the DTC transient performance and robustness are preserved and the steady-state torque ripple is reduced. Additionally, the switching frequency is constant and totally under controlled.

The classical DTC system is based on the instantaneous values and directly calculated inverter's control signals. The

* Corresponding author
E-mail address: hafeezulhaq88@yahoo.com (H. Haq)

control logic in DTC-SVM method is based on averaged values whereas the switching signals for the inverter are calculated by space vector modulation. This is main difference between classical DTC and DTC-SVM control system.

2. SVM Direct Torque Control

2.1. Overview

In conventional simple DTC systems, the torque error and flux error are used for the generation of next switching condition of the two-level inverter. However, the SVM-DTC, involves the determination of the power switch conduction times in each modulation period, leading to controlled switching frequency DTC technique [3]. The SVM method uses a special switching scheme of the six power transistors of a 3-phase inverter. In fact the SVM technique involve eight rules for switching modes of inverter to control the stator flux to move with the reference flux vector in circle. It achieves the higher controlling. Eight types of switching modes are corresponding respectively to eight space voltage vectors that contain six active voltage vectors and two zero voltage vectors. The axes of hexagon contain six active voltage vectors. And at the origin there are two zero voltage vectors. All these are the basic space vectors [3]. In short the SVM-DTC method selects one of the six nonzero and two zero voltage vectors of the inverter on the basis of the instantaneous errors in torque and stator flux magnitude. These sectors are shown in Fig 1.

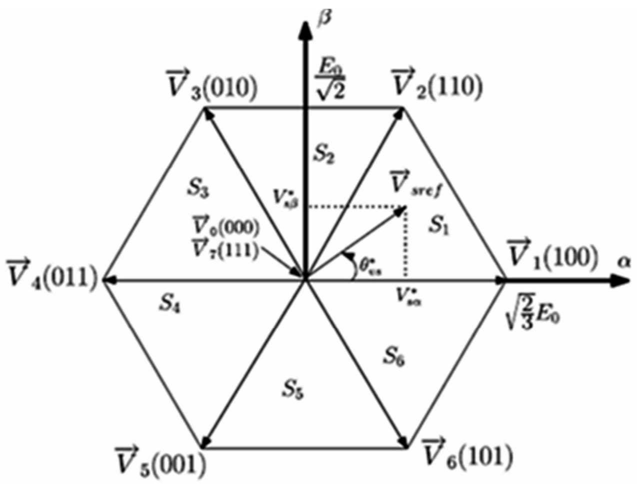

Figure 1. Basic switching vectors and sectors.

Voltage vectors, produced by a PWM inverter, divide the space vector plane into six sectors and each sector is represented as:

$$(i-1)\frac{\pi}{3} < Si \leq i\frac{\pi}{3}, i = 1 \ldots 6 \tag{1}$$

The reference voltage vector is determined by the following equation:

$$\theta_{vs}^{*} = arctan\left(\frac{v_{\beta s}^{*}}{v_{\alpha s}^{*}}\right) \tag{2}$$

The principle used by SVM is to project the desired stator voltage vector Vsref on the two adjacent vectors Vi and Vi+1 corresponding to two switching states of the inverter [4]. By these projections the required commutation time Ti and Ti+1 is calculated and further for inverter the two non-zero switching states are calculated by these values. For maintaining the constant commutation frequency, in the case where Ti+Ti+1≤Tmod, a zero state of the inverter is applied during the rest of the period Tmod, i.e. T0=Tmod-(Ti+Ti+1). The explanation here is for sector S1, as presented in Fig 2. As the reference voltage vector Vsref is in sector S1, it can be the result of the active voltage vectors V1 and V2 [4]. The projection on these adjacent vectors are represented by following equation:

$$V_{sref} = V_{s\alpha}^{*} + jV_{s\beta}^{*} = \frac{T_1}{T_{mod}}V1 + \frac{T_2}{T_{mod}}V2 \tag{3}$$

Where Tmod=T1+T2+T0. D1 and D2 are duties relative to voltages V1 and V2 [4].

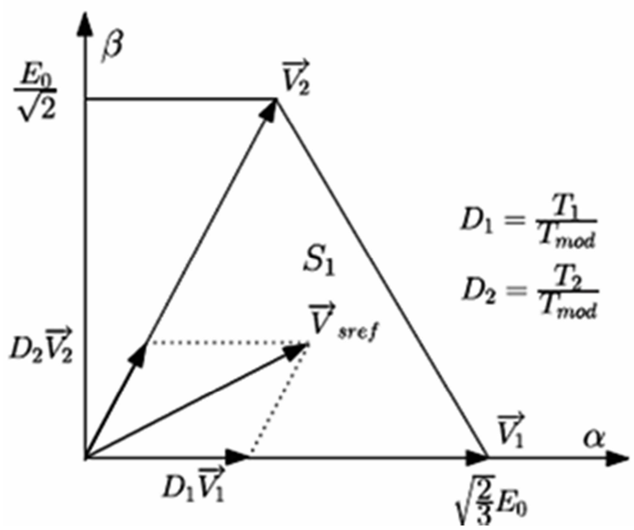

Figure 2. Projection of the reference voltage vector on two adjacent vectors.

2.2. Block Diagram of SVM-DTC System

The block diagram of SVM-DTC system is shown in Fig 3.

In this DTC technique the Proportional-Integral controller for flux and torque are using for controlling of the amplitude of the stator voltage. By rotor angular frequency and slip angular frequency the stator flux angle is controlled. [7]. This control system have PI control system for slip angular frequency, for torque and for flux controller and for the calculation of the amplitude of stator voltage there is a Cartesian to polar transformation, while in the next sampling period for the calculation of stator voltage in direct and quadrature reference frame there is a polar to Cartesian system [7]. In this way, the PI speed controller is used to optimize the reference torque (Tref) of the motor from the error between reference speed and the rotor speed respectively as:

$$T_{ref} = k_p\left(\Delta\omega + \frac{1}{T_i}\int \Delta\omega dt\right) \tag{4}$$

where Δω=ω_ref-ω_r

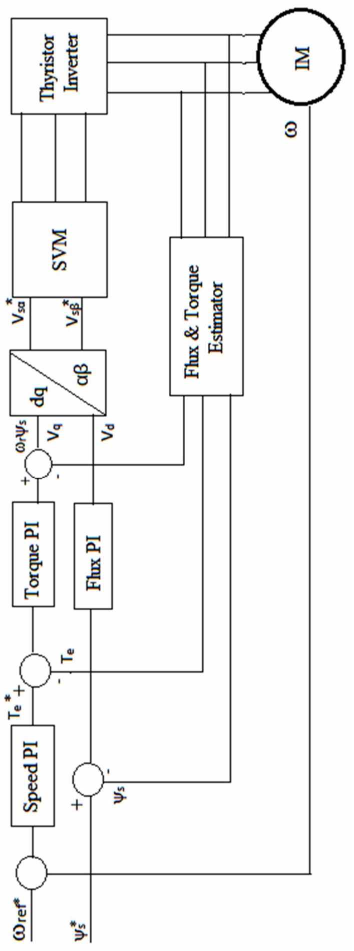

Figure 3. Block diagram of SVM-DTC.

Then, the optimized torque is compared with the estimated torque to generate an error signal. This signal is the input of PI torque controller that computes the value of q- axis voltage [7]. The output of torque controller can be represented as:

$$V_{sq} = k_p\left(\Delta T_e + \frac{1}{T_i}\int \Delta T_e dt\right) \tag{5}$$

where ΔT_e=T_ref-T_estimated

For generating the error signal the reference flux and estimated flux are compared and this error signal is applied to PI flux controller to calculate the value of d-axis of the voltage [7]. The d-axis voltage can be derived as:

$$V_{sd} = k_p\left(\Delta\psi + \frac{1}{T_i}\int \Delta\psi dt\right) \tag{6}$$

Where Δψ=ψ_ref-ψ_estimated

After these the d and q frames are converted to α and β frame by Inverse park transformation and then inputted to SVM block. The signal generated at the output of SVM block is the control signal for inverter which is further applied to inverter gates and the speed of induction motor is forced toward the reference.

2.3. Flux and Torque Estimator

This block calculate the flux and torque from the terminal voltage and current of machine and then the sector number is derived for the flux vector. The voltage and current in dq frame are given in below equations [6].

$$v_{ds} = \frac{1}{\sqrt{3}}(v_c - v_b) \tag{7}$$

$$v_{qs} = \frac{1}{3}(2v_a - v_b - v_c) \tag{8}$$

$$i_{ds} = -\frac{1}{\sqrt{3}}(i_a + 2i_b) \tag{9}$$

$$i_{qs} = i_a \tag{10}$$

The elements of stator flux are represented as:

$$\psi_{ds} = \int(v_{ds} - i_{ds}R_s)dt \tag{11}$$

$$\psi_{qs} = \int(v_{qs} - i_{qs}R_s)dt \tag{12}$$

The magnitude of stator flux can be calculated as:

$$\psi = \sqrt{\psi_{ds}^2 + \psi_{qs}^2} \tag{13}$$

By using the stator flux components the flux vector zone can be derived. From flux component, current component and the number of poles of the machine the electromagnetic torque can be calculated as:

$$T_e = \frac{3}{2}\frac{P}{2}\left(\psi_{ds}i_{qs} - \psi_{qs}i_{ds}\right) \tag{14}$$

2.4. Speed Controller

In this block an error signal is generated from actual and reference speed, and this error signal is applied to PI controller which process it and give output as a reference torque.

3. Simulink Model of SVM Direct Torque Control

The Simulink model of SVM Direct Torque Control is shown in Fig 4.

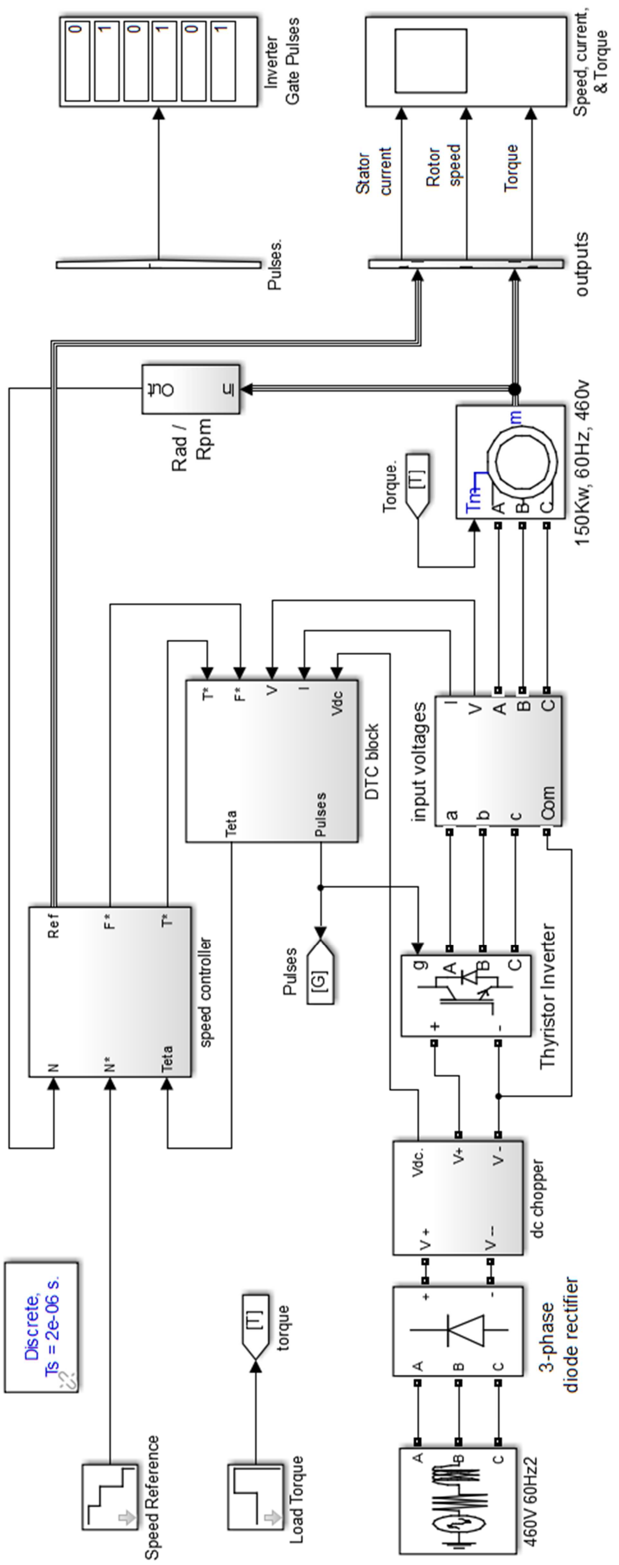

Figure 4. Simulink model of SVM Direct Torque Control of Induction Motor.

4. Simulation Results

The Simulation of SVM-DTC circuit is performed for the step inputs of speed reference and load torque. The reference speed is given as 500rpm for 0 to 1.5sec, 250rpm for 1.5 to 3sec, -250 for 3 to 4.5sec and -500rpm after 5sec of time. The load torque is applied as 0Nm for 0 to 2sec, 700Nm for 2 to 3.5sec and -700 after 3.5sec. The simulation results is obtained for the stator current, rotor speed and torque. The simulation results are shown in Fig 5 & Fig 6.

From Fig 5, it is cleared that the speed and torque of motor is controlled as required and the torque ripples are reduced to a very low level.

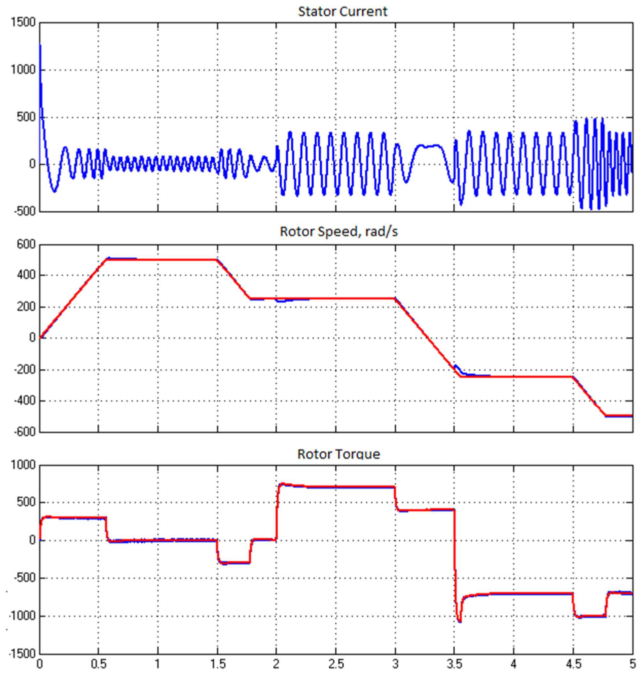

Figure 5. Stator current, Rotor Speed & Rotor Torque.

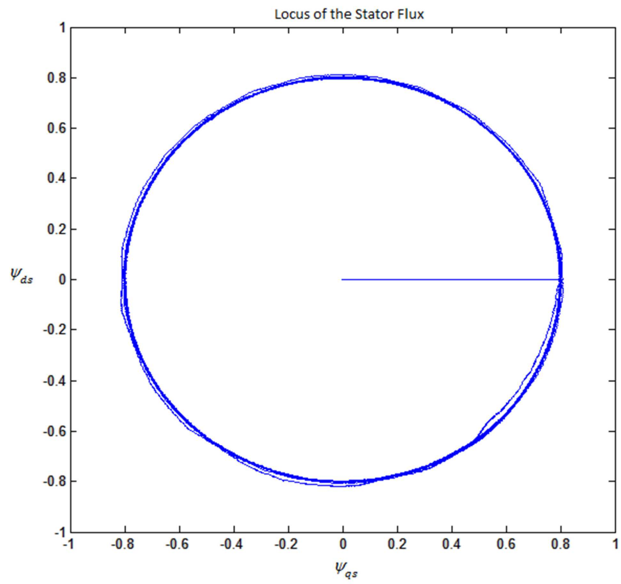

Figure 6. Locus of the Stator Flux.

5. Conclusion

In this paper the direct torque control of Induction Motor is achieved using SVM and PI controller and the results and analysis is done with Matlab/Simulink software. If we see to result's graph the Rotor speed is controlled very accurately and the exact applied reference speed is achieved. And it work for both of positive and negative reference value, means that it work in four quadrants. Only a small ripple is appear when a large change is occur in reference but that is not a countable ripple. The same is occur to rotor torque. The Rotor gain the load torque very quickly. It gives best results also for the torque controlling. So as a result the SVM and PI based Direct Torque Control method is a best method for controlling the Induction Motor.

6. Specification of Induction Motor and PI Controller

The specification of induction motor and PI controllers are given in Table 1.

Table 1. Specification of motor and controllers.

Parameter	Value
Motor type	150Kw, 460v, 60Hz
Stator resistance, Rs	14.85mΩ
Stator Inductance, Ls	0.3027mH
Rotor Resistance, Rr	9.295mΩ
Rotor Inductance, Lr	0.3027mH
Mutual Inductance, Lm	10.46mH
Inertia, J	3.1kgm^2
Friction factor, F	0.08Nms
Pole pairs	2
Speed controller-Proportional gain	30
Speed controller-Integral gain	200
Torque controller - proportional gain	1.5
Torque controller - integral gain	100
Flux controller - proportional gain	250
Flux controller - integral gain	4000
Sampling time	20µs

References

[1] Cristian Lascu, Ion Boldea, Fellow, IEEE, and Frede Blaabjerg, Senior Member, IEEE 'A Modified Direct Torque Control for Induction Motor Sensorless Drive' *IEEE Transactions on Industry Applications,* Vol. 36, No. 1, Jan/ Feb 2000.

[2] M. Zelechowski, M. P. Kazmierkowski and F. Blaabjerg 'Controller Design for Direct Torque Controlled Space Vector Modulated (DTC-SVM) Induction Motor Drives' *IEEE ISIE 2005*, June 20-23, 2005.

[3] Ameni Ouarda and Fatma Ben Salem 'Induction Machine DTC-SVM: A Comparison Between Two Approaches' 2013 10th International Multi-Conference on Systems, Signals & Devices (SSD) Hammamet, Tunisia, March 18-21, 2013.

[4] Fatma Ben Salem and Nabil Derbel 'Direct Torque Control of Induction Motors Based on Discrete Space Vector Modulation Using Adaptive Sliding Mode Control' *Taylor & Francis Group, LLC, Electric Power Components and Systems, ISSN: 1532-5008 print / 1532-5016 online,* 42: 1598–1610, 2014.

[5] Arpit S. Bhugul, Dr. Archana G. Thosar 'Simulation of Direct Torque Control of Induction motor using Space Vector Modulation Methodology' *International journal of Modern Engineering Research (IJMER), ISSN: 2249–6645,* Vol. 4, Iss. 5, May. 2014.

[6] Anjana Manuel, Jebin Francis 'Simulation of Direct Torque Controlled Induction Motor Drive by using Space Vector Pulse Width Modulation for Torque Ripple Reduction' *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering,* Vol. 2, Issue 9, September 2013.

[7] Hassan Farhan Rashag, 'DTC-SVM Based on PI Torque and PI Flux Controllers to Achieve High Performance of Induction Motor' *Research Journal of Applied Sciences, Engineering and Technology* 7(4): 875-891, 2014.

[8] 'Direct Torque control and Space vector modulation', *http://www.en.wikipedia.org,* access: 29 May 2015.

[9] Peter Vas, "Sensorless Vector and Direct Torque Control" *(Oxford Science Publications).*

[10] Jose L. Azcue P. and Ernesto Ruppert "Three-phase Induction Motor DTC-SVM Scheme with Self-Tuning PI-Type Fuzzy Controller" *Seventh International Conference on Fuzzy Systems and Knowledge Discovery* (FSKD 10-12 Aug. 2010), IEEE.

[11] Abhijit A. Gade, Dr. Kailash J. Karande, Amol B. Jagadale "Space Vector Modulation Based Feed Control Using Three Phase Induction Motor" *International Journal of Modern Trends in Engineering and Research,* e-ISSN No.: 2349-9745, Date: 2-4 July, 2015.

[12] T.Sravani, S. Sridhar "SVM-DTC of an Induction motor based on voltage and stator flux angle using fuzzy logic controller" *International Research Journal of Engineering and Technology (IRJET)* Volume: 02 Issue: 04 July-2015.

[13] Dr. E. V. C. Sekhara Rao "Space Vector Modulated Direct Torque Control of IPMSM Drive" *International Advanced Research Journal in Science, Engineering and Technology* Vol. 2, Issue 8, August 2015.