Research Inventy: International Journal of Engineering And Science
Vol.5, Issue 3 (March 2015), PP -20-26
Issn (e): 2278-4721, Issn (p):2319-6483, www.researchinventy.com

Analysis of 2-Level and 3-Level Inverter Fed Direct Torque Control of Induction Motor Drive.

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Abstract: *AC drives are more predominant than dc drives. Ac drives require control of frequency, current and voltage for variable-speed applications. The difference between the traditional vector control and the DTC is that the DTC has no fixed switching pattern. The DTC switches the inverter according to the load needs. Though conventional DTC (CDTC) is simple, easy to implement generates substantial steady state ripples in torque and flux and acoustical noise. Also, with CDTC the switching frequency is not maintained constant. In recent years several PWM techniques were developed to reduce the steady state ripple and to get the constant switching frequency. CSVPWM results in higher line side voltage and less line current harmonic distortion than sine triangle PWM with constant switching frequency. CSVPWM-based DTC could eliminate some tribulations that are with the CDTC, such as steady state ripples in torque and flux, variable switching frequency, etc., at higher line side voltages. This paper discusses the implementation of a high-performance direct torque control (DTC) of induction machine drive using SVPWM technique for two level and three level inverter and results are compared. The software used for this project is MATLAB/SIMULINK.*
Keywords: *CDTC,CSVPWM-DTC,CSVPWM*

I. Introduction

The most economical IM speed control methods are realized by using frequency converters and hence pulse width modulated voltage inverter is the most applied used in industry. Variable frequency IM control methods are divided into two groups: scalar and vector.

In the middle of 80s new strategies for the torque control of induction motor was presented by I. Takahashi and T. Noguchi as *Direct Torque Control* (DTC) [7] and by M. Depenbrock as *Direct Self Control* (DSC).The difference between the traditional vector control and the DTC [5] is that the DTC has no fixed switching pattern. The DTC switches the inverter according to the load needs. Though conventional DTC (CDTC) is simple, easy to implement generates substantial steady state ripples in torque and flux and acoustical noise [3]. Also, with CDTC the switching frequency is not maintained constant.

In recent years several PWM techniques were developed to reduce the steady state ripple and to get the constant switching frequency. CSVPWM [6] results in higher line side voltage and less line current harmonic distortion than sine triangle PWM with constant switching frequency. CSVPWM-based DTC could eliminate some tribulations that are with the CDTC [1], such as steady state ripples in torque and flux, variable switching frequency, etc., at higher line side voltages. In the next sections, induction motor is presented in d-q model and implementation of classical DTC and also high-performance direct torque control (DTC) of induction machine drive using SVPWM technique for two level and three level inverter area analyzed and results are compared.

II. Classical DTC Scheme

The closed loop torque and flux control of induction motor drive consists mainly of three functional blocks:

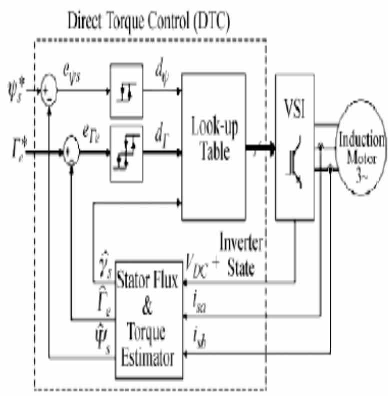

Figure-1

A. Torque and Flux Estimator

The feedback flux and torque are calculated from the machine terminal voltages and currents. The computation block also calculates the sector number in which the flux vector lies. The phase voltage and currents in stationary reference are given as

$V_{s\alpha} = V_a$ (1)

$V_{s\beta} = \left(-\frac{1}{\sqrt{3}}\right)(V_a + 2V_b)$ (2)

$I_{s\alpha} = I_a$ (3)

$I_{s\beta} = \left(-\frac{1}{\sqrt{3}}\right)(I_a + 2I_b$ (4)

The components of stator flux is given by

$\varphi_{s\alpha} = \int (V_{s\alpha} - R_s I_{s\alpha})dt$ (5)

$\varphi_{s\beta} = \int (V_{s\beta} - R_s I_{s\beta})dt$ (6)

The magnitude of the stator flux can be estimated by

$\varphi_s = \sqrt{\varphi_{s\alpha}^2 + \varphi_{s\alpha}^2}$ (7)

By using the stator flux components stator flux angle is determine to know the flux sector. Also with flux components, current components and IM number of poles, the electromagnetic torque can be calculated by

$T_e = \left(\frac{3}{2}\right)\left(\frac{p}{2}\right)(\varphi_{s\alpha} I_{s\beta} - \varphi_{s\beta} I_{s\alpha})$ (8)

B. Torque and flux controller

The command stator flux and torque magnitude are compared with their respective estimated values and the errors are processed by the hysteresis band controllers. The flux loop controller has two levels of digital output according to following

$H_\psi = 1 \; for \; E_\psi > +HB_\psi$ (9)

$H_\psi = -1 \; for \; E_\psi > -HB_\psi$ (10)

Where $2HB_\psi$ is the total hysteresis bandwidth of the controller. The actual stator flux is constrained within the hysteresis band and tracks the command flux. The torque control loop has three levels of digital output represented by the following equations.

$H_T = 1 \; for \; E_T > +HB_T$ (11)

$H_T = -1 \; for \; E_T > -HB_T$ (12)

$H_T = 0 \; for - HB_T < E_T > +HB_T$ (13)

C. Switching Table

With the torque and flux errors obtained from controller block, for the possible combinations of these errors switching table is formulated and is fed to the inverter which receives as pulses to each switch

H_φ	H_T	S(1)	S(2)	S(3)	S(4)	S(5)	S(6)
1	1	V_2	V_3	V_4	V_5	V_6	V_1
	0	V_0	V_7	V_0	V_7	V_0	V_7
	-1	V_6	V_1	V_2	V_3	V_4	V_5
-1	1	V_3	V_4	V_5	V_6	V_1	V_2
	0	V_7	V_0	V_7	V_0	V_7	V_0
	-1	V_5	V_6	V_1	V_2	V_3	V_4

TABLE I SWITCHING TABLE OF 2-LEVEL INVERTER VOLTAGEVECTORS

III. Space Vector

MODULATED DTC SCHEME

The basic functional blocks used to implement the DTC-SVM scheme is shown in Fig. 2. In the proposed system, flux and torque estimators are used to determine the actual value of the flux linkage and torque. Instead of the switching table and hysteresis controllers, a PI controller and numeric calculation are used to determine the duration time of voltage vectors, such that the error vector in flux and torque can be fully compensated. Two proportional integral (PI) type controllers regulate the flux and torque error. Since the controllers produce the voltage command vector, appropriate space voltage vector can be generated with SVM and fixed switching frequency can be achieved.The output of the PI flux and torque controllers can be interpreted as the reference stator voltage components in d-q co-ordinate system. These dc voltage commands are then transformed into stationary frame (α-β), the command values are delivered to SVM block. The SVM block performs the space vector modulation of Vs to obtain the gate drive pulses for the inverter circuit.

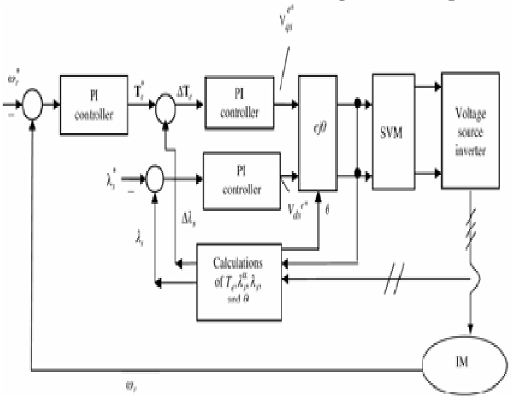

Figure-2

A. Space Vector Modulation

Space Vector Modulation (SVM) Technique has become the most popular and important PWM technique for three phase Voltage Source Inverters(VSI) for the control of AC motors. It has been shown to generate less harmonic distortion in the output voltages and or currents applied to the phases of an AC motor and to provide more efficient use of supply voltage. The SVM technique is used to create a reference vector by modulating the switching time of space vectors in each of the sectors shown in Fig.3 for 2-level inverter and in Fig.4 for 3-level inverter.

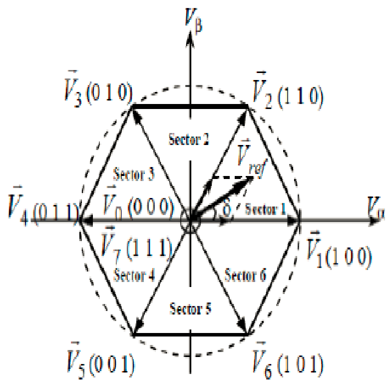

Figure-3

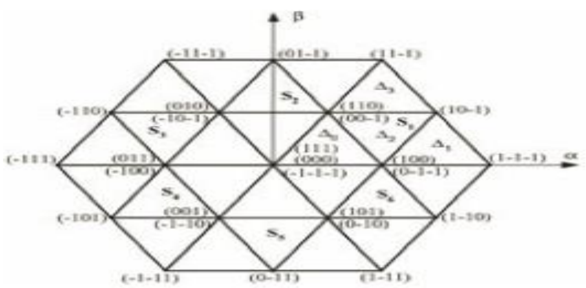

Figure-4

Space vector PWM can be implemented by the following steps:

1. Transform 3-phase to 2-phase quantity and determine Vs and angle
2. Determine time duration T1, T2 and T0

1) Determination of space vector magnitude and angle

In this modulation technique the three phase quantities can be transformed to their equivalent 2-phase quantity in stationary frame. The magnitude of reference vector used for modulating inverter output is,

$$V_s = \sqrt{V_\alpha^2 + V_\beta^2} \qquad (14)$$

Angle is calculated as,

$$\delta = tan^{-1}\frac{V_\beta}{V_\alpha} \qquad (15)$$

2) Determination of time duration

$$T_1 = T_z a \frac{\sin(\Pi/_3 - \delta)}{\sin(\Pi/_3)} \qquad (16)$$

$$T_2 = T_z a \frac{\sin(\delta)}{\sin(\Pi/_3)} \qquad (17)$$

$$T_o = T_z - (T_1 + T_2) \qquad (18)$$

Where T_z denotes half the switching period T_s and a=$\frac{V_s}{2/3(V_{dc})}$

IV. Simulink Model

A.Classical DTC model

The inverter switching pulses are obtained from the switching table which decides the pulses from the error signals of flux and torque. The flux position is also determined in the flux and angle calculation block. The estimation of flux and torque is done from the motor parameters such as phase voltage and phase currents.

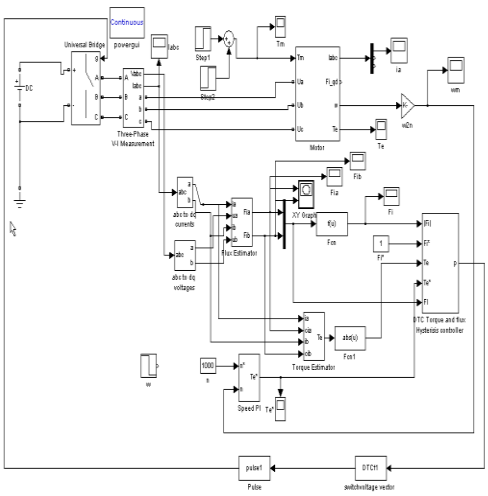

Figure-5

B. DTC-SVM Model

The simulation block of the DTC-SVM control scheme is shown in Fig.6.The system is composed of the motor , three phase voltage source inverter, PI controllers, reference frame transformation blocks etc. The IGBT switches are controlled using space vector modulation technique.

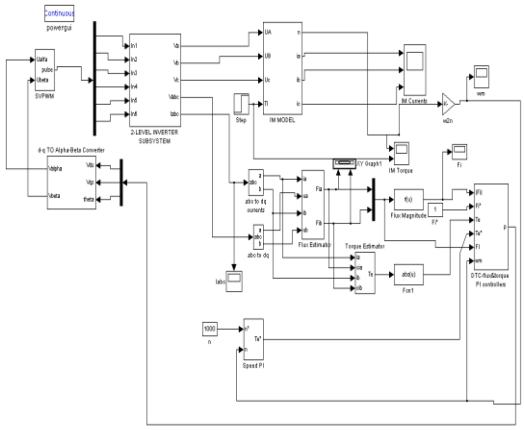

Figure-6

V. Simulation Results

Both DTC and DTC-SVM circuits are simulated for 2-level and 3-level inverter and results are compared.

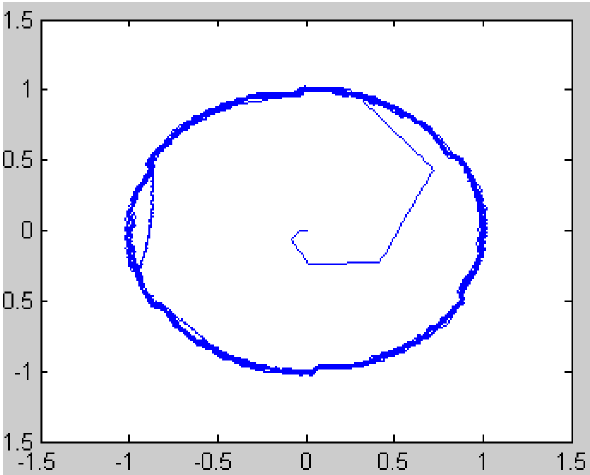

Figure-7 Classical-DTC

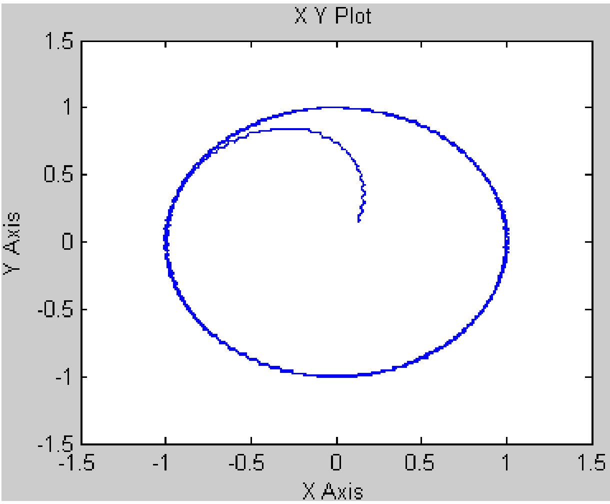

Figure-8 DTC-SVM(2-Level)

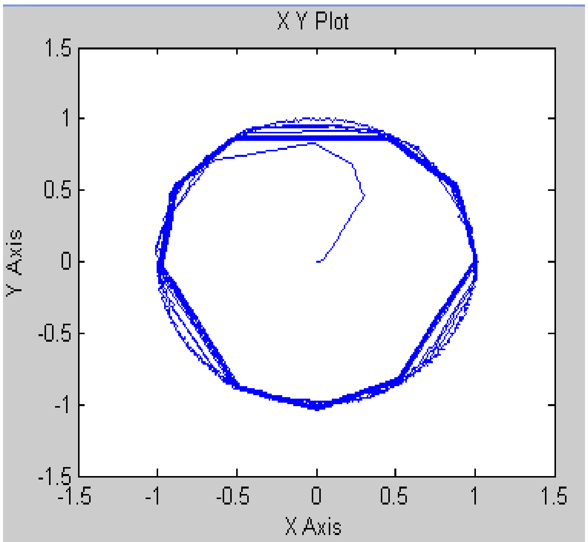

Figure-9 DTC-SVM(3-Level)

The Fig.7,Fig.8&Fig.9 shows the stator flux trajectory of the obtained flux components from the currents and voltages of the IM.

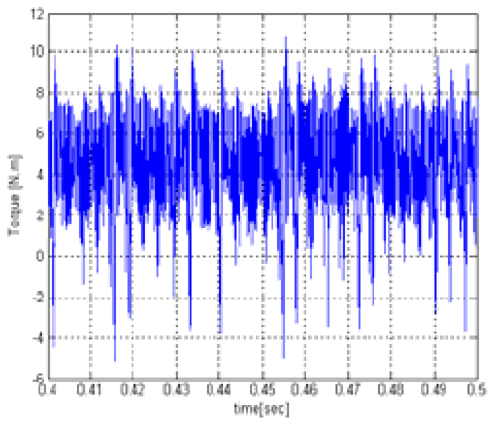

Figure-10 Classical-DTC

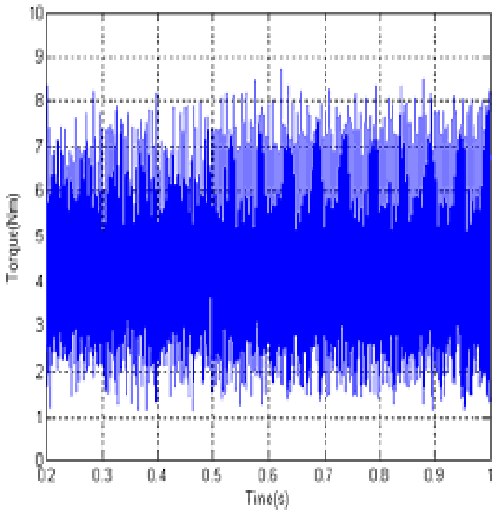

Figure-11 DTC-SVM(2-Level)

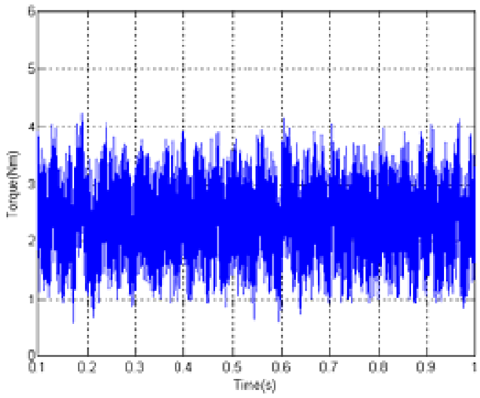

Figure-12 DTC-SVM (Three Level Inverter)

The Fig.10,Fig.11,Fig.12 show the torque response,in the torque waveform of basic DTC scheme contains large amount of high frequency ripples and it is also reflected in the current waveform. It is clear from the simulation results of DTC-SVM scheme, the torque and current ripples have been reduced when compared basic DTC induction motor drive.Also three level DTC-SVM shows less torque ripple than two level.

VI. Conclusion

This project has reviewed Direct Torque Control strategies for SVPWM inverter-fed AC motor drives. The DTC represents a viable alternative to Field Oriented Control (FOC) being also a general philosophy for controlling the AC drives DTC strategies have been divided into two groups: hysteresis-based switching table DTC, and constant switching frequency schemes operating with space vector modulators (SVM-DTC). Constant switching frequency SVM-DTC schemes improve considerably the drive performance in terms of reduced torque and flux pulsations, reliable start up and low speed operation, well-defined harmonic spectrum as well as radiated noise. In conclusion, it is believed that the DTC principle will continue to play a strategic role in the development of high performance drives.

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