Scientific Journal of Impact Factor(SJIF): 3.134
e-ISSN(O): 2348-4470
p-ISSN(P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 2,Issue 5, May -2015

Reduced Torque Ripple DTC of Induction Motor by Modifying Vector Table

H. B. Jani

Electrical Engineering Department,Dr.J.N.M.Government Polytechnic,Amreli

Abstract- *Direct Torque Control is a control technique used in AC drive systems to obtain high performance torque control. The conventional DTC drive contains a pair of hysteresis comparators, a flux and torque estimator and a voltage vector selection table. The torque and flux are controlled simultaneously by applying suitable voltage vectors, and by limiting these quantities within their hysteresis bands, de-coupled control of torque and flux can be achieved. However, as with other hysteresis-bases systems, DTC drives utilizing hysteresis comparators suffer from high torque ripple and variable switching frequency.*

For solution of these problems, in present work an attempt has been made to modify switching vector table by using like SVPWM voltage vector pattern. By controlling the time of this SVPWM like vector, torque slop can be controlled. Modification of switching vector table results in reduced torque ripple and application of SVPWM like vector pattern may gives regular switching frequency. It is expected that modifications made in this work may result in lower electromagnetic torque ripple.

Keywords- **CDTC, MDTC, SVPWM,VSI,DTC**

I. INTRODUCTION

Direct Torque Control was first introduced by Takahashi in 1986[1]. The principle is based on limit cycle control and it enables both quick torque response and efficiency operation. DTC control the torque and speed of the motor, which is directly based on the electromagnetic state of the motor. It has many advantages compare to FOC, such as less machine parameter dependence, simpler implementation and quicker dynamic torque response .It only needs to know the stator resistance and terminal quantities (*v* and *i*) in order to perform the stator flux and torque estimations. The configuration of DTC is simpler than the FOC system due to the absence of frame transformer, current controlled inverter and position encoder, which introduces delays and requires mechanical transducer. In 1996, ABB has introduced the first industrial, speed-sensor less DTC induction motor drive. This simple control scheme has gained popularity and it is believed that they will soon replace the vector control drives commonly found in industry applications.

In this proposed MDTC[3] method voltage vector table is modified. Voltage vector table is modified by using SVPWM pattern like voltage vector pattern. In SVPWM two active vectors surrounded by two null vectors are applied in each sector. Voltage is always applied perpendicular to the flux vector. In this method vector is applied at perpendicular direction to stator flux linkage vector. This produces change in torque and flux. This changes produced by applied voltage vectors in electromagnetic torque and stator flux are used to modify the vector table.

II THE CONVENTIONAL DTC

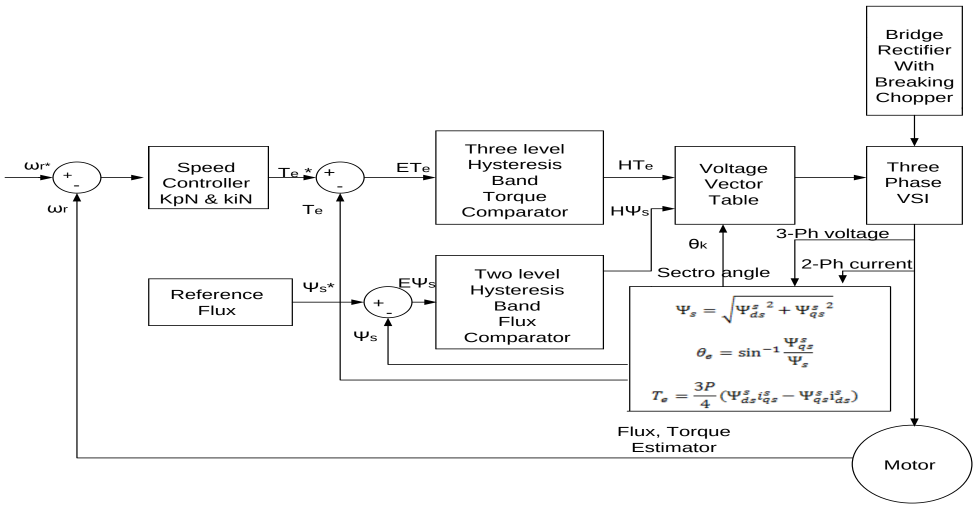

Fig.1 Conventional DTC drive configuration

The basic configuration of the conventional DTC drive proposed by Takahashi is as shown in Fig. 1. It consists of a pair of hysteresis comparator, torque and flux estimators, voltage vector selector and a Voltage Source Inverter (VSI).

According to the combination of the switching modes, the voltage vectors are specified for eight different voltage vectors. The switching vectors associated with DTC are shown in Fig. 2. There are six active voltage vectors $(V_1 - V_6)$ and two zero voltage vectors (V_0 and V_7) at the origin. It can be shown that the voltage vector is given by

$$V_s = \frac{2}{3}V_{dc}(S_a + S_b e^{\frac{2\pi}{3}} + S_c e^{4\pi/3}) \text{ ------ (1)}$$

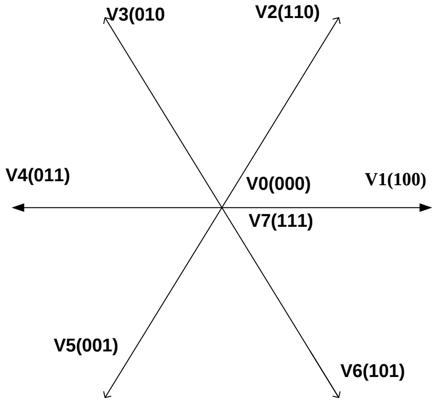

Fig. 2 Voltage space vector

A Direct Flux Control

The stator flux in stationary frame can be written as

$$\Psi_s = \int (V - R_s.i_s) \qquad \text{----- (2)}$$

Analysis is simplified if the stator resistance voltage drop is neglected; hence the flux variation direction is fixed along the selected voltage vector. Over a small period of time, it can be written as

$$\Delta\psi_s = v_s.\text{dt} \qquad \text{----- (3)}$$

The magnitude and orientation of the stator flux must be known in order to directly control the stator flux by selecting appropriate voltage vector[6] .It is proposed that the stator flux plane is divided into six sectors. Each sector will have a different set of voltage vectors to increase (voltage vector highlighted in gray) or decrease (voltage vector highlighted in black) the stator flux as illustrated in Fig. 3.

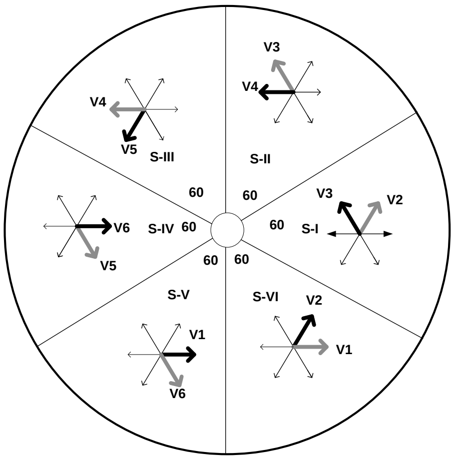

Fig. 3 six equally sectors with different set of voltage vector

If the stator flux lies in sector k then the voltage vector V_{k+1} or V_{k+2} can be selected to increase or decrease the stator flux. The radial voltage vectors (V_k, and V_{k+3}), which can be used to quickly affect the flux, are generally avoided.

The estimated stator flux is subtracted from the corresponding reference values to obtain the error, which is then fed to the hysteresis comparator .The hysteresis comparator will produce flux error status, which can be either 1 or 0.

B *Direct Torque Control*

Equation (4) gives the instantaneous torque in terms of stator and rotor flux linkages.

$$T_e = \frac{3}{2}\frac{L_m}{L_s L_r}\Psi_s\Psi_r = \frac{3}{2}\frac{L_m}{L_s L_r}\sin\theta_{SR} \qquad \text{----- (4)}$$

The above equation shows that, in order to obtain high dynamic performance it is necessary to vary θ_{SR} quickly. The analysis of the variation θ_{SR} and the electromagnetic torque with the application of different voltage vectors is discussed. It can be summarized that, assuming the rotor is rotating counterclockwise continuously, the stator flux, which lies in sector *k*, plays an important role in controlling θ_{SR} by applying an appropriate voltage vector as tabulated in Table 1.

In DTC, the torque is controlled within its hysteresis band similar to the stator flux. Three-level hysteresis comparator is employed because the machine may operate in motoring mode as well as braking mode.

Table 1 The variation of θsr with different voltage vector

Voltage vector	Effect on stator flux	θ_{SR} and T_e
Active Forward V_{k+1} and V_{k+2}	$\Psi_s$advance forward	Increase
Zero V_0 V_7	Ideally Ψ_s freezes Practically Ψ_s weakens due to R_s drop	Decrease
Radial V_k and V_{k+3}	$\Psi_s$increase or Decrease rapidly	Decrease
Reverse active V_{k-1} and V_{k-2}	$\Psi_s$rotate in reverse direction	Decrease rapidly

C Switching Selection

Due to the decoupled control of torque and stator flux in DTC, a high performance torque control can be established. If the stator flux lies in sector *k* with the motor rotating in counter clockwise, active voltage vector V_{k+1} is used to increase both the stator flux and torque. V_{k+2} is selected to increase the torque but decrease the stator flux.

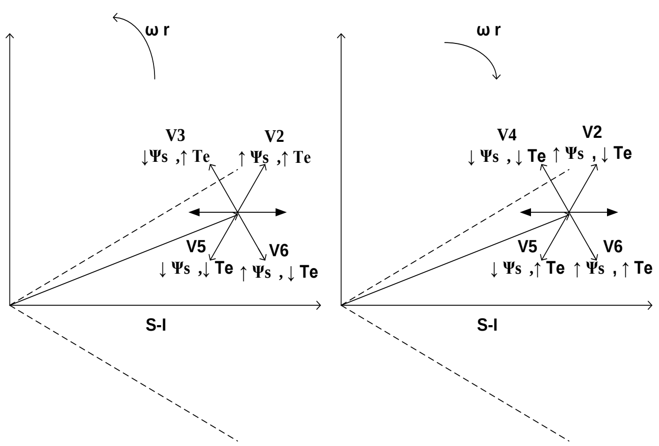

Fig.4. Optimum switching voltage vector in Sector II for shaft rotation (a)Counter- clockwise, (b) clockwise.

The two zero voltage vectors ($V_0$and V_7) are used to reduce the torque and at the same time, freezes the stator flux. Reverse voltage vector V_{k-2} is used to decrease the torque and flux in forward braking mode. Whereas V_{k-1} will reduce the torque and increase the flux.

Table 2 Voltage vector selection table

	Flux Error status	Torque Error status	SI	SII	SIII	SIV	SV	SVI
Counter clockwise	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
Clockwise	1	1	V_6	V_1	V_2	V_3	V_4	V_5
		0	V_7	V_0	V_7	V_0	V_7	V_0
		-1	V_2	V_3	V_4	V_5	V_6	V_1
	-1	1	V_5	V_6	V_1	V_2	V_3	V_4
		0	V_0	V_7	V_0	V_7	V_0	V_7
		-1	V_3	V_4	V_5	V_6	V_1	V_2

Here Active Switching vector V_1(100), V_2 (110), V_3 (010), V_4 (011), V_5 (001), V_6(101). Null switching vector V_0(000), V_7(111)

Small torque hysteresis band is ideal to produce a smooth torque. However for microprocessor-based implementation, if the hysteresis band is set too small, the torque may overshoot and touch the upper band. Once it exceeds the upper band the hysteresis comparator will produce a signal that will select a reverse voltage vector instead of zero voltage vector to reduce the torque .Due to this incorrect voltage vector selection, the undershoot may occur and as a result, the torque ripple is increased drastically.

III THE PROPOSED DTC

n this proposed method voltage vector table is modified. Voltage vector table is modified by using SVPWM pattern like voltage vector pattern. In SVPWM two active vectors surrounded by two null vectors are applied in each sector. Voltage is always applied perpendicular to the flux vector. In this method vector is applied at perpendicular direction to stator flux linkage vector. This produces change in torque and flux. This changes produced by applied voltage vectors in electromagnetic torque and stator flux are used to modify the vector table.

Here in this method sector is also modified according to the SVPWM criteria. By controlling the time of this applied known vector we can control the torque slop. This will give reduce torque ripple. The other part of this modified method is similar to the conventional direct torque control method.

A Principle of Space Vector Pulse Width Modulation

In this modulation technique the three phase quantities can be transformed to their equivalent two-phase quantity either in synchronously rotating frame (or) stationary frame. From these two-phase components, the reference vector magnitude can be found and used for modulating the inverter output.

To implement the space vector PWM, the voltage equations in the *abc* reference frame can be transformed into the stationary *dq* reference frame that consists of the horizontal (d) and vertical (q) axes as depicted in Fig. 4.

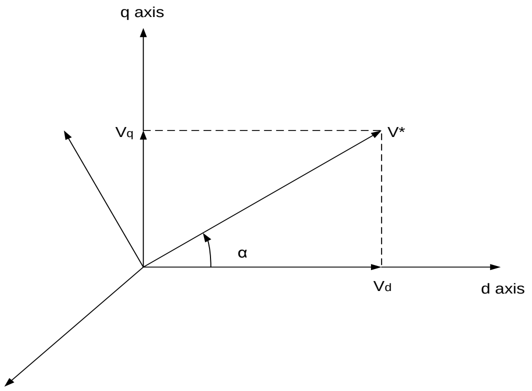

Fig. 4 The relationship of abc reference frame and stationary dq reference frame.

The objective of Space Vector switching is to appropriate the sinusoidal line modulating signal (reference voltage vector) V^*, with the eight space vector (Vn, n = 0,1,…7). These eight space vectors form a hexagon (Fig. 5.3) which can be seen as consisting of six sector spanning 60° each.

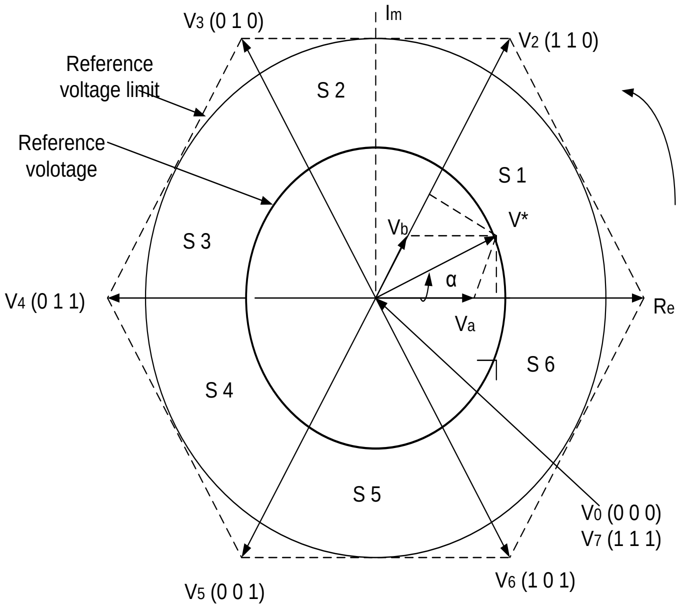

Fig. 5 Phase voltage space vector

In order to obtain fixed switching frequency and optimum harmonic performance from SVPWM, each leg should change its state only once in one switching period. This is achieved by applying zero state vectors followed by two adjacent active state vectors in half switching period. The next half of the switching period is the mirror image of the first half.

The total switching period is divided into parts, the zero vectors is applied for 1/4th of the total zero vector time first followed by the application of active vectors for half of their application time and then again zero vector is applied for 1/4th of the zero vector time. This is then repeated in the next half of the switching period. This is how symmetrical SVPWM is obtained. The leg voltage in one switching period is depicted in Fig. 6 for sector I.

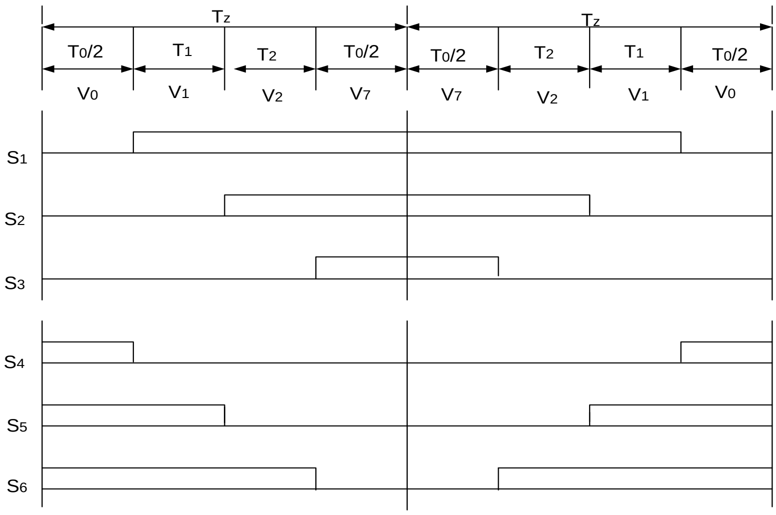

Fig. 6 Switching pattern for sector I

B Principle of Proposed Method

In this proposed method[3] voltage vector table is modified by using like SVPWM voltage vector pattern. By controlling the time of this applied vector we can control the torque slop. In SVPWM in odd sector voltage vector is applied in sequence $V_0 - V_k - V_{k+1} - V_7$ in half time period and reverse in next half time period. In even sector vector are applied in sequence $V_0 - V_{k+1} - V_k - V_7$ in half time period and reverse in next half.

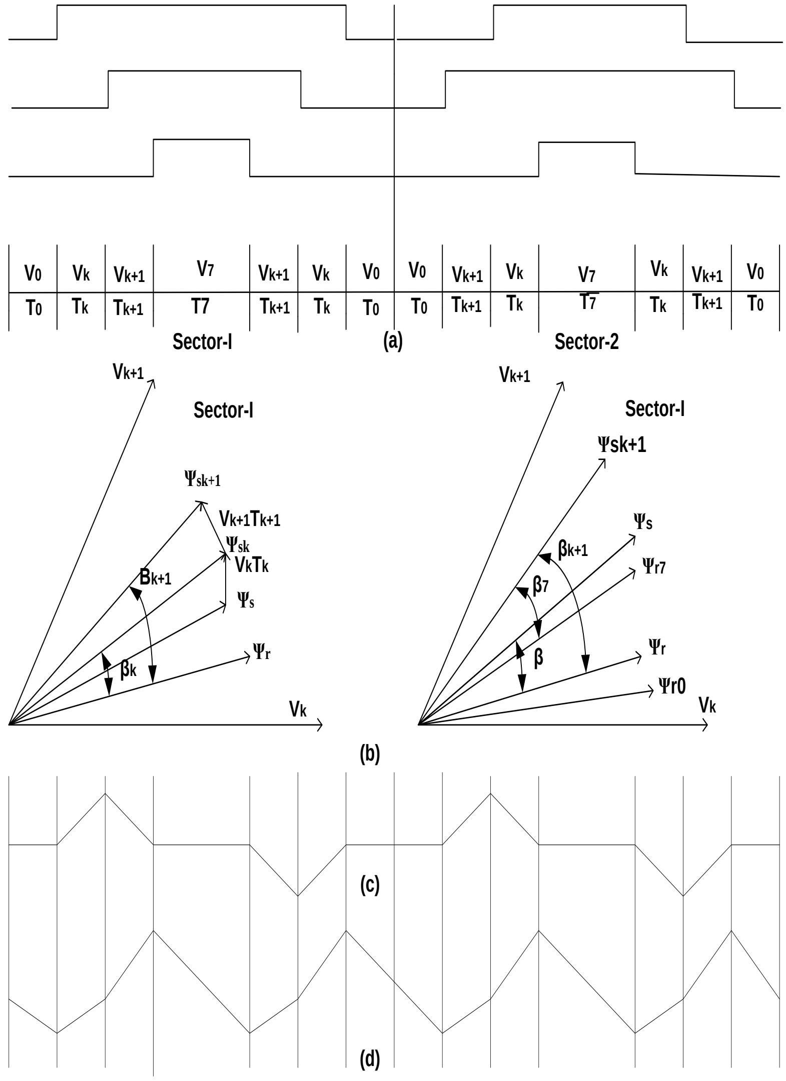

Fig.7 (a) Voltage vector pattern in successive sector S-I and S-II(b) Its effect on stator flux Linkage (c) Its effect on stator flux (d) Its effect of electromagnetic torque.

In this modified method like CDTC we have decoupled control of torque and flux. Output of two hysteresis comparator is used with sector angle for the selection of appropriate voltage vector. This selected voltage vector is used to increase or decrease the torque and flux. This selected voltage vector change its state when it touches the boundaries of two hysteresis band. Hysteresis band determine the time for which particular vector is applied.

In this method with the application of active vector torque is increase and with the application of null vector torque is decrease. The application of vector v_k increase the stator flux and vector v_{k+1} decrease the stator flux. The application of two null vectors has no any change on stator flux and it remains constant. The variation of electromagnetic torque and stator flux is shown in table.

Table 3 Variations of torque and stator flux with voltage vector.

	Increase	Decrease	Remain Constant
Torque	V_k, V_{k+1}	V_0, V_7	--
Stator Flux	V_k	V_{k+1}	V_0, V_7

Table 5 Modified Voltage Vectors selection table

Stator Flux Error Status	Torque Error Status	SI	S-II	S III	S IV	S V	S VI
1	1	V_1	V_2	V_3	V_4	V_5	V_6
	-1	V_0	V_7	V_0	V_7	V_0	V_7
-1	1	V_2	V_3	V_4	V_5	V_6	V_1
	-1	V_7	V_0	V_7	V_0	V_7	V_0

In this method the sector is modified as below. According to sector voltage vector is selected form the vector table. Sector is selected form the stator flux angle. This sector is determined by the stator flux angle.

Table 6 Modified sector

Angle	sector
0 to <= 60	1
60 to <= 120	2
120 to <= 180	3
180 to <= -120	4
-120 to <= -60	5
-60 to <= 0	6

C Schematic Diagram and Matlab simulation of Modified DTC

The schematic diagram of modified method is similar to conventional method . Three level hysteresis band comparator of CDTC is replaced by two levels hysteresis band comparator. Vector table is modified by using SVPWM like voltage vector pattern. Input of the vector table are torque error status, flux status error and sector. Sector is also modified according to SVPWM method.

IV INTERPRETATION RESULTS

The CDTC uses pair of hysteresis band comparator, torque and flux estimator, voltage vector table and VSI, the vector table is unknown and random in manner.

The MDTC uses pair of hysteresis band comparator with two level torque comparator, torque and flux estimator, modified voltage vector table and VSI,SVPWM pattern like known voltage vector patter is used perpendicularly to modify voltage vector table. In MDTC by controlling the time of applied known pattern it is possible to control the torque slop. This will give reduced torque ripple. Results shown in fig. 8 and fig.9

Here for PI controller parameter used for speed controller are K_p=20 and K_i = 3 .Here simulation time is 1 second . Load torque of 20 (N*m) is applied at 0.5 second and load torque of 40 (N*m) is applied at 0.7 second. Reference Speed of motor is 500 r.p.m.

V CONCLUSION

The CDTC uses hysteresis band comparator which select the appropriate voltage vector and period for which this vector is applied. Use of this hysteresis band makes the CDTC having high torque ripple and variable switching frequency. CDTC has a torque ripple up to 12 (N*m). It is possible to apply known voltage vectors for a required time period to the machine for getting better control of electromagnetic torque and speedin MDTC. It also provides an opportunity to reduced electromagnetic torque ripple of motor using the proposed technique. MDTC has a torque ripple up to 6 (N*m)

APPENDIX-I
Motor rating and parameters

Motor rating	7.5kW
Load torque	40 N-m.
Speed	1800 r.p.m.
Pole pair	2
Stator resistance	0.6837 Ohm
Stator leakage inductance	0.004152 H
Rotor leakage inductance	0.004152H
Mutual inductance	0.1486 H
Moment of inertia J	0.05Kg.m^2

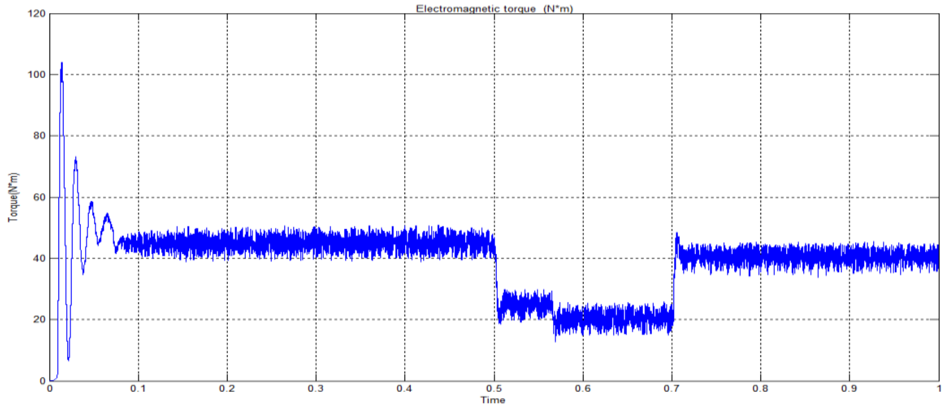

Fig. 8 Simulation results of CDTC; a 20 N-m load is applied at 0.5 sec and 40 N-m load is applied at 0.7 sec.

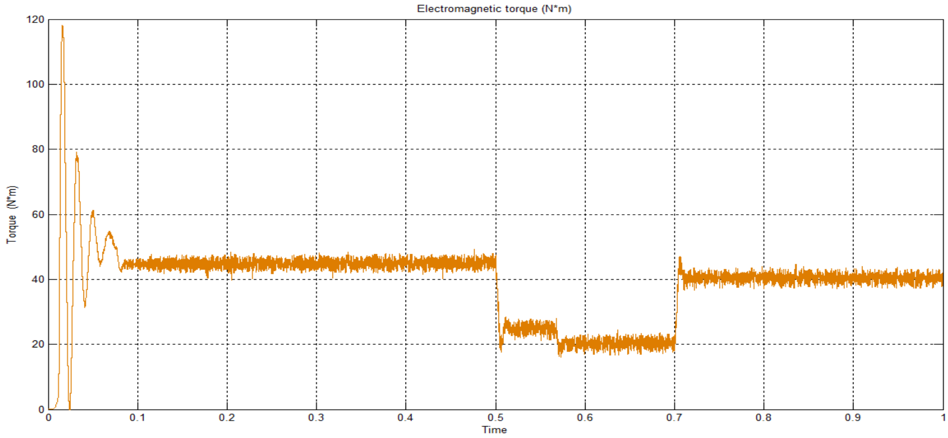

Fig. 9 Simulation results of MDTC; a 20 N-m load is applied at 0.5 sec and 40 N-m load is applied at 0.7 sec.

REFERENCES

[1]. Takahashi, T. Noguchi, ″A new quickresponse and high- efficiency control strategy of induction motor″, IEEE Trans.On IA, Vol.22, N°.5, Sept/Oct 1986, PP.820-827.

[2]. M. Depenbrock, ″Direct self – control (DSC) of inverter fed induction machine″, IEEE Trans. Power Electronics, vol.3, No.4, Oct 1988,PP.420-829.

[3] Dr S. N .Pandya and J. K. Chatterjee ,"Torque Ripple Minimization in DTC based Induction Motor Drive using Carrier Space Vector Modulation Technique.", POWERCON 2010, New Delhi, India.

[4] Nik Rumzi Nik Idris , Abdul Halim Mohd Yatim, Naziha Ahmad Azli ,"Direct Torque Control of Induction Machine With Constant Switching Frequency And Improved Stator Flux Estimation".

[5] . Chitti Babu and C.Poongothai "High Performance Direct Torque Controlled Induction Motor Drive For Adjustable Speed Drive Applications".

[6] T. Brahmananda Reddy, J. Amarnath and D. Subba Rayudu," Direct Torque Control of Induction Motor Based on Hybrid PWM Method for Reduced Ripple: A Sliding Mode Control Approach".

[7] . G. Habetler, F. Pmfumo, M. Pastarelli, and L. M. Talben , "Direct Torque Control of Induction Machines Using Space Vector Modulation" , IEEE Trans. On India, Appl. , Vol. 28, 1992, pp. 104- 1053.

BOOK

[1] Bimal K. Bose , "Modern Power electronics and A.C. Drives" Low priceedition, Printice Hall (2007), pp . 78-2, 246-251, 430-435.