DIRECT TORQUE CONTROL OF MATRIX CONVERTER FED PMSM

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Abstract- This paper proposes a direct torque control (DTC) scheme for a matrix-converter-fed PMSM drive system. DTC is a high performance motor control scheme with fast torque and flux responses. However, the main disadvantage of conventional DTC is electromagnetic torque ripple. Besides, the matrix converter is a single-stage ac-ac power conversion device without dc-link energy storage elements. Due to the properties of the matrix converter, the pseudodc-link will provide with three different types of voltage: the high, middle, and low voltages. Therefore, based on space vector modulation generated by a matrix converter, there are three states on each space vector location. By suitably selecting switching pattern, the electromagnetic torque ripple of the motor is effectively reduced. Using this switching strategy, the advantages of the DTC schemes and the benefits of the matrix converters can be combined. As a result, a satisfactory servo drive can be achieved.

Keywords: *Direct matrix converter (DMC), Permanent magnet synchronous Motor, PI Controller, Voltage source inverter (VSI), Space Vector Modulation (SVM).*

I.INTRODUCTION

MATRIX converters (MCs) are a kind of compact ac–ac converters without an intermediate dc link. It is attracting extensive attention due to their advantages such as high power density, sinusoidal input/output currents, and controllable input power factor. Recently, research works on commutation technology, operation stability, and control/modulation strategy of MCs have been widely reported. Driven by the achievements of these research works, MCs have been increasingly applied in many industrial fields, such as elevators, wind power generation, and mechanical manufacture.

A large amount of research focusing on control and modulations strategies of MCs, developed up to now, can be divided into scalar techniques, pulse width modulation (PWM), predictive control, and direct torque control(DTC). Space vector modulation (SVM), which is based on the instantaneous space vector representation of input and output voltages and currents and belongs to pulse width modulation, was developed and improved in the1990s. As a modern technique, predictive control evaluates the effect of each possible switching state by a cost function.

The switching state which minimizes the cost function will be selected to output. DTC, which employs the structure of hysteresis comparators and heuristic switching tables to obtain high-performance ac drives, was extended to MC-fed induction machines (MC-DTC) in 2001. Since MC-DTC can effectively control not only the torque and flux of the motor but also the input power factor of the grid side, it has been developed rapidly in the last decade. Show that MC-DTC has merits of simple structure and quick torque dynamic response.

DTC was introduced into voltage source inverter(VSI)-fed induction machinesin1986(VSI-DTC).It has attracted the interest of researchers due to advantages such as simple structure, no need for rotary coordinate transformation, and independence of motor parameters. With the control and modulation technology getting mature, MC has become a new choice for motor drive. In MC-based DTC is reported, which can keep the power factor close to unity and realize the simultaneous control of torque and flux. Generally, MC-DTC adopts hysteresis comparators and switching tables similar to those of VSI-DTC. Both the MC- DTC and the VSI-DTC strategy have two major shortcomings: significant torque ripples and variable switching frequency. To overcome the shortcomings, some enhanced DTC strategies have been proposed.

II. MATRIX CONVERTER (MC)

Matrix Converter has an array of $m \times n$ bidirectional switches directly connect a "m" input phases to "n" output phases with variable magnitude and frequency output voltage. Matrix converters have the capability of power regeneration and suppression of input current harmonics, hence they are identified as optimum drives for applications ranging from cranes, elevators and centrifugal pumps, to air-conditioning fans and feed-water pumps. Basic topologies of MC are direct matrix converter(DMC), indirect matrix converter(IMC) and sparse matrix converter.

A. Direct Matrix Converter(DMC)

Despite some drawbacks such as high number of power semiconductor devices, the limitation of maximum load voltage to 86% of the supply voltage, no need for energy storage element, the matrix converters have received recently a wide attention especially in motion control. The three-phase to three-phase matrix converter has been extensively researched due to its potential as a replacement for the traditional AC-DC-AC converter in AC motor drives for the following benefits.

- Adjustable input displacement factor, irrespective of the load
- the capability of regeneration.
- High quality input and output waveforms
- The lack of bulky and limited lifetime energy storage components, such as electrolytic capacitors.

The DMC converter (seeFig.1) is based on bi-directional switches and replaces the rectifier, inverter and energy storage element of an AC-DC-AC converter in only one stage there by reducing the size of the conversion chain but increasing the control complexity.

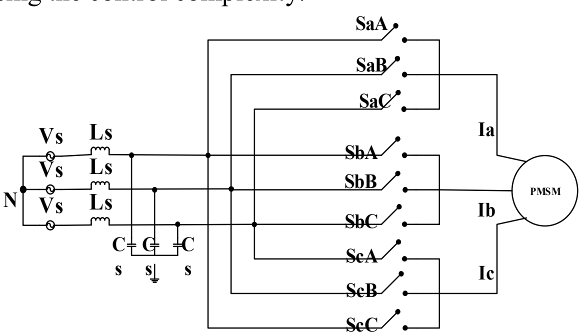

Figure 1.Direct Matrix Converter

B. Indirect Matrix Converter

As shown in Fig.2, the Indirect Matrix Converter IMC consists ofafour-quadrant current source rectifier and a two-level voltage source inverter. This IMC converter topology is preferred in some applications due to its simpler and safer commutation of switches, also the control is simpler and less complex than in DMC converter.

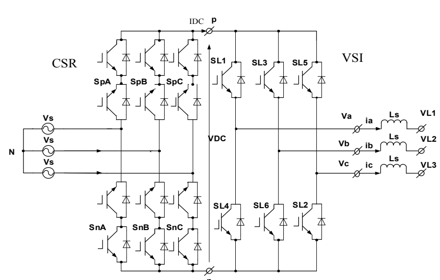

Figure.2. Indirect Matrix Converter

III.SPACE VECTOR MODULATION FOR DMC

The space vector modulation technique is used to control the inverter output voltage and frequency it constructs the desired sinusoidal output three phase voltage by selecting the valid switching states of a three phase matrix converter and calculating their corresponding on time duration. The valid switching states of a procedures, switching vector selection and vector on time calculation.

For three phase matrix converters there are 27 valid switch combinations giving thus 27 voltage vectors. These can be divided in to three vectors, they are as follows synchronously rotating vectors, stationary vectors, zero vectors, which was in table 1.

A. Synchronously rotating vectors:

Switching state connecting every output phase to a different input phase.

It produce voltage space vectors rotating with thee input angular frequency. Constant magnitude and angular frequency.

B. Zero vectors:

All output phases are connected to same input phase.

It produce zero output voltage.

From 5 – 8 , the output voltage vector and the current vector can be determined for each switching configuration

From the figure 2 the three-phase matrix converter module includes nine bidirectional switches. a, b and c are the voltage and current at the input side of the matrix converter and the output side are denoted by A, B and C.

$$V_a = V_m \cos(\omega t) \quad (1)$$

$$V_a = V_m \cos(\omega t \quad 2\pi/3) \quad (2)$$

$$V_a = V_m \cos(\omega t \quad 4\pi/3) \quad (3)$$

The switching function of a switch s_{ij} in figure 2 is defined as

$S_{ij}(t) = 1$ (s_{ij} closed), if it is 0 (s_{ij} open)

I is (a, b, c) and J is (A, B, C)

At any time, there is always only one switch connecting one output phase to one input phase.

$$S_{aj} + S_{bj} + S_{cj} = 1 \quad (4)$$

The space vector approach is based on the instantaneous space vector representation of input and output voltages and currents. We can describe the input/output current and voltage vectors as follows:

$$V_i e^{j\alpha_i} = {}^2/_3 \left(V_a + V_b e^{j2\pi/3} + V_c e^{j4\pi/3}\right) \quad (5)$$

$$V_o e^{j\alpha_o} = {}^2/_3 \left(V_A + V_B e^{j2\pi/3} + V_C e^{j4\pi/3}\right) \quad (6)$$

$$I_i e^{j\alpha_i} = {}^2/_3 \left(I_a + I_b e^{j2\pi/3} + I_c e^{j4\pi/3}\right) \quad (7)$$

$$I_o e^{j\alpha_o} = {}^2/_3 \left(I_A + I_B e^{j2\pi/3} + I_C e^{j4\pi/3}\right) \quad (8)$$

From 5 – 8 , the output voltage vector and the current vector can be determined for each switching configuration

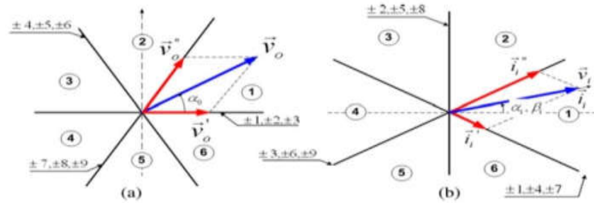

Figure 3.(a)Output line-to-neutral voltage vector.(b)Input line Current Vector

Table 1–Swiching configuration using MC

Switching Configurations		Output voltage		Input current	
SC. NO.	a b c	Vo	αo	Ii	βi
+1	a b b	2/3Vab	0	$2/\sqrt{3}I_A$	$-\pi/6$
-1	b a a	-2/3Vab	0	$-2/\sqrt{3}I_A$	$-\pi/6$
+2	b c c	2/3Vab	0	$2/\sqrt{3}I_A$	$\pi/2$
-2	c b b	-2/3Vab	0	$-2/\sqrt{3}I_A$	$\pi/2$
+3	c a a	2/3Vab	0	$2/\sqrt{3}I_A$	$7\pi/6$
-3	a c c	-2/3Vab	0	$-2/\sqrt{3}I_A$	$7\pi/6$
+4	b a b	2/3Vab	$2\pi/3$	$2/\sqrt{3}I_A$	$\pi/6$
-4	a b a	-2/3Vab	$2\pi/3$	$-2/\sqrt{3}I_A$	$\pi/6$
+5	c b c	2/3Vab	$2\pi/3$	$-2/\sqrt{3}I_A$	$\pi/2$
-5	b c b	-2/3Vab	$2\pi/3$	$2/\sqrt{3}I_A$	$\pi/2$
+6	a c a	2/3Vab	$2\pi/3$	$-2/\sqrt{3}I_A$	$7\pi/6$
-6	c a c	-2/3Vab	$2\pi/3$	$2/\sqrt{3}I_A$	$7\pi/6$
+7	b b a	2/3Vab	$4\pi/3$	$-2/\sqrt{3}I_A$	$\pi/6$
-7	a a b	-2/3Vab	$4\pi/3$	$2/\sqrt{3}I_A$	$\pi/6$
+8	c c b	2/3Vab	$4\pi/3$	$-2/\sqrt{3}I_A$	$\pi/2$
-8	b b c	-2/3Vab	$4\pi/3$	$-2/\sqrt{3}I_A$	$\pi/2$
+9	a a c	2/3Vab	$4\pi/3$	$2/\sqrt{3}I_A$	$7\pi/6$
-9	c c a	-2/3Vab	$4\pi/3$	$-2/\sqrt{3}I_A$	$7\pi/6$
0_a	a a a	0	X	0	X
0_b	b b b	0	X	0	X

0_c	c c c	0	X	0	X
x_1	a b c	X	X	X	X
x_2	a c b	X	X	X	X
x_2	b c a	X	X	X	X
x_3	b a c	X	X	X	X
x_4	c a b	X	X	X	X
x_5	c b a	X	X	X	x

IV.DIRECTTORQUECONTROL

The basic functional blocks used to implement the DTC scheme in an permanent magnet synchronous motor is shown in Fig.4. Three phase AC supply is given to the matrix converter which produces a AC voltage. The Matrix converter switches are controlled by the direct torque control algorithm. The output of the Matrix is connected to the stator terminals of permanent magnet synchronous motor.

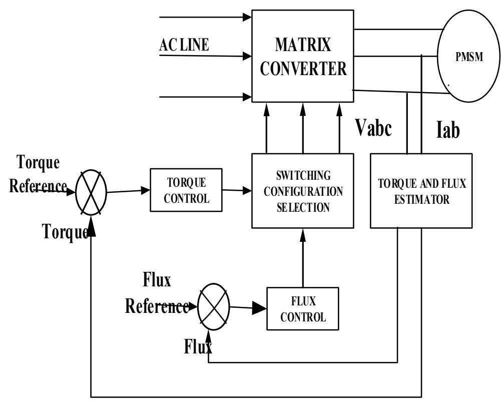

Figure 4. DTC Block Diagram

Table2 DTC Look-up table using matrix converter

	INPUTVOLTAGESECTOR											
	S1		**S2**		**S3**		**S4**		**S5**		**S6**	
HΨ	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1
V1	-3	1	2	-3	-1	2	3	-1	2	3	1	-2
V2	9	-7	-8	-9	7	-8	-9	7	8	-9	-7	8
V3	-6	4	5	-6	-4	5	6	-4	-5	6	4	-5
V4	3	-1	-2	3	1	-2	-3	1	2	-3	-1	2
V5	-9	7	8	-9	-7	8	9	-7	-8	9	7	-8
V6	6	-4	-5	6	4	-5	-6	4	5	-6	-4	5

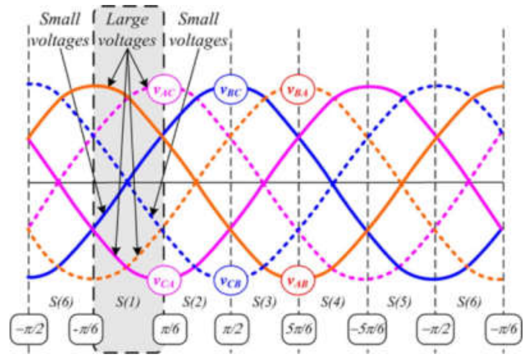

Figure 5 Amplitude variation of input voltage,six vector division

Fig.5 shows the input line-to-line voltages, which are related to the magnitude of the active vectors of TableI, and defines the sector in which the input voltage vector lies. The input voltage vector path has been divided into six sectors.

Since the smaller-amplitude voltages change their sign in the middle of a given sector, only those having larger amplitudes area adequate to be employed in DTC.

In addition to the voltage vectors, there are six input current vectors for a given sector

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V.CLOSED LOOP MATRIX CONVERTER FED PMSM

The simulation environment of Simulink has a high flexibility and expandability which allows the possibility of development of a set of function for a detailed analysis of the electrical drive. The equations that describe permanent synchronous motor equations can be solved analytically or numerically. But such methods are time consuming. Hence moving towards modeling and designing of circuits in simulation using various components which are define below.

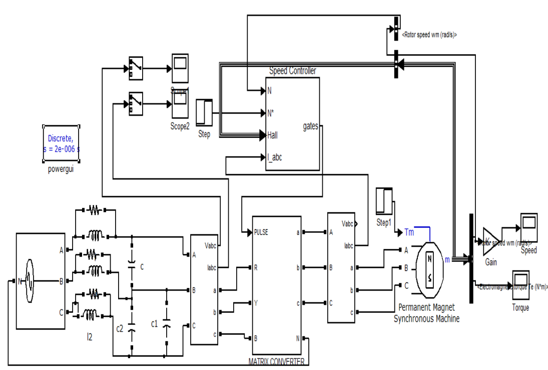


Figure.6 Matlab model of closed loop matrix converter fed PMSM

A. Speed controller

Speed controller calculates the difference between the reference speed and the actual speed producing an error, which his fed to the PI controller. PI controllers are used widely for motion control systems. They consists of a proportional gain that produces an output proportional to the input error and an integration to make the steady state error zero for a step change in the input. Block diagram of the PI controller. It can be modeled like a dc motor. The design begins with the inner most current loop by drawing the block diagram. But in PMSM drive system the motor has current controllers which make the current loop. The current control is performed by the comparison of the reference currents with the actual motor currents. The motor parameters the values of ki and kp are2.678and 48.976 respectively.

B .Current Controller

In PMSM motor the reference torque is proportional to stator current. Hence the desired torque is obtained by injecting the stator current in the motor windings through a power electronic converter.

The reference torque is proportional to stator current and the current reference $(I_{Ref})$is obtained from the speed controller.

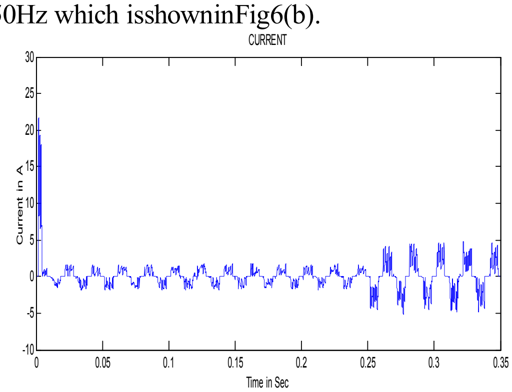
$I_{Ref} = {T_{ref}}/{K_t}$

Where K_t - Torque constant

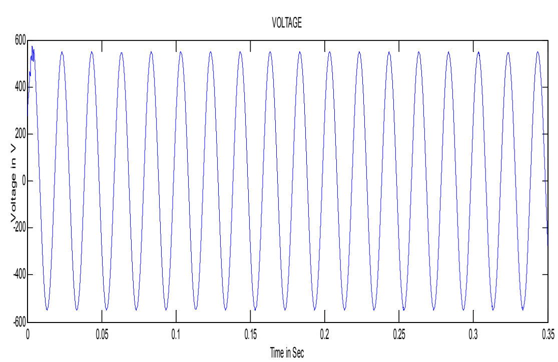
C. Hysteresis Controller

Hysteresis current controller can also be implemented to control the inverter currents.The controller will generate the reference currents with the inverter within arange which is fixed by the width of the bandgap. In this controller the desired current of a given phase is summed with the negative of the measured current. The error is fed to a comparator having a hysteresis band.When the error crosses the lower limit of the hysteresis band, the upper switch of the inverter leg is turned on.But when the current attempts to be come less than the upper reference band, the bottom switch is turned on. This controller doesnot have a specific switching frequency and changes continuously but it is related with the bandwidth.

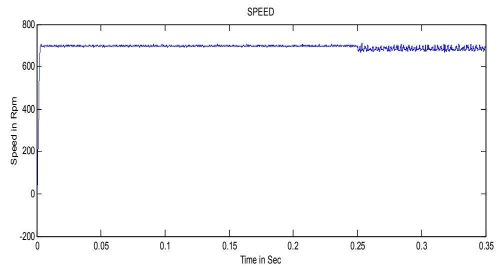
The simulation is done for a time of 0.35 Seconds and the simulated diagram of closed loop system is shown infig 6.The motor isstarted at noload with reference speed of 700 rpm whichshownas Fig6(C) and the motor develops rated torque to bring the motor to the new operating point.The load of 3 Nm is applied at 0.25s which is shown in Fig6 (d). At this point the motor draws the required higher current from the supply to meet the requirement of the load torque.The input current is shown in fig6 (a)and The input rms voltage is 580and frequency is50Hz which isshowninFig6(b).



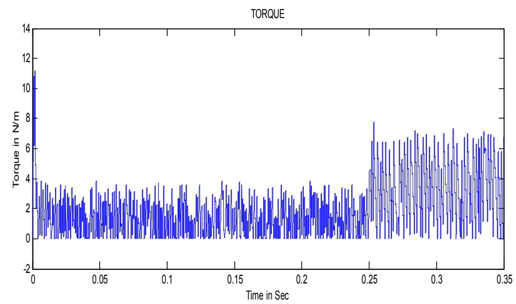
(a)



(b)



(c)



(d)

Figure.7. Simulated Waveforms of Closed loop a) Stator current b) input voltage c)speed d) torque

VI.DIRECT TORQUE CONTROL OF MATRIX CONVERTER FED PMSM

The simulation is done for a time of 0.35 Seconds and the simulated diagram of closed loop system is shown in fig8.The motor is started at noload with reference speed of 700 rpm which shown as8(C) and the motor develops rated torque to bring the motor to the new operating point.The load of 3 Nm i s applied at 0.25s which is shown infigure8(d).At this point the motor draws the required higher current from the supply to meet the requirement of the load torque.The input current is shown in fig8(a) and The input rms voltage is580 and frequency is50Hz whichisshowninFig8(b).

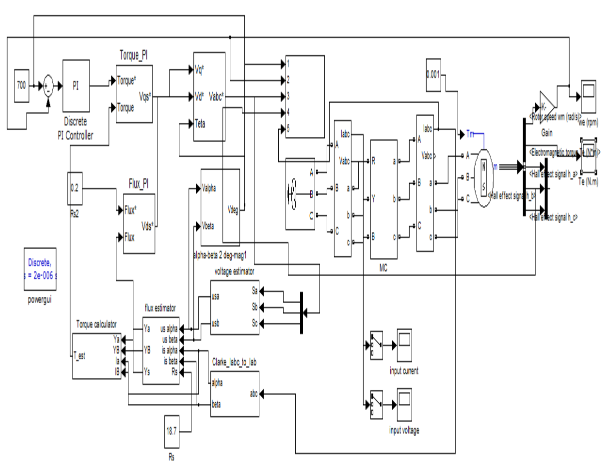
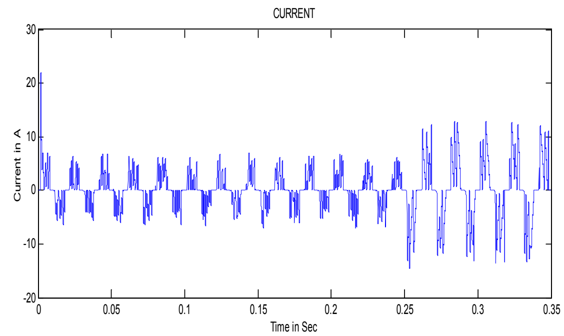
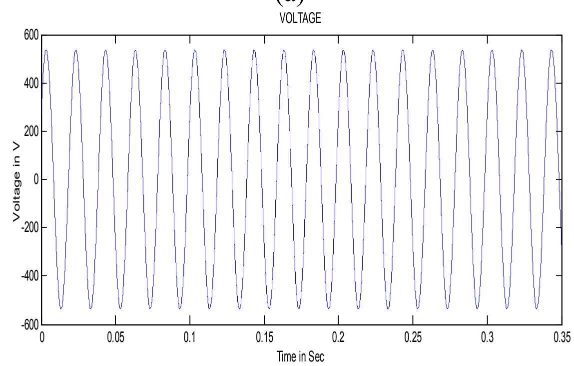


Figure. 8 Matlab model of direct torque control of matrix converter fed PMSM



(a)



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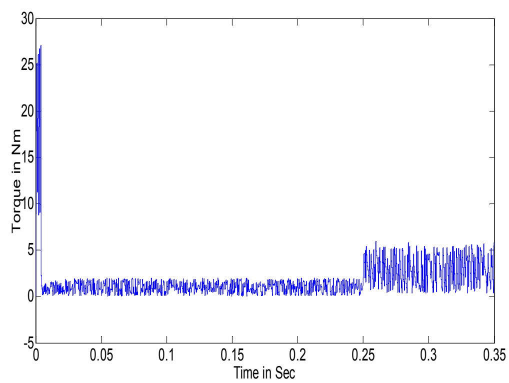
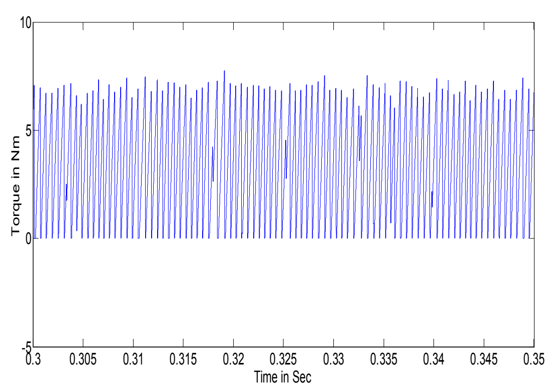


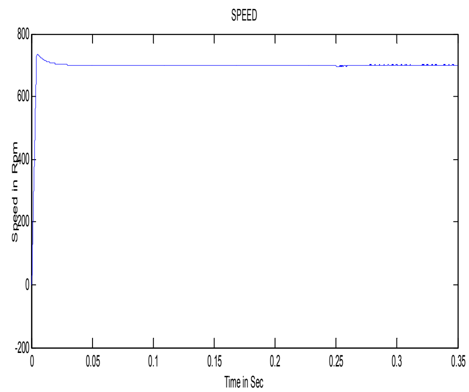
(c)

Figure.8. Simulated Waveforms of Direct Torque Control

VII. TORQUE ANALYSIS OF CLOSED LOOP AND DIRECT TORQUE CONTROL OF MC FED PMSM



(a)



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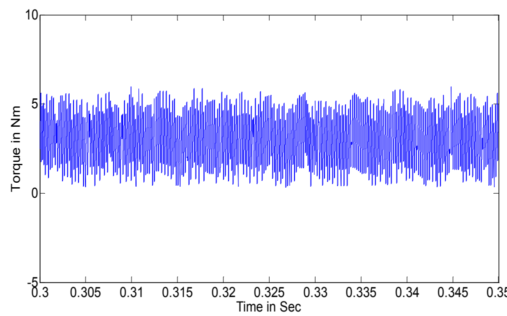

(c)

Figure 9.Simulated waveforms for Torque analysis

Fig 9(a) &(b) shows the load torque of closed loop and direct torque control respectively. The closed loop has more torque ripples lie sinthe range between**0.2-7Nm**. In the Direct torque controller reduces the torque ripples in between **0.5-5.8Nm**. For the load torque of 3Nm, the difference between the torque ripple is **6.8Nm** in closed loop where as **5.3Nm** in the Directtorque control.

VIII.CONCLUSION

This paper proposes a DTC scheme for a matrix-converter-fed PMSM drive system. Adopting the scheme proposed by the paper, the drive system which needs not any additional power switch element can attaina high performance.Moreover,no complicated computation is involved in the proposed scheme. By suitably selecting switching pattern according to this proposed scheme, the torque ripple of the motor is effectively reduced. Consequently, the paper combines the merits of DTC and the matrix converter to achieve a precise servo drive control system.

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