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International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-5, January 2020

Implementation of DTC-Controlled PMSM Driven By A Matrix Converter

R. G. Shriwastava, N. B. Wagh, Dr. Santaji K. Shinde

Abstract*: This paper deals with implementation of direct torque control (DTC) Permanent-Magnet Synchronous Motor (PMSM) driven by a matrix converter for industry applications. A field oriented vector & direct torque control (DTC) is implemented. The simulation test results are presented for converters with Space vector modulation techniques. The advantages of all solutions are indicated. The main focus is given to the drive control in the low speed range and to present drive systems with a matrix converter as an optimum solution for Industry Applications for precision control of speed and torque. The Simulation results of the novel scheme is carried out by using Matlab. The simulation results show that the proposed novel control scheme has a good dynamic response in terms of three phase stator current, speed and torque response. It can also reduce the torque ripple and THD of voltage and current gives better motor performance.

Keywords: Direct torque control (DTC), frequency converter, Matrix converter (MC), Permanent-Magnet Synchronous Motor (PMSM), Space vector modulation (SVM).

I. INTRODUCTION

The Adjustable Speed Drives are widely used in application such as elevators, electric vehicles and hybrid electric vehicles, pumps, robotics, wind generation systems, ship propulsion, etc. [1]-[2]

Electric propulsion systems are the hearts of EV, which functions as internal combustion engine in Conventional vehicle. PMSM can offer many advantages, including high efficiency, high torque density and high reliability. it is widely used in the modern EV [3]-[4]. For electric vehicles application drive consist of electric motors, power converters and electronic controllers which requires high dynamic performance.Currently,a high-performancecontrol technique, called DTC has also been investigated [5]-[7]. The DTC has more advantages as compared FOC in term of torque, flux regulation, elimination of current and robustness to rotor parameters variation. The all calculations are implemented in stationary reference frame. Therefore, the coordinate transformation and continuous rotor position information are not required [8]-[9]. Despite the merits mentioned above, DTC also presents some drawbacks, including large torque ripple and variable switching frequency [10]-[11]. In nature DTC is hysteresis control and voltage vector is the final output variable. Conventional DTC uses switching table as hysteresis control principle to select proper voltage vectors [12]-[13]. Thus to get proper voltage vector selection strategy is critical to suppress torque ripple. Some voltage vector selection strategies were proposed in [14]-[16]. But they can only be used for surface PMSM which can't produce reluctance torque or the motor whose parameters are known. In this paper, An SVM is primarily used as the drive controller for the PMSM motor.

The contents of this paper are listed as follows. The load modeling of PMSM system is analyzed in Section II, In Sections III, the methodology of DTC-Controlled PMSM driven by a matrix converter system is presented. In Section IV, the simulation results of DTC-Controlled PMSM driven by a matrix converter driven PMSM drive is investigated for the steady and transient condition. The discussion of the results are presented in Section V.

Manuscript published on January 30, 2020.
* Correspondence Author
Dr. R.G.Shriwastava*, Electrical department, MCOERC,Nashik, India.
Email: rakesh_shriwastava@rediffmail.com
Dr. N.B.Wagh,Electrical department, VPKBIET, Baramati, India.
Email: nbwagh@gmail.com
Dr. Santaji K.Shinde,Computer Engineering department, VPKBIET, Baramati, India Email;santaji@rediffmail.com

II. MATHEMATICAL MODEL OF PMSM

The PMSM model equations are:

$$V_d = RI_d + L_d(dI_d/dt) - P\omega L_q I_q \quad (1)$$

$$V_q = RI_q + L_q(dI_q/dt) + P\omega L_d I_d + P\omega\lambda_f \quad (2)$$

$$T_e = T_L + B\omega + J_m(d\omega/dt) \quad (3)$$

$$T_e = K_t I_q + (3/2)P(L_d - L_q)I_d I_q \quad (4)$$

The d axis & q axis components of the inductances are the same in Surface mounted permanent magnet motor,
Hence,

$$T_e = K_t I_q \quad (5)$$

$$K_t = (3/2)P\lambda_f \quad (6)$$

From the above equation (5) the torque producing current is along the quadrature-axis.
The d, q variables are converted in to a, b, c variables through the Park's transformation

$$\begin{bmatrix} V_q \\ V_d \\ V_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos(\theta-2\pi/3) & \cos(\theta+2\pi/3) \\ \cos\theta & \cos(\theta-2\pi/3) & \cos(\theta+2\pi/3) \\ 1/2 & 1/2 & 1/2 \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (7)$$

The inverse Parks transformation is defined below:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta - 2\pi/3) & \sin(\theta - 2\pi/3) & 1 \\ \cos(\theta + 2\pi/3) & \sin(\theta + 2\pi/3) & 1 \end{bmatrix} \begin{bmatrix} V_q \\ V_d \\ V_0 \end{bmatrix} \quad (8)$$

For a balanced system the power equation is:

$$V_a I_a + V_b I_b + V_c I_c = (3/2)(V_d I_d + V_q I_q) \quad (9)$$

III. CONTROL TOPOLOGY

A. Field Oriented Control

The Block diagram of FOC based three level DCMLI using CBSVM driven PMSM is presented in fig.1.The measured currents and the voltages into a-β reference frame are transform into d-q frame using Park transformation. The error is given to the PI controller after comparing the reference speed with the motor speed. The output of the PI controller is taken as q- axis current goes to current controller with reference id =0. The reference waves compared with the triangular waves and the pulses are given to the 12 IGBT's of the three level DCMLI.

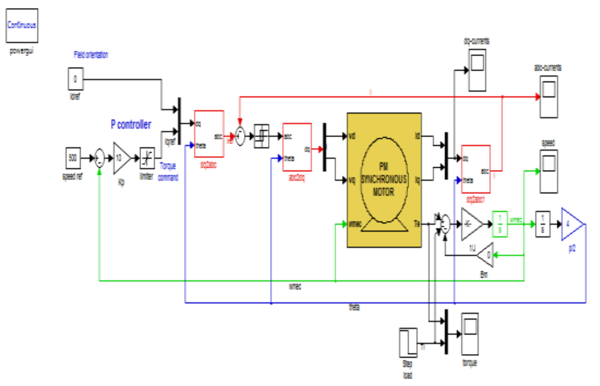

Fig. 1.Simulink Block Diagram of FOC

B. Principles of conventional DTC

The basic objective of DTC is controlling the stator flux vector in amplitude and angular position. Let λs be the flux linkage vector in stator and λr be the rotor flux linkage vector in d-q coordinate. In DTC-SVM the hysteresis comparators are replaced by an torque and flux estimator which calculates the correct voltage vector to compensate for torque and flux errors. By using Clarke transformation, the measured currents are transformed to α-β.

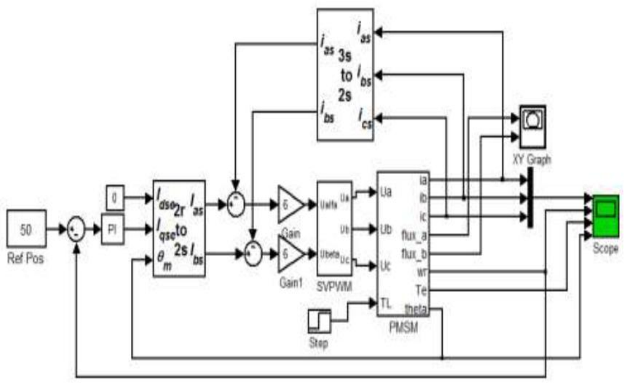

Fig. 2.Simulink Block Diagram of SVM-DTC

C. Proposed DTC with Matrix Converter Circuit

Vector-switching topology are used in design of vector-switching Matrix Converter using unit vector method. Sinusoidal waveform Vref is compared with a carrier waveform Vc. At 50 Hz, the unit vector switching topology are used to have a output of 50 Hz . Table 1.2 shows the switching operation for switch TA1 to TC3.

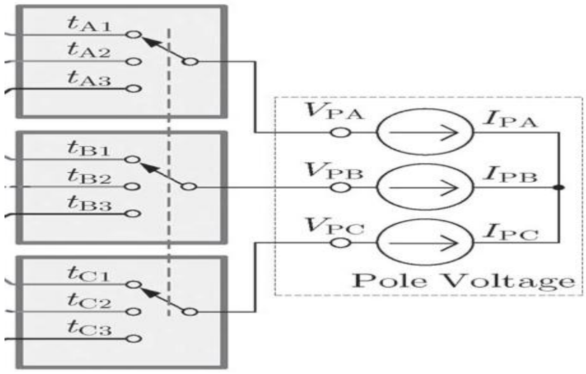

Fig. 3. Switching logic of vector switching matrix converter

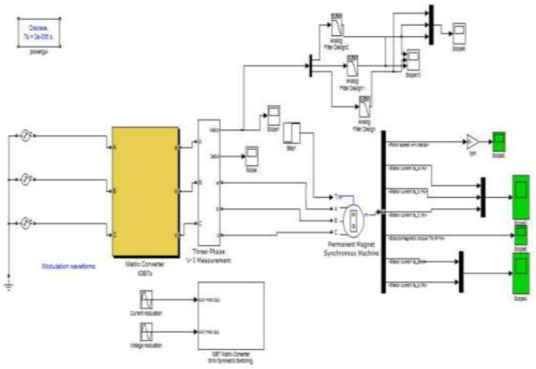

Fig. 4. Simulink Block diagram of DTC with Matrix Converter

IV. SIMULATION RESULTS RESULTS

These control methods of Permanent Magnet Synchronous Motor method are simulated using MATLAB/Simulink The inputs of the simulink model is Rotor speeds. The model then calculates the stator current & electromagnetic torque.

Ld=0.006365H; Lq=0.006365H; R=1.6Ω;

PM_flux=0.1852Wb; P=2; F=0.00005396 Nm-s;

J=0.0001854 Kgm^2

A. Transient Performance

The transient response of the each of the three control methods of PMSM are evaluated by simulating step changes in the torque responses. Fig5, Fig6& Fig7 illustrates the stator current, speed & torque responses obtained using FOC, conventional DTC and proposed DTC with matrix converter (MC) at 500rpm.table I & table II shows the torque ripple & THD results of PMSM at different speed.

Torque ripple can be calculated

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DOI:10.35940/ijrte.E6641.018520
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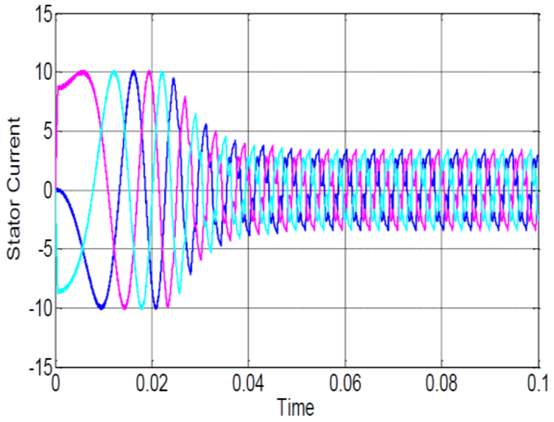
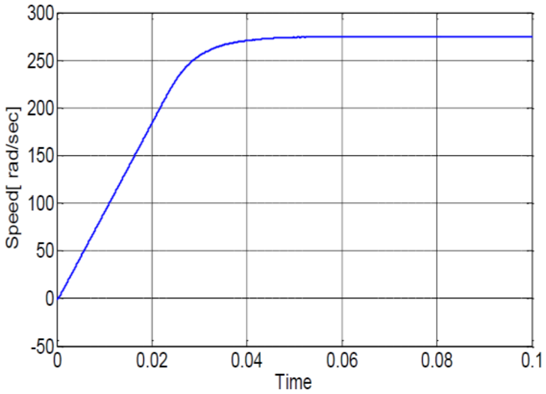
$$\%\text{Torque ripple} = (Tmax - Tmin)/Tavg * 100$$



(a)



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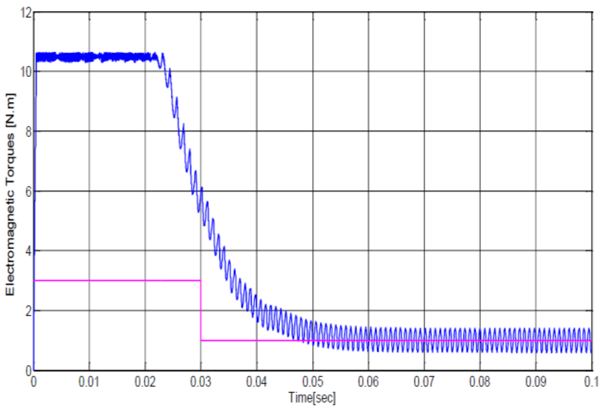
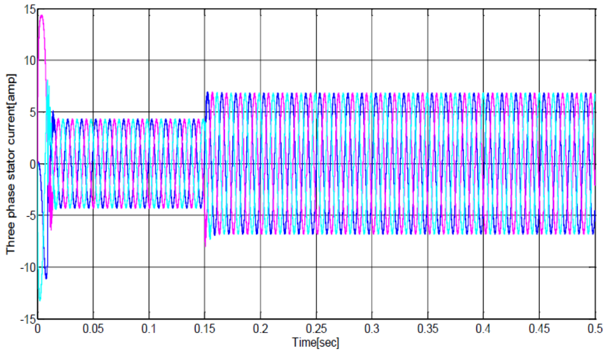


(c)

Fig. 5 Transient Response of FOC

(a) Stator current (b) Speed (C) Torque



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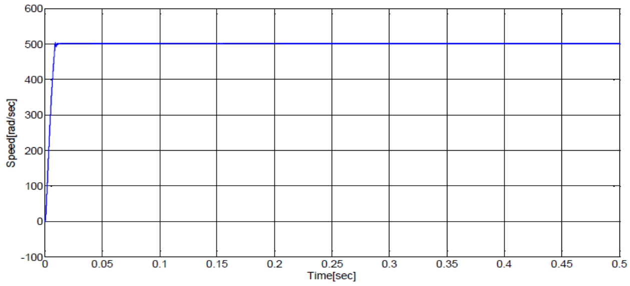

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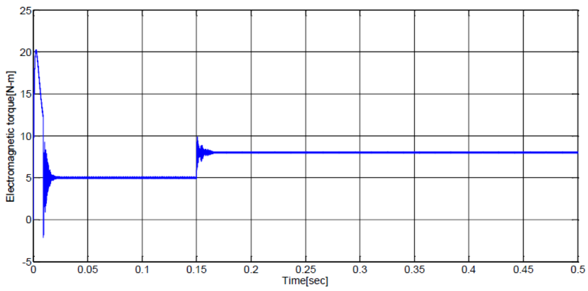
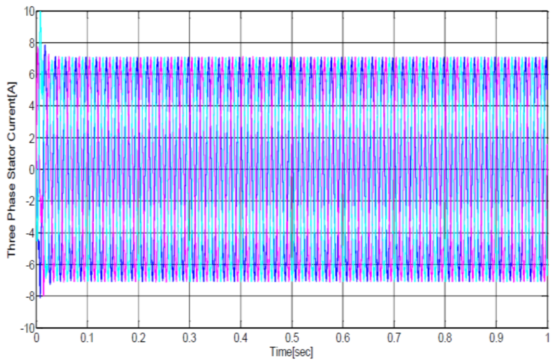


(c)

Fig. 6 Conventional DTC transient Response

(a) Stator current (b) Speed (C) Torque



(a)

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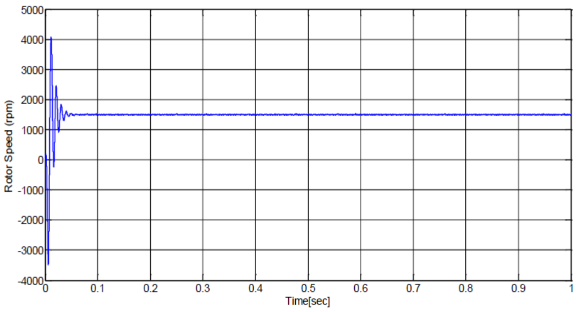

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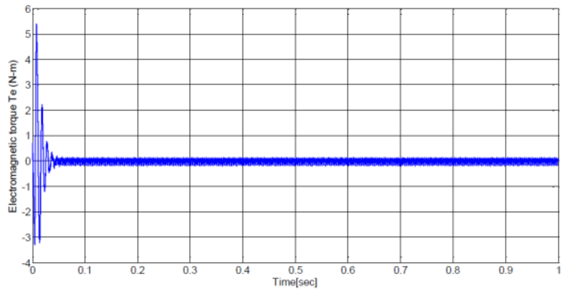

(c)

Fig. 7 Transient Response of DTC with Matrix Converter.
Conventional DTC.
(a) Stator current (b) Speed (C) Torque

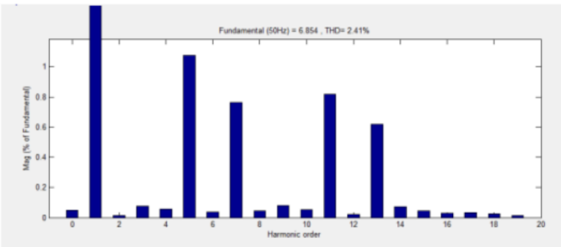

Fig.8. FFT results of DTC with Matrix Converter.

TABLE.1 Torque ripple results

Controller Speed	FOC	Conventional SVPWM	DTC with Matrix Converter
500 rpm	27.95%	30.26%	18.54%
200 rpm	18.97%	29.08%	12.85%
100 rpm	10.98%	25.58%	10.96%

TABLE.2THD results

THD	THD Results		
	PWM	***SVM***	***CBSVM***
Line Voltage	89.74%	10.89%	10.04%
Line Current	4.75%	2.33%	0.73%

V. CONCLUSION

This paper analyze the performance of drive systems by different power converters in Simulation models. The simulation results of PMSM drive systems with Matrix converter and VSI with diode rectifier are investigated for industry applications. It conclude that ,the shape of source current waveforms of the Matrix converter is the sinusoidal compared to the VSI with diode rectifier.The main advantage of the Matrix converter is to reduced torque ripples in the medium speed range. Another area of operation where the MC shows its supremacy is in the low speed range. The MC is an optimum solution for industry applications for precision control of speed and torque.

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AUTHORS PROFILE

Dr. Rakesh Shriwastava, obtained the B.E.Degree in Power Electronics Engineering from RTM Nagpur University,India in 1994. He received the M.E.Degree in Control Engineering from Walchand college of Engineering, Sangli, (MS) India in 2007. He received Ph.D Degree in Electrical Engineering specializing in power electronics and drives from RTM Nagpur University,(India) in 2017.

Retrieval Number: E6641018520/2020©BEIESP
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He occupied various positions to serve the engineering institutes for about 22 years. He is currently Working as Professor in Electrical Engineering Department of Matoshri College of Engineering & Research Center, Nashik.His research interests include results and control of electrical drives, particularly in hybrid and electric vehicle applications. He has about Number of publications in the national and international journals. He attended International and National conferences and also worked as jury member. He is a member of the professional bodies such as ISTE and IAENG.

Mr. Nandkumar Wagh, obtained his B.E. (Electronics & Power) and M.E. (EPS) degree from Govt.College of Engineering, Amravati (M.S.) in the year 1986 and 1996 respectively. He has been awarded Doctoral degree in Electrical Engineering from Maulana Azad National Institute of Technology, Bhopal (M.P.) in May2015.

He occupied various positions to serve the engineering institutes for about 30 years. He is presently working as Professor in Electrical Engineering department at Vidya Pratishthan's Kamalnayan Bajaj Institute of Engineering and Technology. Baramati (India). His research interest is in power system operation and control and the applications of AI in power system. He has about 35 publications in the national and international journals of repute and is a reviewer of international journals. He attended International and National conferences and also worked as jury member. He is a member of the professional bodies such as IE(I),ISTE,IETE and IAENG.

Mr. D.R.Bhise, obtained M.E (Electrical Power System) and B.E (Electrical Engineering) degrees from Shri Sant Gajanan Maharaj College of Engineering (SSGMCE), Shegaon 2016 and 2012 respectively. He is presently working as an Assistant Professor in Electrical Engineering Department at Matoshri College of Engineering & Research Center, Nashik.India. His area of Distributed Generation, Electrical Drives and renewable energy sources. He has published many research papers in International Journals & international conferences. . He is a member of the professional bodies such as ISRD and IAENG.