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Simulation analysis of Matrix Converter fed PMSM drive

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Abstract: In this paper, the DTC technique using matrix converter fed PMSM drive system is proposed. This reduces the torque ripples. Also it does not require the calculation of duty cycle. Instead of switching table, an improved voltage vector selection strategy used in conventional DTC Based. This paper presents a comparative analysis of FOC, conventional DTC and proposed DTC with matrix converter. The main characteristics of FOC, DTC and proposed DTC with matrix converter (MC) method are studied by simulation with their advantages and limitations. The in depth transient analysis of three control methods is performed in terms of ripples in torque, current and also in speed which has shown that the proposed method will improve the performance by combining a low torque & current ripple characteristics along with the faster torque response.

Keywords: DTC, Matrix converter (MC), PMSM, SVM.

1.1 Introduction

The Adjustable Speed Drives are widely employed in application such as elevators, electric vehicles and hybrid electric vehicles, pumps, etc. [1]-[2]

Electric vehicles are the part of Electric propulsion systems, which functions as internal combustion engine in Conventional vehicle. As 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 which requires high dynamic performance. Currently, a high-performance control technique, called DTC has also been investigated [5]-[7]. The main advantages of DTC as Compared with FOC is faster torque response and good flux regulation, removal of current regulators and PWM generators, robustness to rotor parameters variation. Furthermore, all calculations are implemented in stationary reference frame.[8]-[9]. Despite the merits mentioned above, DTC also presents some drawbacks, including high torque ripple and varying switching frequency [10]. 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. But switching table can’t control the torque. Thus to get proper voltage vector selection method is complicated to suppress torque ripple. Some voltage vector selection methods were proposed. 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 SVPWM is primarily used as the drive controller for the PMSM motor.

1.2 Mathematical model of a PMSM

In mathematical model of a PMSM, the rotor of synchronous motor is replaced with high resistivity PM material. Due to this the induced current in the rotor are nearly equal to zero. The PMSM model equations are

$V_d = RI_d + L_d(dI_d/dt) - P\omega L_q I_q$ (1)
$V_q = RI_q + L_q(dI_q/dt) + P\omega L_d I_d + P\omega\lambda_f$ (2)
$T_e = T_L + B\omega + J_m(d\omega/dt)$ (3)
$T_e = K_t I_q + (3/2)P\,(L_d - L_q)I_d I_q$ (4)
For SMPM, the direct & quadrature components of the inductances are the same.
Hence $Te = K_t I_q$ (5)
$K_t = (3/2)P\,\lambda_f$ (6)

$$\begin{bmatrix} Vq \\ Vd \\ Vo \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos(\theta - 2\pi/3) & \cos(\theta + 2\pi/3) \\ \sin\theta & \sin(\theta - 2\pi/3) & \sin(\theta + 2\pi/3) \\ 1/2 & 1/2 & 1/2 \end{bmatrix}$$

The inverse Parks transformation is given by:

$$\begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta - 2\pi/3) & \sin(\theta - 2\pi/3) & 1 \\ \cos(\theta + 2\pi/3) & \sin(\theta + 2\pi/3) & 1 \end{bmatrix} . \begin{bmatrix} Vq \\ Vd \\ Vo \end{bmatrix}$$

For a balanced system the power equation is:

$V_a I_a + V_b I_b + V_c I_c = (3/2)(V_d I_d + V_q I_q)$ (7)

1.2.1 Principles of FOC

In FOC the angle between rotor and stator field components is 90°. For above 90° it referred as field angle control. The motor torque is dependent upon the stator current which has the components *id* and *iq*. It is possible to control motor torque by *id* and *iq*. Current id is for excitation. *id = 0* is set for the control strategy. Let *id = 0,* through control the *iq,* we are achieving Maximum torque control in the PMSM vector control can be achieved by controlling *iq* and *id = 0.*

The principle of the FOC is based on an analogy to the separate excited d.c motor. FOC of PMSM is an important variation of vector control methods. In FOC the magnetic field and electromagnetic torque are controlled by the d and q axes components of the stator currents. This method can effectively control the motor torque and the flux by using information received from the stator reference currents and the rotor angle. To maintain the amplitude of the rotor flux linkage Ψ_r at a constant value is the main objective of FOC, without field weakening operation and to modify a torque-producing q component for controlling the torque of the alternating machine. This control method is projection based. quadrature -axis current controls electromagnetic torque.

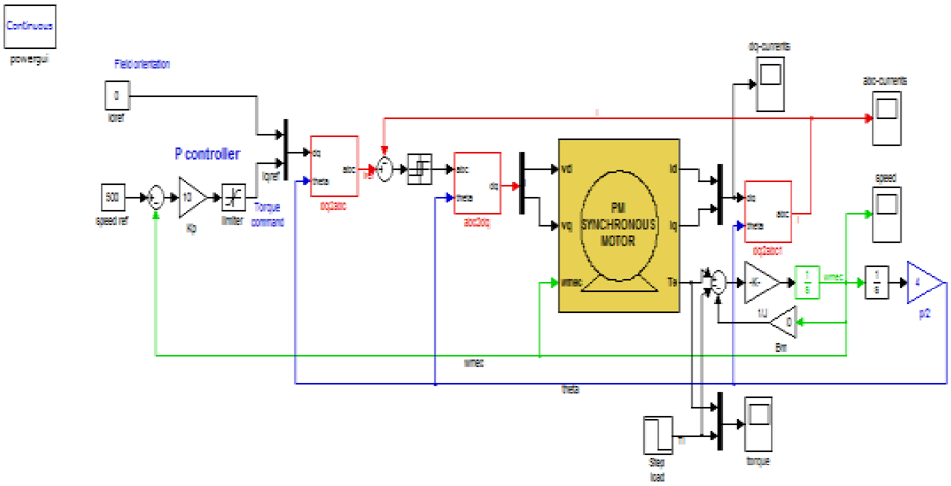

Fig.1.1. Simulink Block Diagram of FOC

1.2.2 Principles of DTC

The basic objective of DTC is controlling the stator flux vector in amplitude and angular position. Let λ_s & λ_r *are the* flux linkage vector in stator and rotor in d-q coordinate. The torque and flux estimator are used in DTC-SVM as a hysteresis comparators which calculates the correct voltage vector for torque and flux errors. By using Clarke transformation, the measured currents are transformed to α-β.

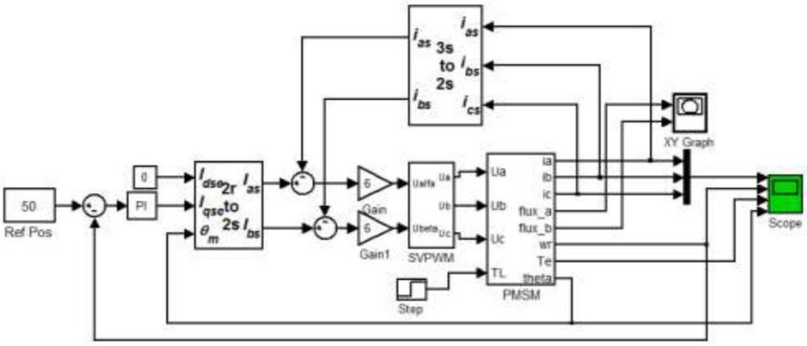

Fig.1.2. Simulink Block Diagram of SVM-DTC

1.2.3 Proposed DTC with Matrix Converter Circuit

Vector-switching topology is 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 1.1 shows the switching operation for switch TA1 to TC3 .

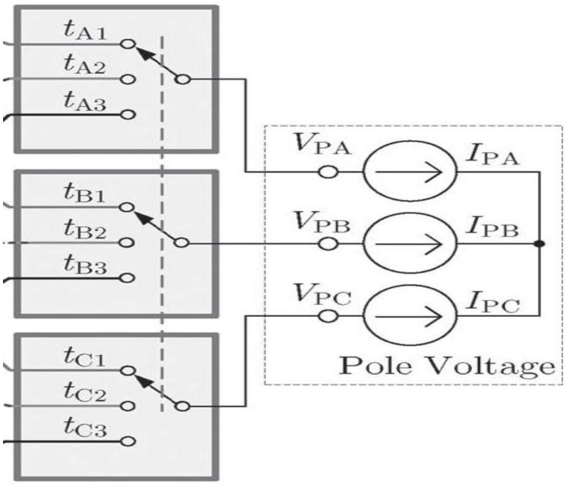

Fig.1.3. Switching logic of vector switching matrix converter

Table 1.1. Switching Operation of Matrix Converter

Switches	Zero sequence	*Positive sequence*	*Negative sequence*
TA1	ON	OFF	OFF
TA2	OFF	ON	OFF
TA3	OFF	OFF	ON
TB1	ON	OFF	OFF
TB2	OFF	ON	OFF
TB3	OFF	OFF	ON
TC1	ON	OFF	OFF
TC2	OFF	ON	OFF
TC3	OFF	OFF	ON

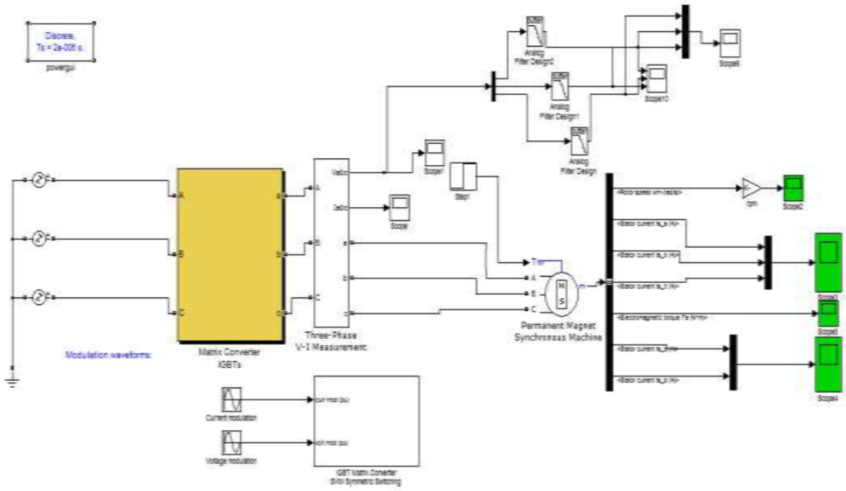

Fig.1.4. Simulink Block diagram of DTC with Matrix Converter

1.3. Simulation and results

The simulation of DTC with Matrix Converter of PMSM are performed using MATLAB/Simulink. The rotor speeds is the inputs the stator current & electromagnetic torque are the outputs.

1.3.1Transient Performance

The transient response of the each of the three control methods of permanent magnet synchronous motor are evaluated by simulating step changes in the torque responses. Fig1.5.1.6 & 1.7 illustrates the torque responses obtained using FOC, conventional DTC and proposed DTC with matrix converter (MC) at 500rpm.Table1.1.shows Matrix Converter.Table1.2 shows the torque ripple analysis of Permanent Magnet Synchronous Motor at different speed & Table1.3 shows that specification PMSM specification.

Torque ripple analysis of FOC, Conventional DTC, Proposed DTC with Matrix Converter. Calculated by formula

Torque Ripple (%) = $(Tmax - Tmin\ )/Tavg * 100$

Table 1.2. Torque Ripples analysis

Controller Speed	FOC	Conventional SVPWM	DTC with Matrix Converter
100 rpm	27.9538%	30.2601%	18.5449%
200 rpm	18.9723%	29.0872%	12.8531%
500 rpm	10.9823%	25.5832%	10.9628%

Table 1.3. Specification of PMSM

Sr. No.	PMSM Parameter	Value
1.	Stator Resistance Rs	2.875Ω
2.	d-axis Inductance Ld	8.5x10^{-3}H
3.	q-axis Inductance Lq	8.5x10^{-3} H
4.	Permanent Magnet Flux	0.175Wb
5.	No of Pole pairs	4
6.	Torque	0.051Nm
7.	Movement of Inertia(J)	2.26x10^{-5}Kg/m^{2}
8.	Viscous coefficient(f)	1.349x10^{-5}Nms

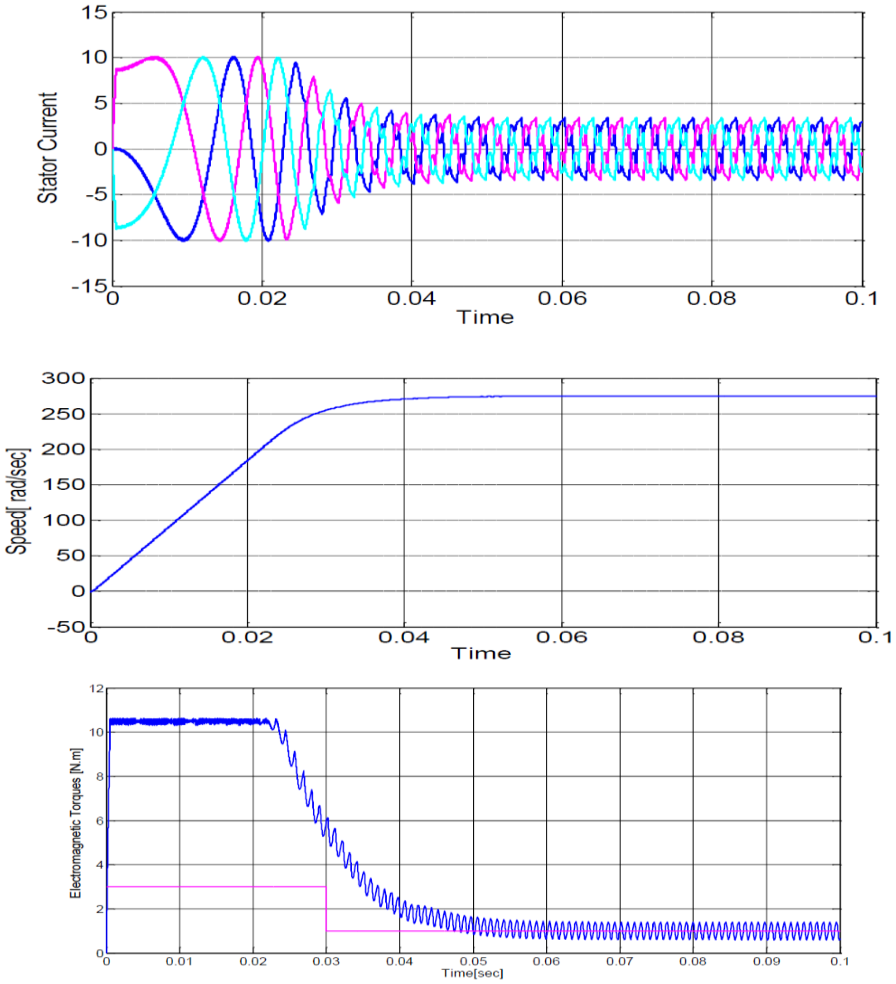

Fig.1.5. Transient Response of FOC

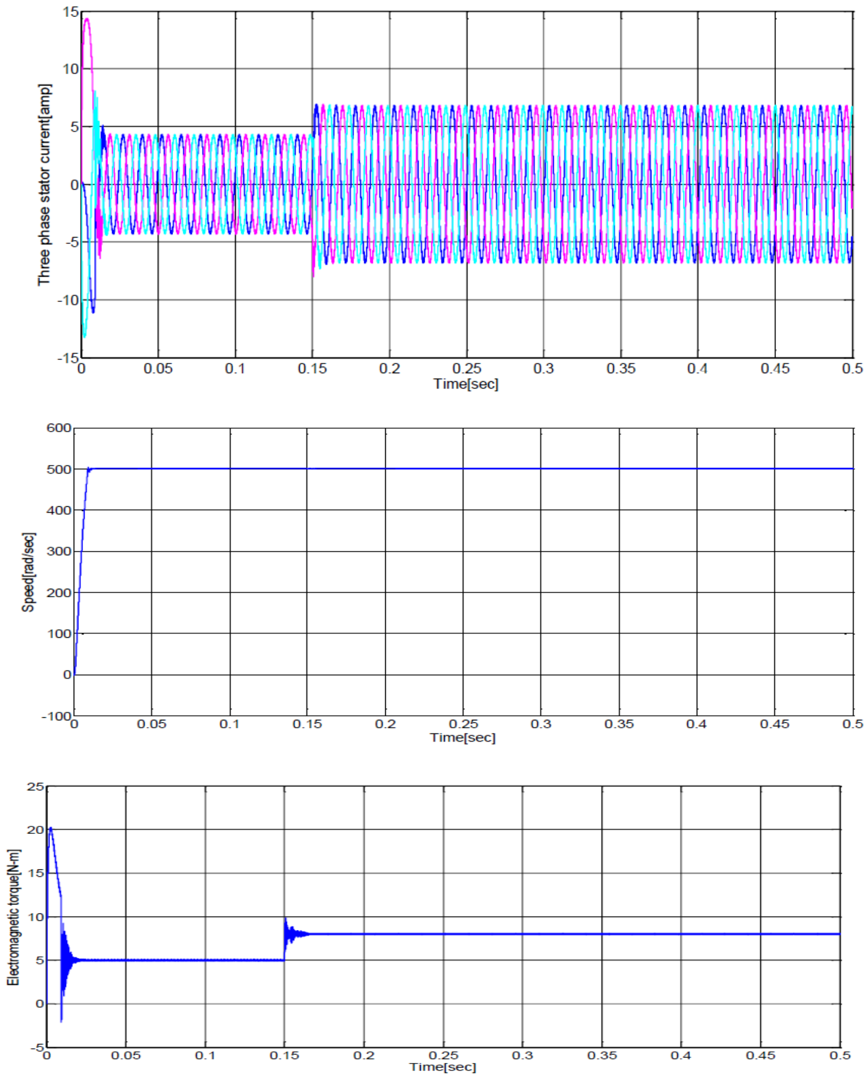

Fig.1.6. Transient Response of conventional DTC

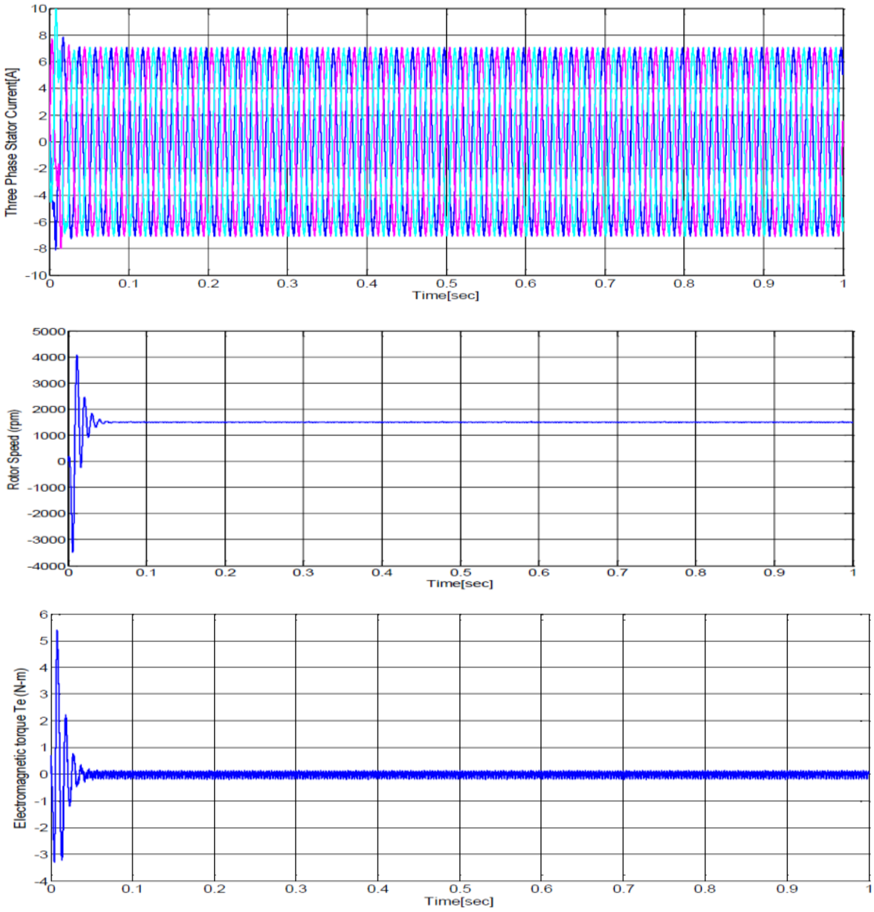

Fig.1.7. Transient Response of DTC with Matrix Converter.

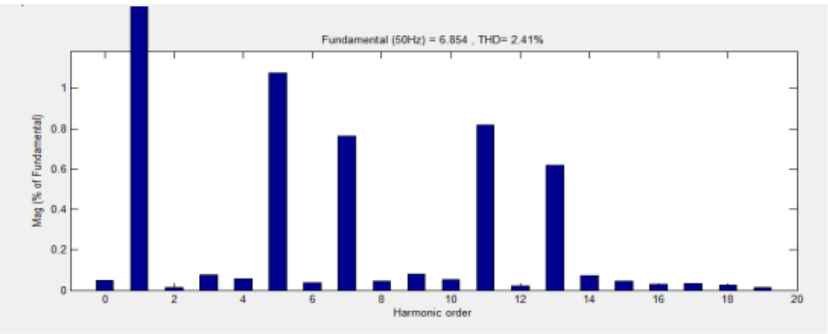

Fig.1.8..FFT analysis of DTC with Matrix Converter.

1.4. Conclusion

This paper shows a comparison between three torque control methods for PMSM drive. The description of three control method and their principle of operation have been presented. DTC was DTC is developed as an alternative to FOC.The proposed DTC with matrix converter (MC) combines the best features of the DTC such as fast dynamic response as DTC and low steady state torque ripple and compared to FOC. The proposed methodology has improved torque response. The FFT analysis of DTC with Matrix Converter is 2.41% as shown in fig.1.8.It is very less as compare to FOC, conventional DTC.

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