Implementation of DTC-Controlled PMSM Driven By A Matrix Converter

Rakesh G. Shriwastava, Nandkumar B. Wagh, 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-performance control technique, called DTC has also been investigated [5]-[7]. The DTC has more advantages as compared to 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.

II. MATHEMATICAL MODEL OF PMSM

The PMSM model equations are:

\[ V_d = R_I d + L_I d (dI_d / dt) - P \omega L_q I_q \]  
\[ V_q = R_I q + L_I q (dI_q / dt) + P \omega L_d I_d + P \omega \lambda_f \]  
\[ T_e = T_e + B \omega + J_m (d\omega / dt) \]  
\[ T_e = K_I I_q + (3/2) P \lambda_f \]  

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

\[ T_e = K_i I_q \]  
\[ K_i = (3/2) P \lambda_f \]  

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

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

The inverse Parks transformation is defined below:

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

For a balanced system the power equation is:
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\[ V_a I_a + V_b I_b + V_c I_c = (3/2)(V_d I_d + V_q I_q) \]  \hspace{1cm} (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 \(a-\beta\) 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 \(i_d = 0\). 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 \(\lambda_s\) be the flux linkage vector in stator and \(\lambda_r\) 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 \(a-\beta\).

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 \(V_{\text{ref}}\) is compared with a carrier waveform \(V_c\). 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

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.

\[ L_d=0.006365\, \text{H}; \quad L_q=0.006365\, \text{H}; \quad R=1.6\, \Omega; \]
\[ PM_{\text{flux}}=0.1852\, \text{Wb}; \quad P=2; \quad F=0.00005396\, \text{Nm.s}; \]
\[ J=0.001854\, \text{Kgm}^2 \]

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 500 rpm. Table I & table II shows the torque ripple & THD results of PMSM at different speed.

\[ \% \text{Torque ripple} = \left( \frac{T_{\text{max}} - T_{\text{min}}}{T_{\text{avg}}} \right) \times 100 \]
Fig. 5 Transient Response of FOC
(a) Stator current (b) Speed (C) Torque

Fig. 6 Conventional DTC transient Response
(a) Stator current (b) Speed (C) Torque
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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

<table>
<thead>
<tr>
<th>Controller Speed</th>
<th>FOC</th>
<th>Conventional SVPWM</th>
<th>DTC with Matrix Converter</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 rpm</td>
<td>27.95%</td>
<td>30.26%</td>
<td>18.54%</td>
</tr>
<tr>
<td>200 rpm</td>
<td>18.97%</td>
<td>29.08%</td>
<td>12.85%</td>
</tr>
<tr>
<td>100 rpm</td>
<td>10.98%</td>
<td>25.58%</td>
<td>10.96%</td>
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TABLE.2 THD results

<table>
<thead>
<tr>
<th>THD</th>
<th>PWM</th>
<th>SVM</th>
<th>CBSVM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line Voltage</td>
<td>89.74%</td>
<td>10.89%</td>
<td>10.04%</td>
</tr>
<tr>
<td>Line Current</td>
<td>4.75%</td>
<td>2.33%</td>
<td>0.73%</td>
</tr>
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</table>

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.

REFERENCES

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