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Direct Torque Control based SVPWM Technique for Permanent Magnet Synchronous Motor Drives using Torque and Flux linkage Estimators

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ABSTRACT

A new approach to improve the performance of PMSM dynamically, a Direct Torque Control (DTC-SVM) scheme of Permanent Magnet Synchronous Motor (PMSM) is vividly presented in this paper. Based on valid depth technical analysis of PMSM mathematical model and the operating principle of Direct torque control system, MATLAB/ Simulink is used to establish a simulation model of this system, and extensive research of simulation is conducted to present in this paper. An efficient control technique called DTC-SVM for a PMSM is studied and simulated and the results are validated using MATLAB/SIMULINK environment which are clearly present in this paper which has fast response and good dynamic performance.

Key words: Direct torque control, PMSM drives, inverter, DTC-SVPWM technique, flux linkage estimation

1. INTRODUCTION

In past few decades, Permanent magnet synchronous motors (PMSM) has become a very interesting motor for the fast-ranging applications in motor drives, because of its properties such as high efficiency, less weight, fast dynamic response, high power factor and low rotor inertia.
Field oriented control (FOC) scheme is also used to improve the characteristics of the motor to reduce the order of torque equation [1]. FOC also involves tedious work when compared to DTC. Hence, Steady state response has better characteristics if FOC is used, Dynamic response is better is characteristics if DTC is used. Therefore, DTC includes high torque ripples in steady state response [10]. The direct torque control approach controls the stator flux and the Electromagnetic torque simultaneously using the hysteresis controllers and PI (Proportional Integral) blocks.
After the vector control of AC drives (which includes Field oriented control), the new technique which has come into existence is Direct Torque control (DTC) which does not include any current controlled closed loops [2],[3]. The DTC technique involves the operation of look up tables which uses the data from hysteresis control loops. The decoupling thought which is present in the Vector control is totally eliminated in the DTC technique and the stator flux linkage is directly used to control the flux and torque of the PMSM.
But the traditional DTC, does not meet the system requirements of both flux linkage and torque simultaneously which leads to large fluctuations in flux and torque which in turn are responsible for high noise generation due to higher switching frequency [7].
Due to some potential advantages of Space vector pulse width modulation (SVPWM) technique it is widely used in the area of motor speed control [4], they are constant switching frequency of the inverter, small distortion in current waveform and reducing torque ripples [5].
Now-a-days the direct torque control is implement on AC machines without sensors and decoders given in [6].
The concept of SVPWM inverter used in the paper can also be replaced with a Multi-level DC link inverter with reduced switch count which reduces the number of heatsinks and gate driver circuits [8]. A tens witch topology UPQC connected for AC machines can also reduce the switching losses [9]

The concept implemented in this paper is DTC-SVPWM technique for a PMSM motor drive which has advantage of fast response and good dynamic performance.

2. MODELING OF PMSM MACHINE

Dynamic model of PMSM Machine:

The three Phase stator currents system with angular frequency w_0 can be defined in a fixed three phase coordinate frame as

$$I_a = I \sin (w_0 t)$$

$I_b = I \sin (w_0 t+2*\pi/3)$

$I_c = I \sin (w_0 t+4*\pi/3)$

The transformation from three phase to two phase systems for stator currents is described by

$I_s = 2/3\ (i_a + a i_b + a^2 i_c)$

Where $a = e^{j2\pi/3}$, $a^2 = e^{j4\pi/3}$

Electrical system equations:

Considering a salient pole machine where L_d (Direct axis inductance) is not equal to (Quadrature Axis inductance) L_q

$V_q = R_s i_q + L_q * (dI_q/dt) + L_d\ \omega_r\ I_d + \lambda_f\ \omega_r$ -------------(1)

$V_d = R_s i_d + L_d * (dI_d/dt) – L_q\ \omega_r\ I_q$ ----------------------(2)

From equations (1) and (2) we get the values of I_q and I_d

$I_q = \int\{ (V_q / L_q) – (\lambda_f\ \omega_e/L_q) – (\omega_e L_d I_d/L_q) – (R_s I_q/L_q)\}dt$—(3)

$I_d = \int\{ (V_d / L_d) + (\omega_e L_q I_q/L_d) – (R_s I_d/L_d)\}dt$-------------------(4)

Equations (3) and (4) which are to be build in MATLAB environment as shown in figure 1 and 2 respectively

$= L_m (i_r \times i_s)$

$= L_m/L_r (f_r \times i_s)$

Therefore, by using the above equations model of Induction machine is created in Simulink 9.3 as shown in figure 1.

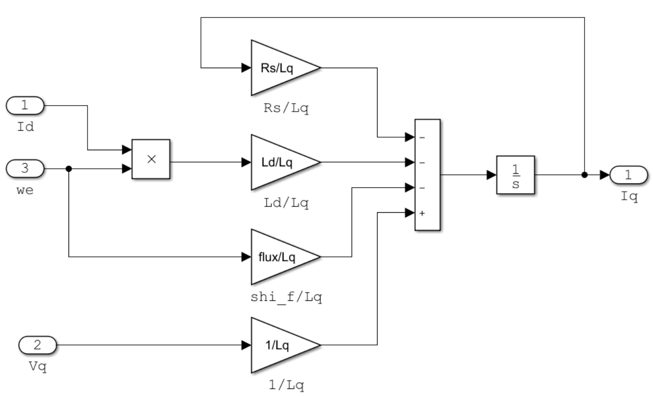

Figure 1: Calculation of I_q(Electrical)

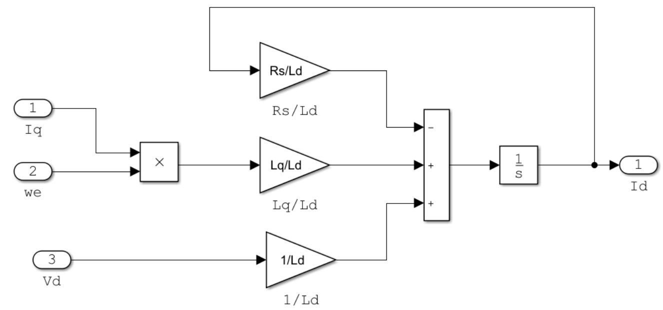

Figure 2: Calculation of I_d (Electrical)

Mechanical system equations:

$J* d\omega_m/dt + B*\omega_m = T_e - T_m$ ----(5)

$\omega_m * P/2 = \omega_m$ -------(6)

$\int\omega_e\ dt = \Theta$ ---------(7)

From Equation 5 we get

$\omega_m = \int(- B\ \omega_m + T_e – T_m) * 1/T\ dt$ --------------(8)

Hence from the above equation, the mechanical block of the PMSM is implemented in MATLAB Simulink Environment as shown in figure 3.

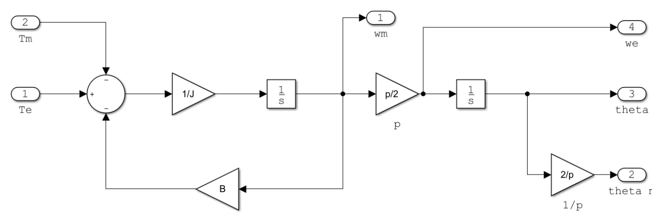

Figure 3: Mechanical model of PMSM

3. PROPOSED CIRCUIT DIAGRAM

The proposed circuit is simulated in MATLAB Simulink 9.3 and the brief model is as shown in figure 4.

Referring to the figure 4, there are blocks namely torque estimator, flux linkage estimator and Voltage estimator which are implemented separately in MATLAB/SIMULINK environment.

The closed loop operation can be explained from the figure 4, where the speed of the machine is fed back to the voltage estimator circuit using PI controllers. The stator currents I_a I_b and I_c are fed back through the torque estimators and flux linkage estimator blocks,

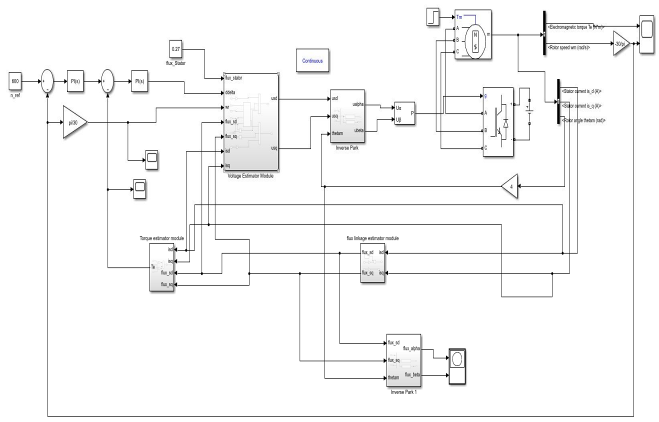

Figure 4: Proposed Circuit Diagram of PMSM Control (DTC-SVPWM)

The torque equation is given by

$T_e = 6*(flux\_sd * i_{sq} – flux\_sq * i_{sd})$ ---------------(9)

The detailed circuit of Torque estimator is shown in the figure 5.

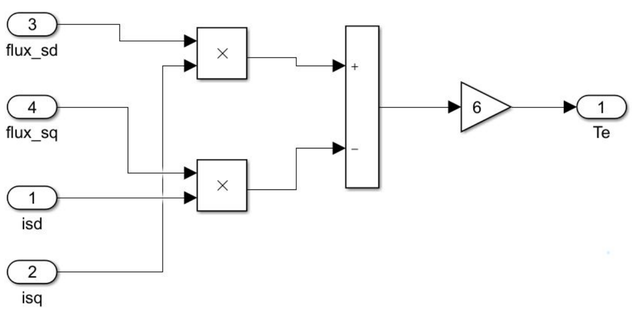

Figure 5: Torque Estimator block

The flux estimator block is implemented in MATLAB/SIMULINK by using the following equations.
$flux\_sq = L_q * i_{sq}$ -----------------------------(10)
$flux\_sd = L_d * i_{sd} + flux\_Rotor$ -------------(11)

The detailed circuit of flux linkage estimator is shown in the figure 6.

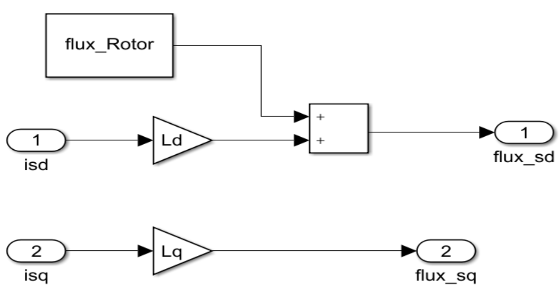

Figure 6: Flux Linkage estimator block

4. SIMULATION RESULTS

The torque and speed curves are shown in figure 7.

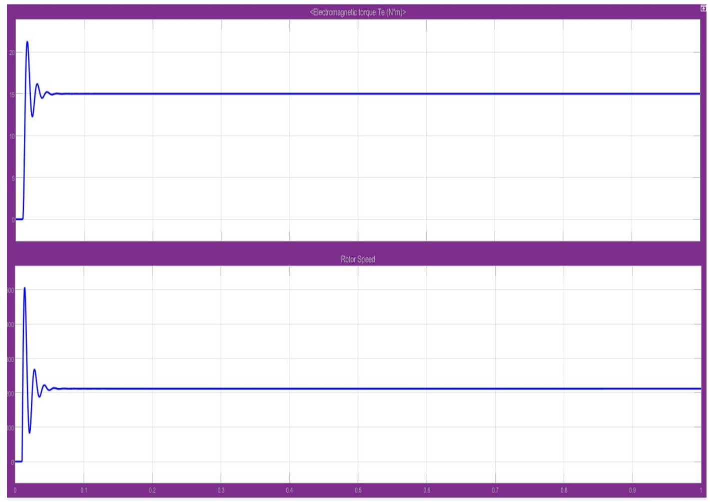

Figure 7: Torque and Speed of the PMSM machine

The relation between torque and speed of PMSM machine is described in the mechanical system of machine model. The torque load of 15 Nm on induction motor is given at 0.01seconds.
The direct axis current and quadrature axis currents are shown in the figure 8.

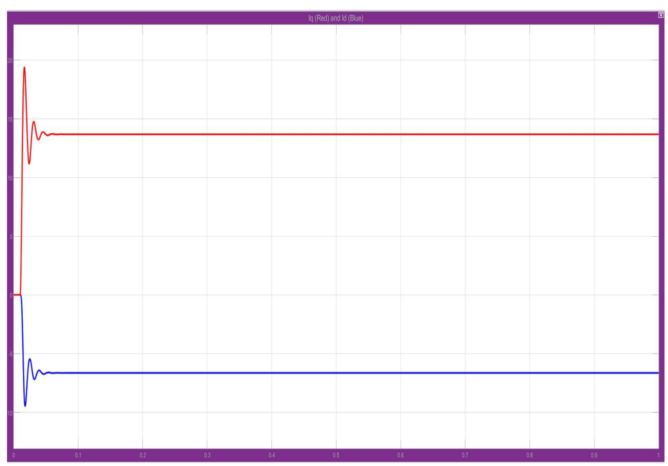

Figure 8: Iq and Id of the PMSM

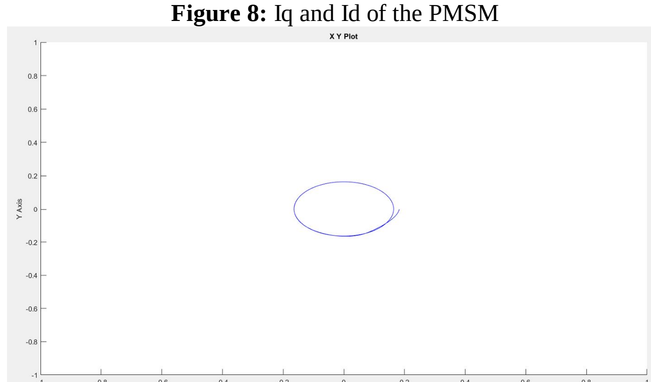

Figure 8: Graph between flux_aplha and flux_beta

5.CONCLUSION

In this paper, a new direct torque control SVPWM method is presented. The features of the proposed direct torque control method include providing constant inverter switching frequency and significantly reducing the torque and speed ripple. The flux and torque Estimator is used to estimate the torque and flux of the machine and the estimated speed is fed back to the DTC controller by using PI controllers. Various transformation techniques are involved to model the induction motor Electrical and Mechanical. The speed of the PMSM machine can be controlled directly by using torque or stator flux in the proposed model and the simulation results are explained very clearly.

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