DTC PERMANENT MAGNET SYNCHRONOUS GENERATOR

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Abstract
The direct torque control technique has achieved great success in the control of induction motor. Many attempts have been made to implement the idea of DTC of induction motor to PMSM since 1990's. The DTC is implemented by selecting the proper voltage vector according to the switching status of inverter which was determined by the error signals of reference flux linkage and torque with their measured real value acquired by calculating in the stationary reference frame by means of simply detecting the motor voltage or currents. Aiming at the DTC in PMSM Drives, this paper explained the theoretical basis of the direct torque control (DTC) for PMSM. Finally the Matlab /Simulink models were developed to examine the DTC for PMSM. The simulation results is presented and explained in detail.

Keywords: Direct Torque Control; Permanent Magnet synchronous Motor; stationary reference frame .

1. INTRODUCTION

The original concept of DTC was proposed by Takahashi and Noguchi i n 1986 for application in Induction Motors. Their idea was to control the stator flux linkage and the torque directly, not via controlling the stator current. This was accomplished by controlling the power switches directly using the outputs of hysteresis comparators for the torque and the modulus of the stator flux linkage and selecting an appropriate voltage vector from a predefined switching table. The table was called the 'optimum switching table". The measurement of the rotor angle was not used.

A same kind of control was proposed by Depenbrock (1987).At first , Takahashi and Noguchi did not give any name to their new control principle. In a later paper by Takahasi and Ohmori (1987) the control system was named the direct torque control (DTC).Depen brock called his control method Direct Self Control , DSC. Tiitenen et al discussed the first industrial application of the DTC. After that, the number of papers on the DTC has grown tremendously on different aspects of the DTC for asynchronous motors. In recent years there has been interest to apply the DTC to permanent magnet synchronous motors.

L. Zhong et al discussed the implementation of DTC in PMSM Drives. In 1998, Rahman et al proposed a DTC scheme for a wide speed range operation of an interior PMSM drive. The proposed scheme possesses some attractive features compared to the conventional current-controlled drives like field oriented control (FOC). Later on, Tang et al proposed a DTC control schemes for the IPM featuring almost fixed switching frequency.

In 2002, Rahman et al, proposed a completely sensorless DTC control for an IPM drive, which uses a new speed estimator from the stator flux linkage vector and the torque angle. To reduce the torque ripples, Sun et al proposed a fuzzy logic algorithm to refine the selection of the voltage vectors. Today, the DTC has become an accepted control method beside the field oriented control.

2. SYSTEM MODEL

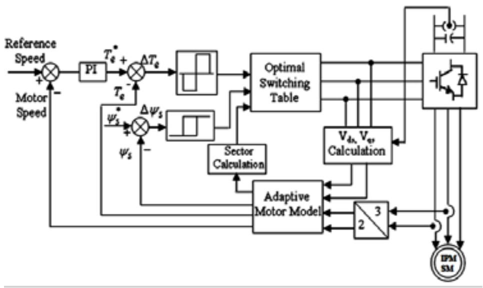

Figure 1 Block Diagram of the basic DTC for PMSM

The basic DTC scheme is indicated in figure 1, torque and flux signals are obtained from the estimator. These are regulated by using two hysteresis controllers. The hysteresis controller's outputs in turn switch the three inverter legs, applying a set of voltage vectors across the motor. In the DTC there are no extra sensors needed compared to FOC except the dc- bus voltage sensors. The continuous rotor position which is essential for torque control in the FOC is not required if the initial rotor position is known.

TABLE II
SWITCHING TABLE

Flux Φ	**Torque τ**	**θ -Section (stator flux linkage**					
		θ1	**θ2**	**θ3**	**θ4**	**θ5**	**θ6**
φ= 1	τ = 1	V2 11-1	V3 -11-1	V4 -111	V5 -1-11	V6 1-11	V1 1-1-1
	τ = 0	V7 111	V0 -1-1-1	V7 111	V0 -1-1-1	V7 111	V0 -1-1-1
	τ = -1	V4 -111	V5 -1-11	V6 1-11	V1 1-1-1	V2 11-1	V3 -11-1
φ= 0	τ = 1	V1 1-1-1	V2 11-1	V3 -11-1	V4 -111	V5 -1-11	V6 1-11
	τ = 0	V0 -1-1-1	V7 111	V0 -1-1-1	V7 111	V0 -1-1-1	V7 111
	τ = -1	V5 -1-11	V6 1-11	V1 1-1-1	V2 11-1	V3 -11-1	V4 -111

The hysteresis comparator states, φ and τ, together with the section number θ, are now used by the switching table block to choose an appropriate voltage vector. The switching table used in this project is shown in Table 1. A high hysteresis state increases the corresponding quantity and vice versa. The selected voltage vector is sent to the Voltage Source Inverter then synthesized.

3. SIMULATION MODEL

The simulation models of PMSM with DTC are programmed in Matlab Simulink. The simulation models are presented and discussed. The PMSM parameter used in this project are given in

Table 2: Parameter Values of PMSM used in Simulation

Resistance Rs(ohm)	2.875Ω
Inductance [Ld,]H	0.185 H
Inductance [Lq,]H	0.069H
Flux Induced by magnets	0.175
Inertia[Jkgm^2]	0.0008
Friction factor	0.0001
Pairs of pole	8

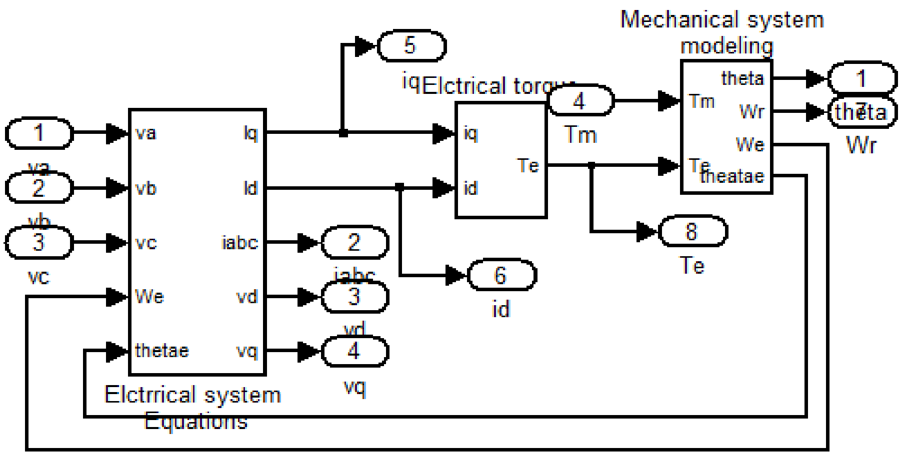

Figure 2 Simulink Block of PMSM

Figure 2 Shows the Matlab/Simulink Modeling Block of PMSM. This can be modeled using Electrical and Mechanical System of Equations, and Electrical Torque Equation. Electrical System of Equations Modeling Block contains Parks Transformation (abc to dq/dq to abc), Direct Axis Current (i_d), quadrature Axis Current (i_q) Modeling Equations. All Equations are Chosen With respect to Stationary Reference Frame.

Figure 3 was modeled using below System of Equations

$$\frac{di_q}{dt} = \frac{v_q - Ri_q - \omega_r L_d i_d - \omega_r \psi_f}{L_q} \quad (1)$$

$$\frac{di_d}{dt} = \frac{v_d - Ri_d + \omega_r L_q i_q}{L_d} \quad (2)$$

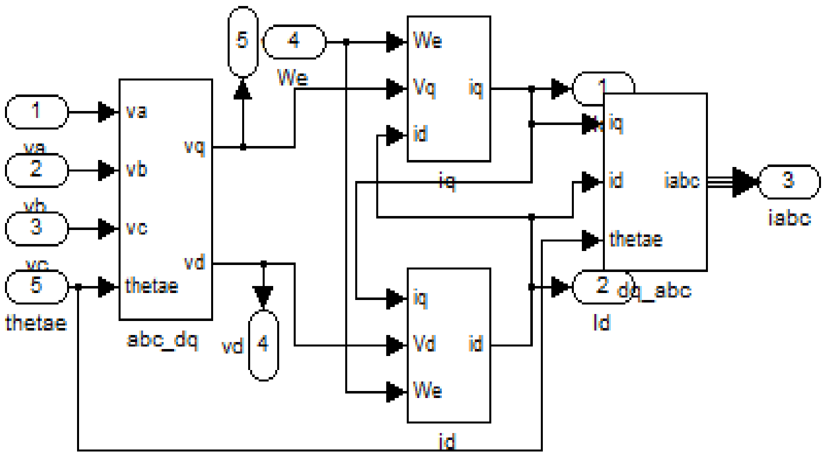

Figure 3 Simulink Block of Electrical System of Equations

Figure 4 was modeled using below System of Equations i.e. Electrical Torque and Mechanical System of Equations.

$$T_e = \frac{3P[\psi_f i_q + (L_d - L_q) i_d i_q]}{2} \quad (3)$$

$$\frac{d\omega_m}{dt} = \frac{T_e - B\omega_m - T_l}{J} \quad (4)$$

$$= \omega_m \quad (5)$$

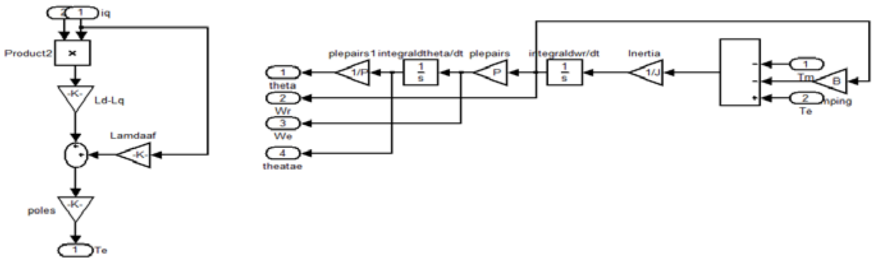

Figure 4 Simulink Block of Electrical Torque and Mechanical System of Equations

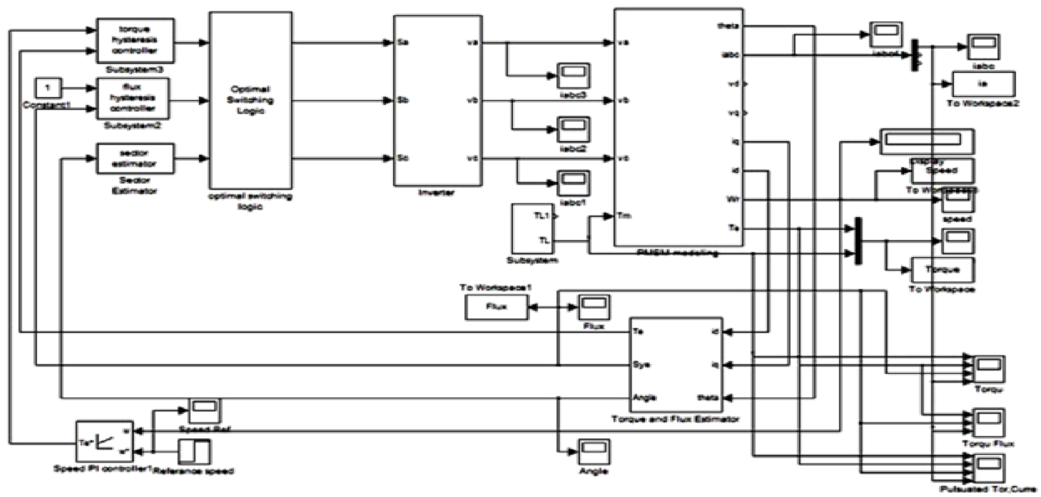

Figure 5 Simulink Block of DTC for PMSM

Figure 5 shows the Matlab/Simulink Block of DTC for PMSM. This contains Mainly Torque and Flux Estimator, Torque and Flux Hysteresis Controller, Optimal Switching Logic and Voltage Source Inverter (VSI).Torque. Optimal Switching Logic table implemented using Table 1. Optimal Switching Logic Generating pulses to inverter depending upon Torque and Flux errors Generated by Torque and Flux Hysteresis Controllers.

4. RESULTS AND DISCUSSIONS

Matlab/Simulink models were developed to examine the basic Direct Torque Control for Permanent Magnet Synchronous Motor. The simulation results presents the steady-state performance of DTC systems with PMSM. The waveforms are flux linkage, torque and Current respectively. The reference torque given is 2NM and the reference stator flux linkage is set at the rated value 0.5Web.

4.1. DTC performance of PMSM with reference torque is 2NM and rated flux linkage is 0.5Web

The PMSM parameter used for this simulation table 2 .The torque and flux linkage reference is set at 2 N M and 0.5Web respectively. The waveforms of torque, flux, current are presented to show the performance of DTC in PMSM. Figure 6 shows the actual flux, torque and is about the reference values. There are ripples exist in both waveforms. Torque waveform settled at -2NM to 2NM and flux waveform settled at 0.5 Web. Harmonics are present in the current waveform and it is settled between -40 to 40 Amps.

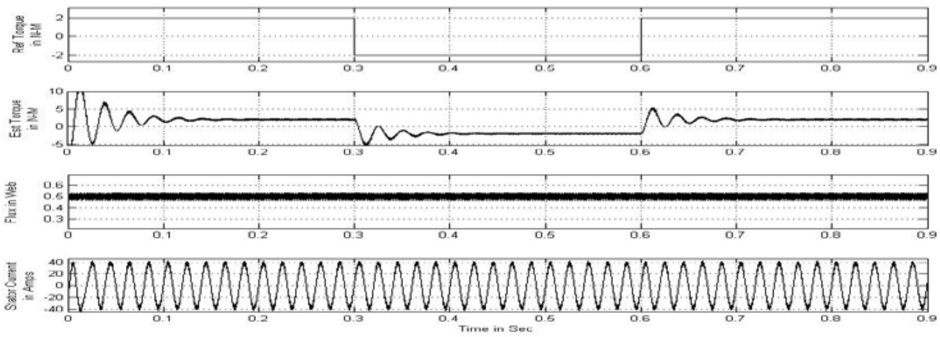

Figure 6 The Waveform of Reference Torque, Developed Torque, Stator flux linkage, Stator Current of the PMSM. Tref at -2NM to 2NM and 0.5 Web flux linkage

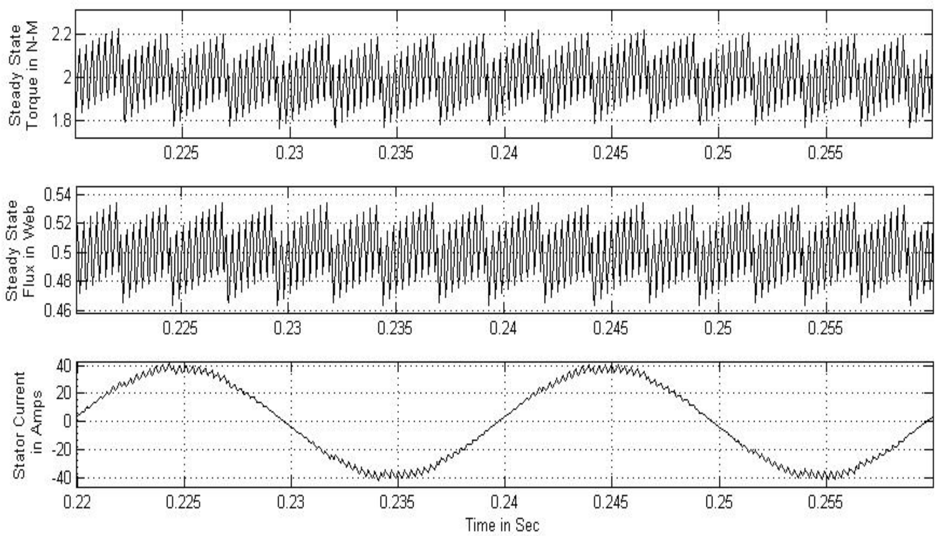

Figure 7 The Waveform of Developed Torque, Stator flux linkage, Stator Current of the PMSM. Tref at -2NM to 2NM and 0.5Web flux linkage in Steady State Condition.

Figure 7 shows the actual flux, torque and is about the reference values in Steady state condition. There are ripples exist in both waveforms. In torque waveform ripple content varies between 1.8NM to 2.2NM. In flux waveform ripple content varies between 0.47Web to 0.53Web.

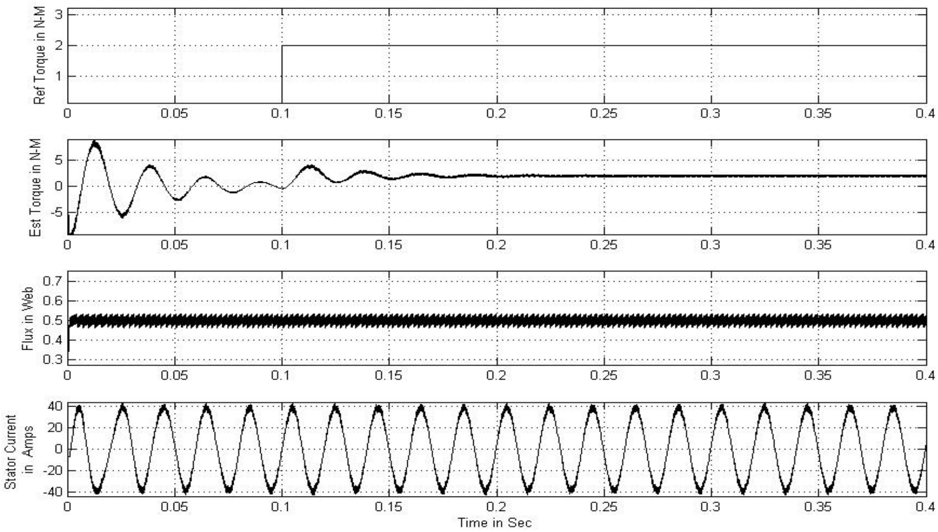

Figure 8 The Waveform of Reference Torque, Developed Torque, Stator flux linkage, Stator Current of the PMSM. Tref at 2NM with time delay of 0.1 sec and 0.5Web flux linkage.

Figure 8 shows the actual flux, torque and is about the reference values. There are ripples exist in both waveforms. Torque waveform settled at 2NM and flux waveform settled at 0.5 Web. Harmonics are present in the current waveform and it is settled between -40 to 40 Amps.

CONCLUSION

In this paper explained the mathematical equations related to the application of DTC in PMSM. The equations show that the change of torque can be controlled by keeping the amplitude of the stator flux linkage constant and increasing the rotating speed of the stator flux linkage as fast as possible. The amplitude and rotating speed of the stator flux linkage can be controlled by selecting the proper stator voltage vectors. The Simulink block of DTC in PMSM is presented. The simulation results examined the implementation of the direct torque control in permanent magnet synchronous motor. By the introduction of DTC a lot of research has been done to improve the performance of DTC drives while maintaining the good properties such as low complexity, good dynamic response, high robustness.

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