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The Modeling and Simulation of Improved DTC of PMSM Drives using Matlab/Simulink

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Abstract

Permanent Magnet Synchronous Motor offers many advantages over the induction machine, DC motor and synchronous motor. The PMSM has lower inertia, higher efficiency and power density, smaller losses and more compact motor size. Because of the advantages, PMSM are indeed excellent for use in many applications. Usually, the AC machine control technique can be classified as scalar control and vector control. The AC machine vector controlled drives are used in various drive applications since they offer high dynamic performance. Field oriented control and direct torque control stand out as the foremost vector control methodologies in widespread use. The DTC method has more advantages such as lower parameter dependency and lower complexity of control structure compared to the FOC. The DTC is not use current controller and not depend motor parameters. DTC offers rapid and accurate torque response without the need for intricate field orientation systems or current controllers.

Currently, there's a significant focus on researching DTC for PMSMs due to its straightforward control setup, which yields high efficiency. This leads to superior torque and speed performance compared to DTC implemented in induction machine drives. Similarly, the common problem due to hysteresis torque controller in basic DTC scheme such that high torque ripples still occurs. To reduce the torque ripple, a fast switching frequency that optimized the capability of

power switch devices can be applied. However this is limited by processor used. A widely adopted approach to reduce torque ripple is through Space Vector Modulation (SVM) technique. SVM ensures a consistent switching frequency, simplifying the filtration of undesirable harmonics in sensed currents as the primary harmonic content can be anticipated. However, employing SVM with PMSMs can lead to a complex control framework and may somewhat compromise the high performance achieved by DTC. Additionally, effectively implementing SVM demands a high-speed processor to generate swift switching frequencies for minimizing torque ripple. This paper presents the constant switching frequency torque controller (CSFT) proposed to be employed in DTC of PMSM to decrease the torque ripple. The simple control structure in basic DTC scheme is retained since only minor modification is made such that only the hysteresis torque controller is replaced by the CSFT. By doing so, a constant and high switching frequency can be achieved which can greatly reduce the torque ripple.

Keywords: Direct Torque Control, Field Oriented Control, Permanent Magnet Synchronous Motor.

1. Introduction

The basic structure of DTC scheme of Permanent Magnet Synchronous Motor is shown below.

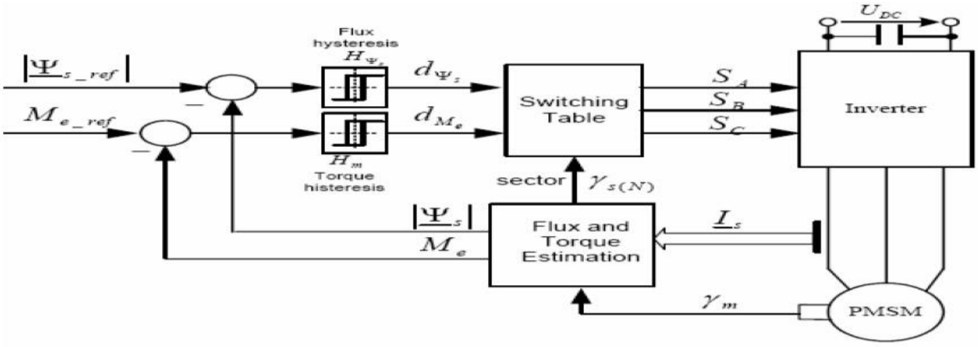

Figure.1. Basic DTC scheme

However, they differ in the switching tables design as indicated below

1.1. Eight-state table (switching table 1)

Switching table provides zero inverter state.

Table.1. Eight State Table

C_ψ	C_T	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6
1	1	V_2	V_3	V_4	V_5	V_6	V_1
1	0	V_7	V_0	V_7	V_0	V_7	V_0
0	1	V_3	V_4	V_5	V_6	V_1	V_2
0	0	V_0	V_7	V_0	V_7	V_0	V_7

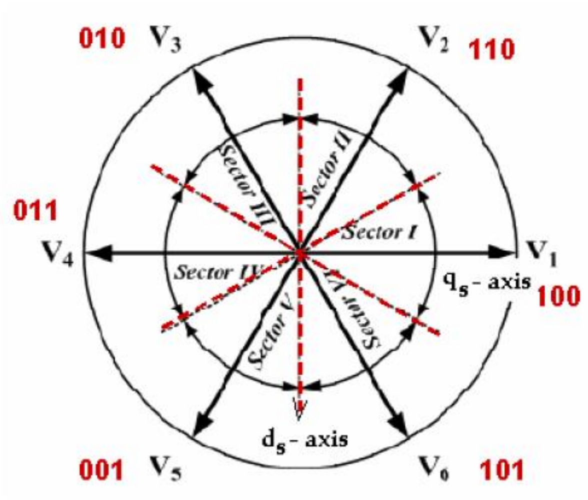

Figure 2: Voltage vectors

1.2. Six-state table (switching table 2)

This scheme has been adopted in studies

Table.2. Six State Table

C_ψ	C_T	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6
1	1	V_2	V_3	V_4	V_5	V_6	V_1
1	0	V_6	V_1	V_2	V_3	V_4	V_5
0	1	V_3	V_4	V_5	V_6	V_1	V_2
0	0	V_5	V_6	V_1	V_2	V_3	V_4

2. Bipolar Torque/eight-state table:

The switching table produces a zero state only when the torque controller output is in the middle level (C_T=0), which can be interpreted as no significant torque change is required. This is shown in Table 3. In the study had been presented in not only the switching table has been modified, but also the hysteresis controller (a two-level controller) has been replaced by a three-level controller.

Table.3. Bipolar Torque/Eight State Table

C_ψ	C_T	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6
1	1	V_2	V_3	V_4	V_5	V_6	V_1
1	0	V_7	V_0	V_7	V_0	V_7	V_0
1	-1	V_6	V_1	V_2	V_3	V_4	V_5
0	1	V_3	V_4	V_5	V_6	V_1	V_2
0	0	V_0	V_7	V_0	V_7	V_0	V_7
0	-1	V_5	V_6	V_1	V_2	V_3	V_4

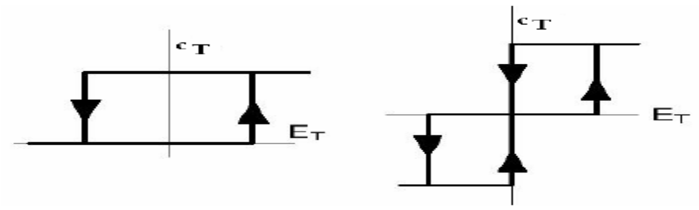

Figure 3 Two and three level torque hysteresis controller characteristics

While the Direct Torque Control (DTC) scheme presents an enticing solution, its basic implementation for PMSM drives exhibits several drawbacks. These include variable switching frequency, torque and flux ripples, high sampling time requirements, current and torque distortion, and drift in the flux estimator. To achieve superior performance, numerous modifications to the basic DTC have been proposed over the last decade. These modifications, akin to those used in induction machine drives, encompass strategies such as employing new switching tables, modifying inverter structures, and adjusting hysteresis controllers.

While many of the aforementioned modifications enhance the performance of DTC for PMSM drives, they often result in more complex schemes. However, a novel DTC scheme for induction motors addresses these complexities by introducing a pair of torque and flux controllers to replace hysteresis-based controllers. This approach significantly mitigates torque and stator flux ripples, maintains a fixed switching frequency of 10.4 kHz, and yields more sinusoidal phase currents. With its simplicity and rapid response, this DTC method supports the operation of high-performance induction motor drives.

This paper proposes the implementation of a constant torque controller, with any necessary modifications, to enhance the DTC scheme for PMSMs, aiming for improved constant torque output.

3. The Modeling and Simulation of Improved DTC of PMSM Drive

Proposed DTC scheme for PMSM is shown below.

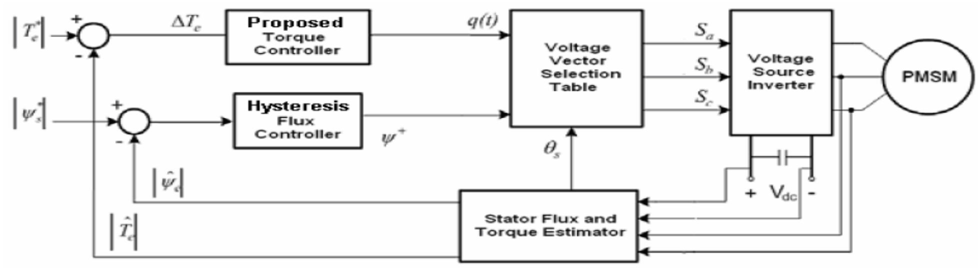

Figure.4. Proposed DTC Scheme

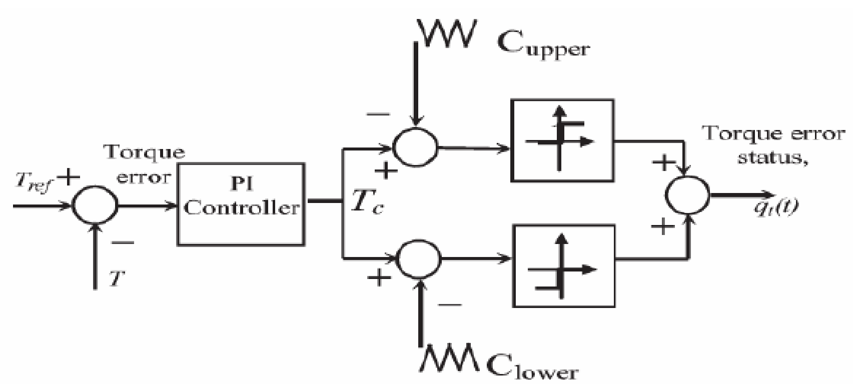

Figure.5. Torque Controllers

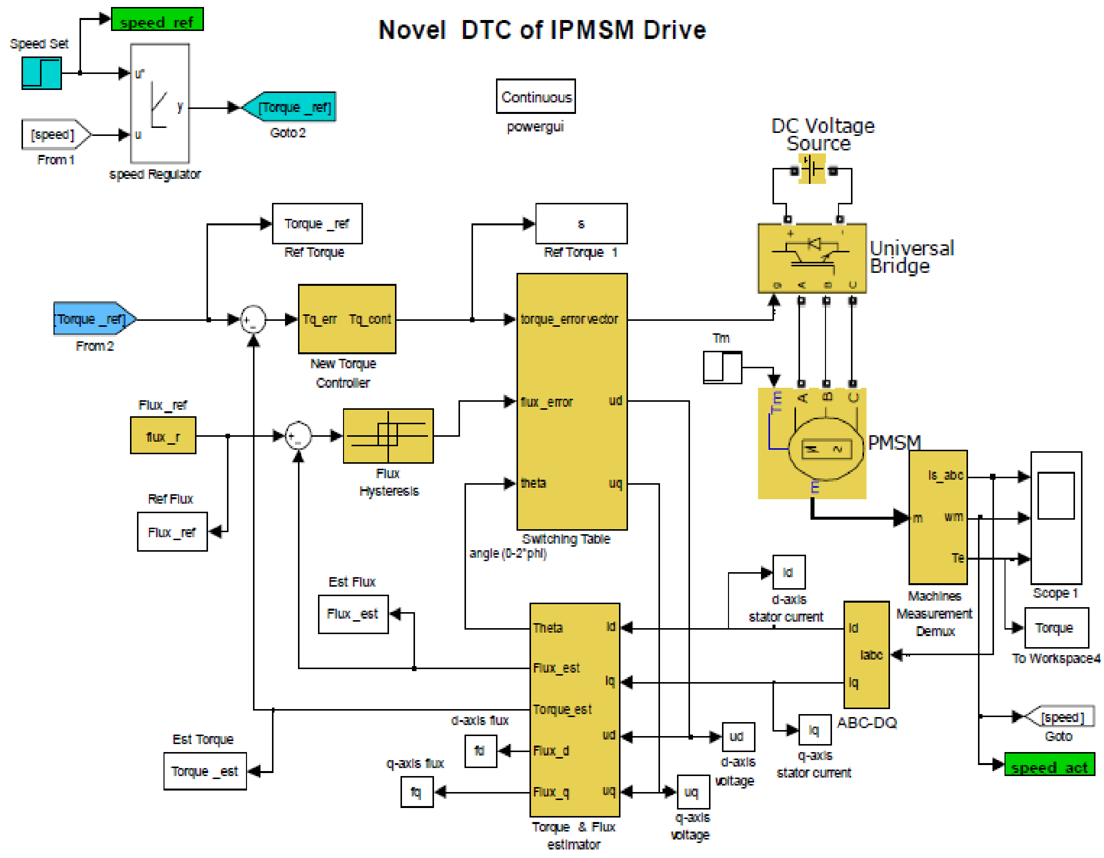

Figure.6. Novel DTC Scheme

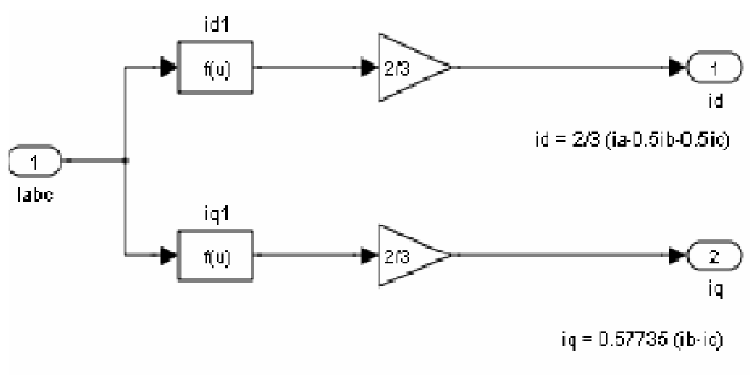

Figure.7. ABC to DQ Transformation State

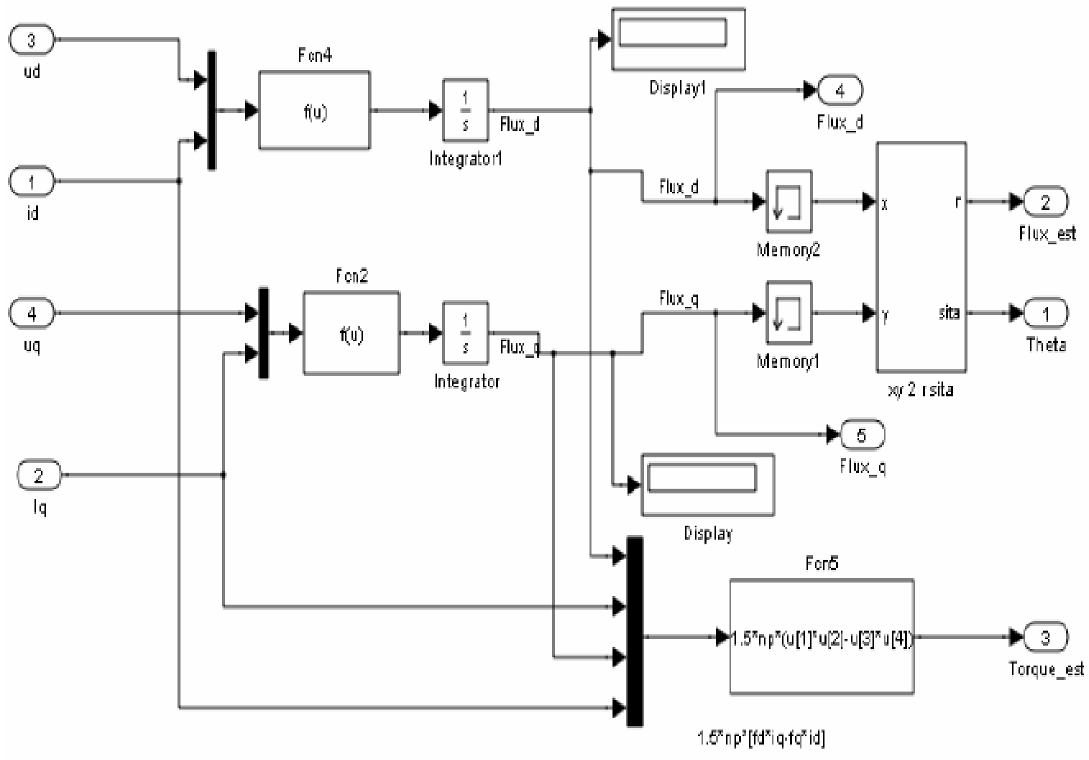

Figure.8. Torque and flux estimator in PMSM

The torque and flux estimator are calculated by equation followed:

$$\psi_d = \int (u_d - R_s i_d)dt + \psi_{d|t=0} \quad (1)$$

$$\psi_q = \int (u_q - R_s i_q)dt + \psi_{q|t=0} \quad (2)$$

$$\psi_s = \sqrt{\psi_d^2 + \psi_q^2} \quad (3)$$

$$T_e = \frac{3}{2} n_p (\psi_s \times i_s) = \frac{3}{2} n_p (\psi_d i_q - \psi_q i_d) \quad (4)$$

where: $U_d = 0.66667\ U_{dc}$ (Sa-0.5Sb-0.5Sc) $U_q = 0.57735\ U_{dc}$ (Sb-Sc)

In the DTC system, the command torque is obtained from the speed PI regulator.

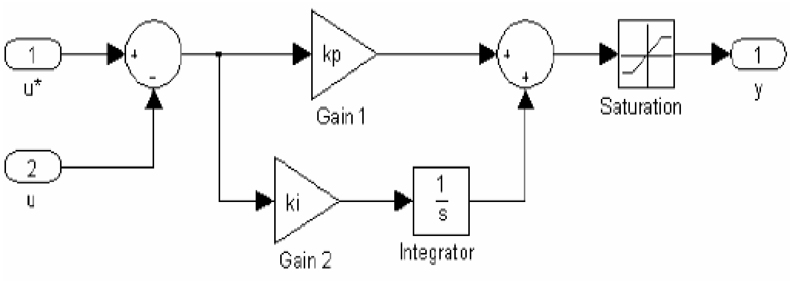

Figure.9. Torque

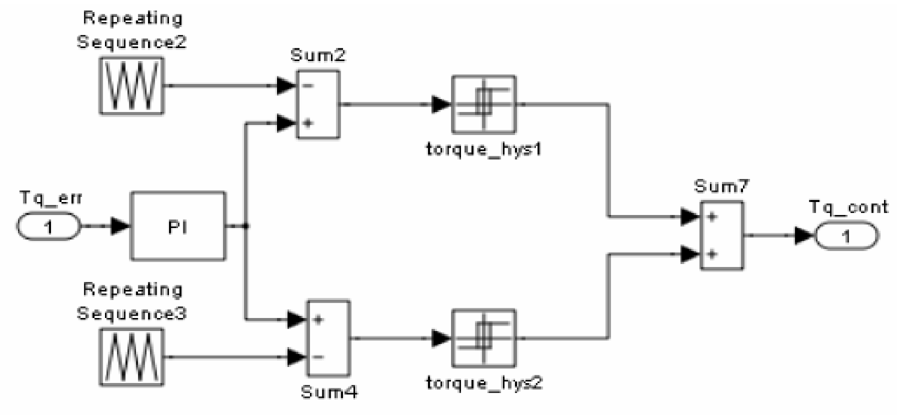

Figure.10. Torque Controller

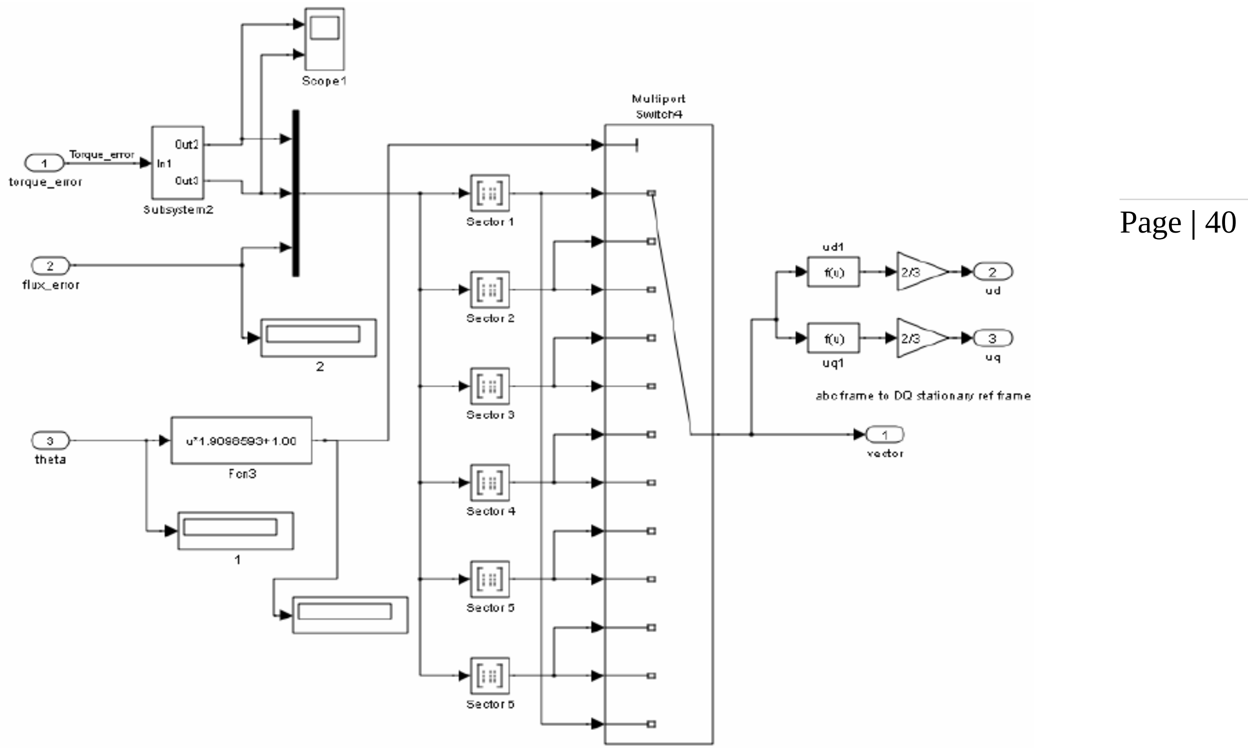

Figure.11. Switching Table

4. Simulation Results and Discussion

Electromagnetic torque response simulation under the basic DTC was using switching table 1, table 2, and table 3

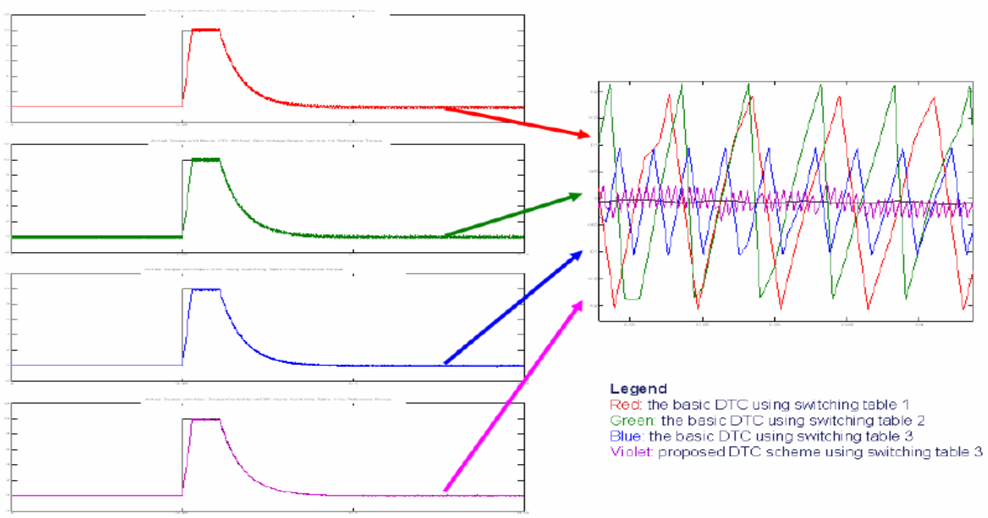

Figure.12. Comparison of the electromagnetic torque response under the basic DTC using switching table 1, using switching table 2, using switching table 3, and under proposed DTC scheme

The parameters for IPMSM,

d-axis stator inductance (Ld)	=	0.0446 H
q-axis stator inductance (Lq)	=	0.1027 H
number of pole-pairs (np)	=	2
stator resistance (Rs)	=	5.8 ohm
flux linkage of magnet (fluxm)	=	0.533 Wb
reference flux linkage (flux_r)	=	0.55 Wb
dc voltage of VSI (vdc)	=	340 V
band of torque (bdwt)	=	0.2
band of flux (bdwf)	=	0.0055

5. Conclusion

The paper presents a simulation model for a novel torque controller designed for Direct Torque Control (DTC) of PMSM drives. Through simulations, comparisons with the basic DTC method have been conducted. Utilizing MATLAB/Simulink, the simulations accurately depict the behaviour of DTC, demonstrating the effectiveness of the proposed method.

The simulation results highlight a significant reduction in torque and flux ripple compared to the basic DTC approach. This reduction is evident as the proposed method achieves smaller torque and flux ripple values.

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