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# *Sliding Mode Direct Torque Control of Variable Flux Memory Machine*

**Wei Wang[1, a], Jingwen Wang[1, b *]**

[1]*School of Information Engineering, Ordos Institute of Technology, Ordos 017010, China*
[a]*wwordos@163.com*, [b]*wjwwhsjmh@126.com*,
**Corresponding author*

***Keywords:*** Variable fux memory machine, direct torque control, flux manipulation.

***Abstract:*** In order to realize air-gap flux on-line adjustment of permanent magnet machine, researchers proposes a variety of new variable flux memory machine (VFMM). This paper proposes a sliding mode (SM) based direct torque control (DTC) strategy for VFMM. The normal operation utilizes a DTC incorporating id = 0 condition method while reference stator flux linkage pulses are energized in MS manipulation regions. This avoids continuous magnetizing current and complicated decupling algorithm. Compared with vector control, the proposed DTC method has more simple structure with better dynamic performance and exhibits less dependence on topology parameters. Finally, the effectiveness of the proposed control scheme is validated by simulation results.

## 1. Introduction

Compared with traditional PM machines, VFMM can be more flexibly controlled due to their variable flux. DTC is a new high-performance AC variable frequency speed Control technology developed after vector Control technology [1-2]. DTC utilizes bang-bang control to generate PWM signal of the inverter, so as to obtain high dynamic performance of the torque. DTC abandones the traditional decoupling vector control and rotating coordinate transformation and takes the stator flux orientation instead which features robust performance to motor parameter. The desired space voltage vector is applied directly by the torque and flux regulator, so as to achieve the direct control of flux and torque. Field orientation control (FOC) tries to keep the rotor magnetic field constant, while DTC tries to keep the stator magnetic field constant. Specific process is to guide the trajectory of the stator flux linkage space vector along a predefined curve (such as round, hexagonal or ten octagon trajectory etc.) to do rotary motion, and the actual stator flux was controlled within the preset error band. As the error band is small, so the amplitude of stator flux linkage can be regard as a constant [3-4].

## 2. Control scheme of Sliding Mode DTC

There are many uncertain factors in the actual DTC system, such as stator resistance variations with temperature, current and voltage measurement error, etc., all of which can be attributed to disturbance. In order to obtain high performance torque control, it is necessary to require the DTC system to have strong robustness. The Sliding Mode (SM) control is an effective high frequency switching control method in uncertain nonlinear systems. It has the characteristics of simple implementation, anti-disturbance, strong robustness and quick response. Fig. 1 shows the control block diagram of DTC variable flux motor based on sliding mode controller. Its outer loop is speed PI controller, which generates a given torque signal. The inner loop is a torque and stator flux variable structure controller that generates a reference voltage vector $u_s$ send to Space Vector Modulation (SVM) module.

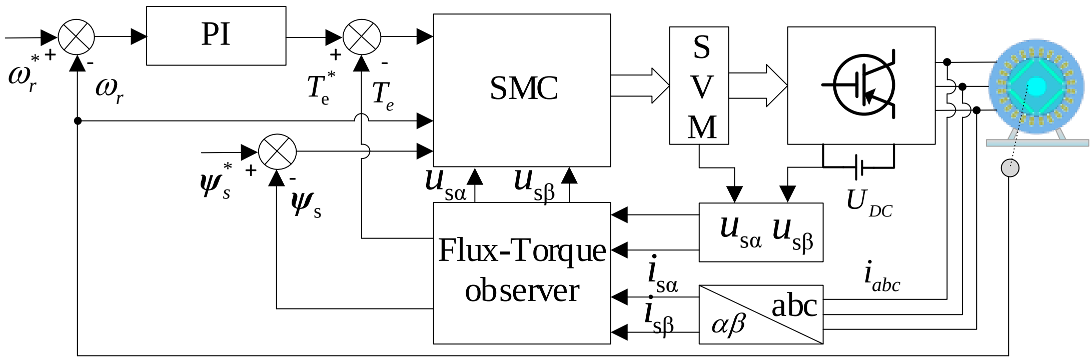


*Figure 1: SM-DTC block diagram*

## 3. Simulation Results

DTC control model of VFMM can be simulated in DTC flux-weaken mode under the condition of $i_d$=0. The VFMM adopts $i_d$=0 control method in starting and lightening stages with rated load. In this process, the given value of the stator flux can be automatically adjusted according to the load so as to always keep the average value of d-axis current as 0. In order to increase the motor speed, flux-weaken operation is required, during which the d-axis current will generate a negative narrow pulse waveform, thus realizing flux-weaken modulation of the variable magnetic material, and then restoring to $i_d$=0 DTC control mode. Here, the load is reduced to 2 Nm and the speed command increases to 1400 r/min. The flux-weaken operation conducts at 1.5 s and finishes at 1.6 s, and the speed command increases to 1900 r/min. The motor speed, torque, flux track trajectory and d/q-axis current waveforms under SM-DTC are shown in Fig. 2 - Fig. 5.

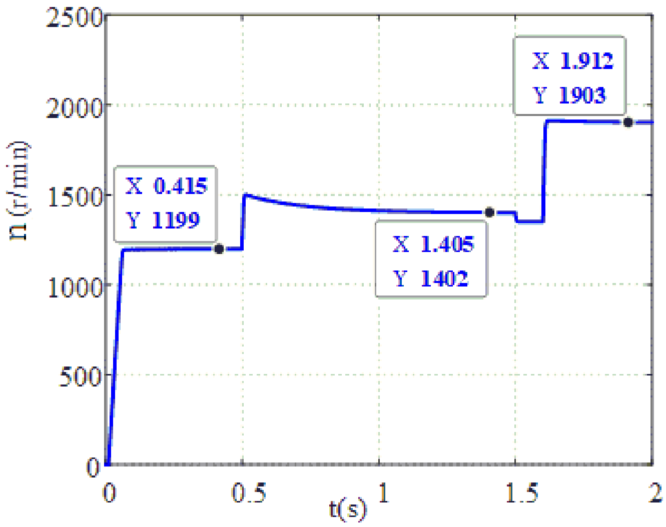


*Figure 2: Speed waveform*

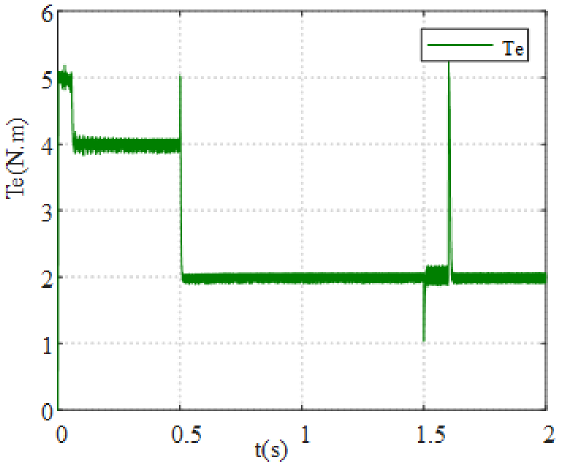


*Figure 3: Torque waveform*

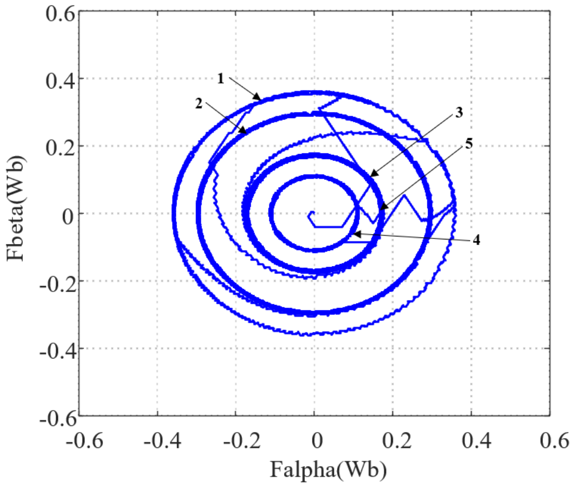


*Figure 4: Flux track trajectory*

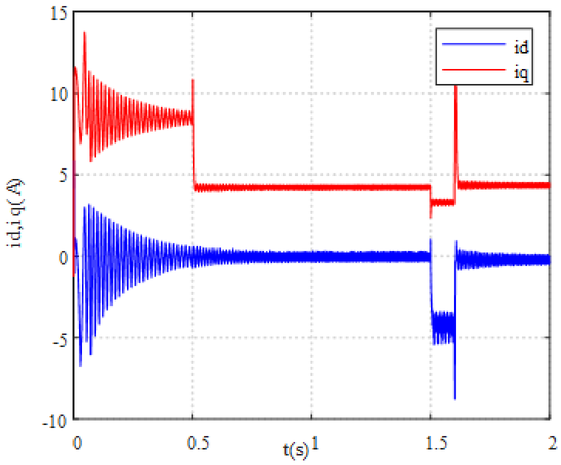


*Figure 5: d/q-axis current waveform*

It can be seen from the simulation results that after starting with rated load, the motor enters a stable operation state after a dynamic adjustment process of 0.1s. The speed is maintained at 1200 r/min, and the torque is balanced with the load torque of 4 N.m.At 1s, the electric vehicle was simulated to enter the high-speed light load state, and the motor load torque decreased to 2 N.m while the given speed increased to 1400 r/min. After a short dynamic adjustment, the motor stably tracked the given command signal.It should be noted that the motor can only increase to 1400 r/min under the condition of fixed permanent magnet flux linkage and load torque of 2 N.m. In order to further increase the motor speed, weak magnetic operation is carried out on the motor at 1.5 s. After dynamic adjustment, the motor speed increases to 1900 r/min and the torque can keep balance with the load torque. The maximum expansion speed ratio reaches 1.6.

Motor flux amplitude in the steady state in the process of running with the default values conform to the basic remains the same, and flux linkage locus can keep good circular trajectory, in the process of the whole simulation of magnetic chain round after four times of change, namely the starting process for the greatest circular path 1, motor flux is about 0.35 Wb, the flux linkage locus of measurement under the rated torque contraction of circular flux track 2, The motor flux is about 0.2956 Wb, and the motor flux shrinks to circular track 3 and 0.1755 Wb after stable operation under load shedding. The motor flux track continues to shrink to circular track 4 and the motor flux is about 0.1102 Wb, and the motor flux ends after 0.1s. The permanent magnet flux decreases from 0.1046 Wb to 0.09998 Wb, and the stator flux is stabilized at 0.172 Wb after dynamic adjustment. The flux track runs stably to circular track 5, which is close to flux track 3. It can be seen from Fig. 5 that the waveform always fluctuates near 0 which can effectively reduce the loss and prevent accidental demagnetization.

## 4. Conclusion

The proposed sliding mode DTC control strategy can maintain the stable torque performance and resist the interference of system parameters at the same time. The flux observer offers the prediction value and provides reference signal for the magnetic modulation. Thus, the VFMM can realize preferable flux regulation feature while running stable in non-modulated state, which is helpful to broaden the efficient working range.

## Acknowledgements

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