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Modeling and Simulation of Variable Flux Memory Machine Control System

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Abstract: Recently, variable flux memory machine (VFMM) shows strong competitiveness and wide application prospects. To realize the magnetic flux and torque decoupling control of VFMM, the field orientation control (FOC) control strategy of DC-type modulated VFMM is propoped in this paper. During the steady state, i_d=0 control method is adopted. In order to improve the speed response, the speed loop employs proportional-integral (PI) controller while the current loop adopts feedforward PI controller to reduce loss and regulation time. The flux modulation circuit consists of Buck circuit and H-bridge inverter, in which the Buck circuit adjusts the output voltage and then the amplitude of the magneto-electric current, the latter controls the direction and the duration of the magnetization current.

1. Introduction

With the development of rare earth Permanent Magnet materials and power electronics devices, permanent magnet synchronous machine (PMSM) is widely used in aerospace, ships, automobiles and other fields for its characteristics of high power density, efficiency and reliability [1-2]. However, the significant disadvantage of PMSM is that its air gap magnetic field is not easy to adjust. VFMM can charge and demagnetize permanent magnet repeatedly and has almost no excitation loss, so it is considered as a kind of adjustable flux permanent magnet motor [3-4]. VFMM adjusts magnetic field by changing magnetization of low-coercivity permanent magnet through pulse current of stator windings or additional coils. As the magnetic density level of permanent magnet can be remembered by permanent magnet, it is called "memory motor". VFMM provides a new way to broaden the speed range of permanent magnet machine.

2. Mathematical Model of Flux Linkage

The motor flux equation can be expressed as:

$$\begin{cases}\psi_{\mathrm{d}}=L_{\mathrm{d}}i_{\mathrm{d}}+\psi_{\mathrm{PM1}}+k\psi_{\mathrm{PM2}}\\ \psi_{\mathrm{q}}=L_{\mathrm{q}}i_{\mathrm{q}}\end{cases} \tag{1}$$

Where the ψ_d is the direct axis flux, ψ_q is the alternating axis flux, L_d is the straight-axis inductance, L_d is the intersecting axis inductance, i_d is the straight-axis current, i_q is the cross-axis current, ψ_{PM1} is the fixed permanent magnet flux, ψ_{PM2} is the variable permanent magnet flux, k is magnetic modulation coefficient, and its variation range is [-1,1].

3. Modeling based on Matlab/Simulink

According to the mathematical model, the simulation model of the control system is built in Matlab/Simulink environment, including the motor, three-phase inverter, SVPWM module, coordinate transformation module, closed-loop control, flux regulation and other parts. To achieve a more realistic simulation effect, the magnetic adjustment process is adopted to replace the mathematical simulation. The motor model is established according to the simulation parameters, as shown in Fig. 1.

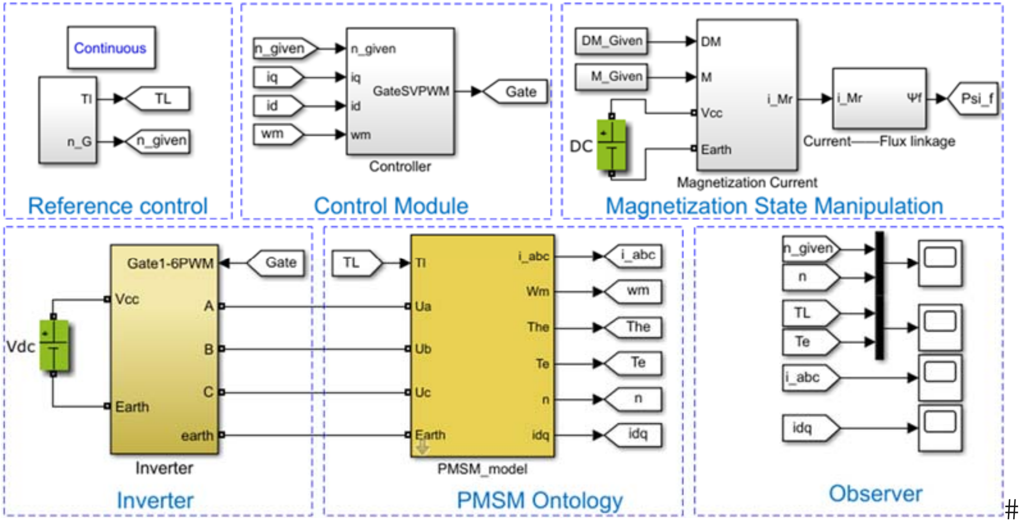

Figure 1: Simulation model of VFMM

The motor model includes motor ontology, three-phase inverter, control unit, magnetic modulation unit, signal setting module and observer. The magneto-electric circuit is modulated by Buck circuit and H-bridge inverter, in which the Buck circuit adjusts the output voltage and then the amplitude of the magneto-electric current, the latter controls the direction and duration of magnetization current. Magnetic modulation control circuit mainly completes the generation of Buck circuit PWM signal and H inverter bridge control. The PWM signal of Buck circuit is modulated by closed-loop PID algorithm, and two closed-loop modules are needed to realize it according to different directions of magnetization current. The magnetization direction is determined by D. When $D \geq 0$, T_1T_4 is conducted and the machine is magnetized, otherwise, T_2T_3 is conducted and the machine is demagnetized.

4. Simulation Results

For electric vehicles application, the simulation waveform results of DC magnetics-modulated VFMM are shown in Fig. 2. (1) State 1# refers to the starting process of the motor with rated load of 4 Nm. The system with rated load starts continuously increasing the given speed signal, and it can be determined that the turning speed under rated load is 1630 r/min. If the signal continues to increase, the system will oscillate. (2) State 2# refers to the high-speed operation process, in which the load torque decreases. When set at 0.2 s in the simulation, the load torque decreases to 50%, that is, 2Nm. The motor speed will rise briefly, but returns to the given speed after dynamic adjustment, and the given speed increases to 1760 r/min at 2 Nm. That is, the turning speed of the motor under 2 Nm load torque is 1760 r/min;(3) At this time, in order to further increase the motor speed, weak magnetic operation is carried out at 0.6 s, the amplitude of weak magnetic current is -5 A, that is, State 3# is the operation process after weak magnetic, and the motor speed increases to 2230 r/min;(4) After 1.4

s, the motor recovered load was 4 Nm, and the rated speed signal was restored at the same time at 1200 r/min. At this time, in order to ensure the normal output of the motor, magnetizing measures were implemented, and the amplitude of magnetizing current was 50 A, that is, State 4# was the rated working process after magnetizing. It can be seen from the simulation waveform that the motor can be stable in the rated working state.

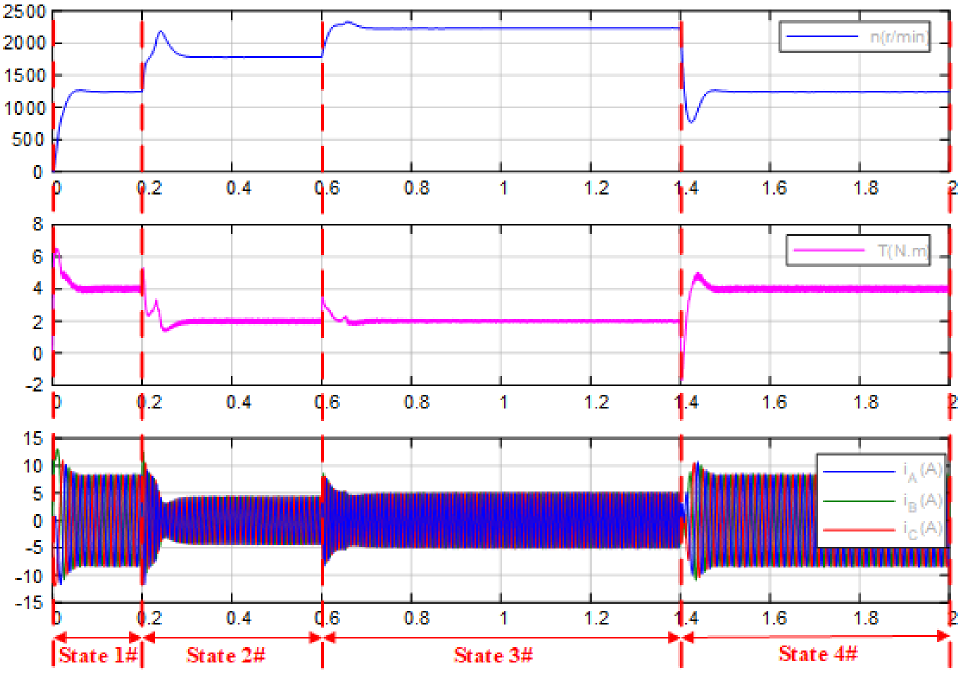

Figure 2: Simulation waveforms of DC magnetic modulated VFMM

5. Conclusion

This paper proposes a magnetic flux and torque decoupling control strategy for a VFMM. By adopting this method, the dynamic response is improved and the flux adjustment is simplified of the machine. The results demonstrate that the studied VFMM system is a promising choice for wide constant power speed range requirement applications, e.g., electric vehicles.

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References

[1] T.A. Lipo. Analysis of synchronous machines [M]. Second Edition. CRC Press, 2012.

[2] R. Krishnan. Permanent magnet synchronous and brushless DC motor drives [M]. CRC Press, 2009.

[3] V. Ostovic, "Memory motors - a new class of controllable flux pm machines for a true wide speed operation", pp. 2577-2584, 2001.

[4] S. Maekawa, K. Yuki, M. Matsushita, et al. Study of the magnetization method suitable for fractional-slot concentrated-winding variable magnetomotive-force memory motor [J]. IEEE Transactions on Power Electronics, 2014, 29(9): 4877-4887.