FINITE-CONTROL-SET MODEL PREDICTIVE CONTROL OF AXIALLY LAMINATED FLUX-SWITCHING PERMANENT MAGNET MACHINE WITH EXTENDED VOLTAGE SPACE VECTORS

by

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CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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LIST OF SYMBOLS

*	Reference value
$\alpha\beta$	Stationary stator reference frame axes
dq	Rotary rotor reference frame axes
f	Frequency (Hz)
$\psi_a,\ \psi_b,\ \psi_c$	Three-phase flux linkages (Wb)
ψ_α, ψ_β	α- and β- axis stator flux linkages (Wb)
ψ_d, ψ_q	d- and q-axis stator flux linkages (Wb)
θ_r	Angle between two stator reference frame and rotor reference frame
L_d, L_q	d- and q-axis inductance (H)
ψ_f	Flux linkage generated by the rotor permanent magnet (Wb)
p	Number of the machine pole pairs
u_a, u_b, u_c	Stator voltages (V)
u_α, u_β	α- and β- axis stator voltages (V)
u_s, u_d, u_q	stator voltage vector, d- axis and q-axis stator voltage (V)
i_a, i_b, i_c	Stator currents (A)
i_α, i_β	α- and β- axis stator currents (A)
i_d, i_q	d- and q-axis stator currents (A)
R_s	Per-phase stator winding resistance (Ω)
T_e	Electromagnetic torque (Nm)
T_L	Load torque applied on the rotor shaft
$u_0 \cdots u_6$	Space voltage vectors produced by the two level inverter (V)
P_{in}	Total input power of a motor (W)
P_{em}	Electromagnetic power obtained by subtracting the mechanical loss from the input power (W)

ω_r	Rotor mechanical speed
ω_e	Electrical speed
u_s^k, u_d^k, u_q^k, i_d^k, i_q^k	Stator voltage vector , *d*- axis and *q*-axis stator voltage, *d*- axis and *q*-axis stator current at *(k)th* sampling instant
T_e^{k+1}, ψ_s^{k+1}, i_d^{k+1}, i_q^{k+1}	Predicted value of torque, flux, *d*- axis and *q*-axis stator current at *(k+1)th* sampling instant
k_1	Weighting factor
T_s	Sampling period (s)
η_{sys}	Efficiency of the drive system
P_{dc}	Power output of DC power supply (W)

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ABSTRACT

The Flux-switching permanent magnet machine (FSPMM) has recently attracted considerable interest for high performance drive applications due to their high torque and high power density features. The laminations of traditional FSPMMs are radially laminated, i.e. steel sheets are laminated perpendicular to the shaft axis. Due to the nonlinear magnetic path, the radial laminations can have serious partial magnetic saturation at the edges/tips of stator teeth or rotor poles. The rated frequency of FSPMMs is usually much higher than traditional rotor-inserted PM machines at a given speed. In this case, the core loss of FSPMMs becomes evident especially beyond the rated speed, which leads to decrease of output power, torque/power density and efficiency.

The reluctance motor with axially laminated rotor has received growing interest in recent years. This type of motor can achieve a higher torque density compared with segmented rotors and flux-barrier rotors. In this thesis, an axially laminated flux-switching permanent magnet machine (ALFSPMM) with HiB grain oriented silicon steel stator and rotor cores is proposed. The HiB silicon steel features high permeability and low specific core loss, and as a result, the total power loss of proposed motor is much lower than the conventional FSPMMs. The detailed fabrication procedures are presented. The theoretical characteristics of ALFSPMM are calculated by 2D finite element method (FEM). Experimental measurements of the prototype machine are presented to validate the FEM calculation.

On the machine control side, the direct torque control (DTC) is one of the most popular control algorithms. It features simple structure and fast dynamic response. However, the performance of DTC in terms of torque and flux ripples and drive system efficiency is unsatisfactory since the voltage space vector (VSV) is selected heuristically. Recently, the finite-control-set model predictive direct torque control (FCS-MPDTC) has been developed as a simple and promising control technique to overcome these problems.

The FCS-MPDTC still suffers from relatively high torque and flux ripples due to the limited number of VSVs.

This thesis proposes a novel FCS-MPDTC with an extended set of twenty modulated VSVs, which are formed by eight basic VSVs and twelve extended VSVs by modulating eight basic VSVs with fixed duty ratio. To mitigate the computational burden caused by the increased number of VSVs, a pre-selective scheme is designed for the proposed FCS-MPDTC to filter out the impractical VSVs. The drive system efficiency is also investigated. The theory and simulation are validated by experimental results on the ALFSPMM prototype.