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Abstract

This thesis represents a culmination of the studies that have been taken place in the last few years. The increase in automation leads to the electrification of several existing systems, e.g. transportation system, which require electrical machines (EMs) as primary power equipments. Permanent magnet (PM) machines currently prevail as a primary choice for high-performance electrical machines (EMs) because of their high torque/power density and high efficiency. However, the limited resources and the unstable cost of rare-earth metals, and the fault-tolerant issues of PM machines appeal to the researchers for an attractive alternative to PM based motors. Switched reluctance motors (SRMs) are gaining attention because of their simple construction, low cost, ability to work in harsh environments, absence of PM and wide-speed operation. Unipolar current excitation encourages the design of low-cost inverters for SRMs, requiring only one controlling switch per phase. However, low torque/power density, low efficiency, high torque ripple and high acoustic noise demand further improvements in such motors. Using high silicon steel or amorphous steel and improving slot-fill factor enhance the efficiency of SRMs. The emersion of the double-stator SRMs (DSSRMs) as a new SRM topology with two stators and a segmented rotor exhibits significant improvement in torque density. Such machines have lower values of the normal component of air-gap flux density, which results in lower vibration and lower acoustic noise. The single-tooth winding add-on further improves its compactness and high-efficiency speed range. High torque ripple of such motors is a key issue that limits their adaptability in industrial applications. Many active and passive techniques are developed to reduce the torque ripple for the different topology of SRMs. However, this specific topology still lacks such effective techniques.

In this thesis, firstly, the design concepts of single-tooth winding radial-flux DSSRM are presented. The torque equation of this topology is derived. The calculation of stator poles and rotor segments arc angles for high output torque, selection procedure for slot/segment combination and the effect of winding polarities on motor performance are discussed in details. It is observed through finite-element method (FEM) analysis that such motor possess high torque ripple. Therefore, some design modifications are investigated for such motor topology for reducing the torque ripple. In the presented work, shifting of the rotor segments and stator/rotor surfaces are investigated to reduce the torque ripple. In this regard, the finite-element models are developed, and their static and dynamic responses are simulated. The effect of these shifts on the magnetic flux distribution in different parts of the motor is studied, and their influences on motor performance are analyzed. Besides these, the design of a new DSSRM is proposed, which has a significantly low torque ripple in a higher speed range when single-pulse control mode is active. Many of the torque ripple reduction techniques are only effective in the current chopping control mode, which is only possible in a lower speed range. In the proposed motor, the outer stator is shifted by half of the stroke angle compared to the inner stator. The respective phase windings of the inner and outer stators are excited parallelly with the same phase shift. Each rotor segment is constructed with two half rotor segments, and a wide non-magnetic region is inserted between them. In this regard, the modifications are carried out in the outer stator poles and outer half rotor segments. The efficacy of the proposed motor is investigated through FEM based simulation results. The proposed motor shows significantly reduced torque ripple for a higher speed range when single-pulse control is active.

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List of Symbols

T_{avg}	Average torque
T_{max}	Maximum torque
T_{min}	Minimum torque
T_{pk2pk}	Peak-to-peak torque ripple
T_{ripple}	Torque ripple
L_u	Unaligned inductance
L_a	Aligned inductance
B_g	Air-gap flux density
B_{max}	Maximum core flux density
I_p	Peak phase current
N_s	Number of stator poles
N_r	Number of rotor segments
q	Number of phases
N_{slot}	Number of conductor per slot
N_{ph}	Number of turn per phase
m	Multiplicity of motor
l	Axial length of motor
l_g	Air-gap length
D_o	Outer diameter of motor
D_i	Inner diameter of motor
D_r	Average diameter of rotor

h_{ys}	Height of stator yoke
h_{pr}	Height of rotor segment
w_{exc}	Width of exciting pole
w_{aux}	Width of auxiliary pole
h_{psi}	Height of inner stator pole
h_{pso}	Height of outer stator pole
β_{exc}	Arc angle of exciting pole
β_{aux}	Arc angle of auxiliary pole
β_r	Arc angle of rotor segment
β_{so}	Stator slot opening angle
β_{ro}	Rotor segments separartion angle
β_{ps}	Stator pole pitch angle
β_{pr}	Rotor pole pitch angle
N	Rated speed
θ_{stk}	Stroke angle
P_{Fe}	Iron loss
P_{Cu}	Copper loss
η	Efficiency
δ	Angualr shift in rotor segment
δ_r	Angular shift in rotor surface
δ_s	Angular shift in stator surface
δ_t	Total surface shift angle

B_n	Normal component of air-gap flux density
B_t	Tangential component of air-gap flux density
f_r	Radial force density
f_t	Tangential force density
\$	U.S. Dollar

List of Abbreviations

EM	Electrical machine
EV	Electric vehicle
SRM	Switched reluctance motor
TSRM	Toothed switched reluctance motor
SSRM	Segmented rotor switched reluctance motor
DSSRM	Double-stator switched reluctance motor
BSRM	Bearingless switched reluctance motor
BSSRM	Bearingless segmented rotor switched reluctance motor
MCSRM	Mutually-coupled switched reluctance motor
PM	Permanent magnet
IPM	Interior permanent magnet
AFPM	Axial-flux permanent magnet
CCW	Counter clock-wise
CW	Clock-wise
FEM	Finite-element method
SFF	Slot fill factort
rpm	Revolution per minute
EMF	Electro motive force
MMF	Magneto motive force
VSI	Voltage source inverter
TSF	Torque sharing functions

DITC	Direct instantaneous torque control
RPSO	Robust particle swarm optimization
SPC	Single-pulse control
i.e.	That is
e.g.	For example