DESIGN AND ANALYSIS OF A NEW MULTIPHASE POLYGONAL-WINDING PERMANENT- MAGNET BRUSHLESS DC MACHINE

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Purpose

The permanent-magnet brushless dc machine (PMBDM) inherently suffers from a short constant-power operating range [1]. This paper proposes a new multiphase polygonal-winding PMBDM which can offer high-speed constant-power operation while maintaining high power density and high efficiency for electric vehicle (EV) propulsion.

Principle of operation

Fig.1 shows the configuration of the proposed machine. The originality lies on the multiphase polygonal-winding stator, and the surface-inset PM rotor. As shown in Fig.2, by electronically controlling the inlets and outlets of the stator current flowing through the polygonal windings, the air-gap flux can be easily adjusted to achieve high-speed constant-power operation. Meanwhile, the surface-inset PM rotor can generate both PM torque (alike a conventional PMBDM) and electromagnetic torque (alike a dc series machine).

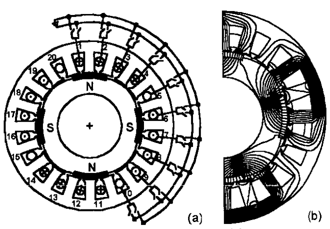

Fig.1. Proposed machine.

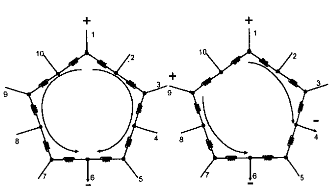

Fig.2. Polygonal-winding excitations.

Analysis and results

A 5-phase 1-kW 48-V 1000-rpm prototype has been designed for an electric scooter. Time-stepping finite element analysis has been employed to analyze the steady-state and dynamic performances. Fig.3 verifies that the proposed machine offers a much better torque-speed characteristic than that of a conventional PMBDM.

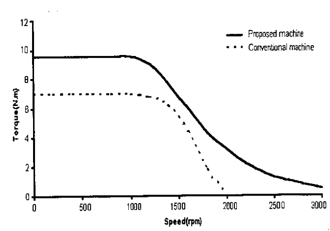

Fig.3. Torque-speed characteristics.

[1] J.Y. Gan, K.T. Chau, C.C. Chan and J.Z. Jiang, "A new surface-inset, permanent-magnet brushless dc motor drive for electric vehicles," IEEE Trans. Magnetics, Vol. 36, 2000, pp. 3810-3818.

MATHEMATICAL MODELS OF SWITCHED RELUCTANCE MACHINE SYSTEM

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The mathematical models of Switched Reluctance machine system could be based on the integral whole of the reluctance machine, the power converter and the control strategy, and those are the nonlinear model of the electrical network integrated with the two dimensions finite element model of the machine, which are as follows,

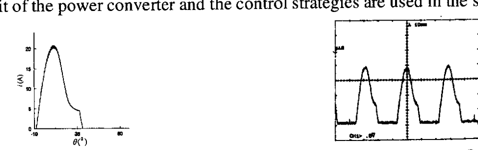
$$\begin{bmatrix} U_A(\theta_A) \\ U_B(\theta_A-\theta_r/m) \\ \cdot \\ \cdot \\ \cdot \\ U_m[\theta_A-\theta_r(m-1)/m] \end{bmatrix} = \begin{bmatrix} R_A+\frac{\partial\psi_A}{\partial i_A}\cdot D & 0 & \cdots & 0 \\ 0 & R_B+\frac{\partial\psi_B}{\partial i_B}\cdot D & & \cdot \\ \cdot & 0 & \ddots & \cdot \\ \cdot & \cdot & & 0 \\ 0 & 0 & \cdots\ 0 & R_m+\frac{\partial\psi_m}{\partial i_m}\cdot D \end{bmatrix} \begin{bmatrix} i_A \\ i_B \\ \cdot \\ \cdot \\ i_m \end{bmatrix} + \Omega\cdot \begin{bmatrix} \frac{\partial\psi_A}{\partial\theta_A} \\ \frac{\partial\psi_B}{\partial(\theta_A-\theta_r/m)} \\ \cdot \\ \cdot \\ \frac{\partial\psi_m}{\partial[\theta_A-\theta_r(m-1)/m]} \end{bmatrix} \quad (1)$$

Where, m is the phase numbers, $Di_k = di_k/dt$, ($k = A, B, \ldots m$), U_k, is the each phase voltage, respectively, R_k, is the each phase resistance, respectively, i_k, is the each phase current, respectively, θ_A, is the rotor position of A phase, θ_r, is one rotor period, Ω, is the rotor angular velocity, t, is the time, ψ_k, is the each phase flux linkage, respectively, and,

$$\psi_k = \frac{Nl}{3S}\sum (A_i\Delta_i - A_h\Delta_h)_k \quad k=A,B,\cdots,m \quad (2)$$

Where, N is the turn numbers of each phase winding, S is the exciting source area of stator pole at one side, l is the effective length of iron core of the machine, Δ_i and Δ_h is the area of the split unit at the right side of the stator poles and at the left side of the stator poles in the calculation of the reluctance machine with the two dimensions finite element method, respectively, A_i and A_h is magnetomotive force vector of the split unit at the right side of the stator poles and at the left side of the stator poles, respectively.

The prototype is a kind of three-phase system, which consists of the three-phase 6/4 reluctance machine, the three-phase asymmetric bridge power converter. The pulse width modulation control strategy is adopted in the prototype. The simulated waveforms and the measured waveforms of the phase current at the same conditions are shown in Fig.1. It is shown that the simulated waveforms of the phase current are similar to the measured waveforms of the phase current. The calculated errors of the performance are within ±5%. It is shown that the developed mathematical models have the advantage in high precision. The mathematical models are general for all types of the Switched Reluctance machine systems, no matter what the topologies of the main circuit of the power converter and the control strategies are used in the system.



a) Simulated b) Measured (Abscissa: 10.0 ms/div, Ordinate: 5.0 A/div.)
Fig.1. Waveforms of the phase current

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