Electric Power Systems Research 131 (2016) 19–30

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

A common sharing method for current and flux-linkage control of switched reluctance motor☆

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ARTICLE INFO

Article history:
Received 27 June 2015
Received in revised form 30 August 2015
Accepted 17 September 2015

Keywords:
Switched reluctance motor
Current-sharing method
Flux-linkage-sharing method
Adaptive linear element
Sliding mode learning algorithm

ABSTRACT

In this paper, a common sharing method for current and flux-linkage control is proposed for high performance control of the switched reluctance motor (SRM). The proposed method not only can realize the current and flux-linkage sharing between different phases of the SRM, but also can reduce the torque ripple to a very low level. With the current-sharing method (CSM), the SRM can be controlled without any model information besides the phase number of the SRM. While with the flux-linkage-sharing method (FSM), high control performance can be achieved with inner flux-linkage loop alone. Six control parameters of the common sharing method can make the method possess high adjusting freedom. The CSM and the FSM are applied to speed control of a four-phase 8/6 SRM respectively. The speed controller is composed of the proportional plus derivative (PD) controller and adaptive linear element (Adaline) with sliding mode learning algorithm (SMLA). The comparisons between the control performance of the CSM and the FSM are given. Simulation results certify that the common sharing method can be applied to the current and flux-linkage control of the SRM effectively, and the combined controller can enhance the accuracy and robustness of the speed controller.

1. Introduction

Switched reluctance motor (SRM) has vary large potentiality in motor drive area due to its many advantages, such like rugged structure, low cost, inherent fault tolerance and excellent torque–speed characteristics [1–4]. Although SRM has so many advantages, there still exit many problems that confine the application of the SRM. The double-salient structure and high magnetic saturation make the modeling of SRM more complex than that of induction motor (IM) and permanent-magnet synchronous motor (PMSM). No analytical model is found for the SRM that can describe its performance completely at present. The model of the SRM cannot be decoupled as IM and PMSM to realize high control performance. The problems of acoustic noise and torque ripple of SRM are more severe than these of other traditional motors [5–7]. As the author knows, there is no widely accepted control method for the control of the SRM as field orientated control (FOC) or Direct torque control (DTC) for IM and PMSM. The effective control methods for the SRM are still in searching for the researchers.

The modeling of the SRM is an important researching aspect to realize high performance control of the SRM [8–20]. The objective of the modeling for the SRM can be concluded to acquire the relationship of flux-linkage, inductance or electromagnetic torque with current and position. In [8], the exponential flux-linkage model is firstly given. A rectified exponential flux-linkage model is shown in [9]. In [10], an analytical inductance model is given with three terms Fourier series. In [11], an invertible torque model of the SRM is shown, which can be used to the torque-ripple minimization control. The methods for the modeling of the SRM can be broadly classified into three aspects, such as nonlinear method, finite element method (FEM) and intelligent method. Linear method is based on the analysis of circuit with current-independent parameters. And the nonlinear method is based on circuits with current-dependent parameters that consider saturation into the magnetic circuit as in [8,9,11–14]. In [15], 2-D finite-element model is used to simulate magnetic properties of the SRM, and a multiphysics model is used to simulate its operating conditions. In [16,17], artificial neural networks (ANNs) are applied to the inductance and flux linkage modeling of the SRM. In [18–20], the fuzzy logic method is used for the modeling and estimation of the SRM and high control performance is achieved. Although the above modeling method for the SRM can enhance the control performance, it need off-line experiment or on-line study. This adds the complexity of the control design for the SRM. The preferred control method for the SRM

☆ Supported by National Natural Science Foundation of China (61273086).
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http://dx.doi.org/10.1016/j.epsr.2015.09.015
0378-7796/

is the design that does not need any model information of the SRM. This is one of the researching objective of this paper in following part.

In the position or speed control of the SRM, the inner control loop is composed with current loop, flux-linkage loop, torque loop, or their combination [21–27]. In [21], the hysteresis current controller is adopted as current control unit, and the speed control is realized with the optimization of the turn-off and turn-on angles of the SRM. In [22], the current profile strategy is used to realize the optimum current waveform control in the inner control loop. In [23], the inner loop include the torque and flux-linkage control based on the philosophy of direct torque control of IM. The torque and flux-linkage of a three-phase 6/4 SRM are controlled with the hysteresis controllers through the selection of the space vector. In [24,25], a direct instantaneous torque control (DITC) method is proposed, which can realize the direct torque control through a novel torque hysteresis switching modes. The torque sharing function (TSF) method is a combination of the current and torque control in the inner control loop design. An early effort to develop exponential TSF for minimizing torque ripple was given in [26], and those functions are referred as m-functions. In [27], five kinds of TSFs are given to reduce the torque ripple of the SRM in the inner loop. TSF method has become very important method to reduce the torque ripple of the SRM. Many improvement on TSF are given to enhance the control performance of the SRM [27–31]. In the above inner control loop design, the model information or online measurement of the flux-linkage or the electromagnetic torque is necessary for high performance control of the SRM. In this paper, a common sharing method is found for current and flux-linkage control of the SRM, which can be used for the inner loop design with only current loop or flux-linkage loop.

The controller design is also an important aspect of the SRM control. Sliding mode control (SMC) is widely applied in the motor control. In [32], an approximate sliding mode input power controller and feedforward sliding mode speed controller are combined with space voltage vector modulation. The resultant drive has rapid and robust speed response. In [33], second order SMC with super-twisting algorithm is applied to the speed control of the SRM. In this paper, the SMC is not used to the controller design of the SRM. The SMC is applied to the training of the weights of the Adaline.

The main contributions of this paper can be given as following five aspects.

(1) A common sharing method for current and flux-linkage is proposed for the control of the SRM. And a novel control structure can be realized with the proposed CSM and FSM.
(2) The CSM can be used to the current loop design of the SRM without any model information besides the phase number of the SRM.
(3) The FSM can be used to the inner loop design of the SRM with the flux-linkage loop alone.
(4) The speed controller is the combination of PD controller and Adaline with SMLA, which has integration advantages of PD controller, Adaline and SMC.
(5) The common sharing method not only can realize the current or flux-linkage sharing between different phases, but also can reduce the torque ripple of the SRM effectively.

This paper is organized as following six sections. Section 2 introduces the procedure of common sharing method step by step. Section 3 gives the controller design of the SRM. Section 4 shows the simulation results and analysis of the common sharing method. Section 5 gives some discussions. And Section 6 concludes the work presented in this paper.

2. The design of the common sharing method

In this paper, a four-phase 8/6 SRM is selected as the target SRM, and the data of the SRM are given in Appendix. In the speed control of the SRM, the output variable of speed loop can be seen as the reference torque, current or flux-linkage for the design of the inner loop. From the present research, the reference torque can be shared to each phase torque with the TSF method. Because the nonlinearity between torque, current and flux-linkage, there are few references that consider the sharing of the reference current or flux-linkage to phase value. The design of the proposed common sharing method can be divided into four steps, which are phase splitting, positive transforming, width-overlap processing, and amplitude adjusting.

2.1. Phase splitting

In the speed control of the SRM, the output variable of the speed control loop is a scalar variable, which can not be directly used in the design of the current or flux-linkage control loop. Fig. 1(a) shows the distribution of the stator windings of the four-phase 8/6 SRM in space. As one-side magnetizing motor, the current or flux-linkage vector of each phase is static with the state windings. The relation between the current and flux-linkage of the SRM can be presented as following equation

$$\psi_x(\theta, i) = L_x(\theta, i) i_x, \quad (1)$$

where $x = A, B, C$ or D, $\psi_x(\theta, i)$, $L_x(\theta, i)$ and i_x present flux-linkage, inductance and current of phase x respectively. According to (1), it

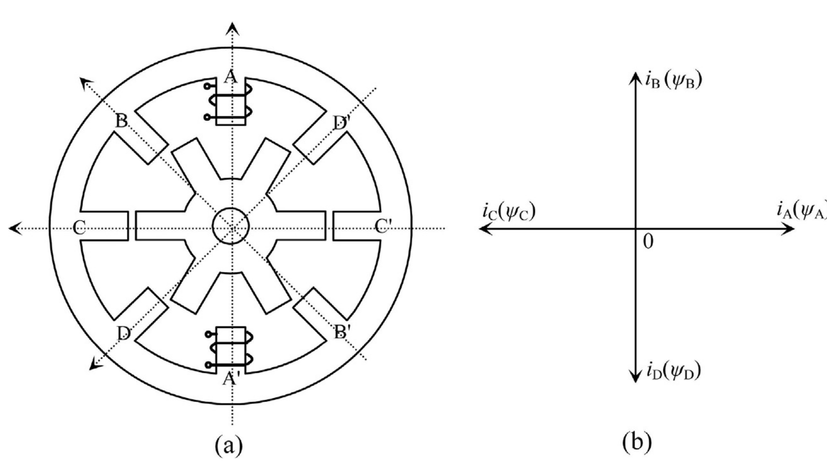

Fig. 1. (a) The stator windings. (b) The distribution of current and flux-linkage vectors.