

Abstract

This paper presents the literature review of torque ripple minimization technique of the switched reluctance motor (SRM). Due to doubly salient structure & non-linear behavior, it has inherent torque ripples, which affects its performance.

Keywords: reluctance motor, torque ripples.

Introduction

The Switched reluctance motor (SRM) is an old member of the electric machine family. The main advantages of SRM are their simple structure, ruggedness and they are inexpensive to manufacture. However, it has the main disadvantages such as the torque ripple, acoustic noise & difficulty in controlling its torque. This is the reason of its limited application in industries.

Research has been done to reduce the torque ripple. Several control methods, motor design & power electronics inverter topologies have been proposed which now possible to make the wide SRM drive applications in industries, such as Electric vehicle.

Switched reluctance motor drive

1. *Basics structure:* It has concentrated coils on the stator and neither winding, nor brushes on the rotor.

2. *Working principle:* The operation principle is based on the difference in magnetic reluctance for magnetic field lines between aligned and unaligned rotor position when a stator coil is excited, the rotor experiences a force which will pull the rotor to the

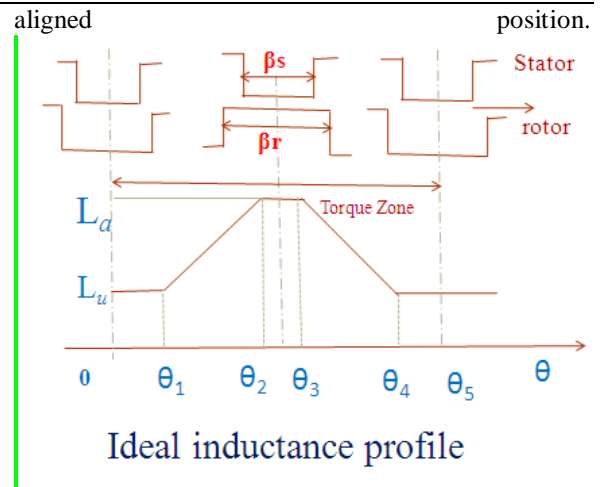


Figure 1.

3. *Working:* Fig 1. Illustrate the periodic change of inductance versus rotor position. Where β_s and β_r are the stator & rotor pole arcs. Torque zone is a region within which a phase can produce torque. At θ_1 stator and rotor poles started overlapping. At θ_2 the stator & rotor poles are fully overlapped. Between the θ_1 and θ_2 the phase inductance increases linearly as rotor moves. At θ_3 the overlapping of stator and rotor poles ends and the phase inductance decreases linearly until rotor position reaches θ_4 position and the phase inductance becomes minimum, L_u . The region between θ_2 and θ_3 is called as dead zone. During this interval phase inductance is maximum L_a .

4. *Disadvantages:* The torque ripple is an inherent drawback of switched reluctance motor drives. As it has non-linear magnetic characteristics, the problems of acoustic noise and torque ripple are more severe than these of other traditional motors.

5. *The causes of the torque ripple:* the geometric structure of motor including doubly salient motor.

6. How to minimize the torque ripple:

The torque ripple can be minimized through magnetic circuit design, a motor design stage or by using torque control techniques. By controlling the torque of the SRM, low torque ripple, noise reduction or even increasing of the efficiency can be achieved.

Literature review

Paper [1] proposed a novel Lyapunov function-based direct torque controller for minimization of torque ripples in a switched reluctance motor (SRM) drive system. The traditional direct torque control (DTC) scheme uses a hysteresis-type torque controller and it leads to large amount of torque ripples when implemented digitally. The controller used in this paper had considered nonlinear system dynamics of magnetic characteristics associated with accurate torque control using DTC scheme. In the Lyapunov function-based controller, the feedback gain is varied using a heuristic technique. A model 1-hp, 4-phase SRM is used for experimental analysis. Advantages of this controller are the torque ripples are within 10% peak-to-peak, the performance of the drive is quite satisfactory for low speeds. There are some torque ripples present during the acceleration and deceleration of SRM drive during speed transients. In paper [2] presents a control technique for torque ripple minimization SRM drive, based on a torque-sharing function (TSF) concept. In this method, the reference torque is directly translated into the reference current waveform using the analytical expression. This paper also explain the concept of optimization criteria of a TSF i.e. minimization of copper losses or maximization of drive performance. Also the novel family of TSFs is introduced. An optimal TSF can be easily extracted from the proposed family. Control performances of the two extracted TSFs and the two optimized conventional TSFs are compared. The model considered in this paper is three-phase 6/4 SRM drive. The advantages of implemented TSF optimization procedure is that provide better torque-speed characteristics and lower torque ripple than the conventional TSFs, improvement of the drive efficiency, enlargement of the possible torque-ripple-free speed range, and reduction of the peak phase current requirement. But during experimental analysis Phase currents are controlled by applying the hard-switching scheme on the classic converter variable duty cycle of the converter switches. The duty cycle is changed by the digital controller. The result i.e. phases current,

voltage & torque parameter are obtained by applying the reduced supply voltage, which deteriorates the drive performance. Also, the reference current cannot be ideally tracked, since the duty cycle, and therefore the averaged phase voltage, is discretely changed.

In the paper [3] the instantaneous torque control method is suggested. For simulation & experimental analysis, the linear magnetic model which has the 12/8 structure is used in this paper. Advantage of this control method is that it reduces the torque ripple & copper losses as well. The idea of the control method implemented in this work is to define the commutation angle, at which two adjacent phases can produce the same torque for same current. The control method used in this paper, assigns the *strong* phase to produce desired torque as much as possible, it assures low currents in phases other than the strong phase, which achieves a secondary objective of minimizing the copper losses. But this control method has disadvantage that it reduces the average torque than the rated average torque. To overcome this limitation it is necessary to obtain robust controllers in order to minimize the non desired torque ripple.

The paper [4] present design of a 2-phase 4/2 SRM for a high-speed air blower. Based on the output torque analysis at the rotor position for the given air gap, the air gap is modified to reduce the torque ripple. The torque ripple during the commutation region is higher than expected due to the short commutation time in the high speed region. In the experiments, the proposed motor has higher efficiency and lower acoustic noise than that of a conventional universal motor. The drawback of this proposed worked is that the torque ripple during the commutation region is high than expected due to the short commutation time in the high speed region.

The Paper [6] proposed a high dynamic control technique called Direct Instantaneous Torque Control (DITC). To obtain the results, torque is maintained within a hysteresis band by changing the switching states of the phases. The model used in this paper is 4-phase 8/6 SRM. By using this controlled torque ripple are minimized.

Paper [5] proposed the advanced proportional-integral and proportional-differential controllers for speed and position controls, In this paper the problem of high-precision position control associated with SRM is studied, to overcome this problem a gain-scheduling technique is adopted. The turn-on and turn-off angles are online determined through simple formulas so as to reduce the torque ripple. The disadvantage of this proposed controller is the difficulty in the controller design for achieving robust

position tracking response. The proposed control scheme is applied on the model four-phase 8/6 1-hp SRM. Also advanced PI and PD controllers for SRM position control have been presented.

Paper [8] proposed a novel flux-linkage controller using sliding mode technique with integral compensation (SM-I). This SM-I controller consist of advantages of proportion–integration (PI) and conventional SM controller. The torque ripples are reduced by correctly selecting the flux ramps in the limit of available dc-link voltage. The model used in this paper is 12/8 SRM. The advantages of this controller is that it can provide a feasible low-cost, low-ripple .But it is having drawback that this controller has serious chattering problem .

Paper [7] proposed three criteria to evaluate the motoring operation of SRM drives in EVs. They are average torque, the average torque per rms current, and the torque smoothness factor. Also this paper suggested the two improved torque-sharing functions for implementing torque ripple minimization (TRM) control. These torque-sharing functions are dependent on the turn-on angle, overlap angle, and the expected torque. This paper is used a genetic algorithm to optimize the turn-on angle and the overlap angle at various expected torque demands operating under the proposed TRM control. To implement the above methodology, the model four-phase SRM is used .The drawback of this control method is optimal control method can result in a larger average torque is increased by over 10% only. The investigation on the motoring operation of the in-wheel SRM drive has shown that the turn on and turn-off angles can be optimized to obtain maximum average torque, maximum average torque per rms current, or maximum torque smoothness factor.

In paper [9] A novel and simple nonlinear logical torque-sharing function (TSF) for a (SRM) drive is Proposed to manipulates currents in two adjacent phases during commutation to improve efficiency and torque ripple in an SRM drive .For constant torque generation, the switching of one-phase windings is regulated, and torque reference for the other phase stays at the previous state under the condition of a certain current limit given by the overall drive power rating Limitation of this control scheme is that As the speed goes up, torque ripple increases due to the lack of commutation time.

Conclusion

The torque ripples of the SRM are due to the doubly salient structure of the machine. The above literature studies suggested many techniques to control the

torque ripple .However, it has been concluded that the torque ripples can be minimized upto 5% -10%.

In the future it will be interesting to obtain the robust controller for minimization of torque ripple during high speed operation and also to explore the possibility of minimizing the chattering problem.

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