

# **Torque Ripple Minimization in 8/6 Switched Reluctance Motor by Controlling Turn ON and Turn OFF Angle**

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**ABSTRACT:** Switched reluctance motor (SRM) has a non linear inductance profile with rising and falling edges. Exciting the phase windings in rising edge produces positive torque, and in the falling edge produces negative torque. Depends on the loading conditions and speed of the motor switching point will be continuously tuned to get the good average torque. But continuous tuning increases torque ripple and EMI[1]-[3]. So the only solution is to select the optimum angles for fixed operating regions. A mathematical model has been designed for a 1KW 8/6 Switched Reluctance Machine (SRM) using Matlab/Simulink environment which operates in the optimum region that will be compared with the conventional regions.

**KEYWORDS:** Switched Reluctance Motor (SRM), Torque Ripple Minimization, Current and inductance Profile, Commutation strategy, Optimization, Turn On-Off angle.

## **I. INTRODUCTION**

In recent years, there is a growing concern about the use of energy efficient motors for industrial and domestic applications. SRM is a Specific kind of doubly-salient drive. It has the advantages of robust structure, high reliability, simple control, wide range of constant power operation, and low manufacturing cost, the inherent simplicity in both motor construction and power converter requirement, together with the availability of fast-acting high-performance semiconductor switches has made SRM an attractive alternative in adjustable speed drives, though it has tremendous advantages Compared to other conventional machine but it suffers from the drawbacks of more torque ripple, special converter configuration, and high nonlinearities. Its intrinsic simplicity and ruggedness make it superior to other electrical machines. Its high speed capability, high torque to inertia ratio, reliability and high robustness has been attracted by many researchers' interest all over the world. They are known to have high peak torque-to-inertia ratios and the rotor mechanical structure is well suited for high speed applications[9]. However, SRMs have been limited in their use due to the high ripple content of torque inherent in their doubly salient design.

Torque ripple:

The magnetization pattern of the each phases together with the static

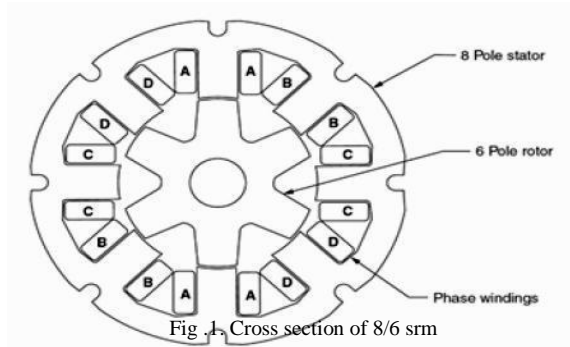


Fig. 1. Cross section of 8/6 srm

characteristics of the motor decide the amount of torque ripple during operation. Both machine design and electronic control approaches have been used for Torque Ripple Minimization in SRMs[6][8]. This paper represents technique using electronic control method to tune and fix the conduction period based on the several constraints. Torque ripple can be calculated by the following equation,

$$----(1) \quad \text{Torque ripple} = \frac{T_{\max} - T_{\min}}{|T_{\text{avg}}|}$$

Inductance Profile:

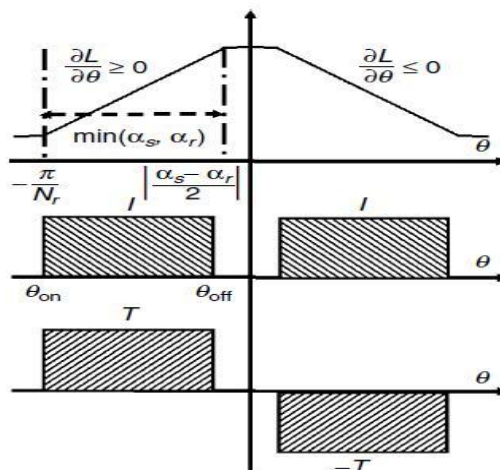


Fig . 2. Inductance profile

Control of electromagnetic torque is the main differentiating factor between various types of adjustable speed motor drives. In switched reluctance motor drives, electromagnetic torque is primarily controlled by tuning the commutation instants and the profile of phase current

$$E = \omega \frac{\partial^2 W_c}{\partial i \partial \theta} \approx \frac{dL(\theta)}{d\theta} i \omega \quad ----(2)$$

Where  $W_c$ ,  $L$ ,  $\theta$ ,  $i$ , and  $\omega$  stand for co-energy, phase inductance, rotor position, and phase current and angular speed,

respectively. It must be noted that the nonlinear effects of magnetic saturation are neglected here. It is evident that a positive torque is achieved only if the current pulse is positioned in a region with an increasing inductance profile. Similarly, a generating mode of operation is achieved when excitation is positioned in a region with a decreasing inductance profile. In order to enhance the productivity of the SRM drive, the commutation instants, i.e.,  $\theta_{on}$ ,  $\theta_{off}$ , need to be tuned as a function of the angular speed and phase current. To fulfill this goal, optimization of the torque per ampere is a meaningful objective. Therefore, exciting the phase when inductance has a flat shape should be avoided. At the same time, the phase current needs to be removed well before the aligned position to avoid generation of the negative torque.

Computation of the commutation thresholds:

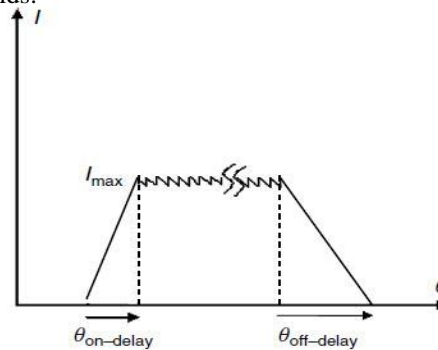


Fig . 3. Current pulse

An optimal performance of the machine is targeted, effects of rotational speed and current must be taken into account. Figure 3 shows a typical current pulse for an SRM drive. To achieve an optimal control, the delay angles during the turn-on and turn-off process need to be taken into account

$$\theta_{on-delay}^{(2a)} = \frac{\omega L_u}{r} \ln \left( \frac{V}{V - r I_{max}} \right)$$

$$\theta_{off-delay}^{(2b)} = \theta_{on-delay} \left( \frac{L_a (I_{max})}{L_u} \right)$$

In equation 2a and 2b shows delay angle calculation for optimal control. Where  $L_u$ ,  $L_a$ ,  $\omega$ ,  $V$ , and  $r$  denote unaligned inductance, aligned inductance, angular speed, bus voltage, and stator phase resistance, respectively.

Modelling of srm:

The mathematical model of SRM is a set of differential equations obtained using dynamic electric machine theory. The mathematical description of electronic controller includes the modeling of inverter, current controller, commutation logic, and reference current generator. The detailed modeling of electronic controller has been presented elsewhere[4]. The SRM is a nonlinear control structure and therefore it is important to develop relevant model representing the plant dynamics under various operating conditions. The model equations of SR motor are,

$$d\psi_j/dt = -r_{ij} + v_j \quad \text{---(3a)}$$

$$d\omega/dt = (T_e - T_l)/J \quad \text{---(3b)}$$

$$d\theta/dt = \omega \quad \text{---(3c)}$$

terms of starting time, overshoot, undershoot and settling time is selected as optimum.

Simulation results:

Where  $j=1,2,3,4$  represents the phase of the SRM,  $r$  is the winding resistance per phase,  $v_j$ ,  $i_j$ ,  $\psi_j$  are applied voltage, current, and flux-linkage respectively of phase  $j$ ,  $T_e$  is electromagnetic torque developed by the motor, and  $T_l$  is the load torque[14].

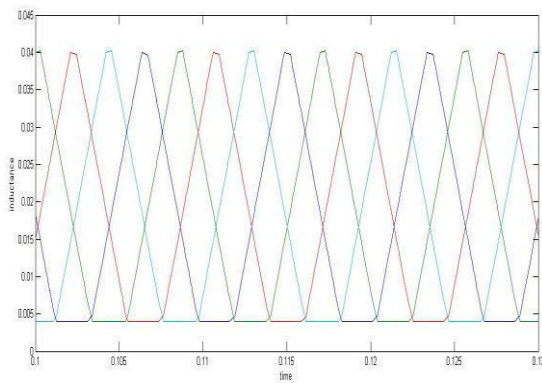


Fig. 4. Simulation diagram

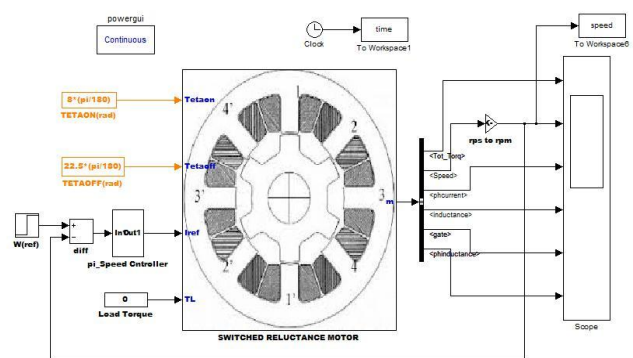


Fig. 5. Inductance profile of one phase

Determination of optimum switching angle:

The optimum single pair of switching angle is the one which gives best performance of the SRM on full load at rated speed. The magnitude of reference current is kept maximum permissible value to allow the SRM to develop maximum possible electromagnetic torque with the given pair of turn-on and turn-off angle[7][11]-[13]. The turn-on angle is selected between end of minimum inductance zone and beginning of rising inductance zone, the turn-off angle selected between end of rising inductance zone and beginning of maximum inductance zone.

First case, turn-off angle is kept constant and turn-on angle is varied by 2degrees and the performance variation for the every angle is noted. Second case, turn-on angle is kept constant and turn-off angle is varied by 2degrees and the performance variation for the every angle is noted[5].

All the selected pairs are tested one by one to drive the SRM with controller present in speed loop, and the performance on full load is analyzed for the given performance parameters. It is ensured that fixed value of controller constants are used so that their effect is uniform for all pair of switching angles[15]. The pair of turn-on and turn-off angle that produces minimum torque ripple on full load in steady state, while ensuring a smooth starting response in

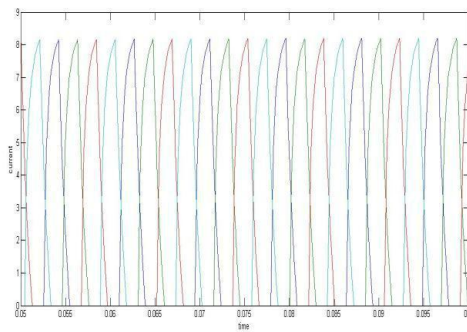


Fig. 6. Phase current

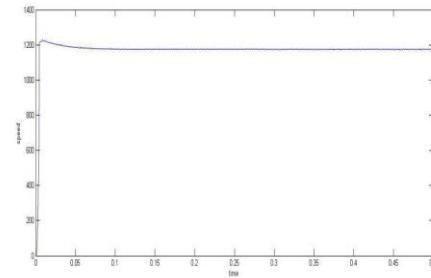


Fig. 7. Actual speed

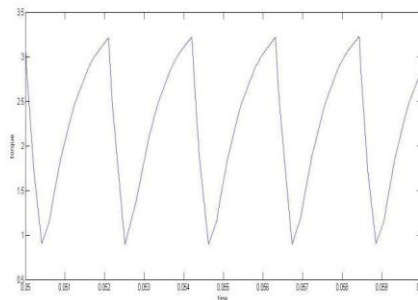


Fig. 8. Average torque

## II. CONCLUSION

This paper presents the study on determination of fixed pair of turn-on and turn-off angles of a 8/6 SRM drive. which will gives the minimum torque ripple value[10-11].This switching angles also gives the high level performances expected from the SRM. By operating the SRM in the selected optimum switching angles we can also get the low starting time, reduced speed overshoot, and low steady state error.

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