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MINIMIZATION OF TORQUE RIPPLES IN A SWITCHED RELUCTANCE MACHINE BY AN OPTIMAL SWITCHING ANGLE WITHIN A LOW INDUCTANCE REGION

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Abstract

Because of its high starting torque and improved performance in a variety of operating situations, the switched reluctance machine (SRM) has emerged as a potential challenger in the family of electrical machines. SRM has been a new addition to the industrial market in recent years. Drawbacks of SRMs are the torque ripple and acoustic noise. This research focuses on the minimization of torque ripples in a Switched Reluctance Machine by optimal switching angle in a low inductance region for a range of speed. For this, simulation is performed with the aim that SRM operation in a low inductance region will take place with low torque ripples. The finding of this research will help in better performance of the machine when operated at the desired angle.

Keywords: Experimental Validation, Switched Reluctance Machine, Static Torque, Torque Ripples.

I. Introduction

SRM (switched reluctance motor) is an electric motor that runs by the reluctance torque. In that type of motor power can be supplied to windings within the stator windings rather than the rotor, unlike ordinary brushed DC motors [I]. VRM is another name for this motor (Variable Reluctance Motor). A switching inverter is used to improve the performance of this motor. This motor has the same control characteristics as dc motors that are electronically commutated. These motors are used in applications where sizing and horsepower (hp) to weight ratios are important [II]. The Switched Reluctance Motor (SRM) comprises field coils that are wound type as are in a DC motor for the stator coil windings. Hence the rotor does not contain any magnets or coils. The rotor is a silent pole type and has projected magnetic poles made from laminated steel metal or we can say a type of soft magnetic material. The magnetic reluctance of the rotor produced a force when the power is being applied to the stator winding which tries to line up the rotor pole with the stator coil pole which is very closest to it. For the sake of to preserve the rotation an electronic control system comprised of the switches is used on the successive stator winding and is used in an arrangement such that the rotor pole will lead the stator magnetic field and use it to pull it ahead. The primary attractive factor of SRM is that its structure is very easy. The stator only consists of the winding and in some cases in required the permanent magnets are also positioned on it but the rotor most effectively consists slack of ferromagnetic material-based laminations. SRM possesses the simplest structure that is the main important hallmark [III]. Take an iron piece to demonstrate the operating principle of a switching reluctance motor. As the names suggest, a switching inverter is essential for this type of switched reluctance motor. It is based on the concept of variable reluctance that implies that the rotor will indeed try to associate itself along the path with the least amount of reluctance. The rotor's minimal reluctance segment tries to align itself with the magnetic field of the stator. As a result, the rotor develops reluctance torque [IV]. This work proposes an optimal switch on an angle that helps in torque ripple reduction. A detailed literature review is listed in Table 1.

Table 1: Literature review

Sr No	Name	Year	Summary
01	**Ghousia et al**	**2012**	The main cause of torque ripple is due to a slow shift of the current due to excitation between adjacent phases.
02	Y.Z. Xu et al	**2012**	For the selection of an optimal angle i.e., turn on and turn off analytical method is used.
03	Rohit Suryadevara et al	**2013**	An overview of numerous control strategies for the minimization of torque ripple in SRM is discussed. Firstly, Indirect torque control strategies are expressed in which the torque is transferred into equivalent current or flux references and this is the kind of quantity that's to be controlled to limit the torque ripple. Again, Direct torque control techniques are cited later in which the torque to current or flux conversion is neglected and direct torque is controlled.
04	Maged N.F et al	**2014**	The main focus of this paper is variable switching angles which influence the performance of the machine.
05	Ali Shahabi et al	**2016**	The author describes the torque ripple problems in current-controlled SRM drives in this paper. The main point is detecting the appropriate firing angles at which the SRM drives involves low ripples in torque. A scheme to amend the firing angles values was also offered. The proper turn-off angle is determined offline by computing a multi-objective optimization function based on the torque ripple factor and copper loss. However, the appropriate value of the turn-on angle is adjusted by the online method.
06	Ye Wei et al	**2016**	In this study, the torque sharing function (TSF) to limit the torque ripple of switched reluctance motor is given. The optimization standard of a TSF relates to an optimization issue that includes decreasing the copper loss and increasing the absolute value of the rate of the change of flux linkage. The dynamic simulation model is created by which an optimal Torque Sharing Function can be computed. The

			consequences suggest that ripples in the torque can be minimized more clearly in high speed as compared to low speed.
07	AA Memon et al	**2018**	The non-linear characteristics of SRM are due to saturation for its double salient pole structure. A Simulink/MATLAB environment-based model is presented which highlights all mandatory operating modes of this machine.
10	Zeineb et al	**2021**	this work presents a static characteristic for a switched reluctance motor (SRM) that is dependent on a scheme FEA (finite element analysis). The controller used here is a PI corrector which delivers sufficient results. Hence electromagnetic torque is directly influenced by the varying two angles turn-on and turn-off angles therefore this connection is later employed to reduce torque ripple. For a speed of 750 rpm, total electromagnetic torque and SRM current were calculated using three different sets of turn-on and turn-off angles are the (10°, 35°), (7°, 35°) and (3°, 34°). To examine the values of torque ripples we will determine the effects of switching angles.
11	Ping Ren et al	**2021**	The torque ripple of a switched reluctance motor (SRM) is minimized using control strategy depending on a scheme model predictive control (MPC) and another is the torque sharing function (TSF) in this paper. To begin, a correct model of SRM is created using the characteristic of flux-linkage curves derived from the locked test of a rotor that can forecast the SRM drive system's future operation state. Second, an improved TSF curve is presented, and TSF parameters are optimized using a genetic algorithm to minimize torque ripple in the commutation region.

II. Simulation results

Simulations are carried out in MATLAB under the operating conditions given in different cases separately.

- **CASE 1**
- **OPERATING VALUES FOR DIFFERENT PARAMETERS**

- Machine Operating at Turn-on Angle = -37 deg
- Machine Operating at Turn-off Angle = -7 deg
- Winding of machine resistance =3.373 ohms
- Number of phases of machine= 4
- Supply voltage dc =100Volts
- Number of switches = 8
- Number of diodes =8
- Speed=1311 rpm
- Average Torque= 4.128

Torque Ripple is given by the relation,

$$Tr = (Tmax-Tmin) / Tavg \quad (1)$$

Fig.1 shows total torque and ripples are clearly visible. Fig.2 shows the instantaneous torque of four phases of a 4-phase SRM.

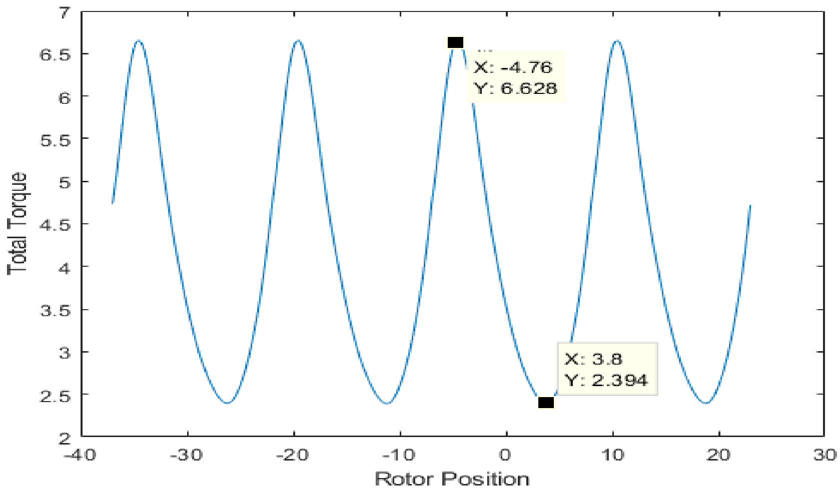

Figure 1. Total torque of a 4-phase machine

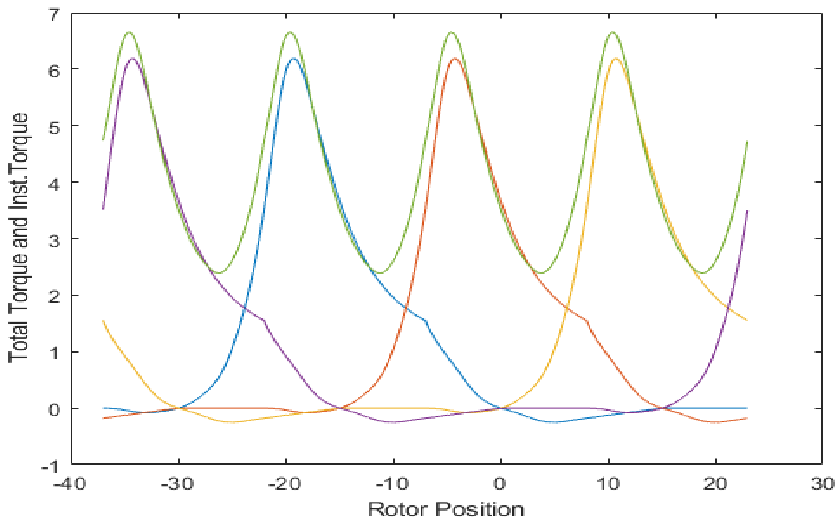

Figure 2. Instantaneous torque of a 4-phases

Table 2 shows different speeds, different switch on and switch off angles, and resultant torque ripples. Fig.3 is an ample view of Table 2.

Table 2. Torque ripples under variable speed and different switch on and switch off angles of SRM

Speed	Switch on Angle	Switch off Angle	Torque Ripple Tr
1311 Rpm	37	7	1.056
1311 Rpm	36	6	1.112
1311 Rpm	25	5	1.2455
1311 Rpm	30	0	4.829
1311 Rpm	29	1	13.4586
1311 Rpm	28	2	8.7906

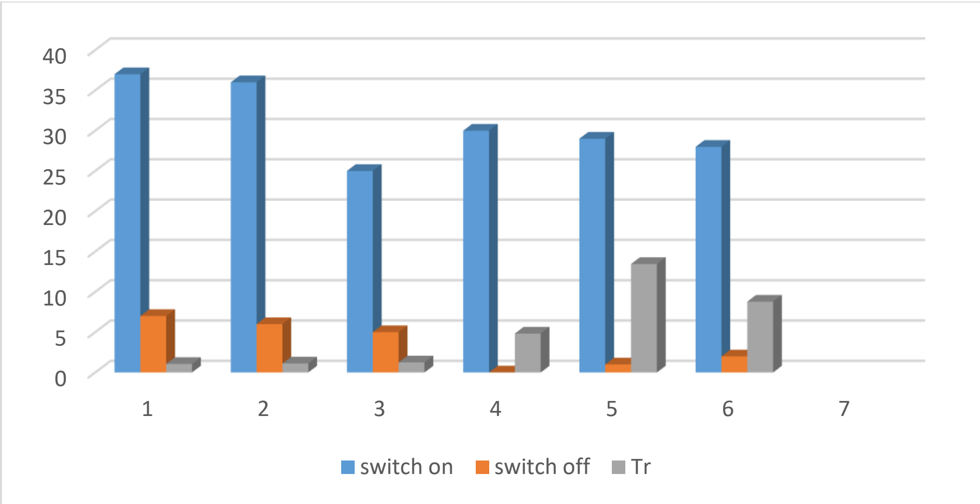

Figure 3. Torque ripple as a consequence of different switching angle

Table 3 is a representation of a comparison of obtained torque ripple at different speeds and constant conduction angle of the SRM. Fig.4 is a graphical representation of Table 3.

Table 3 Comparison of obtained torque ripple at different speeds and constant conduction angle of the SRM

Speed	Switch on Angle	Switch off Angle	Torque Ripple Tr
1311 rpm	30	0	4.829
1500 rpm	30	0	5.1981
1800 rpm	30	0	8.10007
2000 rpm	30	0	14.0356

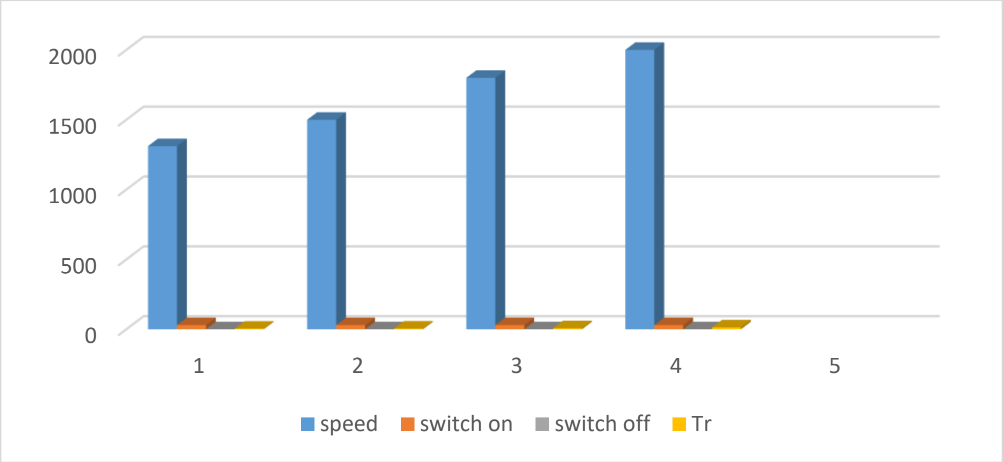

Figure 4. Torque ripple at different speeds and constant conduction angle of the SRM

III. Conclusion

A unique and simple approach to torque ripple minimization is presented. It has been observed that torque ripple is greatly reduced if SRM is switched on at a low inductance region. It has also been concluded that for higher speed the fixed conduction angle, the torque ripple is also increased. Therefore, a better choice of a switch on an angle is important to take care of for low torque ripples.

Conflict of Interest:

There is no conflict of interest regarding this article

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