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Torque Ripple Reduction of Switched Reluctance Motor by Changing the Rotor Pole Tip Radius

Nirav A. Salunke, Amit N. Patel and Tejas H. Panchal

Abstract**:** ***Switched Reluctance Motor has the main limitation of high torque ripple because of its doubly salient structure. This paper presents the Finite Element (FE) analysis of 5 hp, 655 V, 8/6 Switched Reluctance Motor with rotor pole shaping to reduce torque ripple. It is observed that rotor pole tip radius variation significantly affects torque ripple. Tapered rotor pole having high tip radius results into reduced torque ripple. Rotor pole tip radius is changed from 0 to 5 mm in step of 1 mm and FE analysis is carried out to obtain average torque and torque ripple. It is examined that torque ripple is reduced from 69.1 % to 39.3 % with this technique.***

Keywords: Switched Reluctance Motor, Torque ripple, Rotor pole tip radius, Finite Element Analysis, Torque profile

I. INTRODUCTION

Switched Reluctance Motor (SRM) is progressively used in industrial and domestic applications. It offers many advantages like robustness, loss free excitation, less maintenance, wide speed range, high reliability and wide range of operating temperature. Major disadvantage of SRM is high torque ripple. High torque ripple creates vibration, noise and worsens overall performance of the motor. The influence of torque ripple is substantial near low speed region while at high speed its effect is reasonably low due to high momentum [1]. It is very important to decrease the torque ripple to enhance the performance of the motor. It is the current topic of research to reduce the torque ripple of SRM. The torque ripple is quit inherent in SRM due to its doubly salient structure. The torque ripple can be reduced with proper design modifications and improved control techniques. This paper focuses on reduction of torque ripple with design modification. Any modification in control technique results into lower operational efficiency of SRM. SRM of 5 hp, 655 V is initially designed assuming various design variables and considered as reference design for the analysis. The reference design is validated using Finite Element (FE) analysis. The reference motor generates average torque of 23.6 N.m. with torque ripple of 69.1 %. The reference design is enhanced by changing rotor pole tip radius. The reference design has rotor pole tip radius of 0 mm. The rotor pole tip radius is varied from 0 mm to 5 mm in step of 1 mm in improved design and its effect on torque is analyzed. Section II describes design aspects of reference SRM. Section III defines torque ripple of SRM and techniques for its improvement. Section IV explains design improvement of SRM with pole tip radius variation. Concluding remark is presented in Section V.

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***** Corresponding Author

Nirav A. Salunke*, Electrical Engineering Department, R.N.G.P.I.T., Isroli, Bardoli, India.

Amit N. Patel*, Electrical Engineering Department, Institute of Technology, Nirma University, Ahmedabad, India.

Tejas H. Panchal, Electrical Engineering Department, Institute of Technology, Nirma University, Ahmedabad, India.

II. REFERENCE SWITCHED RELUCTANCE MOTOR

The investigation that is introduced in this paper is based on SRM having 8 stator poles and 6 rotor poles as shown in Fig. 1. The stator comprises concentric winding. The dimensions are calculated based on assumed design variables, availability of material and geometric constraints [1]. Initially, the stator bore diameter D and stack length L have been calculated based on the output equation of the SRM. Stator and rotor pole arcs of 22° and 26° are selected respectively. The specific electric loading and specific magnetic loading are assumed as 26000 A/m. and 0.6 T respectively.

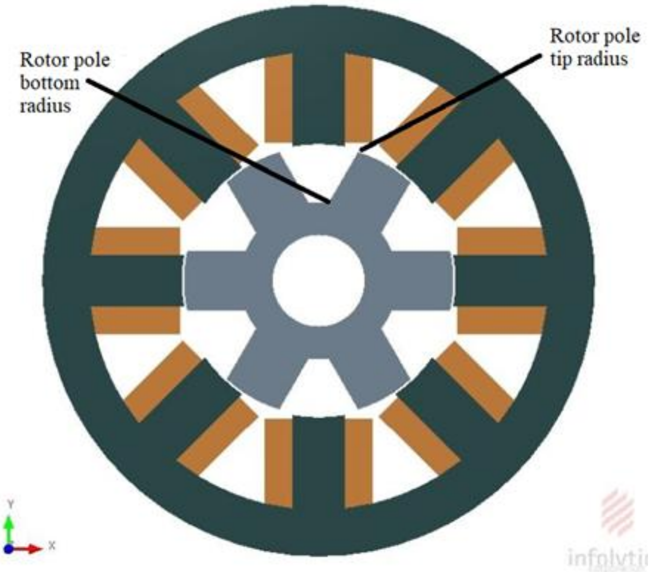

Fig. 1. Initial model of 8/6 SRM having rotor pole tip radius = 0 mm

The magnified view of rotor of reference design showing rotor pole tip radius is shown in Fig. 2. The rotor pole tip radius is kept 0 mm in reference design as shown in Fig. 2. The SRM is gradually finding its usefulness in various applications such as home appliances, automobile, aerospace applications, medical equipments, defense equipments, etc.

Fig. 2. Magnified view of rotor of reference design

Torque in the motor is generated due to the rate of change of flux linkage [2]. This paper proposes the technique to reduce torque ripple of SRM. Inductance profile of the motor is changed by changing the rotor pole tip radius. Hence, torque ripple of the motor is changed. The parameters and material used for the reference motor is shown in Table I and Table II.

Table- I: Parameters of Reference Motor

Parameters	*Symbol*	*Value*
Stator pole no.	P_s	8
Rotor pole no.	P_r	6
Stator pole arc (degree)	B_s	22
Rotor pole arc (degree)	B_r	26
No. of phases	q	4
Outer diameter of stator (mm)	D_o	200
Outer diameter of rotor (mm)	D_r	97.9
Axial length (mm)	L	119.3
Depth of stator back iron (mm)	b_{sy}	13.7
Depth of rotor back iron (mm)	b_{ry}	11.9

Table- II: Material used in Motor

Component	*Material*	*Mass density (kg/m^3)*
Stator pole, Stator back iron	M43 26Ga	7700
Rotor pole, Rotor back iron	M43 26Ga	7700
Winding	Copper	8954

A simulation exercise is conducted to obtained torque profile of SRM. The torque profile of reference motor is shown in Fig. 3. The average torque obtained is 23.6 N.m.

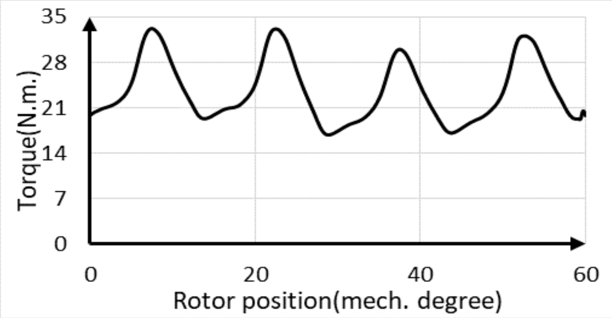

Fig. 3. Torque profile of Initial model of 8/6 SRM having rotor pole tip radius = 0 mm

III. TORQUE RIPPLE

The torque ripple is defined as the difference between the maximum and minimum instantaneous torque expressed as a percentage of average torque. High torque ripple in inherent in SRM due to its doubly salient structure. Torque generation of SRM depends on flux linkage variation with respect to rotor position and pole shapes. Torque ripple can be reduced with minimizing difference between maximum and minimum torque.

$$T_{ripple} = \frac{T_{max.} - T_{min.}}{T_{avg.}} \times 100\% \qquad (1)$$

There are several methods to reduce the torque ripple [3]-[10]. These methods are as under

1. Varying the stator and rotor pole arc
2. Varying the turn on and turn off angle
3. Varying the pole tip shape design
4. Varying the rotor pole tip radius
5. Varying rotor pole tip & bottom radius as well as stator pole bottom fillet & tooth tang radius.

This paper presents variation in rotor pole tip radius to reduce torque ripple of SRM.

IV. IMPROVED DESIGN OF SWITCHED RELUCTANCE MOTOR

The reference design is improved by changing the rotor pole tip radius. The rotor pole tip radius is increased from 0 mm to 5 mm in step of 1 mm. The cross sectional view of improved design with rotor pole tip radius of 5 mm is shown in Fig. 4. The effect of rotor pole tip radius on torque of SRM is analyzed. Two dimensional (2D) finite element model of SRM has been prepared for simulation and analysis. Rotor pole tip radius of SRM is varied keeping other dimensions unchanged and simulation is performed to obtain torque profile.

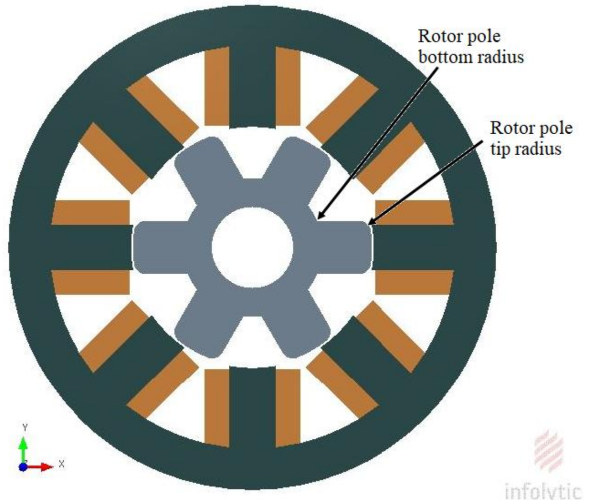

Fig. 4. Improved design of 8/6 SRM with rotor pole tip radius = 5 mm

The magnified view of rotor of improved design showing rotor pole tip radius is shown in Fig. 5. The rotor pole tip radius is kept 5 mm as shown in Fig. 5.

Fig. 5. Magnified view of rotor of SRM having rotor pole tip radius = 5 mm

Torque profile of improved design with rotor pole tip radius of 5 mm is shown in Fig. 6. The torque ripple has been reduced considerably as compared to reference design of SRM.

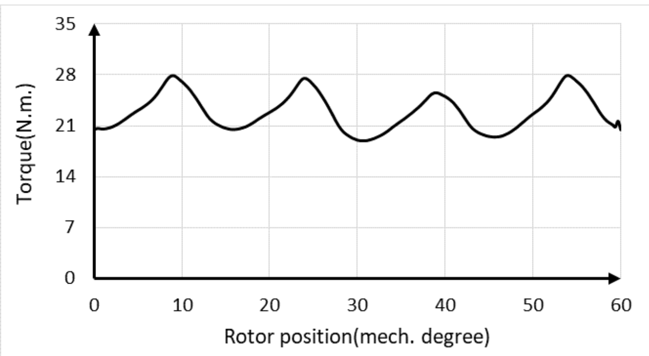

Fig. 6. Torque profile of Improved model with rotor pole tip radius value = 5 mm.

Torque ripple variation of 8/6 SRM for various values of rotor pole tip radius has been shown in Table III. It is analyzed that as rotor pole tip radius increases the torque ripple reduces with marginal reduction in average torque.

Table- III: Comparision of Torque Ripple

Sr. No.	*Design*	*Rotor pole Tip radius (mm)*	*Average Torque (N.m.)*	*Torque Ripple (%)*
1.	Initial	0	23.6	69.1
2.	Improved	1	23.6	66.6
3.		2	23.5	60.9
4.		3	23.4	55.6
5.		4	23.2	48.7
6.		5	22.9	39.3

The effect of rotor pole tip radius on torque profile of SRM is presented in Fig. 7. The torque ripple reduces as rotor pole tip radius increases. The reference design with rotor pole tip radius of 0 mm has torque ripple of 69.1 %. The minimum torque ripple of 39.3 % is obtained for rotor pole tip radius of 5 mm. This technique is based on shaping of rotor pole only hence it is implementable technique in any rating of SRM. There is no additional increase in cost, manufacturing complexity with proposed technique.

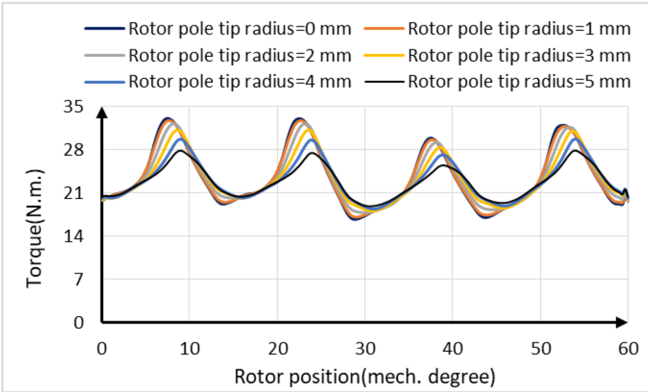

Fig. 7. Comparison of torque profiles for variation in rotor pole tip radius

V. CONCLUSION

This paper presents rotor pole shaping technique to reduce torque ripple of Switched Reluctance Motor. A 5 hp, 655 V, 8/6 pole SRM is initially designed with rotor pole tip radius equal to 0 mm and considered as reference design for analysis. The torque profile of reference design is obtained using FE analysis. The reference design has torque ripple of 69.1 %. The design is improved by shaping the rotor pole. The rotor pole tip radius is increased from 0 to 5 mm in step of 1 mm and effect of it on torque profile is analyzed. It is observed that as rotor pole tip radius is increased the torque ripple is reduced. Minimum torque ripple of 39.3 % is obtained for rotor pole tip radius of 5 mm. Rotor pole shaping is an effective technique to reduce torque ripple of SRM.

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AUTHORS PROFILE

Nirav A. Salunke has Completed Bachelor Degree in Electrical Engineering from R.N.G.P.I.T., Bardoli, Gujarat, India. He has Completed M. Tech. in Power Electronics, Machines and Drives (Electrical Department) from Institute of Technology, Nirma University, Ahmedabad, India. He is recently working as an Assistant Professor in Electrical Engineering Department at R.N.G.P.I.T., Bardoli, Gujarat, India.

Amit N. Patel obtained degrees of B.E. and M. E. in Elect. Engg. in 1999 and 2004 respectively from Gujarat University, Ahmadabad, India. Currently he is Assistant Professor at Nirma University. He has published several papers in international journals & conferences. His research area includes design of conventional and advanced electrical machines.

Tejas H. Panchal has obtained degrees of B.E. and M. E. in Elect. Engg.in 2001 and 2004 respectively from Gujarat University, Ahmadabad, India. He has been working as Assistant Professor in Nirma University since 2005. He has published several technical papers at International level. His research area includes design of advanced electrical machines and electrical drives.