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Variation of Inductance in A Switched Reluctance Motor Under Various Rotor Faults

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Abstract-In order to Electric Motor have required the regular monitoring for higher efficiency, performance, reliability the regular monitoring of an electrical motor is required. This article elaborates the novel approach for air-gap magnetic field analysis of switched reluctance motor in case of rotor cracks and rotor tilt around its shaft axis. The fault diagnosis is illustrated on the basis of a 3-D model of the SRM using of a technique known as finite element analysis (FEA). The flux linkage analytical equations are used for the derivation of inductance expressions. The results obtained from the 3-D FEA of an SRM having 6 stator and 4 rotor poles shows the variation of mutual inductance with the cracked rotor conditions and the tilting of the rotor shaft. The results obtained to explain the usefulness of the detection of cracked rotors and shaft tilting.

Keywords-Switched Reluctance Motor, Finite Element Analysis, Cracked Rotor, 3-D Modeling of SRM

I. INTRODUCTION

A switched reluctance motor (SRM) considered being one of the most popular motors having different applications in this modern era because of the fact that its rotor has no winding and requires very little maintenance when compared with induction motors. The faults occurring in an SRM are categorized into two types; the first are electrical faults that usually occurs when. When there is some abnormal behavior of voltages or currents in the stator windings and the. The mechanical faults are the second type of faults that originate in the SRM is due to the cracks in the stator or rotor body and due to the eccentricity, i.e. dislocation of the bearings or the tilting of the rotor shaft. As SRMs are increasingly finding applications in many industries, nowadays these are used especially in air compressors and hybrid vehicles. The fault diagnosis of SRM has become the need of the hour.

Because of its fault-tolerant capabilities, SRM has the ability to continue its operation even when undergone through mechanical and/or electrical faults; nevertheless, these faults should diagnose as early as possible so that the motor will not be damaged. In reference [i] 3-D FEM is used for three-phase outer rotor SRM for both healthy and faulty rotor, i.e. having dynamic eccentricity. Various rotor structures of SRMs have been analyzed and diagnosis under rotor faults has been presented in reference [ii]. In reference [iii], an effective way of optimizing rotor shape has been analyzed in order to reduce torque ripples in a double stator SRM by mainly using 3-D FEM. Reference [iv] discusses the flux reversal and excitation of a two-phase exterior rotor SRM by using 3-DFEM. Reference [v] covers the angular misalignment faults of an SRM using 3-D FEM at various operations conditions. In reference [vi] the fault tolerant capabilities and electrical faults detection of an SRM have been discussed. Using 2-D FEA (Finite Element Analysis) dynamic and static eccentricity faults and their detection techniques of an SRM has been discussed in reference [vii]. By using 3-D FEM modeling static and dynamic eccentricity faults are diagnosed and also the effect of these faults on the mutual and self-inductances on the stator windings have been analyzed in references [viii] and [ix]. In reference [x] due to eccentricity faults in SRM the behavior of flux linkages and torque using 2D-FEM modeling has been studied. In reference[i] 3-D FEM is used for three-phase outer rotor SRM for both healthy and faulty rotor, i.e. having dynamic eccentricity. Various rotor structures of SRMs have been analyzed and diagnosis under rotor faults has been presented in reference[ii]. In reference[iii], an efficient way of optimizing rotor shape has been analyzedin order to reduce torque ripples in a double stator SRM by mainly using 3-D FEM. Reference[iv] discusses the flux reversal and excitation of a two-phase exterior rotor SRM by using 3-DFEM. Reference[v] covers the angular misalignment faults of an SRM using 3-D FEM at various operations conditions. In reference [vi] the fault tolerant capabilities and electrical faults detection of an SRM have been discussed. Using 2-D FEA (Finite Element Analysis) dynamic and static eccentricity faults and their detection techniques of an SRM has been discussed in reference [vii]. By using 3-D FEM modeling static and dynamic eccentricity faults are diagnosed and also the effect of these faults on the mutual and self-inductances on the stator windings have been analyzed in references [viii] and [ix]. In reference [x] due to eccentricity faults in SRM the behavior of flux linkages and torque using 2D-FEM modeling has been studied. In this paper, we present the variation of mutual inductance, under rotor tilt and rotor cracks of an SRM with the help of 3-D FEM.

The Section II of this paper explains 3-D modeling of an SRM; geometrical parameters of an SRM are used. Description of cracks in the rotor and the tilting of rotor shaft are explained in section III. The results of a 3-D FEM of the SRM have been discussed in section IV in case of healthy and faulty conditions, and the conclusions are discussed in section V. Waveforms of current were observed under both normal and faulty conditions.

II. Literature Review

In references [xi]-[xii] [viii, xi-xii] flux linkages and mutual inductances of one phase coil have been shown under eccentricity fault but the inductance variations and flux variations have been done on 3-D FEM with rotor movement but on invariant values of current (non-sinusoidal currents) at rotor rotation from 0 to 44 degrees. The variations are required; that is why it does not matter. Eccentricity faults have been discussed in these papers, i.e. static as well as dynamic. In reference [xiii] [ix-x, xiii] the 2-D FEM on eccentricity faults and flux linkages have been discussed with current variations as well. As it is not a 3-D model, so the results are not reliable. In [xiv] the effect of mutual inductance of SRM is analysed.

In our article, using the 3-D FEM model of an SRM we have discussed rotor tilt and cracks in the rotor which have never been studied before. We have done FEM with rotating rotor from 0 to 44 degrees with current variations as well with 50 Hz frequency. That is why our inductance variation in healthy and faulty conditions are showing exact variations of inductance as we took sinusoidal currents. We have increased cracks and tilt in order to see their effects: the tilt has been varied from 1 to 3 degree and the cracks from 5 % to 10% of the rotor.

III. Switched Reluctance Motor 3-D Modeling

For the determination of magnetic flux linkages of SRM, a process of 3-D finite element analysis is used. The field winding of SRM have the AC current which circulates in it and magnetic flux plots are drawn: numerous parameters of the motor have been calculated and discussed.

In order to have the knowledge about SRM operation and to know the characteristics of SRM while the rotor has different positions, we assume the rotor to rotate from 0 to 44°. The SRM which is under study have the specifications shown in Table I.

TABLE I
Specification of the SRM (6/4) Used in the Study [VIII].

Sr. #No.	Parameters	Values
1.	Diameter of Rotor Core	40.5mm
2.	Diameterof Stator Core	72 mm
3.	Diameter of Shaft	10 mm
4.	Stator pole arc	28°
5.	Rotor pole arc	32°
6.	Length of Stack	35 mm
7.	Length of Air gap	0.25mm
8.	Number of turns	120

Table I: Switched Reluctance Motor specification under Study

The cores of stator and rotor are laminated with silicon steel which is non-oriented, in this study, and the winding of each phase is rated at 300 ampere-turns.

A. *Rotor tilts and cracks*

In Figures 1 and 2 the rotor shown is tilted along its axis

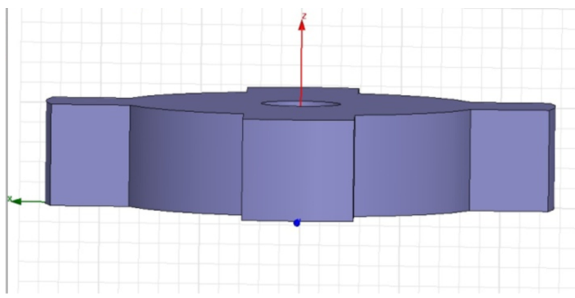

Fig. 1. Normal rotor position of SRM.

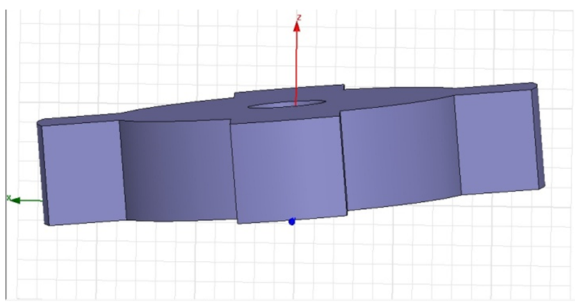

Fig.ure 2. Tilted rotor position of SRM.

The air gap length of the rotor is 0.25 mm and the rotor will allow a tilt of 4o if the tilt allowed angle is greater than 4o then the values of inductance value becomes irrational in the design of 3-D modeling. The rotor tilting arises due to faults of bearing or due to the mechanical misalignment of the rotor, i.e. stress.

The second kind of faults is due to the cracks in the rotor which may occur because of the mishandling, stresses on the rotor or may be caused during manufacturing. These cracks are placed in all the poles of the rotor so that it should be symmetrical and the percentage crack can be measured by the following relation:

$$\%crack = \frac{crackvolume}{rotorvolume} \times 100$$

$$\text{Percentage Crack} = \frac{\text{Crack Volume}}{\text{Rotor Volume}} \times 100$$

The poles of rotor that are cracked showed in Fig. 3 and a complete 3-D model of the SRM shown by the Fig. 4.

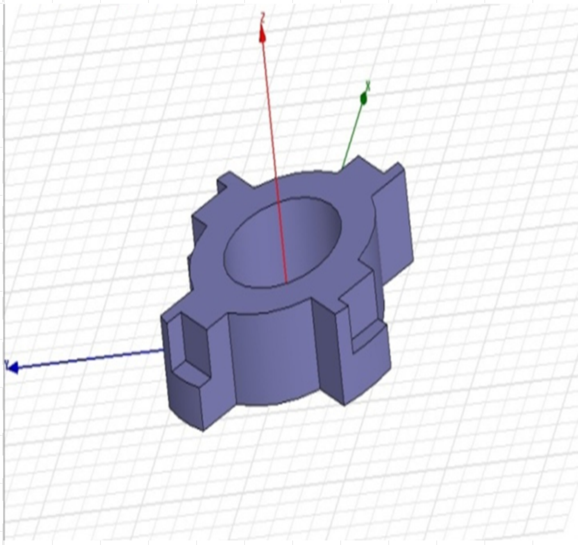

Fig. 3. Cracked Rotor of SRM

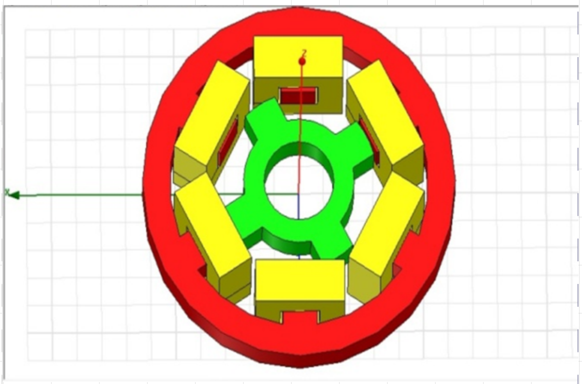

Fig. 4. 3-D Model of 6/4 SRM

B. Numerical analysis

To analyze the consequences of rotor faults on the behavior of the SRM, the SRM has been simulated in ANSYS Maxwell for the utilization of 3-D FEA.

For the first step, the mutual inductance of coil 2 having the phase B is calculated. After that, the rotor is titled in the second step, from 1o to 3o and the mutual inductance of the same coil is being calculated. In the third step we add 5% and 10% cracks in the healthy rotor and the mutual inductances, of same the coil, respectively have been determined. The results obtained, during all the above steps, are given in Table II and plotted in Figures 5 and 6.

TABLE II
MUTUAL INDUCTANCE OF 2ND COIL HAVING PHASE B.

Angle (degree)	Healthy Case	1-degree angle tilt	3-degree angle tilt	5% cracks in rotor	10% cracks in rotor
0	-0.3182	-0.673	-0.986	-0.724	-1.186
4	-0.2363	-0.449	-0.724	-0.668	-1.040
8	-0.1659	-0.28	-0.398	-0.592	-0.990
12	-0.1126	-0.221	-0.324	-0.483	-0.713
16	-0.0932	-0.280	-0.456	-0.332	-0.440
20	-0.1339	-0.439	-0.704	-0.268	-0.400
24	-0.2076	-0.680	-1.168	-0.302	-0.572
28	-0.2761	-0.702	-1.184	-0.431	-0.858
32	-0.3541	-0.639	-0.94	-0.634	-0.948
36	-0.4939	-0.640	-0.808	-0.928	-1.092
40	-0.4444	-0.539	-0.632	-0.898	-0.998
44	-0.3396	-0.480	-0.606	-0.640	-0.800

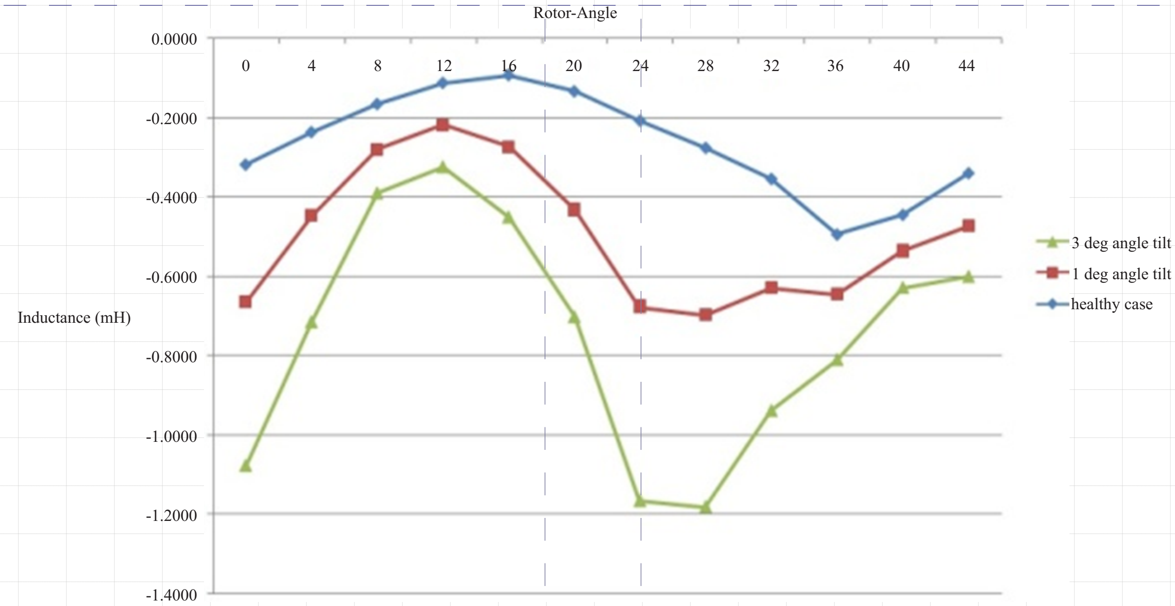

Fig. 5. Mutual inductance of coil 2 of phase-B with and without cracks

The variations of mutual inductances illustrate that the flux linkages disturbances arise as a result of faults in the rotor assembly: these rotor faults produce stresses and vibrations on the SRM and affects its uniform operation. The mutual inductance of motor increases with the increase in rotor tilt. The rotor cracks also produce the similar effect, but the effect of the motor is more prominent now as the mutual inductance increases more profoundly when compared with the tilted-rotor scenario. The cracks in the rotor significantly disturb the stator current when compared with that in the tilted-rotor fault.

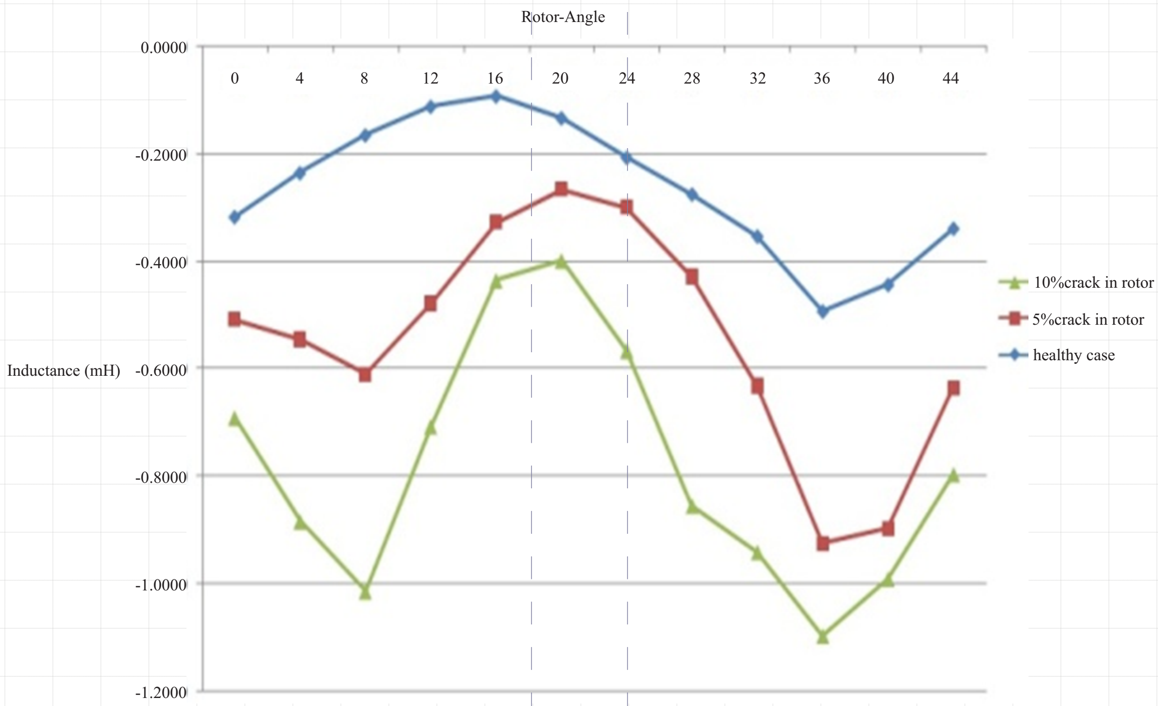

Fig. 6. Mutual inductance of coil 2 of phase B with and without rotor tilt

The graphical results show that the mutual inductance in healthy case is near to its positive value but as we introduce 5 % rotor crack in SRM the values of mutual inductance become more negative and its values goes on decreasing as we add 10% rotor cracks in it. It shows that both the coils are moving away from each other as the mutual inductance is dependent on the primary and secondary coils. Same is the case when we introduce rotor tilt in SRM. In 2-degree rotor tilts the value is negative then healthy case and when the tilt is increased from 2 to 3 degree the values of mutual inductance become more negative that shows that the coils are moving away from each other resulting in the decrement of mutual inductance.

IV. CONCLUSION

The paper has been investigated and analyzed and simulated the efficiency of a switched reluctance motor. The SRM have different types of faults such as shaft tilts and rotor cracks that are analyzed by utilizing a three-dimensional finite element method. In this respect, the effects of rotor faults on the mutual inductances in one of the coils of SRM have been evaluated. These results, obtained under rotor faults, have been compared with those from a healthy SRM operating under normal conditions.

The paper This study illustrates that the variation of the mutual inductance of a switched reluctance motor under rotor tilt and rotor cracks will easily be recognize and precautionary measures can be done before any severe kind of faults. As the SRM is analyzed under different faulty conditions we have the advantage of these results that we can easily resolve the problem associated with the switched reluctance motor. And furthermore these results are helpful for the industries where SRM is a major component. In future these types of faults associated with SRM can easily be diagnosed and precautionary measures can be done. can be confidently used in the diagnosis of these faults, which are otherwise harder to distinguish. The mutual inductance of coil 2 having the phase B is calculated. The rotor is titled in from 1o to 3o and the mutual inductance of the same coil is being calculated. By adding 5% and 10% cracks in the healthy rotor and the mutual inductances, of same the coil, respectively have been determined. In future, this can be extended to other types of motors for the fault diagnosing efficiently.

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