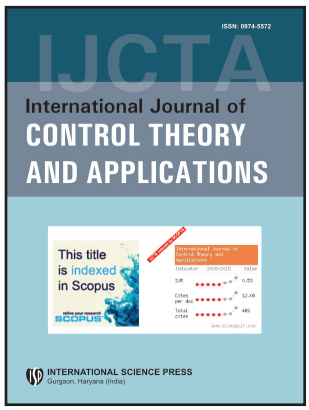

International Journal of Control Theory and Applications

ISSN : 0974-5572

Volume 10 • Number 16 • 2017

Effect of Open Circuit Fault on Characteristics of Switched Reluctance Motor using FEM

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Abstract: Increasing concerns about global warming have necessitated the development of electric vehicles (EVs) and hybrid electric vehicles (HEVs) to reduce the carbon foot print and reduce the emissions. Switched reluctance motors (SRMs) with their tolerance to faults and wide speed ranges have become the most preferred choice for EV/HEV applications.SRM is an economical alternative to induction motor due to less cost, greatly robust and variable speed motor. This paper presents the effects of open circuit fault on the characteristics torque, current, flux. The simulation results are obtained by using Ansys Maxwell software.

Keywords: SR motor, performance character, istics, torque, stator current, inductance, flux, linkages, stator coil open.

1. INTRODUCTION

The switched reluctance motor is one of the oldest electric machine designs. This development is partly due to recent demand for industrial drives and partly as a result of development of technology in power electronic drives.SRM has found a multitude of application in different domains because of its simple and elegant build. However the fault tolerance of the Switched Reluctance Motor (SRM) cannot be granted for absolute and should be analyzed under different operating conditions.

In [1] Simulation of Switched reluctance motor (SRM) using ANSOFT has been done. Applications of Ansoft in electro magnets in [2] and in [3] air gap eccentricity's are explained. Dynamic Performance Estimation under Internal and External Faulty Conditions [4], Design Considerations [5]. In majority of the papers dealing only one parameter like mutual inductance or flux distribution.

Even though some phases are having fault but they can continue their movement with one or more faulty phases. This can cause some power reduction of machine which is proportional to the number of faulty phases out of total number of phases and it increases the ripple content of torque.

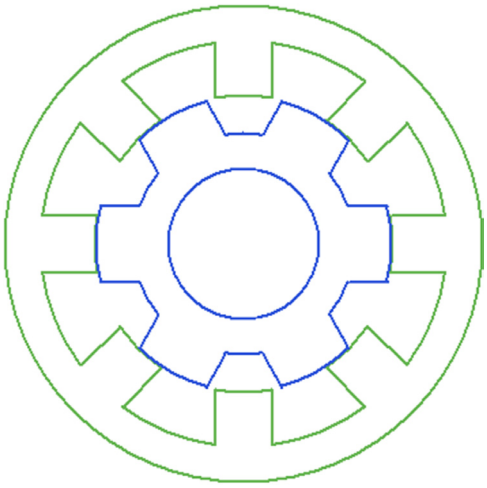

Figure 1: The switched reluctance machine

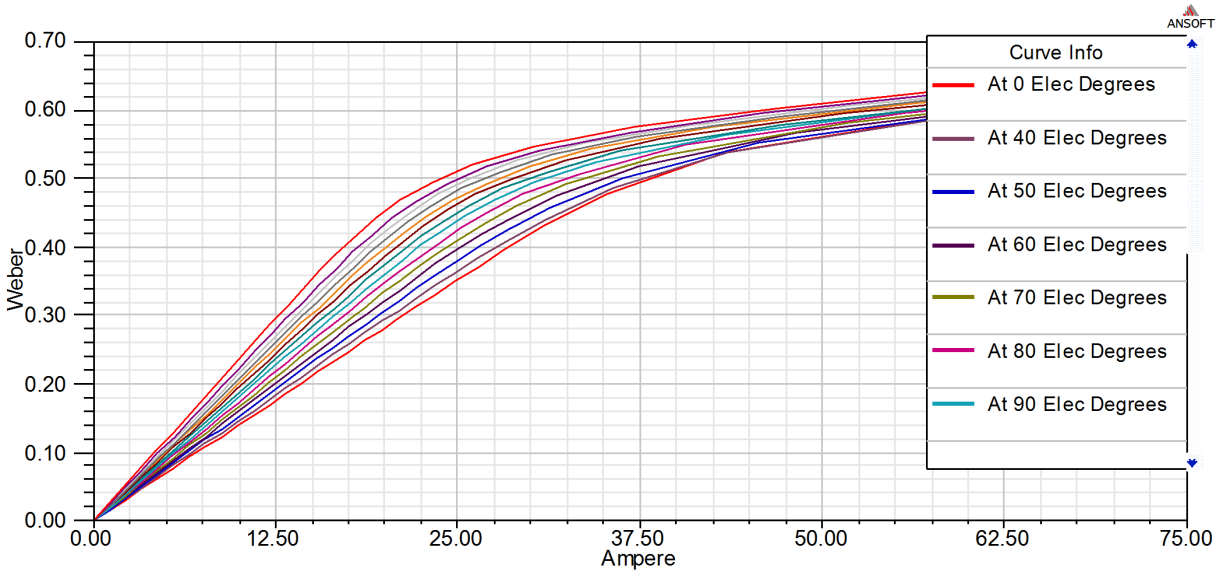

Figure 2: Magnetization characteristics

In the paper the main stator faults occurring in SRM are presented in Section II. The healthy and stator coil open circuit cases are designed using ANSYS MAXWELL (2D) presented in Section III. The sample SRM characteristics are obtained by 2D-FEM analysis, the comparison of simulation results being presented and discussed in Section IV. The final conclusion points are given in Section V.

2. FAULTS IN A SWITCHED RELUCTANCE MOTOR

The switched reluctance motor windings can experience several faults.

(i) Single winding of a phase Open circuit

(ii) Windings of a multi phases Open circuit

(iii) One winding of a phase Short circuit

(iv) Whole winding short circuit

The failures in windings may be due to mechanical vibrations, more heat, aging, damages caused under installation, failures in components of converter etc.

In this paper mainly concentrating on (i) open circuit occur in single winding of a phase (ii) open circuit in windings of a multi phases. The main problem with an open winding fault is decrement in production torque. The flux becomes uneven and non uniform so different magnetic unbalance causes to pull the rotor to one side.

3. DESIGN OF A HEALTHY AND FAULTY SWITCHED RELUCTANCE MOTOR

The SR Motor 2D model in healthy and faulty conditions is designed using ANSYS MAXWELL software. The design parameters are shown in Table 1.

Table 1
Dimensions Data

S.No	*Parameter*	*Value*
1	Stator poles	8
2	Rotor poles	6
3	Stator outer diameter	120mm
4	Stator inner diameter	75 mm
5	Rotor outer diameter	74.5 mm
6	Rotor inner diameter	38 mm
7	Air gap	0.5 mm
8	Power	550 W
9	Speed	1500 rpm
10	Voltage	300V

The proposed 8/6 motor model is given in Figure 1 and its magnetization characteristics are shown in Figure 2. Figure 3 shows the SRM 2D design in healthy condition, the windings fault i.e. open circuit in one winding (coil-1) of a phase is shown in Figure 4. Second case is open circuit in the windings of multiple phases (coil-0, coil-1) shown in Figure 5.

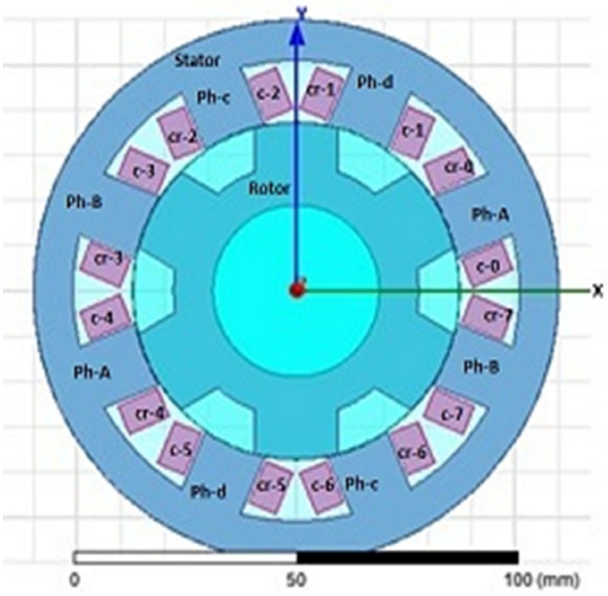

Figure 3: SRM Healthy 2D Model

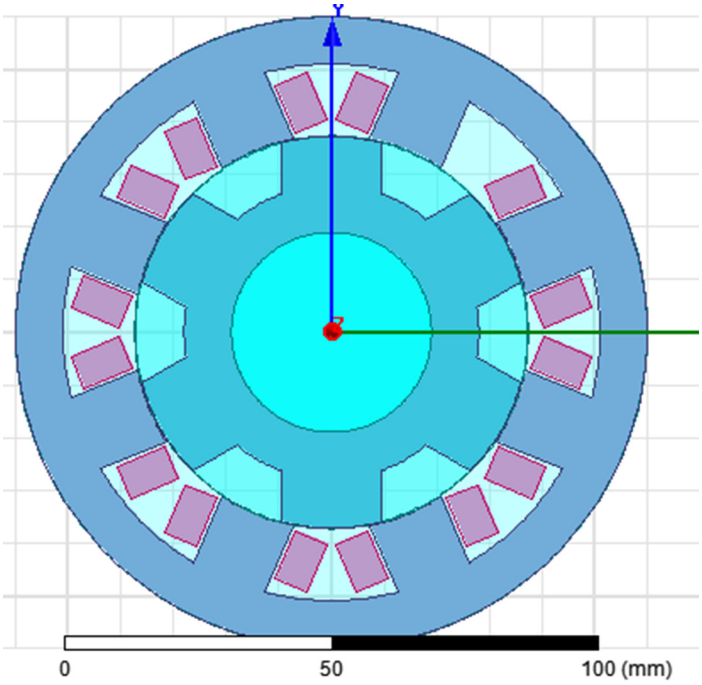

Figure 4: SRM with one stator coil open

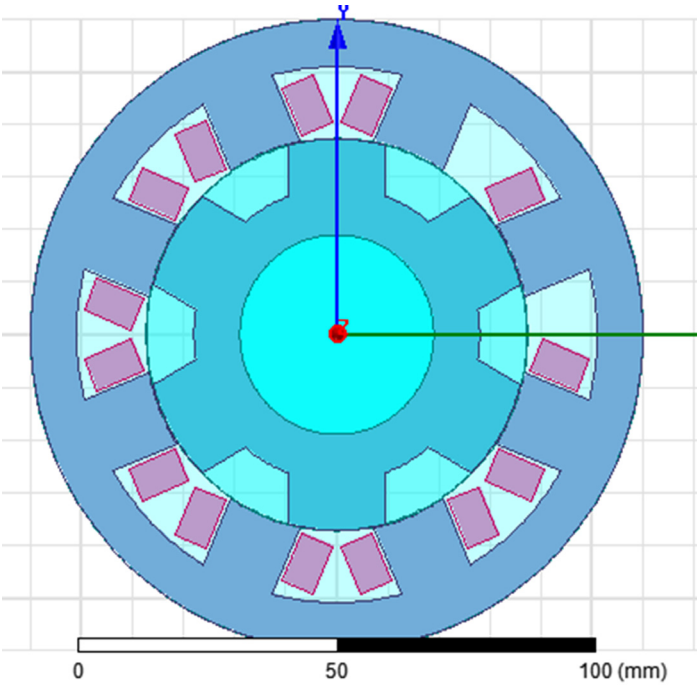

Figure 5: SRM with two stator coil open

Double salient pole configuration, inductance profiles of switched reluctance motor is a function of the rotor position. When one phase is excited, then the torque produces force on the aligned poles. When a rotor pole is reaching another stator pole, the torque due to the corresponding phase, is almost constant with the motion of rotor direction, which is a motoring action. The control action is, therefore, depends on the rotor positioning. The voltage expression for each phase is described by:

$$V = iR + Ldi/dt + idL/dt. \tag{1}$$

The applied phase voltage in terms of flux linkages as shown:

$$V = \frac{d\lambda}{dt} + iR \tag{2}$$

The *di/dt* expression can be obtained from the above equation as follows:

$$\frac{di}{dt} = \frac{1}{d\lambda/di}\left(V - iR - \frac{d\lambda}{di}\omega\right) \tag{3}$$

The torque in SRM is obtained from the following expression.

$$T = \frac{\partial W'_f}{\partial \theta}, \text{ where, } i = \text{constant} \tag{4}$$

When stator winding in a SRM is open and excitation to that faulty phase is absent and hence no more production of torque from faulty one. The controller requires more torque from the other healthy phases in order to maintain the desired speed.

4. SIMULATION RESULTS

(a) Healthy Motor Case

The performance characteristics of SR Motor under different faults are analyzed and the waveforms of the torque (N-m), current (A) and flux (wb) in the faulty/healthy phases are shown. The machine considered is a 4-phase, 8/6, 550w SRM.

The characteristics of switched reluctance motor under healthy condition are as shown below Figure 6. The overall torque is 3.41 N-m and it is varying between two limits and is proportional to currents and the tendency of variation is also similar to overall currents. For better understanding only phase A is considered for flux (0.1225wb) and its profile is shown in Figure 6(c).

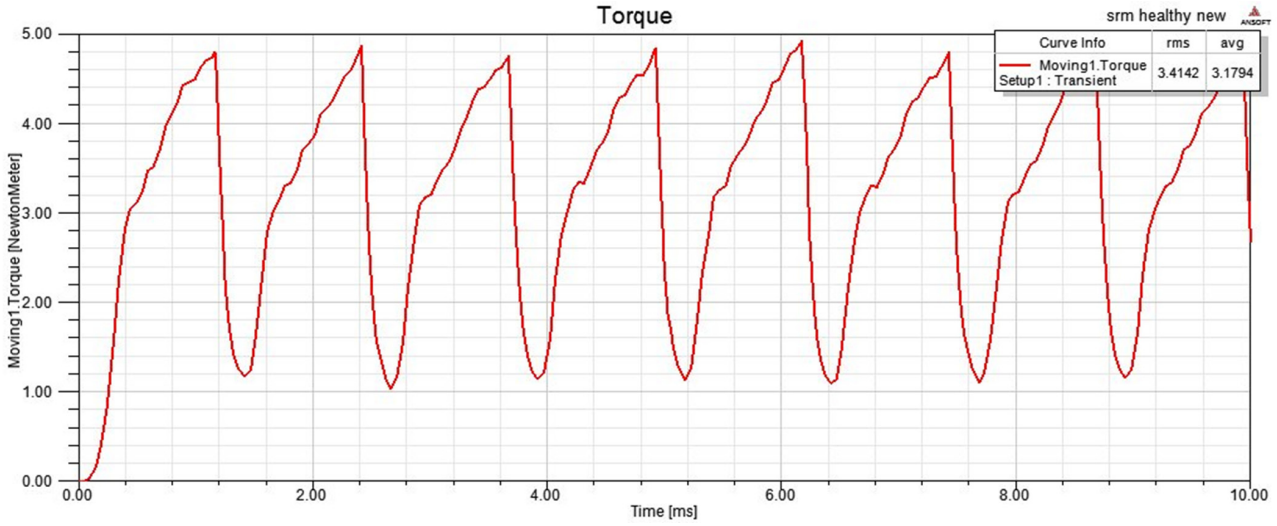

Figure 6: (a) Torque

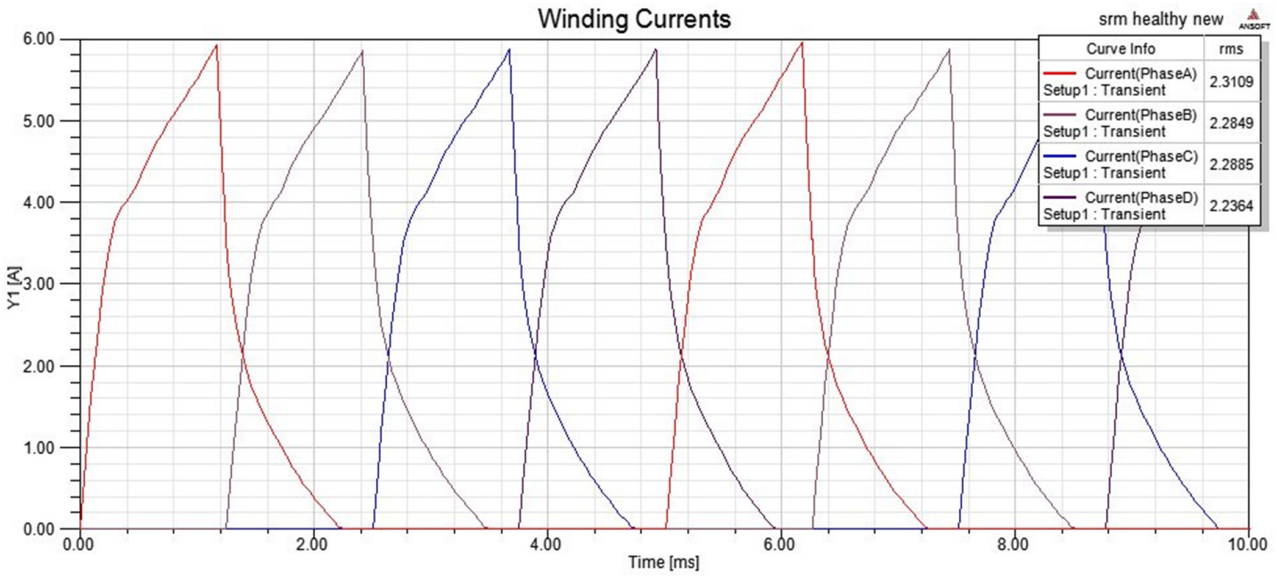

Figure 6: (b) Currents

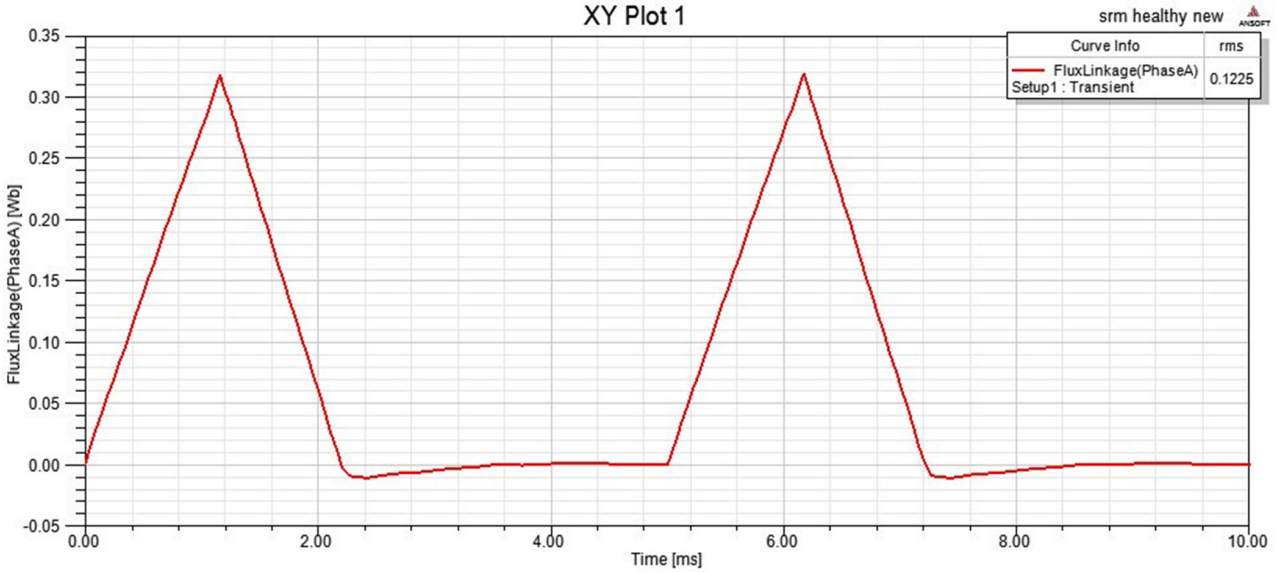

Figure 6: (c) Flux profile (phase-A)

The SR machine phase windings are shown with two opposite pole-coil pairs. Normally the pole-coils sown have the same ampere-turns F, produces a balanced flux linkages ϕ that crosses the rotor with balanced symmetry.

(b) Single Winding of a Phase Open Circuit

The characteristics of switched reluctance motor under one coil open condition are as shown below Figure 7. The overall torque decreases to 2.93 N-m and the ripple content in torque and current waveforms increases than healthy condition. The current in the faulty phase is decreased to a considerable extent where as the remaining same. The open circuit in one phase decreases the overall flux to 0.1214 Wb in the air gap of the machine, its profiles is very less deviated from the healthy one.

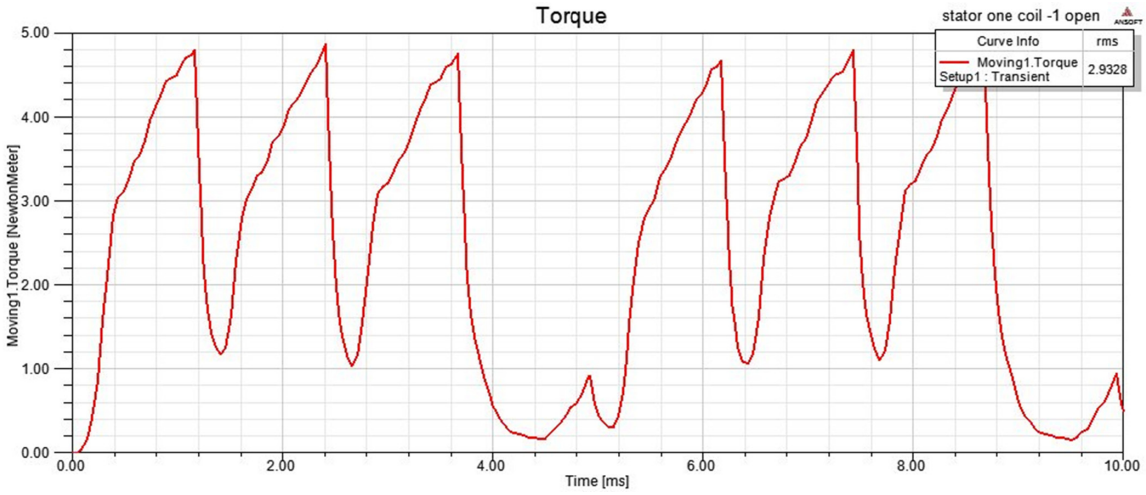

Figure 7: (a) Torque

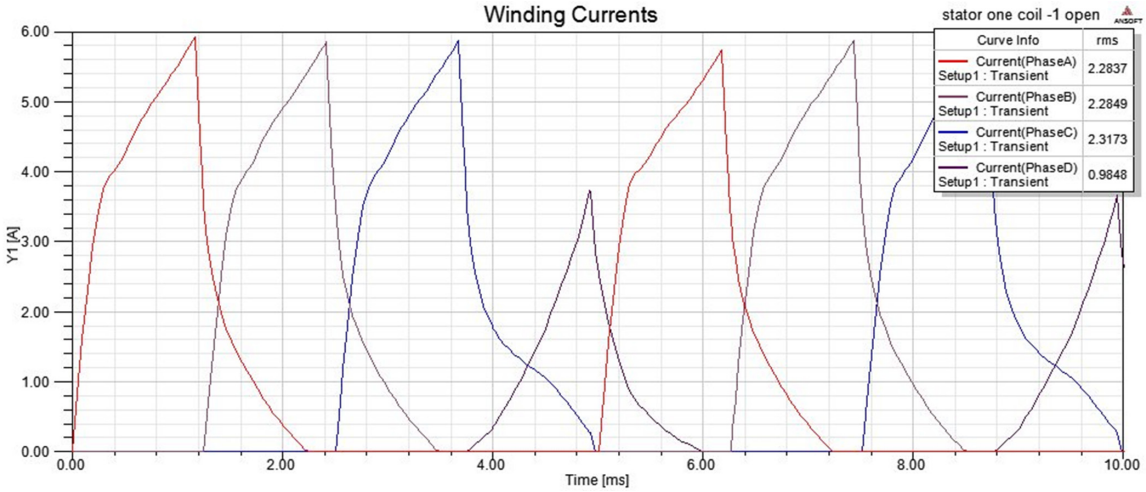

Figure 7: (b) Currents

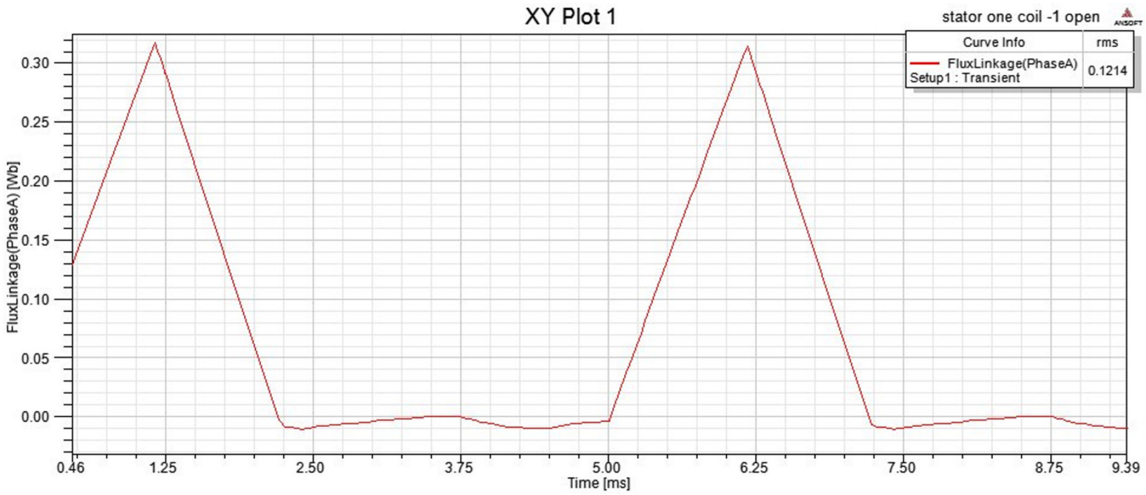

Figure 7: (c) Flux profile (phase-A)

(c) Windings of a Multi Phases Open Circuit

The characteristics of switched reluctance motor under two coils open condition are as shown overall torque profile shown in Figure 8(a), currents shown in 8(b), flux profile of phase-A in 8(c).

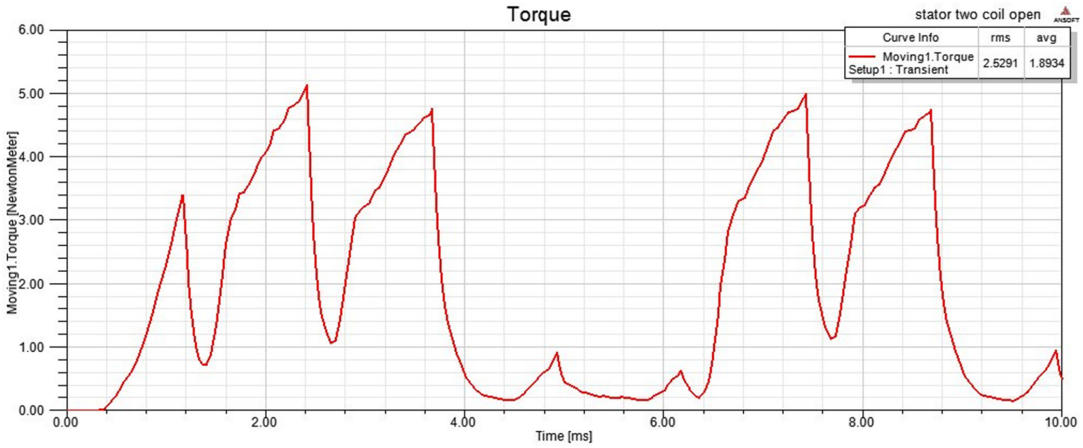

Figure 8: (a) Torque

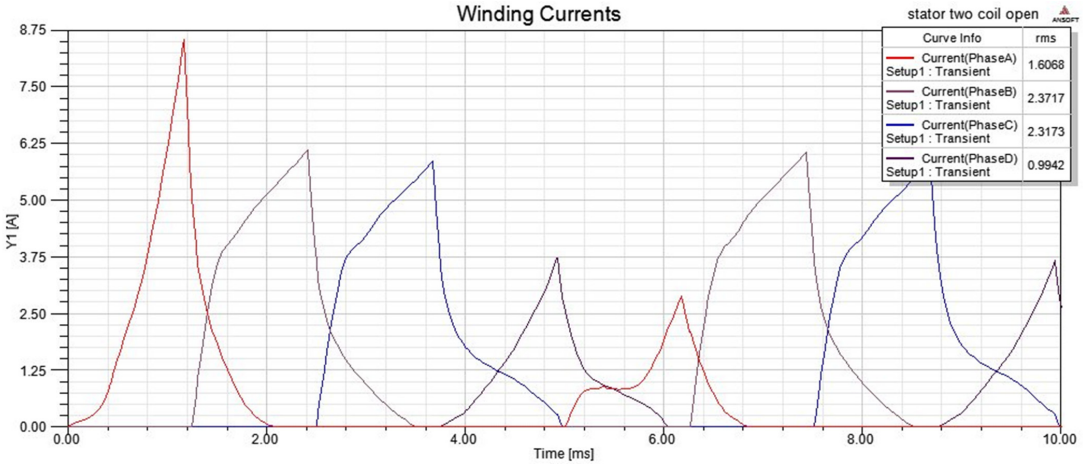

Figure 8: (b) Current

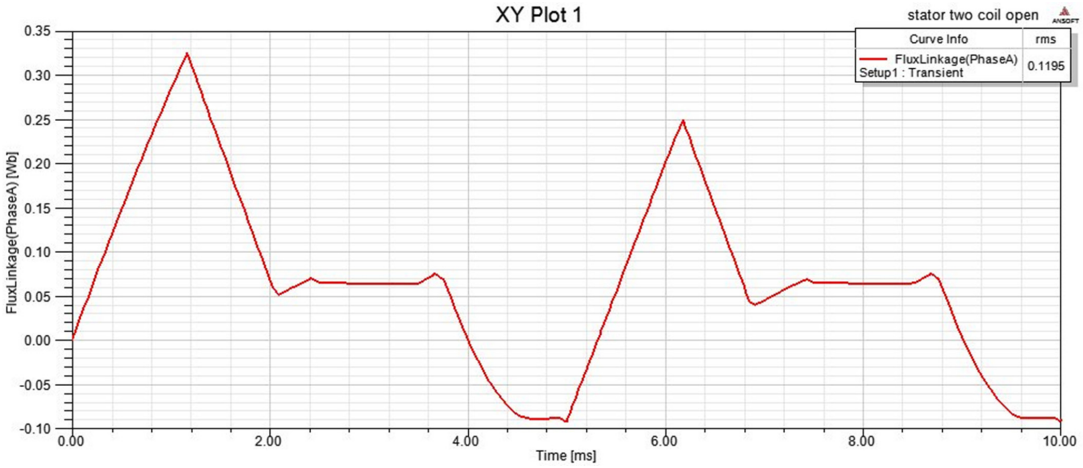

Figure 8: (c) Fluxprofile (phase-A)

In faulty motor when two coils open, the torque characteristic shown is the overall torque Decreased to (2.52 N-m) and it is deviating from limits very large extent with more ripple content than previous and in between t = 4 ms to t = 6.5 ms almost it reaches to zero. This opening of two coils causes its phase currents uneven some phases with large magnitudes, some with very less magnitudes this creates huge unbalanced magnetic pull. The open circuit in two phases decreases the overall flux to 0.11 Wb and its profile is entering into the negative region as shown in Figure 8(c).

5. CONCLUSIONS

In this work the effect of open circuit coil fault on the characteristics torque, current, flux of 8/6 SR Motor is investigated through 2-D finite element software. It is observed that if the number of open circuited coils increases then the overall torque decreases and creates large ripple content in the waveforms. The current in faulty phases falls down to very low values and the magnitude of air gap flux also decreases. This analysis is useful to take some remedies to overcome this type of faults so that it improves the performance characteristics of a motor and also fault tolerant capacity of switched reluctance motor increases.

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