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Design and Finite Element AnalysisofSwitched Reluctance Motor with Exterior Rotor

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***Abstract*— This paper presents the design procedure for two phase switched reluctance motor with exterior rotor. This design is mainly concentrated on excitation and flux reversal. The flux reversal is one of the main source of vibration, a new winding topology is investigated to eliminate the flux reversal in theback iron of stator .The Finite Element Analysis (FEA) will be done in electricalaspects, to verify the design in this project simulation work will be carried out using MagNet electromagnetic simulation package.**

***Keywords*— Exterior Rotor, Switched Reluctance Motor, Flux Reversal,Finite Element Analysis (FEA).**

I. INTRODUCTION

In switched reluctance motor torque will be produced with an interaction of stator and rotor saliency. This machine has various advantages especially in the field of automotive applications such as simplicity in construction, high speed applications, high power density, phase windings are electrically separated, low moment of inertia[4].But this motor has the disadvantage of acoustic noise, excitation. This paper deals with designof an exterior rotor switched reluctance motor to overcome the two main problems (A) excitation (B) flux reversal. (A) Excitation: Normally, the conventional and in-wheel SRM are excited during the unaligned condition and that phase has to be turned off with aligned condition. The reason behind this is, if we excite the machine beyond the aligned condition, it leads to negative torque. (B) Flux Reversal: the one of the major problem with the machine is vibration, which results in acoustic noise. Thus the flux reversal of the machine is occurred by the both stator as well as rotor, so in order to eliminate this new winding topology is investigated. The construction of Exterior Rotor motor is varies from conventional motor by having an outer rotor and inner stator configuration. Even though conventional motor used for EV applications requires gear coupling arrangements. But this setup is not necessary for Exterior Rotor.

II. DESIGN

We know that perimeter, $P = 2\pi r$
Where

$2\pi r = 817$ mm (1)
From that r is found by

$$r = \frac{817}{2\pi} \quad (2)$$

$$= 130\ mm$$

Outer diameter, D_0=2* 130 = 260 mm
No of stator poles, $P_s = 6$ (3)
No of rotor poles, $P_r = 3$ (4)
Stack length, L = 50 mm

The required torque, T_{req} is calculated from the output power, P_0 of the machine, given as

$$P_0 = \frac{2\pi N T_{req}}{60} \text{ Watts} \quad (5)$$

$$T = \frac{250*60}{2\pi*1000} \quad (6)$$

T=2.5 N-m. (7)
Where P_0 = 250 watts, N rated speed of the motor = 1000 rpm, then,
From the feasible triangle choose stator pole arc and rotor pole arc
Stator Pole arc, $\beta_s = 62^0$ (8)
Rotor pole arc, $\beta r = 100^0$ (9)
Frame size, $D = \frac{D_0}{2} + 50$
D= 180 mm (10)
The material used to fabricate the Hub motor is M-19 silicon steel.
For M43 Steel, Flux density B_s= B_{max}= 1.6 T

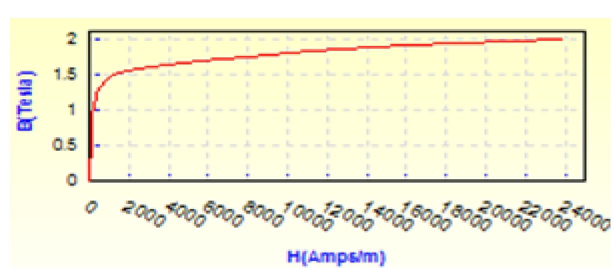

Fig 1. B-H curve for M-43 USS Armature Steel

Area of the stator, A_s is given as

$$A_s = \left(\left(\frac{D}{2}\right) - g\right) * L * \beta s \quad (m^2)(11)$$

$$A_s = \left(\left(\frac{180}{2}\right) - 1\right) * 50 * 62 * \frac{\pi}{180}$$

$A_s = 0.004815\ m^2$ (12)

Flux in the stator, Φ is given as

$$\Phi = B_s * A_s Wb \quad (13)$$

$$\Phi = 1.6 * 0.004815$$

$$\Phi = 0.007704\ wb \quad (14)$$

Area of the rotor A_r is given as

$$A_r = ((D/2) * L * \beta_r) \quad A_r = ((180/2) * 50 * 100 * \frac{\pi}{180})$$

$$A_r = 0.0078539\ m^2 \quad (15)$$

Flux density in the rotor, B_r is given as

$$B_r = (B_s * A_s) / A_r \quad (16)$$

$$B_r = (1.6 * 0.004815) / 0.0078593$$

$$B_r = 0.98097T$$

Area of the yoke, A_y is given as

$$A_y = \frac{A_r}{2.1}$$

$$A_y = \frac{0.0078539}{2.1} \quad (17)$$

$$A_y = 0.0037399\ m^2$$

Flux in the yoke, Φ_y is given as

$$\Phi_y = \Phi_{sc} = \frac{\Phi}{2} \quad (18)$$

$$\Phi_y = \Phi_{sc} = \frac{0.0077045}{2}$$

$$\Phi_y = 0.0038522\ Wb \quad (19)$$

Flux density in the yoke, B_y is given as

$$B_y = \frac{\phi_y}{A_y} \quad (20)$$

$$B_y = \frac{0.003852}{0.0037399}$$

$$B_y = 1.03004T \quad (21)$$

Assume,

Area of the stator core, $A_{sc} = A_s = 0.004875\ m^2$

Then,

Flux density in the stator core,

$$B_{sc} = \frac{\phi_{sc}}{A_{sc}} \quad (22)$$

$$B_{sc} = \frac{0.003852}{0.004875}$$

$$B_{sc} = 0.790205\ T \quad (23)$$

Area of the air gap, A_g is given as

$$A_g = \left[\frac{D}{2} - \frac{g}{2}\right]\left[\frac{\beta_r + \beta_s}{2}\right] * \frac{\pi}{180} * 75 * 10^{-6} m$$

$$A_g = \left[\frac{180}{2} - \frac{1}{2}\right]\left[\frac{100 + 62}{2}\right] * \frac{\pi}{180} * 75 * 10^{-6}$$

$A_g = 0.009485\ m^2$ (24)

Air gap flux density is given as, B_g

$$B_g = \frac{A_s B_s}{A_g}$$

$$= \frac{0.004815 * 1.6}{0.009485}$$

$$= 0.81228T$$

Air gap field intensity, H_g is calculated as

$$H_g = \frac{B_g}{\mu_0} = \frac{0.81228}{4\pi * 10^{-7}}$$

$$= 646393.916 AT/m$$

$$h_{sc} = \frac{A_{sc}}{L} \quad (25)$$

$$= 40.08269 mm$$

Height of the stator pole h_s is given as

$$(26) \quad h_s = \frac{D}{2} - g - \frac{D_{sh}}{2} - \frac{A_{sc}}{L}$$

$$h_s = 39.448 mm \quad (27)$$

Height of the rotor pole h_r is given as

$$(28) \quad h_r = \frac{D_o}{2} - C - \frac{D}{2}$$

$$h_r = \left[\frac{260}{2} - 16.489 - \frac{180}{2}\right]$$

$$= 23.811 mm$$

$$l_y = \pi * \left[\frac{D_o}{2} - \frac{C}{2}\right] \quad (29)$$

$$l_y = \pi * \left[\frac{260}{2} - \frac{16.489}{2}\right] \quad (30)$$

$$l_y = 382.50 mm$$

$$l_{sc} = \pi * \left[\frac{D}{4} - \frac{g}{2} - \frac{h_s}{2} - \frac{D_{sh}}{4}\right] \quad (31)$$

$$l_{sc} = \pi * \left[\frac{180}{4} - \frac{1}{2} - \frac{32.81}{2} + \frac{35}{4} \right]$$

$$= 60.774mm$$

$$l_r = h_r + \frac{c}{2} \quad (32)$$

$$l_r = 23.811 + \frac{16.48}{2} \quad (33)$$

$$= 32.052mm$$

Br = 0.98097 T (34)

By = 1.0300 T (35)

Bs = 1.6 T(36) $B_{sc} = 0.790245T$

III. DESIGN SPECIFICATIONS

Table 1 shows the machine dimensions of the proposed two phase 6/3 Exterior Rotor SRM topology.

Table 1: Machine Dimensions

Power	250 Watts
Peak Voltage	48 Volt
Peak Current	8 Amps
No. of Phases	2
No. of stator poles	6
No. of Rotor poles	3
Stack length	50mm
Speed	1000rpm
Material	(M-43) Steel
Stator Pole Arc	62degree
Rotor Pole Arc	100 degree

IV. NEW WINDING TOPOLOGY

In this new winding topology X_0, Y_0 are the main windings similarly X_1, X2 and Y1, Y2are the auxiliary windings. Considering the aspect of flux reversal, the auxiliary windings are connected in parallel which is connected in series to the main field winding as shown in the figure [7].

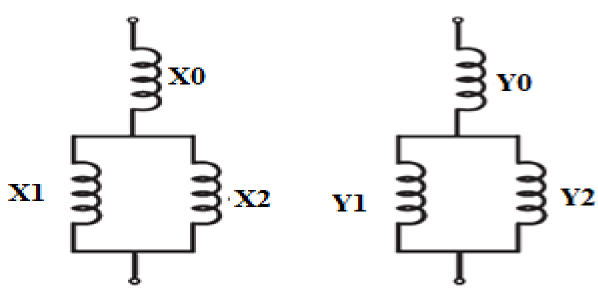

Fig. 2 New winding Topology

IV. PROPOSED EXTERIOR ROTORSWITCHED RELUCTANCE MOTOR

In this proposed model, new winding topology is implemented in order to obtain the flux reversal free stator. The fig.4 shows the proposed 6/3 Direct Drive SRM. The stator consists of two main poles and four auxiliary poles and the rotor consists of three poles. The fig 5 and 6 shows the flux direction for excitation of phase a and phase b respectively. The flux direction is similar to all excitations [1].

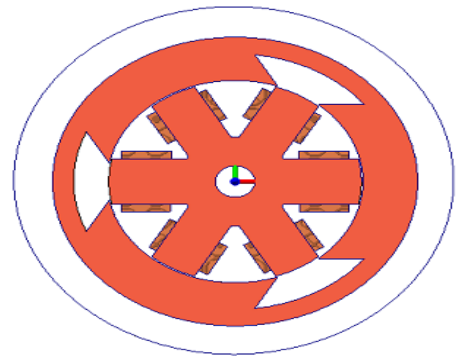

Fig.3 Proposed 6/3Exterior rotor SRM

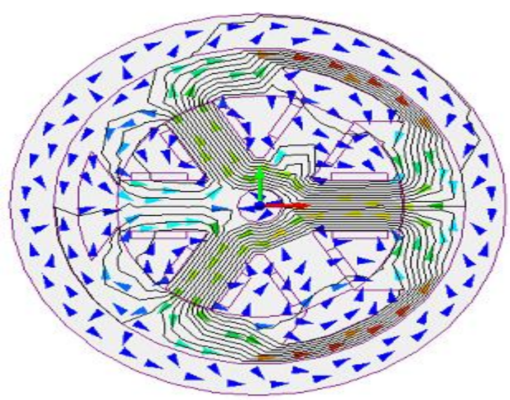

Fig. 4 Excitation of Phase A

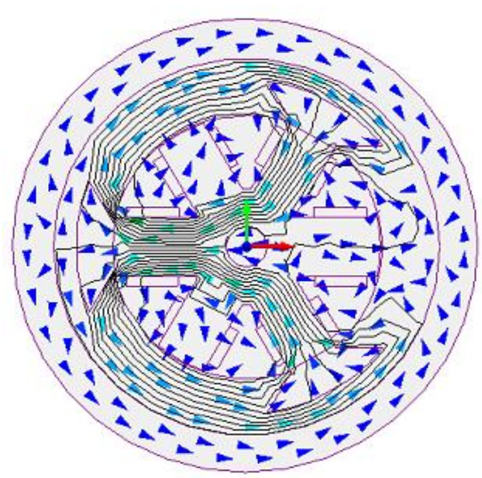

Fig. 5 Excitation of Phase B

VII . FINITE ELEMENT ANALYSIS

Using the software package FEA analysis of an Direct Drive switched reluctance motor is carried out for static and transient analysis to predict the performance characteristics in 2D model.

1. STATIC

In static FEA analysis various parameters like torque, flux linkages, ohmic losses, iron losses, current and energy are obtained with respect to instantaneous rotor position. In fig 8 and 9 shows the static flux density and flux distribution of Phase A and Phase B. The flux density for Phase A and Phase B is 2.18825Wb and 2.58549Wb. Fig 10 shows the static torque. Fig 11 and 12 shows the flux linkage for Phase A and Phase B. Fig 13 shows the static magnetic energy, fig 14 shows the static co-energy.

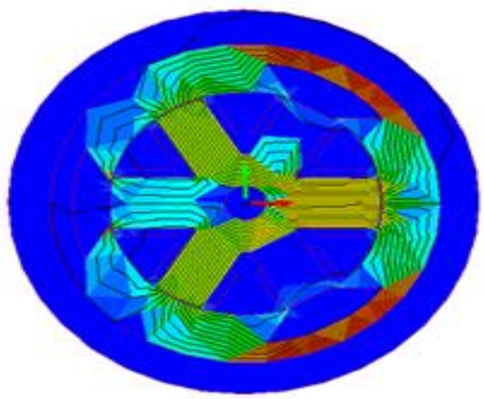

Fig.6 Static Flux Density and Flux Distribution for Phase A Excitation

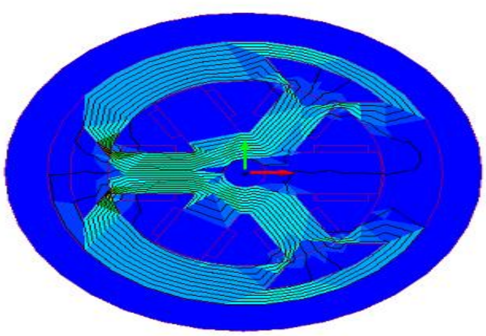

Fig. 7 Static Flux Density and Flux Distribution for Phase B Excitation

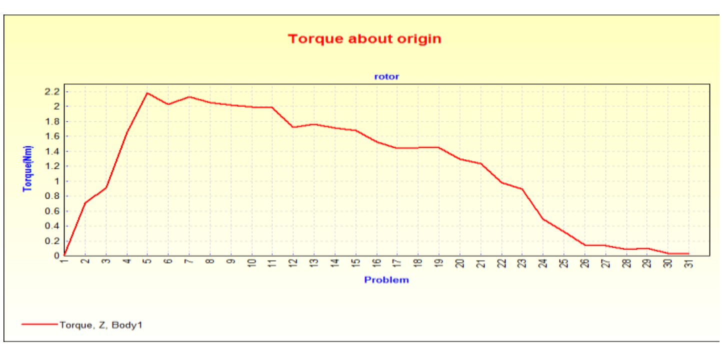

Fig. 8 Static Torque with respect to various rotor position

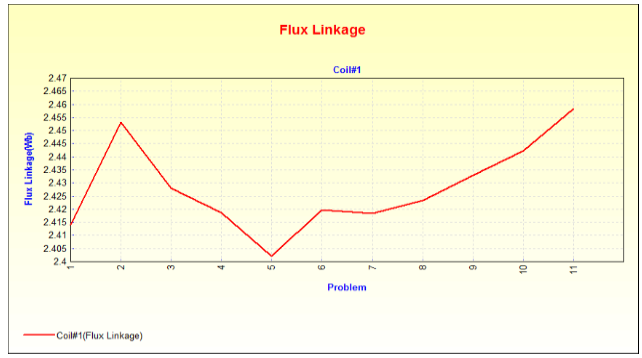

Fig. 9 Fluxlinkage for Phase A

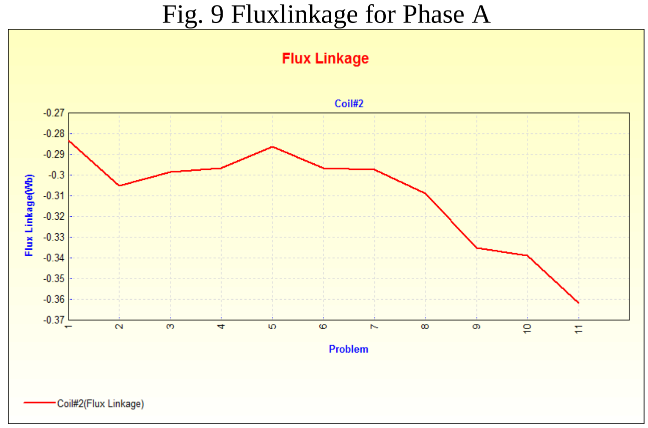

Fig.10 Fluxlinkage Phase B

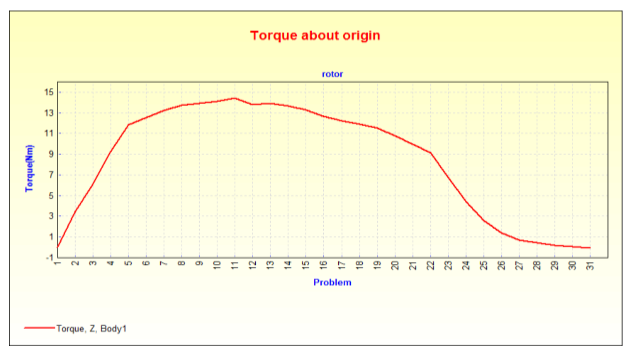

Fig. 11 Static Torque with respect to various rotor position

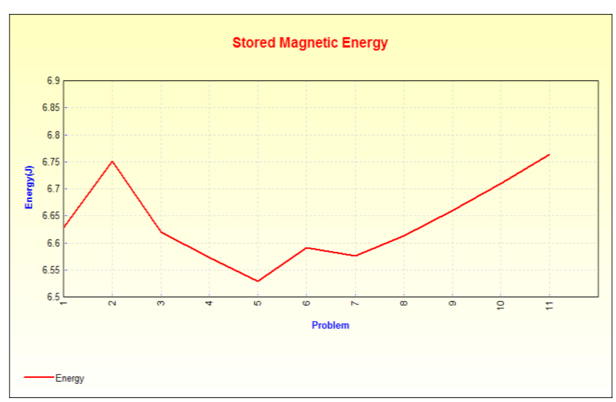

Fig. 12 Static Magnetic Energy

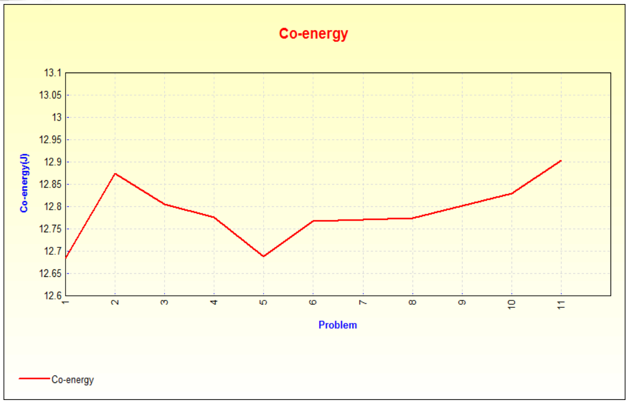

Fig.13 Static Co-Energy

2. TRANSIENT ANALYSIS

In order to predict the performance characteristics like torque, flux linkages, current, iron losses, ohmic losses, energy with respect to time transient analysis is preferred. The driver circuit is shown below in the fig 15. The circuit consists of two switches S1 and S2 which is connected to the winding as shown below. The fig 16 and 17 shows the Transient torque and transient magnetic energy respectively. Then the fig 18 and 19 shows the transient co-energy and Flux linkage for Phase A[5].

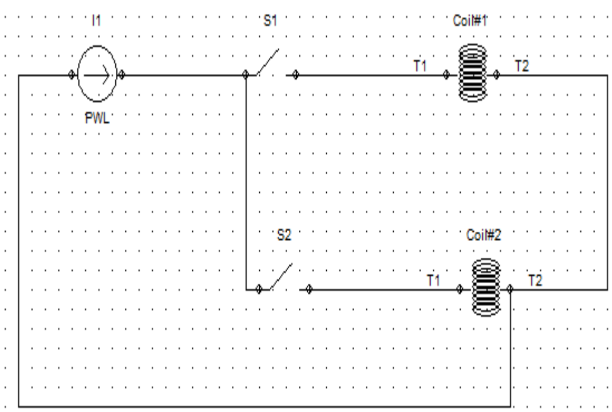

Fig. 14 Driver Circuit

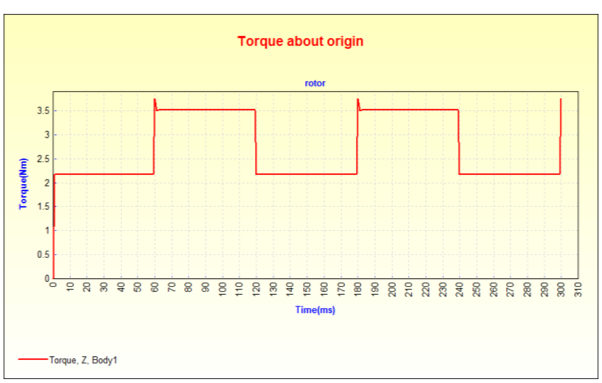

Fig. 15 Transient Torque

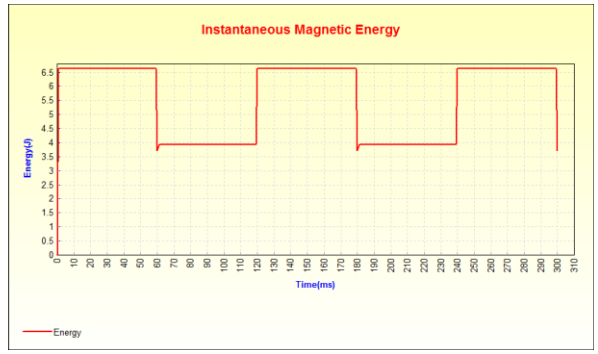

Fig. 16 Transient Magnetic Energy

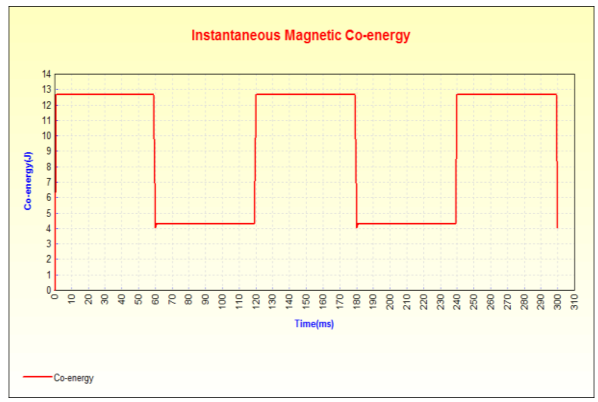

Fig. 17 Transient Co-Energy

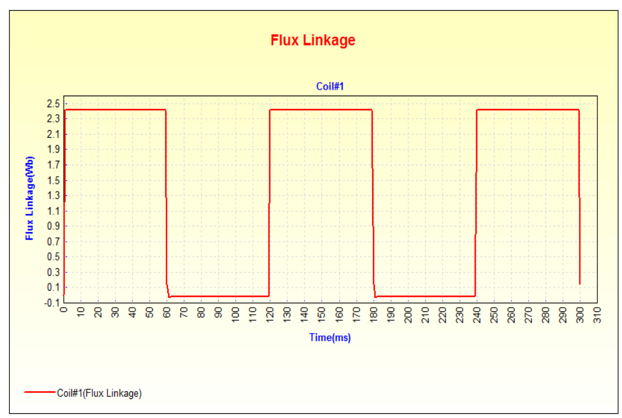

Fig. 18 Transient Flux Linkage

VIII.CONCLUSION

This paper delivers the concept of flux reversal in the stator core during the excitation of all phases by new winding topology. The future scope of this work is to do transient with motion, torque ripple reduction, vibration, thermal and computational fluid dynamics (CFD) analysis for 6/3 switched reluctance motor with exterior rotor.

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