Design of switched Reluctance Motor with Exterior and Interior Rotor

K. Sree Varshini

Abstract— **This paper presents the design procedure for three phase Switched Reluctance Motor (SRM) with two different cases case1: Design of SRM with Exterior case2: Design of SRM with Interior Rotor. It describes the comparison results and the performance characteristics of the SRM with two cases of SRM. In electrical aspects, Finite Element Analysis (FEA) is done in order to verify the design of SRM. The proposed design is done in order to obtain high torque compared with conventional motor. It describes with minimum leakage flux, high torque is obtained. This can be applied for applications such as fans, compressor, electric vehicle etc. The design procedure in this work is carried out using MagNet electromagnetic simulation package. Obtained results using Finite Element Analysis gives the conditions of flux linkages, static torque, of both rotor configurations.**

Index Terms— **Reluctance Motor, SRM, FEA**

I. INTRODUCTION

The applications of SRM drive have been increased in years due to its simple construction. They have rotor and stator poles with no windings on the rotor and the concentrated windings on the stator. The windings in the stator are wounded externally and slid on to the stator poles. This forms the very simple manufacturing process and reduction in the cost of the machine. The design of the rotor in the SRM gives a rugged structure with stack of iron and does not carry any coils or magnets in them. This provides the advantage of the machine that they can be operated at high speeds and with better withstands high temperature. They are highly employed in such applications which required high performance as well as low cost. Other advantage of SRM includes High range of operating speeds, reduction in the number of power switches, possibility of high speed operation with wide constant power region. In reference [9] [10] authors indicates that SRM drive works excellent in traction applications, electric vehicle which contributes high torque and low acoustic noise. With the interaction of the stator and the rotor saliency, torque is produced in SRM.

Electromagnetic torque in the SRM is produced by the tendency of the salient rotor poles to align with the excited stator poles and attain the least reluctance position. The torque developed depends upon the relative position of the phase current with respect to the inductance profile. The machine is said to be in the Generating mode whenever the inductance profile falls on the negative slope. To improve the machine efficiency, design considerations of the machine can be taken into account. In [3] [4] [12] authors tried to improve the efficiency of the motor with the design of SRM with higher number of rotor poles than the stator poles. In this paper, designs of SRM with two different cases are rotor constructions are done. The back EMF developed depends upon the magnetic parameters of the machine, rotor position and the geometry of SRM. The construction of the exterior rotor motor readily distracts from the conventional motor by which they have an outer rotor and the inner stator configuration. The major drawback of SRM falls for acoustic noise and higher torque ripple [13] [14]. The concept of the external rotor or outer rotor arises with the rising demand for the higher torque machine. They have advantage that coils and the cooling can be placed near the shaft. They results with the higher output torque whereas in the design considerations, rotor and the stator poles takes main role. In recent years, application of external rotor are implemented for fan, compressor etc. They are also readily used in smaller space in machines, which forms the simpler construction of the motor.

In this paper, a new SRM with exterior and interior rotor are proposed and their characteristics are analyzed with Finite Element Analysis. E.Annie Elisabeth Jebaselli and S.Paramasivam indicates in [7] that Numerical Analysis is one of the most promising technologies to design the electrical machines.

K. Sree Varshini, Research Scholar Department of Electrical and Electronics Engineering (Marine), AMET University, Chennai

II. DESIGN CONSIDERATIONS

In order to obtain the improved machine torque density and efficiency, attention should be paid to the design consideration [9]. SRM has a simple construction. However, this does not mean its design is simple. Due to the double salient structure, continuously varying inductance and high saturation of pole tips, and the fringing effect of poles and slots, the design of SRM suffers great difficulty in using the magnetic circuit approach. These types of machines are used in high speed applications and high temperature environments. In most cases, the electromagnetic finite element analysis is used to determine the motor parameters and performances [1].

A. NUMBER OF STATOR AND ROTOR POLES

For continuous rotating, the stator and Rotor poles should satisfy some special conditions, that is stator poles and rotor poles must be equally distributed on the circumferences, and pole numbers of the stator and rotor must satisfy.

The relationship is given as,

$$N_s = 2mq \qquad (1)$$

$$N_r = 2(mq \pm 1) \qquad (2)$$

Where,

N_r = Number of Rotor poles

N_s= Number of Stator poles

q = Phase number of the machine.

B. *STATOR OUTER DIAMETER:-* It is mainly designed based on the available space given in desired specifications.

In fact, main compromise has to be made between the length of the machine and its outer diameter.

C. ROTOR OUTER DIAMETER:- The torque developed in SRM and machine parameters can be represented by the following equation,

$$T \propto D_r^2 l(Ni)^2 \quad (3)$$

Where,

D_r = Outer diameter of the rotor

Ni= Equivalent ampere turn of one phase,

l = Length of the machine

Once the diameter of the SRM is fixed, any increase in rotor outer diameter will result in a reduction of equivalent ampere turn thereby reducing the torque developed by SRM. Because of this and considering the fact that SRM is highly saturated, rotor being should be equal or slightly larger than the stator outer radius. Here the rotor geometry enhances the moment of inertia and vibration modes of the machine.

D. AIR GAP:- It has an important impact on the generated torque and dynamic behaviour of the SRM. In fact, by reducing the air gap inductance at the aligned position will increase resulting in higher torque density. On the other hand, a very small air gap will cause severe saturation in stator and rotor pole areas. In addition, mechanical manufacture of a very small air gap might not be feasible.

$$\delta = 1 + \frac{D_r}{1000} \quad (4)$$ Where, δ= Air gap

III. BASIC DESIGN STRATEGY

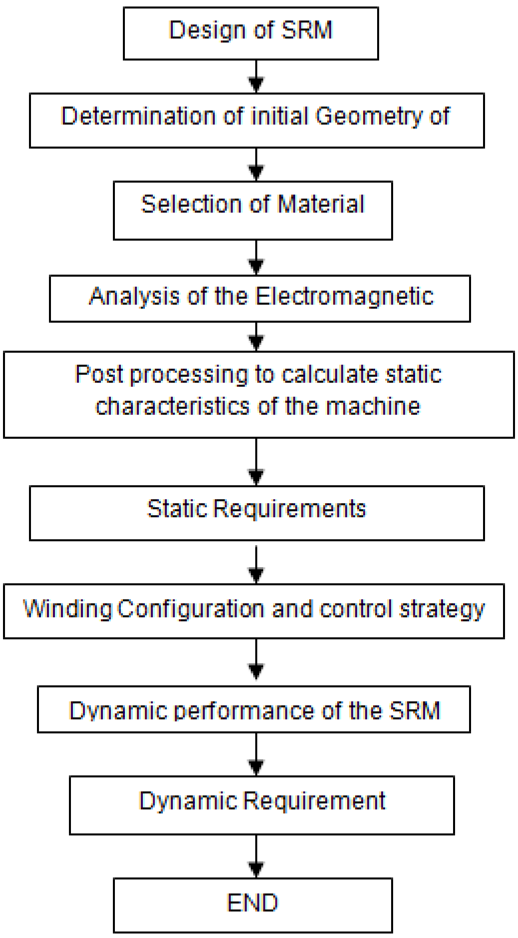

Fig. 1. Flow chart for Design and Analysis Procedure

IV. FINITE ELEMENT ANALYSIS

Using the software package MagNet analysis of Switched Reluctance motor is carried out in order to obtain the performance characteristics. In references [1] [8] authors indicates the design of exterior rotor and analyzing the design with the finite element method.

A. *DESIGN SPECIFICATIONS*

Table 1 gives the specifications for designing of the Switched Reluctance Motor with Interior and Exterior Rotor

No. of Phases	3
No. of Stator poles	6
Stator outer Diameter	130mm
No. of Rotor poles	3
Stack Length	90mm
Material	(M-43) steel
Stator pole and Rotor Pole arc	62°

Table 1 variation in the power obtained

B. *STATIC*

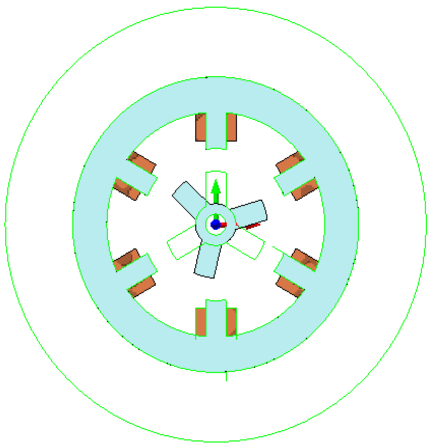

Fig.2. Static model of SRM with Exterior Rotor

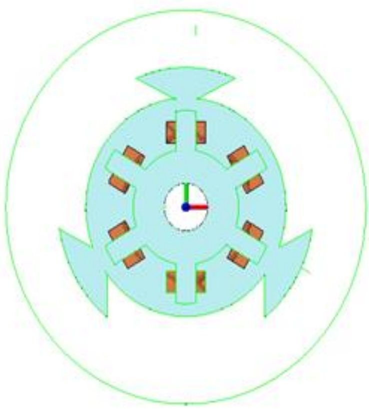

Fig. 3. Static model of SRM with Interior Rotor

Current, Torque, flux linkages are obtained with respect to the instantaneous rotor position in static FEA analysis. The SRM model also includes excitation current, rotor position and flux linkages In Fig.2 and 3 shows the solid model of the SRM with interior and exterior rotor respectively. Fig, 4 and 5 gives the static flux density and flux distribution with respect to their phase. Torque is the product of a motor and is the parameter that governs the machine [11]

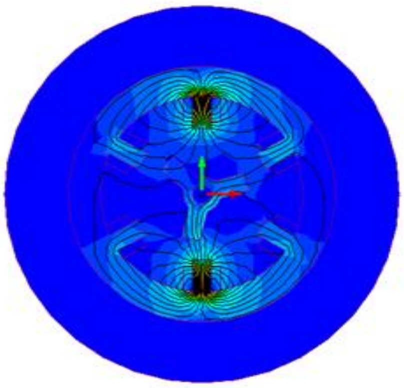

Fig .4. Flux Distribution of SRM with Interior Rotor

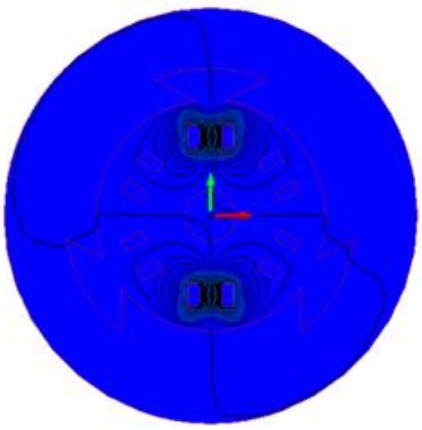

Fig. 5. Flux Distribution of SRM with Exterior Rotor

In the exterior type of rotor, the torque produced is based on the principle of reaching the minimum reluctance for the excited phase [8]. The results of the study fig.6 show that the most significant fact that design considerations plays a major role in obtaining higher torque. In a SRM, inductance and reluctance are functions of phase current, which causes the establishment of flux and rotational motion.

At aligned position and higher current levels magnetic iron begins to saturate. Due to saturation, fringing, and leakage, nonlinearities are introduced.Fig7 and fig.8 shows the values for flux function for Interior and Exterior Rotor. At unaligned position, phase inductance has minimum value as a result of high reluctance presented by large air gap. Since the stator and rotor poles overlap, pole corners display local saturation due to concentration of flux into the relatively small area of the pole corners and hence flux linkage curve begin to be nonlinear.

The advantages of introducing Exterior type rotor implies that the higher inertia and optimized magnetic design of outer rotor technology minimizes cogging[4], outer rotor motors larger air gap reduces torque ripple, Higher pole count inertia mean more stable low speed performance without feedback, outer rotor designs are axially shorter than inner rotor designs for the same performance level.

V. RESULT AND ANALYSIS

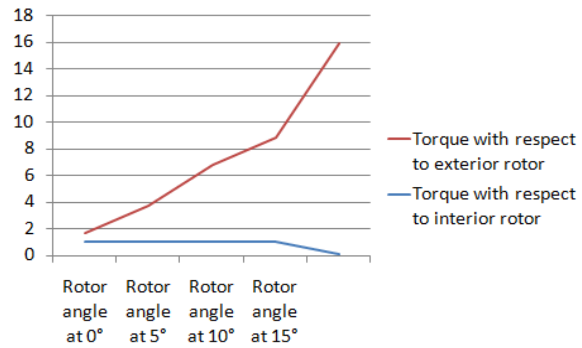

Fig. 6. Static Torque with respect to various rotor positions for Interior and Exterior Rotor

Torque production in an SRM is based on the change of reluctance with respect to the rotor position [3].

Torque is given by,

$$T = \frac{I^2}{2}\frac{dL(\theta,I)}{d\theta} \qquad (5)$$

Where,

dL = change in the inductance with rotor positions

Dθ= change in rotor positions, which should be as small a possible [10].

When a rotor pole is at the unaligned position, reluctance is at maximum; therefore, inductance is at minimum. When concentrated windings around the stat pole are energized, the stator poles become magnetically polarized. This causes the stator pole to attract the rotor pole in order to reduce reluctance and reach the aligned position. Since torque is generated due to the natural tendency of the rotor to move to the minimum reluctance position, it is called reluctance torque. When the machine is composed of more than one phase, continuous torque can be generated as all phases contribute to the torque production.

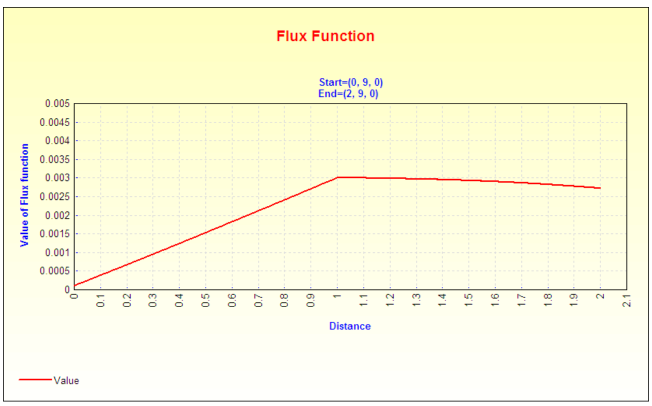

Fig. 7. Flux linkage for Interior rotor

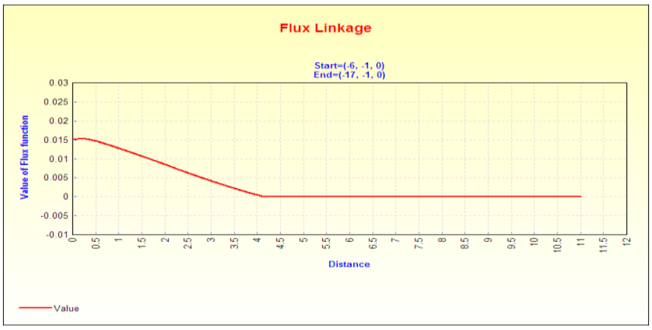

Fig. 8. Flux linkage for Exterior rotor

The function of winding current and the rotor position gives the flux linkage[12]. The flux linkage here is noted between the unaligned and the aligned conditions. A comparison of the flux linkage for both rotor configuration of SRM is obtained. When the change in the flux increases with respect to the rotor movement, Positive torque is developed [13]. It is seen here that with reference to the rotor angle positions, the acceleration in the flux linkages takes place.

VI. CONCLUSION

In this paper, a novel new exterior rotor switched reluctance motor was designed, modeled, and then analyzed. The motor parameters were numerically calculated, compared with interior rotor SRM. An advantage of the proposed exterior rotor SRM is the higher torque. This attribute leads to a reduction of the size and costs, and it will be possible to produce SRMs in smaller fractional diameter with improved horse power. It is noticeable that the new configuration can be applicable to any number of phases in Exterior rotor SRMs. Consequently, the improvement of the motor rating in the different range affirms the most favorable performance of the new configuration, which helps develop a suitable motor for various applications like hybrid electric vehicles and household applications.

REFERENCES

[1]R.subashraj,S.prabhu,V.Chandrasekar,N.c.LeninA.Manikandan,R.Arumugam, “Design and Finite Element Analysis of Switched Reluctance Motor with Exterior Rotor,” International Journal of Engineering Research Volume No.3, Issue No.6, pp:390-395, 01 June 2014.

[2] Jawad Faiz, F.Tahvilipour and G. Shahgholian, “Performance Improvement of a Switched Reluctance motor”, PIEERS proceedings, Kuala Lumpur, Malaysia, March 27-30,2012.

[3] Berker Bilgin, Ali Emadi, Mahesh Krishnamurthy, “Design considerations for Switched Reluctance machines with a Higher Number of Rotor poles”, IEEE transactions on Industrial Electronics, VOL.59, NO.10,October 2012.

[4] M.Cosovic, S.Smaka, I.Salihbegovic, S.Masic, “Design Optimization f of 8/14 Switched Reluctance Machine for Electric vehicle”.

[5] X.D.Xue, K.W.E.Cheng ,T.W.Ng and N.C.Cheung “ Multi-Objective Optimization Design of In-Wheel Switched Reluctance Motors in Electric Vehicles”, IEEE transaction on Industrial Electronics, VOL.57, NO.9,September 2010.

[6] P.Bala koteswararao, J.Hema Sunder, “A closed loop Speed control of a Switched Reluctance Motor with a New converter Topology” International Journal of Emerging Technology and Advanced Engineering, vol.3, Issue9, September 2013.

[7] E.Annie Elisabeth Jebaseeli and S.Paramasivam “Steady State and Transient Thermal Analysis of Switched Reluctance Machine:, International Journal of computer and Electrical Engineering, Vol.4, NO.5, October 2012.

[8] H. Torkaman · E. Afjei · A. Gorgani · N. Faraji · H. Karim · N. Arbab, “External rotor SRM with high torque per volume: design, analysis, and experiments”, 22 November 2012 © Springer-Verlag Berlin Heidelberg 2012.

[9] Shuanghong Wang, Qionghua Zhan, Zhiyuan Ma, and Libing Zhou, “Implementation of a 50-kW Four-Phase Switched Reluctance Motor Drive System for Hybrid Electric Vehicle”, IEEE Transactions On Magnetics, Vol. 41, No. 1, January 2005

[10] T. Dinesh Kumar A. Nagarajan, “ Design Of Switched Reluctance Motor For Elevator Application”, Journal of Asian Scientific Research, 2013, 3(3):258-267

[11] Tobias Mansson, “FEM-Based Shape-Optimization of Electrical Motors”, LTH THESIS Article January,2010

[12] Mohammad Reza Besmi, “Geometry Design of Switched Reluctance Motor to Reduce the Torque Ripple by Finite Element Method and Sensitive Analysis”, Journal Of Electrical Power And Energy Conversion Systems (JEPECS) JEPECS Vol. 1, No. 1, Pp. 23-31, Autumn 2013.

[13] P. Srinivas, P. V. N. Prasad, “Comparative Analysis of DTC Based Switched Reluctance Motor Drive Using Torque Equation and FEA Models”, International Journal of Electrical, Computer, Electronics and Communication Engineering Vol:8, No:3, 2014.

[14] S. Vetriselvan, Dr. S. Srinivasan, “Reduce Torque Ripple Using Novel Torque Distribution Function for High-Speed Applications Using Embedded System Technology”, International Journal of Advanced Research in Computer Science and Software Engineering Volume 4, Issue 10, October 2014.

[15] N. Abdullah, 2 Kasrul Abdul Karim, 3R.N. Firdaus, 4M.L.Mohd Jamil,5M.N. Othman, “ Design Of Switched Reluctance Motor Using Finite Element Method” International Symposium on Research in Innovation and Sustainability 2014 (ISoRIS ’14) 15-16 October 2014, Malacca, Malaysia Special issue .

[16] Dong-Hee Lee, IEEE, Trung Hieu Pham, and Jin-Woo Ahn, “Design and Operation Characteristics of Four-Two Pole High-Speed SRM for Torque Ripple Reduction”, IEEE Transactions On Industrial Electronics, Vol. 60, No. 9, September 2013.