Magnetic Performance of 3-phase 12/8 Poles Switched Reluctance Motor

[1]J.Kartigeyan, [2]G.Nithya

[1]Associate Professor, [2]Research Scholar

[1]Electrical and Electronics Engineering, [2]Electronics and Communication Engineering

[1]J. B. Institute of Engineering and Technology, Hyderabad, Telangana, India

[2]Annamalai University, Chidambaram, Tamil Nadu, India

Abstract : Nowadays, switched reluctance motors (SRMs) attract more and more attention. Switched reluctance machines have emerged as an important technology in industrial automation. They represent a real alternative to conventional variable speed drives in many applications. It not only features a salient pole stator with concentrated coils, which allows earlier winding and shorter end turns than other types of motors, but also features a salient pole rotor, which has no conductors or magnets and is thus the simplest of all electric machine rotors. Simplicity makes the SRM inexpensive and reliable, and together with its high speed capacity and high torque to inertia ratio, makes it a superior choice in different applications. The configuration and working principle of a three-phase 12/8 poles switched reluctance motor are introduced in this paper, based on the design parameters, an experiment prototype of the 1.5kW three-phase 12/8 poles SRM has designed with finite element method (FEM). The magnetic flux density and magnetic field intensity path structure of the machine are analysed using various non-oriented steels (M19G29 and M15G29) by using a FEM software (Maxwell 2D of ANSOFT). This simulation model can then be used see the impact of SRM behaviour.

***IndexTerms* - FEM, magnetic characteristics, mathematical model, non-oriented steels, SRM, working principle.**

I. INTRODUCTION

Switched reluctance motor (SRM), as mechanical and electrical integrated equipment, was developed in the 1980's. It is take on the merits such as simple structure, flexible control, excellent performance, high reliability, low-cost, and so on. However, as SRM utilization in industry is still relatively limited compared to other machine types, the practical issues regarding the drive implementation have not yet been fully explored [1]–[4]. SRM does not employ permanent magnets or rotor windings. So it does not possess shorted winding problem. SRM has double salient poles construction with concentrated coils, which allows simpler winding and shorter end turns than in other types of motors, and its rotor has no conductors or magnets and is thus the simplest of all electrical machine rotors. So its working principle is different from traditional AC electrical machines. The behaviour of the SRM is strongly affected by the nonlinear magnetization characteristics of the constructed magnetic materials. Therefore, the magnetization behaviours of the SRMs are, in particular, important parameters to predict their performances and to the study of advanced control strategies [5]-[6].

Optimal design of different types of SRMs involves the selection of the motor's geometrical parameters to produce high output torque respects to its volume with considering the minimum ripples [7]-[8]. Therefore, the efficient design of SRM is a considerable way to achieve high performance and output torque [9]. The efficient design of SRM has been undertaken based on various aspects as; (a) Modification of the rotor, stator shapes [10]; for instance; Double- layer per phase isolated and multilayer SRMs are introduced in [11] by authors to improve the torque ripple and noise with considering the maximum performance. (b) The use of numerical methods to efficient design and analysis process such as finite element method [12]-[13]. (c) The intelligent and heuristics methods namely as Neural Network (NN) [14, 15], and Genetic algorithm (GA) [16] play important role in the mentioned purpose of design. (d) Optimum design of control and derive unites of motor [17]-[19]. This paper investigates the design consideration of a novel type of switched reluctance motor, which its characteristic and profile are verified with numerical verification.

II. CONFIGURATION AND WORKING PRINCIPLE

The SRM is referred to as a doubly salient pole due to the salient pole of its stator and rotor structure [20]. Salient pole refers to the structure of the element protruding from the yoke into the air gap. The rotor and the stator are made of steel laminations, and only the stator poles have windings concentrated around it [21]. The rotor, on the other hand, is free from windings, magnets and brushes. The windings on one of the stator pole are connected in series with the opposite stator to form one phase. It can be arranged in such a way that more than 2 opposite stator poles can form one phase. The typical configuration of the machine includes 3 phase 6 stator or 4 rotor (6/4) or 12/ 8 and 4 phase 8/6 or 16/12. Fig.1 shows the 3 phase SR machine with 12/8 configuration.

The operation of SRM depends entirely on synchronized excitation of the set of stator windings to create continuous rotation of the rotor poles [21]. The movement of the rotor with respect to the excited stator phase varies the inductance of the machine periodically from maximum, where rotor and stator poles are aligned, to minimum unaligned rotor and stator poles. The inductance is maximum at the aligned position and minimum during the unaligned position.

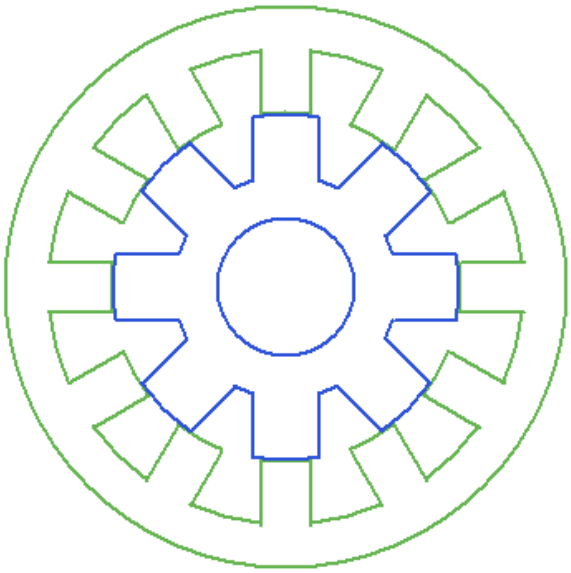

Fig. 1 12/8, 3 Phase switched reluctance motor

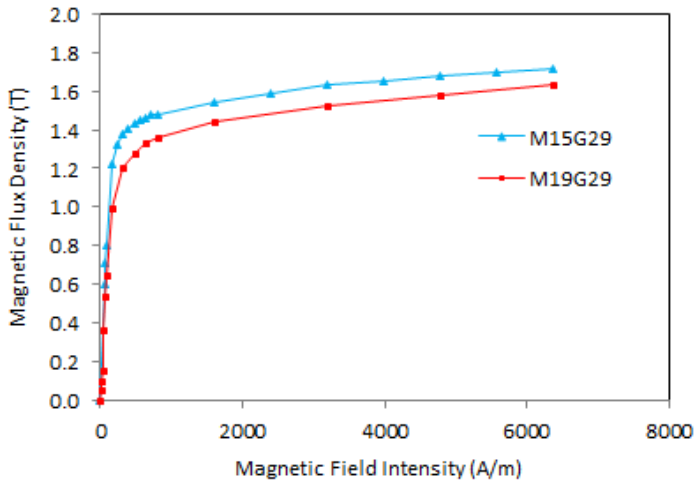

Fig. 2 B-H characteristics of M15G29 and M19G29

Fig. 2 shows the B-H curve of non-oriented electrical steel (M19G29 and M15G29), the including the effect of magnetic saturation in order to obtain reliable characteristics with FEM modelling. The areas of the air and copper are fixed with a relative magnetic permeability unit, while the relative magnetic permeability of the areas of the stator and the rotor is obtained from the magnetization curve of the material shown in Fig. 2.

III. Finite Element Method

A precise model is needed for the physical motor simulation to incorporate the essential dynamics of the motor [22]. Among numerous numerical methods, FEA is the most frequently used approach for providing realistic and precise model. In this paper, to obtain the field distribution for switched reluctance motor the two-dimensional finite element method (2D-FEM) is used which can be conveniently calculating the motor parameters. The modeling and analysis of the 12/8 SRM using various non-oriented steels (M19G29 and M15G29) are performed by ANSOFT software. The specification of the machine is listed in Table 1 and its prototype is shown in Fig. 4. It should be noted that the machine operates in saturation region, based on its nature. Fig.3 shows the flow charts of the general procedure for solving the electromagnetic problems.

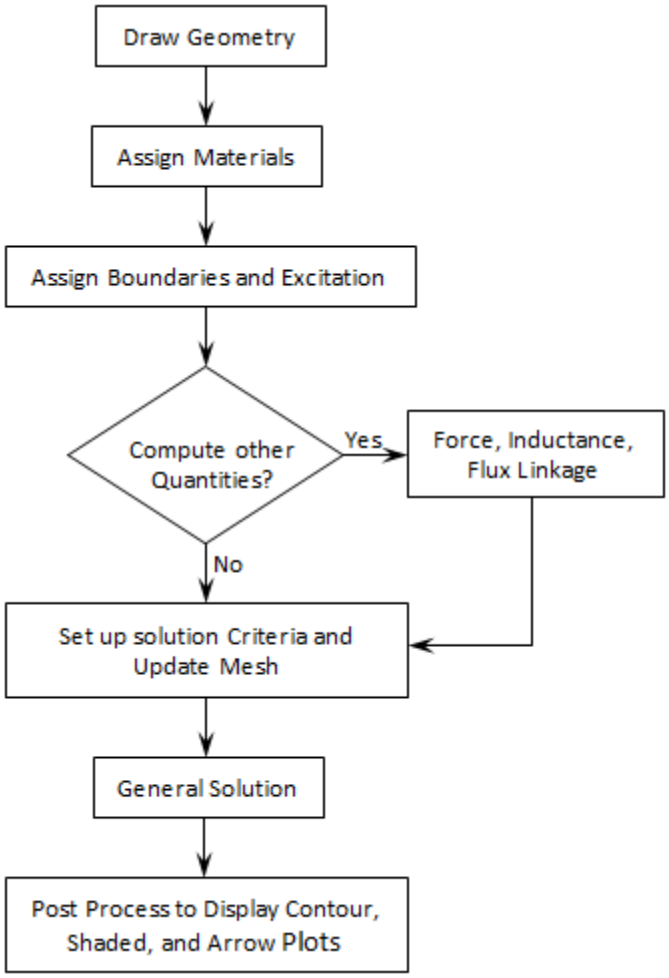

Fig. 3 Sequence of solving problem in FEM

The general procedure summarized below can be used to create a model of a 2D structure for computing the magnetic fields.

1. Build the model of the motor according to its physical dimension and material.
2. Build the model of the power converter according to its topology.
3. Set the terminal and boundary conditions.
4. Add driving sources.
5. Choosing the post process to display contour, shaded, and arrow plots of the electromagnetic field patterns and to manipulate the corresponding field solutions.

3.1 Magnetic Analysis of Switched Reluctance Motor

The performance analysis of switched reluctance motor is summarized as follows,

The Maxwell's equation describing the magneto static field is

$$\nabla \times H = J \tag{1}$$

$$\nabla \cdot B = 0 \tag{2}$$

$$H = vB \tag{3}$$

Where H is the magnetic field intensity, J is the current density, B is the magnetic flux density, and v is the magnetic reluctivity.

The divergence-free field B introduces a magnetic vector potential A is

$$B = \nabla \times A \tag{4}$$

Then, the Eq. (1) becomes

$$\nabla \times (v \nabla \times A) = J \tag{5}$$

The theory assumes that the current density J has only a z direction component in 2D analysis. Likewise, the magnetic vector potential A has only a z direction component. Then, the Poisson equation is

$$-\frac{\partial}{\partial x}\left(v\frac{\partial A_z}{\partial x}\right) - \frac{\partial}{\partial y}\left(v\frac{\partial A_z}{\partial y}\right) = J_z \tag{6}$$

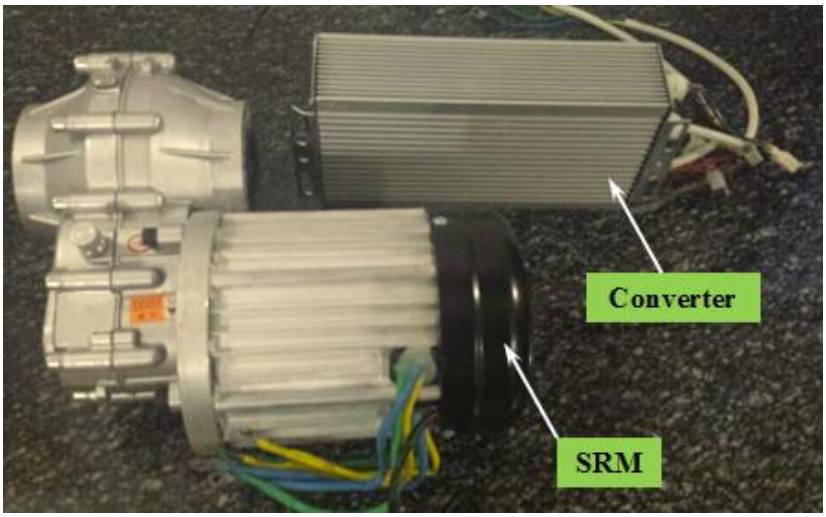

Fig. 4 Switched reluctance motor prototype

Table 1 Specification of SRM

Sl. No.	Item	Specification
1	No. of phases	3
2	No. of stator/rotor poles	12/8
3	Stator outer diameter	120 mm
4	Stator yoke thickness	11 mm
5	Stator-rotor gap	0.3 mm
6	Rotor outer diameter	70 mm
7	Rotor yoke thickness	7 mm
8	Shaft diameter	30 mm

IV. Results and Discussion

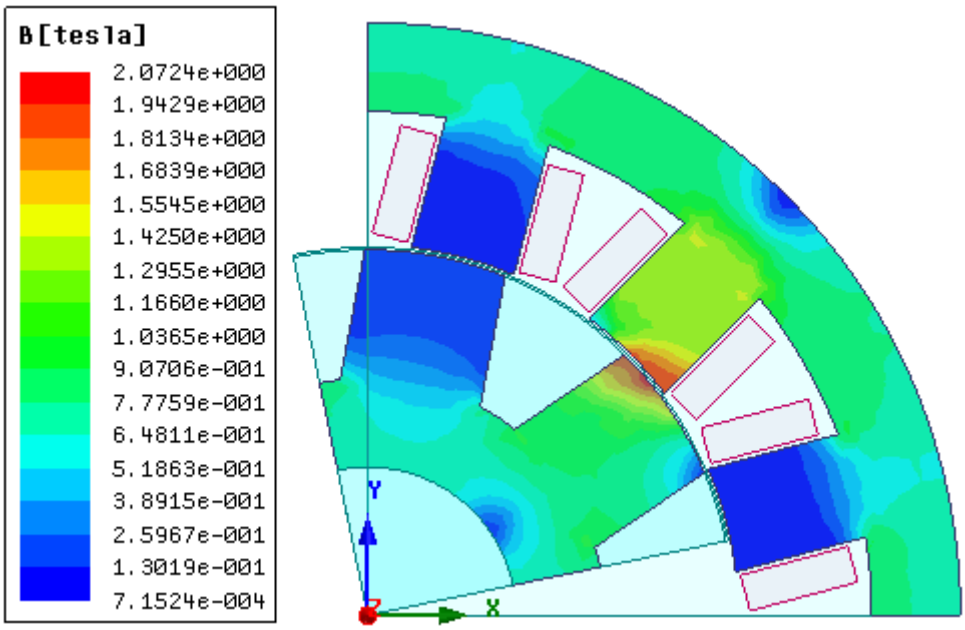

Fig. 5 Magnetic flux density of SRM using M19G29

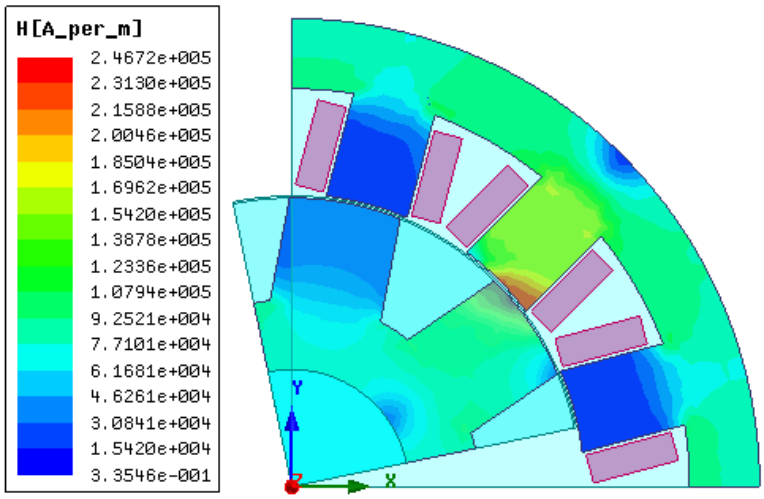

Fig. 6 Magnetic field intensity of SRM using M19G29

The magnetic flux density (*B*) and magnetic field intensity (H) of the switched reluctance motor using M19G29 is illustrated in Fig.5 and Fig.6 for the beginning of alignment. As illustrated in Figures the maximum value of the flux density and magnetic field intensity is about 1.81T and 215880 A/m respectively..

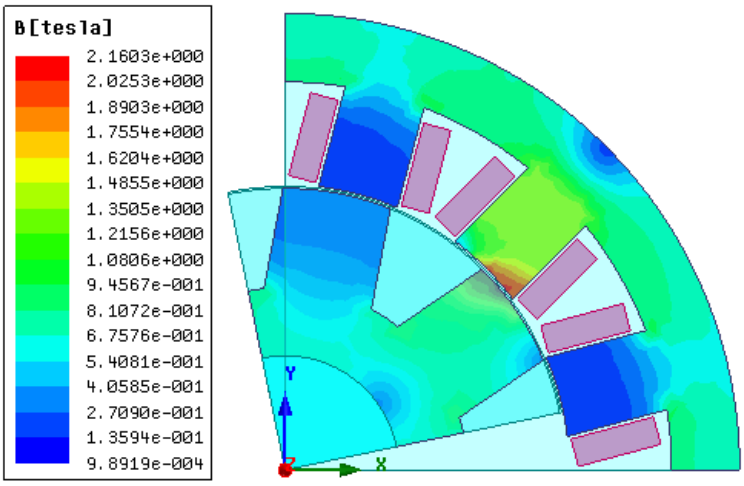

Fig. 7 Magnetic flux density of SRM using M15G29

The magnetic flux density (*B*) and magnetic field intensity (H) of the switched reluctance motor using M15G29 is illustrated in Fig.7 and Fig.8. As illustrated in Figures the maximum value of the flux density and magnetic field intensity is about 1.89T and 158240 A/m respectively.

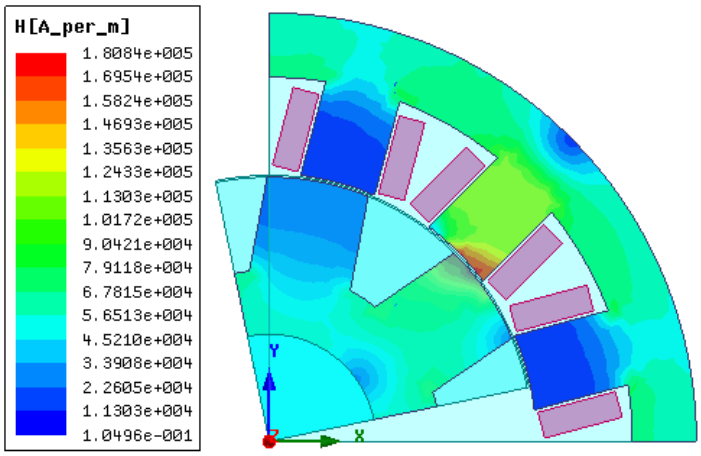

Fig. 8 Magnetic field intensity of SRM using M15G29

Fig. 5 – Fig. 8 provides a comparison of M15G29 and M19G29 about magnetic flux density and magnetic field strength of switched reluctance motor. As can be seen, the magnetic field required to attain the magnetic flux density is lower in M-15G29 than in, M19G29. Especially, in high magnetic flux density region, the difference of the required magnetic field is larger.

V. CONCLUSION

In this paper, switched reluctance motor is proposed, analytically designed and modeled utilizing 2D ANSOFT using various non-oriented steels. The comparative study with SRM using M15G29 was shown that the magnitude of flux density has been faced with an increase in SRM .Furthermore, the magnetic field required to attain the magnetic flux density is lower in M15G29 than in M19G29. Therefore M15G29 is thought to be the best property to select electrical steel as core material for switched reluctance motor and the emphasis has been laid to explore newer varieties of core material and foray fresh areas of drive applications for the SRM.

REFERENCES

[1] L.L.N. Dos Reis, A.A.R. Coelho, O.M. Almeida and J.C.T. Campos, "Modeling and controller performance assessment for a switched reluctance motor drive based on set point relay," ISA Transactions, vol. 48, no. 2, pp. 206–212, 2009.

[2] S. Song, W. Liu, D. Peitsch and U. Schaefer, " Detailed design of a high speed switched reluctance starter/generator for more/all electric aircraft," Chinese Journal of Aeronautics, vol. 23, no. 2, pp. 216–226, 2010.

[3] Y.A. Kwon, "Computation of optimal excitation of a switched reluctance motor using variable voltage," IEEE Transactions on Industrial Electronics, vol. 45, no. 1, pp. 177–180, 1998.

[4] H.M. Hasanien and S.M. Muyeen, "Speed control of grid-connected switched reluctance generator driven by variable speed wind turbine using adaptive neural network controller," Electric Power Systems Research, vol. 84, no. 1, pp. 206–213, 2012.

[5] H.J. Chen, S.L. Lu and X.L. Shi, "Development and validation of a general-purpose ASIC chip for the control of switched reluctance machines," Energy Conversion and Management, vol. 50, no. 3, pp. 592–599, 2009.

[6] S.C. Wang, "An fully-automated measurement system for identifying magnetization characteristics of switched reluctance motors," Measurement, vol. 45, no. 5, pp. 1226–1238, 2012.

[7] G. Baoming, A. T. Almeida and F. Ferreira, "Design of transverse flux linear switched reluctance motor," *IEEE Transactions on Magnetics,* Vol. 45, no. 1, pp. 113-119, 2009.

[8] H. Lim, R. Krishnan and N. S. Lobo, "Design and control of a linear propulsion system for an elevator using linear switched reluctance motor drives," IEEE Transactions on Industrial Electronics, Vol. 55, no. 2, pp. 534-542, 2008.

[9] M. Takeno, A. Chiba, N. Hoshi, S. Ogasawara, M. Takemoto and M. A. Rahman, "Test results and torque improvement of the 50-kW switched reluctance motor designed for hybrid electric vehicles," IEEE Transactions on Industry Applications, Vol. 48, no. 4, pp. 1327-1334, 2012.

[10] Y. Kano, T. Kosaka and N. Matsui, "Optimum design approach for a two-phase switched reluctance compressor drive," IEEE Transactions on Industry Applications, Vol. 46, no. 3, pp. 955-964, 2010.

[11] H.Torkaman, E. Afjei and M. S. Toulabi, "New double-layer- per-phase isolated switched reluctance motor: Concept, numerical analysis, and experimental confirmation," IEEE Transactions on Industrial Electronics, Vol. 59, no. 2, pp. 830-838, 2012.

[12] J.W. Lee, H. S. Kim, B. Kwon and B. Taek, "New rotor shape design for minimum torque ripple of SRM using FEM," IEEE Transactions on Magnetics, Vol. 40, no. 2, pp. 754-757, 2004.

[13] H. Torkaman, E. Afjei and P. Yadegari, "Static, dynamic, and mixed eccentricity faults diagnosis in switched reluctance motors using transient finite element method and experiments," IEEE Transactions on Magnetics, Vol. 48, no. 8, pp. 2254-2264, 2012.

[14] A. Kechroud, J. J. H. Paulides and E. A. Lomonova, "B-spline neural network approach to inverse problems in switched reluctance motor optimal design," IEEE Transactions on Magnetics, Vol. 47, no. 10, pp. 4179-4182, 2011.

[15] J. Cai, Z. Q. Deng, R. Y. Qi, Z. Y. Liu and Y. H. Cai, "A novel BVC-RBF neural network based system simulation model for switched reluctance motor," IEEE Transactions on Magnetics, Vol. 47, no. 4, pp. 830-838, 2011.

[16] L.A. Belfore and A. A. Arkadan, "A methodology for characterizing fault tolerant switched reluctance motors using neuro-genetically derived models," IEEE Transactions on Energy Conversion, Vol. 17, no. 3, pp. 380-384, 2002.

[17] H. Torkaman, E. Afjei, H. Babaee and P. Yadegari, "A novel method in ACO and its application to rotor position estimation in SRM under normal and faulty conditions," Journal of Power Electronics, Vol. 11, no. 6, pp. 856-863, 2011.

[18] S.I. Nabeta, I. E. Chabu, L. Lebensztajn, D. A. P. Correa, W. M. Silva and K. Hameyer, "Mitigation of the torque ripple of a switched reluctance motor through a multi objective optimization," IEEE Transactions on Magnetics, Vol. 44, no. 6, pp. 1018-1021, 2008.

[19] H. Torkaman and E. Afjei, "Sensorless method for eccentricity fault monitoring and diagnosis in switched reluctance machines based on stator voltage signature," IEEE Transactions on Magnetics, Vol. 49, no. 2, pp. 912-920, 2013.

[20] R. Krishnan, "Switched reluctance motor drives: modeling, simulation, analysis, design, and applications," CRC Press, Taylor & Francis Group, Boca Raton, 2001.

[21] C. Pollock and A. Michaelides, "Switched reluctance drives: A comparative evaluation," Power Engineering Journal, Vol. 9, no. 6, pp. 257-266, 1995.

[22] A. Mahmoudi, S. Kahourzade, N. A. Rahim, H. W. Ping, and N. F. Ershad, "Slot-less torus solid-rotor-ringed line-start axial- flux permanent-magnet motor," Progress in Electromagnetics Research, Vol. 131, pp. 331-355, 2012.