Electromagnetic Analysis Of Switched Reluctance Motor Using Finite Element Method

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Abstract

Switched Reluctance motor is more attractive as a variable speed drive. It has its own advantages such as high speed capability, high torque inertia etc. Modelling of electrical machines plays an important role to study its performance and optimizing process. In this paper, modeling 8/6 switched reluctance motor is done using finite element method. Even though it is a time consuming method, it provides accurate results. Here Electromagnetic analysis is carried out using finite element method to study the nonlinear flux distribution. The performance of the motor is analysed by injecting current in the motor windings. The simulated results are obtained i at various rotor positions corresponding to excitation current.

Keywords: Electromagnetic Analysis, Finite Element Metod, Flux Linkage, Switched Relucyance Motor

1. Introduction

Switched Reluctance Motor[SRM] is a special machinery with simple robust construction high speed operation, high efficiency, high degree of independence between phases, high reliability, and high torque to inertia ratio¹⁻⁴. Its application ranges from low-power servomotor to high power traction drives. It has a drawback due to vibration and acoustic noise present in it⁵. The nonlinear flux magnetization is a reason for torque ripple, which is unavoidable. The excessive limit of a torque ripple will affect the application of Switched Reluctance motor. It can be reduced by design constrains and other way by electronic techniques. To achieve this, Electromagnetic analysis is carried out on an 8/6 SRM using finite element method.

2. Switched Reluctance Motor

Electrical machines are classified into two types based on the production of torque as electromagnetic machines and variable reluctance machines. In the electromagnetic type, torque is produced by the interaction of stator and rotor magnetic field. The mutual coupling tempts to rotate the motor. In the variable reluctance type, reluctance in the air gap between the stator and rotor makes the machine to rotate. Switch reluctance motor is a Variable reluctance Motor.

SRM is a simplest of all electrical machines, where the stator has windings and rotor has no windings or permanent magnets. Because of the lack of conductor and magnets, SRM can operate at a very high speed compared to other motors. When a stator coil is energized, the rotor will move to the lowest magnetic reluctance. The reluctance between stator and rotor will vary with the position of rotor. The simultaneous excitation of stator coil will make the rotor to move. But the torque and stator current relation is highly non-linear. This non-Linear flux linkage (i, θ) makes the motor difficult to control.

The single phase voltage equation is given by equation (1)

$$V = RI + \frac{d\phi}{dt}$$
(1)

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where, V is dc supply voltage, R is stator winding resistance and \emptyset is flux linkage. The motor inductance varies with the function of rotor angle. So the torque in terms of current and inductance is given as shown in equation (2).

$$T = \frac{i^2}{2} \frac{dL}{d\theta}$$
(2)

where, L is the phase inductance, θ is a rotor angle, and i is the phase current. The flux distribution will vary in different part of the machine for an unchanged current. The torque calculation is made by finding the flux distribution with excitation current of stator. The leakage flux in aligned position of rotor is negligible, but for unaligned position of rotor it is not negligible, so finding flux linkage is difficult⁶. The torque also varies depending on the sequence of excitation and load condition⁷.

SRM is an oldest motor too, it cannot be replaced in some applications. A 200hp of SR motor can replace the induction motor. In friction application Switched reluctance motor tends to run cool whereas the other motor get too hot after 20 minutes. In textile application SRM can spin around 25000rpm with constant torque, at the same time if a thread breaks motor, it can stop within one revolution.

3. Finite Element Method

Finite Element Method (FEM) is a numerical technique to get an approximate solution by partial differential equation. FEM is a computational tool to know the performance in engineering applications. The complicated solid structure with moving boundaries can be analyzed over FEM. A field solution can be obtained with time variables and with non-linear materials⁸. Any Electrical machine can be analysed accurately with FEM. So the study of flux distribution in switched reluctance motor can be analyzed by this method. To analyze the flux distribution of Switch Reluctance Motor, the machine has been modeled with the specified dimensions of rotor, stator and windings as shown in Figure 1.

This finite element method is a powerful design tool used to improve the performance of standard design in many industries. FEM based analyzing areas are thermal, electromagnetic, fluid and structural working environment. Here the FEM package of ANSYS can be used to analyse the flux linkages on the different part of a machine.



Figure 1. D model of 8/6 SR motor.

4. Electromagnetic Analysis of SRM

The Electromagnetic analysis can be done by the ANSYS package of FEM. The Magnetic and electric potential can be calculated by finite element solution which can be made in 2D or 3D. The ANSYS program supports for high frequency electromagnetic analysis which will vary with current. First step of analysis in FEM is to mesh the critical structure of a machine. The Geometrical model of a Switched Reluctance motor is meshed up into different polynomial elements. One sample can be analyzed by ANSYS software. The flux linkage, (i, θ) can be determined in each element as in ⁹. The magneto static problem in two-dimension is expressed by non-linear Poisson's equation¹⁰ as shown in equation (3).

$$\frac{\partial}{\partial x} \left(\gamma \frac{\partial A}{\partial x} \right) + \frac{\partial}{\partial y} \left(\gamma \frac{\partial A}{\partial y} \right) = -Jz \tag{3}$$

where, γ is magnetic reluctivity, *Jz* is source current. The flux path on a different part of a machine is examined with various position of a rotor angle. By Steinmetz parameters the core loss is also calculated in11.The improved Steinmetz equation is given in equation (4).

$$\mathbf{P}_{c} = \mathbf{K}_{cf} \mathbf{C}_{h} \mathbf{f} \mathbf{B}_{max}^{a+bB} + \frac{1}{2\pi^{2}} \mathbf{C}_{e} (\frac{dB^{2}}{dt}) \text{ avg.}$$
(4)

where, Bmax is the maximum flux density, f is the frequency, C_ha , b and C_e are the Steinmetz parameters. Core loss will be higher than the copper loss in lower excitation current¹². By studying the losses of electrical machine the temperature analysis can be done¹³. Here Electromagnetic analysis been made in ANSYS for different rotor position. Analytical method of finding torque is difficult¹⁴. Rotor displacement is examined within 0 -30 degrees. The simulated result is exhibited in 3Dimensional geometry.

The geometric model of Switched Reluctance Motor of 8/6 have been modeled in 3-D.The dimension of 8/6 are shown in Table 1.

The electromagnetic simulation model totally created with the CATIA software. CATIA is one of the designing software which provides advanced technologies of surfacing. The designed model of Switched Reluctance Motor using CATIA V5 is shown in Figure 2.

For Electromagnetic Analysis, the modeled motor is imported in ANSYS software. In this model, plane97 element is used for analysis. The materials used to design each part of machine are given on Table 2. The properties of material for each part of a machine is given as input during preprocessing. Material properties of Switched Reluctance Motor are illustrated in Table 3. Non-oriented electrical steel of M19 is used to design stator and rotor. M19 has an advantage of stress free core and economic for large designs.

In finite element analysis, the total structure of motor is subdivided into small dimension, to increase

Table 1. Specification of 8/6 SR motor

1		
Parts	Dimensions in mm	
Stator outer diameter	180	
Stator inner diameter	96.5	
Stator pole width	17	
Stator pole height	29.6	
Rotor outer diameter	96	
Rotor inner diameter	40	
Rotor pole width	18.5	
Rotor pole height	18.7	
Body length	225	
Stack length	110	



Figure 2. 3-D geometrical model of 8/6 SRM.

Table2. Material used in SR motor

PARTS	MATERIAL USED	
Stator	M19	
Rotor	M19	
Windings	Copper.	
Air gap	Air	

Table3.Material properties

MATERIAL	ELECTROMAGNETIC PROPERTIES	VALUES
M19 Steel	Relative Permittivity	1150 F/m
ĺ	Loss Tangent	0.2
Copper	Relative Permeability	1000 H/m
Air	Relative permeability	1 H/m

the accuracy. The subdivided element can be triangles, rectangles and quadrilaterals. The meshed model of total machine of 8/6 is shown in Figure 3.

The fine discretization is done in each part of machine, one by one at area basis by meshing tool in ANSYS.

5. Simulation Result

The Electromagnetic analysis of Switched Reluctance Motor with the flux linkage with respect to current are simulated for various position of rotor. An 8/6 SRM with 2 h.p motor was used for analysis. The stator winding is excited with current density of various values of 4A, 8A, and 12A.

Rotor position is also varied between angles of 0° to 30° where it tends to be from unaligned to aligned position. Generally, the flux waveform will be non-sinusoidal and have different shapes for different values of frequencies¹⁵. The higher the material permeability, the larger the value of torque at all angular displacements for a given winding current.

The value of flux density for 4A with an aligned position of rotor is shown in Figure 4. For same displacement of rotor position the winding current varied for different values. The winding current with 8A and 12A for 0 rotor displacement is shown in Figure 5 and Figure 6.

The rotor angle of an aligned position is changed with a displacement of 15^o where rotor tends to move from aligned to unaligned position. Flux density waveform for



Figure 3. Meshed model of 8/6 SRM.



Figure 4. Flux density for displacement of 0 with winding current of 4A.



Figure 5. Flux density for displacement of 0^o with current 8A.



Figure 6. Flux density for displacement of 0^o with current 12A.

various current input on 15⁰ rotor displacement are shown in Figures 7 to 9.

The simulated results of these 8/6 SRM, for various winding current of various rotor displacement are plotted as a graph. The Flux density versus winding current for aligned and unaligned position of rotor. Measured value of flux density of aligned and unaligned of rotor position¹⁶. The test result of graph shows that in an aligned position of rotor the flux density will be higher than the unaligned position of rotor for same input current excitation. This flux density for different position of rotor can be done by using ANSYS software. By this, ANSYS is considered as one of the efficient analysis software to predict the characteristics of any Electrical Machine.



Figure 7. Flux density for displacement of 15^o with winding current of 4A.



Figure 8. Flux density for displacement of 15[°] with winding current of 8A.



Figure 9. Flux density for displacement of 15[°] with winding current of 12A.

7. Conclusion

Using ANSYS finite element package, the important characteristic of electromagnetic analysis of Switched Reluctance Motor was introduced with 3-D finite element method. The simulated result present in this paper shows that finite element method can be used to study the electromagnetic characteristic of SRM. Structural and performance of various part of machine can be improved in a better manner by predicting its characteristics. The efficiency of motor can be improved by reducing torque ripple, which is propositional to uneven flux distribution.

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