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Modelling of Switched Reluctance Motor Using Finite Element Analysis

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Abstract
Induction Motors (IM) are widely used motors in industries due to its simple construction, rugged nature and low costs. But the drawbacks of these motors are low starting torque and large inrush currents. They operate under poor lagging power factors due to which I2 R losses in the system would increase causing reduced efficiency of the system. At present Switched reluctance motor is finding enormous application in various fields due to itshigh performance. A switched reluctance motor is a type of stepper motor which runs by reluctance torque. In this type of motor power is delivered to stator windings instead of rotor and no permanent magnets required for rotor.It combines the desirable features of induction motors, permanent magnet brushless dc motors. There are numerous software's available for the modelling of electrical machines such MATLAB, Comsol, Motor solve, Ansys Maxwell etc. ANSYS RMxprt is efficient and low cost tool suitable for design of various electrical machines. This paper, the authors presents themodelling, analysis of 8/6 switched reluctance motor using ANSYS RMxprtr and the Electromagnetic calculation along with 2-D and 3-D geometry.

Keywords: *Switched Reluctance Motor (SRM),RMxprt,Finite Element Analysis (FEA),ANSYS Maxwell*

I.INTRODUCTION

Switched reluctance motor (SRM) finds more applications [4,6] with the improvement in power electronic in recent years though the motor principle is known since 100 years. The motor design is simple. The stator windings have field coils wound as in dc motors. The rotor is a solid salient pole rotor having no permanent magnets or windings attached. When stator windings are excited by giving supply, the force created by rotor magnetic reluctance tries to align rotor pole with nearest stator pole. In contrast to commutator in traditional motors an electronic control system switches successive stator poles. With the absence of slipin reluctance motor it is possible to predict the exact position of rotor.The advantages of these motors are ease of construction, high efficiency, high speed of operation and fault tolerance Due to these desirable features these motors are useful in traction systems, wind systems and electric vehicles.

Furthermore, the efficiency is much greater than that of hydraulics and pneumatics. The second important application area is the electric vehicle traction.

Simulation tools are helpful in designing electric machines. The ANSYS' Maxwell is programs are extremely useful in machine design [7]. Iron losses, nonlinearity of the magnetic material, the influence of the winding slots can be determined using this software.RMxprt is a electrical machine design tool which yields quick machineperformance calculations of and 2-D and 3-D geometry. It can also used to simulate and analyzeseveral types of electrical machines [7]. This proposed work presents materialconsumption details and g performance characteristics of Switched Reluctance motor using ANSYS'RMxprt.

ANSYS Maxwell has two design interfaces for electric machines and power converters as:[6]

RMxprt – Rotating Electric Machines;PExprt – Electronic Transformers and Inductors

II.DESIGN AND MATHEMATICALMODELLING OF SWITCHED RELUCTANCE MOTOR

A. Electromagneticequations:According to Faraday's law ,the instantaneous voltage across the terminals of a phase of an SR motor winding in terms of flux linked in the winding as shown in equation (1)

$$V=IR+\frac{d\psi}{dt} \quad (1)$$

Where V is the terminal voltage, I is the phase current, R is the phase resistance, and $\boldsymbol{\psi}$ is the flux linked by the winding. Due to the double salience construction of the SR motor and the magnetic saturation effects, the flux linked in phase of motor varies as a function of rotor position ş and the phase current. Eq. (1) can bewritten as

$$V=RI+\frac{\partial\psi}{\partial I}\frac{dI}{dt}+\frac{\partial\psi}{\partial\theta}\frac{d\theta}{dt} \quad (2)$$

RI is the resistive voltage drop , the second term is the inductive voltage drop, and the third one is the induced emf, which can be very high at high speeds.

In the real switched reluctance motor, the energy conversion process in an SRM [3] can be evaluated using the power balance relationship as in equation3.

$$P_{in}=i_{ph}R_s+\frac{d}{dt}\left(\frac{1}{2}L_{ph}i_{ph}^2\right)+\frac{1}{2}i_{ph}^2\frac{dL_{ph}}{d\theta}\omega..(3)$$

The first term is the stator winding loss; and the second term represents the rate of change of magnetic stored energy and the third term denotes the mechanical output power.

B. Torque production: In SRM, torque is obtained by the tendency of its movable part to move to a position where the inductance of the excited winding is maximized [8].

The motor can be described by convex function relating rotor position ş and currents in the n phases. $I=(I_1, I_2, \dots . I_n)^t$. This function is the co-energy W^-(I,). The function energy W($\boldsymbol{\psi}$,$\boldsymbol{\theta}$) whose variables are the fluxes of n phases $\boldsymbol{\psi}$ = t($\psi_1, \psi_2, \dots, \psi_n$) ^{t} [1] and the rotor position, can also be used to describe SRM The function of co-energy and energy verify the following inequality as represented in eq.4.

$$W^-(I,)+W(\boldsymbol{\psi},\boldsymbol{\theta}) \geq \psi^t I \quad (4)$$

When one phase is energised, the torque appears so that the rotor.

C.Design Details

Table I. Machine Specification

S.No	Parameter	Value
1	Rated Output Power (Kw)	2.2
2	Rated Voltage (V)	230
3	Rated Speed (rpm)	1880
4	Number of Stator Poles	8
5	Number of rotor poles	6
6	Rated current (A)	10

TABLE II. SRM Machine Dimensions

S.No	Parameter	Value in mm

1	Outer Diameter of Stator	194
2	Inner Diameter of Stator	99
3	Air Gap	0.5
4	Outer Diameter of Rotor	98
5	Inner Diameter of Rotor	36
6	Stator Yoke Thickness	15
7	Rotor Yoke Thickness	15
8	Stack Length of Stator	110
9	Stack Length of Rotor	110
10	Parallel Branches	1 No

TABLE III.Stator Data

S No	Parameter	Value
1	Number of Stator Poles	8
2	Pole Embrace	0.5
3	Stacking Factor of Stator Core	0.95
4	Type of Steel	Steel_1008
5	Number of wires per conductor	1
6	Wire Diameter (mm)	2.174
7	Wire Wrap thickness (mm)	0
8	Slot fill factor (%)	45.992

TABLE IV. Rotor Core Data

S.No	Parameter	Value
1	Length of Air gap (mm)	0.5
2	Inner Diameter of Rotor (mm)	36
3	Yoke thickness (mm)	15
4	Pole Embrace	0.5
5	Stacking factor	0.95
6	Type of steel	steel_1008
7	Magnetic Shaft	Yes

III. RMXPRT RESULT OF SRMMACHINE

SRM machine geometry using RMxprt

A reduced order model is automatically generated by RMxprt by considering the eddy effects and nonlinearities, and transfers it to Simplorer, where further electric drive analysis can be accomplished.

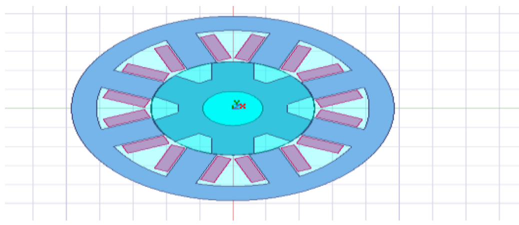

Figure a.SRM machine geometry using RMxprt

In same manner, RMxprt sets up the customized driving circuit topology as a stand-alone component in Simplorer to be connected with the corresponding electric machine reduced order model[7].

Fig b shows external excitation circuit which is generated automatically in the ANSYS software Which is useful for magneto static and transient

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analysis.

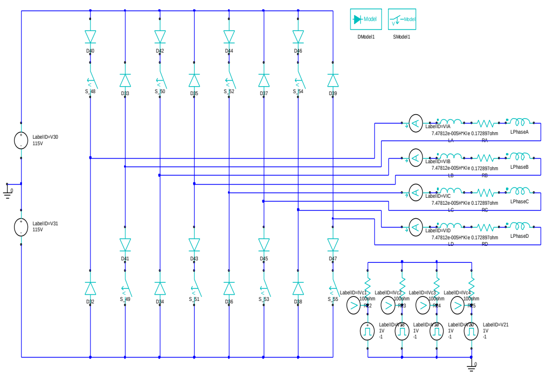
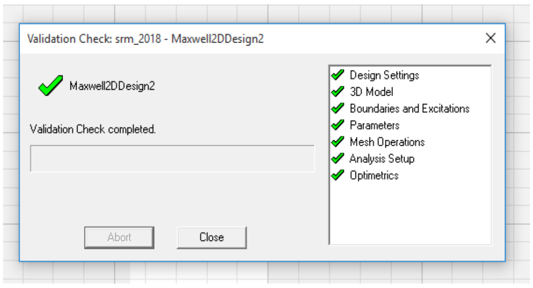


Figure b. ANSYS-Simplorer Excitation Circuit

Static electric fields, static magnetic fields, time varying magnetic fields and transient magnetic fieldswill be computed using Maxwell.Startingwith a model in both RMxprt and Maxwell ,validation check consists of Design settings like symmetry multiplier, Maxwell model, Boundary and Excitations, Parameters, Mesh operations, Analysis set up and optimetrics.



A.Performance analysis of SRM:

Table V. Full load operation:

S.No	**Performance parameter**	**result**
1	Frictional &Windage loss (W)	14.2335
2	Iron-Core loss(W)	0.0065601
3	Winding Copper loss (W)	68.539
4	Transistor loss (W)	38.435
5	Total loss (W)	139.54
6	Output Power (W)	2164.1
7	Efficiency (%)	93.9429 %
8	Rated Shaft Speed (rpm)	2229.2
9	Rated Torque (Nm)	9.2676
10	Input DC Current (A)	10.016
11	Phase RMS Current (A)	9.9551
12	P[hase Current Density (A/mm^2)	2.68186
13	Diode loss (W)	18.3242
14	Input Power (W)	2303.68
15	Flux linkage (wb)	0.326716
16	Maximum Output Power (W)	6077.19
17	Stator-Pole Flux Density (Tesla)	1.58702
18	Coil Length per Turn (mm):	289.958
19	Stator yoke flux density (Tesla)	1.02172
20	Rotor pole flux density (Tesla)	1.20846

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Table VI. No load operation:

S.No	Performance parameter	As per simulation result
1	No load speed (rpm)	26024.2
2	No load DC Current (Ma)	745.47
3	No load Input Power (Mw)	171460

Table VII. Material Consumption Details:

S.No	Performance parameter	As per simulation result
1	Stator Copper Density (kg/m^3)	8900
2	Stator Core Steel Density (kg/m^3)	7872
3	Stator Copper Weight (Kg)	7.81672
4	Stator Core Steel Weight (kg)	11.085
5	Rotor core steel Density (kg/m^3)	7872
6	Rotor core steel consumption (kg)	6.24307
7	Rotor Core Steel Weight (kg)	4.01497
8	Total Net Weight (Kg)	22.917
9	Stator Core Steel Consumption (kg)	24.813

B. Performance characteristics

Performance characteristics of proposedSRM machinedisplays the following graphs that were automatically generated by the solver.

- Efficiency Vs Speed
- Flux linkage curve
- Output power Vs Speed
- Rated Phase Current
- Rated Phase Voltage
- Air Gap Inductance Curve
- Maximum Phase Current

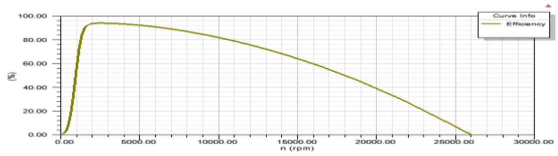

Figure.a.EffeciencyVs Speed

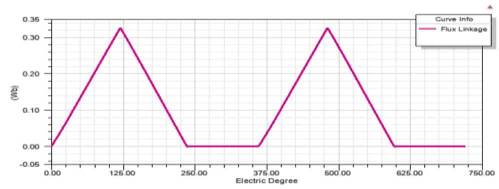

Figure b. Fux Linkage curve

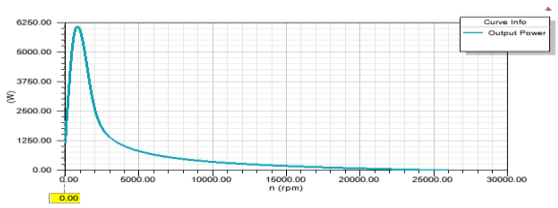

Figure c.Speed Curve

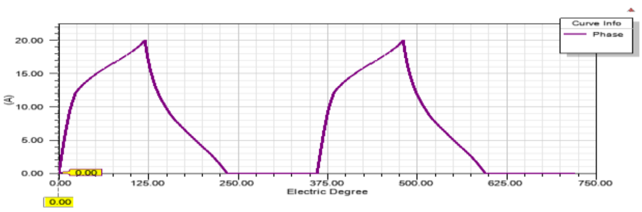

Fig.d.Rated Phase current

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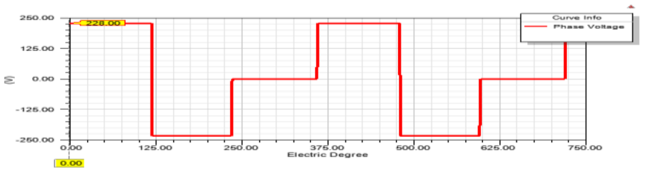

Figure e.Rated phase voltage

IV. RESULT OF SRM-MAXWELL 2D

A.Mesh Operations

Finite Element Method (FEM) is used to interpretthe Maxwell's electro-magnetic field equations.In order to get the solution of these equations the geometry of the problem is discretized significantly intoTraingles in 2D i.e,1/6th of full model and Tetrahedron in 3D i.e,1/12th of full model. The assembly of all Tetrahedra/Triangles is called as Finite Element Mesh of the model.Mesh plays main role in accuracy of the computed results and thus it is refined in the regions where the flux density is predicted to be high, where there is rapid structural difference of the field and in the air gap. The stator coil side is depictedby the simple geometrical shape for accurate work it is necessary to try to reproduce the exact cross section of the coil and even of each conductor within it to know the total flux.

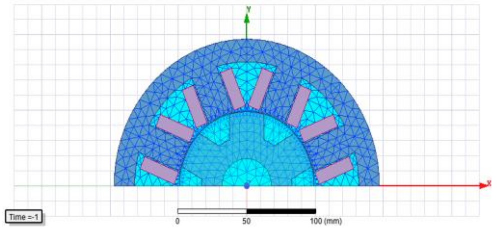

Figure a.Mesh operation of SRM

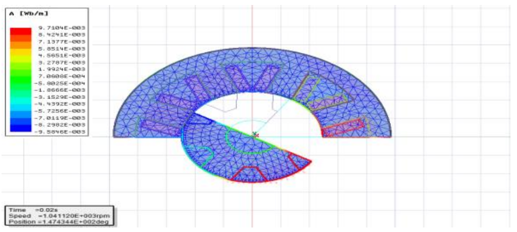

Figure b.Maxwell 2D Flux Lines

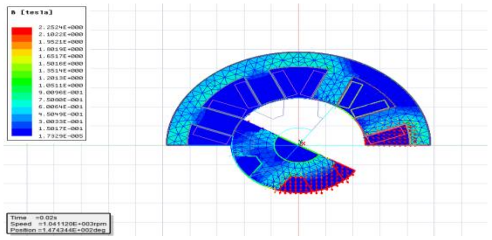

Figure c.Maxwell 2D Magnetic Flux Density View

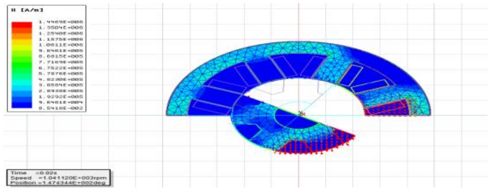

Figure d.Maxwell 2D Magnetic Field Intensity View

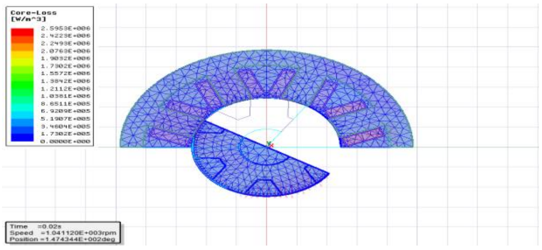

Figure e .Maxwell 2D Core loss

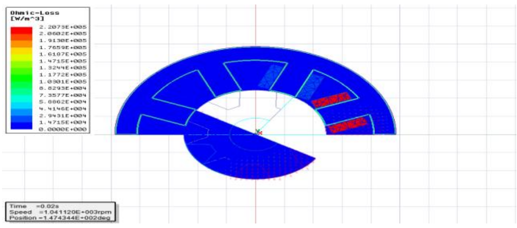

Figure f .Maxwell 2D Ohmic loss

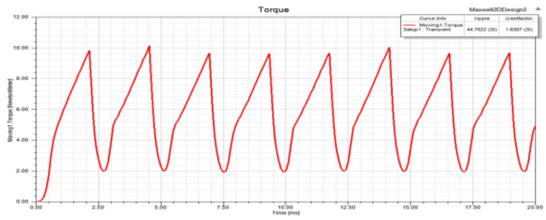

Figure g. Moving Torque waveform

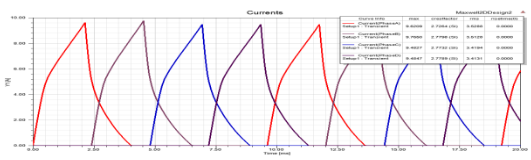

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Figure h . Phase Current waveform

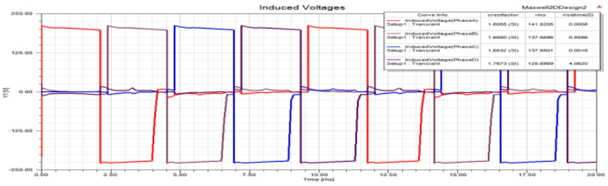

Figure i. Induced Voltage Waveform

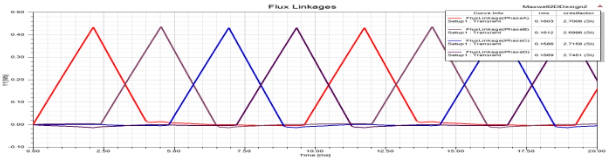

Figure j.Flux linkages waveform

V.MAXWELL 3D RESULT OF SRM-

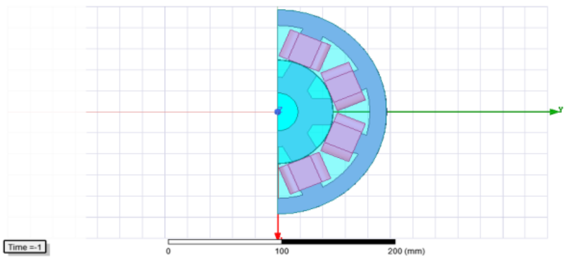

Figure a. Maxwell 3D geometry

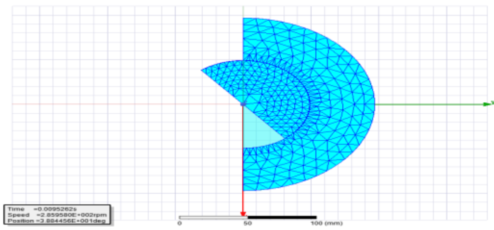

Figure b. Three dimensional view of the partitioning SRM

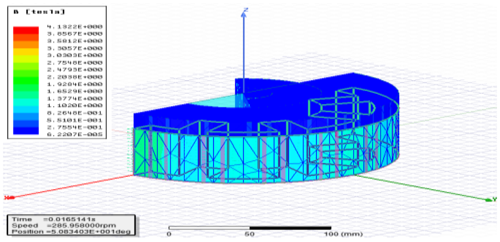

Figure c. Maxwell 3D Magnetic Flux Density View in SRM

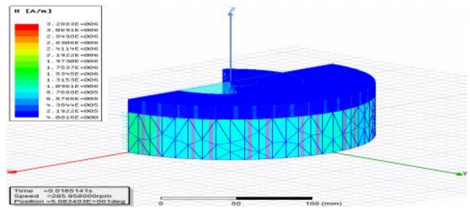

Figure d. Maxwell 3D Magnetic Field Intensity View in SRM

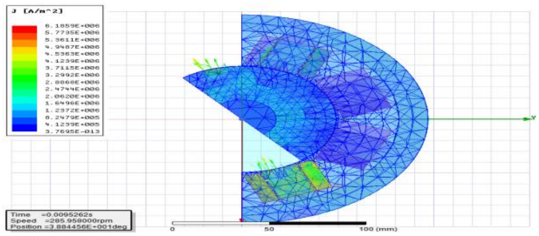

Figure e. Maxwell 3D current density in SRM

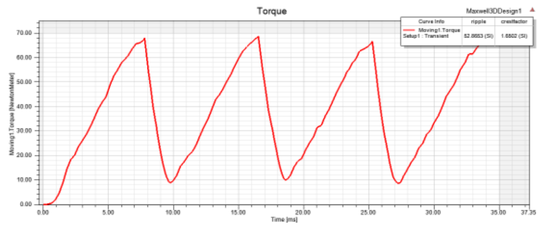

Figure f .Moving Torque (Nm)V/s time(ms)

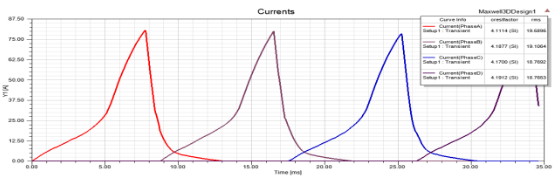

Figure g.Winding currents (A)V/s time(ms)

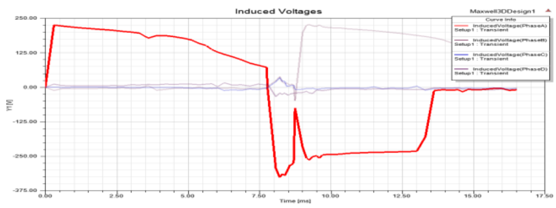

Figure h.Inducedvoltages (V)V/s time(ms)

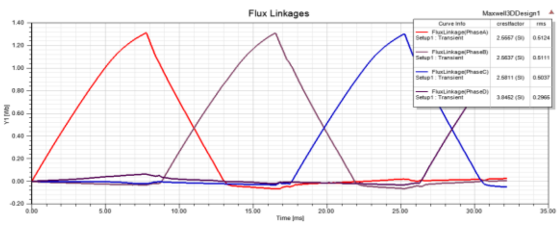

Figure i.Fluxlinkages V/s time(ms)

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A. 2D /3D Observations:

Table VIII. Observations from2Dand 3D Plots.

Machine	2D Model	3D Model
8 slot,6 pole	Moving Torque: 1.Crest factor:1.6357 2.Ripple:44.75	Moving Torque: 1.Crest factor:1.6254 2.Ripple:52.86
	Winding Currents: 1.RMS:3.5A 2.Crest factor:2.77	Winding Currents: 1.RMS:19.01 A 2.Crest factor:4.17
	Induced Voltages: 1.RMS:140 V 2.Crest factor:1.65	Induced Voltages: 1.RMS:133.4 V 2.Crest factor:5.52
	Flux linkages: 1.RMS:0.15 Wb 2.Crest factor:2.71	Flux linkages: 1.RMS:0.47 Wb 2.Crest factor:2.75

VI CONCLUSION

Switched reluctance motor performs better than normal induction motors and other adjustable speed motors. ANSYSRMxprt is useful machine design tool for analyzingmachine performance characteristics. This analysis is very much useful for material selection and to design the electrical and mechanical parameters for optimal performance.

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