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Design and Simulation of Switched Reluctance Motor using Ansys Maxwell Software for Electric Vehicle Application

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ABSTRACT: Over the past decade there has been a growing interest, bordering on enthusiasm, for electric vehicles and the coming decade is expected to be the decade of the fully electric vehicle. Switched reluctance motors (SRM) are one of the most energy efficient, reliable and cost effective motors and are taking more prominent roles in industrial, commercial and vehicular applications. Now Switched Reluctance Motor can be significantly more efficient than comparable BLDC Motors, Induction Motors and drives in several applications due to its simple and robust construction, no windings, no slip rings, no brushes, no permanent magnets, no back EMF, high speed, less maintenance. In this project we are planning to Design Switched Reluctance Motor and we will simulate the design using professional software i.e ANSYS Maxwell, the design and analysis of Switched Reluctance will help us to increase the efficiency of the Motor for e-vehicle applications.

KEYWORDS: Energy efficient, BLDC Motor, Induction motors, Switched Reluctance Motor, ANSYS Maxwell Software, E-vehicle.

I. INTRODUCTION

Switched Reluctance Motor is most demanding solution for electric vehicle (EV) applications and it is considered as real drive for electrical vehicle. The drive with SRM is becoming a very strong competitor to the drives with Induction Motor. Hence motoring mode of SRMs is important for electric vehicle with high performances. SRM has a single rotor construction, essentially made of iron, and usually have no magnets in the rotor and stator, and thus SRMs are simple in construction low cost because no rotor winding and permanent magnet are there in SRM. To improve the torque of SRM permanent magnets are used. The main advantage of SRM is that it achieves high torque at very less amount of current. Torque ripple and noise are main disadvantage of SRMS. The implementation of machine operation and its salient features are derived from the torque expression. Its use may be limited in design but it has a larger impact on the high performance controller derivations and understanding.

In this paper we are planning to Design Switched Reluctance Motor and we simulate the design using professional software i.e. ANSYS MAXWELL, the design and analysis of Switched Reluctance Motor (SRM) will help us to increase the efficiency of the motor for E- vehicle application.

II. OBJECTIVE OF PROJECT

We can see that today Air and Noise pollution has greater impact on our environment which not only leads to degrade the quality of life but also sometime responsible for death, but people are still not aware of that. We know that EV have that potential which will help to achieve environment protection notion, But today electric vehicle are still not recognized well. We hope our project will help in developing EV throughout the world and will be big part of transport system till 2030 and contribute in the betterment of quality of life. Many research have been done on EV and found that SRM is better option than other available in the market (BLDC, Induction motor). We have done some literature review and found that not a single motor is suitable for whole EV application and has all required properties.

III. ADVANTAGES AND DISADVANTAGES OF EV

The advantages of EV are :

1. Pollution free
2. Less noise
3. High efficient than IC Engines
4. Control is simple
5. Less maintenance
6. Low running cost
7. Support country in term of economy

The disadvantages of EV are :

1. Life span of battery
2. Less Speed
3. Automatic discharge/ limited life span of battery
4. Small Size
5. Charging time is more

III. LITERATURE SURVEY

[1]. Kabir, M.A. and Husain, I., 2016. Design of mutually coupled switched reluctance motors (MCSRMs) for extended speed applications using 3-phase standard inverters. IEEE Transactions on Energy Conversion, 31(2), pp.436-445.

For multiple steps and better control of the motor full rotation of the stepper motor done. Kabir and Husain design a model that can be helpful to minimize power consumption, by the help of this efficiency is increase and cost is reduced, The resultant torque is reduced with the increment of speed and back Emf. Various techniques of efficiency enhance is optimizing the applied waveform of voltage. The number of turns on the average torque and torque ripple helps Kabir in showing the effect of small change in these values

[2]Shahgholian, G., Sahafi, A.R. and Faiz, J., 2015. Torque ripple reduction in switched reluctance motors—A review. Journal ELECTROMOTION, 22, pp.35-56

To get the maximum output torque as well as efficiency the stepping angle should be in an optimal range. The power factor can be helpful to achieve stepping angles. According to Shahgholian a variety of topology is there which decrease the number of switches and by this fast execution is there but the polarity of the torque is to be changed for inductance and negative torque surrounded by rotor position converter or drive circuit controls it. The degree of torque is developed in each stage equal to the square of the current. Converter or drive circuit controls it.

III. RESEARCH METHODOLOGY

Research methodology is basically the procedure which is used to evaluate a topic which includes:

1. The current situation of Electric Vehicle in the market and the steps which government are taking to improve the motor and battery that are used in EV..
2. As calculations are done on the basis of rating selected of the motor and analysis of the simulation result using the ansys software where we have different parameter stator and rotor size, pole embrace, stacking factor, Copper los, Iron loss, torque and speed for 48 V, 3 KW and 3000 rpm SRM motor.

Machine Specification:

Power output P(KW)
Speed N(rpm)
Phase current I(amp)
Supply Voltage Vac(volt)

Frame Size Selection: The frame size of the motor is practically fixed as it depend on the stator outer diameter :

$$D_o = (\text{Frame Size} - 3) * 2$$

The frame size is according to the IEC recommendations. For foot mounting 3mm is subtracted from the frame size.

Pole Selection: Keeping in mind the Torque 8/6 stator/rotor poles taken into consideration as it has low torque ripple compared to other combination.

Stator and Rotor Pole Angle Selection: both are the essential parameter of motor which has to be chosen for standard design.

Stator pole arc angle (β_s)

Rotor pole arc angle (β_r)

[1] Rotor pole arc angle is greater than stator pole arc angle i.e. $\beta_r > \beta_s$

[2] The effective torque zone is greater than the stroke angle ε but lesser than the stator pole angle β_s . Stroke angle

$$\varepsilon = \frac{2\pi}{\frac{N_s}{2} N_r}$$

In an 8/6 stator/rotor motor the stroke angle is

$$\varepsilon = \frac{2\pi}{\frac{8}{2} \cdot 6} = 0.2618 \text{ rads} = 15 \text{ degree.}$$

[3] Corners of neighbour rotor poles should be greater than stator pole arc as if not stator and rotor poles will be in scattered alignment which will lead to overlap.

Calculation of Average Torque: to calculate the average torque of Switched Reluctance Motor:

$$T_{av} = \frac{W N_s N_r}{4\pi} \text{ N.m.}$$

Where

W = total work done,

which is calculated by the subtraction of unaligned work from the aligned work.

Copper Losses: Copper loss can be calculated by the help of resistance in each phase winding of motor.

The mean length of a winding turn is,

$$l_m = (2L + 4Wt + 2D \sin(\frac{\beta_s}{2})) * 10^{-3} \text{ m}$$

The resistance of a single phase is

$$R_s = \frac{0.0177 * l_m T_p h}{a} \Omega$$

The copper losses will be

$$P_{cu} = i_p^2 R_s \text{ W}$$

Iron Losses: The iron losses has two component Eddy-Current Losses and Hysteresis Losses called as fixed losses.

3. Calculations done and then design and simulation of the motor done using ANSYS MAXWELL Software.

IV. DESIGN SPECIFICATION

The specification of selected machine is-

Operation type: Switched Reluctance Motor

Type of Load: Constant Power (EV requires constant power)

Rated Output Power: 3kW

Rated Voltage: 48V

Given Rated Speed: 3000rpm

Type of Circuit: Full- Voltage

Operating Temperature: 75 degree C

STATOR CONSTRUCTION

Number of Stator Poles: 8

Outer Diameter of Stator (mm): 240

Inner Diameter of Stator (mm): 150

Yoke Thickness (mm): 18

Length of Stator Core (mm): 130

Type of Steel: steel_1010 (because it has high tensile strength and yield strength as compared to steel_1008)

Pole Embrace	Efficiency%	Total Loss (W)	Rated Torque (N-m)
0.10	84.9557	529.273	9.34564
0.20	89.8885	336.215	10.4225
0.22	90.4123	317.331	11.113
0.30	89.2772	359.184	16.7084

(Table 1)

We observe that as the pole embrace increases the rated speed decreases so we have selected the pole embrace.

Pole Embrace: 0.20

Stacking Factor	Efficiency %	Total Loss (W)	Rated Torque (N-m)
0.90	89.8468	337.686	10.4321
0.95	89.8885	336.215	10.4225
0.97	89.8977	335.912	10.4227

(Table 2)

We have selected stacking factor 0.95 which is more convenient one.

Slot insulation thickness (mm): 0.3

Number of Turns per Pole: 20

Wire Diameter (mm): 1.628 (Round type, 14 Gauge)

ROTOR CONSTRUCTION

Number of Rotor Poles: 6

Outer Diameter of Rotor (mm): 148

Inner Diameter of Rotor (mm): 60

Yoke Thickness (mm): 18

Length of Rotor Core (mm): 130

Type of Steel: steel_1010

MATERIAL CONSUMPTIONStator Copper Density (kg/m^3): 8900Stator Core Steel Density (kg/m^3): 7872Rotor Core Steel Density (kg/m^3): 7872

Stator Copper Weight (kg): 12.8925

Stator Core Steel Weight (kg): 14.678

Rotor Core Steel Weight (kg): 6.64102

Total Net Weight (kg): 34.2115

Stator Core Steel Consumption (kg): 39.3455

Rotor Core Steel Consumption (kg): 16.7928

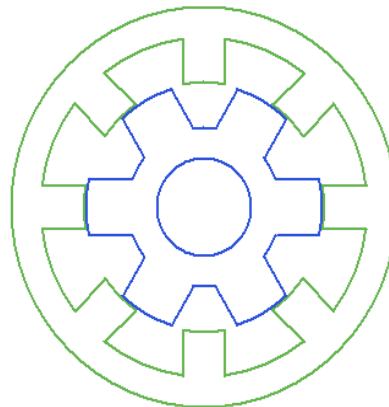
V. OPTIMIZED DESIGN AND ANALYSIS

Number of observation done for different parameters (pole embrace, stacking factor , stator and rotor size) and the optimization of design done and following result are obtained.

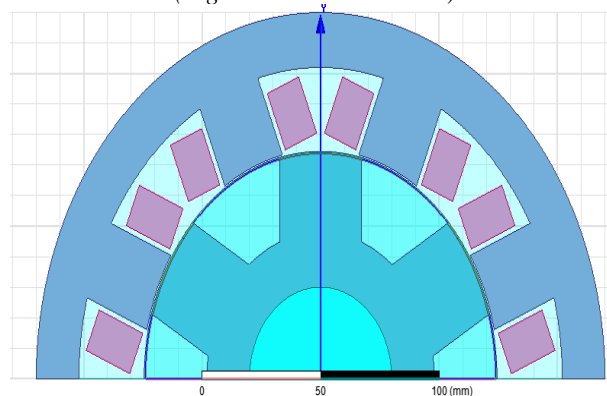


Specification	Value
Rated Output Power (kW):	3
Rated Voltage (V):	48
Given Rated Speed (rpm):	3000
Frictional Loss (W):	8
Windage Loss (W):	4
Type of Load:	Constant Power
Type of Circuit:	Full-Voltage
Lead Angle of Trigger in Elec. Degrees:	0
Trigger Pulse Width in Elec. Degrees:	120
Total Transistor Voltage Drop (V):	0.5
Total Diode Voltage Drop (V):	0.5
Operating Temperature (C):	75
Number of Stator Poles:	8
Outer Diameter of Stator (mm):	240
Inner Diameter of Stator (mm):	150
Yoke Thickness (mm):	18
Pole Embrace:	0.2
Length of Stator Core (mm):	130
Stacking Factor of Stator Core:	0.95
Type of Steel:	steel_1010
Slot Insulation Thickness (mm):	0.3
End Length Adjustment (mm):	0
Number of Parallel Branches:	1
Number of Turns per Pole:	20
Number of Wires per Conductor:	6
Wire Diameter (mm):	1.628
Wire Wrap Thickness (mm):	0.08
Slot Fill Factor (%):	46.0024
Number of Rotor Poles:	6
Length of Air Gap (mm):	1
Inner Diameter of Rotor (mm):	60
Yoke thickness(mm):	18
Pole embrace:	0.2
Length of Rotor Core (mm):	130
Magnetic Shaft:	Yes
Input DC Current (A):	69.2726
Phase RMS Current (A):	50.8191
Phase Current Density (A/mm ²):	4.0689
Frictional and Windage Loss (W):	10.345
Iron-Core Loss (W):	0.0016416
Winding Copper Loss (W):	260.214
Diode Loss (W):	15.5115
Transistor Loss (W):	50.1427
Total Loss (W):	336.215
Output Power (W):	2988.87
Input Power (W):	3325.08
Efficiency (%):	89.8885
Rated Speed (rpm):	2738.46
Rated Torque (N-m):	10.4225
Flux Linkage (Wb):	0.0501318
Stator-Pole Flux Density (Tesla):	0.862286
Stator-Yoke Flux Density (Tesla):	0.281893
Rotor-Pole Flux Density (Tesla):	0.655979

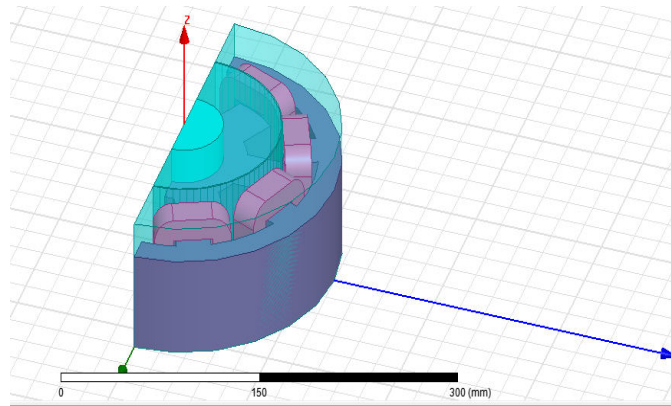
Rotor-Yoke Flux Density (Tesla):	0.10571
Coil Length per Turn (mm):	362.45
Winding Resistance in Phase (ohm):	0.0251894
Winding Resistance at 20C (ohm):	0.0207203
Winding Leakage Inductance (mH):	0.069939
Iron-Core-Loss Resistance (ohm):	2.89393e+006
Frequency of Phase Current (Hz):	273.846
Maximum Output Power (W):	7649.67
No-Load Speed (rpm):	15287.3
No-Load DC Current (A):	12.3825
No-Load Input Power (W):	594.359
Estimated Start Torque (N-m):	338.267
Estimated Start DC Current (A):	2107.43
Maximum Start Current (A):	1885.71
For Armature Winding:	
Number of Turns:	40
Parallel Branches:	1
Terminal Resistance (ohm):	0.0251894
End Leakage Inductance (H):	1.19286e-005
2D Equivalent Value:	
Equivalent Model Depth (mm):	130
Equivalent Stator Stacking Factor:	0.95
Equivalent Rotor Stacking Factor:	0.95
Estimated Rotor Inertial Moment (kg m ²):	0.0477622



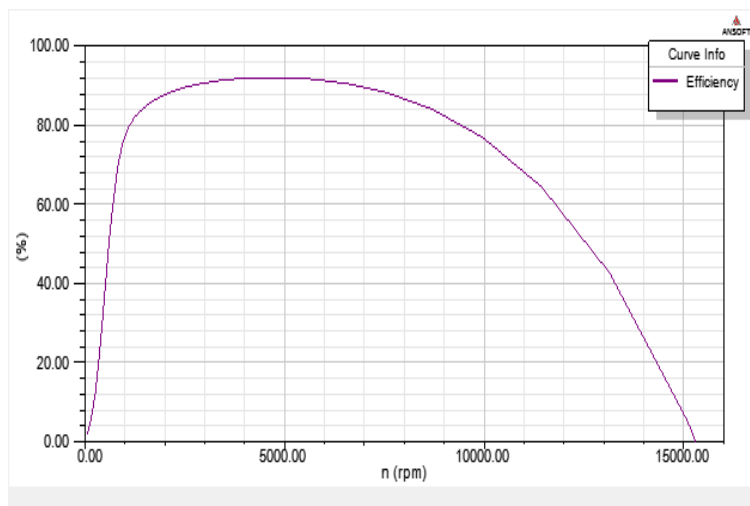
(Fig. 1– Stator and Rotor)



(Fig. 2- Maxwell 2D Design)

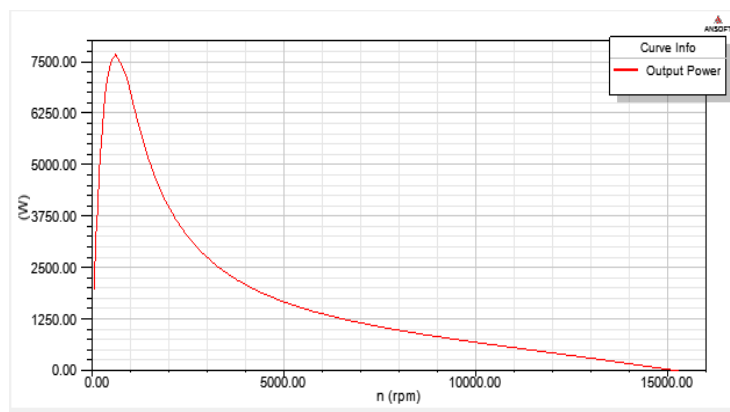


(Fig. 3 – Maxwell 3D Design)



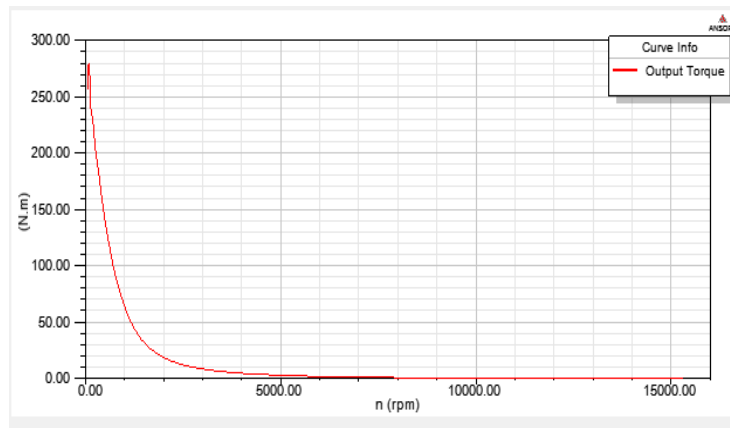
(Fig. 4- Efficiency vs Speed)

From this graph we can conclude that the efficiency first increases and then decreases.



(Fig. 5 – Power Output vs Speed)

From this graph we can conclude that the motor gives the highest output power during starting and decreases when speed increases.



(Fig. 6 – Output Torque vs speed)

From the above graph we can conclude that speed increases torque decreases after starting of the motor.

VI. CONCLUSION

The proposed Switched Reluctance Motor will have high efficiency and torque. As from the Finite Element Analysis (FEA) and calculation of design, the rating of motor is 3 kW, 3000 rpm, 48 V, 8/6 Pole, rated torque 10.4225 N-m and efficiency of 89.8885% keeping pole embrace 0.2 and stacking factor 0.95. To achieve the best performance of the motor the variation in the stator and rotor within the limit also in pole embrace and stacking factor done. There is chance of general manufacturing error may occur in the stator and rotor alignment.

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