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Design and Simulation of Switched Reluctance Motor using Ansys Maxwell Software

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ABSTRACT: The rapid growth of motor vehicle activity is resulting in higher level of air pollution which is indeed an agitating issue for future generation. This result in fast development of renewable sources and innovative technologies in the automotive factory such as Electrical Vehicle. The main component of Electric Vehicle is the drive system (electric motor), in which motor with minimum magnetic mass and less magnet construction is preferred more in spite of the BLDC motor, Induction motor and Permanent Magnet motor which has more magnetic construction. Less weight, easy construction, variable speed range, high efficiency, high torque and inertia ratio and low cost makes it more economic. In this project we are planning to design and simulate Switched Reluctance Motor to obtain high motor efficiency by using analytical design equation and simulating it on "Ansys Maxwell" software. Submitted research work will help to design the SRM for the working of E-rikshaw.

KEYWORDS: Switched Reluctance Motor, "Ansys Maxwell" Software, E-rikshaw

I. INTRODUCTION

In recent years, the switched reluctance motor (SRM) has received considerable attention for variable speed drive applications. The basic concepts of SRM and fundamentals of control were introduced by Lawrenson PJ, Stephenson JM, Blenkinsop PT, Corda J, Fulton NN.^[1] Compared to induction and synchronous motors, switched reluctance motor drives are simple in construction, therefore, gained popular recognition in electric drives market due to power density, speed range, efficiency, torque/inertia ratio, manufacturing cost, and reliability and its converter has a minimum number of switching devices due to the unidirectional current requirement.^[2]

Reluctance motor is an electric motor in which torque generates through magnetic reluctance and rotor tries to align itself in the minimum reluctance position.^[3] To investigate the SRM performance, including the design of the control circuit, it is necessary to know its parameters, such as flux linkage, inductance and static torque.^[5]

This paper processes Analytical design equations to assume the performance and to guide the design of SRM. This paper focus on design and simulate Switched Reluctance Motor to obtain high motor efficiency by using analytical design equation and simulating it on "Ansys Maxwell" software. Submitted research work will help to design the SRM for the working of E-rikshaw.^[6]

II. OBJECTIVE OF PROJECT

The main goal of this incentive is to reduce fossil fuel use and greenhouse gas emission. Now a new study in Nature Sustainability shows that by reducing air pollution, a growing fleet of EVs in the nation could also save thousands of lives.

If just over a quarter of privately owned cars a slightly larger share of commercial vehicles were electric, researchers say in the study, the cuts in the air pollution could avoid almost 17500 deaths.

As diesel and gas truck only make up a small portion of the vehicles on our roads and highways, they generate massive amount of climate and air pollution. In the most impact communities, these trucks create diesel "death zone" with more severe respiratory and heart problems.

According to the survey in California, gas and diesel trucks are responsible for nearly half of the transportation related air pollution in state, even though they are vastly outnumbered by cars in the state.

Transportation is one of the largest sources of pollution and green house gas emission around the world.

Another advantage of electric vehicle is that many can be recharged whenever they make their home, whether that's your home or business terminal. This makes electrical vehicle a good solution for truck and bus fleets that returns regularly to the central depot or yard.

III. LITERATURE SURVEY

1. This paper discusses the optimization process of Switched Reluctance Motor during design procedure which uses Finite Element Method (FEM) to improve motor performance and properties. Materials utilization and some improvements are obtained by optimization process by taking four phase 8/6 SRM into account, analytical design given by known equations and formulas. The waveforms and static and dynamic parameters are calculated in this paper. For electrical vehicle application, the output characteristics are torque and power versus speed are given and compared.^[1]
2. Switched Reluctance Machines offer attractive characteristics and various features for automotive application. Low cost, high reliability, and competitive weight and efficiency combine to make the switched reluctance (SR) motor drive a strong candidate for application in future electric vehicle (EV) propulsion systems. This paper proposes a methodology to determine separately the peak and continuous power ratings of a switched reluctance motor (SRM) for electric propulsion of an electric vehicle (EV). Same machine has to deliver peak and continuous power for different road load condition of vehicle. Then gives switched reluctance design guidelines for battery operated electric vehicles. Finally, it presents the design and simulation of a switched reluctance motor power train.^[2]
3. In order to keep global warming under control it is widely accepted that CO₂ emission are required to reduce significantly which led to fast development of renewable energy and sustainable technologies. In automotive industry, hybrid and pure electric vehicles are most popular for the customer transportation. The main part of these vehicles is traction drive. An electric machine with low magnet mass or with less magnetic construction are extremely attractive. Due to the development in power electronics, the switched reluctance motors have gained popularity as a prominent candidate for the application of electric vehicle. This paper discusses the performance comparison a 3-phase 12/8 and a 6/4 switched reluctance machines through finite element analysis by using Infolytica Magnet software. The simulation results conclude that, more the number of stator and rotor poles the lesser the change in geometry of the stator and rotor results in improved magnetic characteristics and the energy efficient in torque production. The SRMs are great replacement of the permanent magnet synchronous machine (PMSM for hybrid and pure electric vehicles).^[3]
4. This presentation helps to understand the machine models investigated in RMxpert that can be exported to Maxwell from within RMxpert. Both 2D and 3D models can be generated through this. The Maxwell Project so created is ready in all aspects for solving using Magnetic Transient Solver. If Parametric investigations have been carried out in RMxpert, the one specific design of user's choice from among the several parametric variants can be picked for creating Maxwell Project in either 2d or 3d.^[4]

IV. PROBLEM STATEMENT

Literature review concluded that there is no single motor suitable for all electric vehicle applications. Switched Reluctance Motor is currently having very limited usage in Electric Vehicles although it is fulfilling almost all characteristics required for electric vehicle applications and having benefit of magnet less construction. Hence, research work planned to develop suitable drive system by using Switched Reluctance Motor for performance enhancement of Electric Vehicle.

V. RESEARCH METHODOLOGY

Research methodology for proposed research work is experimental type of quantitative research which includes:

1. Literature review and scenario of the present situation which includes the study of different research paper along with the situation of e-rickshaw in today's market and the various steps taken by the government to ensure the proper development in the field of e-vehicle with the best used motor and battery.
2. Mathematical design calculations of proposed design along with formula. The design says the design procedure of Switched Reluctance Motor which includes the machine specification, frame size selection, pole selection, stator and rotor pole angle selection, preliminary design process, winding design, and calculation of average torque. Also, we have analyzed the SRM by calculating the various losses in the SRM motor which includes Copper loss and Iron loss. All the values we have calculated for 48 V, 1 KW and 3000 rpm SRM motor.

Machine Specification: The design specification of SRM required the speed N in revolutions per minute, power output P in Kilowatt, supply voltages Vac in volts, and allowable peak phase current I in Ampere.

Frame Size Selection: The frame size of the motor is automatically determined by the outer diameter of the stator.

Practically, the outer diameter of the stator is fixed as follows:

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

Where the frame size is given according to the IEC recommendations. The 3mm subtraction is used in industry to account for the foot of the machine, which is used for mounting.

Pole Selection: This project primarily focuses on the popular combination of 8 stator and 6 rotor poles, also commonly known as the 8/6 machine. This machine has the advantage of lesser torque ripple than the other common combination of 6 stator and 4 rotor poles (6/4 machine) while the disadvantage of machine is that it causes more switching loss and core loss because of using more switches in the converter and two extra terminals.

Stator and Rotor Pole Angle Selection: The stator and rotor pole angle selection are the crucial part of the design process. The standard design normally has the stator pole arc angle (β_s) smaller than the rotor pole angle (β_r).

[1] The stator pole arc angle is less than the rotor pole arc angle, i.e., $\beta_s < \beta_r$.

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

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

In an 8/6 machine the stroke angle is

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

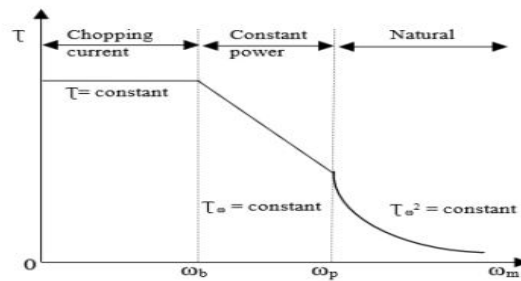
If $\beta_s < \epsilon$, then there may be some positions in the machine from where the machine may not start.

[3] The angle between the corners of adjacent rotor poles must be greater than the stator pole arc or there will be an overlap between the stator and rotor poles in the unaligned position.

Calculation of Average Torque: The average torque of the required SRM is calculated by the formula:

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

Where W is the total work done, which is calculated by the subtraction of unaligned work from the aligned work.

Fig- 1: Torque Speed Characteristic ^[14]

Copper Losses: The first step in calculating the copper losses involves the calculation of the resistance of each phase winding of the SRM. The mean length of a winding turn is given as,

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

The resistance of a single phase is calculated as

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

The copper losses at rated current are given by

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

Iron Losses: The iron losses are classified as Eddy-Current Losses and Hysteresis Losses.

- Design of proposed system using software tools i.e., ANSYS Maxwell.

After the whole calculation part, we have designed the detailed structure of Switched Reluctance Motor using ANSYS Maxwell Software and analyze it thoroughly.

VI. DESIGN SPECIFICATION

The specification of selected machine is-

GENERAL DATA	
Rated Output Power (kW):	1
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

STATOR CONSTRUCTION:

STATOR CORE DATA

Number of Stator Poles:	8
Outer Diameter of Stator (mm):	120
Inner Diameter of Stator (mm):	75
Yoke Thickness (mm):	9
Pole Embrace:	0.5
Length of Stator Core (mm):	65
Stacking Factor of Stator Core:	0.95
Type of Steel:	steel_1010

STATOR COIL DATA

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:	1
Wire Diameter (mm):	1.628
Wire Wrap Thickness (mm):	0.08
Slot Fill Factor (%):	45.7813

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)
0.30	79.1917	262.136	1.0525
0.40	85.3733	171.267	1.9218
0.45	83.8878	191.965	2.89067
0.50	79.9562	247.613	3.9542

Table 1

We observe that as the pole embrace increases the rated torque also increases so we have selected the highest pole embrace.

Pole Embrace: 0.50

Stacking Factor	Efficiency %	Total Loss (W)	Rated Torque (N.m)
0.50	64.67	547.958	3.1008
0.95	79.95	247.613	3.954
0.99	79.98	246.675	4.102

Table 2

We observe that as the stacking factor increases the efficiency and rated torque increases and total loss decreases but the starting torque decreases so we have selected stacking factor 0.95 which is more convenient one.

ROTOR CONSTRUCTION:

ROTOR CORE DATA	
Number of Rotor Poles:	6
Length of Air Gap (mm):	0.5
Inner Diameter of Rotor (mm):	30
Yoke Thickness (mm):	9
Pole Embrace:	0.5
Length of Rotor Core (mm):	65
Stacking Factor of Rotor Core:	0.95
Type of Steel:	steel_1010
Magnetic Shaft:	Yes

MATERIAL CONSUMPTION	
Stator Copper Density (kg/m ³):	8900
Stator Core Steel Density (kg/m ³):	7872
Rotor Core Steel Density (kg/m ³):	7872
Stator Copper Weight (kg):	1.04415
Stator Core Steel Weight (kg):	2.29736
Rotor Core Steel Weight (kg):	1.27536
Total Net Weight (kg):	4.61687
Stator Core Steel Consumption (kg):	4.92722
Rotor Core Steel Consumption (kg):	2.10761

VII. OPTIMIZED DESIGN AND ANALYSIS

After the observation of the motor for the different pole embrace, stacking factor, stator and rotor structure, the design is optimized and the results are obtained.

FULL-LOAD OPERATION DATA	
Input DC Current (A):	25.7366
Phase RMS Current (A):	26.2549
Phase Current Density (A/mm ²):	12.6128
Frictional and Windage Loss (W):	8.37152
Iron-Core Loss (W):	0.00261201
Winding Copper Loss (W):	202.499
Diode Loss (W):	11.8884
Transistor Loss (W):	24.851
Total Loss (W):	247.613
Output Power (W):	987.745
Input Power (W):	1235.36
Efficiency (%):	79.9562
Rated Speed (rpm):	2385.32
Rated Torque (N.m):	3.95429

Flux Linkage (wb):	0.0603669
Stator-Pole Flux Density (Tesla):	1.67034
Stator-Yoke Flux Density (Tesla):	1.35778
Rotor-Pole Flux Density (Tesla):	1.27607
Rotor-Yoke Flux Density (Tesla):	0.509167
Coil Length per Turn (mm):	176.126
Winding Resistance in Phase (ohm):	0.0734418
Winding Resistance at 20C (ohm):	0.0604118
Winding Leakage Inductance (mH):	0.03707
Iron-Core-Loss Resistance (ohm):	2.00493e+006
Frequency of Phase Current (Hz):	238.532
Maximum Output Power (W):	2048.31

NO-LOAD OPERATION DATA

No-Load Speed (rpm):	10758.2
No-Load DC Current (A):	4.88281
No-Load Input Power (W):	234.375

START OPERATION DATA

Estimated Start Torque (N.m):	34.3062
Estimated Start DC Current (A):	813.121
Maximum Start Current (A):	646.771

TRANSIENT FEA INPUT DATA

For Armature Winding:	
Number of Turns:	40
Parallel Branches:	1
Terminal Resistance (ohm):	0.0734418
End Leakage Inductance (H):	1.18958e-005
2D Equivalent Value:	
Equivalent Model Depth (mm):	65
Equivalent Stator Stacking Factor:	0.95
Equivalent Rotor Stacking Factor:	0.95
Estimated Rotor Inertial Moment (kg m ²):	0.00149257

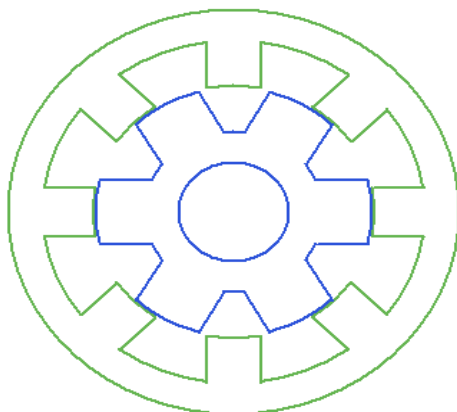


Fig- 2: Stator & Rotor Design

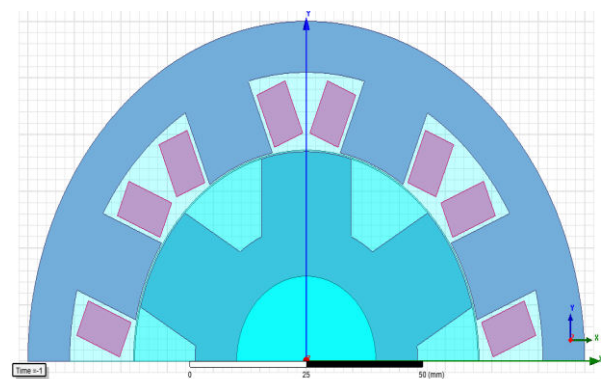


Fig- 3: Maxwell 2D Design

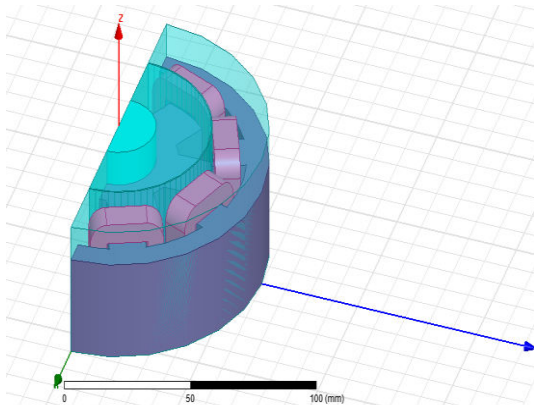


Fig- 4: Maxwell 3D Design

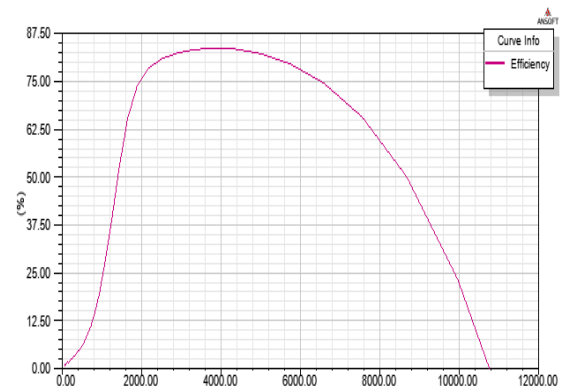


Fig- 5: Efficiency vs Speed

From this graph (Fig- 5) we observe that the efficiency first increases and then decreases and the efficiency is maximum at our rated speed i.e., 3000 rpm.

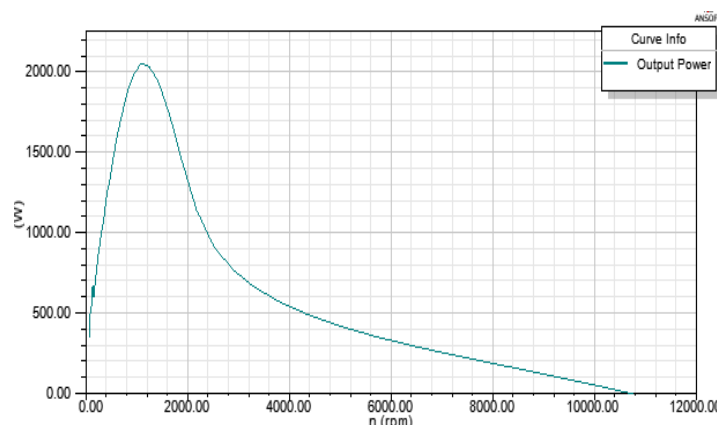


Fig- 6: Power Output vs Speed

From this graph (Fig- 6) we observe that for the given rating of motor, the motor gives the highest output power at nearly 1000 rpm.

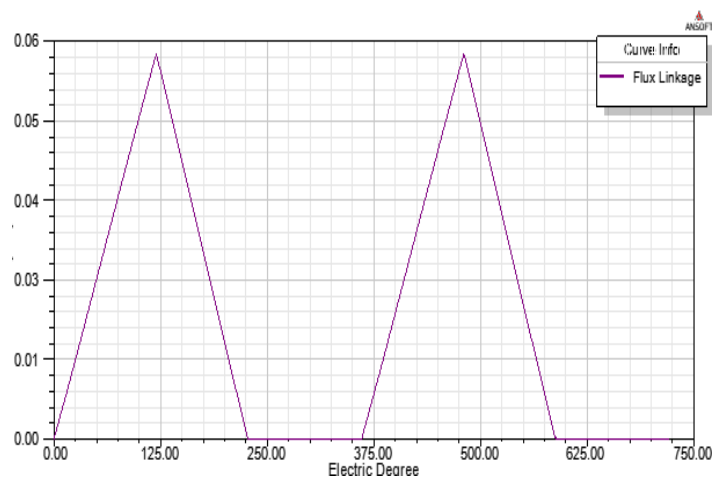


Fig- 7: Flux Linkage

From the above graph it is clear that the flux linkage must be high for the good performance of the motor.

VII. CONCLUSION

For using SRM motor in electric vehicles various characteristics are compared. The characteristics of the motors like the power density, efficiency and their advantages and disadvantages were compared regarding their applicability in electric vehicles. In SRM motor, stator has coil and rotor is simply an iron. There is no conductor on rotor which means there is no I²R loss in rotor, which also improves its efficiency as there is only stator loss and no rotor loss. As loss is caused only with respect to stator, so cooling mechanism reduces and it also does not have permanent magnet on rotor so its weight and size reduces. If we use any other motor, it requires a cooling device which will affect in extra cost and extra size.

Based on a comprehensive relative study, it has been shown that SRM can meet and go above the highest torque to power performance and produces low vibration and low acoustic noise compared to other motors.

Based on a complete relative study, it has been seen that SRM motor is better compare to other motors in application of electric vehicles.

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