Design and Development of Switched Reluctance Motor for Electric Vehicle

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Abstract—**Large scale promotion of smart electric vehicles will result in sustainable energy use and environmental benefits. For development of electric vehicle, innovation technologies contributing to development of this sector needs to be developed. Our work deals with design and implementation of switched reluctance motor (SRM) for electric vehicle, which can change the scenario of smart vehicles if this technology is used on large scale. Switched reluctance motor provide high power density, high torque to weight ratio, wide torque-speed range, rugged structure, high efficiency and also give advantages in terms of high values of magnetic and electric loading. Advantages in terms of high torque to inertia ratio and high torque and power density makes it suitable candidate for electric vehicles. Conventional design of SRM has issues like high acoustic noise and torque ripple. To overcome this problems we have designed and developed 6/10 stator/rotor pole, external rotor configuration motor. This motor is fitted at rear of bicycle. This configuration of motor provide all advantages of conventional motor & also reduce acoustic noise & torque ripple. Analysis of this work is carried out in MATLAB, ANSYS & SOLIDWORKS. The mathematical design is validated using the above mentioned Software's. The hardware model of the motor is developed & motor is fitted at rear end of bicycle. Performance of the system is much better as compared to other types of motor for electric vehicle application in terms of efficiency & energy use. Promotion of this technology can change the future of electric vehicle use in the country.**

Key words: Switched Reluctance Motor (SRM), Electric Vehicle (EV).

I. INTRODUCTION

For sustainable and safe use of energy resources greener & cleaner options are being sorted out all over the world. Electric vehicles are a promising technology for drastically reducing noise pollution and greenhouse gas emission. Electric vehicle are inherently more efficient and cleaner because of the use of electricity as primary fuel source with one or more electric motor for propulsion. There are various types of electric motors that can be used for vehicle propulsion which includes induction motor, dc series motor, brushless dc motors and switched reluctance motors. Except SRM, all the above machine are costly & have complex construction due to the presence of distributed winding. The capabilities of the SRM such as simple & rugged construction with concentrated winding on the stator and maintenance free rotor, four quadrant operation, fault tolerance, high efficiency & reliability and ability to operate in harsh environment makes it a suitable candidate for electric vehicle propulsion system[1].

The objective of this paper is to look for optimized design of SRM with reduced acoustic noise & torque ripple which is possible if the motor is designed appropriately with extended constant power range [2]. Section I introduces the paper. In section II, the design methodology for conventional SRM is given with finite element analysis results done using ANSYS 12.0. In section III, it has been pointed out how the design can be optimized. In section IV, SRM design has been carried out with reduced acoustic noise & torque ripple. Section V, contains the conclusion of the paper together with the future scope of studies which can be carried out.

II. DESIGN OF CONVENTIONAL SRM

A. *Design details*

The basic SRM is a three phase machine with six stator poles & four rotor poles [3].The motor designed here is specifically for three wheeler application. The design process is shown below using ANSYS environment. Steady state & transient response are obtained using MATLAB as shown below.

Rated Torque	3.5 Nm
Rated Speed	3000 RPM
Number of phase	3

Table I-Design Data

B. Simulation results

A detailed study of the flux distribution and density patterns at different rotor position is necessary due to doubly salient structure of SRM. At a particular instant, the flux plot & flux density plot of the SRM with rated current have been obtained using 'static analysis' option of the ANSYS parametric design language (scripting language) by using command prompt mode ,where the applied current is constant throughout the analysis. Described below are the different commands used during the analysis.
PREP7 commands are used to create & setup the SRM model in ANSYS environment. ET command specify element type PLANE53 for low frequency magnetic field analysis which is based on magnetic vector potential formulation. Permeabilities of the stator positive & negative coils, air gap & of the shaft is defined using MP (material property) command respectively. Non-linear material properties in SI units of the stator & rotor has been defined using TB command which activate a Data table. CSYS command will activate a cylindrical coordinate system with Z as the Axis of rotation. Pole arc, Pole shoe, Increment angle for the stator and rotor, height of stator & rotor teeth & depth of yoke diameter can be defined using keywords. key points, lines & areas has been defined using KP,LSTR and AL commands respectively and hence PCIRC command will create a Circular area centered about the working plane origin. AGEN command will generate additional areas from the pattern of areas & AOVLAP command will overlap all these additional areas. Area plot can be obtained by adding separate areas to create a single area using AADD command as shown below. All the magnetic solutions can be obtained using MAGSOLV command as shown below.

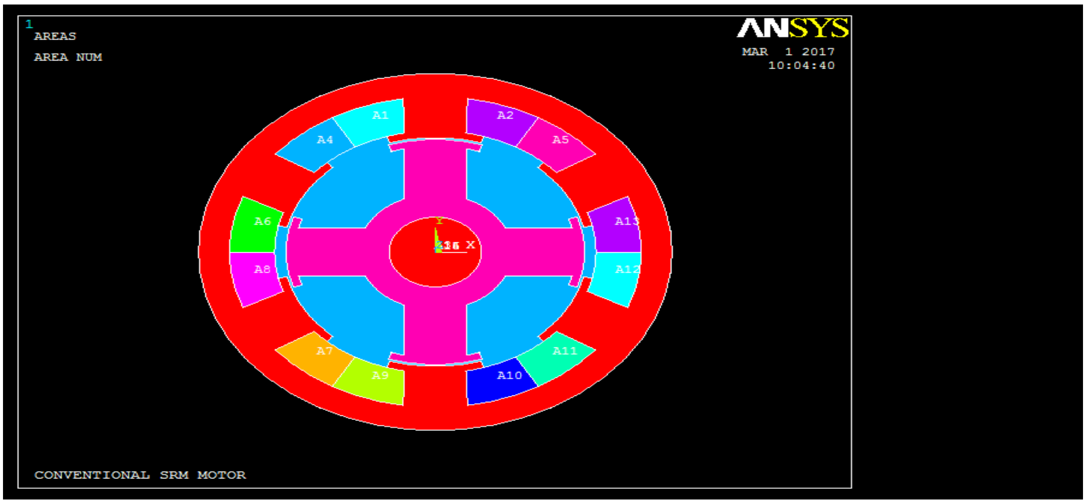

Fig.1.Areas Plot

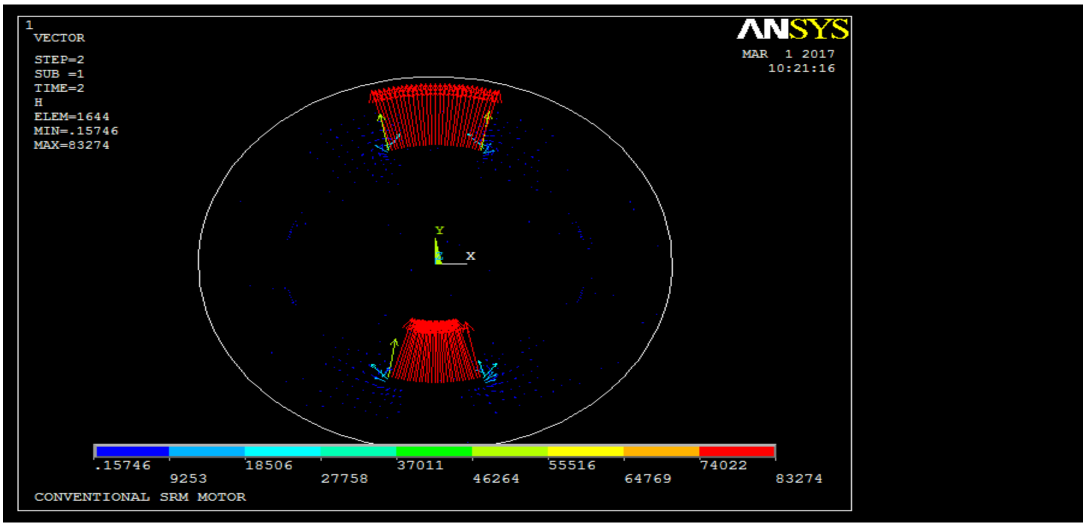

Fig.2.Magnetic flux density Plot

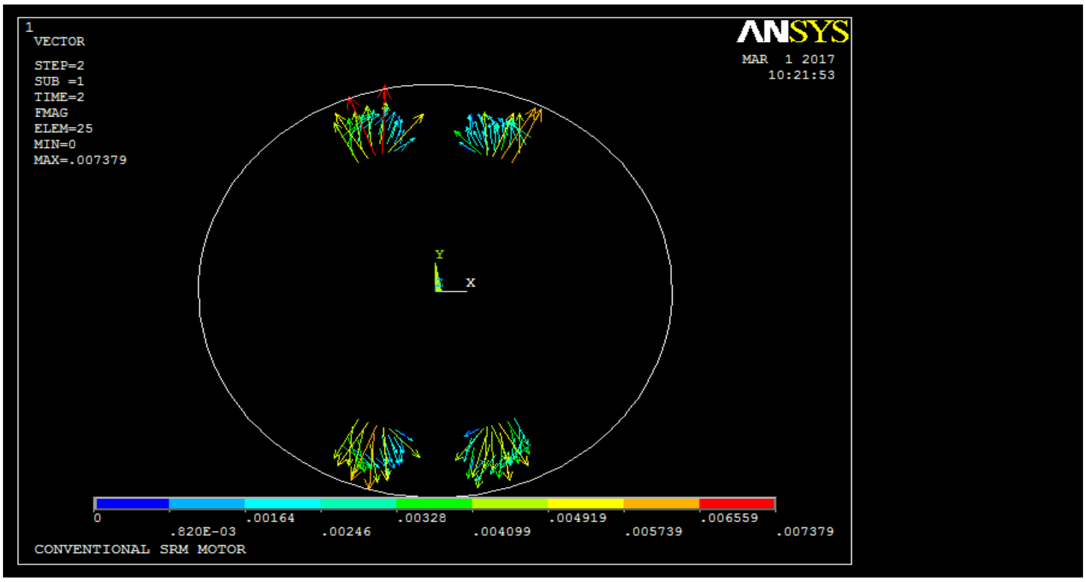

Fig.3.Nodal forces Plot

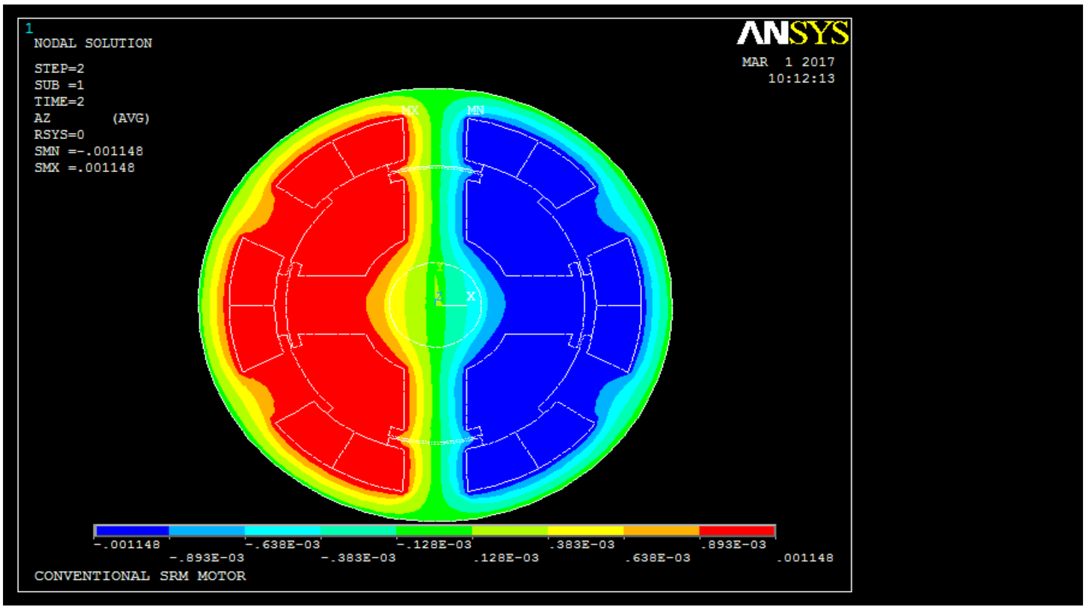

Fig.4.Magnetic vector potential Plot

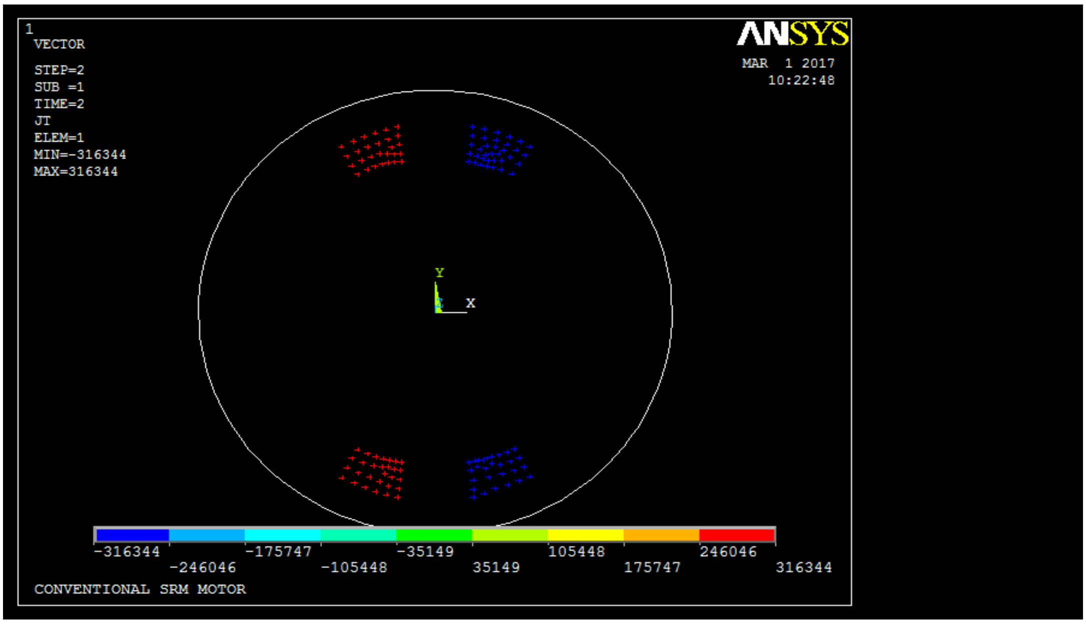

Fig.5.Current density Plot

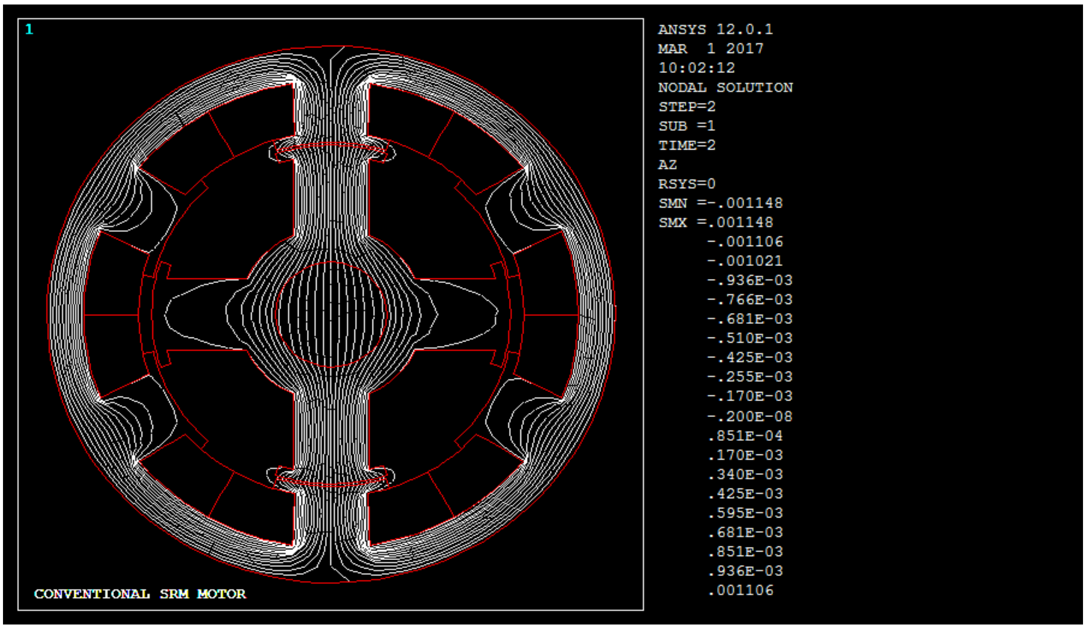

Fig.6.Alined magnetic flux Plot (conventional SRM)

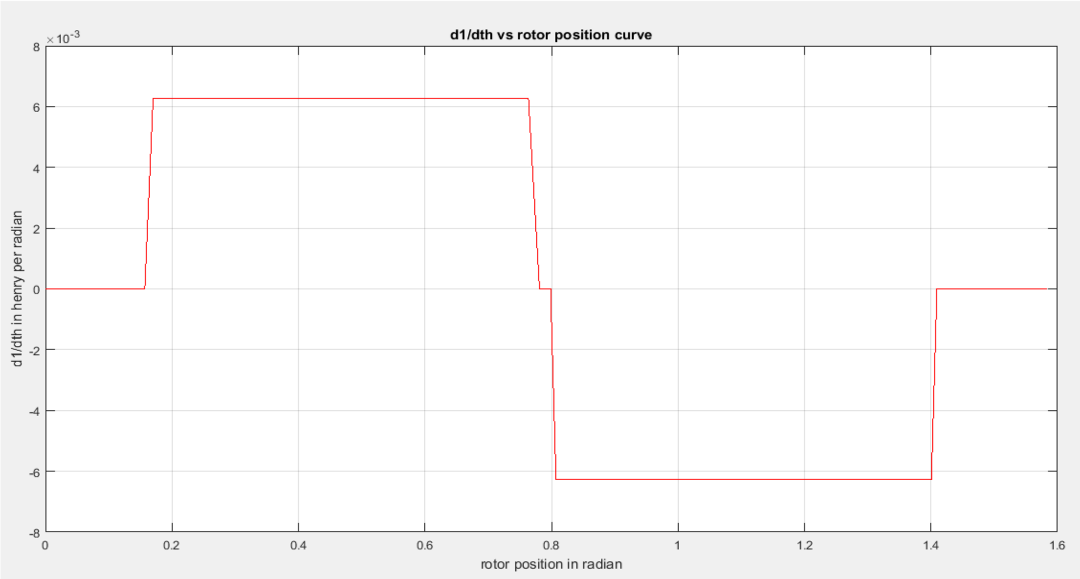

Fig.7. Steady state response obtained in MATLAB

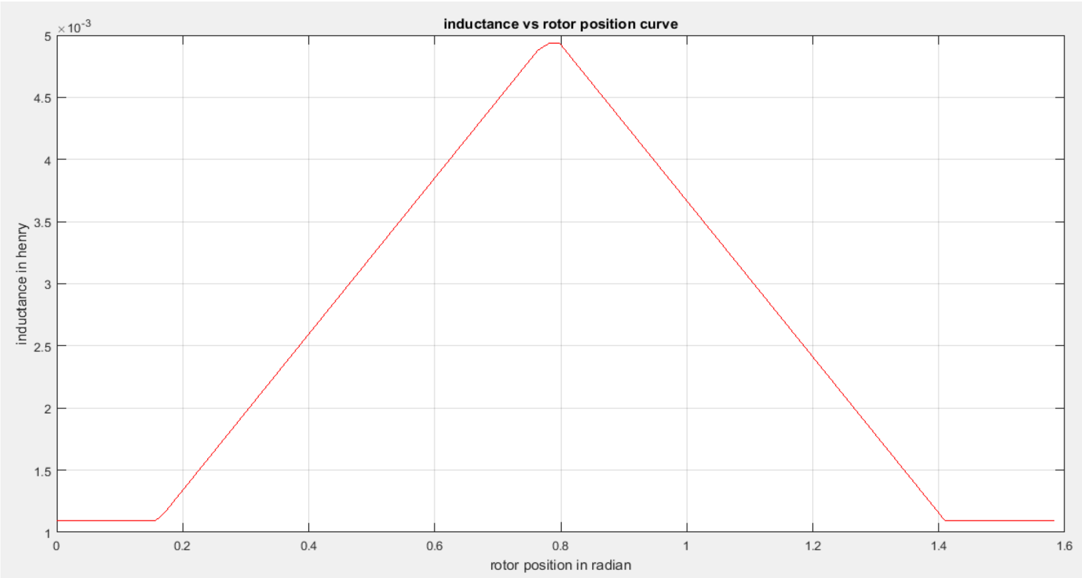

Fig.8.Transient response obtained in MATLAB

In SRM, Inductance - rotor position curve play a significant role for torque production. From the transient response as shown above, it is clear that no torque is produces at aligned position. If the rotor is slightly moved from aligned to unaligned position, a torque is produced due to the tendency of the rotor to attain minimum reluctance position. So, Inductance is a function of rotor position in SRM. Both Motoring & generating torque are produced for positive & negative inductance profile respectively. Direction of rotation can be reversed by changing the phase excitation of SRM.

In order to produce the torque, discrete excitation of phase winding is necessary which is responsible for torque ripples. Radial force generated by excitation as shown in fig.3 will produce acoustic noise in the operation of conventional SRM, which is not desirable. During commutation between two adjacent phases, torque fluctuation is severe. So, in order to upgrade the performance of SRM, the mitigation of acoustic noise and torque ripple is desired while employed in electric vehicles. Performance of the SRM can be upgraded by choosing efficient control & energizing strategies. Environmental performance, Safety and comfort can also improve the performance of SRM in electric vehicle.

III. DESIGN OPTIMIZATION

Switched reluctance motor operation depend upon numerous factors such as number of phases, Number of poles on the stator and rotor as well as magnetic properties of the lamination material. Converter and control strategy also modify SRM operation [4]

There are many methods available in the literature to reduce the acoustic noise which includes optimal combination of current waveform and pole configuration [5], decreasing the pole arc which results in decreasing the overlapping area between the stator & rotor poles [6], increasing the mechanical strength of the stator [7] and current shaping [8]. Active, passive and reactive Control methods are generally available to control the noise. Active noise control method create destructive interference with a noise source by generating an out of phase signal. Passive noise control is generally inexpensive & can be combined with active approaches. Reactive noise control method can only reduce low frequency noise.

Similarly, there are many methods available in the literature to reduce the torque ripple which includes optimization of rotor geometrical shape & tooth width [9], stator tooth width and by increasing the number of poles on the rotor as compared to the stator [10].

Parameters	Conventional SRM	Modified SRM
Number of stator poles	6	6
Number of rotor poles	4	10
Stator pole arc (in degrees)	39	15
Rotor pole arc (in degrees)	40	16
Air gap (in mm)	0.5	0.4
Stator tooth width (in mm)	16.6	21
Rotor tooth width (in mm)	17.2	22.4
Rotor outer diameter (in mm)	74	220
Supply voltage (in volts)	48	48
Wire gauge	15	8
Material used	M47A	M47A

Table II- Comparison of conventional and modified SRM

In modified SRM, number of rotor poles are higher than the number of stator poles to reduce the torque ripple and acoustic noise as it reduce the overlapping area between the stator and rotor poles. In addition to this output torque can be increased by increasing the diameter of the rotor. Small rotor diameter enable operation at high speed with minimal iron losses and large rotor diameter makes the rotor heavier and putting some limitation on the maximum speed of the rotor hence make it suitable for low speed applications[11] .

IV. SRM DESIGN WITH REDUCED ACOUSTIC NOISE & TORQUE RIPPLE

The conventional SRM has considerable acoustic noise & torque ripple which should be minimized to effectively utilize SRM for EV applications. Therefore, SRM design with reduced acoustic noise and torque ripple is shown below which can be utilized for electric bicycle application [12].

Rated torque	9.5 Nm
Rated speed	500 RPM
Number of phase	3

Table III-design details

Stator & Rotor are developed in SOLIDWORKS (Solid Modeler) and imported in ANSYS workbench. Models are developed using parts and dimensions. These models can be rotated in 3D drawing view mode as shown below. For efficient Multiphysics solution, meshing is required. Meshing (Discretization) of Stator & rotor part is shown below which determine the efficiency & effectiveness of the analysis, which is the process of dividing up the model into elements consisting of nodes.

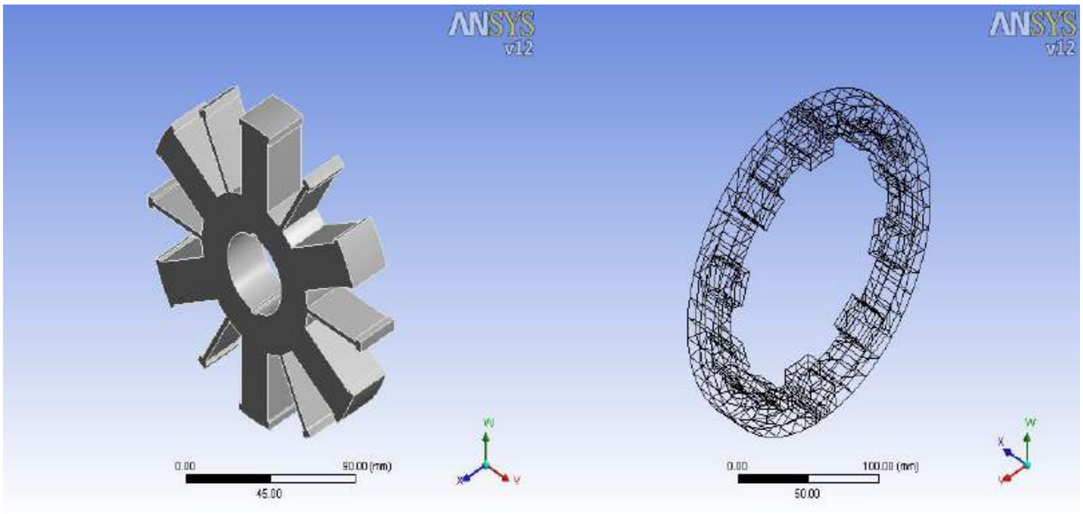

Fig.9.Stator & Rotor of the modified SRM

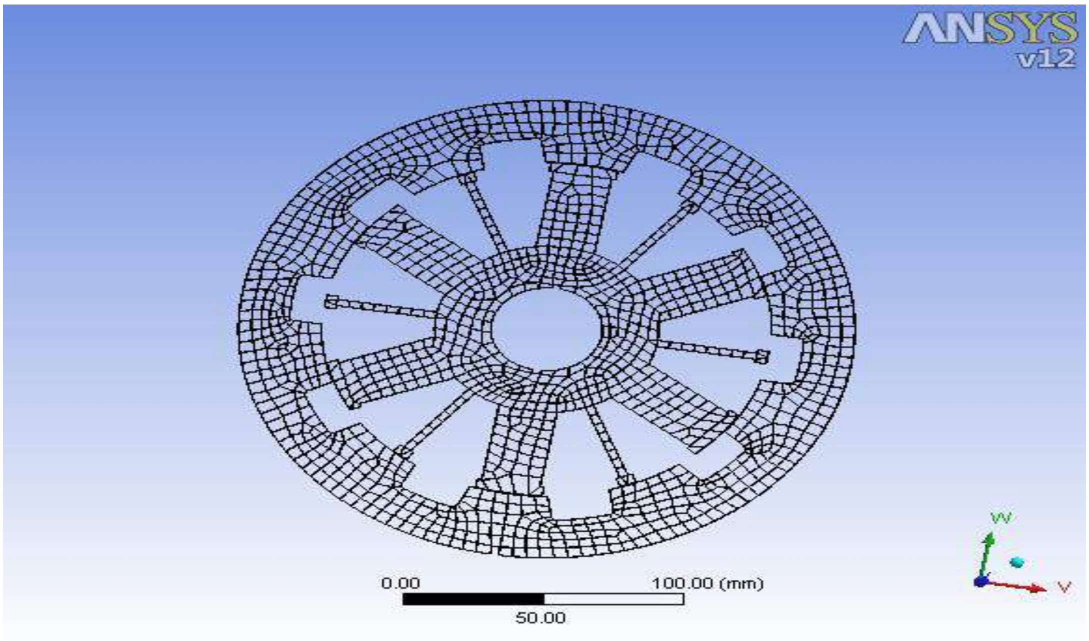

Fig.10. Modified SRM meshing in ANSYS workbench

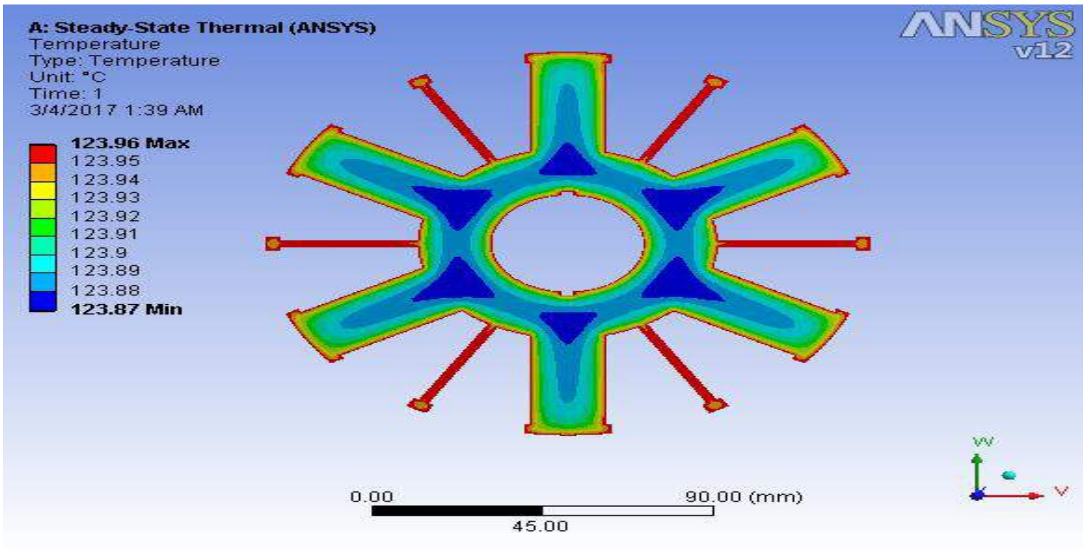

Fig.11.Thermal Analysis of Stator

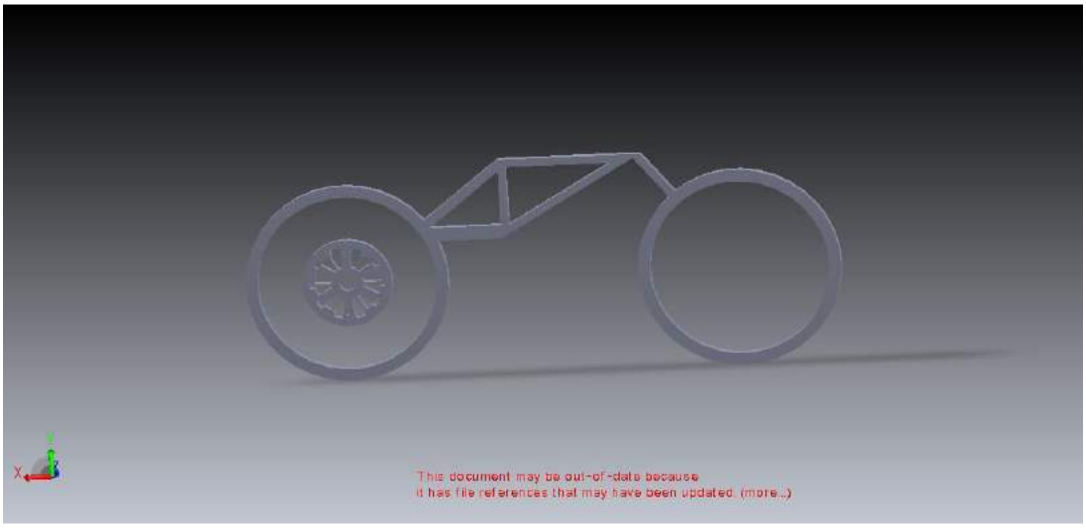

Fig.12. Implementation of modified SRM in Bicycle developed in SOLIDWORKS

Wedge tips are required to support the winding on the stator. Thermal analysis shows that temperature rise will be more near the wedge tips and coil & cooling can be placed near the shaft. The amount of force and speed requirement is taken into account while calculating the power produced by the hub motor which also depends upon the wheel specifications. The force is basically the sum of grade resistance, drag resistance, rolling resistance and the inertia. The product of this sum of force and speed of the bicycle is equal to the power required from the motor. Since the power always remain same but as the speed increase, torque will automatically decrease proportionally & vice versa. This motor can be fitted at the rear of the bicycle to drive it. It can be partially assist or fully assist means can be powered by the motor only, pedals only and by the combination of motor & pedals [13].

V. CONCLUSION & FUTURE WORKS

Two approaches for switched reluctance motor were presented in this paper for electric vehicle application. The first method was based on internal rotor configuration, whereas the second method utilize outer rotor configuration to reduce the drawbacks of internal rotor configuration that is acoustic noise and torque ripple. Therefore, large scale implementation of this modified SRM in bicycle will change the scenario of electric vehicle in the country. Various internet of things based possibilities such as speed and driving cycle measurement and control and energizing strategies should be investigated in future.

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