Design and Analysis of Permanent Magnet Brushless DC Motor for Solar Vehicle using Ansys Software

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***Abstract*—This paper presents design and performance analysis of Permanent magnet Brushless DC motor of 1.5 KW used in solar vehicle and hybrid electric vehicle. Finite element method (FEM) is used for determining the performance characteristics of motor. Permanent magnet brushless DC motor, design and its dynamic performance analysis is done on ANSYS/RM Expert and then its electromagnetic studies has done on ANSYS/Maxwell 3D.In last motor is analyze by varying the lead angle in control circuit.**

***Keywords-* *Permanent magnet brushless DC motor, FEM method , Ansys software*.**

I. INTRODUCTION

The power sector experienced its largest annual increase in capacity ever, with significant growth in all regions. Wind and solar PV had record additions for the second consecutive year according to global status report 2016. Developing countries (e.g., Kenya, Uganda and Tanzania in Africa; China, India and Nepal in Asia; Brazil and Guyana in Latin America) are seeing rapid expansion of small-scale renewable systems, including renewables-based mini-grids, to provide electricity for people living far from the grid.

India's current solar power installed capacity is 4879 MW. To promote electricity generation using solar energy Government of India launched Jawaharlal Nehru National Solar Mission in January 2010. The objective is to achieve large-scale deployment of Solar Energy Systems and also to assist domestic production of critical raw materials, components and products to achieve grid parity by 2022.

There are number of advantages of Electric vehicle over conventional internal combustion energy automobiles. By using Electric vehicle air pollution and green house emission effect can be reduced with large scale. Dependency on non-renewable energy sources can be decreased, which are limited in nature.

A BLDC motor is considered to be a high performance motor that is capable of providing large amounts of torque over a vast speed range [4]. BLDC motors do not have brushes (hence the name "brushless DC") and must be electronically commutated.

Advantages-

- High Speed Operation – A BLDC motor can operate at speeds above 10,000 rpm under loaded and unloaded conditions.
- Responsiveness & Quick Acceleration – Inner rotor Brushless DC motors have low rotor inertia, allowing them to accelerate, decelerate, and reverse direction quickly.
- High Power Density – BLDC motors have the highest running torque per cubic inch of any DC motor.
- High Reliability – BLDC motors do not have brushes, meaning they are more reliable and have life expectancies of over 10,000 hours. This results in fewer instances of replacement or repair and less overall down time for your project.

II. FINITE ELEMENT METHOD

There are number of techniques which have been developed to solve electromagnetic related problems not amenable to exact solution.The Finite element method is used to convert the complex partial differential equation into nonlinear algebric equation The finite element method can be applied to the vector Helmholtz wave equation, which is derived from the Maxwell's equations, or it can be derived from a scalar-vector potential formulation of the fields.There are variety of commercial geometrical modelling tools to accurately model any three–dimensional geometry and to generate the required mesh with any kind of elements such as triangles,tetragonals and hexagonals[2].

FEM involves the following for the solving a boundary value problem:

i) Discretization of the domain
ii) Derivation of the element equations
iii) Assembly of the elements
iv) Solutions of the system equations.

The field analysis using FEM has three steps

i. Preprocessing stage
ii. Processor stage
iii. Postprocessor stage

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III. BASIC MATHMETICAL FORMULAS USED IN ELECTROMAGNETIC FIELD

In magnetic field numbers of quantities are used. They are interrelated with each other. Magnetic flux (ø) in magnetic field is very similar to electric current (I) in electric field.

Magnetic flux is related with magnetic field density (B) as

$$Ø = B.A \qquad (1)$$

Here A is the area of the magnetic flux path. Magnetic flux unit is weber and the unit of magnetic field density is weber/m².

Magnetic flux can be calculated with magneto-motive force (F) and reluctance(R) of the path.

$$F=NI \qquad (2)$$

Where N is the number of turns used and I is the current flow through the coil. Then

$$Ø=F/R \qquad (3)$$

Using equation (2) equation (3) can be represented

$$Ø= NI/R \qquad (4)$$

Reluctance of the magnetic path is depends on length of the magnetic path (l), permeability of magnetic material(μ) and area of flux flowing path .

$$R=l/\mu A \qquad (5)$$

Magneto-motive force (F) in magnetic circuit is similar to electromotive force (E) in electric circuit. Magnetic field density (B) is similar to electric field density (D).

Maxwell's equations represent one of the most elegant and concise way to explain the fundamentals of the electricity and magnetism. With the help of Maxwell's equations one can develop most of the working relationship in static or time varying electromagnetic field.

The differential for of maxwell's equations for the time varying condition is given below.

(1) $\nabla.D = \rho_v$

(2) $\nabla.B = 0$

(3) $\nabla X E= -\partial B/\partial t$

(4) $\nabla X H=J+ \partial D/\partial t$

A. BASICS OF MOTOR STRUCTURE SPECIFICATION

Torque (T) generated by BLDC motor is depends on rotor diameter (D) and axial length of the rotor (L) .It can be represented as

$$T = KD^2L \qquad (6)$$

With equation (6) it can be understood that the Torque generated by a motor is mainly depends on diameter of rotor. As the diameter of rotor increases circumference area availability for permanent magnet increases. It can be interpreted that if the axial length is double, Torque will also double at constant power [3,4].

Cogging torque is defined as the unwanted torque that is produced in the PM BLDC motor due to the interaction of the rotor magnets and slots and poles of the machine. The cogging torque reduces the average torque produced by the machine and introduces unwanted torque ripple in the PM BLDC motor. The expression for the cogging torque is given by

$$T_{cog} = -½\, Ø_g^2 dR/d\Theta \qquad (7)$$

Where $Ø_g$ is the air gap flux and dR/dϴ is the change in air gap reluctance with respect rotor angle. It is important to note that most techniques used to reduce the cogging torque will reduce the effective back EMF and hence the resulting mutual torque production.

B. MOTOR DESIGN

The basic design of the motor is done in RMxpert^tm of Ansys Maxwell and Finite Element Method has been done in Maxwell 2D. Parameters given in the table are used as an input to the software.

a) RMxpert^tm- It offers numerous machine-specific, template-based interface for induction, synchronous and electronically and brush commutated machines. These templates allow to easily enter design parameters and to evaluate design trade-offs early in the process. Critical performance data such as torque versus speed, power loss, flux in the air gap, power factor and efficiency can be quickly calculated. The model designed in RMxpert can be easily exported in Maxwell project (2D/3D) for Finite Element Method and electromagnetic transient analysis.

b) STATOR DESIGN- Stator is the static part of any motor or generator. Table 1 shows the parameters of analysis setup for design. On the basis of table 1 parameters the stator data will be mentioned in table 2[1].

Table.1

SR.NO.	PARAMETER	VALUE
1	Rated power(w)	1500
2	Rated voltage(volt)	100
3	Rated speed(rpm)	3000
4	No. of pole	4
5	Frictional loss(W)	10
6	Windage loss(W)	2

Table 2

SR.NO.	PARAMETER	VALUE
1	Number of slot	12
2	Outer Diameter(mm)	120
3	Inner Diameter(mm)	62
4	Length of stator core(mm)	55
5	Number of slots	12
6	Stacking factor	.95
7	Conductor per slot	120

Stator in Figure 1 is constructed with the help of table 2.

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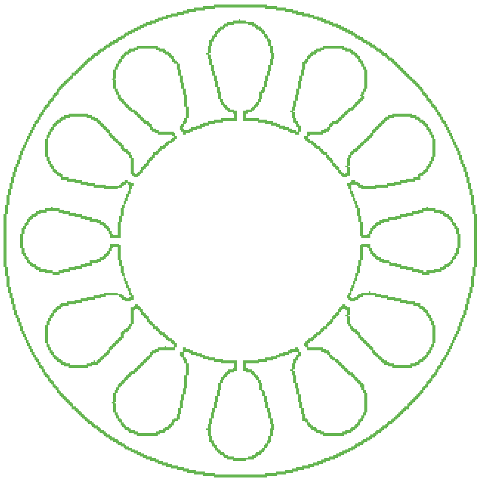

Fig.1. Stator geometry

c) Slot parameters- Shape and dimensions of the slot are mentioned in figure 2 and table 3.

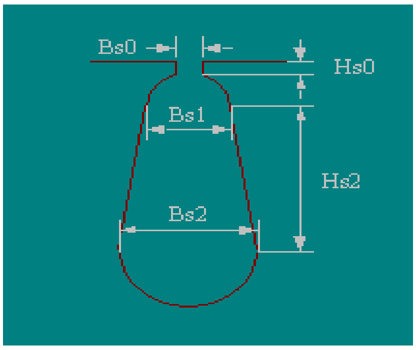

Fig.2.Slot Dimension

TABLE 3. Slot Dimension

Sr. No.	PARAMETER	VALUE
1	H_s0(mm)	1.5
2	H_s2(mm)	9.4
3	B_s0(mm)	2.5
4	B_s1(mm)	11.41
5	B_s2(mm)	16.83

d) ROTOR DESIGN- It is the moving component of the electromagnetic system in the electric motor or generator. For the rotor permanent magnet pole many shapes are given in RMxprt but the given figure 3 is taken.

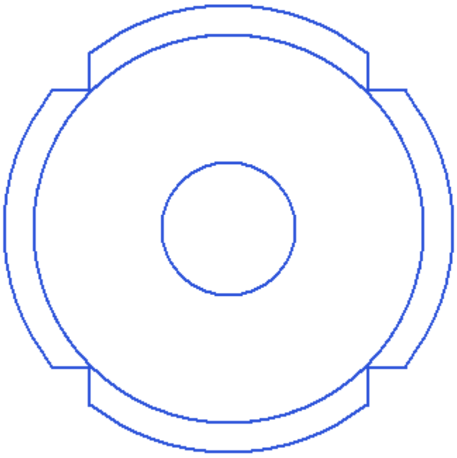

Fig.3. Rotor Geometry

Rotor parameters are given in table Table 4

Table.4

Sr.No.	PARAMETER	VALUE
1	Minimum air gap(mm)	1
2	Inner Diameter(mm)	18
3	Outer Diameter(mm)	60
4	Length of rotor(mm)	55
5	Type of steel	Steel_1008
6	Embrace	.85
7	Thickness of magnet(mm)	4
8	Magnet Type	NdFe35
9	Width of Magnet(mm)	36.73

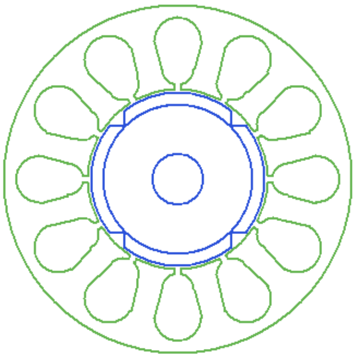

Figure 4 cross-section view of BLDC motor.

Table.5. other important parameter for motor

Sr.No.	PARAMETER	VALUE
1	Residual Flux Density(Tesla)	1.23
2	Coercive Force(A/m)	890000
3	Maximum Energy Density(kj/m^3)	273.675
4	Average Input Current(A)	15.94
5	RMS Armature current(A)	15.94
6	Armature Current Density(A/mm^2)	.55821
7	Frictional and Windage Loss(W)	10.38
8	Iron core Loss(W)	.002127
9	Armature Copper Loss(W)	10.38
10	Transistor Loss(W)	68.526
11	Diode Loss(W)	4.69
12	Total Loss(W)	94.5853
13	Output Power(W)	1499.3

14	Input Power(W)	1594.52
15	Efficiency	94.0681
16	Rated Speed(RPM)	2804.4
17	Rated Torque(N-m)	5.1074
18	Maximum Output Power(W)	6062.87
19	Air Gap Ampere Turn(A.T)	573.567
20	Magnet Ampere Turn(A.T)	-1218.1
21	Leakage Flux Factor	1

Some important plots ore given below when the simulation of the model was executed in the RMxpert.

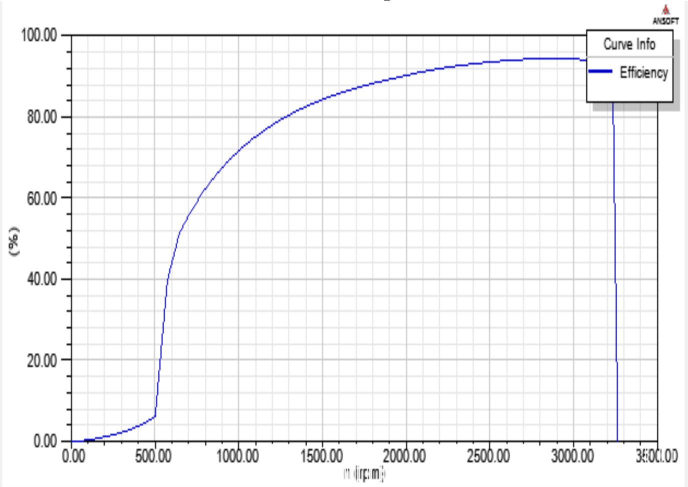

Fig.5. Efficiency vs speed

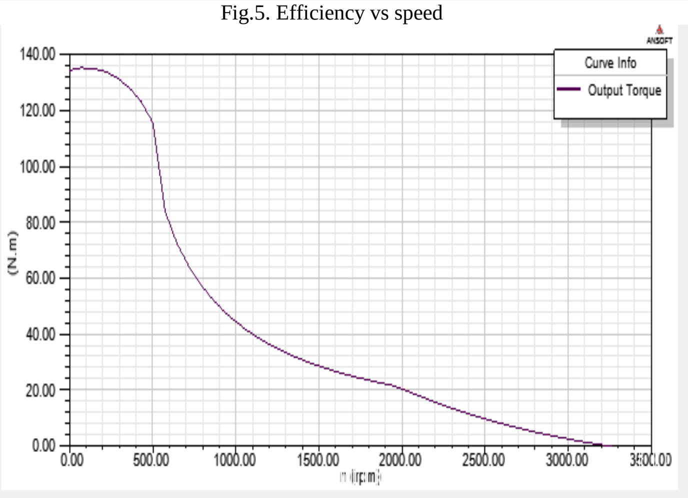

Fig.6.Torque vs Speed

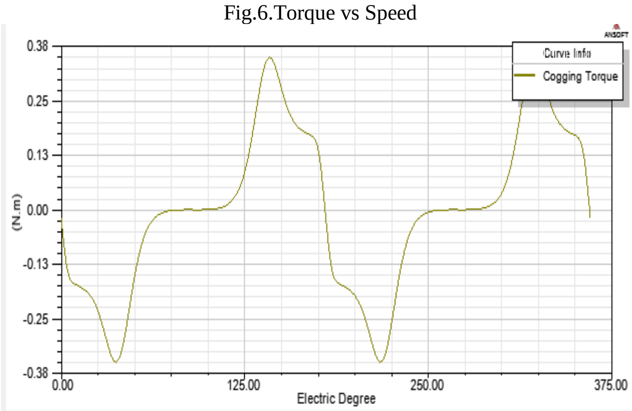

Fig.7. Cogging Torque vs Electric Degree

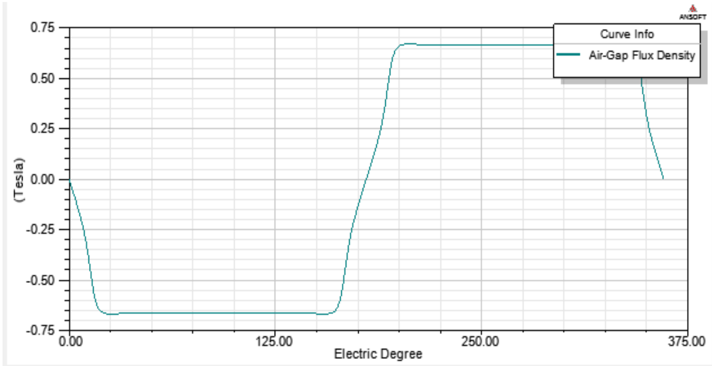

Fig.8. Air Gap Flux Density vs Electric Degree

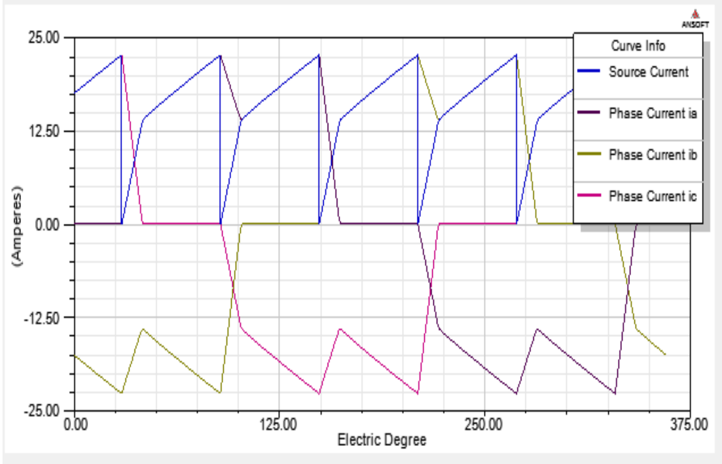

Fig.9. Winding Current under load vs electric degree

IV. MAXWELL 2D SIMULATION

Motor design create on RMxprt is export in Maxwell 2D.This software is used to create meshing for FEA [2]. Electromagnetic analysis is done with the help of Maxwell 2D.Motor in Maxwell 2D is shown in fig.10.

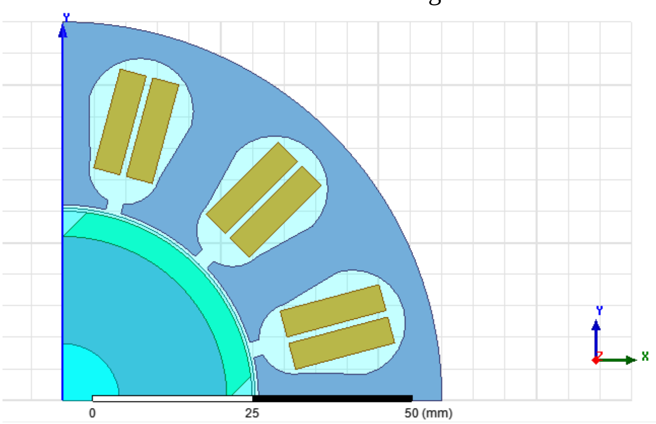

Fig.10. motor in Maxwell 2D

There are some analysis are done on the basis of simulation in Maxwell 2D .Fig 11 shows the mesh formation at specific time of rotor position.

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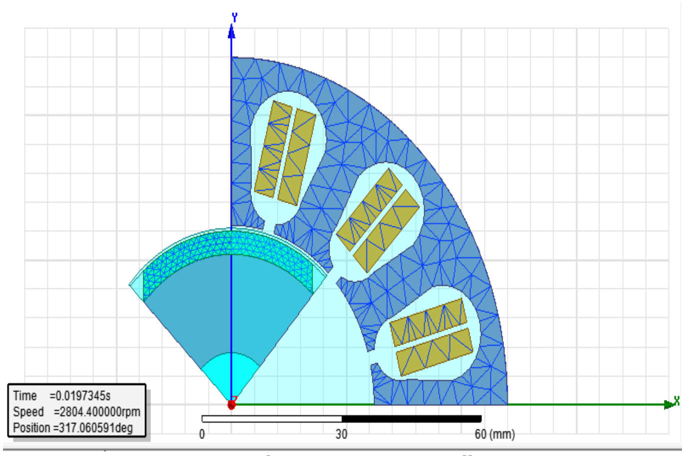

Fig.11. Mesh Formation in Maxwell 2D

In fig.12. magnetic field density is shown at specific time of rotor position.

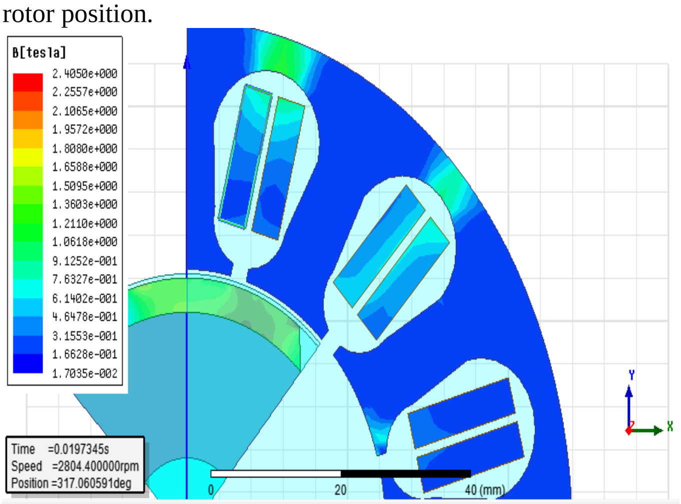

Fig.12. Magnetic Field Density at specific rotor position

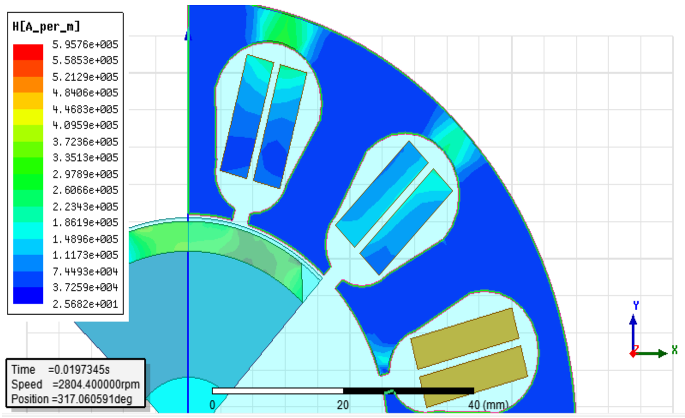

Fig.13. Magnetic Field Intensity at specific rotor position.

Motor torque generated by the motor at different time is shown in Fig.14

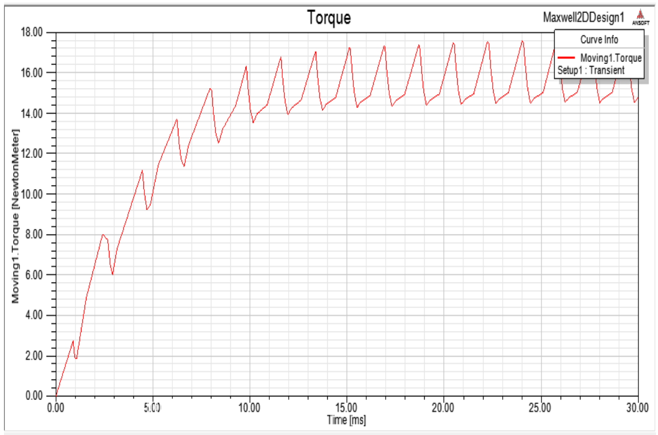

Fig.14. Motor torque at 0 degree lead angle

V. Analysis after increasing lead angle of control circuit- Above motor designing is done when lead angle is taken 0 degree. For improving motor performance lead angle is varying and the change in motor performance is analyzed. After changing motor lead angle efficiency of motor is increased. Lead angle shows how early the phase voltage is injected. When lead angle increases, phase current excites the earlier winding. As each phase current has the same phase angle as each phase back emf, the BLDC motor gives the given torque demand while needing a lower demand current and achieves higher efficiency as copper loss is reduced.
Table 6 shows some important parameter when lead angle is varying from 0 degree to 30 degree.

TABLE.6

Sr.No.	PARAMETER	VALUE
1	Residual Flux Density(Tesla)	1.23
2	Coercive Force(A/m)	890000
3	Maximum Energy Density(kj/m^3)	273.67
4	Average Input Current(A)	15.91
5	RMS Armature current(A)	14.04
6	Armature Current Density(A/mm^2)	.528
7	Frictional and Windage Loss(W)	12.9316
8	Iron core Loss(W)	.0024
9	Armature Copper Loss(W)	9.29
10	Transistor Loss(W)	66.725
11	Diode Loss(W)	2.794
12	Total Loss(W)	91.747
13	Output Power(W)	1499.54
14	Input Power(W)	1591.29
15	Efficiency	94.234
16	Rated Speed(RPM)	3170.96
17	Rated Torque(N-m)	4.51
18	Maximum Output Power(W)	7397.92
19	Air Gap Ampere Turn(A.T)	573.56
20	Magnet Ampere Turn(A.T)	-1218.1

On lead angle 30 degree the torque produced by motor is shown in fig.15

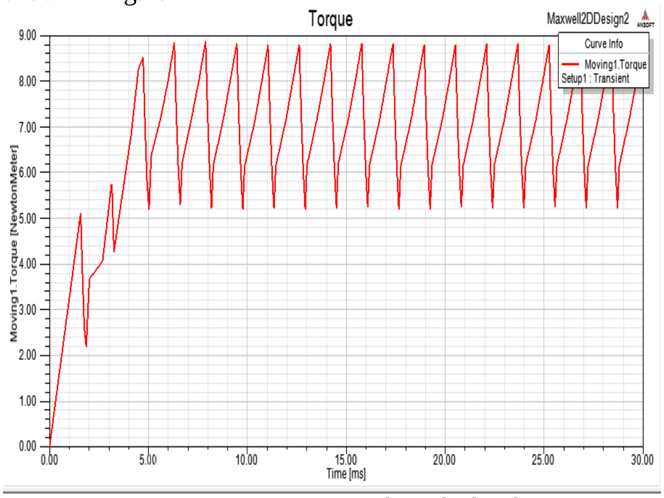

Fig.15. Motor Torque at 30 degree lead angle

VI. CONCLUSION

This paper represent the basic design idea of Permanent Brushless DC Motor. First of all basics of magnetic circuit is explain and then required basic equation used in electromagnetic field is describes. In this paper Permanent BLDC motor used in solar vehicle of 1500W and 3000 rpm is design. This paper shows that motor gives considerably good efficiency at rated torque and at rated speed.Motor is design in RMxprt and the its electromagnetic field analysis is done on Maxwell 2D. After designing of motor, analysis is done by varying the lead angle of control circuit. It is seen that when the lead angle is increased from 0 degree to 30 degree efficiency of the Permanent BLDC Motor is increased. By increasing lead angle rated speed of motor is increased. Increase in efficiency is achieved at the cost of decrease in rated torque and increase in ripple in torque.

VII. REFERENCE

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