Scientific Journal of Impact Factor (SJIF): 4.72
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406
International Journal of Advance Engineering and Research Development
Volume 4, Issue 10, October -2017

Healthy BLDC Motor Simulation Using Finite Element Analysis

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Abstract:- *Brushless Direct Current motors are used primarily in industries and home appliances. It is necessary to develop new prognosis methods for BLDC motor so that breakdown time can be reduced to its minimum level. Finite Element Analysis is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations of BLDC motors by subdividing Motor components into smaller, simpler parts that are called finite element. In this paper, the components of healthy BLDC motor are modelled for detailed analysis using ANSOFT RMXPRT 2D FE model and performance of its components is analysed.*

Keywords: *BLDC Motor, RmXprt,FEA, FEM and Simulation*

1. INTRODUCTION

In order to enhance the performance BLDC motor and its components, it is necessary to identify the diagnosis techniques to detect the faults at early stages to avoid any breakdown of faulty component and other components [1]. To develop diagnosis techniques, it is essential to model each component of the motor and develop techniques to simulate machine components and identify the characteristics of faults in motor components. This paper presents the Brushless DC simulation and modelling techniques with options to configure various parameters to generate faults such as rotor eccentricity faults by changes in the air gap.

2. DESIGN PARAMETERS OF BLDC MOTOR

The design of BLDC motor requires selection of number of parameters and configuration of specific values of each of the parameters[1]. The number of poles of varies from 6 poles to 18 poles. The next parameter is reference speed of the motor that is configured at 1500 rpm. The design of stator includes deciding of number of slots configured as 18. The power of motor is configured as 2KW. The air gap between rotor magnet and stator is kept at 0.75mm. The motor is designed using Finite-element (FE) simulations using ANSOFT® RMxprt2D FE model.The six-pole BLDC motor is used to design the following motor characteristics:

- Stator material and dimensions
- Rotor material and dimensions
- Number of stator slots
- Winding arrangement
- Number of poles
- Air-gap length
- Type of inverter connected to the stator.

With no current flowing in the windings, the magnetic fields are solved by ANSOFT® MAXWELL 2D for a specific rotor position. The geometry of surface mounted permanent Magnet BLDC motor is shown in Figure 1:

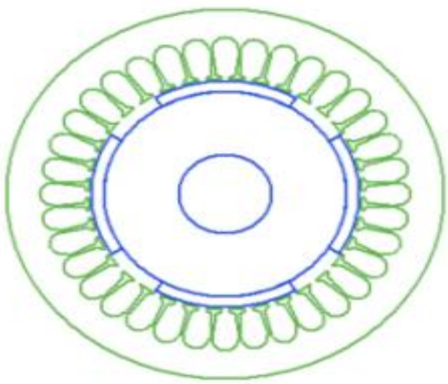


Figure 1: Stator Design

The permanent magnets are placed onto the rotor. Multi-phase winding is wound in the stator slots which creates rotating magnetic field in the air gap of motor. Magnetic flux of PMs is crossed through the air gap and travels into the stator core and then returns back to rotor [2].

3. APPROACH OF BLDC MOTOR DESIGN

For designing the BLDC Motor five step approach is followed with designing of Maxwell Rampart design with configuration of parameters of rotor, stator, windings and machine [3, 4]. As the next step, Maxwell 2D parametric design is created with defined project variables as Magnetic flux density and Magneto motive force. As the final step, reviewed the solution data as look up table and generated various data curves.

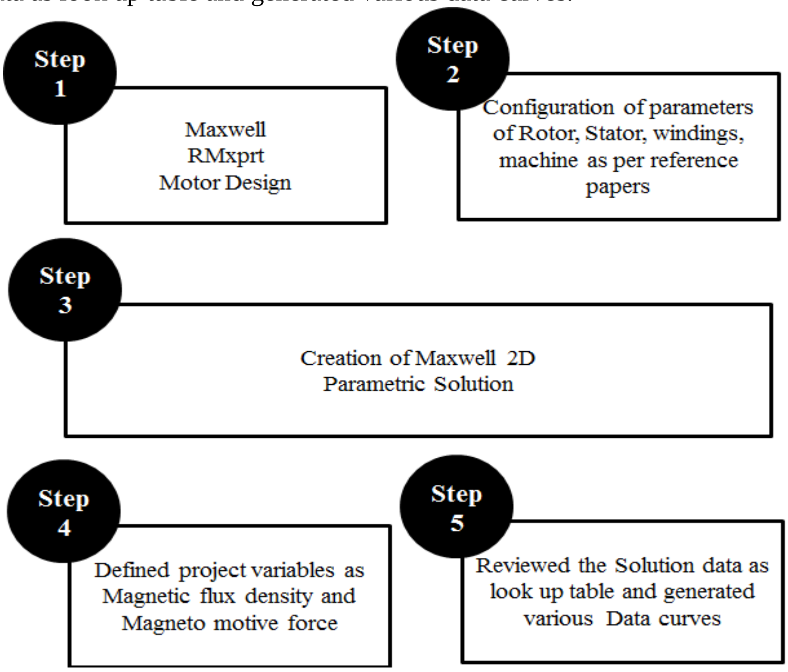


Figure 2: Steps to Simulate Healthy Motor

4. Design Parameters of BLDC Motor

The BLDC motor is designed using basic template design of motor in RMxprt ofAnsys Maxwell using configuration of various parameters as listed in the table below:

4A: Motor Specifications

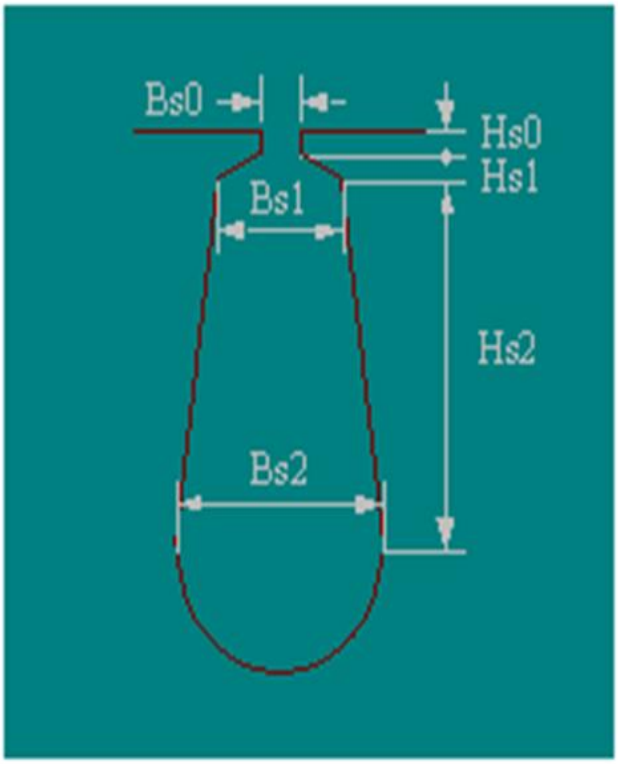
BLDC motor is designed with following specifications using :

Name	Value	Unit	Evaluated Value	Description
Machine Type	Brushless Permanent-Magnet DC Motor			
Number of Poles	4	No.	NA	Number of poles of the machine
Rotor Position	Inner Rotor		NA	Inner rotor or outer rotor
Frictional Loss	12	W	12W	The frictional loss measured at the reference speed
Windage Loss	0	W	0W	The windage loss measured at the reference speed
Reference Speed	1500	Rpm	NA	The reference speed at which the frictional and windage losses are measured
Control Type	DC	NA	NA	Control Type: DC, CCC (chopped current control)
Circuit Type	Y3		NA	Drive circuit type

4B: Stator Specifications

Name	Value	Unit	Evaluated Value	Description
Outer Diameter	120	Mm	120mm	Outer diameter of the stator core
Inner Diameter	75	Mm	75mm	Inner diameter of the stator core
Length	65	Mm	65mm	Length of the stator core
Stacking Factor	0.95	NA	NA	Stacking factor of the stator core
Steel Type	steel_1008		NA	Steel type of the stator core
Number of Slots	24	NA	NA	Number of slots of the stator core
Slot Type	2			Slot type of the stator core
Skew Width	1		1	Skew width measured in slot number

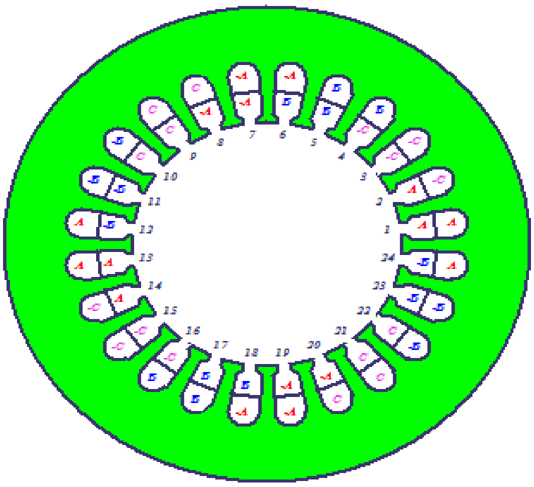
4C: Slots of Stator



4D : Specifications of Stator Slots

Name	Value	Unit	Evaluated Value	Description
Auto Design	FALSE			Auto design Hs2, Bs1 and Bs2
Parallel Tooth	FALSE			Design Bs1 and Bs2 based on Tooth Width
Hs0	0.5	Mm	0.5mm	Slot dimension: Hs0
Hs1	1	Mm	1mm	Slot dimension: Hs1
Hs2	8.2	Mm	8.2mm	Slot dimension: Hs2
Bs0	2.5	Mm	2.5mm	Slot dimension: Bs0
Bs1	5.6	mm	5.6mm	Slot dimension: Bs1
Bs2	7.6	mm	7.6mm	Slot dimension: Bs2

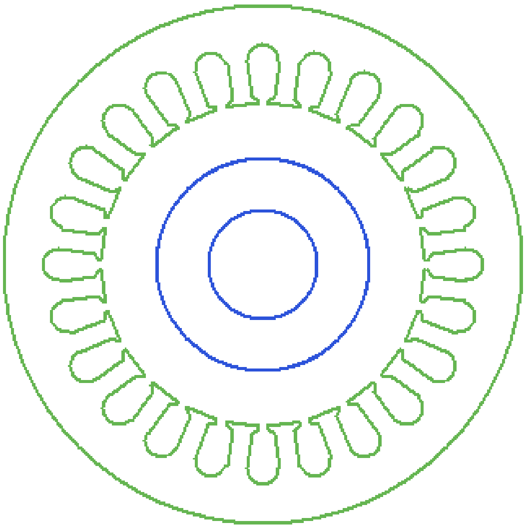
4E: Windings Specifications



4F :Configuration of parameters of Winding

Name	Value	Unit	Evaluated Value	Description
Winding Layers	2			Number of winding layers
Winding Type	Whole-Coiled			Stator winding type
Parallel Branches	1			Number of parallel branches of stator winding
Conductors per Slot	60		60	Number of conductors per slot, 0 for auto-design
Coil Pitch	5			Coil pitch measured in number of slots
Number of Strands	0		0	Number of strands (number of wires per conductor), 0 for auto-design
Wire Wrap	0	mm		Double-side wire wrap thickness, 0 for auto-pickup in the wire library
Wire Size	Diameter: 0mm			Wire size, 0 for auto-design

4F :Configuration of parameters of Rotor



Name	Value	Unit	Evaluated Value	Description
Outer Diameter	50	mm	50mm	Outer diameter of the rotor core
Inner Diameter	26	mm	26mm	Inner diameter of the rotor core
Length	65	mm	65mm	Length of the rotor core
Steel Type	steel_1010			Steel type of the rotor core
Stacking Factor	0.95			Stacking factor of the rotor core
Pole Type	2			Pole type of the rotor

4G :Configuration of parameters of Pole

Name	Value	Unit	Evaluated Value	Description
Embrace	0.7		0.7	Pole embrace
Offset	0	mm	0mm	Pole-arc center offset from the rotor center, 0 for a uniform air gap
Magnet Type	Alnico5			Magnet type
Magnet Thickness	3.7	um	3.7um	Maximum thickness of magnet

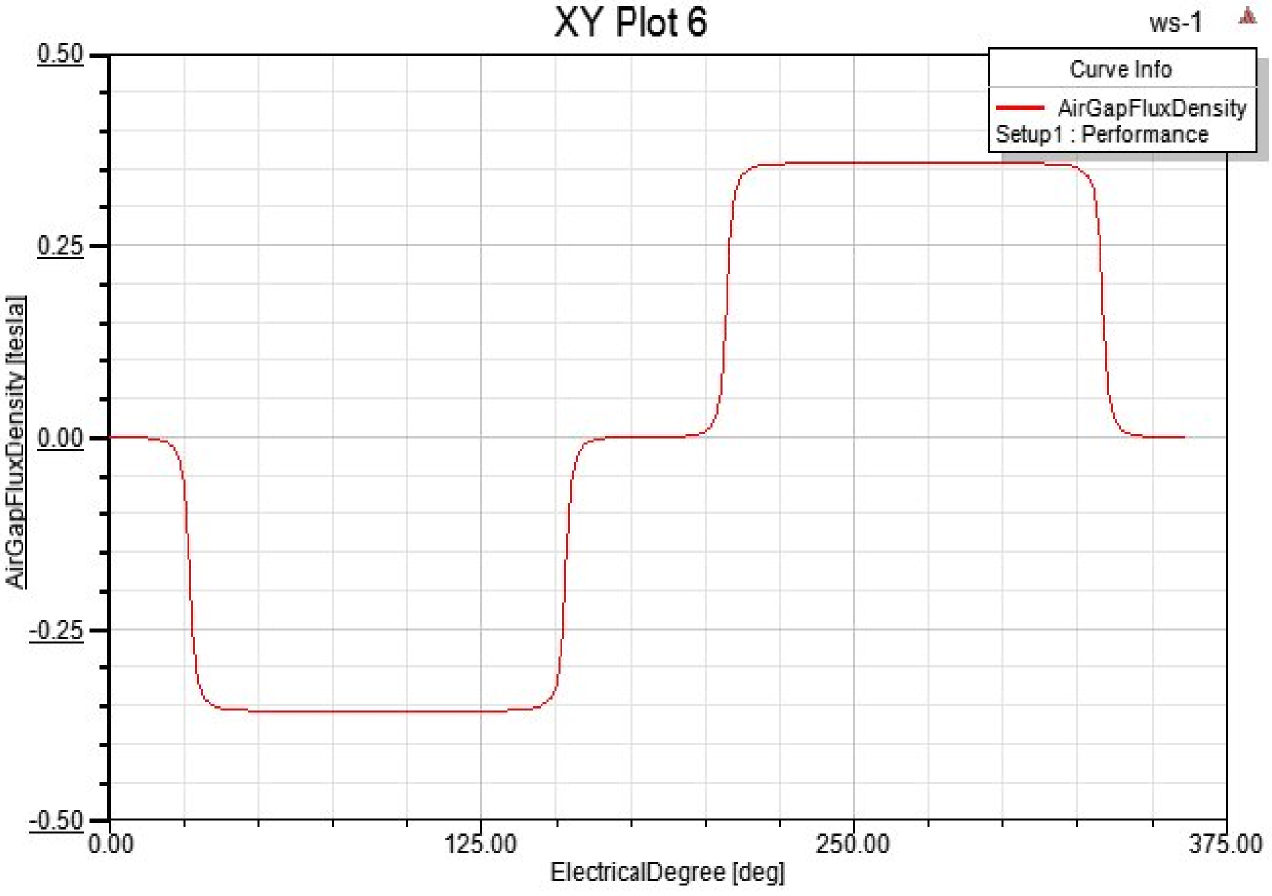
4 H: Addition of Project Variables and Sweeping Definitions

Name	Value	Unit	Evaluated Value
$flux	**10**	**Wb**	**10Wb**
$mmf	**10**	**At**	**10at**

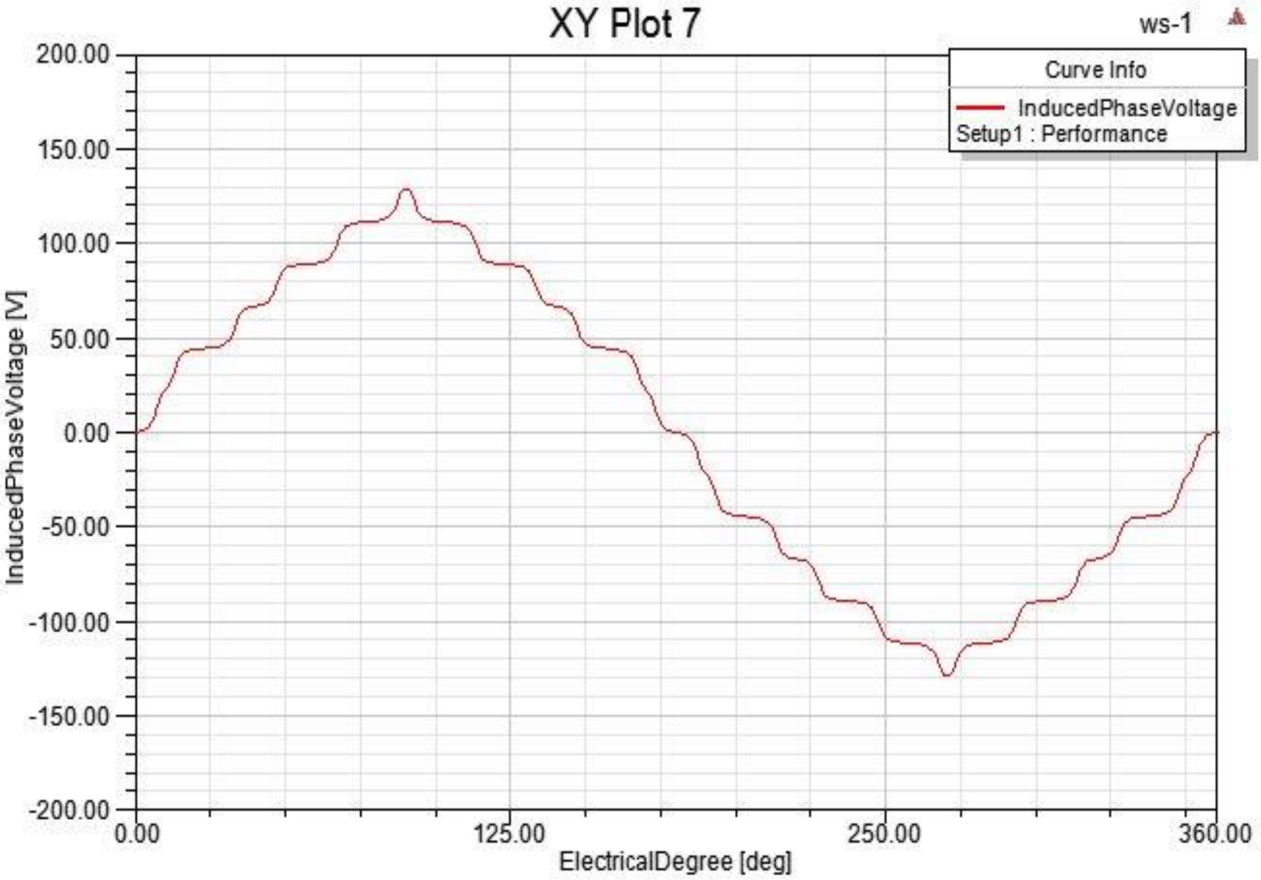
5. Outputs of BLDC Motor Simulation

After simulation of the motor as per aforementioned specification, the characteristics of the brushless motor were analysed on various aspects as depicted below to understand the behaviour of various components using Finite Element Analysis [10]. This analysis can be useful in early diagnosis of faults in the various components of faults.

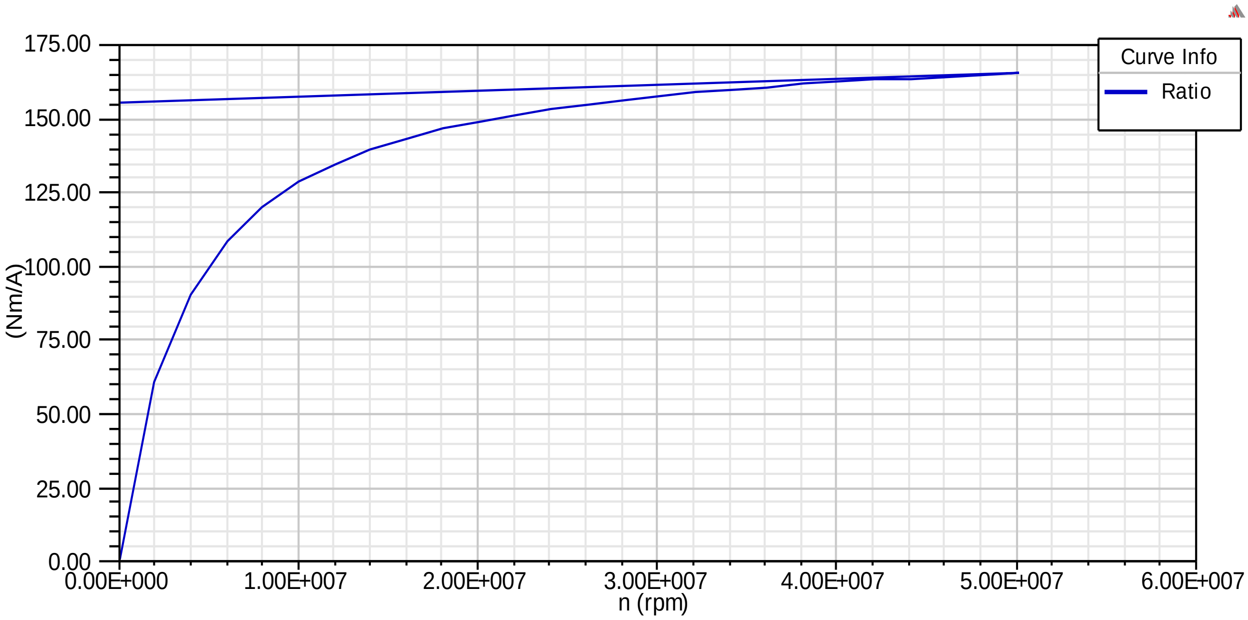
5A Results - Air gap flux density vs electrical degree(Le Roux results [1])



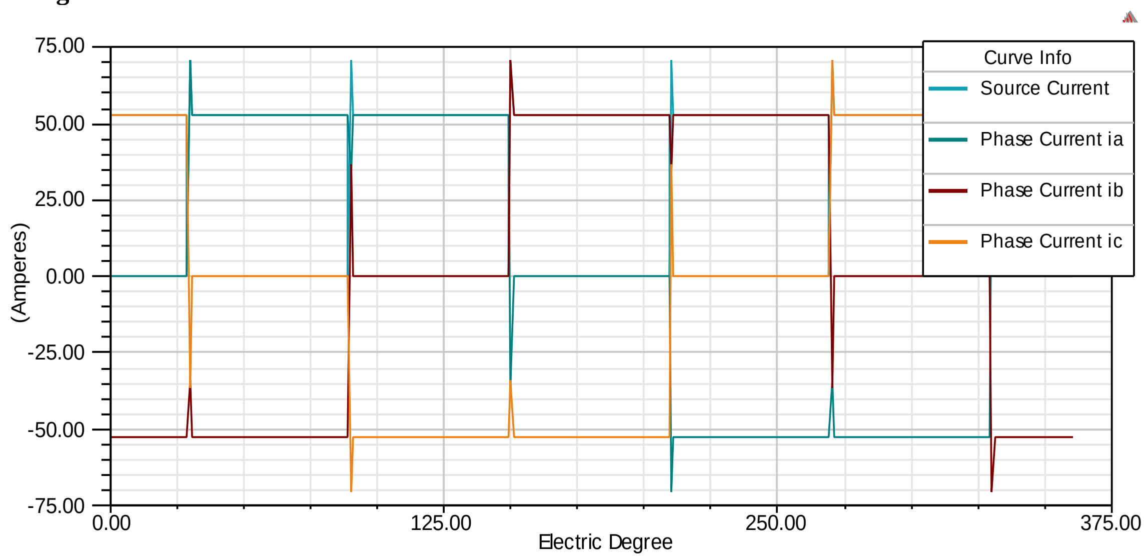
5B Induced phase voltage vs electrical degree [1]



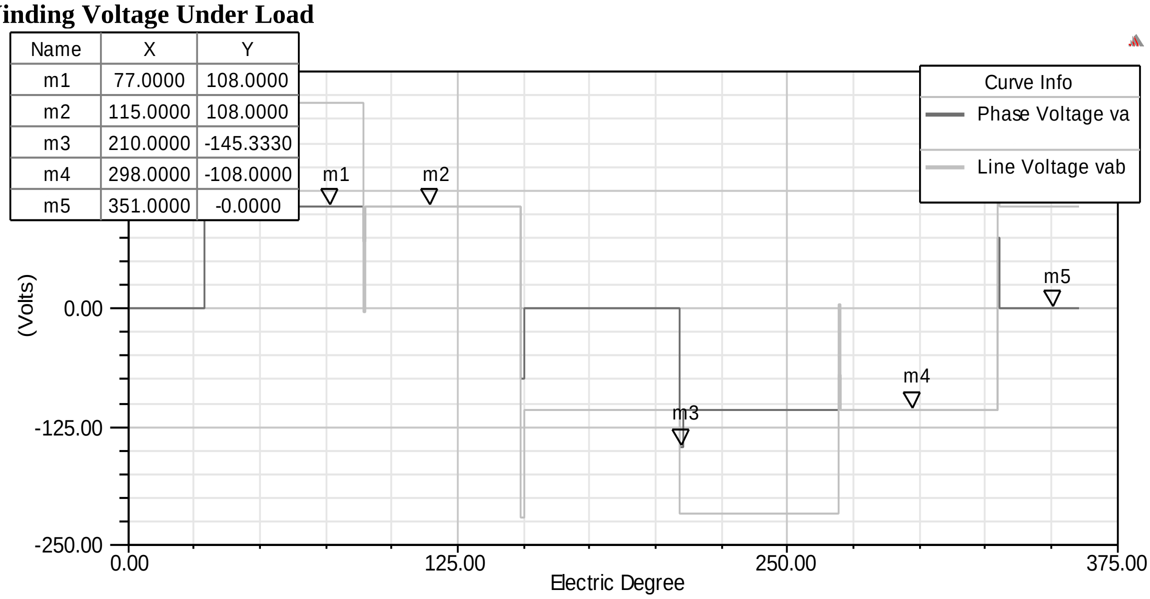
5C :Ratio of air-gap torque to DC current Vs Speed



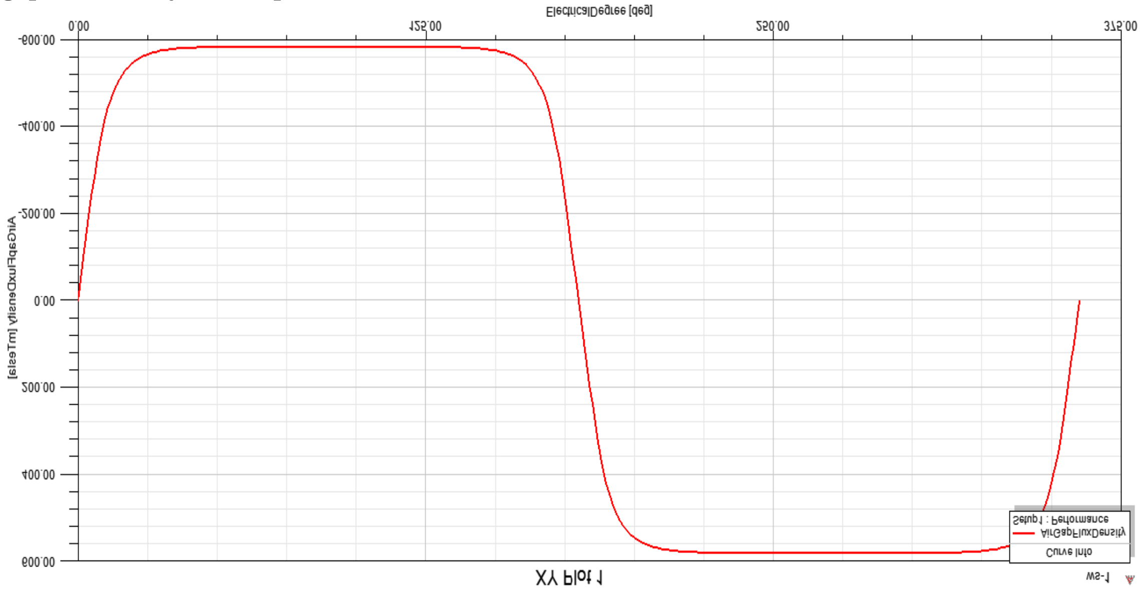
5D :Winding Currents Under Load



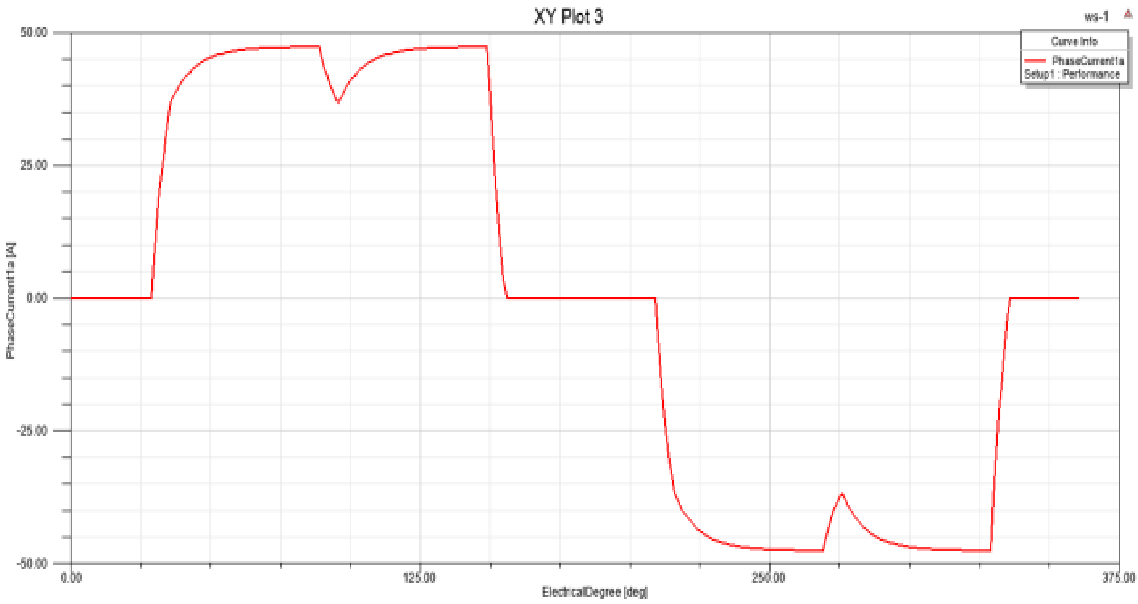
5E :Winding Voltage Under Load



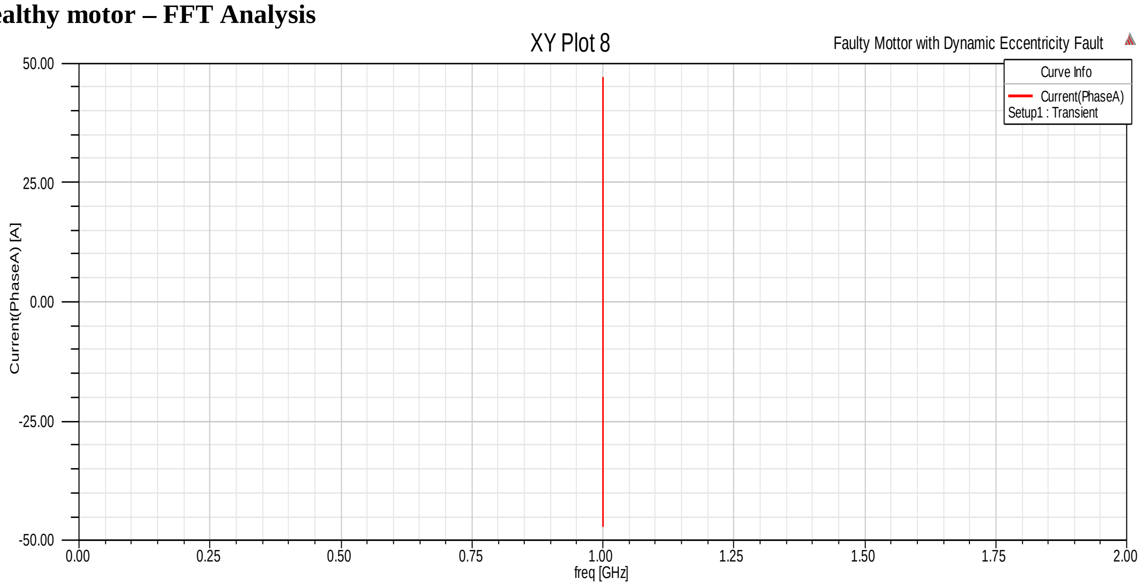
5F :Airgap flux density – RMXprt model



5G :Phase current- RMXPrt



5H :Healthy motor – FFT Analysis



5I :Solution Data : Steady State Parameters

Steady State Parameters	Values
Stator Winding Factor	0.933013
D-Axis Reactive Inductance Lad (H)	0.00389478
Q-Axis Reactive Inductance Laq (H)	0.00389478
D-Axis Inductance L1+Lad(H)	0.00770272
Q-Axis Inductance L1+Laq(H)	0.00770272
Armature Leakage Inductance L1 (H)	0.00380794
Zero-Sequence Inductance L0 (H)	0.0026125
Armature Phase Resistance R1 (ohm)	2.06651
Armature Phase Resistance at 20C (ohm)	1.69987
D-Axis Time Constant (s)	0.00188472
Q-Axis Time Constant (s)	0.00188472
Ideal Back-EMF Constant KE (Vs/rad)	2.25499e-005
Start Torque Constant KT (Nm/A)	0.00146409
Rated Torque Constant KT (Nm/A)	0.00146409

5J :Solution Data : Full Load Parameters

Full-Load Data	Values
Average Input Current (A)	52.1789
Root-Mean-Square Armature Current (A)	42.6361
Armature Thermal Load (A^2/mm^3)	15190.1
Specific Electric Loading (A/mm)	260.572
Armature Current Density (A/mm^2)	58.2952
Frictional and Windage Loss (W)	0
Iron-Core Loss (W)	0
Armature Copper Loss (W)	11269.7
Transistor Loss (W)	208.177
Diode Loss (W)	1.47323
Total Loss (W)	11479.4
Output Power (W)	0
Input Power (W)	11479.4
Efficiency (%)	0
Rated Speed (rpm)	0
Rated Torque (N.m)	-1
Locked-Rotor Torque (N.m)	0
Locked-Rotor Current (A)	52.1789

5K :Solution Data : Full Load Data

FULL-LOAD DATA	
Average Input Current (A)	52.1789
Root-Mean-Square Armature Current (A)	42.6361
Armature Thermal Load (A^2/mm^3)	15190.1
Specific Electric Loading (A/mm)	260.572
Armature Current Density (A/mm^2)	58.2952
Frictional and Windage Loss (W)	0
Iron-Core Loss (W)	0
Armature Copper Loss (W)	11269.7
Transistor Loss (W)	208.177
Diode Loss (W)	1.47323
Total Loss (W)	11479.4
Output Power (W)	0
Input Power (W)	11479.4
Efficiency (%)	0
Rated Speed (rpm)	0
Rated Torque (N.m)	-1
Locked-Rotor Torque (N.m)	0
Locked-Rotor Current (A)	52.1789

5L: Solution Data :No-Load Magnetic Data

No-Load Magnetic Data	Values
Stator-Teeth Flux Density (Tesla)	2.87566e-005
Stator-Yoke Flux Density (Tesla)	2.47886e-005
Rotor-Yoke Flux Density (Tesla)	2.12142e-005
Air-Gap Flux Density (Tesla)	8.94566e-006
Magnet Flux Density (Tesla)	1.95495e-005
Stator-Teeth By-Pass Factor	0.00127308
Stator-Yoke By-Pass Factor	4.56386e-005
Rotor-Yoke By-Pass Factor	8.01198e-005
Stator-Teeth Ampere Turns (A.T)	0.000199233
Stator-Yoke Ampere Turns (A.T)	0.000551552
Rotor-Yoke Ampere Turns (A.T)	0.000293868
Air-Gap Ampere Turns (A.T)	0.110046
Magnet Ampere Turns (A.T)	-0.178404
Armature Reactive Ampere Turns at Start Operation (A.T)	3559.14
Leakage-Flux Factor	1
Circuit Length of Stator Yoke	0.779088
Circuit Length of Rotor Yoke	0.779088
No-Load Speed (rpm)	5.21245e+007
Cogging Torque (N.m)	5.28041e-021

6. Maxwell 2D Design of Healthy BLDC Motor

Creation of analytical design of the motor model is done in RMxprt and it is analyzed analytically[7,8].
The FEA Analysis is done in MAXWELL 2D
Flux density, Radial Air gap flux, Torque plots from the FEA model:

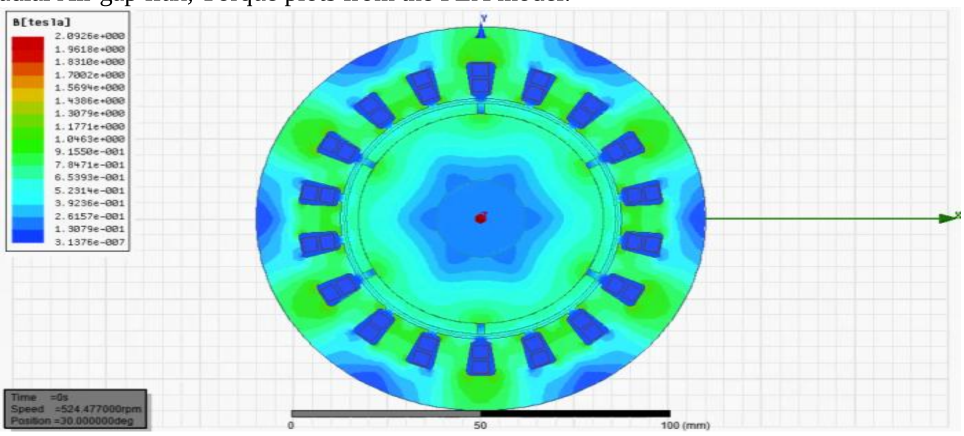
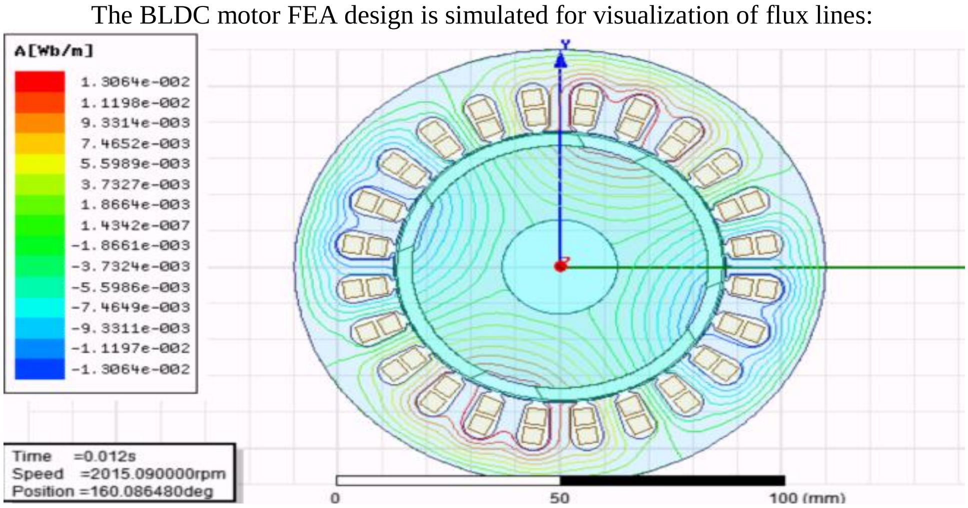
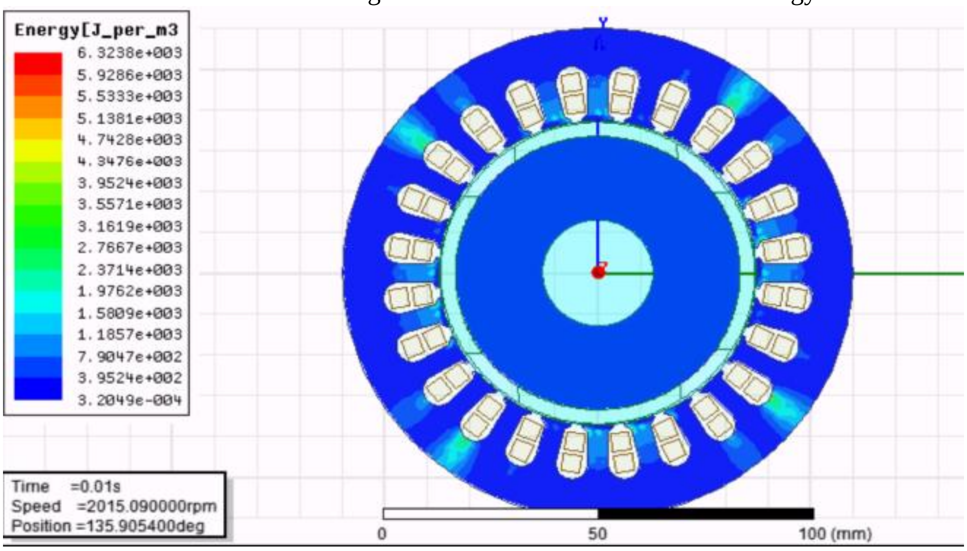


Figure 3: Simulation Model of BLDC Motor

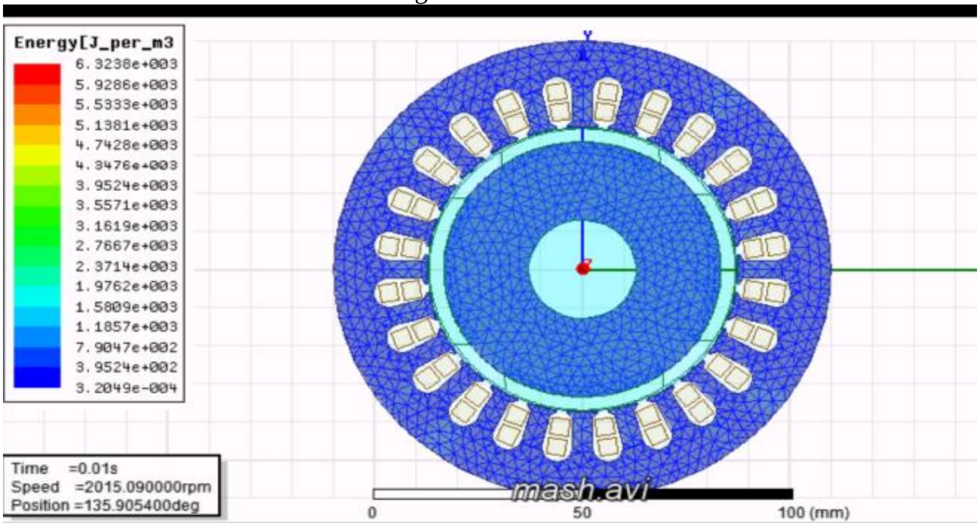
The BLDC motor FEA design is simulated for visualization of flux lines:



The BLDC motor FEA design is simulated for visualization of energy flows:



The BLDC motor FEA design is simulated for visualization of mash:



7. Conclusion and Future Scope of Work

In this paper the 2D design of Brushless DC motor is simulated with analysis of key parameters of the each of the motor components with the data curves on the basis changing patterns[12].The flux density of the motor is analysed, which is closely linked to the air gap and magnetic flux of the in between stator permanent magnet and motor. After understanding of the analysis as the next step various faults will be created, diagnosed using MCSA techniques[14].

8. References

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