Design and Control of E-Machine PMSM

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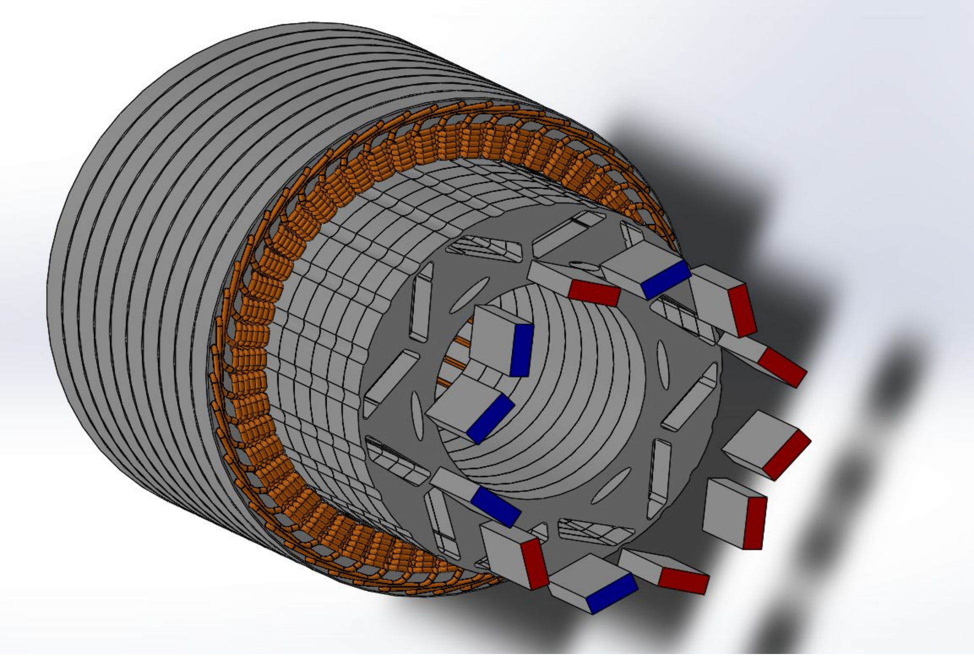
3D Design of the E-Machine



CONTENT:

a. Vehicle parameters.
b. Drive cycle calculations.
c. Torque and speed calculation..
d. Analytic calculation of machine design.
e. FEA Simulation results and detailed inference.
f. Performance Comparison.
g. Space for innovation and improvement.

INTRODUCTION:

This research project aims to optimize PMSM motors in Mahindra trio zor Cargo EVs to significantly reduce heat formation, enhancing their efficiency for urban use and last-mile deliveries.

The India electric three-wheeler market size reached US$ 890 Million in 2022. Looking forward, IMARC Group expects the market to reach US$ 2,156 Million by 2028, exhibiting a growth rate (CAGR) of 15.8% during 2023-2028

By modifying rotor design parameters, introducing an internal oil cooling system, and employing advanced modeling techniques, the goal is to achieve over 90% improvement in heat management.

This optimization will lower operational costs, benefiting small business owners by ensuring smoother and more cost-effective operations in congested areas, ultimately reducing the vehicles' operating current costs.

VEHICLE PARAMETERS:

We chose the Mahindra Treo Zor to design a machine that can help small businesses and improve efficiency aim to lower operational costs, benefiting small business owners by ensuring smoother and more cost-effective operations in congested areas, ultimately reducing the vehicles' operating current costs.

Treo Zor Specifications:

Dimension Length*Weight*Height - 3100*1460*1762

Weight with Load: 1000 kg

Top Speed: 50Km/h

Peak Power: 8kW

Peak Torque: 42Nm

DRIVE CYCLE CALCULATIONS:

CALCULATION OF POWER AND TORQUE FOR MAHINDRA ZOR DV 3W

Dimensions - (3100*1460*1762)
GVW - 995 kg ~ 1000kg
Gradeability - 0-7 degree (0 degree is considered)
Air density - 1.2 kg/m^3 @27 degree celsius

Velocity - 0-20 km/hr in 2.3 sec (Uniform velocity is considered)
0.5s – 1.2075 m/s
1s – 2.4152 m/s
1.5s – 3.6230 m/s
2.0s – 4.830 m/s
2.3s – 5.556 m/s

Acceleration – (final velocity – initial velocity)/change in time
Max acceleration – 2.415 m/s^2 (At high velocity acceleration is low and at low velocity acceleration is high. Hence acceleration considered 1.3m/s^2.)

TORQUE AND SPEED PLOT:

CONDITION-2(Considering transmission)

WHEEL RPM:

Omega = v/r = 5.556/0.276 [r-radius of wheel]

= 20.129 rad/sec

Now,

N_{wheel}=(omega*60)/(2*3.14) = 192.218 rpm @ 20km/hr (@50km/hr - 480 rpm)

WHEEL TORQUE:

Wheel torque = F_{total}*perpendicular distance(Radius of wheel)

= 1968.05*0.276 = 543.18 Nm

GEAR RATIO :

Gear ratio = (RPS/Top speed)*tyre circumference

= (4000/13.88*60)*(2*3.14*0.276) [@50km/hr the rpm will be 3000]

= 8.3 ~ 8

{FOR gear ratio 10:1

Nm = 10*192.218=1922.18

Tmotor = 543.18/10=54.3

power of motor = 10.86kW}

Now,

Speed of motor(N_m) = gear ratio * N_{wheel} = 4*480 = 1819 rpm ~ 1800 rpm

Torque of motor (T_m) = Peak power*60/(2*3.14*1920) = 8000*60/(2*3.14*1800) = 42.46 Nm

ANALYTICAL DATAS OF E-MACHINE DESIGN:

Number of Stator slots	54
Stator lamination outer diameter	195 mm
Stator lamination inner diameter	148mm
Lamination stack length	130mm
Lamination stacking factor (estimated)	0.95

Table:1 Parameters for Stator lamination stack

End winding axial overhanging	40 mm
Number of phases	3
Parallel paths	3
Number of turns	2
Phase resistance at 20°C	0.00580 ohm
Number of pole pairs	3

Table2: Parameters measured from motor

Rotor lamination outer diameter	146.6 mm
Rotor lamination inner diameter	85mm
Magnet dimension	33*19.91 * 7.5 mm

STATOR AND ROTOR DESIGN:

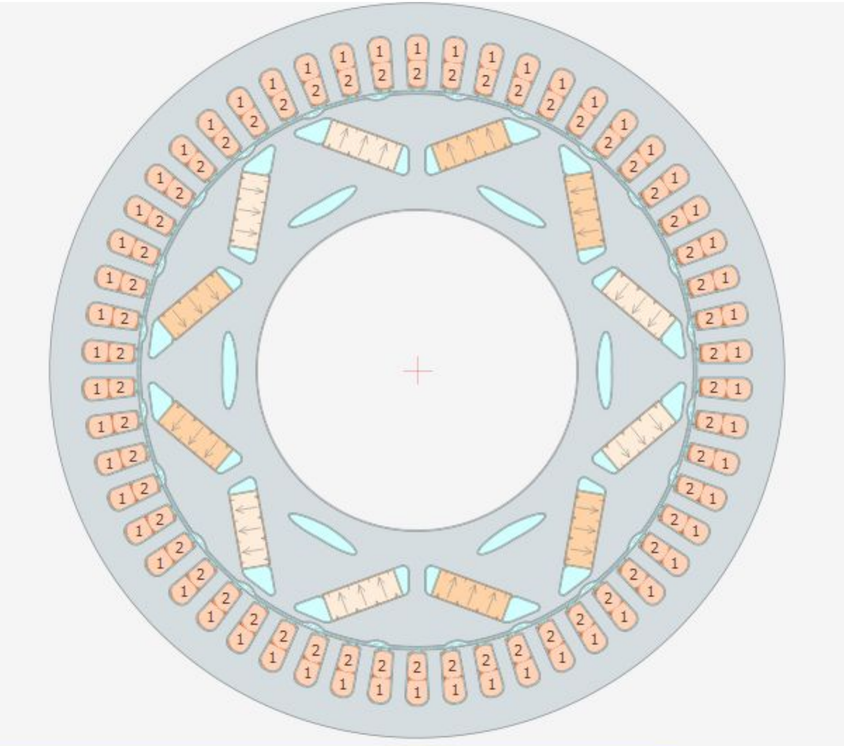


Fig 1: Stator and Rotor geometry

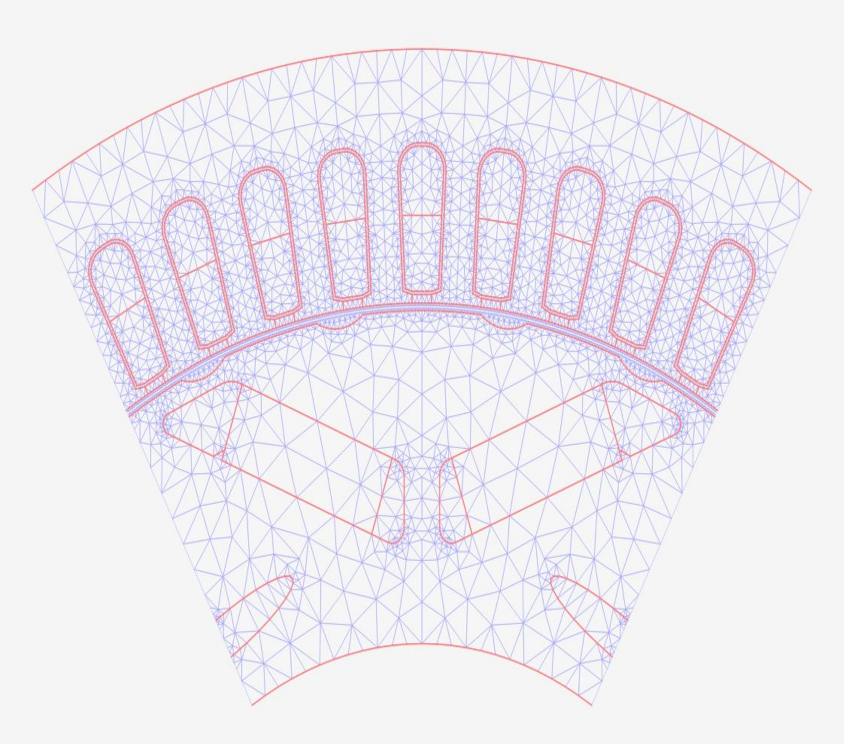


Fig 2: Meshing results

ROTOR MAGNET GEOMETRY AND ITS ARRANGEMENT:

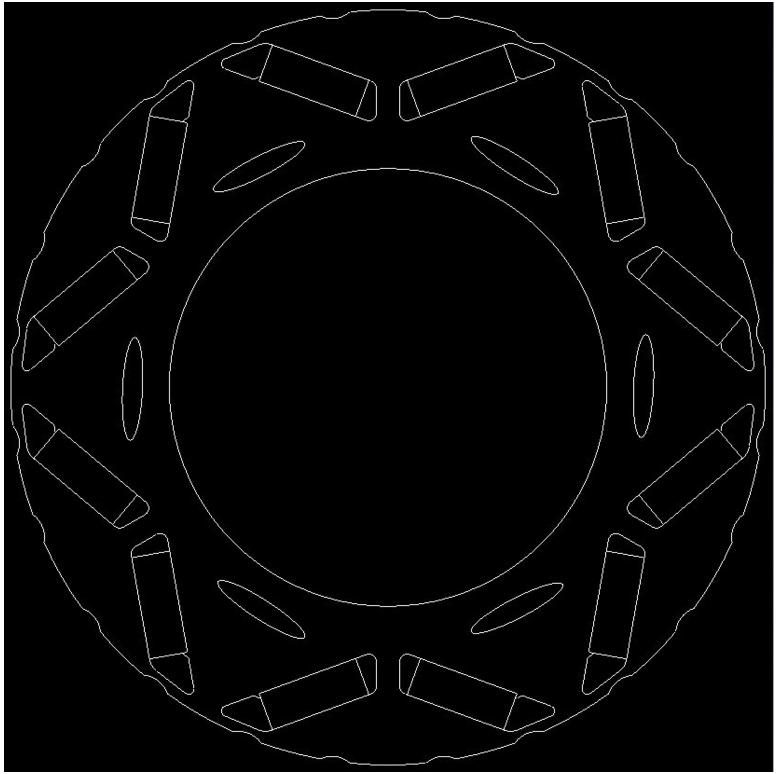


Fig 3: DXF file of Rotor geometry

Magnetic Flux Densities:

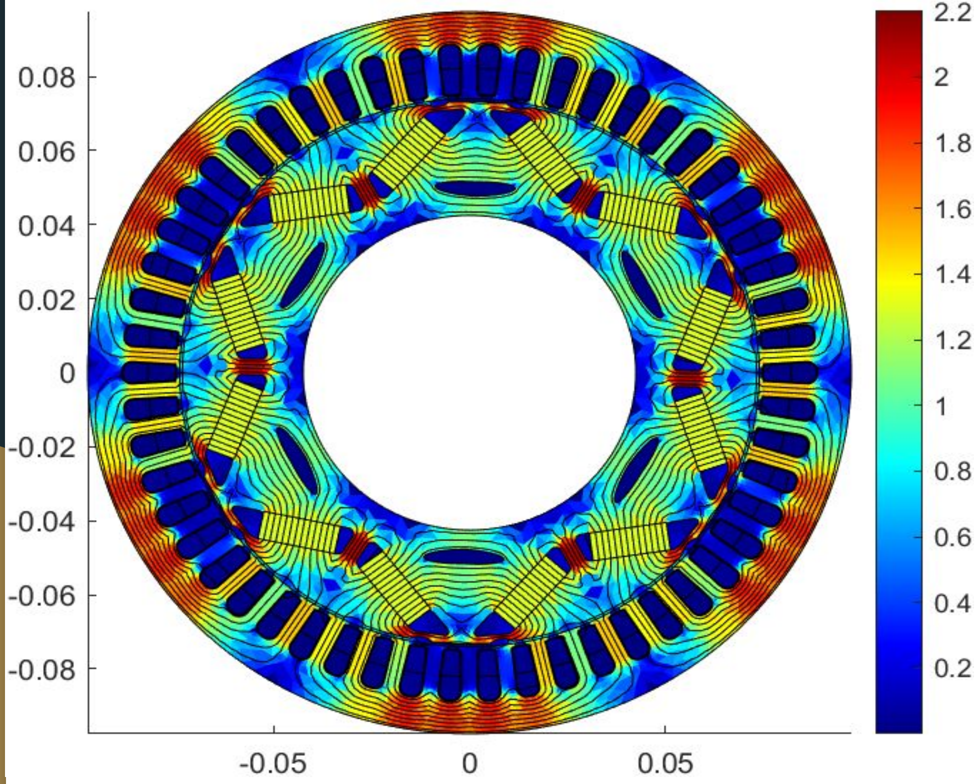


Fig 4:Magnetic Flux Density levels(a)

Average airgap flux density:	0.476659	T
Maximum airgap flux density:	0.846541	T
Peak of stator tooth average flux density:	1.48217	T
Peak of stator back iron average flux density:	1.84814	T
Peak of rotor back iron average flux density:	0.927533	T

Fig 5:Magnetic Flux Density levels(b)

Back EMF and Cogging Torque:

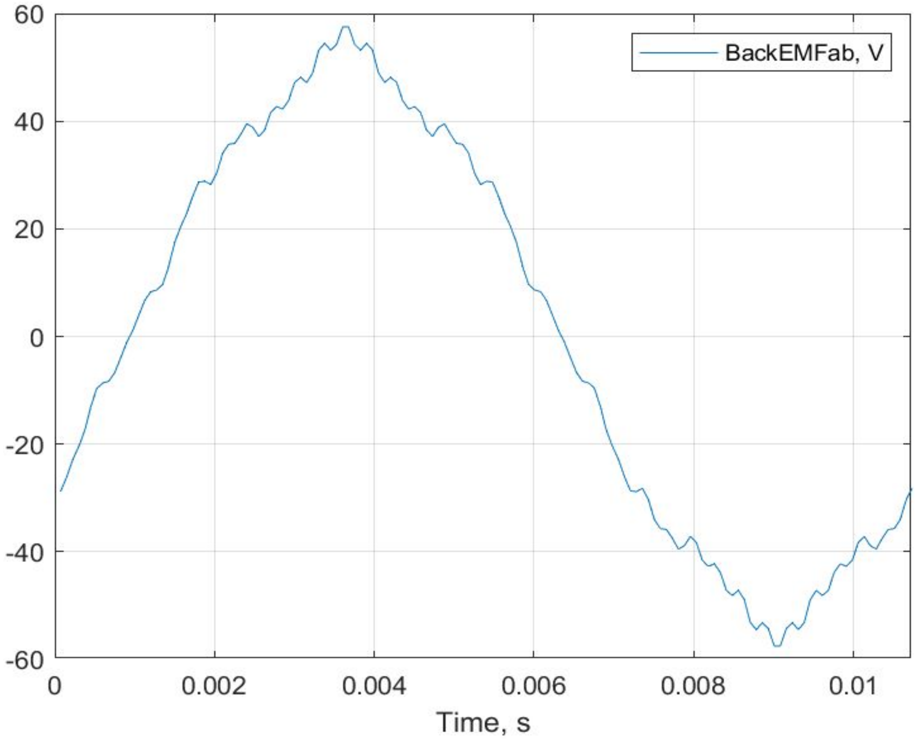


Fig 6: Back EMF analysis

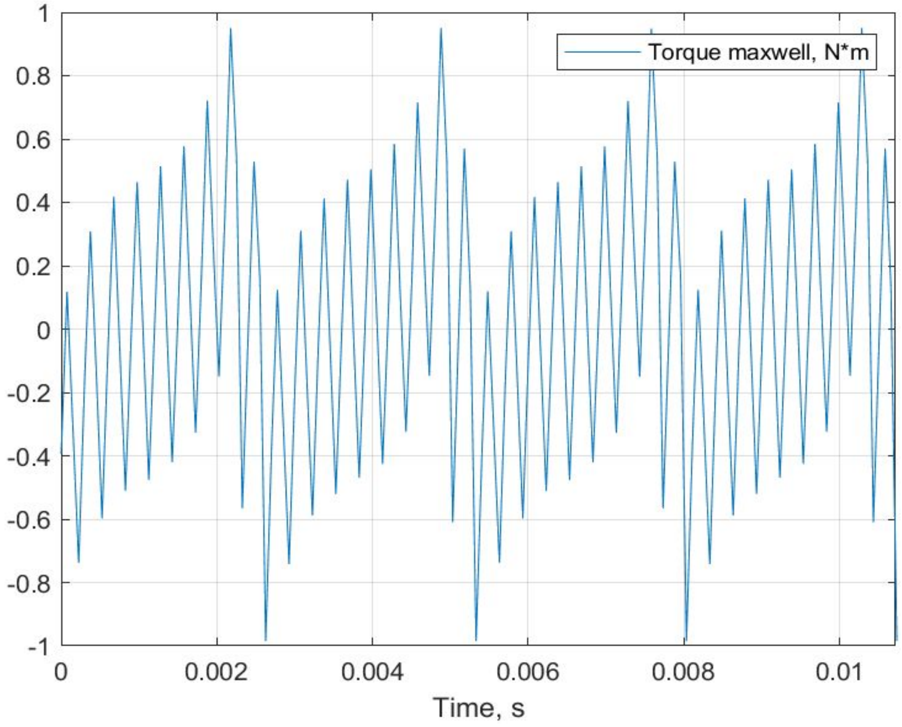


Fig 7: Cogging Torque analysis

FEA RESULTS:

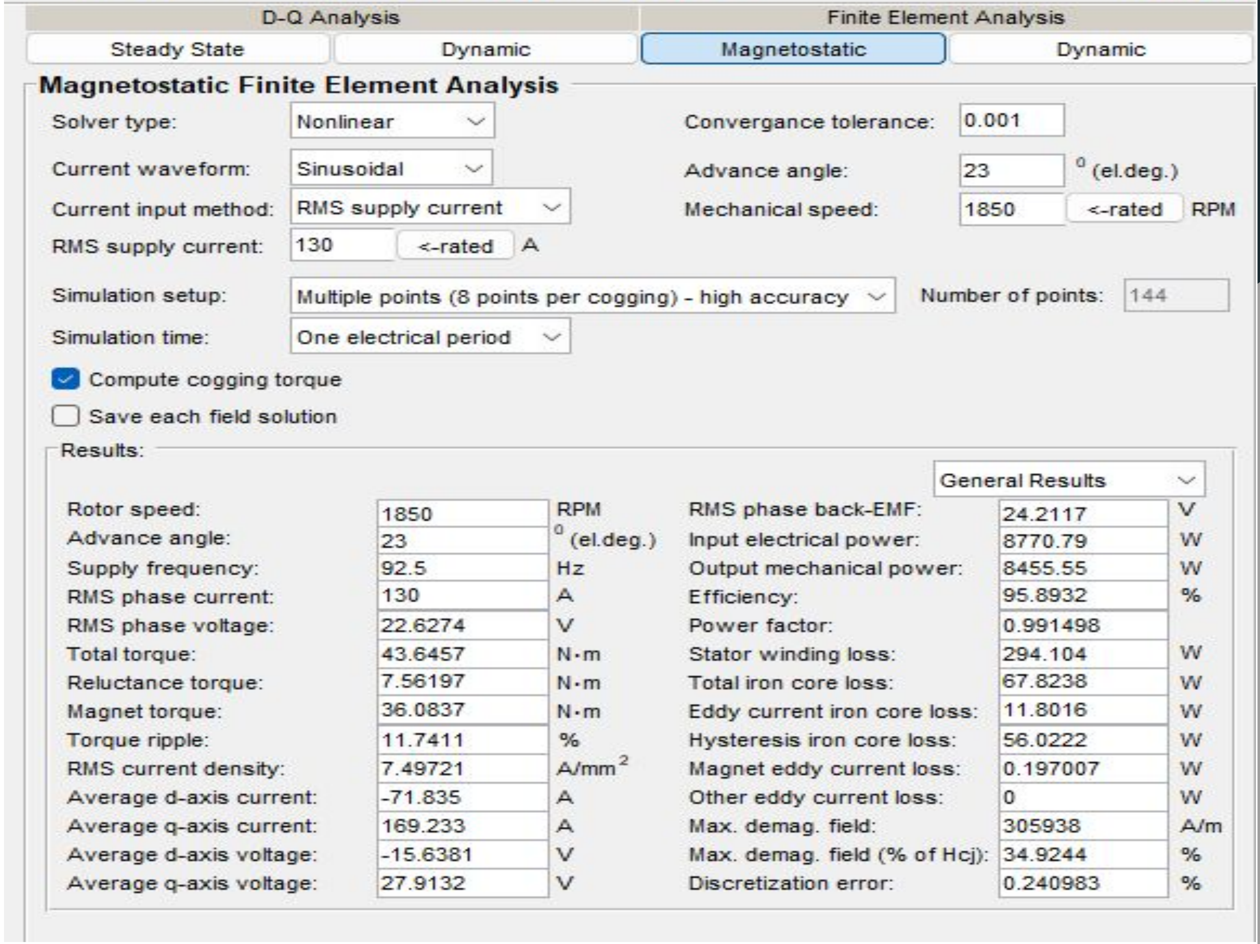


Fig 8: Finite Element Analysis data

PERFORMANCE ANALYSIS:

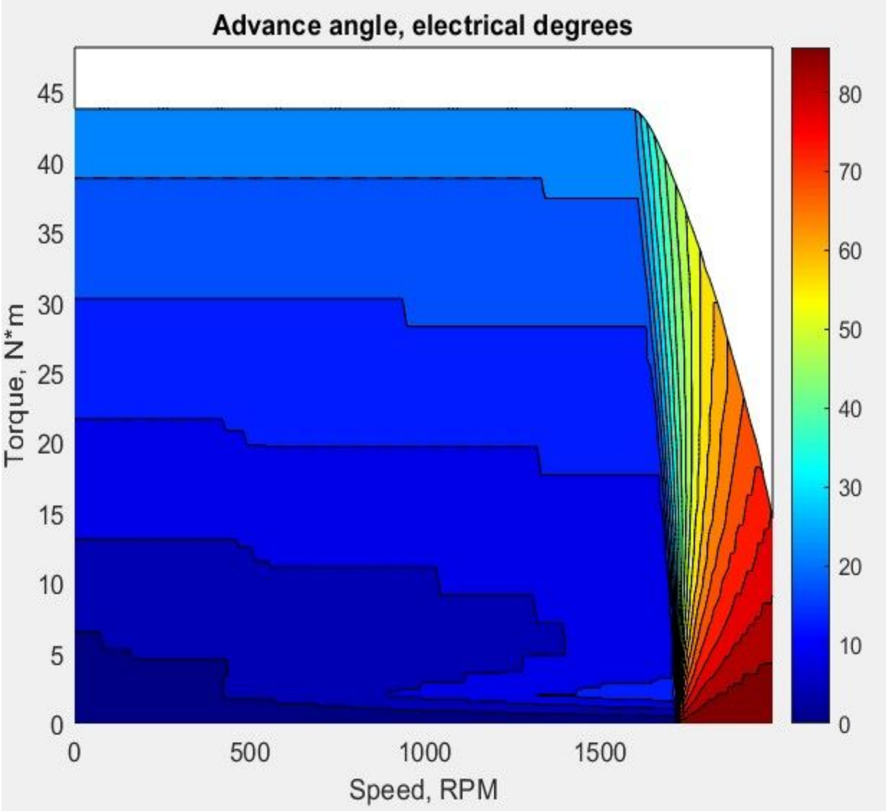


Fig 9-Analysis Chart: Advance Angle

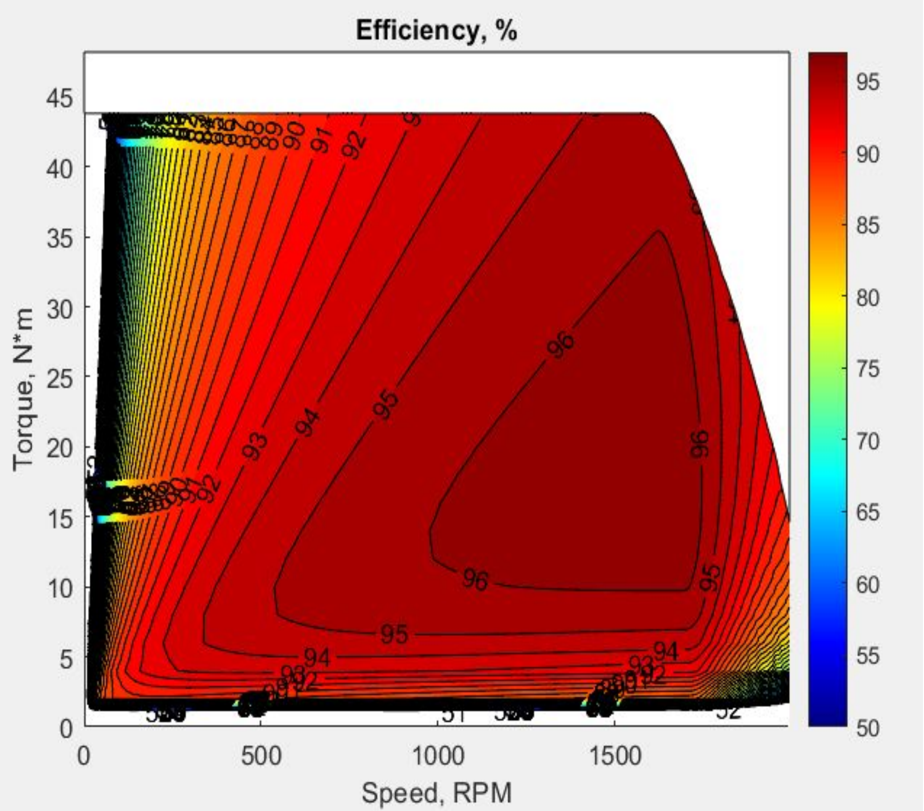


Fig 10-Analysis Chart: Efficiency

PERFORMANCE ANALYSIS:

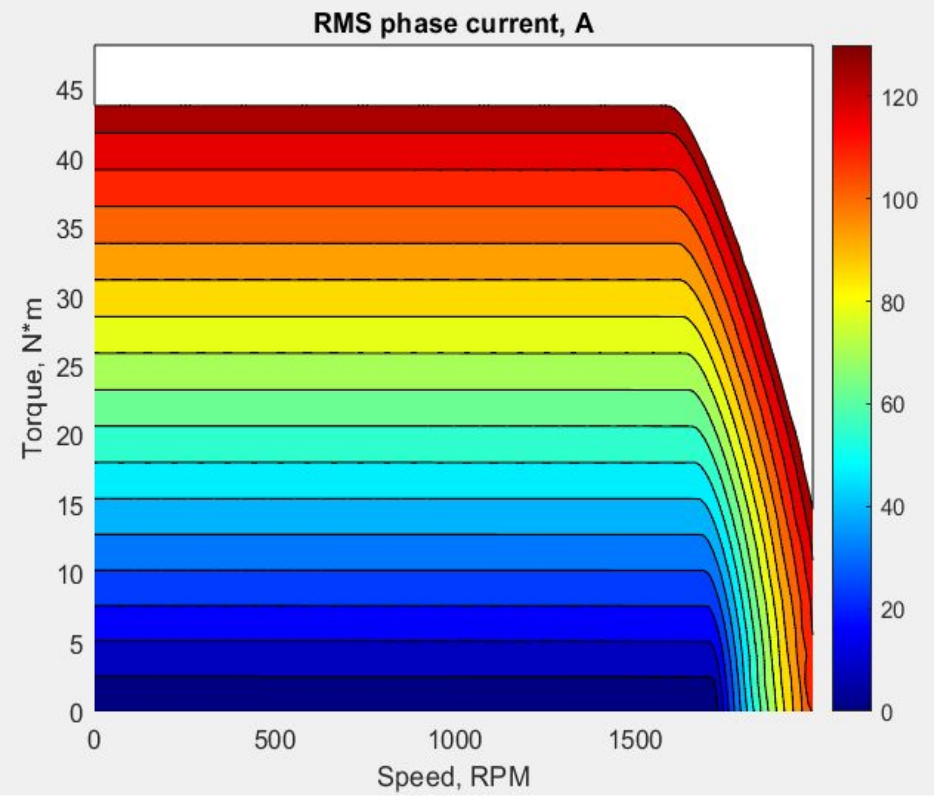


Fig 11-Analysis Chart: RMS Phase Current

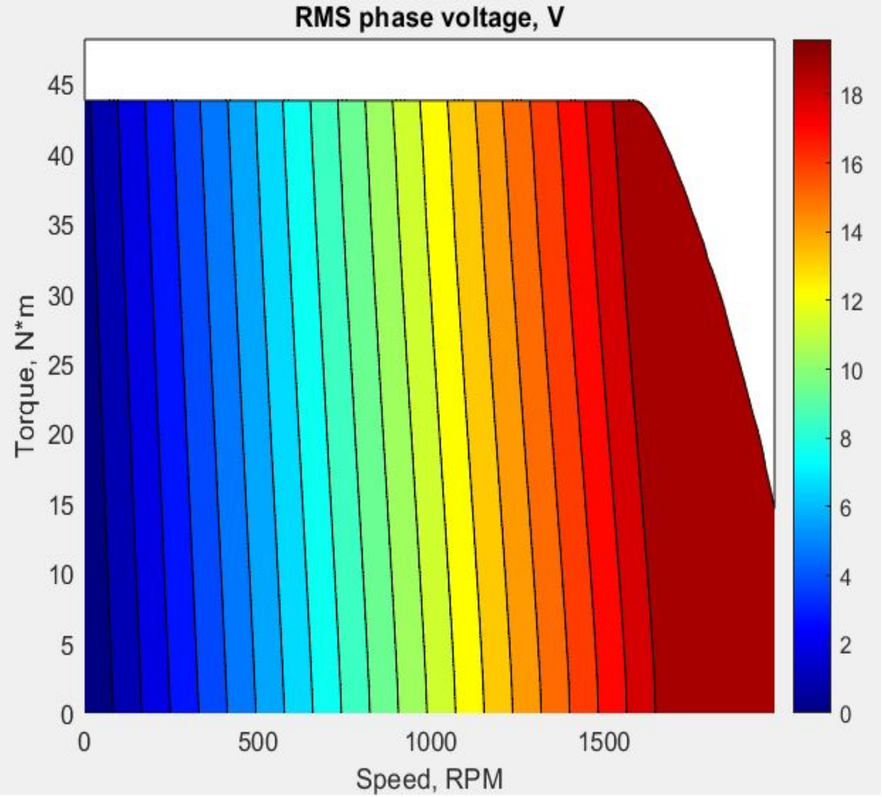
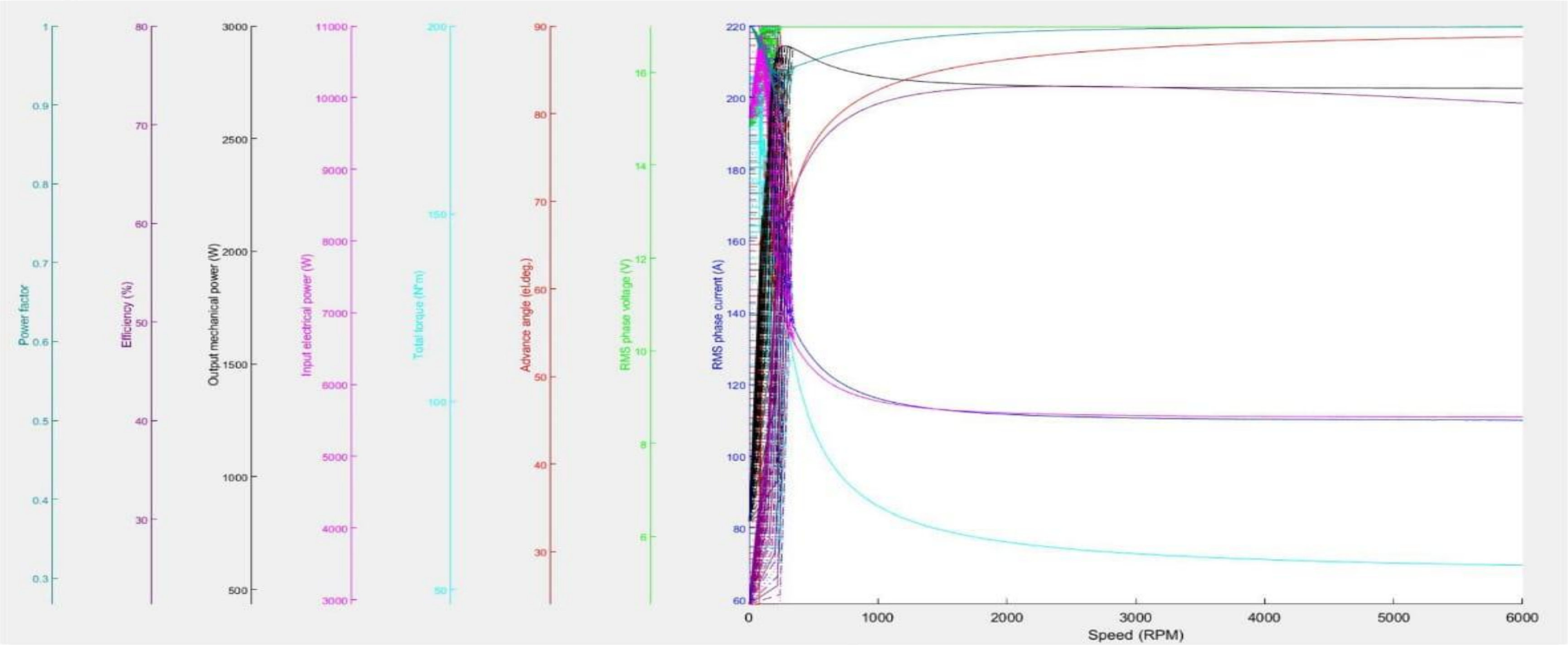


Fig 12-Analysis Chart: RMS Phase voltage

INITIAL MOTOR DESIGN RESULTS:

Design Result



PERFORMANCE ANALYSIS:

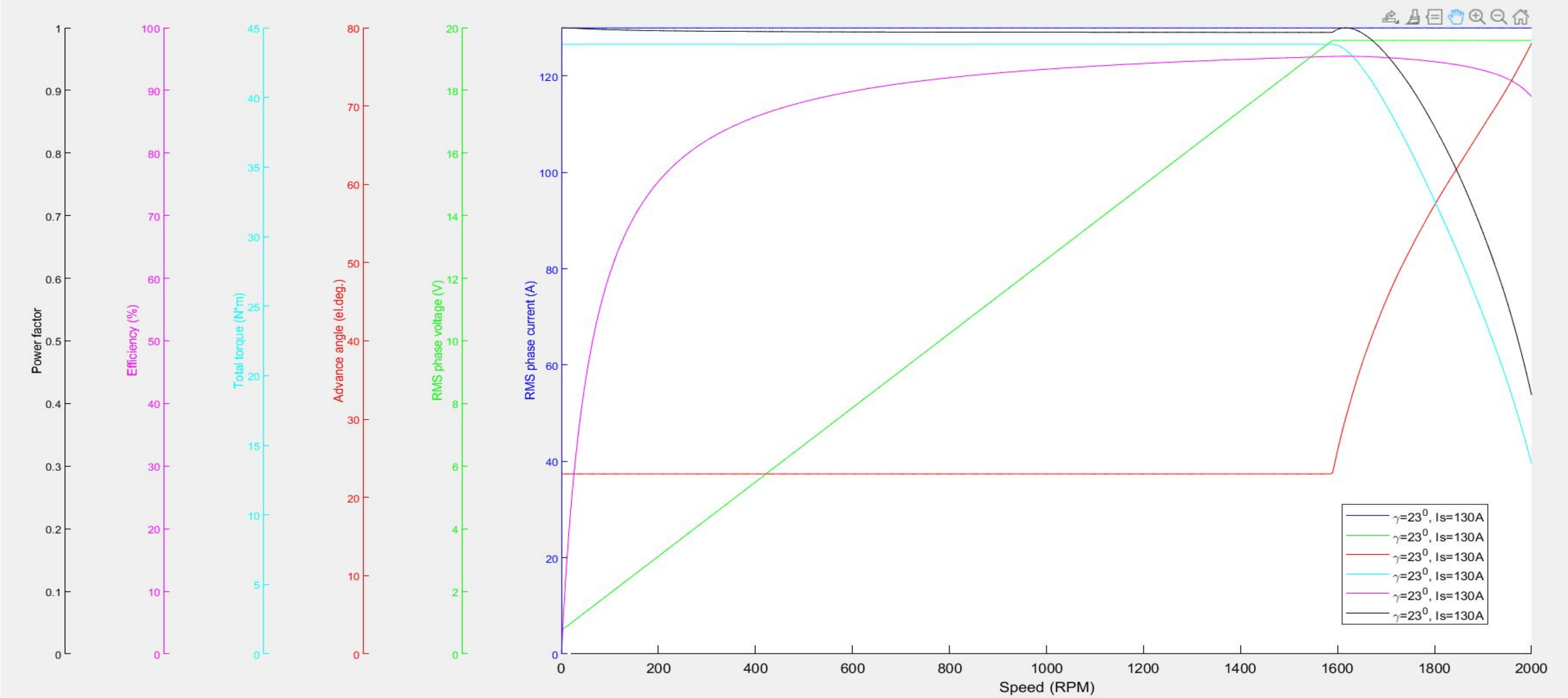


Fig 13: Analysis Graph on Power Factor, Efficiency, Total Torque, Advance angle, RMS Phase Voltage, RMS Phase current.

PERFORMANCE ANALYSIS:

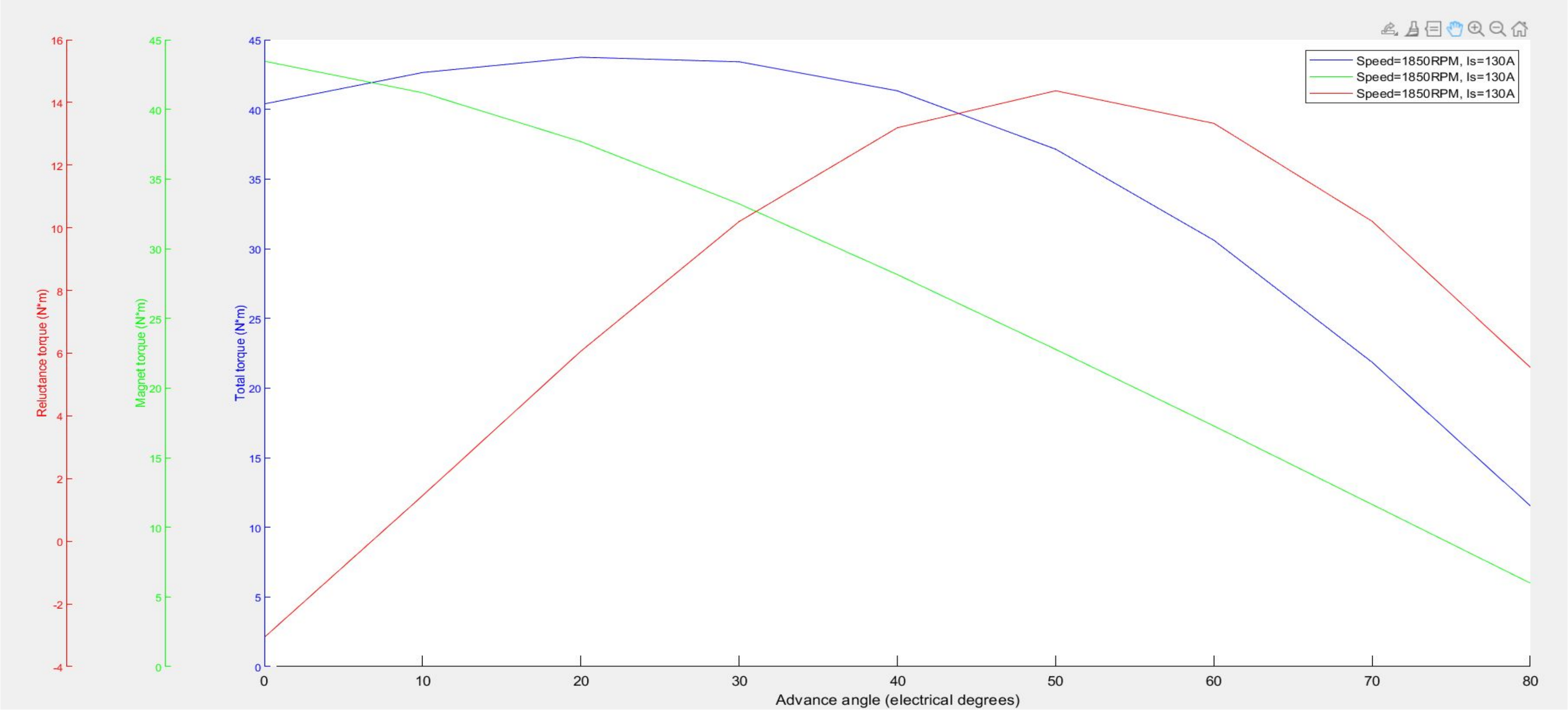


Fig 14: Analysis graph on Reluctance Torque, Magnetic Torque, Total Torque.

Reference paper: Thermal Analysis of Solid Rotor in PMSM Used for EV, https://ieeexplore.ieee.org/document/5289644

In solid rotor PMSM, the highest temperature locates at the rotor core, and temperature of core is close to that of permanent magnet. Permanent magnet even does not suffer from thermal demagnetization while motor running without fan, which reflects the excellent thermal performance of the prototype, and this kind of PMSM may be redesigned with a higher power level in some degree.

TABLE I. COMPARISON OF CALCULATED RESULTS WITH TEST DATA

position	Test value/℃	Calculated value/℃	error
A	83.8	82.613	-1.42%
B	86.8	84.658	-2.47%
C	85.7	84.147	-1.81%

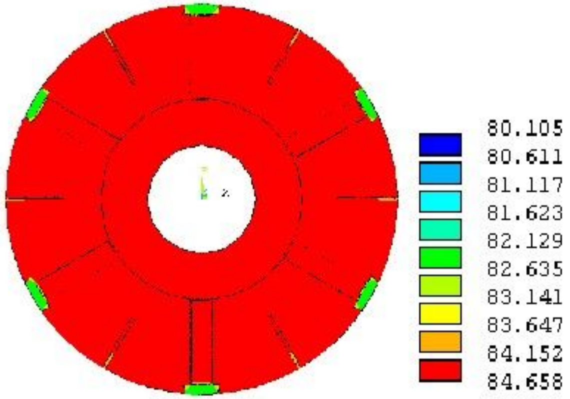


Figure 9. Temperature distribution in solving region (℃)

Innovation IN IMPROVEMENT OF OIL COOLING SYSTEM :

Heat generation in a Permanent Magnet Synchronous Motor (PMSM) rotor can have several effects on the magnets used within the motor, including demagnetization, changes in magnetic properties, reduced performance, and the potential for degradation. To address these issues, we propose the design of an internal oil cooling system.

The construction of this system is inspired by a double stator PMSM motor, in which we replace the internal stator with an oil cooling system. The primary objective of this system is to efficiently dissipate the heat generated in rotor during motor operation, thereby preventing adverse effects on the magnets and ensuring optimal performance and longevity.

Double stator PMSM:

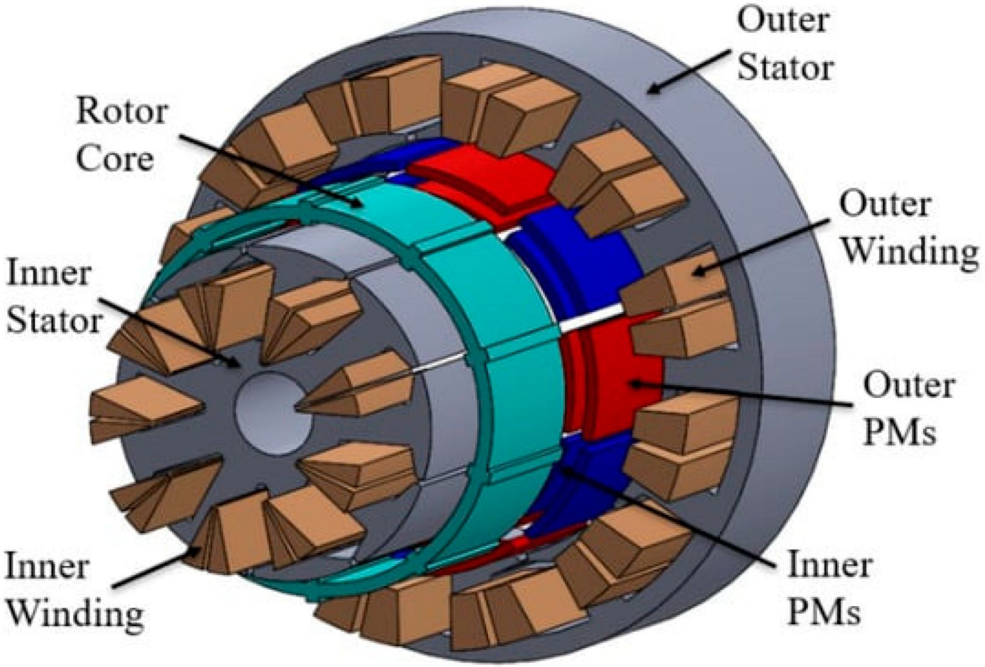


Figure 10: Double stator PMSM construction model for understanding

Proposed Model:

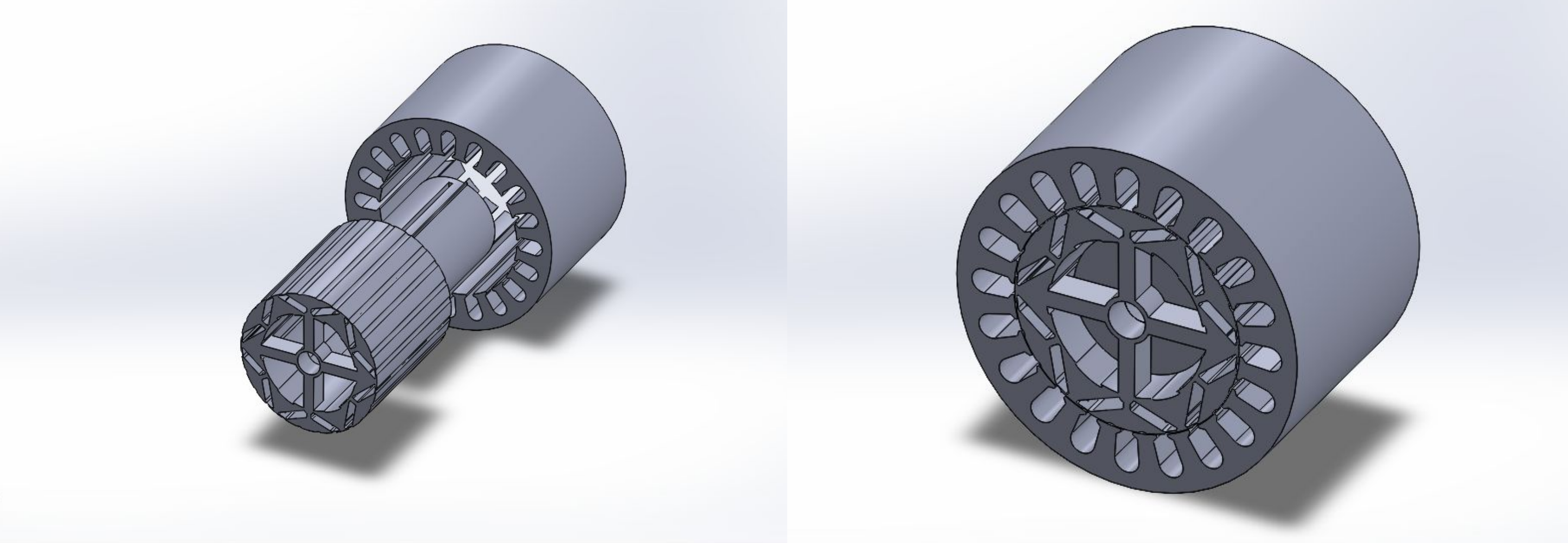


Figure 11: Isometric view of Internal oil cooling e-machine model.