

MIDDLE EAST TECHNICAL UNIVERSITY

Electrical and Electronics Engineering Department

EE568 Selected Topics on Electrical Machines

PROJECT 3

PM MOTOR COMPARISON ANALYSIS

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# Introduction

In this report surface-mount permanent magnet (SMPM) machines will be investigated. In the first section, magnetic loading of given SMPM machine will be analyzed analytically and the results are validated by FEA tool. In the second section, we design of the stator side of this machine and we will calculate electrical loading analytically and magnetic stress from tangential part of the magnetic field. In addition, the output power will be calculated for rotor speed of 1500 rpm. Third section, we will design a PMSM with rectangular slot-tooth with a 160mm outer diameter. Slot ratio and rotor diameter is estimated for maximum torque. In addition, electrical and magnetic loading will be calculated for the estimations. The results are compared with section 1 and 2 design by using FEA. After design, the magnet NdFeB is replaced by Ferrite magnets and machine with same parameters will be investigated. In addition, the machine will be optimized and compared with previous design.

# Magnetic Loading

In this section, we analyzed the PMSM with constant parameters in table 1.

Table 1 Parameter of the SMPM machine

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|  |  |

1. Magnetic equivalent circuit for one pole-pair includes the flux sources and reluctances which are belongs to magnets, airgap, stator and rotor material and leakage. The equivalent circuit is shown figure 1 and we can simplify the circuit as figure 2.

|  |  |
| --- | --- |
| Figure 1 The equivalent circuit for one pole-pair | Figure 2 The simplified circuit for one pole-pair |

The magnetic circuit can be solved in two ways. One of them is load-line method. The characteristic of the magnet and airgap are drawn in B-H coordinate system. The load line method is shown in figure 3.

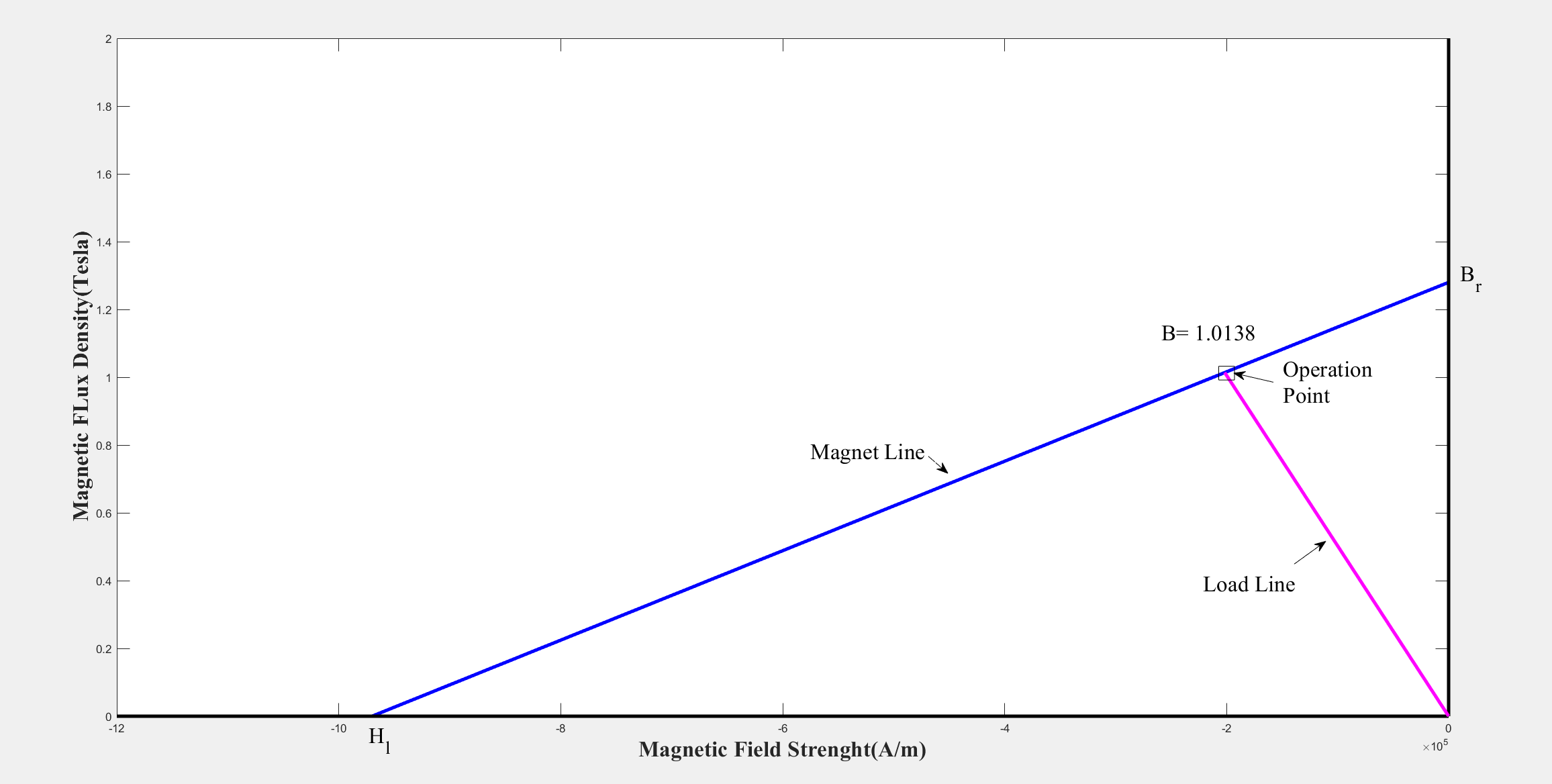


Figure 3 Load-line Method

Also, we can solve the problem with analytically. In figure 2 , we MMF is found with respect to magnet parameters. In addition, the is also written in the kind of .

(1)

(2)

(3)

(4)

We can calculate operation point of magnetic field density in the kind of remanence magnetic field of magnets, magnet length, airgap length and relative permeability of the magnet. We solved the equation and we find that:

(5)

1. Magnetic loading is the total flux in the airgap of a machine. We know that magnet to pole pitch ratio is 0.8 and the total pole area is calculated as:

(6)

Then we know that flux density at airgap is 1.0138 T. Then magnetic loading is :

(7)

1. The airgap flux density is found by using Maxwell 2D model shown in figure 4.

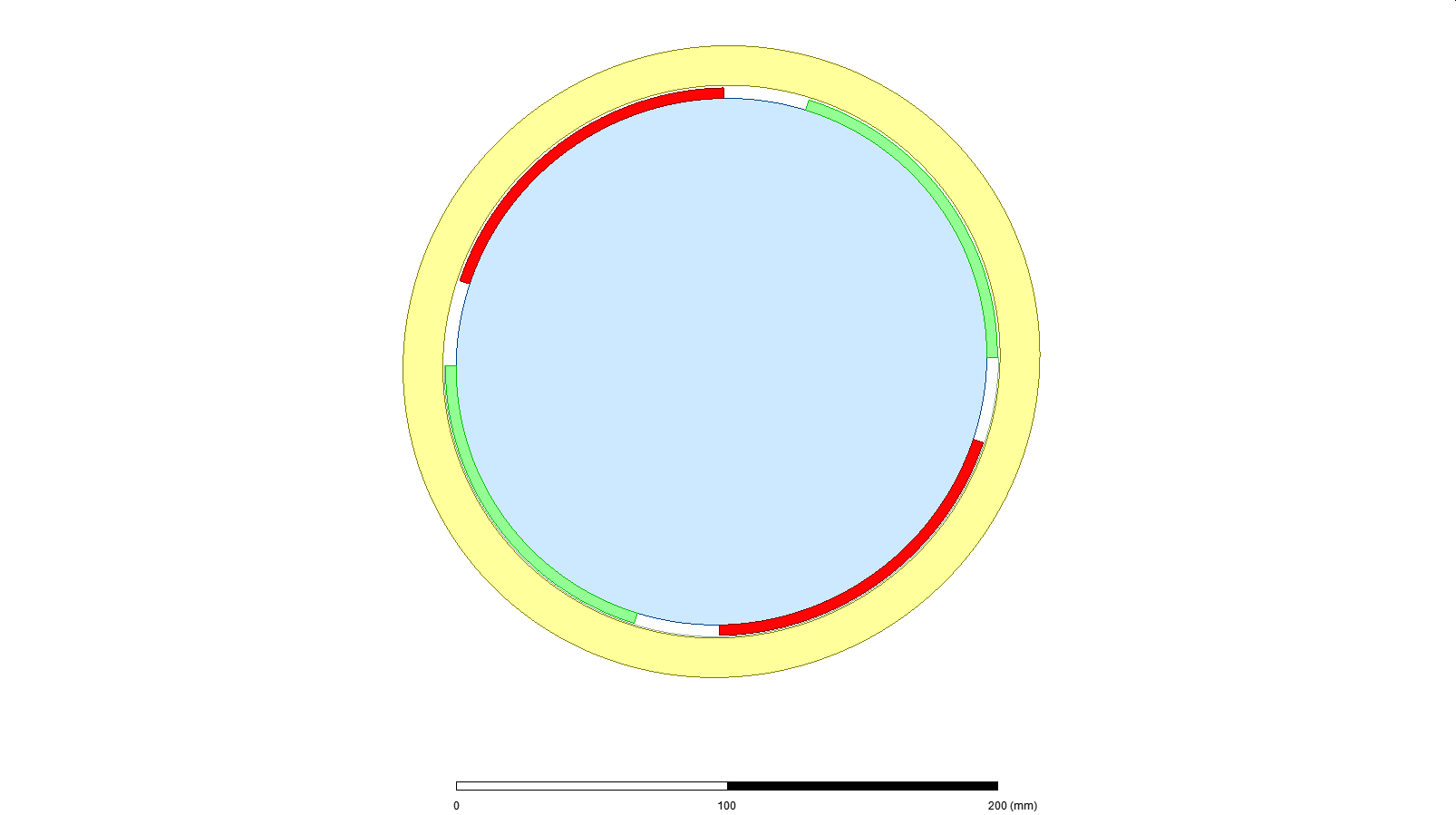


Figure 4 4-pole PMSM machine with solid stator

(Red: North Poles, Green: South Poles, Yellow: Stator, Blue: Rotor)

The airgap flux density is calculated mid-point airgap. The flux density from FEA distribution are shown at figure 5 and also the data points are drawn by matlab at figure 6.

|  |
| --- |
| Figure 5 Airgap Flux Distribution from FEA plot |
| Figure 6 Airgap Flux Distribution from matlab plot |

The FEA results show that at airgap. The difference between analytical and FEA is . FEA result is smaller than analytical result. The stator and rotor permeability are taken as infinite and leakage flux is ignored at analytical calculation. The differences are stem from these assumptions.

# Electrical Loading and Machine Sizing

1. In this section, we choose a slot number for the machine, used at first section. We choose the slot number is 12 by using the [online winding factor calculator](https://www.emetor.com/windings/). Thus, the motor is integral slot and slot per pole per phase is one. Thus, winding factor is 1.
2. By using current and maximum current density, we calculate the required diameter of the cable to provide the current rating.

(8)

(9)

We can choose AWG-20 cable (). The cable is in safe for the rating.

1. We can use rule of thumbs and choose outer diameter is 198 cm (for 4 pole). Also, we know that slot ratio of 0.5 gives the maximum torque. However, the outer diameter restricts the slot ratio. We choose the slot ratio is 0.75 which gives 35 mm slot height with inner diameter 105 mm and outer diameter 140 mm.

Also, we have 12 slots and total slot-tooth length is which give a per slot-tooth. We choose the half of them is slot and other is tooth. It gives space for cables. The winding factor is given as 0.6 and we use AWG-20 cable.

1. Electrical loading is the total turn ratio of the cables for unit length of the airgap.

In the lecture, the desired electrical loading of the PMSM machine between 35-65 A/m. Thus, we say that our electrical loading is proper.

1. Average tangential stress depends on electrical loading and magnetic loading. taken as 90 for PMSM machines.

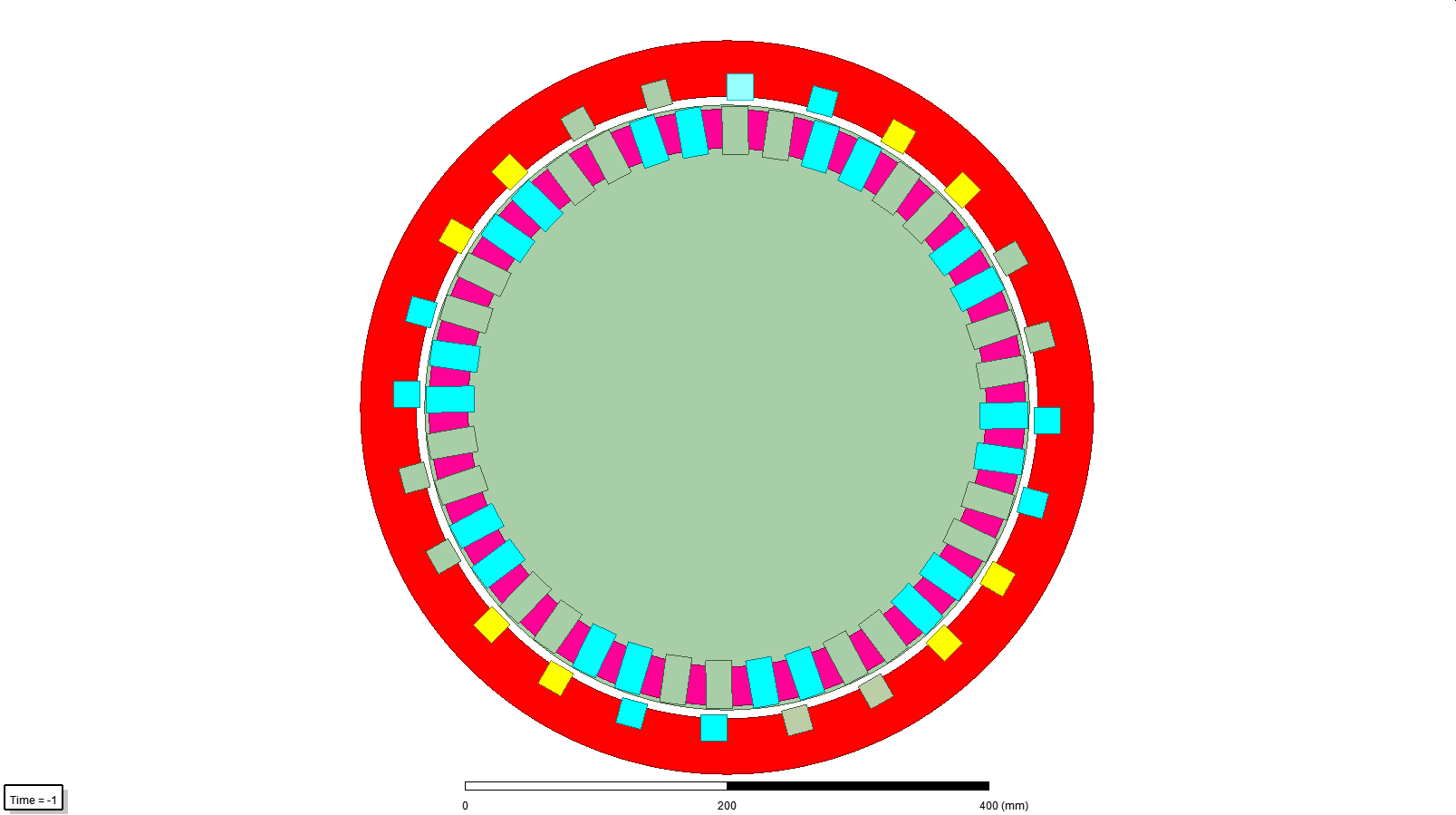
Force depends on torque and radius of the machine. Torque is calculated by volume of the rotor and tangential stress.

1. We can calculate the power by using Torque and motor speed. Motor speed is given 1500 rpm ().

# 2D FEA Modelling

24 slot 20 pole 3 phase machine is drawn by Maxwell 2D. Field is fed by DC current to create the magnetic poles. Stator side is 3 phase fractional pitch coil. The field is 20 pole and 200A.Turn and conductor number of phases is 80. The rotor diameter is 47 cm and airgap is 5mm.

A



Field Neg

Field Pos

spPos

C

-B

Figure 12 2D Drawing of Motor

* The airgap flux density is drawn by using a search coil and the rotor is rotated by rated speed. The flux density repeated for each 36 degree mechanical.

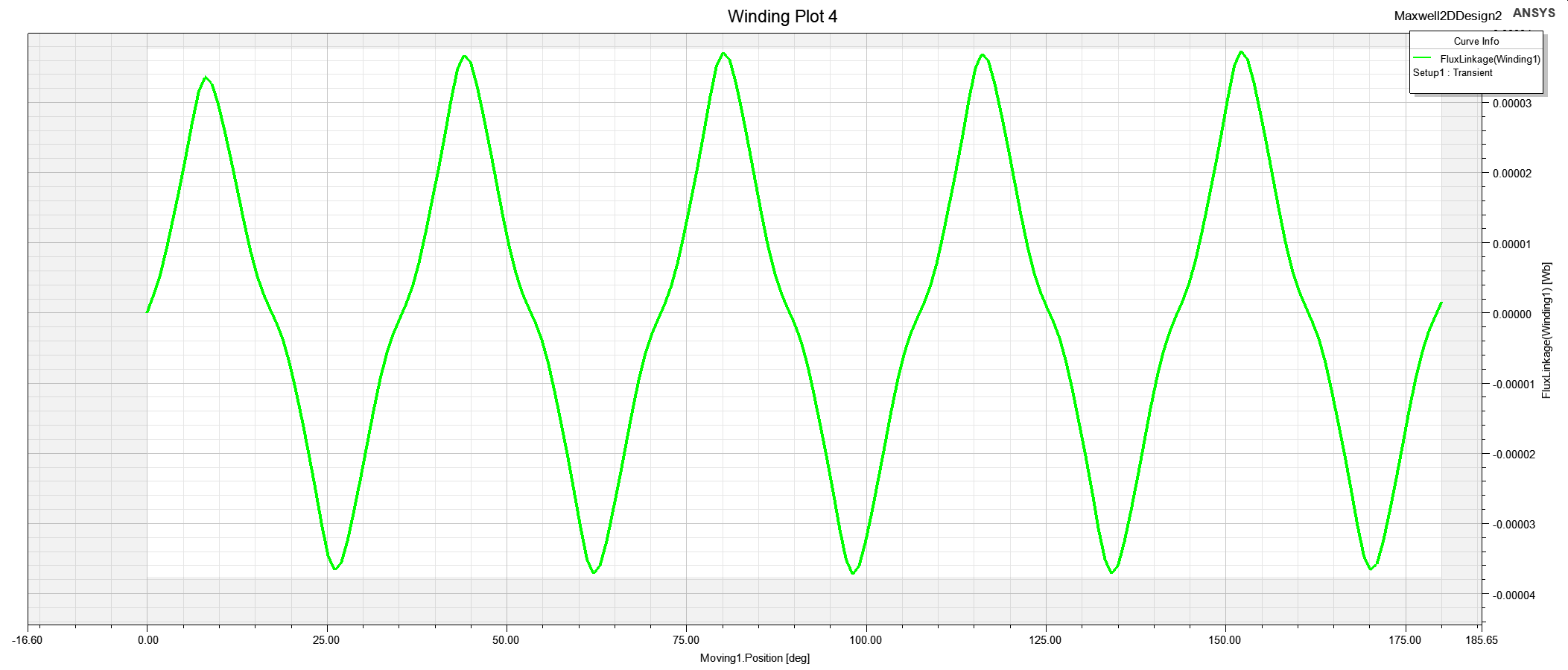


Figure 13 Distribution of Airgap Flux Density Maxwell Raw Plot

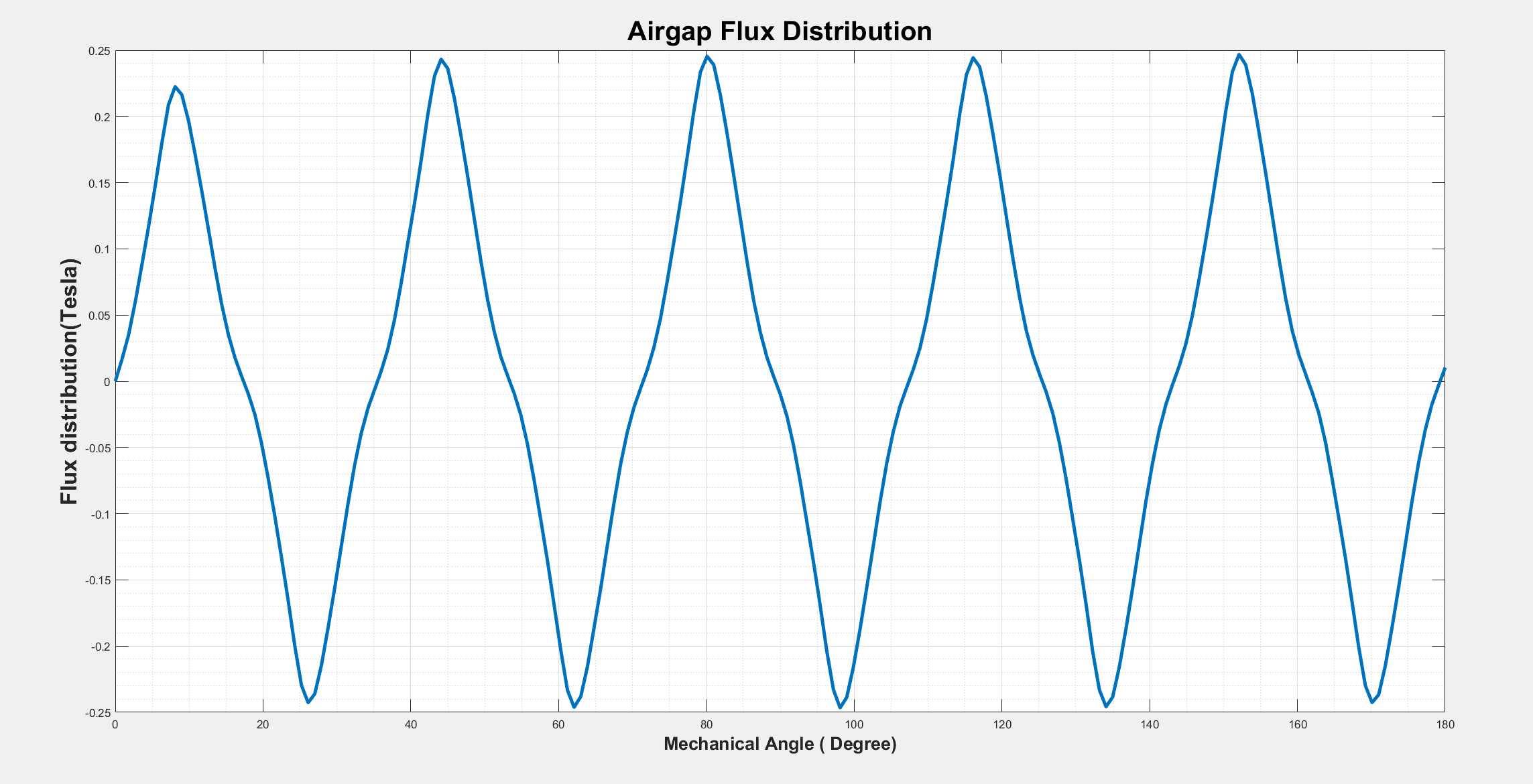


Figure 14 Distribution of Airgap Flux Density

* The phase voltages are disturbed sinusoidal waveform. It includes 3rd and 5th harmonics. The line voltage is more sinusoidal.

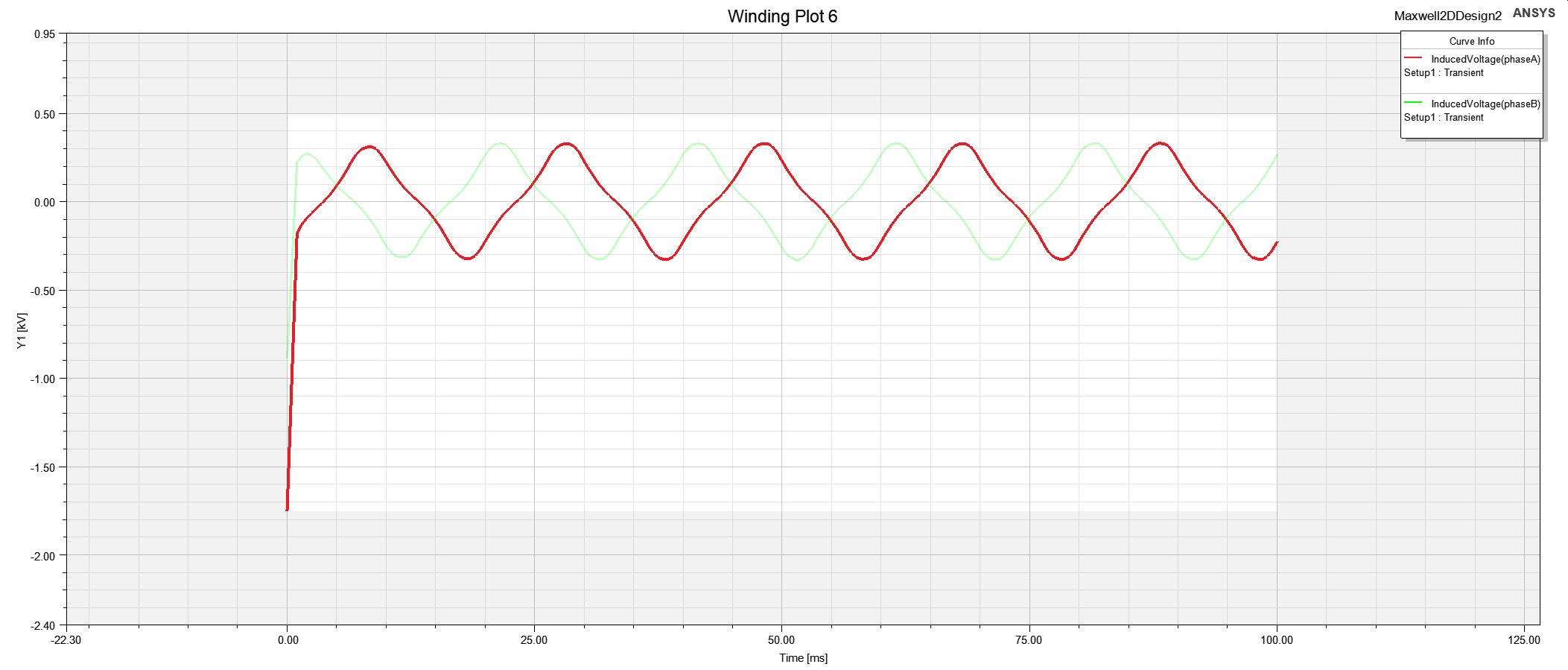


Figure 15 Phase A and Phase B Voltages Maxwell

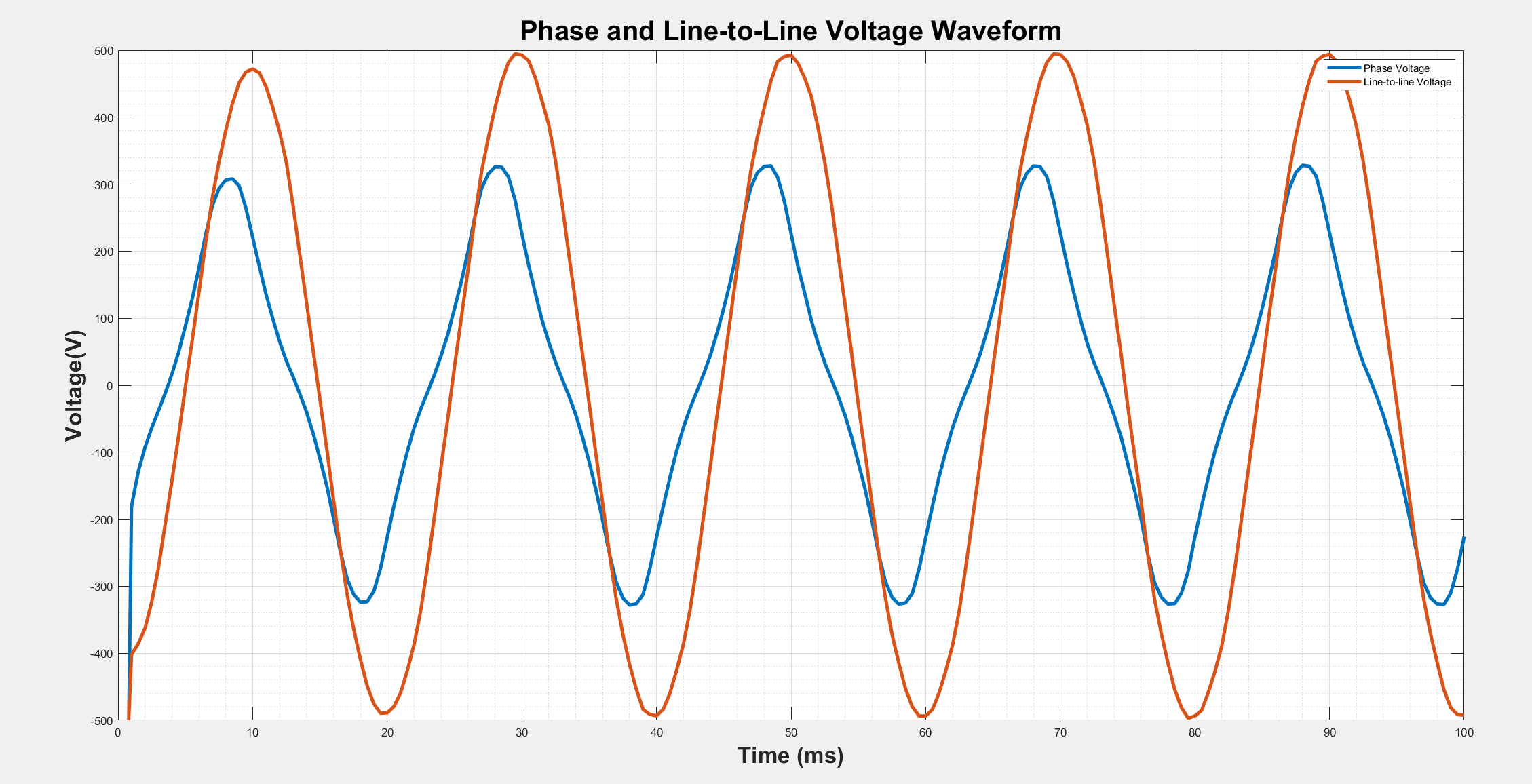


Figure 16 Phase and Line Voltages Matlab Plot

# Conclusion

In this report, different motor winding designs are compared. Firstly, integral slot winding was investigated and we observed that winding factor is attenuated with increasing harmonics. Thus, fundamental induced voltage of coil is dominant. Secondly, different fractional slot winding designs were investigated. It was observed that the fractional slot windings decrease end windings for the same vectors of voltage phasors. Also, it was observed that fractional slot windings can be used to eliminate some harmonics. Finally, finite element analysis for motor design is made and the analytical calculation for a design is validated by finite element analysis.