# **CHAPTER 5**

# **FEA VERIFICATION**

## Introduction

In the previous chapter, optimization procedure of the proposed AFPM generator was described and required design parameters were determined and presented by using genetic algorithm optimization. As a principle in electrical machine design, it is important to verify the design in terms of electromagnetic and electrical performance before the production [1], [2]. For this purpose, modern analysis techniques and computer programs are used. In this chapter, design parameters of the optimized generator will be used in the 3D FEA modelling and analysis in order to verify the electromagnetic and electrical performance of the proposed AFPM generator. ANSYS Maxwell® is employed during the 3D finite element analyses. Analysis configurations of the magnetostatic, no-load transient and full load transient simulations will be presented in the following subsections. As mentioned in Chapter-3, air gap flux density and no-load induced emf values are investigated during the analyses. In addition, full load analysis of the proposed AFPM generator is made in order to calculate the coefficient of eddy losses acting on the permanent magnets. Related graphs and simulation results will be given in the following subsections. At the end of the chapter, comparison of the optimization results of analytical design and the 3D FEA analysis will be given for the proposed AFPM generator with related error rates. Another comparison will be made between commercial MW level wind turbines and the proposed AFPM wind turbine generator.

## Magnetostatic Analysis

In the finite element computation environment, magnetostatic analyses are done in order to estimate the electromagnetic behaviour of the electromechanical systems under static conditions, i.e. no-motion. For our study, magnetostatic analysis is applied to proposed generator model in order to calculate air gap flux density and flux path in the machine. Before these verifications, ANSYS Maxwell magnetostatic FEA configuration setup will be presented.

## Magnetostatic FEA Configurations

In the modelling stage of the generator in ANSYS Maxwell, 1/54 symmetrical model is employed. Therefore excessive mesh computation and analysis time can be saved. In Fig. 5-1, mesh plot of the magnetostatic model is given.

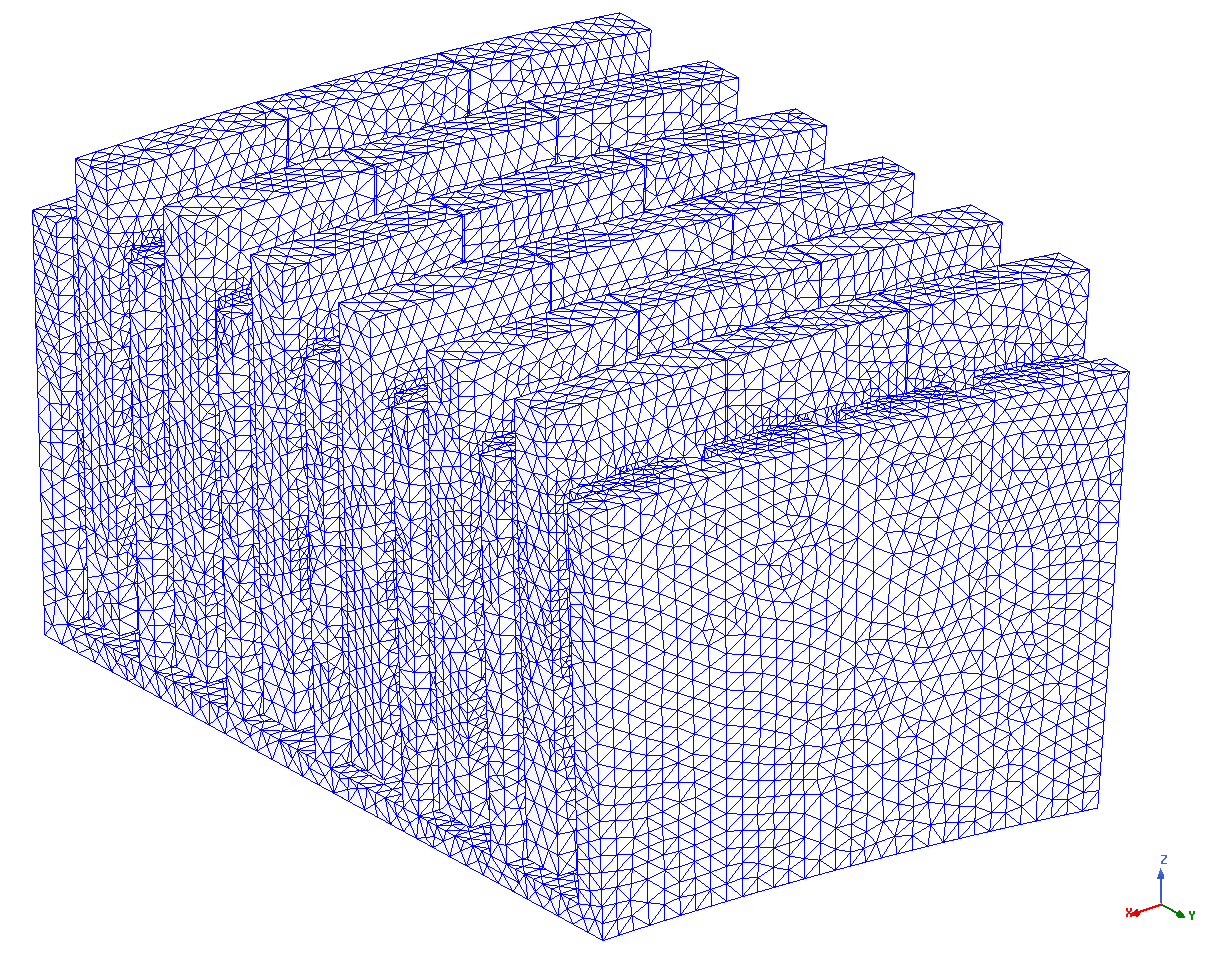


Fig. 5-1. Magnetostatic model mesh plot

Magnetostatic analysis setup configurations and mesh size configurations are given in Table 5-1.

Table 5-1. Magnetostatic FEA Configurations

|  |  |
| --- | --- |
| **Property** | **Value** |
| Mesh size | 25 mm |
| Percent error | 0.5 |
| Maximum number of passes | 15 |
| Refinement Per Pass | 30% |

## Air gap Flux Density verification

In this section, air gap flux density value of the proposed generator is investigated and compared with the analytically calculated air gap flux density value in order to verify the proposed 5MW 12 rpm design. In Fig. 5-2, air gap flux density values with respect to position in the air gap between magnets are depicted.

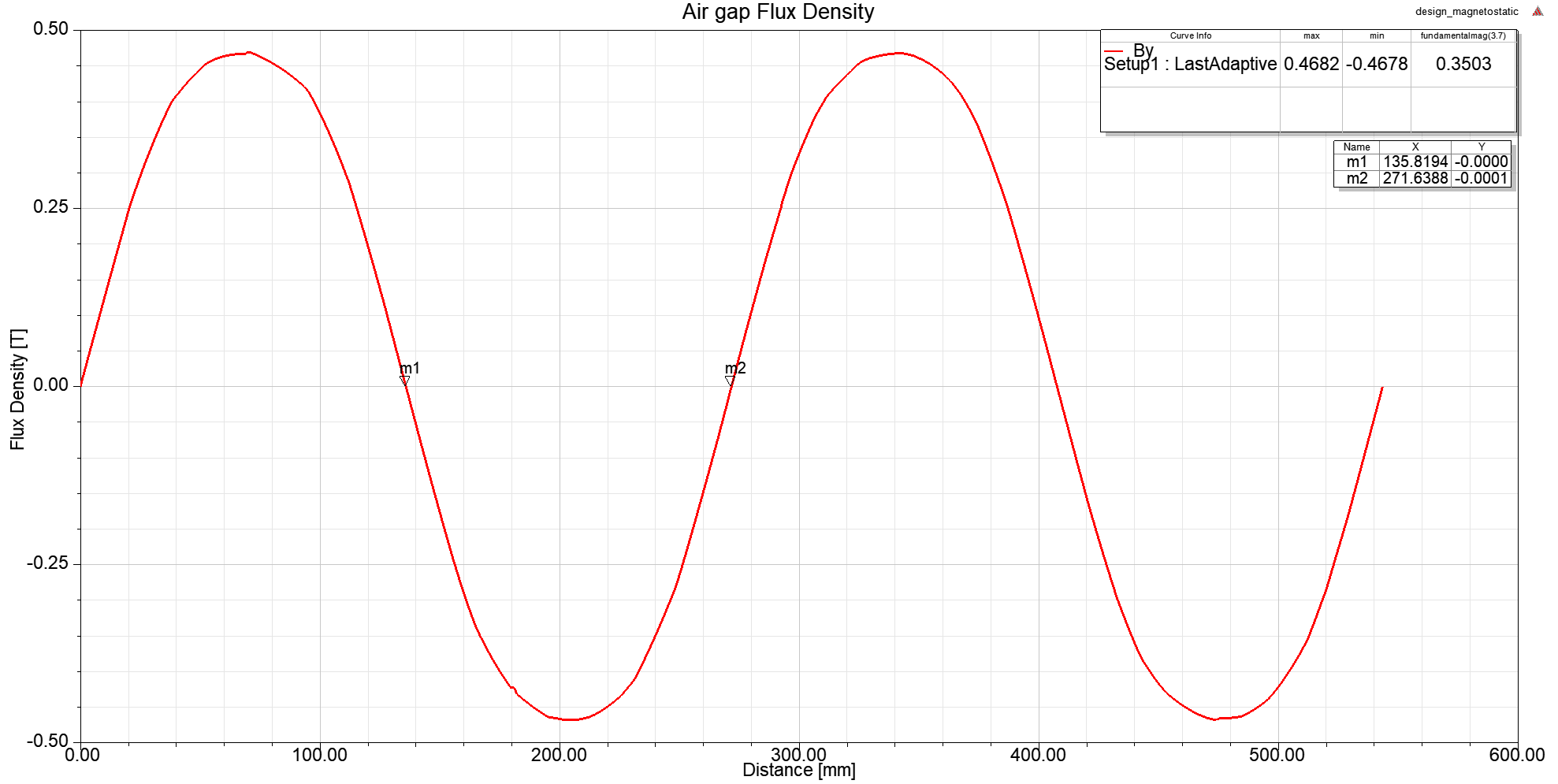


Fig. 5-2. Proposed design air gap flux density graph from FEA

According to these FEA results, air gap flux density characteristics of the proposed design and comparison with analytical calculation results are summarized in Table 5-2. In Fig. 5-3, variation of the air gap flux density together with analytical and FEA results are shown. Black labeled flux density is the calculated flux density value with a flat-top value of 0.453 T while red and blue labels show the analytically calculated fundamental harmonic peak air gap flux density and FEA results, respectively.

Table 5-2. Comparison of the analytical and FEA results for the air gap flux density

|  |  |  |  |
| --- | --- | --- | --- |
| **Property** | **FEA Value (T)** | **Analytical Value (T)** | **Error** |
| Air gap flux density -peak | 0.468 | 0.453 (flat-top) | 3.2% |
| Air gap flux density fundamental-peak | 0.494 | 0.510 | 3.2% |

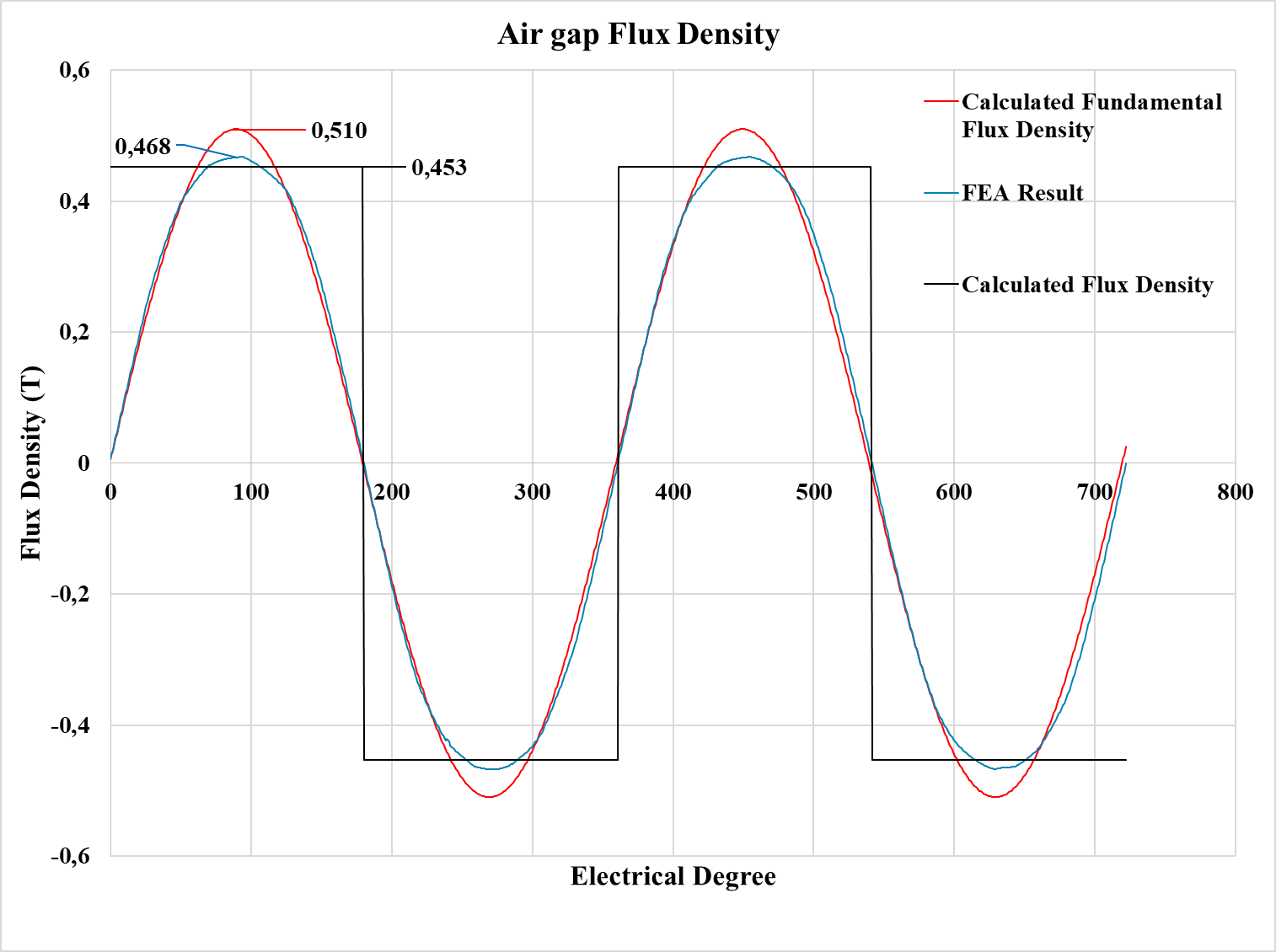


Fig. 5-3. Airgap flux density graph with analytical results for the 5 MW design.

As mentioned in previous chapters, air gap flux density value is a critical value that has to be verified before the production stage of the electrical machine. It can be seen from the Table 5-2 and Fig.5-3 that analytically calculated values and finite element analysis results of the air gap flux density of proposed AFPM generator are in good agreement and related error values are reasonable. Small difference between FEA results and analytically calculated flux density is due to leakage fluxes that can not be calculated by the analytical method in this study. In Fig. 5-4, top view of the flux density vectors is shown around the poles and air gaps. In Fig. 5-5, flux density distribution over the steel core parts is shown.

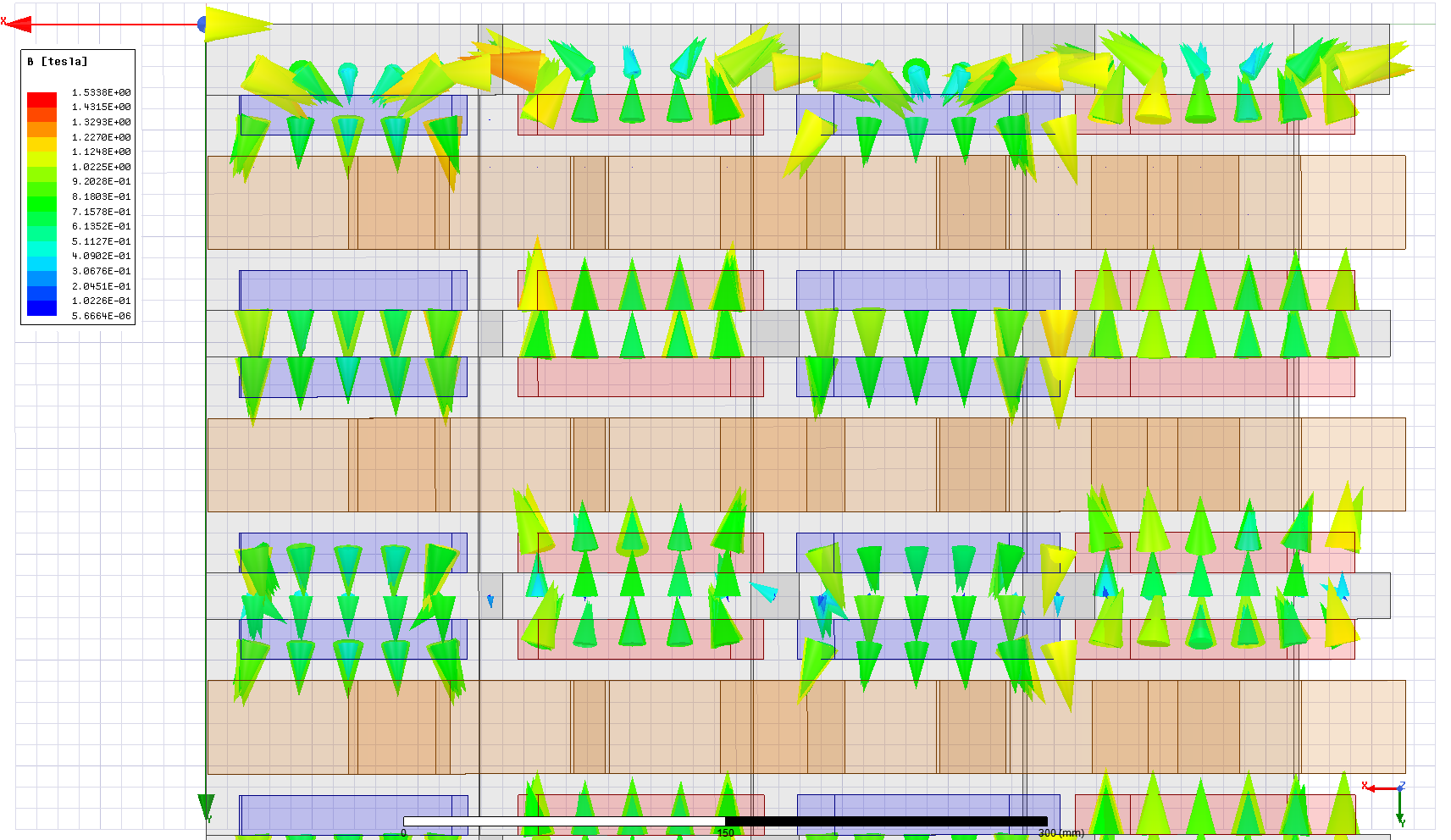


Fig. 5-4. Airgap flux density vectors for the 5 MW design.

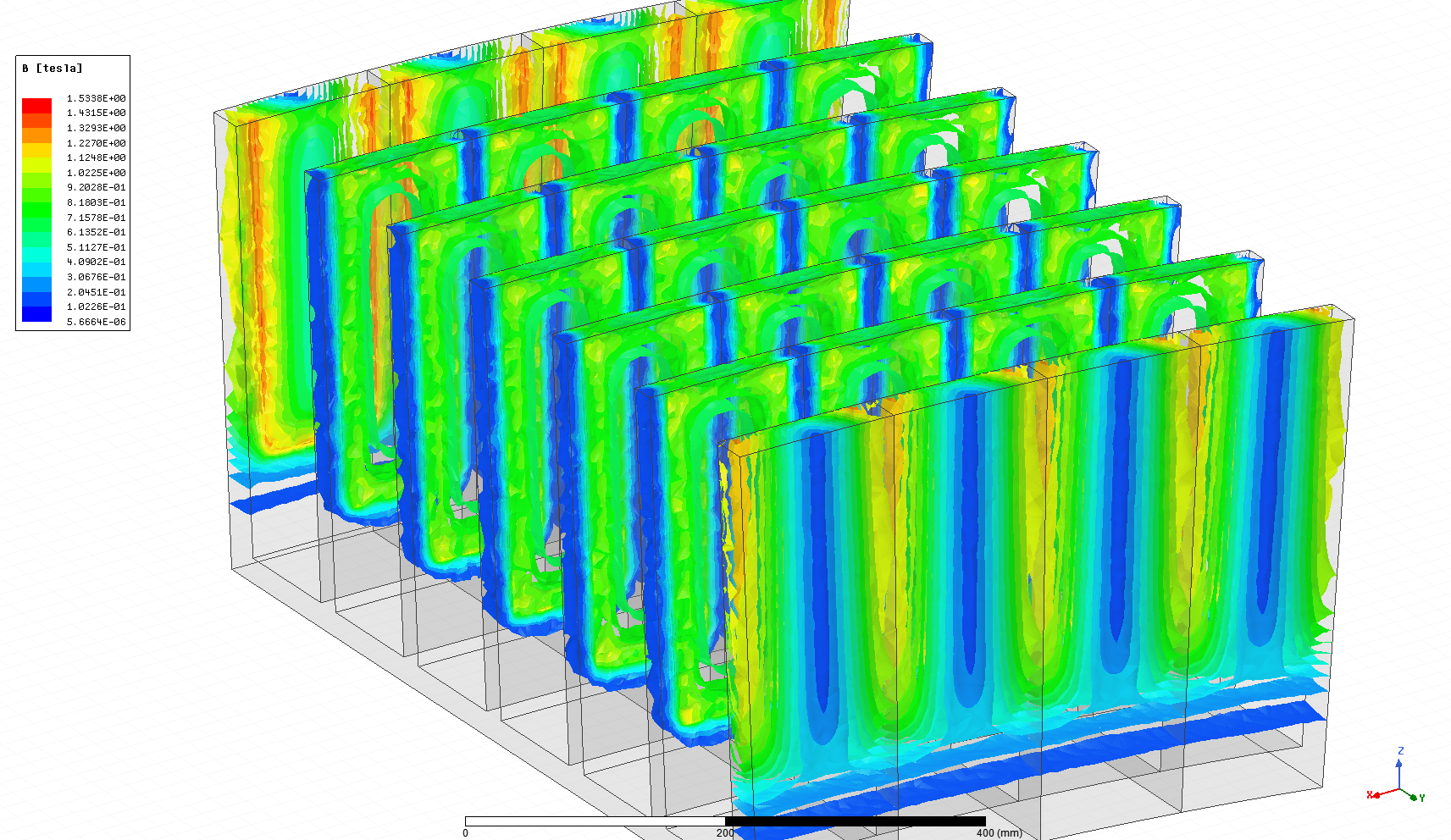


Fig. 5-5. Flux density distribution over the steel cores of the proposed 5MW design.

## Transient Analysis

In the transient finite element environment, analyses are done in order to estimate the electromagnetic behaviors of the electromechanical systems under dynamic conditions, i.e. moving. Three main objectives are followed in terms of transient FEA in this thesis. These are; no-load induced emf, full-load phase voltage and full-load eddy current coefficient estimation. In the following subsections, these objectives will be described and related verifications of the proposed AFPM generator will be presented. Before these verifications, ANSYS Maxwell transient FEA configuration setup will be presented.

## Transient FEA Configurations

In the transient model, same mesh size (25 mm) is used as it was in the magnetostatic analysis. 1/54 symmetrical model is employed again in order to avoid computational burden. Configurations of the transient FEA is given below in Table 5-3.

Table 5-3. Transient FEA Configurations

|  |  |
| --- | --- |
| **Property** | **Value** |
| Mesh size | 25 mm |
| Time step | 1 ms |
| Stop time | 0.1 s |
| Speed | 12 rpm (rated) |

## No-load Model

In this section, only induced emf of the proposed AFPM generator will be investigated under no-load conditions. For this purpose, zero current value is assigned to three phase windings together with infinitely high resistance values.

## Induced emf verification

If we recall the circuit diagram given with Fig. 3-12 in Chapter-3, induced emf  corresponds to the voltage measured across open phase windings when no current flows through and machine rotates at rated speed of 12 rpm. In Fig. 5-6, circuit diagram of the machine is given and induced emf is indicated with red circle. In Fig. 5-7, induced emf graph from the finite element analysis is given. According to this figure, induced emf per phase rms value is measured as 410.6 V.

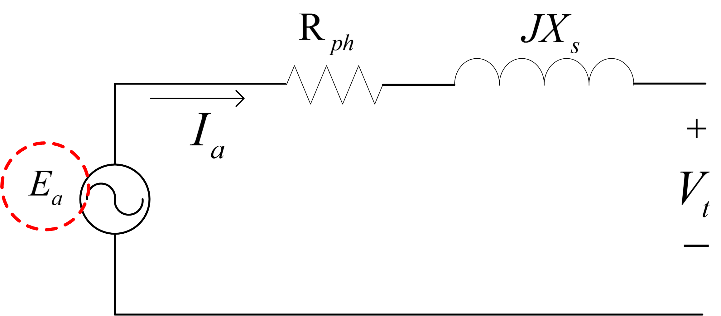


Fig. 5-6. FEA induced emf () measurement equivalent circuit

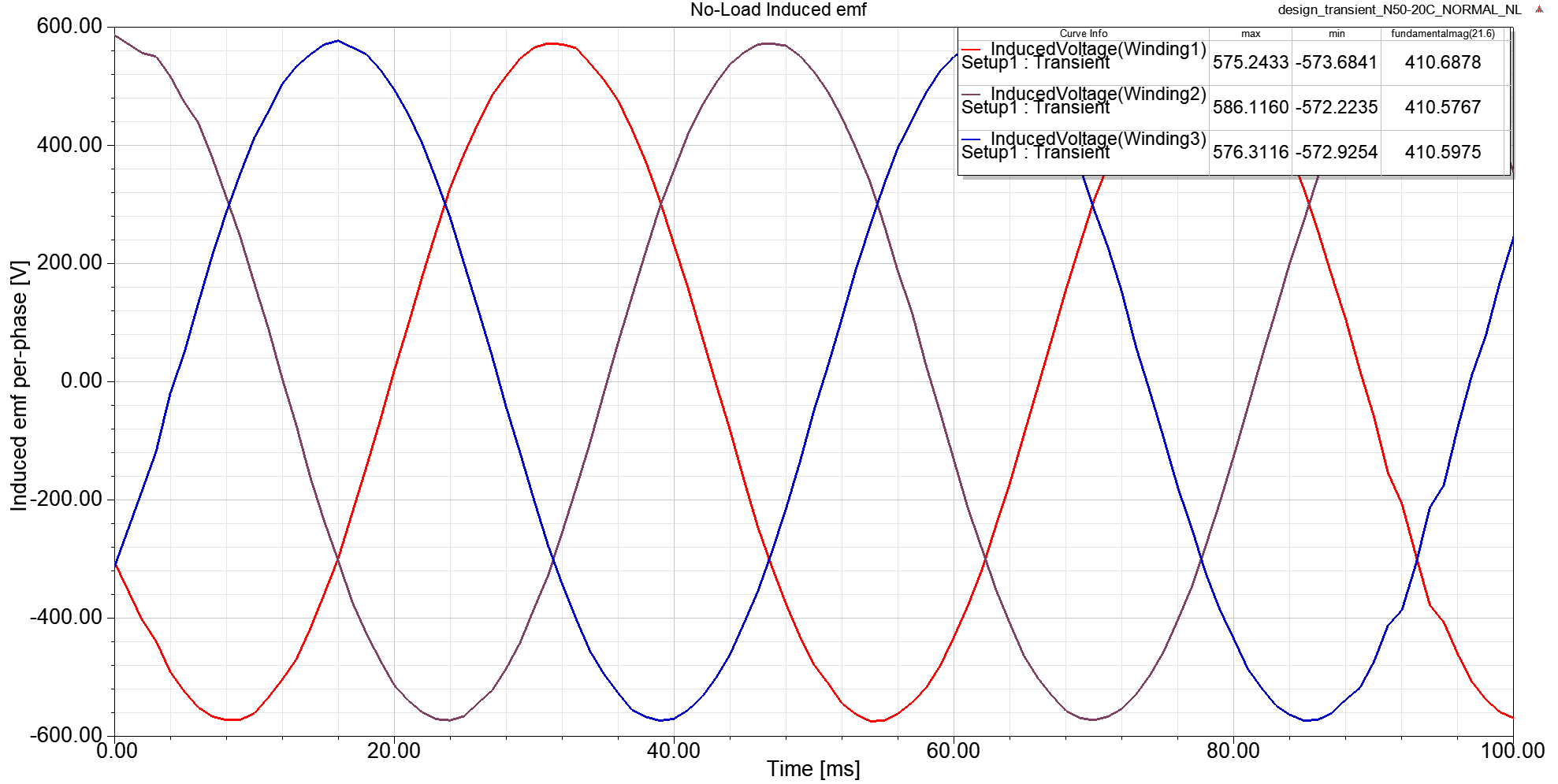


Fig. 5-7. Proposed design induced emf per phase results from FEA

Comparison of the analytically calculated results with FEA results for the induced emf per phase is given in Table 5-4 below. As it can be seen from this table, error rate is very low. Therefore, analytical design method is verified with FEA in terms of induced emf values.

Table 5-4. Comparison of the analytical and FEA results for the induced emf per-phase

|  |  |  |  |
| --- | --- | --- | --- |
| **Property** | **FEA Value (V)** | **Analytical Value (V)** | **Error** |
| Induced emf per-phase rms | 410.6 | 412.4 | 0.43% |

## Full-load Model

## Phase Voltage verification

## Eddy loss coefficient estimation

## Proposed model comparison

## Conclusion

**References**

[1] N. Rostami, M. R. Feyzi, J. Pyrhonen, A. Parviainen, and V. Behjat, “Genetic Algorithm Approach for Improved Design of a Variable Speed Axial-Flux Permanent-Magnet Synchronous Generator,” *IEEE Trans. Magn.*, vol. 48, no. 12, pp. 4860–4865, 2012.

[2] J. F. Gieras, R.-J. Wang, and M. J. Kamper, *Axial Flux Permanent Magnet Brushless Machines*, vol. 3 ed. Dordrecht: Springer Netherlands, 2008.