Losses in Windings of Superconducting Traction Transformer, 2D and 3D Model

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Abstract: - The paper deals with a superconducting traction transformer. The idea of this usage originated in the SKODA Research Ltd., Pilsen. The aim of this article is comparison between 2D and 3D models. For calculations were used FEM programs OPERA and FEMM. Losses in superconducting windings are calculated with using users program. Results of calculation are discussed in conclusion.

Key-Words: Superconducting transformer, winding, Bi2223, FEM,

1 Introduction

Today's classical transformers with their electrical steel cores and copper windings are very efficient device (about 99,7%). They present a mature technology, with little room for efficiency improvement. The possibility of significant efficiency improvements in transformers with superconductor windings has long been recognized. However, the high refrigeration costs associated with very low temperature (<20 K) operation using helium have been a major barrier to the marketplace.

From a utility perspective, a transformer must have low initial and operating costs, and be light weight, compact, and environmentally benign with a lifetime of typically 30 years. To a great extent, a HTS transformer does have a potential to offer these advantages. Conventional transformers are highly reliable in terms of their use in an electrical system. However, the dominant component of losses is the I^2 R loss [4].

The higher current density capacity of superconductors compared to copper leads to a more compact and lighter design of transformers. Even for the identical core diameters, the core window width could be reduced in proportion to the space saving due to the utilization of superconducting windings. This reduces the iron core weight. Lighter core size also leads to lower core losses. A compact and light weight transformer might see new applications which were not feasible with the conventional transformers. Lower weight and compact size would make them acceptable for more urban applications. Smaller core windows also lead to lower leakage inductance which helps to improve dynamic stability of a power system. The low leakage inductance also improves the voltage regulation to the load, and therefore, it might eliminate complex and expensive tap changers.

2 Model of transformer

2.1 Construction setting

Geometrical sizes of the HTS transformer shows Fig. 1. and parameters.

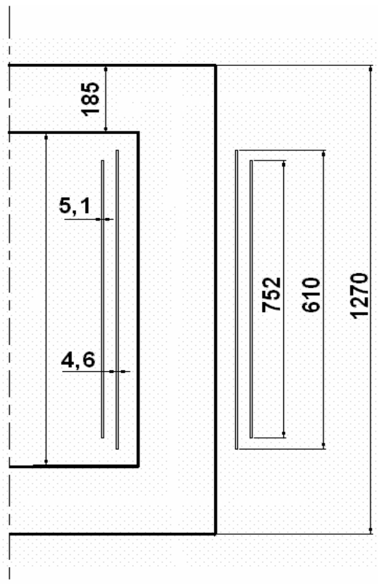


Fig. 1. Geometrical sizes of HTS transformer

Parameters:

$S = 1800$ kVA

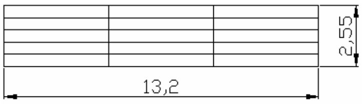
$U_1 = 25$ kV

$U_2 = 2x860$ V

$N_1 = 3314$ turns

$N_2 = 2x114$ turns

Conductor, Bi2223



Conductor of secondary winding

2.2 2D model of HTS transformer

2D model of the HTS transformer was calculated with using program FEMM.[2] Fig. 2.,3. shows areas of the model and distribution of the magnetic field.

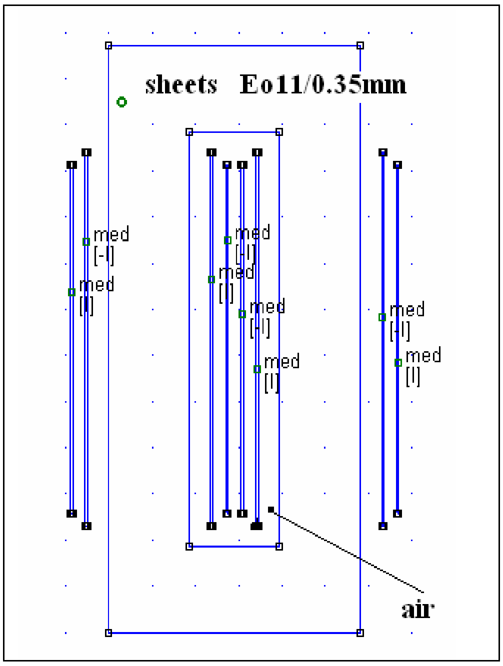


Fig. 2. 2D model of HTS transformer

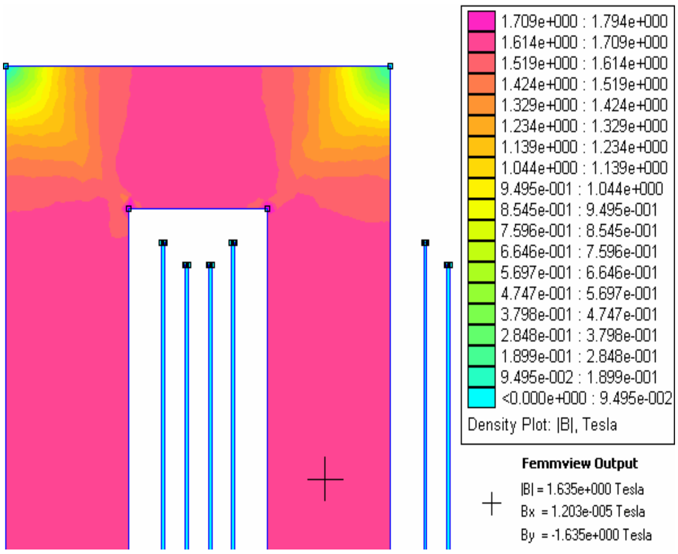


Fig. 3. Distribution of magnetic field

2.3 3D model of HTS transformer

3D model of the HTS transformer was calculated with using program OPERA – TOSCA.[3] Fig. 4. shows the 3D model and distribution of the magnetic field.

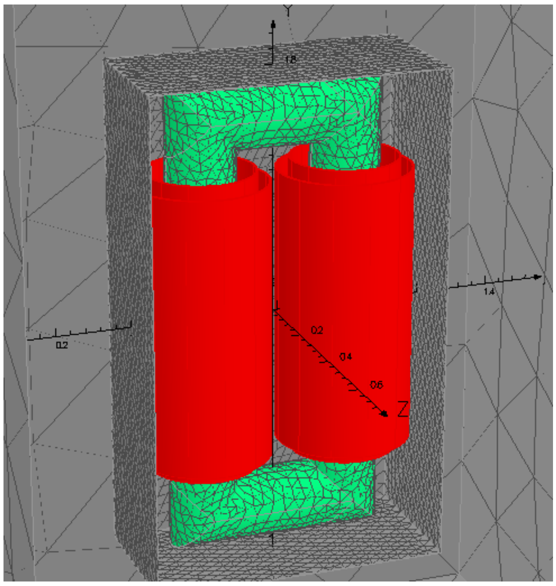


Fig. 4. 3D model of HTS transformer

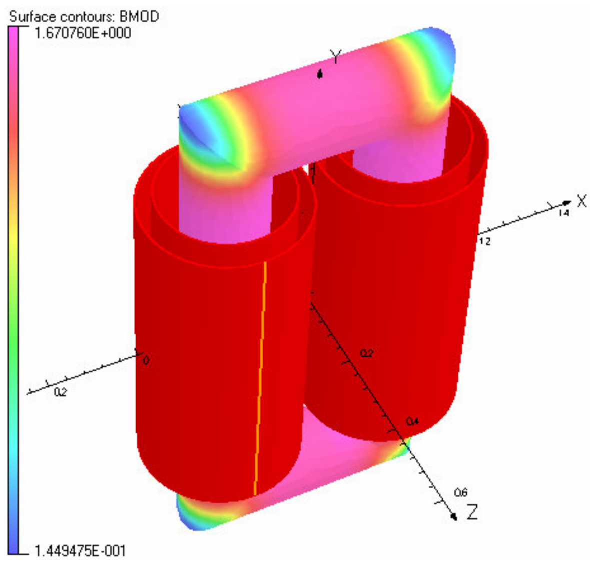


Fig. 5. Distribution of magnetic field

3 Results of Calculations

3.1 Comparison between 2D and 3D model

Fig. 6. shows comparison between 2D and 3D model, the magnetic flux density along coil.

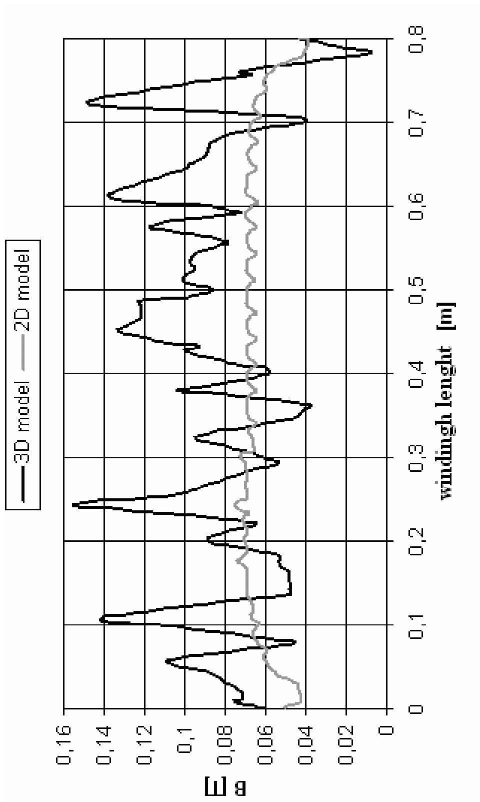


Fig. 6. Comparison between 2D and 3D model – magnetic flux density

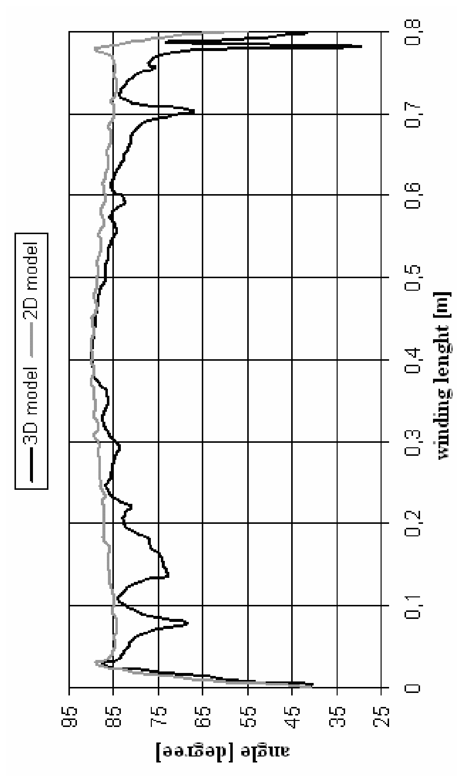


Fig. 7. Comparison between 2D and 3D model – angle turning

3.2 Losses in windings

Total losses of transformer in windings – 2D model [1].

$$\Delta P_K = \Delta P_{K1} + \Delta P_{K2} = 572 + 886 = \underline{\underline{1458 W}}$$

Total losses of transformer in windings – 3D model

$$\Delta P_K = \Delta P_{K1} + \Delta P_{K2} = 766 + 1192 = \underline{\underline{1958 W}}$$

4 Conclusion

Final losses of windings of superconducting transformer calculated by means of 3D and 2D model are different. The losses calculated by means of 2D model are approximately about 25% lower according to the losses calculated by means of 3D model.

First reason is differently calculated angle α see picture 7. in 2D and 3D model. In 3D model was calculated smaller angle than expected in some places. It was propably caused by not so fine mashing in the model. Smaller angle of flux density effecting on the conductor means higher losses in calculated conductor. It can be said that the results of 2D model in this case are more relevant.

On the other hand second reason of difference is real geometry of transformer using 3D model and thus we obtained more real distribution of electromagnetic field. The profile of iron core is z-axis dependent in 3D model. It caused increase of flux density effecting on superconductors see picture 6. In this case is definitely better 3D model which describes the real electrical device with higher accuracy.

Acknowledgement

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