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High Frequency Proximity Losses Determination for Rectangular Cross Section Conductors

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Abstract— This paper proposes a methodology to predict proximity losses in conductors of power electronics transformers working at high frequencies. The method is based on the concept of equivalent complex permeability applied to rectangular conductors. Two different approaches are compared with a good accuracy and economic computation time.

I. INTRODUCTION

In power electronics, conductors carrying currents are exposed to non-uniformed alternative magnetic fields associated to neighboring current carrying conductors. This leads to increase ohmic resistance in conductors known as proximity losses. For high frequency applications, modeling by FEM need a very fine mesh up to the skin depth. Moreover, the number of conductors is important so that 3D modeling is still impossible to carry out.

A classical technique consist in using the concept of complex permeability (μ_{complex} or μ^*) associated with homogenization approach. It has been successfully applied to transformers with circular cross section conductors [1]. This paper proposes two original approaches to apply this method to rectangular conductors.

II. PROXIMITY LOSSES AND COMPLEX PERMEABILITY

To compute losses correctly without involving a fine mesh, complex permeability concept is employed. The principle consists in replacing the conductor material by an equivalent non conductive magnetic material, which gives the same active and reactive power loss for the given geometry with a coarse FE mesh.

For circular cross section conductor [1], analytical solution coupled with homogenization technique is available. For rectangular one [2], 1D analytical approach responds weakly when we are far from ideal conditions. We propose two approaches to solve numerically and simply the complex permeability problem:

A. μ^* calculation for an isolated conductor and homogenization

The first step consist in determining the equivalent μ^* for an isolated conductor. The rectangular conductor is placed in an alternative inductor field. The 2D FE eddy current problem is solved and active and passive losses are computed. Afterward, the equivalent complex permeability problem is coupled with a optimization process to obtain the same losses values. Optimal μ^* is then obtained for one single conductor. It is then not necessary to mesh in the skin depth to model the device. This method is particularly efficient to model devices with scattered conductors.

If conductors are uniformly grouped like in the most part of transformer structure, a homogenization technique can be added to reduce the number of unknown even more. Based on an equivalent reluctance network, an equivalent μ^* can be calculated and imposed on a homogenized region representing conductors and the surrounded air region [2].

B. Direct μ^* evaluation for a large number of conductors

If there are a large number of conductors stacking in a regular manner, we will consider an elementary cell of the geometry placed in an inductor field H_0 . Firstly, we compute this small cell taking into account the eddy current effects. The problem is imposed by appropriate boundary conditions which consider the regular stack of conductors. Losses (P and Q) are calculated with an economic computation cost thanks to reduced size of the cell. Subsequently, these losses will be equalized with that provided by the equivalent μ_{complex} problem. The equivalent μ^* is then directly and simply obtained.

III. NUMERICAL RESULTS

Both methods have been tested with a package of conductors. They propose two complement approaches to consider losses caused by proximity effects using numeric complex permeability. They lead to a strong reduction in memory requirement and computation time. Numerical results provided by complex permeability show a good agreement with classical eddy current computation. They are also improved essentially compared with 1D analytical approach [2].

| Number of conductors | 2x2 | | 2x5 | |
|--|------------|------------|------------|------------|
| | Error in P | Error in Q | Error in P | Error in Q |
| Identification for isolated conductor and homogenization | 7.9 % | 0.02 % | 3.2 % | 0.03 % |
| Direct evaluation for a large number of conductors | 5.01 % | 0.02 % | 0.16 % | 0.11 % |
| 1D analytical approach | 41.4 % | 7 % | 35.7 % | 4.8 % |

This result has been obtained thanks to 2D modeling. These techniques have been also applied successfully for 3D case.

IV. REFERENCES

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