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Effects of splitting and twisting conductors on the AC Joule losses

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***Abstract*— In this paper, the effects of splitting and twisting conductors on the AC Joule losses are studied. The splitting effects are studied using 2D finite element harmonic analysis. 3D finite element harmonic analyses are performed to study the twisting effects. The results give insights in the understanding of Litz wires and their efficiency in reducing AC Joule losses.**

***Index Terms*— AC Joule losses, splitting effects, twisting effects, finite element harmonic analyses.**

I. Introduction

AC Joule losses in the copper of winding may compromise the efficiency of high speed electric machines [1]. At high speed operations, AC losses are two to three times the DC losses [2][3]. Often, these losses are reduced by splitting solid conductors into several thin parallel wires grouped into strands. Strands may be grouped into bundles depending on the frequency range. However, splitting conductors into high number of parallel strands can increase instead of decreasing AC losses [4].

Several papers [1-5] advise the use of Litz wires to reduce Joule losses. Litz wires are made of very thin twisted strands or wires. This paper aims first to quantify the splitting effects on the AC Joule losses using 2D Finite Element Harmonic Analysis (2D FEHA). Then the twisting effects are studied using impedance matrices obtained by 2D FEHA and combined with permutation matrices describing the different conductor locations along the axial direction. Eventually, 3D FEHA are performed to get more accurate results.

II. Study of AC Joule Losses

A. Influence of splitting the conductor

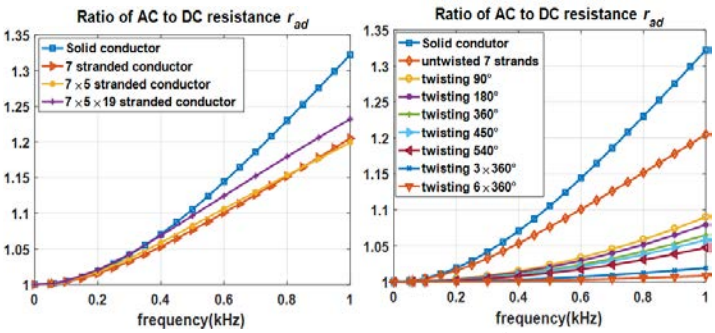
To analyse the splitting of conductors on AC Joule losses 2D FEHA are performed. This study takes several steps. During the all steps, the total section of copper is kept constant. In the following the ratio of AC to DC resistance is named r_{ad}. First one coil with one turn and made of one solid conductor with a circular cross section of a diameter of 8.3 mm is studied. In a second step this conductor is split into 7 parallel strands. In a third step each strand is split again into 5 strands. In the last step each strand is split in 19 wires.

At each step FEHA are performed to calculate AC Joule losses the ratio r_{ad} is deduced. The results are shown on Fig. 1.a. For the solid conductor at 1kHz the ratio is about 1.32. In the second step, the decrease in the ratio is about 38% compared to the solid conductor. In the third step, the decrease in the ratio is about 41%. In the last step, the decrease is only about 28%. The results of 2D FEHA show that splitting allows reducing the AC losses until a certain limit.

B. Twisting influence

To analyse the effects of the twisting of conductors on AC Joule losses, 3D FEHA are performed. From previous results (Fig.1.a), the twisting studies are applied on the 7 parallel strands on the axial length L_m. By twisting the strands from 90° to 6×360°, the ratio r_{ad} is reduced from 1.2 to 1.01 using 3D FEHA (Fig.1. b). The best twisting is 6×360° which corresponds to a lay length equals to $L_m/6$.

The model and the results using the impedance matrices from 2D FEHA and permutation matrices will be detailed in the final paper.



(a) (b)

Fig. 1. Ratio of AC to DC resistance r_{ad}: (a) 2D FEHA splitting effects, (b) 3D FEHA twisting effects.

III. Conclusion

Splitting a solid conductor into parallel strands reduces AC losses but to a certain limit. The twisting applied on the optimal number of parallel strands allows reducing significantly the AC losses. These studies allow finding the number and the lay length of twisted strands minimizing the AC losses. They provide also a better understanding of the Litz wires construction and its necessity in high frequency electric machines.

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